GB – User's Manual

CHAUVIN® ARNOUX
CHAUVIN ARNOUX GROUP

C.A 1875

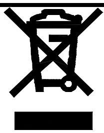
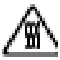
Thermography bench

Mesurer pour mieux Agir

You have just purchased a **C.A 1875 thermography tutorial bench** and we thank you for your confidence.
For best results from your instrument:

- **read** these operating instructions carefully,
- **observe** the precautions for use

MEANINGS OF THE SYMBOLS USED

	Selective sorting of wastes for the recycling of electrical and electronic equipment within the European Union. In accordance with directive WEEE 2002/96/EC: this equipment must not be processed as household waste.
	Possible hazard. Refer to the operating instructions before using the device.
	The CE marking guarantees conformity with European directives and with regulations concerning EMC.
	Attention, hot surface

PRECAUTIONS FOR USE

If this device is damaged or a part is missing, please immediately contact the seller.

Non-observance of the instructions or of the precautions for use may impair the protection provided by the device.

Refer to these instructions concerning each danger symbol encountered.

CONTENTS

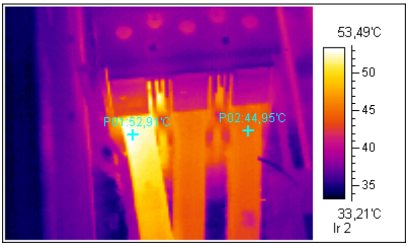
1. INTRODUCTION

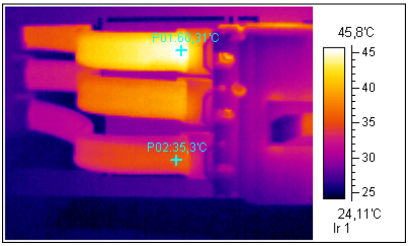
Infrared thermography detection technology has become an essential means of guaranteeing the safety of industrial production conditions. It is used in sectors of industry as varied as metallurgy and steel-making, electric power, the oil industry, automation, the extraction of natural gas, the transport industry, and other professions active in fire fighting and border surveillance. In all of these activities, characterized by just-in-time operating procedures, production equipment at high voltage, powerful electric currents, or high operating speeds, infrared thermal imaging can be a useful contact-free real-time inspection method.

This detection method requires no breaking of current, no stopping of machines or interruption of production. It can diagnose latent defects in advance, and so forestall the occurrence of malfunctions and prevent production incidents. Thermal imaging is an innovative "contact-free" evaluation technique that is all at once safe, reliable, and rapid.

A thermal camera does not measure temperatures, but radiant fluxes. After the adjustment of a few parameters by the thermography operator, the camera calculates the temperatures of the target. It then gives the user a map of the temperatures, or "thermogram": each temperature is represented by a colour.

Here are two examples of thermograms:





Inside views of three-phase electrical boxes

First of all, we can see that these two thermograms are practically identical: we observe one phase that is hotter than the other two (the one on the left in the left-hand thermogram, the top one in the right-hand thermogram). As it happens, their colour is light yellow, which indicates according to the colour scale to the right of the IR image that the temperature is higher there.
Let's take a closer look at these two images, by inserting temperature cursors.
Left-hand thermogram:

- Cursor 1: 52.9°C
- Cursor 2: 44.9°C

In accordance with the rules of classical thermography (see below), there is no particular problem.
Right-hand thermogram:

- Cursor 1: 60.3°C
- Cursor 2: 35.3°C

In this case, the temperature difference is 25°C! We can conclude that there is a real problem in the installation and corrective action must be taken.

In conclusion, it is necessary to pay attention to the colour scales and to perform a genuine analysis. Dark means colder and light means hotter, but that does not mean that there is a problem to be detected! Bear in mind that the camera is a measurement tool and that the investigations must be continued!

2. PRESENTATION

Growing demand for training in infrared thermography has led CHAUVIN ARNOUX to develop measurement equipment specially designed for instructional purposes.

Far from being exhaustive, the manipulations proposed are intended only to illustrate, through a few examples, the false measurement records it is possible to produce in infrared thermography.
The objective is to make people aware that an infrared camera is a precision measurement tool that requires much training and experience to use correctly.

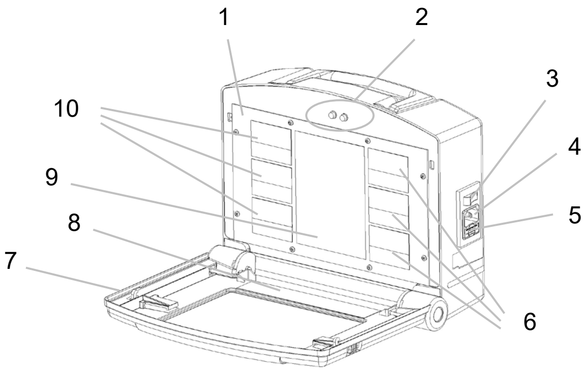
The **C.A 1875 tutorial bench** comprises a hot plate with several targets having different surface conditions and made of different materials, along with test screens that are affixed to the front of the bench using magnets. (See the diagram below).

The purpose of this bench is to allow the student to discover the main possible causes of error when making a measurement using an infrared camera.

This equipment can be used to perform the following experiments:

- Problem of emissivity of the materials
- Problems of positioning
- Problem of reflection
- Problem of transmission
- Problem of spatial resolution

Presentation of the C.A 1875 thermography tutorial bench:

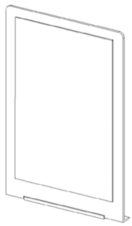


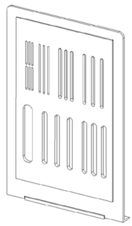
1: Hot plate
2: LEDs indicating rising or falling temperature
3: On / Off switch
4: Power cord connection
5: Fuse compartment
6: 10: Plates of different materials
7: Cover protecting the bench
8: Test screen attachment plate
9: Black reference plate for the various tests

Presentation of the test screens

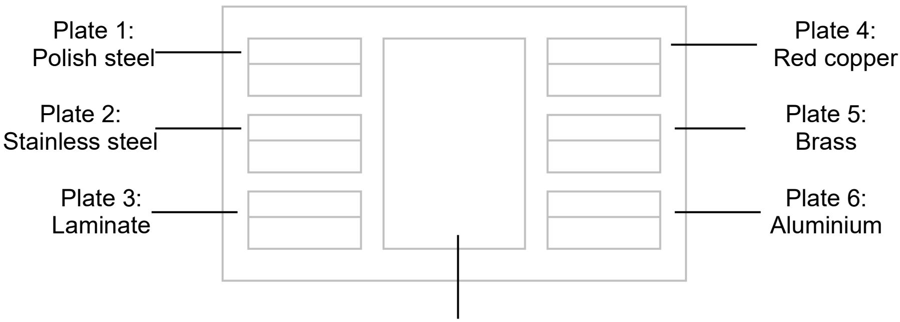
Test screen no. 1:
Plexiglas pane

Test screen no. 2:
Slits of variable width





Presentation of the hot targets



3. CHARACTERISTICS

3.1 GENERAL CHARACTERISTICS OF THE BENCH

Power supply: 230 V
50 / 60 Hz
Consumption: 400 mA
Temperature of hot plate: 50 to 55°C ± 3°C

Dimensions: 280 x 225 x 110 mm
Weight: 1.8 kg

Environmental conditions:
Indoor use:
0 to 40°C and 10 to 90% RH
Altitude less than 2000 m
Degree of pollution 2
Storage:
-20 to + 65°C and 10 to 90% RH
Altitude less than 12,000 m.
NB: storage at a higher temperature is possible but requires manually resetting the safety thermostat to render the device functional.

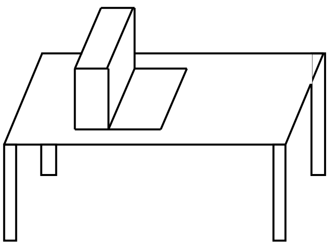
Conformity to international standards:
- Safety as per IEC 61010
- EMC as per IEC 61326-1

3.2 CHARACTERISTICS OF THE FUSE

Dimensions: 5 x 20 mm
Rating: 0.5 A fast-blow – 250 V

4. COMMISSIONING

The **C.A 1875 thermography tutorial bench** must be placed on a flat, level surface. The hot plate must be perpendicular to the work top.



