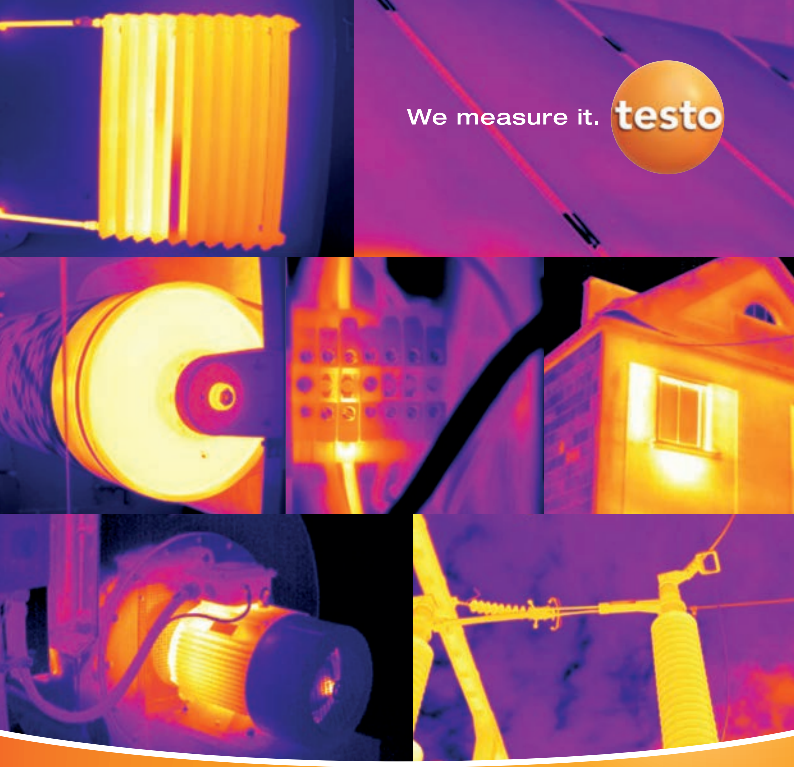


Pocket Guide Thermography

Theory – Practical Application – Tips & Tricks

Testo AG, October 2012

Foreword

Dear Testo customer,

“A picture says more than a thousand words”.
During times of rising energy prices and high costs for machinery downtimes, non-contact temperature measurement has established itself both for the assessment of building efficiency and for industrial maintenance. However, not all thermography is the same, and there are a few basic ground rules to be followed in non-contact temperature measurement.

The “Pocket Guide Thermography” handbook was created by summarising the questions raised by our customers on a day-to-day basis. Peppered with lots of interesting information and tips and tricks from practical measurement applications, this Pocket Guide is designed to offer you useful, practical help and support you in your daily work.

Have fun reading through it!

Daniel Auer,
Director, Thermography Division

Contents

1 Theory of thermography

Every object with a temperature above absolute zero (0 Kelvin = -273.15 °C) emits infrared radiation. This infrared radiation is invisible to the human eye.

As the physicists Josef Stefan and Ludwig Boltzmann proved as far back as 1884, there is a correlation between the temperature of a body and the intensity of the infrared radiation it emits. A thermal imager measures the long-wave infrared radiation received within its field of view. From this it calculates the temperature of the object to be measured. The calculation factors in the emissivity (e) of the surface of the measuring object and the compensation of the reflected temperature (RTC = reflected temperature compensation), both variables that can be set manually in the thermal imager. Each pixel of the detector represents a thermal spot that is shown on the display as a false colour image (cf. “Measuring spot and measuring distance”, p. 13).

Thermography (temperature measurement with a thermal imager) is a passive, non-contact measurement method. The thermal image shows the temperature distribution on the surface of an object. For this reason, you cannot look into or even through objects with a thermal imager.

1.1 Emission, reflection, transmission

The radiation recorded by the thermal imager consists of the emitted, reflected and transmitted long-wave infrared radiation emerging from the objects within the field of view of the thermal imager.

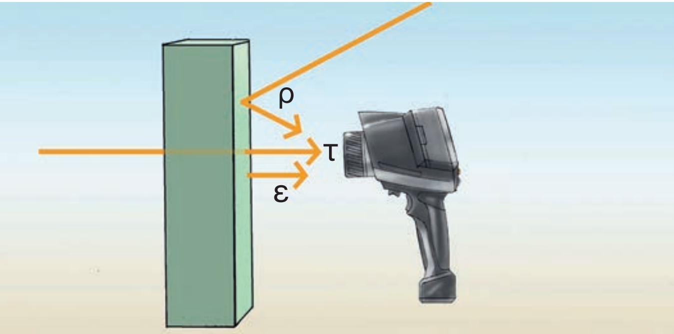
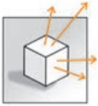


Figure 1.1: Emission, reflection and transmission



Emissivity (ε)
Emissivity (ε) is a measure of the ability of a material to emit (give off) infrared radiation.

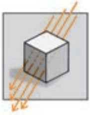
- ε depends on the surface properties, the material and, for some materials, also the temperature of the measuring object, as well as the spectral range of the thermal imager used.
- Maximum emissivity: e = 1 (100 %) (cf. “black body radiators”, p. 39). e = 1 never occurs in reality.

- Real bodies: ε < 1, because real bodies also reflect and possibly transmit radiation.
- Many non-metallic materials (e.g. PVC, concrete, organic substances) have high emissivity in the long-wave infrared range that is not dependent on the temperature (ε ≈ 0.8 – 0.95).
- Metals, particularly those with a shiny surface, have low emissivity that fluctuates with the temperature.
- ε can be set manually in the thermal imager.

Reflectance (ρ)

Reflectance (r) is a measure of the ability of a material to reflect infrared radiation.

- ρ depends on the surface properties, the temperature and the type of material.
- In general, smooth, polished surfaces reflect more strongly than rough, matt surfaces made of the same material.
- The temperature of the reflected radiation can be set manually in the thermal imager (RTC).
- In many measurement applications, the RTC corresponds to the ambient temperature (mainly in indoor thermography). In most cases you can measure this using the testo 810 air thermometer, for example.
- The RTC can be determined using a Lambert radiator (cf. “Measurement of reflected temperature using an (improvised) Lambert radiator”, p. 27).
- The angle of reflection of the reflected infrared radiation is always the same as the angle of incidence (cf. “specular reflection”, p. 31).



Transmittance (τ)

Transmittance (τ) is a measure of the ability of a material to transmit (allow through) infrared radiation.

- τ depends on the type and thickness of the material.
- Most materials are not transmissive, i.e. permeable, to long-wave infrared radiation.