Once the bench is in place, connect it to a mains outlet with an earth and power up using the On/Off button.
Wait a few minutes for the plate to warm up before running the first tests.

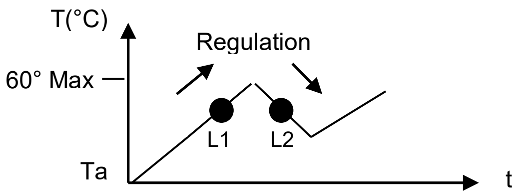


Diagram of operation of the LEDs and of the temperature variation of the hot plate.
When the bench is started up, L1 lights until the plate reaches approximately 55°C. When this temperature is reached, L2 lights and the plate cools to approximately 50°C. Heating resumes, with the lighting of L1, and so on. This cycle continues indefinitely for as long as the bench is in operation.

5. MANIPULATIONS

Look up the operating instructions for the use of the RayCAm.
Before any new manipulation, create a new thermogram recording folder.
During the manipulations, save as many images as possible.

5.1 THERMAL TRANSFERS

5.1.1 Theory

To correctly understand the events involved, it is important to know the phenomena that underlie evolutions or changes of temperature.
There are three thermal transfer modes:

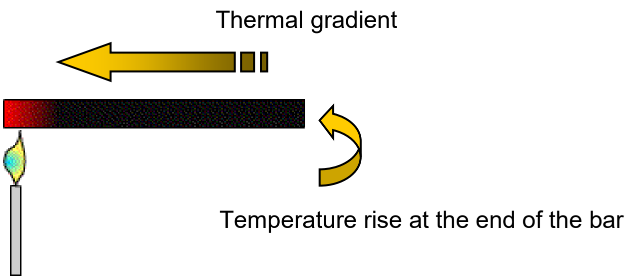
- Conduction
- Convection
- Radiation

These three modes can be present simultaneously, independently of one another.
A heat flux is a quantity of thermal energy per unit of time. A transfer flow occurs only when there is a temperature difference. Thermal energy is transferred from a hot body to a cold body.
It is necessary first of all to understand the thermal phenomena involved.

Conduction.

In physics, thermal conductivity is the parameter used to quantify the ability of a body to conduct heat. It represents the quantity of heat transferred per unit of area and per unit of time under the action of a temperature difference between the two ends of a sample of the body, and therefore in the presence of a temperature gradient.

Consider the example of a metal bar that is heated at one of its ends: the thermal agitation of the atoms located at the heated end of the bar increases and is transmitted step by step in the direction opposite the thermal gradient.

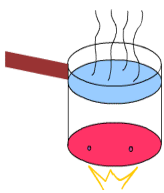


Application: see Appendix 3, exercise 1

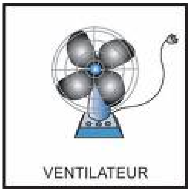
Convection.

A flow or circulation of a liquid or gas can transport with it a certain quantity of thermal energy. This transport of heat is called thermal CONVECTION. In convection, the heat uses the fluid as a vehicle to convey it. There are two types of convective transfers:

- Natural convection: when there is a temperature difference between two points in a fluid, the hot fluid tends to rise because of its buoyancy. This creates a natural circulation of the fluid under the effect of the heat, which is then transported by it: this is called natural convection.



- Forced convection in which the flow of the fluid is forced by some mechanical device (pump or gravity for a liquid, blower for air).



Forced convection is an undesirable phenomenon in infrared thermography. This is because forced convection cools the surface of a body without for all that altering its internal temperature.
For example, wind is a vector of forced convection. When there is wind, people feel cooler and their skin temperature may fall. But their internal temperature will not be modified at all! With or without wind, human body has a very fine regulation of its temperature.

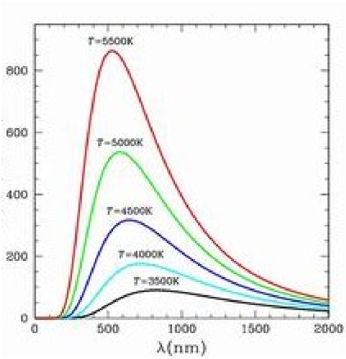
Since we measure only the surface temperatures of objects in thermography, our analysis will be wrong. This is because the surface of the material will be at a uniform temperature because of forced convection, but the internal temperatures may be different.

Application: see Appendix 3, exercise 2

Radiation: case of the full radiator or black body.

Anybody at a temperature above 0 degree kelvin (absolute zero, or -273.15°C) emits electromagnetic radiation called thermal radiation. Infrared radiation is electromagnetic radiation of which the wavelength is between 700 nanometres and 1 millimetre.
Given the law of the conservation of energy, for a body to radiate, it must be the source of the energy: this is an internal energy.
In thermography, the radiation is used to measure the temperature of the body.
For each given temperature and wavelength, there is a maximum radiated energy that nobody can exceed. This information is provided by Planck's curves:

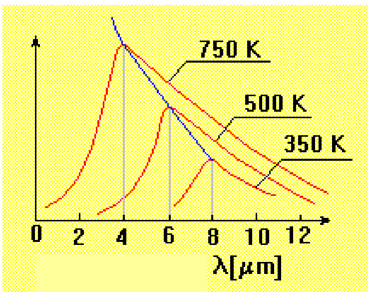
Radiated energy



Wien's law gives the wavelength (in micrometers) corresponding to the maximum radiated energy of a black body at a specified temperature T (in Kelvin).

$$\lambda_{max} = \frac{2898}{T}$$

The wavelength of the infrared radiation maximum decreases as the temperature of the black body increases.



The Stefan-Boltzmann law is used to quantify these exchanges. The energy E radiated by a body is written:

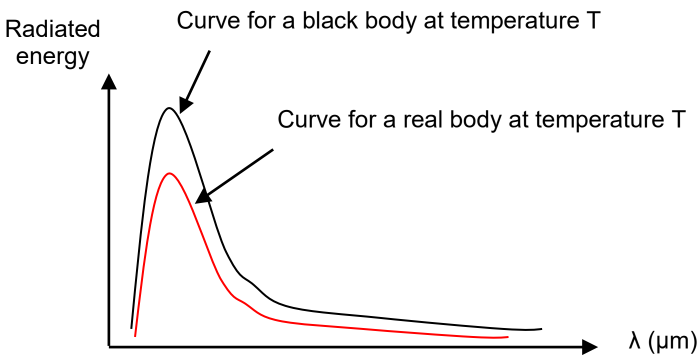
$$E = S.\ \sigma.\ T^4$$

With:
E: radiated energy expressed in W/m².
σ: Stefan-Boltzmann constant = 5.6703 x 10^{-8} W.m^{-2}.K^{-4}
S: area of the body expressed in m²
T: temperature of the body in Kelvin

A black body is a body of which the surface absorbs all radiation received.
NB: a black body is not a real thing, but an idealized object from which the only outgoing radiation is thermal radiation, determined solely by the body's own temperature.
Application: see appendix 3, exercises 3 and 4

Emissivity

The emissivity of a material (often written ε), is the ratio of the energy it radiates to the energy a black body would radiate at the same temperature. It is therefore a measure of the capacity of a body to absorb and re-emit radiant energy.
The emissivity is a quantity between 0 and 1.
The laws stated earlier are not strictly true without qualification, making it necessary to introduce this parameter, the emissivity.
Planck's curve above then becomes:

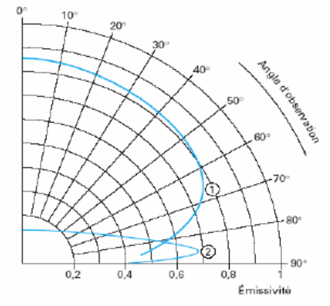


The lower the emissivity, the lower the maximum of the curve.
The Stefan-Boltzmann law then becomes:

$$E = \varepsilon . S . \sigma . T^4$$

The emissivity of a material is a characteristic of that material and of its surface condition. The more capable a body is of absorbing heat, the closer its emissivity to 1. There are nomographs indicating the emissivities of various materials.
To make valid measurements in thermography, it is necessary to perform manipulations on bodies having a high emissivity ($\varepsilon > 0.8$). This applies to opaque plastics, oxidized metals, wood and building materials, paints, etc. If a user must make measurements on materials having a low emissivity, we recommend first applying black paint to them, then performing the manipulation. Very large measurement errors can result from neglecting or misjudging this parameter.