Conservation of radiation energy according to Kirchhoff´s rules

The infrared radiation recorded by the thermal imager consists of:

- the radiation emitted by the measuring object;
- the reflection of ambient radiation and
- the transmission of radiation by the measuring object. (cf. Fig. 1.1, p. 6)

The sum of these parts is always taken to be 1 (100 %):

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

As transmission rarely plays a role in practice, the transmission τ is omitted and the formula

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

is simplified to

$$\varepsilon + \rho = 1.$$

For thermography this means:
The lower the emissivity,

- the higher the share of reflected infrared radiation,
- the harder it is to take an accurate temperature measurement and
- the more important it is that the reflected temperature compensation (RTC) is set correctly.

Correlation between emission and reflection

1. Measuring objects with high emissivity ($\varepsilon \geq 0.8$):
   - have low reflectance (ρ): $\rho = 1 - \varepsilon$
   - their temperature can be measured very easily with the thermal imager

2. Measuring objects with average emissivity ($0.6 < \varepsilon < 0.8$):
   - have average reflectance (ρ): $\rho = 1 - \varepsilon$
   - their temperature can be measured easily with the thermal imager

3. Measuring objects with low emissivity ($\varepsilon \leq 0.6$):
   - have high reflectance (ρ): $\rho = 1 - \varepsilon$
   - measuring the temperature with the thermal imager is possible, but you should examine the results very carefully
   - Setting the reflected temperature compensation (RTC) correctly is essential, as it is a major factor in the temperature calculation

Ensuring the emissivity setting is correct is particularly crucial where there are large differences in temperature between the measuring object and the measuring environment.

1. Where the temperature of the measuring object is higher than the ambient temperature (cf. heater shown in Fig. 1.2, p.11):
   - excessively high emissivity settings result in excessively low temperature readings (cf. imager 2)
   - excessively low emissivity settings result in excessively high temperature readings (cf. imager 1)

2. Where the temperature of the measuring object is lower than the ambient temperature (cf. door shown in Fig. 1.2, p.11):
   - excessively high emissivity settings result in excessively high temperature readings (cf. imager 2)
   - excessively low emissivity settings result in excessively low temperature readings (cf. imager 1)

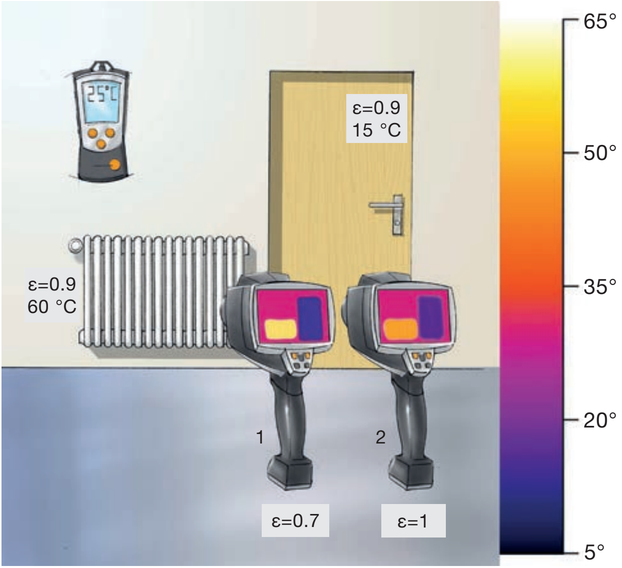


Figure 1.2: Effects of an incorrect emissivity setting on the temperature measurement

Please note: The greater the difference between the temperature of the measuring object and ambient temperature and the lower emissivity is, the greater the measurement errors. These errors increase if the emissivity setting is incorrect.

- You can only ever measure the temperatures of the surfaces with a thermal imager; you cannot look into something or through something.
- Many materials such as glass that are transparent to the human eye are not transmissive (permeable) to long-wave infrared radiation (cf. “Measurements on glass”, p. 30).
- Where necessary, remove any covers from the measuring object, otherwise the thermal imager will only measure the surface temperature of the cover.

  Caution:

  Always follow the operating instructions for the measuring object!
- The few transmissive materials include, for example, thin plastic sheets and germanium, the material from which the lens and the protective glass of a Testo thermal imager are made.
- If elements located underneath the surface affect the temperature distribution on the surface of the measuring object through conduction, structures of the internal design of the measuring object can often be identified on the thermal image. Nevertheless, the thermal imager only ever measures the surface temperature. An exact statement about the temperature values of elements within the measuring object is not possible.

1.2 Measuring spot and measuring distance

Three variables must be taken into account to determine the appropriate measuring distance and the maximum measuring object that is visible or measurable:

- the field of view (FOV);
- the smallest identifiable object ($IFOV_{geo}$), and
- the smallest measurable object / measuring spot ($IFOV_{meas}$).

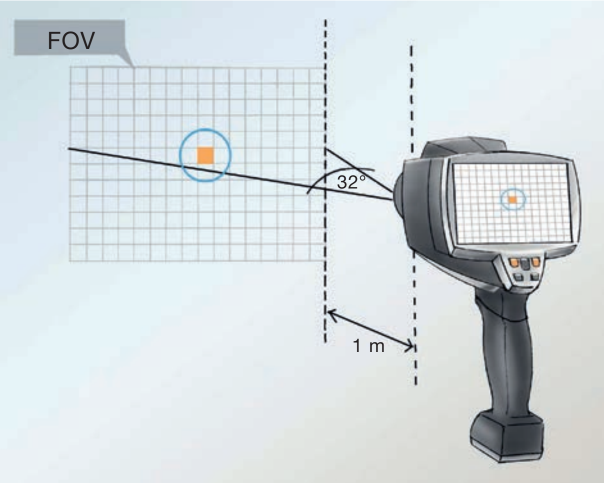


Figure 1.3: The field of view of the thermal imager

The field of view (FOV) of the thermal imager describes the area visible with the thermal imager (cf. Fig. 1.3, p. 13). It is determined by the lens used (e.g. 32° wide-angle lens or 9° telephoto lens – this telephoto lens is available as an accessory for the testo 875i).

To get a large field of view, you should use a wide-angle lens.

In addition, you should know the specification for the smallest identifiable object ($IFOV_{geo}$) of your thermal imager. This defines the size of a pixel according to the distance.
With a spatial resolution of the lens of 3.5 mrad and a measuring distance of 1 m, the smallest identifiable object ($IFOV_{geo}$) has

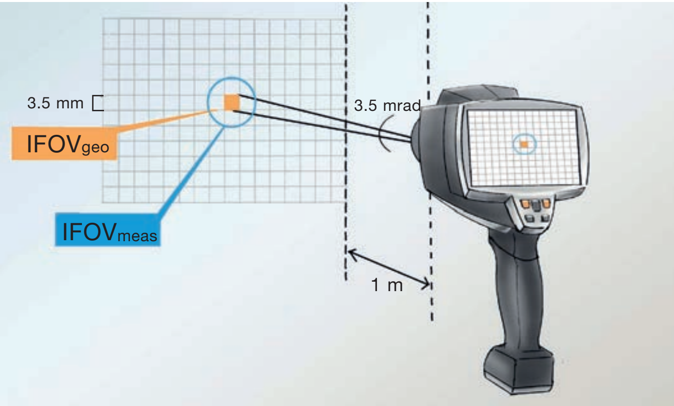


Figure 1.4: Field of view of a single pixel

an edge length of 3.5 mm and is shown on the display as a pixel (cf. Fig. 1.4, p. 14). To obtain a precise measurement, the measuring object should be 2–3 times larger than the smallest identifiable object ($IFOV_{geo}$).

The following rule of thumb therefore applies to the smallest measurable object ($IFOV_{meas}$):

$$IFOV_{meas} \approx 3 \times IFOV_{geo}$$

- For a good spatial resolution, you should use a telephoto lens.
- With the FOV calculator from Testo, you can calculate the values for FOV, $IFOV_{meas}$, and $IFOV_{geo}$ for different distances. Calculate these values online at www.testo.de/FOV.

2 Thermography in practice

2.1 Measuring object

1. Material and emissivity

The surface of each material has a specific emissivity from which the amount of the infrared radiation emitted from the material that is

- reflected and
- emitted (radiated from the object itself) is derived.

2. Colour

The colour of a material has no noticeable effect on the long-wave infrared radiation emitted by the object to be measured when measuring the temperature with a thermal imager. Dark surfaces absorb more short-wave infrared radiation than light surfaces and therefore heat up more quickly. However, the emitted infrared radiation depends on the temperature and not on the colour of the surface of the measuring object. A heater painted black, for example, emits exactly the same amount of long-wave infrared radiation as a heater painted white at the same temperature.

3. Surface of the measuring object

The properties of the surface of the measuring object play a crucial role in the measurement of temperature with a thermal imager. For the emissivity of the surface varies according to the structure of the surface, soiling or coating.

Structure of the surface

Smooth, shiny, reflective and/or polished surfaces generally have a slightly lower emissivity than matt, structured, rough, weathered and/or scratched surfaces of the same material. There are often specular reflections with extremely smooth surfaces (cf. “Specular reflection”, p. 31).

Wetness, snow and frost on the surface

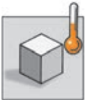
Water, snow and hoarfrost have relatively high emissivities (approx. $0.85 < \varepsilon < 0.96$), so measurement of these substances is generally unproblematic. However, you must bear in mind that the temperature of the measuring object can be distorted by natural coatings of this kind. Wetness cools the surface of measuring object as it evaporates and snow has good insulating properties. Hoarfrost usually does not form a sealed surface, so the emissivity of the hoarfrost as well as that of the surface underneath it must be taken into account when measuring.

Soiling and foreign bodies on the surface

Soiling on the surface of the measuring object such as dust, soot or lubricating oil generally increases the emissivity of the surface. For this reason, measuring dirty objects is generally unproblematic. However, your thermal imager always measures the temperature of the surface, i.e. the dirt, and not the exact temperature of the surface of the measuring object underneath.

- The emissivity of a material depends heavily on the structure of the surface of the material.
- Note the correct emissivity setting according to the covering on the surface of the measuring object.
- Avoid measuring on wet surfaces or surfaces covered with snow or hoarfrost.
- Avoid measuring on loose-lying soiling (distortion of temperature by air pockets).
- When measuring smooth surfaces in particular, be aware of any possible sources of radiation in the vicinity (e.g. sun, heaters etc.).

2.2 Measuring environment



1. Ambient temperature

You should also factor in the setting of the reflected temperature (RTC) as well as the emissivity setting (ε) so that your thermal imager can calculate the temperature of the surface of the measuring object correctly. In many measurement applications, the reflected temperature corresponds to the ambient temperature (cf. “Radiation”, p. 19). You can measure this with an air thermometer, e.g. testo 810. An accurate setting of the emissivity is particularly important where there is a large difference in temperature between the measuring object and the measuring environment (cf. Fig. 1.2, p. 11).

2. Radiation

Every object with a temperature above absolute zero (0 Kelvin = -273.15 °C) emits infrared radiation. In particular, objects with a large difference in temperature from the measuring object can disrupt the infrared measurement as a result of their own radiation. You should avoid or deactivate sources of interference of this kind wherever possible. By screening the sources of interference (e.g. with canvas or a cardboard box), you will reduce this negative effect on the measurement. If the effect of the source of interference cannot be removed, the reflected temperature does not correspond to the ambient temperature.
A Lambert radiator, for example, is recommended for measuring the reflected radiation in conjunction with your thermal imager (cf. “Determining the temperature of the reflected radiation”, p. 27).

Special features of outdoor thermography

The infrared radiation emitted from the clear sky is referred to informally as “cold sky radiation”. If the sky is clear, “cold sky radiation” (~ -50 °C to -60 °C) and hot solar radiation (~ 5500 °C) are reflected during the day. In terms of area, the sky outstrips the sun, which means that the reflected temperature in outdoor thermography is usually below 0 °C, even on a sunny day. Objects heat up in the sun as a result of absorbing sunlight. This affects the surface temperature considerably – in some cases for hours after exposure to solar radiation.