Another parameter that influences the emissivity is the measurement angle. According to the graph below:



Thus, to make a valid measurement, it is necessary to place the camera perpendicular to the measurement target (facing it squarely) so that the emissivity entering the camera reflects reality. A tolerance of +/- 45° is accepted.

The emissivity is a fundamental parameter in thermography. It is essential to set it correctly before making any measurement. For this purpose, it is enough to know the material of which the temperature is to be determined and enter the corresponding emissivity in the camera.
If no information is available about the type of the body concerned, there is a standard that specifies how to determine this parameter (See Appendix 1).

5.1.2 Manipulations: study of the influence of emissivity

Manipulation 1: Highlighting the problems of measurement on materials having different emissivities.

Make sure that the temperature of the bench has been stable for a few moments.
Aim the camera at the hot plate, making sure that you are correctly positioned in front of the bench.

- The field of view of the camera must include the central plate and at least one of the 6 outer plates.
Is this the case?
What conclusion can you draw?

- Using the technique for determining emissivity described in appendix 1, determine the emissivities of the various plates.

- Place a piece of black adhesive tape on one of the 6 outer plates. Aim the camera at this plate again.
What do you observe?
What conclusion can you draw?

Manipulation 2: Highlighting the problems of positioning with respect to the target.

Create a new folder.

- Aim the camera at the hot plate, making sure that you are correctly positioned perpendicular to the bench. Target the black zone in the centre, which has a high emissivity, close to 0.95.

- Make a temperature measurement at the centre of the plate.

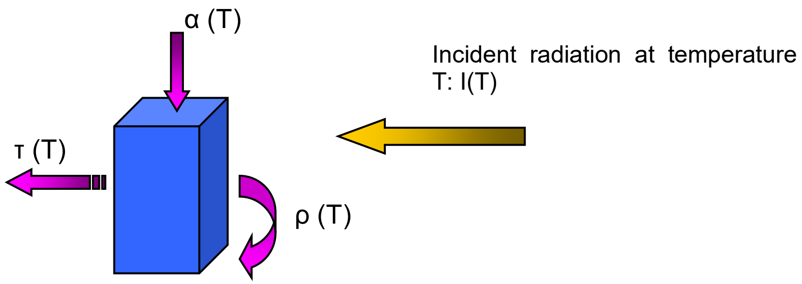
- Tilt your camera slightly. Make another temperature measurement.

- Repeat the operation, tilting your camera again, by approximately 10° each time, and record the temperature.
What conclusion can you draw?

5.2 STUDY OF THE REAL BODY

5.2.1 Theory

The black body is a theoretical object. The formulas given above can be applied to a real object only with a few corrections: real objects absorb only a fraction α of the incident radiation, reflecting a part ρ and transmitting a fraction τ.



The principle of the conservation of energy yields the following equation:

$$\alpha \,.\, I(T) + \rho \,.\, I(T) + \tau \,.\, I(T) = I(T)\ ,$$
$$\text{or } \alpha + \rho + \tau = 1$$

At equilibrium, the object emits ε (T) the same quantity of energy as it absorbs α (T). This gives the following equation:

$$\alpha \,.\, I(T) = \varepsilon \,.\, I(T)$$
$$\text{or } \alpha = \varepsilon$$

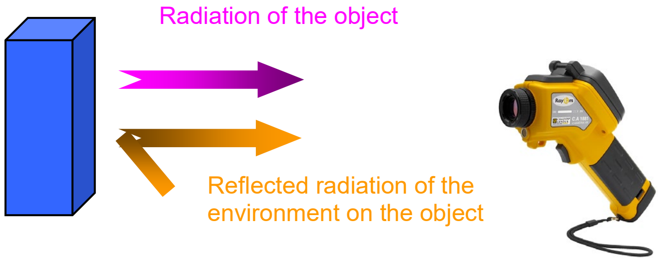
Whence:

$$\varepsilon + \rho + \tau = 1$$

In thermography, it is possible to make measurements only on opaque bodies. The transmission of the materials is therefore zero.
This gives the equation:

$$\varepsilon + \rho = 1$$
$$\text{and } \rho = 1 - \varepsilon$$

Thus, when making a measurement by thermography, it is necessary to make allowance for reflected "ambient" radiation. A real measurement situation is therefore:



And the total radiation received by the camera is therefore:

$$R_{measured} = R_{object} + R_{reflected}$$

$$\varepsilon . \sigma . (T_{object})^4 \qquad \rho . \sigma . (T_{reflected})^4$$

Whence:

$$R_{measured} = \varepsilon . \sigma . (T_{object})^4 + \rho . \sigma . (T_{reflected})^4$$

$$= \varepsilon . \sigma . (T_{object})^4 + (1 - \varepsilon) . \sigma . (T_{reflected})^4$$

To obtain the temperature of the object, it is therefore necessary to enter the emissivity and reflected temperature parameters in the RayCAm.

The reflected temperature corresponds to the ambient temperature near the target. If nothing interferes with the target to be inspected, this temperature corresponds to the ambient temperature.

If a hot or cold source near the target gives off heat, there is a standard that specifies how to determine the resulting reflected temperature (See Appendix 2).

Application: see appendix 3, exercise 5

5.2.2 Manipulations: study of the influence of reflection and transmission

Manipulation 3: Highlighting of the problems of measurement linked to reflection phenomena

Create a new folder.
- Position the camera in front of the aluminium plate: shiny, having a low emissivity, and therefore strongly reflecting.
- Make a measurement with your body in front of the plate.
- Make a measurement with your body shifted so as to be no longer in front of the plate.
- What conclusion can you draw?

Manipulation 4: Highlighting of the problems of measurement linked to problems of transmission.

Create a new folder.

- Make a temperature measurement on the black plate in the centre, the emissivity of which is 0.95.
- Place test screen number 1 (plexiglas window) on the zone provided for it on the bench.
Wait 2-3 minutes for the temperature of the environment to become uniform.
Target the black plate through the plexiglas pane and make a temperature measurement. Remove the pane and take a measurement one more time.
- What conclusion can you draw?

5.3 OPTICS AND THERMOGRAPHY CAMERA

5.3.1 Theory: study of the spatial resolution.

Observation Spatial Resolving Power (PRSO).

The Observation Spatial Resolving Power (PRSO) can be defined by an angle. It is known as the IFOV (Instantaneous Field Of View) angle, and is the angle at which a detector of the matrix sees an elementary surface (Δs) of the thermal scene.
The difficulty in defining IFOV lies in the fact that the dimensions of the matrix sensors are not standardized. So an objective is designated not by its focal length, but by the FOV (Field Of View) angle at which the camera sees the thermal scene. There are in fact two FOVs:

- HFOV: horizontal angle
- VFOV: vertical angle

Starting from this, IFOV can be defined by the equation:

$$\text{IFOV}\ (°) = \frac{\text{HFOV}}{\text{ndH}} = \frac{\text{VFOV}}{\text{ndV}}$$

With:

- ndH: number of detectors on the horizontal of the matrix
- ndV: number of detectors on the vertical of the matrix

In practice, the IFOV is generally expressed at milliradians (mrad), which corresponds to an elementary surface in mm seen at a distance of 1 m (…mm@1m).

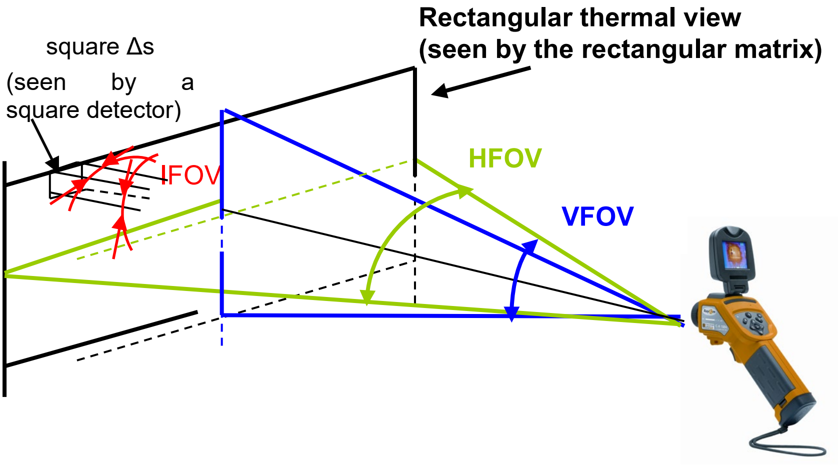
Whence the equation:

$$\text{IFOV (mrad)} = \frac{\text{HFOV} \times \pi \times 1000}{\text{ndH} \times 180°} = \frac{\text{VFOV} \times \pi \times 1000}{\text{ndV} \times 180°} = \text{PRSO}$$

The IFOV corresponds to the spatial resolution of the camera, i.e. to the dimension of the zone a detector can measure. This dimension depends on the camera's distance from the target.