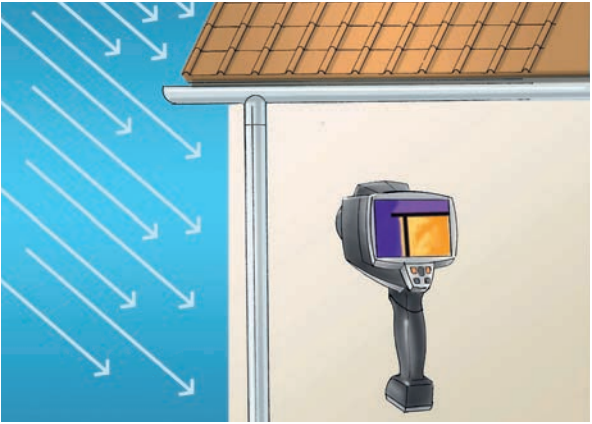


Figure 2.1: Reflection in measurements outdoors

It can be seen in Figure 2.1 that the gutter is shown colder than the house wall on the thermal image. However, both are roughly the same temperature. The image must therefore be interpreted.
Let us assume that the surface of the gutter is galvanised and has extremely low emissivity (ε = 0.1). Only 10 % of the long-wave infrared radiation emitted by the gutter is therefore emitted inherent radiation, 90 % is reflected ambient radiation (RTC). If the sky is clear, “cold sky radiation”(~ -50 °C to -60 °C) among other things is reflected on the gutter. The thermal imager is set to e = 0.95 and RTC = -55 °C to ensure correct measurement of the house wall. Due to the extremely low emissivity and the extremely high reflectance, the gutter is shown too cold on the thermal image. To show the temperatures of both materials correctly on the thermal

image, you can change the emissivity of certain areas retrospectively using analysing software (e.g. Testo IRSoft). We recommend a Lambert radiator for the correct determination of the RTC (cf. “Determining ε and RTC in practical applications”, p. 25).

- Please always be aware of the effect of your own personal infrared radiation.
- Change your position during the measurement in order to identify any reflections. Reflections move, thermal features of the measuring object remain in the same place, even if the slant changes.
- Avoid measurements close to very hot or cold objects, or screen these.
- Avoid direct solar radiation, including for a few hours before the measurement. Take measurements in the early morning.
- Wherever possible, carry out outdoor measurements when it is heavily overcast.

3. Weather

Clouds

A thickly clouded sky offers the ideal conditions for infrared measurements outdoors, as it screens the measuring object from solar radiation and “cold sky radiation” (cf. “Radiation”, p. 19).

Precipitation

Heavy precipitation (rain, snow) can distort the measurement result. Water, ice and snow have high emissivity and are impervious to infrared radiation. In addition, the measurement of wet objects can result in measurement errors, as the surface of the measuring object cools down as the precipitation evaporates (cf. “Surface of the measuring object”, p. 16).

Sun

(cf. “Radiation”, p. 19)

- Ideally, carry out measurements when it is heavily overcast.
- Also make note of the clouds a few hours before the measurement.
- Avoid heavy precipitation during the measurement.

4. Air

Air humidity

The relative air humidity in the measuring environment should be low enough so that there is no condensation in the air (mist), on the measuring object, on the protective glass or the lens of the thermal imager. If the lens (or protective glass) has misted over, some of the infrared radiation hitting the thermal imager will not be received, as the radiation fails to penetrate fully through the water onto the lens.

Extremely dense mist can affect the measurement, as the water droplets in the transmission path let less infrared radiation through.

Air flows

Wind or a draught in the room can affect the temperature measurement with the thermal imager.
As a result of the heat exchange (convection), the air close to the surface is the same temperature as the measuring object. If it is windy or there is a draught, this layer of air is “blown away” and replaced by a new layer of air that has not yet adapted to the temperature of the measuring object. As a result of convection, heat is taken away from the warm measuring object or absorbed by the cold measuring object until the temperature of the air and the surface of the measuring object have adjusted to each other. This effect of the heat exchange increases the greater the temperature difference between the surface of the measuring object and the ambient temperature.

Air pollution

Some suspended particles such as dust, soot and smoke, for example, as well as some vapours have high emissivity and are barely transmissive. This means that they can impair the measurement, as they emit their own infrared radiation that is received by the thermal imager. In addition, only some of the infrared radiation of the measuring object can penetrate through to the thermal imager, as it is scattered and absorbed by the suspended matter.

- Never carry out measurements in thick mist or above water vapour.
- Do not carry out measurements when air humidity is condensing on the thermal imager (cf. “Wetness, snow and frost on the surface”, p. 17).
- Avoid wind and other air flows during the measurement wherever possible.
- Note the speed and direction of air flows during the measurement and factor this data into your analysis of the thermal images.
- Do not carry out measurements in heavily polluted air (e.g. just after dust has been stirred up).
- Always measure with the smallest possible measuring distance for your measurement application in order to minimise the effect of any possible suspended particles in the air.

5. Light

Light or illumination do not have a significant impact on measurement with a thermal imager. You can also take measurements in the dark, as the thermal imager measures long-wave infrared radiation.

However, some light sources emit infrared thermal radiation themselves and can thus affect the temperature of objects in their vicinity. You should therefore not measure in direct sunlight or near a hot light bulb, for example. Cold light sources such as LEDs or neon lights are not critical, as they convert the majority of the energy used into visible light and not infrared radiation.

2.3 Determining ε and RTC in practical applications

To determine the emissivity of the surface of the measuring object, you can, for example:

- refer to the emissivity given in a table (cf. “Emissivity table”, p. 51).

  Caution: Values in emissivity tables are only ever guideline values. The emissivity of the surface of your measuring object may therefore differ from the specified guideline value.
- determine the emissivity by means of a reference measurement with a contact thermometer (e.g. with the testo 905-T2 or testo 925) (cf. “Method using a contact thermometer”, p. 25).
- determine the emissivity by means of a reference measurement with the thermal imager (cf. “Method using the thermal imager”, p. 26).

Determining the emissivity by means of a reference measurement

1. Method using a contact thermometer

First measure the temperature of the surface of the measuring object with a contact thermometer (e.g. testo 905-T2 or testo 925). Now measure the temperature of the surface of the measuring object with the thermal imager with a preset emissivity of one. The difference between the temperature values measured by the contact thermometer and the thermal imager is the result of the emissivity being set too high. By gradually lowering the emissivity setting, you can change the measured temperature until it corresponds to the value obtained in the contact measurement. The emissivity then set corresponds to the emissivity of the surface of the measuring object.

2. Method with the thermal imager

First stick a piece of emissivity adhesive tape (e.g. heat-resistant emissivity adhesive tape from Testo) to your measuring object. After waiting a short time, you can measure the temperature of the surface of the measuring object in the taped-off area using your thermal imager with a set emissivity for the adhesive tape. This temperature is your reference temperature. Now regulate the emissivity setting until the thermal imager measures the same temperature in the area which is not taped as the reference temperature just measured. The emissivity now set is the emissivity of the surface of the measuring object.

As an alternative to the emissivity adhesive tape, you can also:

- coat the measuring object with a coating or paint with a known emissivity.
- coat the measuring object with a thick layer (> 0.13 mm) of heat-resistant oil ($\varepsilon \approx 0.82$).
- coat the measuring object with a thick layer of soot ($\varepsilon \approx 0.95$).