The closer the camera to the zone to be inspected, the smaller the IFOV and the smaller the objects the camera perceives.

Diagram summing up the various concepts:



Application: see appendix 3, exercise 6.

Measurement Spatial Resolving Power (PRSM).

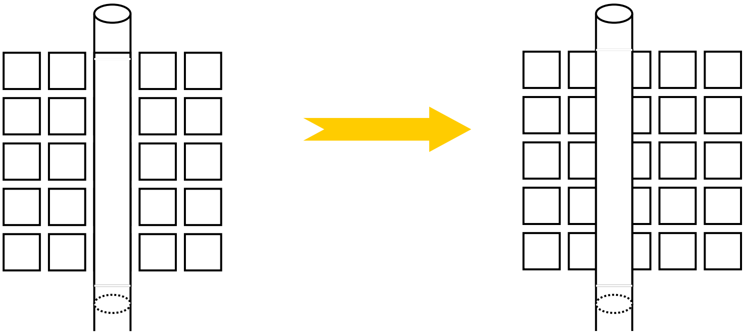
For temperature measurements, as opposed to thermal imaging, it is necessary to consider the metrological character of the camera.

This is because each detector is independent and makes a measurement of the radiation received over the whole of its zone. The detector determines the mean of the total radiation received and indicates the corresponding temperature to the user.

Consider the case of determining the temperature of a wire.

Case no. 1:
The wire is the size of 1 IFOV.
To be sure of making a valid measurement, the wire must be positioned like this:

In reality, there is a greater risk of having this configuration:



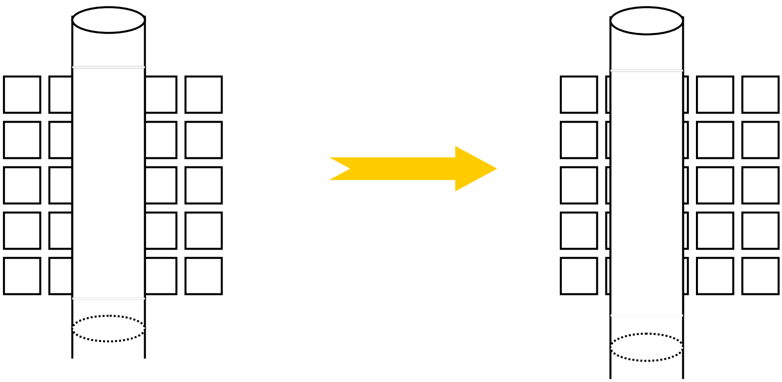
In this configuration, we find the correct temperature

No detector is completely covered: no valid response on any of the detectors!!!

But this configuration is not realistic!

Case no. 2:
The wire is the size of 2 IFOVs.
To be sure of making a valid measurement, the wire must be positioned like this:

In reality, there is a greater risk of having this configuration:

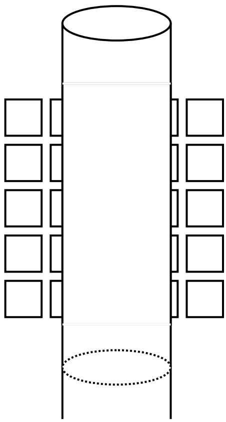


In this configuration, we obtain a valid temperature reading

Once again, no detector is completely covered: no valid response on any of the detectors!!!

We are still not sure of making a valid temperature measurement.
This configuration too is unrealistic!!

Case no. 3:
The wire is the size of 3 IFOVs.



Anywhere the wire is placed, there will necessarily be at least one detector covered!
The measurement is therefore reliable.

Conclusion:

To ensure that a valid measurement is made, the image of the target aimed at must cover at least three detectors.

The smallest zone measurable by the camera therefore corresponds to 3 IFOVs.

Or:

PRSM = 3 PRSO

Application: see appendix 3, exercises 7 to 9.

5.3.2 Manipulation: study of spatial resolution.

Place test screen number 2 (slits) in the zone provided for it on the bench.
Wait 2-3 minutes for the temperature of the environment to become uniform.

- Position the RayCAm 10 cm from screen no. 2.
Make a thermogram of each series of slits.
Using the cursors, determine the temperature of each slit.
What is your conclusion?

- Position the RayCAm 30 cm from screen no. 2.
Make a thermogram of each series of slits.
Using the cursors, determine the temperature of each slit.
What is your conclusion?

- Position the RayCAm 80 cm from screen no. 2.
Make a thermogram of each series of slits.
Using the cursors, determine the temperature of each slit.
What is your conclusion?

What have you learned from this manipulation?

5.4 MANIPULATIONS ON SOFTWARE

See the operating instructions for the use of the RayCAm *report* software.

The objective is to sum up the various measurements explained above using the RayCAm report software and images saved in the camera.

Manipulation 1: transfer and archiving of the thermograms

Connect the camera to a PC using the USB cable provided.
The PC recognizes the RayCAm as an external hard disc.
Open the directory corresponding to the camera, select the various folders, and transfer them to the hard disc of the PC.

Rename the folders according to the various manipulations performed:

- Emissivity of materials
- Positioning
- Reflection
- Transmission
- Spatial resolution

Manipulation 2: study of the influence of emissivity

- Open the software and create as many infrared zones as there are images in the "Emissivity of materials" folder.
Insert one thermogram per zone.
- Insert points on each material and type of surface of each thermogram.

- Create one table zone per thermogram.
Enter the following elements in the table: number and emissivity of IR image, temperature and emissivity of the points.

- Modify the emissivity of the points until you obtain the temperature of the black plate.

- Compare your results with those obtained using the camera.

Manipulation 3: study of spatial resolution

- Open a new report page and create as many infrared zones as there are images in the "Spatial resolution" folder.
Insert one thermogram per zone.

- Insert points on each slit of each thermogram.

- Insert one line on each series of slits.

- Create one analysis line tool zone per thermogram. Possibly, connect several analysis lines if you have inserted several lines in your thermogram.
Determine the temperature of each slit.

- Create one table zone per thermogram.
Enter the following elements in the table: number and emissivity of IR image, temperature of the points.

- Draw the conclusions that follow from the values displayed in the table, in a text box.

- Compare your results with those obtained using the camera.

5.5 THERMOGRAPHY IN PRACTICE

5.5.1 Fault determination modes.

Absolute thermography

This mode provides information about the condition of a component or of a material given its operating conditions at the time.
The question that must then be asked is: is this below or above the maximum indicated by the manufacturer?

When IR thermography is incorporated in predictive maintenance procedures, it is possible to trace the time course of the absolute temperature, then extrapolate in order to know the date on which a component, because of its ageing, will have to be changed.

Qualitative comparative thermography

Considering that it is not always possible to determine temperatures correctly, one may settle in some circumstances for proceeding qualitatively, by adjusting the camera in the same way between two scenes and working only on the apparent differences in the image.

Quantitative comparative thermography

Quantitative comparative thermography consists in comparing a material or a component assumed to be defective with an equivalent, operating under similar conditions, taken as a sound reference.
Here are some data concerning recommendations to be set in place; this manner of determining degrees of maintenance is used for electrical and mechanical maintenance:

Difference (ΔT) based on comparison of identical components working under the same load conditions	Criterion of severity
< 10°C	Possible. Keep under surveillance until the next maintenance already planned
10°C to 20°C	Intermediate. Corrective measures to be set in place, scheduled (~ 3 months)
20°C to 40°C	Serious. Corrective measures are urgent (max. 1 month)
> 40°C	Critical. Corrective measures must be taken immediately (max. 1 week)

Application: see appendix 3, exercise 10

5.5.2 Applications

Electrical maintenance

The purpose of an inspection of this type is to detect, in electrical infrastructure under load, temperature rises of various origins:

- incorrect connections,
- overloads,
- phase imbalances,
- faulty contacts, etc.

This is in order to anticipate and prevent:

- damage to expensive equipment,
- production stoppages,
- operating losses,
- fires, etc.

The objective is to provide information on which to base decisions so that corrective work can be done, and any work needed can be foreseen and anticipated, because identified, and thereby facilitate the maintenance of electrical installations (time saved and safety enhanced)

The methodology to be applied for an electrical maintenance inspection is the following:
A systematic sweep of the whole electrical installation is performed (if needed and where possible, a view from the back is taken).
The systems examined are in operation, and the elements making up the electrical installation are under normal load. In fact, they will appear, in the infrared image, more or less radiant according to their role, their design, their load, their material.
The operator must distinguish between the normal and anomalous operating temperatures. When the anomalies have been physically located, the parameters of the object (emissivity, ambience, etc.) can be adjusted to allow direct calculation of the maximum temperature observed and any overheating.

If the system is not at its normal load, a further calculation can be performed to estimate the overheating referred to normal operation.

It is assumed that a fault is resistive in character. The raw temperature difference must be corrected for the load:

$$\Delta T_{effective} = \Delta T_{raw} \times (I_{nominal}/I_{measured})^2$$

It is the effective difference that must be considered when classifying the fault.

It remains to be determined how urgent maintenance is. This determination is very important, because it provides a veritable location in time; whence easy management of the processing of the anomalies.
An infrared image and a photograph in visible light record the fault.

Application: see appendix 3, exercise 11

Application: mechanical maintenance

Mechanical parts in movement are normally heated because of friction. Infrared thermography is used to reveal abnormal temperature rises due to:

- wear
- misalignment
- a lubrication problem.

This means of investigation is used primarily on motor-pump and motor-blower sets. It is used as a complement to a vibration analysis, which is much more cumbersome to set up.

A single image shows us the soundness of the electric motor, of its power supply (cables), of the bearings, and possibly of the alignment.
It remains to be determined how urgent maintenance is.

Application: building heating and cooling

These applications of infrared thermography concern architects, the installers of heating and sanitary systems, the operators of heating systems, electricians, real estate companies, real estate experts, owners, and insurers.

Using infrared radiation, it is easy to visualize the distribution of heat on the outside wall of a building and it is possible to precisely locate heat losses due to insulation defects. This makes it possible to draw up a thermal assessment of a building.

It is also possible to visualize underground piping:
- In-floor heating:
    - Locating leaks: pipes that convey a hot fluid and are just below the surface of a floor are readily visualized, and it is possible to precisely locate leaks in a network.
    - Location of heating elements: it may be necessary to locate pipes precisely with a view to drilling into a floor for work.
- Heat distribution networks (urban heating systems): tracking underground piping, locating leaks in the underground networks or in gutters.

5.6 PRODUCING A Q19 REPORT

5.6.1 Presentation

An inspection of electrical installations by infrared thermography, performed in accordance with the technical specifications of the APSAD D19 document, leads to the issuance of the Q19: declaration of inspection of an electrical installation by infrared thermography, which may be of use in negotiating the amount of the insurance premium your company pays.

The constraints of such an inspection are the following:
- ➢ Make available to the thermographer, before the inspection:
    - A complete and detailed list of the equipment to be checked.
    - Information about the technological constraints to be taken into consideration (existence of guard plates, particular operating conditions, etc.)

- Information about the existence of locations, zones, or rooms where there is a particular fire or explosion risk.

➢ Agree to:

- Have the thermographer accompanied in the installations by a technician belonging to the relevant department.
- Read the inspection report in order to remedy, within the times indicated, the faults reported, especially when they are likely to cause a fire.
- Communicate a copy of the Q19 declaration to the insurance company within fifteen days after reception of the report.

The commitments of the thermographer:

➢ Record, using the list of equipment to be inspected, the various observations essential to understanding and solving the problems (intensity / current, remarks, type and urgency of anomalies)

➢ Guarantee the competence of the operator: Each member of the inspection team is BR H1V accredited and holds the certificate of "Operator for the inspection of electrical installations by infrared thermography" issued by the CNPP.

➢ Provide, as soon as the inspection is over, a first oral or written report describing the course of the inspection and report the most urgent anomalies.

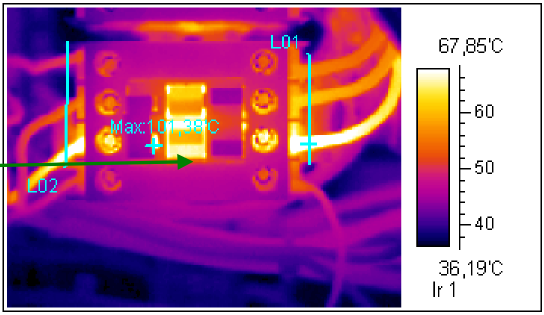
➢ Write and forward, within fifteen days following the inspection, an inspection report including:

- A description of the inspection
- A detailed list of the equipment checked
- A summary table of the anomalies found
- An overall assessment of the electrical installations
- Anomaly sheets containing:
  - An infrared image of the anomaly,
  - A photograph in visible light,
  - The location and definition of the equipment,
  - The maximum temperature observed at the level of the anomaly (+/– 5%),
  - The temperature profile,
  - The estimated degree of urgency.
- The electrical accreditation and APSAD certification of the operator
- The certificate of calibration of the infrared camera
- The Q19 declaration of inspection of an electrical installation by infrared thermography called for in clause no. 27c of the APSAD fire insurance treaties

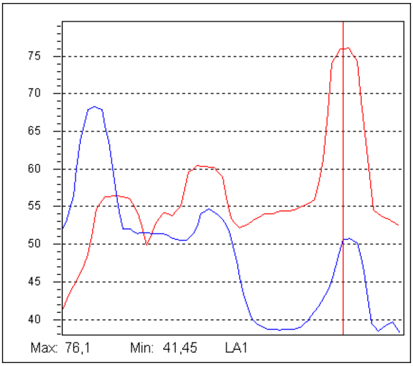
Below is an example of an anomaly sheet corresponding to an inspection by infrared thermography.

THERMOGRAPHIC INSPECTION
Anomaly sheet no. 1
Station:
Equipment:
Load: 100%

CHAUVIN® ARNOUX
CHAUVIN ARNOUX GROUP



IR Info	Value
IrNo	1
ems	0.9
dist	1
envtmp	25
Date	2003-9-3
Time	12:52:39
Label	**Value**
Max:Temp	101.38
Max:ems	0.9
Max:dist	1



Diagnostic:

Recommendation:

CONCLUSION:

..
Checked by: Mr..............

Inspected on: ../../2... by Mr ....
Repair inspected on ../../2... by Mr ....

Degree of urgency:
Immediate repair — X
Repair within 1 month
Surveillance required

5.6.2 Application

Using an electrical cabinet present in the room, make thermograms of the installation and prepare a report based on the Q19 model.

6. MAINTENANCE

The manufacturer cannot be held liable for any accident that occurs following a repair done by a party other than its customer service department or an approved repairer.

Maintenance:
Cleaning:
- Disconnect the device from the power network;
- Clean using a cloth moistened with soapy water and rinse using a cloth moistened with plain water;
- Let dry completely before using again.

Resetting the safety thermostat:

Disconnect the device from the power network; or press the button on the back of the housing
Unhinge the cover by actuating the two clips;
Open the housing by unscrewing the five screws of the bottom;
Press the button at the centre of the thermostat until it trips;
Reassemble the device.

If it trips out again without a real reason, that is a sign of a fault.

6.1 REPAIR

For all repairs before or after expiry of warranty, please return the device to your distributor.

6.2 CHANGE OF FUSE

Disconnect the device from the power network;
Between the plug and the On/Off button, press the two tabs to withdraw the fuse holder.
To preserve the same level of safety, replace the defective fuse only by a fuse having strictly identical characteristics.
A replacement fuse is available in the fuse holder after it is opened.