- Caution: Always follow the operating instructions for the measuring object!
- When coating or bonding the measuring object, take account of the fact that the coating or adhesive tape first has to adjust to the temperature of the object before a correct measurement is possible.

Determining the temperature of the reflected radiation

Once you have eradicated all the possible sources of interference that could affect your measurement, the temperature of the reflected infrared radiation is the same as the ambient temperature. You can measure the ambient temperature with an air thermometer, e.g. testo 810, and enter the RTC in your thermal imager on the basis of this. However, if sources of radiation are present in the measuring environment, you should determine the temperature of the reflected radiation to ensure an accurate measurement result.

Measurement of reflected temperature using an (improvised) Lambert radiator

A Lambert radiator is an object that reflects incident radiation with the optimum diffusion, i.e. in all directions.

You can measure the temperature of the reflected radiation on a Lambert radiator using the thermal imager. A piece of aluminium foil crumpled and then unfolded again is a suitable substitute for a Lambert radiator for this purpose. The foil has high reflectance and thanks to the crumpled structure, the diffuse reflection of the radiation is near-perfect (cf. Fig. 2.3, right side of aluminium foil, p. 32). To measure the temperature of the reflected radiation, place the Lambert radiator near the measuring object or ideally on the surface of the measuring object. Then measure the temperature at the radiator with emissivity set to one. The imager will now calculate the temperature of the incident radiation. You can now input this value as the RTC in your thermal imager and measure the temperature at the measuring object with the set emissivity for the surface of your measuring object.

2.4 Sources of error in infrared measurement

The following factors can distort the result of your infrared measurement:

- Incorrect emissivity setting
  ⇨ Determine and set the correct emissivity (cf. “Determining the emissivity by means of a reference measurement”, p. 25).
- Incorrect RTC setting
  ⇨ Determine and set the reflected temperature (cf. “Determining the temperature of the reflected radiation”, p. 27).
- Unclear thermal image
  ⇨ Focus your thermal image in situ, as the sharpness cannot be changed once the picture has been taken.
- Measuring distance is too long or too short
- Measurement taken with unsuitable lens

- Measuring spot too big
  - ⇨ When taking the measurement, note the minimum focus distance of your thermal imager.
  - ⇨ As when taking an ordinary photograph, use the telephoto lens and wide-angle lens appropriately.
  - ⇨ Choose a small measuring distance where possible.
- Faults in the transmission path (e.g. air pollution, covers etc.)
- Effect of external sources of radiation (e.g. light bulbs, sun, heaters etc.)
- Misinterpretation of thermal image due to reflection
  - ⇨ Avoid measuring where there are sources of interference.
  - ⇨ Deactivate or screen sources of interference wherever possible, or factor their influence into the analysis of the thermal image.
- Quick change of ambient temperature
  - ⇨ If there are changes in ambient temperature from cold to hot, there is a risk of condensation on the lens.
  - ⇨ Wherever possible, use thermal imagers with temperature-stabilised detectors.
- Misinterpretation of the thermal image due to lack of knowledge of the design of the measuring object
  - ⇨ The type and design of the measuring object should be known.
  - ⇨ Also use real images (photos) wherever possible to interpret the thermal images.

Measurements on glass

The human eye can look through glass, but glass is impervious to infrared radiation. The thermal imager therefore only measures the surface temperature of the glass and not the temperature of the materials behind it (cf. Fig. 2.2). For short-wave radiation such as sunlight, however, glass is transmissive. You should therefore note that sunlight shining through the window, for example, could heat your measuring object.
Glass is also a reflective material. Be aware therefore of specular reflection when measuring on glass (cf. “Specular reflection”, p. 31).

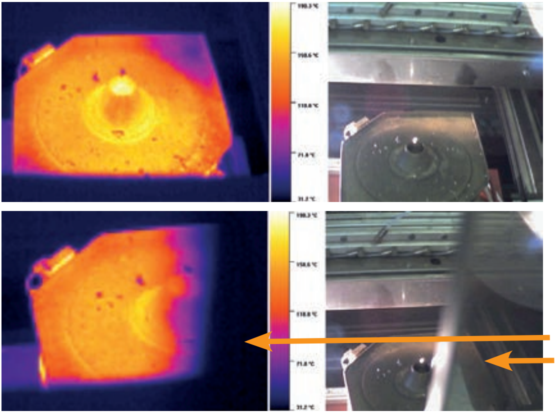


Figure 2.2: Measurements on glass

Measurements on metal

Metals, particularly those with a shiny surface, are strong reflectors of long-wave infrared radiation. They have extremely low emissivity, which can become temperature-dependent at higher temperatures (cf. "Coloured body radiators", p. 40). Measuring the temperature of these with a thermal imager therefore presents problems. Apart from regulating the emissivity, the correct setting of the reflected temperature (cf. "Determining the temperature of the reflected radiation", p. 27) is particularly important. Also note the advice given about specular reflection (cf. "Specular reflection", p. 31). If metals are painted measurement is unproblematic, as paints generally have high emissivity. However, you must again be aware of reflections of the ambient radiation here.

Specular reflection

A clearly visible specular reflection is often an indicator of a highly reflective surface, i.e. a surface with low emissivity. However, highly specular for the human eye does not always mean that it is also highly reflective in the infrared range. For example, specular reflections of the ambient radiation can be seen on the thermal image of a painted surface (e.g. silhouette of person taking the reading), even though paint generally has high emissivity ($\varepsilon \approx 0.95$). Conversely, the outlines of reflected objects in the measuring environment cannot be seen on the thermal image of a sandstone wall, for example, even though sandstone has low emissivity ($\varepsilon \approx 0.67$). Whether the ambient radiation is reflected specularly in clear outlines therefore does not depend primarily on the emissivity but on the structure of the surface.