7. WARRANTY

Our warranty is valid, except as otherwise expressly stipulated, for **24 months**, counting from the date on which the equipment is made available (extract from our General Terms of Sale, communicated on request).
The warranty does not apply following:

- inappropriate use of the equipment or use with incompatible equipment;
- modifications made to the equipment without the explicit permission of the manufacturer's technical staff;
- work done on the device by a person not approved by the manufacturer;
- adaptation to a particular application not anticipated in the definition of the equipment or not indicated in the operating instructions;
- damage by shocks, falls, or floods.

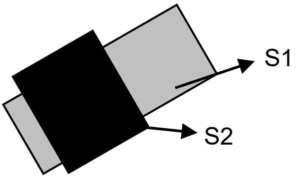
8. TO ORDER

C.A 1875
Supplied with a power cord, two accessory test screens, operating instructions including the problems manual in a carrying bag.

APPENDIX 1: DETERMINATION OF EMISSIVITY

The relevant standard is ASTM E1933-99A:

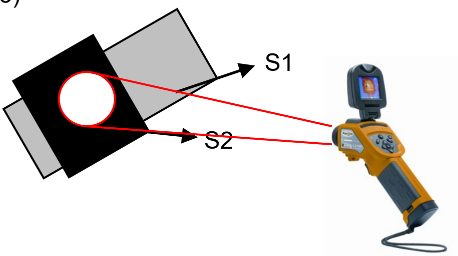
1)



Let S1 be the surface area of the material of which it is desired to determine the emissivity.
Apply to S1 a coat of black paint S2 of which the emissivity is known.

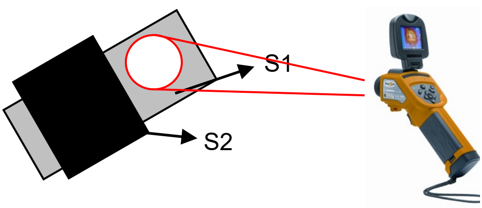
2) S1 and S2 being in the same environmental conditions, the two surfaces are at the same temperature.

3)



With the RayCAm, the temperature of S2 is measured with an emissivity of 0.95 parameterized in the camera.

4)



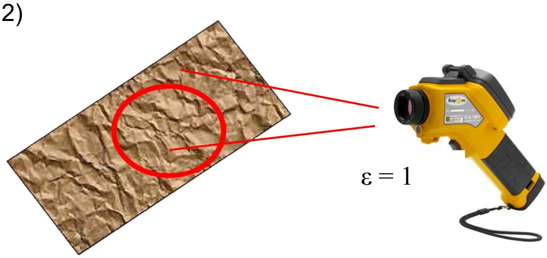
Once the temperature has been determined, the camera is shifted to the target of which the emissivity is unknown. It then suffices to change this parameter on the RayCAm until the temperature reading on the unknown target is the same as the temperature measured on S2. The emissivity of the body is then known.

APPENDIX 2: DETERMINATION OF REFLECTED TEMPERATURE

The relevant standard is ASTM E1933-99A:

1) A sheet of ordinary aluminium foil, crumpled and flattened, is placed as close as possible to the scene viewed, in the same orientation with respect to the camera.

2)



It is assumed that the sheet of aluminium is a perfect reflector on which is reflected a black body equivalent to the mean environment.
The emissivity setting of the camera is therefore: $\varepsilon = 1$

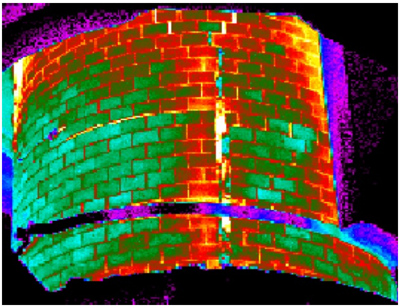
3) The temperature of the black body equivalent to the environment is measured on the sheet of aluminium, using an appropriate analysis tool - spot with averaging over several positions or, better still, the mean calculated over a large area.

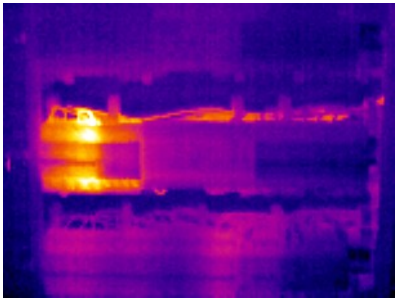
4) This Reflected Temperature must be entered into the computer by hand. It becomes active when the emissivity of a real object is less than 1.

APPENDIX 3: APPLICATION EXERCISES

Exercise 1

Highlighting of conduction in IR thermography:



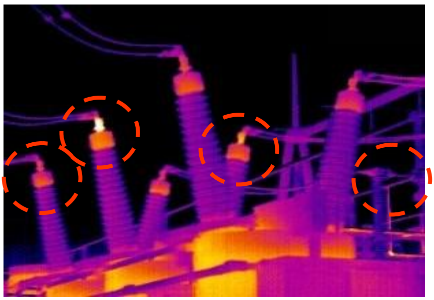


Comment on these two images.

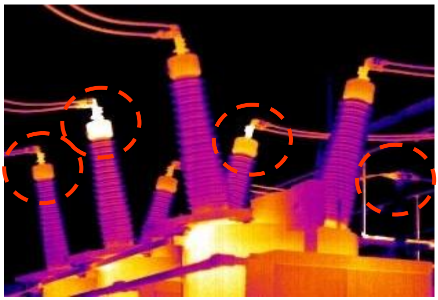
Exercise 2

Highlighting of the problems of forced convection in IR thermography.

Thermogram made in high wind



Thermogram made in still air



Exercise 3

A spherical black body having a radius of 5 cm emits 230 W of radiation.

a) What is the temperature of this body?

b) What is the wavelength corresponding to the maximum of radiated energy?

Exercise 4:

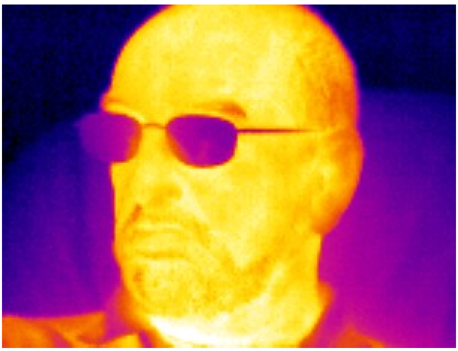
Based on estimates made on Earth, the area of the sun is 6.1×10^{18} m^2 and its radiated power is 3.9×10^{26} W.
Regarding the sun as a black body:

a) What is its surface temperature?

b) What is the wavelength corresponding to the maximum of radiated energy?

Exercise 5:

Highlighting of the problems of transmission in IR thermography.



Comment on this thermogram.

Exercise 6

From the characteristics of the RayCAm, determine the IFOV of the camera in mrad and in …mm@1m:

a) For the vertical elements of the matrix

b) For the horizontal elements of the matrix

c) What is the smallest area the camera can detect?

Exercise 7

a) What is the width d_1 of the smallest zone the RayCAm can measure?

b) What is the width d_2 of the smallest zone the RayCAm can measure at 50 cm?

Exercise 8

From what distance should you measure the temperature:

a) Of a cable of 2 mm in diameter (d_1)?

b) Of a cable of 5 mm in diameter (d_2)?

c) Of a cable of 10 mm in diameter (d_3)?

Exercise 9

We want to determine the temperature of a 1.5 mm^2 cable.

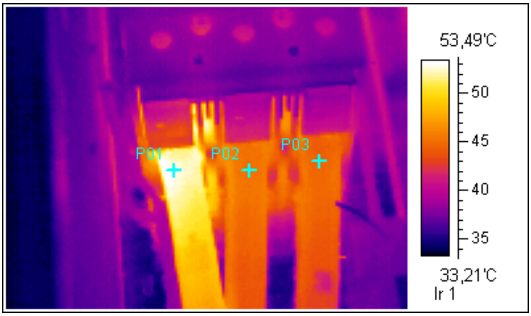
a) Using a standard objective, at what distance d_1 must I be to make a valid measurement?

b) Can I use a wide-IFOV-angle 4.1mrad objective? If so, from what distance?

Exercise 10

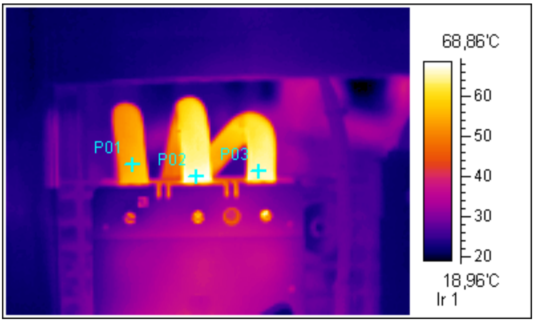
Determine the degrees of urgency of maintenance of the thermograms below.

Thermogram 1



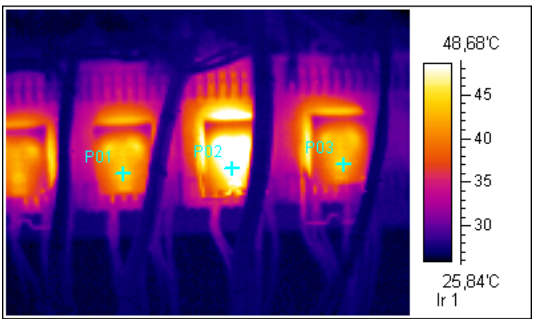
P01	52.8°C
P02	45.5°C
P03	45°C

Thermogram 2



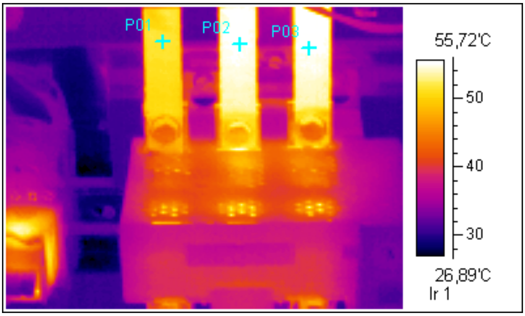
P01	57.9°C
P02	68°C
P03	67.4°C

Thermogram 3



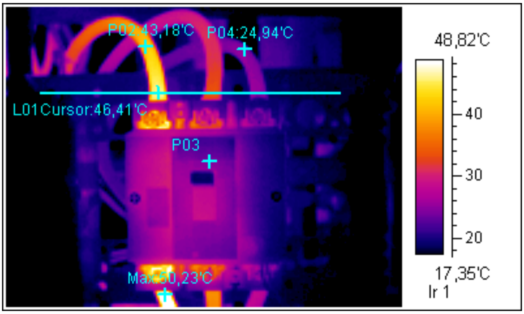
P01	45.5°C
P02	51.6°C
P03	44.7°C

Thermogram 4



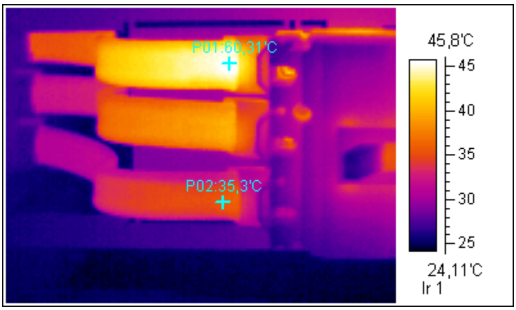
P01	51.3°C
P02	55.3°C
P03	55.4°C

Thermogram 5



P02	43.2°C
P04	24.9°C

Thermogram 6



P01	60.3°C
P04	35.3°C

Exercise 11

Determine the degrees of urgency of maintenance of the thermograms above assuming that:

- Thermogram 1 was made at 60% of nominal load
- Thermogram 2 was made at 90% of nominal load
- Thermogram 3 was made at 85% of nominal load
- Thermogram 4 was made at 40% of nominal load
- Thermogram 5 was made at 90% of nominal load
- Thermogram 6 was made at 100% of nominal load

APPENDIX 4: SOLUTIONS

Solution 1

Thermogram 1:

This concerns the observation of a refractory using an infrared camera. The naked eye sees nothing. Normally, if the stack were correctly insulated, the temperature of the surface of the refractory should be uniform, and so its colour should be uniform. But we see a vertical line that is lighter in colour, and therefore hotter. It can be concluded that there is a defect and that the refractory has started to crack.

Thermogram 2:

By conduction, the heat is propagated along the cable. It can be seen that the wire is hot, but this is not a defect; the problem lies elsewhere!
This illustrates the point that you must be cautious if you find a cable with a higher temperature during the inspection; check on both sides of the hot spot to determine the exact origin of the fault (it is the hottest point that is the source of the problem).

Solution 2

Thermogram 1

The image was made in a high wind, and the air has made the surface temperatures of the surrounding objects uniform. But infrared thermography is a surface measurement technique. In consequence, nothing can be observed using a camera, and any problems will go undetected. The temperature at the surface of the objects is uniform and the thermogram shows a uniform colour.
Wrong interpretation of the image, in which problems may be overlooked.

Thermogram 2

The image was made in still air, which does not affect the results. The surface temperatures of the objects observed therefore correctly correspond to their internal temperatures. Hot spots are revealed in this way, as a lighter colour in some parts of the thermogram.
Correct interpretation of the image and of the system, revealing problems.

Solution 3

<u>Question a</u>
Stefan's law:

$$P = S\ \varepsilon\ \sigma\ T^4$$

With $\varepsilon = 1$ because black body
$\sigma = 5.68 \times 10^{-8}$ Boltzmann's constant
$S = \pi R^2$ surface of a ball

Whence:

$T^4 = P/S\ \varepsilon\ \sigma$ => $T = 847\ °K = 574°C$

<u>Question b</u>
Wien's law:

$\lambda_{max}\ T$ = Constant
= 2 898 µm.K

Whence:

$\lambda_{max} = 2\ 898/T$ => $\lambda_{max} = 3.42$ µm

Solution 4

<u>Question a</u>
Stefan's law:

$$P = S\ \varepsilon\ \sigma\ T^4$$

With $\varepsilon = 1$ because black body
$\sigma = 5.68 \times 10^{-8}$ Boltzmann's constant

Whence:

$T^4 = P/S\ \varepsilon\ \sigma$ => $T = 5{,}792°K$

<u>Question b</u>
Wien's law:

$\lambda_{max}\ T$ = Constant
= 2,898 µm.K

Whence:

$\lambda_{max} = 2{,}898/T$ => $\lambda_{max} = 0.5$ µm

We are in visible light, which is why the sun looks yellow to us, etc.

Solution 5

This is a thermographic image of a face with glasses.
We can see that the glasses are colder than the person's face.
Off hand, we might conclude that the person's eyes are colder than the rest of the person's face.

This analysis is of course false: it simply reveals a transmission problem! As it happens, it is not possible to observe and measure temperatures through glass! Whence this false measurement!

Solution 6

Question a

According to the definition of the IFOV:

$$IFOV\ (°) = \frac{VFOV \times \pi \times 1000}{ndV \times 180°}$$

With VFOV = 15° (vertical viewing angle)

ndV = 120 (number of detectors on the vertical of the matrix)

Whence:

IFOV = 2.18 mrad

A detector sees an elementary surface of 2.18 mm at a distance of 1 m

Question b

According to the definition of the IFOV:

$$IFOV\ (°) = \frac{HFOV \times \pi \times 1000}{ndH \times 180°}$$

With HFOV = 20° (vertical viewing angle

ndH = 160 (number of detectors on the vertical of the matrix)

Whence:

IFOV = 2.18 mrad

A detector sees an elementary surface of 2.18 mm at a distance of 1 m

We find the same IFOV on the vertical elements and on the horizontal elements.

Question c

The minimum focal length of the RayCAm is 10 cm.

Based on the results above, the RayCAm detects a zone measuring 2.18 mm by 2.18 mm at a distance of 1 m.