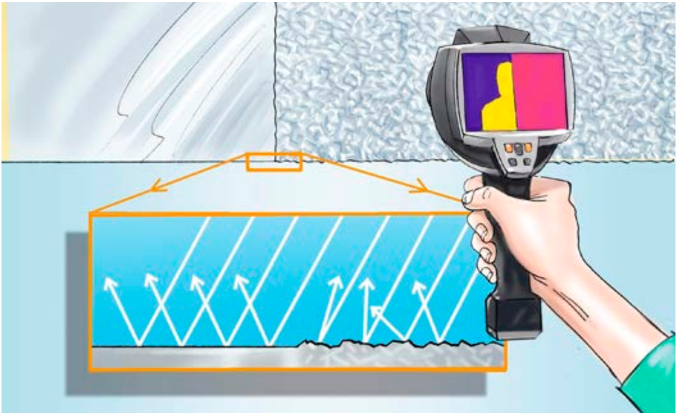


Figure 2.3: Specular and diffuse reflection

All radiation is always reflected at the same angle at which it hits the surface. This means that the following rule of thumb always applies: angle of incidence = angle of reflection. This is clearly recognisable in Figure 2.3 in the enlarged cross-section of the smooth half of the aluminium foil (left-hand side). Here the infrared radiation of the person taking the reading is reflected in the same form in which it hit the surface (specular reflection).
Of course the rule angle of incidence = angle of reflection also applies to the infrared radiation hitting the crumpled aluminium foil (right-hand side). Here, however, the infrared rays fall on partial areas at different angles to each other rather than on a flat surface. As on a Lambert radiator, they are therefore reflected in different

directions. This diffuse reflection means that no outlines of the sources of reflected infrared radiation can be seen. The reflection on the entire crumpled side of the aluminium foil is a mixture of the infrared radiation of the two reflected sources of radiation (person taking the reading and background behind the person taking the reading).

- Highly specular in the visible range does not always mean highly reflective in the infrared range.
- Please always be aware of the effect of your own personal infrared radiation.
- Surfaces on which no specular reflection can be detected can also have high reflectance.
- Measure smooth surfaces from different angles and directions in order to establish which of the irregularities in the temperature distribution are attributable to reflection and which are ascribable to the measuring object.

2.5 The optimum conditions for infrared measurement

Stable ambient conditions, above all, are important for infrared measurement. This means that the climate and objects in the measuring environment as well as any other influences should not change during the measurement. This is the only way to assess possible sources of interference and document them for later analysis.
For measurements outdoors, the weather conditions should be stable and the sky cloudy in order to screen the measuring object from both direct solar radiation and “cold sky radiation”. You must also be aware that measuring objects may still be heated from previous exposure to solar radiation due to their heat storage capacity.

The ideal measuring conditions are:

- Stable weather conditions
- Cloudy sky before and during the measurement (for measurements outdoors)
- No direct solar radiation before and during the measurement
- No precipitation
- Surface of measuring object dry and clear of thermal sources of interference (e.g. no foliage or chips on the surface)
- No wind or draught
- No sources of interference in the measuring environment or transmission path
- The surface of the measuring object has high emissivity that is known exactly

For building thermography, a difference of at least 15 °C between the inside and outside temperature is recommended.

2.6 The perfect thermal image

When taking a thermal image, you should pay attention to two things in particular:

- choosing the right subject area, and
- focussing the thermal image correctly on the area relevant to the measurement.

As with a normal digital picture –you cannot change either the subject area or the focus of the image– once the thermal image has been saved.

To obtain a perfect thermal image, you can make the following changes in your thermal imager and in the analysing software (e.g. Testo IRSoft):

- Change the emissivity and the reflected temperature compensation (RTC) setting. This can also be done point-by-point or in sections with professional analysing software such as Testo IRSoft, for example.
- Choose an appropriate colour palette (e.g. iron, rainbow etc.). Depending on the colour palette, you will get a high-contrast, easy to interpret thermal image.

- Adjust the temperature scale manually.
  This is how you can improve the temperature grading or colour grading of your thermal image (cf. Fig. 2.4).

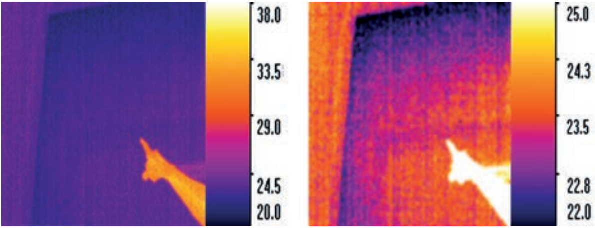


Figure 2.4: Adjusting the temperature scale

Observe the following tips for taking the thermal image:

- Factor in, prevent or screen all sources of interference.
- The surface of the measuring object should be clear of optical and thermal sources of interference. Where possible, remove covers and objects causing interference from the environment.
- Change your position when taking the measurement in order to identify any reflections. Reflections move, thermal features of the measuring object remain in the same place, even if the slant changes.
- Your measuring spot should never be bigger than your measuring object.
- Keep the measuring distance as small as possible.

- Use a lens appropriate to your measuring task.
- For exact measurement of details, it is recommended to use a stand.
- The design of your measuring object should be known in order to be able to correctly identify thermal features.
- Use a thermal imager with a built-in digital camera so that you can use real pictures for analysis at a later date.
- Note all ambient conditions. Measure and document these where necessary for the subsequent analysis of the thermal images.

3 Appendix

3.1 Thermography glossary

A

Absolute zero

Absolute zero is -273.15 °C (0 Kelvin = -459.69 °F). All bodies whose temperature is at the absolute zero point, emit no infrared radiation.

Absorption

When electromagnetic infrared radiation hits an object, the object absorbs some of this energy. The absorption of infrared radiation means that the object heats up. Warmer objects emit more infrared radiation than colder objects. The absorbed infrared radiation is thus converted into emitted infrared radiation (radiating from the object). The absorptivity corresponds to the emissivity.
The incident infrared radiation on the object that is not absorbed is reflected and/or transmitted (let through).

Adjustment time

The adjustment time is the time needed by the camera to adapt to the ambient temperature of the measurement site in order to measure within the specifications. See the instruction manual for the adjustment time of your thermal imager.

B

Black body radiator

An object that absorbs all of the energy from the incident infrared radiation, converts it into its own infrared radiation and emits it in full. The emissivity of black body radiators is exactly one. There is therefore no reflection or transmission of the radiation. Objects with properties of this nature do not occur in the field.
Devices for calibrating thermal imagers are known as black body radiators. However, their emissivity is only just under one.

C

Calibration

Procedure in which the measurement values of an instrument (actual values) and the measurement values of a reference instrument (nominal values) are determined and compared. The result provides clues as to whether the actual measuring values of the instrument are still within a permissible limit/tolerance range. In contrast to an adjustment, the identified deviation from the actual measuring value is merely documented in a calibration and not adjusted to the nominal measuring value. The intervals at which a calibration is to be performed depends on the respective measuring tasks and requirements.

Celsius (°C)
Temperature unit. Under normal pressure, the zero point of the Celsius scale (0 °C) is the freezing temperature of water. A further fixed point for the Celsius scale is the boiling point of water at 100 °C.
°C = (°F - 32) / 1.8 or °C = K - 273.15.