It follows that:

At 1 m Δs_1 = 2.18 mm

At 10 cm Δs_2 = x mm

Whence:

Δs_2 = 0.218 mm

Solution 7

Question a

The IFOV of the RayCAm is 2.2 mrad.
The minimal focal length is 10 cm.
The smallest zone that can be measured corresponds to 3 IFOV.
We therefore find:

$d_1 = 3 \times IFOV_{10\ cm}$

Whence:

$d_1 = 0.66$ mm

Question b

The IFOV of the RayCAm is 2.2 mrad.
It follows that:

at 1 m $\Delta s_1 = 2.2$ mm
at 50 cm $\Delta s_2 = x$ mm

Moreover $d_2 = 3 \times IFOV_{50\ cm}$
$= 3 \times \Delta s_2$

Whence:

$d_2 = 3.3$ mm

Solution 8

Question a

To be sure of making a valid measurement, the following value must not be exceeded:

$d_{Cable} = 3 \times \Delta s_2$

In addition, based on the IFOV of the camera:

at 1 m $\Delta s_1 = 2.2$ mm
at d_1m $\Delta s_2 = d_{Cable}/3$

It follows that:

$d_1 = \Delta s_2 / 2.2$
$= (d_{Cable}/3) / 2.2$

Whence:

$d_1 = 0.30$ m = 30 cm

The camera must be at a distance of not more than 30 cm to make a valid measurement.

Question b

To be sure of making a valid measurement, the following value must not be exceeded:

$d_{Cable} = 3 \times \Delta s_2$

In addition, based on the IFOV of the camera:

at 1 m	$\Delta s_1 = 2.2$ mm
at d_2m	$\Delta s_2 = d_{Cable}/3$

It follows that:

$d_2 = \Delta s_2 / 2.2$

$= (d_{Cable}/3) / 2.2$

Whence:

$d_2 = 0.76$ m = 76 cm

The camera must be at a distance of not more than 76 cm to make a valid measurement.

Question c

To be sure of making a valid measurement, the following value must not be exceeded:

$d_{Cable} = 3 \times \Delta s_2$

In addition, based on the IFOV of the camera:

at 1 m	$\Delta s_1 = 2.2$ mm
at d_3m	$\Delta s_2 = d_{Cable} / 3$

It follows that:

$d_3 = \Delta s_{2\,/}\, 2.2$

$= (d_{Cable}/3) / 2.2$

Whence:

$d_3 = 1.5$ m

The camera must be at a distance of not more than 1.5 m to make a valid measurement.

Solution 9

Question a

The corresponding diameter d of the cable is:

$P = \pi \times (d/2)^2$

Therefore:

$d = ((4 \times P)/\pi)^{1/2}$

To be sure of making a valid measurement, the following value must not be exceeded:

$d_{Cable} = 3 \times \Delta s_2$

In addition, based on the IFOV of the camera:

at 1 m $\Delta s_1 = 2.2$ mm

at d_1m $\Delta s_2 = d_{Cable} / 3$

It follows that:

$d_1 = \Delta s_{2\,/}\, 2.2$

$= (d_{Cable}/3) / 2.2$

$= (((4 \times P)/\pi)^{1/2/}3\ ) / 2.2$

Whence:

$d_1 = 0.21$m = 21 cm

For a valid measurement to be made, the camera must be between 10 cm and 21cm from the target.

Question b

To be sure of making a valid measurement, the following value must not be exceeded:

$d_{Cable} = 3 \times \Delta s_2$

In addition, based on the IFOV of the camera:

at 1 m $\Delta s_1 = 4.1$ mm

at d_1m $\Delta s_2 = d_{Cable} / 3$

It follows that:

$d_1 = \Delta s_{2\,/}\, 2.2$

$= (d_{Cable}/3) / 2.2$

$= (((4 \times P)/\pi)^{1/2/}3) / 4.1$

Whence:

$d_1 = 0.11$ m = 11 cm

It is possible to use a wide-angle lens.

For a valid measurement to be made, the camera must be between 1 cm and 11 cm from the target

Solution 10

Thermogram 1
From the temperatures of the cursors, let us determine the difference of temperature between P01 and P02:

$$\Delta T = T_{P01} - T_{P02}$$
$$= 52.8 - 45.5$$
$$\Delta T = 7.3°C$$

Whence a degree of criticality of level 0, requiring surveillance.

Thermogram 2
From the temperatures of the cursors, let us determine the difference of temperature between P01 and P02:

$$\Delta T = T_{P02} - T_{P01}$$
$$= 68 - 57.9$$
$$\Delta T = 10.1°C$$

Whence a degree of criticality of level 1; plan corrective action in from 3 to 6 months.

Thermogram 3
From the temperatures of the cursors, let us determine the difference of temperature between P01 and P02:

$$\Delta T = T_{P02} - T_{P01}$$
$$= 51.6 - 45.5$$
$$\Delta T = 6.1°C$$

Whence a degree of criticality of level 0, requiring surveillance.

Thermogram 4
From the temperatures of the cursors, let us determine the difference of temperature between P01 and P02:

$$\Delta T = T_{P02} - T_{P01}$$
$$= 55.3 - 51.3$$
$$\Delta T = 4°C$$

Whence a degree of criticality of level 0, requiring surveillance.

Thermogram 5
From the temperatures of the cursors, let us determine the difference of temperature between P02 and P04:

$$\Delta T = T_{P02} - T_{P04}$$
$$= 43.2 - 24.9$$
$$\Delta T = 18.3°C$$

Whence a degree of criticality of level 1; plan corrective action in from 3 to 6 months.

Thermogram 6
From the temperatures of the cursors, let us determine the difference of temperature between P02 and P01:

$\Delta T = T_{P01} - T_{P02}$
$= 60.3 - 35.3$
$\Delta T = 25°C$

Whence a degree of criticality of level 2; plan corrective action in from 1 to 3 months.

Solution 11

Thermogram 1
We find the equation:

$\Delta T_{effective} = \Delta T_{raw} \times (I_{nominal}/I_{measured})^2$

The installation was thermographed at 60% of its load, whence:

$I_{nominal}/I_{measured} = 100/60$

The measured temperature difference was 7.3°C
So:

$\Delta T_{effective} = \Delta T_{raw} \times (100/60)^2$
$= 7.3 \times (100/60)^2$
$= 20.3°C$

In reality, the degree of criticality is level 2, corrective action in from 1 to 3 months must be planned.

Thermogram 2
We find the equation:

$\Delta T_{effective} = \Delta T_{raw} \times (I_{nominal}/I_{measured})^2$

The installation was thermographed at 90% of its load, whence:

$I_{nominal}/I_{measured} = 100/90$

The measured temperature difference was 10.1°C
So:

$\Delta T_{effective} = \Delta T_{raw} \times (100/90)^2$
$= 10.1 \times (100/90)^2$
$= 12.5°C$

The degree of criticality is level 1; plan corrective action in from 3 to 6 months.
There is no significant influence of the load.

Thermogram 3
We find the equation:

$\Delta T_{effective} = \Delta T_{raw} \times (I_{nominal}/I_{measured})^2$

The installation was thermographed at 85% of its load, whence:

$I_{nominal}/I_{measured} = 100/85$

The measured temperature difference was 6.1°C

So:

$$\Delta T_{effective} = \Delta T_{raw} \times (100/85)^2$$
$$= 6.1 \times (100/85)^2$$
$$= 8.5°C$$

The degree of criticality is level 0; the evolution of the installation must be monitored.
There is no significant influence of the load.

Thermogram 4
We find the equation:

$$\Delta T_{effective} = \Delta T_{raw} \times (I_{nominal}/I_{measured})^2$$

The installation was thermographed at 40% of its load, whence:

$$I_{nominal}/I_{measured} = 100/40$$

The measured temperature difference was 4°C
So:

$$\Delta T_{effective} = \Delta T_{raw} \times (100/40)^2$$
$$= 4 \times (100/40)^2$$
$$= 25°C$$

After a first approach in which it seemed that there was no apparent fault, we find a degree of criticality of level 2! Corrective action in from 1 to 3 months must be planned.

Thermogram 5
We find the equation:

$$\Delta T_{effective} = \Delta T_{raw} \times (I_{nominal}/I_{measured})^2$$

The installation was thermographed at 90% of its load, whence:

$$I_{nominal}/I_{measured} = 100/90$$

The measured temperature difference was 18.3°C
So:

$$\Delta T_{effective} = \Delta T_{raw} \times (100/90)^2$$
$$= 4 \times (100/90)^2$$
$$= 22.6°C$$

Following this correction for the load, we go from a degree of criticality of level 1 to level 2! Corrective action in from 1 to 3 months must be planned.

Thermogram 6

The installation is at 100% of its load, so no correction is needed!

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