Coldspot and hotspot
The coldest spot of an area on the thermal image is referred to as a "coldspot", and the hottest spot is referred to as a "hotspot".
Using the function "Auto Hot/Cold Spot Recognition", you can display these two spots directly on your thermal image in the imager display. This function is also available in many of the analysing software packages. e.g. Testo IRSoft. In this software you can also display these two spots for any areas of the thermal image you wish to define.

Coloured body radiator
Coloured body radiators are materials whose degree of emissivity is dependent on the wavelength. If one views the same object with a thermal imager in the long-wave infrared range (LIWR, 8 – 14 µm), and one in the medium-wave infrared range (MIWR, 3 – 5 µm), it can be necessary to set different emissivities in the thermal imager.

Colour palette
Selection of colours for the thermal image in the imager (e.g. colour palette "rainbow", "iron", "grey scale"). The contrasts of the thermal images can be shown with varying quality depending on the measuring task and the colour palette set. The colour palette can also be set individually using analysing software (e.g. Testo IRSoft) after

the thermal image has been saved. Pay heed to the interpretability of your thermal image when choosing the colour palette. Red and yellow colours are intuitively associated by the viewer with heat, green and blue colours with cold.

Condensation

Transition of a substance from gaseous to liquid state. Air humidity can condense on surfaces if the surface temperature, and therefore the temperature of the air on the surface, is lower than the dew point temperature.

Conduction

Heat conduction. Transfer of thermal energy between neighbouring particles. Here, energy is always transferred from the warmer to the colder particle. Unlike convection, there is no mass transport of particles in conduction.

Convection

Heat transfer, whereby thermal energy moves from one fluid or gas to another as a result of the mass transport of particles.

D

Detector

The detector receives the infrared radiation and converts it into an electrical signal. The geometric resolution of the detector is given in pixels, and the thermal resolution with the NETD.

Dew point/dew point temperature

Temperature at which water condenses. At dew point temperature, the air is saturated with more than 100 % water vapour. Once the air cannot absorb any more water vapour, condensate forms.

E

Emissivity (ε)

A measure of the ability of a material to emit (give off) infrared radiation. The emissivity varies according to the surface properties, the material and, for some materials, also according to the temperature of the object.

F

Fahrenheit (°F)

Temperature unit used mainly in North America.
°F = (°C x 1.8) + 32.
Example 20 °C in °F: (20 °C x 1.8) + 32 = 68 °F.

Field of view

Cf. “FOV”, p. 43.

FOV (Field Of View)

Field of view of the thermal imager. This is specified as an angle (e.g. 32°) and defines the area that can be seen with the thermal imager. The field of view is dependent on the detector in the thermal imager and on the lens used. Wide-angle lenses have a large field of view for the same detector, whereas telephoto lenses (e.g. Testo 9° telephoto lens) have a small field of view.

G

Grey body radiator

As no ideal black body radiator (ε = 1) exists in nature, the concept of a grey body radiator (ε < 1) is used as an alternative. Many building materials and organic materials can be described as grey body radiators in a narrow spectral range. The wavelength-dependency of the emissivity is negligible here (cf. "Coloured body radiators"), as the spectral sensitivity of common thermal imagers only records a small spectral excerpt from the infrared spectrum. This thus presents an acceptable approach. Grey body radiators, in contrast to black body radiators, never absorb the infrared radiation immitting on to them to 100%, and for this reason, the intensity of the emitted radiation is lower.

H

Hotspot

Cf. “Coldspot and hotspot”, p. 40.

I

Ideal radiator

Cf. “Black body radiator”, p. 39.

IFOV$_{geo}$ (Instantaneous Field Of View)

The IFOVgeo states the resolution of the imager system. It states which details the imager system, dependent on the detector and the lens, can resolve. The resolution of the imager system (IFOVgeo) is given in mrad (=Milliradiant), and describes the smallest object that, depending on the measuring distance, can still be depicted on the thermal image. The size of this object corresponds to one pixel on the thermal image.

IFOV$_{meas}$ (Measurement Instantaneous Field Of View)

Designation of the smallest object whose temperature can be accurately measured by the thermal imager. It is 2–3 times larger than the smallest identifiable object (IFOV$_{geo}$).

The rule of thumb is: IFOVmeas ≈ 3 x IFOVgeo.

IFOV$_{meas}$ is also known as the smallest measurable measurement spot.

Image refresh rate

Specification in hertz of how often per second the displayed image is refreshed (e.g. 9 Hz / 33 Hz / 60 Hz). An image refresh rate of 9 Hz means that the thermal imager updates the thermal image in the display nine times per second.

Infrared radiation

Infrared radiation is electromagnetic radiation. Every object with a temperature above absolute zero (0 Kelvin = -273.15 °C) emits infrared radiation. Infrared radiation covers the wavelength range from 0.78 mm up to 1,000 mm (= 1 mm) and therefore borders on the wavelength range for light (0.38 – 0.78 µm). Thermal imagers often measure the long-wave infrared radiation in the range from 8 mm to 14 mm (like the testo 875i and testo 882, for example), as the atmosphere in this wavelength range is extremely permeable to infrared radiation.

Isotherms

Lines of the same temperature. You can display isotherms using analysis software (e.g. Testo IRSoft) or with high-quality thermal imagers. All measurement points in the thermal image whose temperature values are within a pre-defined range are then marked in colour.

K

Kelvin (K)

Temperature unit.
0 K corresponds to the absolute zero point (-273.15 °C).
The following applies: 273.15 K = 0 °C = 32 °F.
K = °C + 273.15.
Example 20 °C in K: 20 °C + 273.15 = 293.15 K.

L

Lambert radiator

A Lambert radiator is an object that reflects incident radiation with the optimum diffusion; in other words the incident radiation is reflected with equal strength in all directions.
You can measure the temperature of the reflected radiation on a Lambert radiator using the thermal imager.

Laser marker

With the laser marker, the laser sighting is shown parallax-free, enabling you to see the exact position of the laser spot on the thermal imager display. This function is included in the testo 885 and testo 890 cameras.

Laser pointer

A laser pointer supports homing in on the measuring surface (a red dot is projected onto the measuring object). The laser sighting and the centre of the image do not correspond exactly, as they are on different optical axes. This is why the laser dot is not suitable for the marking exact locations that were aimed at in the display using the crosshairs. It only serves as a guide.

Caution:

Laser class 2: never direct the laser at persons or animals and never look into the laser! This can damage the eyes!

Lenses

The size of the field of view of the thermal imager, and thus the size of the measuring spot, change according to the lens used. A wide-angle lens (e.g. 32° – standard lens for the testo 875i) is particularly suitable if you want an overview of the temperature distribution across a large surface. You can use a telephoto lens (e.g. Testo 9° telephoto lens) to measure small details with precision, even from a great distance away.

M

Measuring spot

Cf. “$IFOV_{meas}$”, p. 44.

N

NETD (Noise Equivalent Temperature Difference)

Key figure for the smallest possible temperature difference that can be resolved by the camera. The smaller this value, the better the measurement resolution of the thermal imager.

Relative humidity (%RH)

Percentage specification of the water vapour saturation level of the air. For example, at 33 %RH the air contains only approx. 1/3 of the maximum volume of water vapour that the air could absorb at the same temperature and the same air pressure. At an air humidity in excess of 100 %, condensate starts to form as the air is fully saturated and cannot absorb any more moisture. The gaseous water vapour in the air liquefies. The warmer the air, the more water vapour it can absorb without condensation being formed. For this reason, condensation always occurs first on cold surfaces.

Real body

Cf. “Grey body radiator”, p. 43.

Reflectance (ρ)

The ability of a material to reflect infrared radiation. The reflectance depends on the surface properties, the temperature and the type of material.

RTC (Reflected Temperature Compensation)

With real bodies, some of the thermal radiation is reflected. This reflected temperature must be factored into the measurement of objects with low emissivity. Using an offset factor in the camera, the reflection is calculated out and the accuracy of the temperature measurement is thus improved. This is generally done by means of a manual input into the camera and/or via the software.

In most cases, the reflected temperature is identical to the ambient temperature (mainly in indoor thermography). If the infrared radiation from sources of interference is reflected on the surface of the measuring object, you should determine the temperature of the reflected radiation (e.g. using a Lambert radiator). The reflected temperature has little effect on objects with very high emissivity.

T

Temperature

State variable for the energy contained in a body.

Thermography

Imaging procedure using measuring technology that visualises thermal radiation or the temperature distributions of object surfaces using a thermal imager.

Thermogram

Cf. “Thermal image”, p. 49.

Transmittance (τ)

Measure of the ability of a material to allow infrared radiation to pass through it. It depends on the thickness and type of the material. Most materials are not permeable to long-wave infrared radiation.

Thermal image

Image that shows the temperature distributions of the surfaces of objects using different colours for different temperature values. Thermal images are taken using a thermal imager.

Thermal imager

Camera that measures infrared radiation and converts the signals into a thermal image. Using a thermal imager, surface temperature distributions can be shown that are not visible to the human eye. Typical areas of application are found, for example, in building thermography and in electrical and industrial thermography.

Two-point measurement

The two-point measurement has two crosshairs in the camera display, which can be used to read off individual temperatures.

3.2 Emissivity table

The following table serves as a guide for adjusting the emissivity for infrared measurement. It gives the emissivity ε of some of the more common materials. As the emissivity changes with the temperature and surface properties, the values shown here should be regarded merely as guidelines for measuring of temperature conditions aor differences. In order to measure the absolute temperature value, the exact emissivity of the material must be determined.

Material (material temperature)	Emissivity
Aluminium, heavily oxidised (93 °C)	0.20
Aluminium, highly polished (100 °C)	0.09
Aluminium, not oxidised (25 °C)	0.02
Aluminium, not oxidised (100 °C)	0.03
Aluminium, rolled blank (170 °C)	0.04
Brass, oxidised (200 °C)	0.61
Brick, mortar, plaster (20 °C)	0.93
Brickwork (40 °C)	0.93
Cast iron, oxidised (200 °C)	0.64
Chrome (40 °C)	0.08
Chrome, polished (150 °C)	0.06
Clay, burnt (70 °C)	0.91
Concrete (25 °C)	0.93
Copper, oxidised (130 °C)	0.76
Copper, polished (40 °C)	0.03
Copper, rolled (40 °C)	0.64
Copper, slightly tarnished (20 °C)	0.04
Cork (20 °C)	0.70
Cotton (20 °C)	0.77
Glass (90 °C)	0.94
Granite (20 °C)	0.45
Gypsum (20 °C)	0.90

Material (material temperature)	Emissivity
Ice, smooth (0 °C)	0.97
Iron, emery-ground (20 °C)	0.24
Iron with casting skin (100 °C)	0.80
Iron with rolling skin (20 °C)	0.77
Lead (40 °C)	0.43
Lead, grey oxidised (40 °C)	0.28
Lead, oxidised (40 °C)	0.43
Marble, white (40 °C)	0.95
Oil paints (all colours) (90 °C)	0.92–0.96
Paint, black, matt (80 °C)	0.97
Paint, blue on aluminium foil (40 °C)	0.78
Paint, white (90 °C)	0.95
Paint, yellow, 2 coats on aluminium foil (40 °C)	0.79
Paper (20 °C)	0.97
Plastics: PE, PP, PVC (20 °C)	0.94
Porcelain (20 °C)	0.92
Radiator, black, anodised (50 °C)	0.98
Rubber, hard (23 °C)	0.94
Rubber, soft, grey (23 °C)	0.89
Sandstone (40 °C)	0.67
Steel, cold-rolled (93 °C)	0.75–0.85
Steel, heat-treated surface (200 °C)	0.52
Steel, oxidised (200 °C)	0.79
Transformer paint (70 °C)	0.94
Wood (70 °C)	0.94
Zinc, oxidised	0.1

3.3 Testo recommends

Calibrating your thermal imager

Testo AG recommends that you have your thermal imager calibrated regularly. At what intervals this should be done depends on your measuring tasks and requirements.

You can find more information on calibrating your thermal imager at www.testo.com.

Thermography training courses

Staying at the cutting edge of knowledge: that is one of the most important requirements for meeting the demands of complex measuring tasks and rising quality requirements. This is why Testo AG offers training courses in thermography for a wide range of areas of application.

You can find more information on the training courses we offer at www.testo.com.

More information at:
www.testo.com/see-more

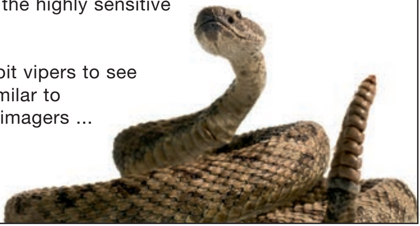
Your personal notes

By the way – did you know?

Thanks to their ability to see thermal radiation, pit vipers perceive – quarry as well as enemies instantly, – even in the dark.

Pit vipers, a subspecies of vipers, perceive even the tiniest temperature differences of around 0.0003 degrees Celsius really quickly. This is made possible by the highly sensitive "pit organ".

This sense organ allows pit vipers to see images which are very similar to those of modern thermal imagers ...



We measure it.

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