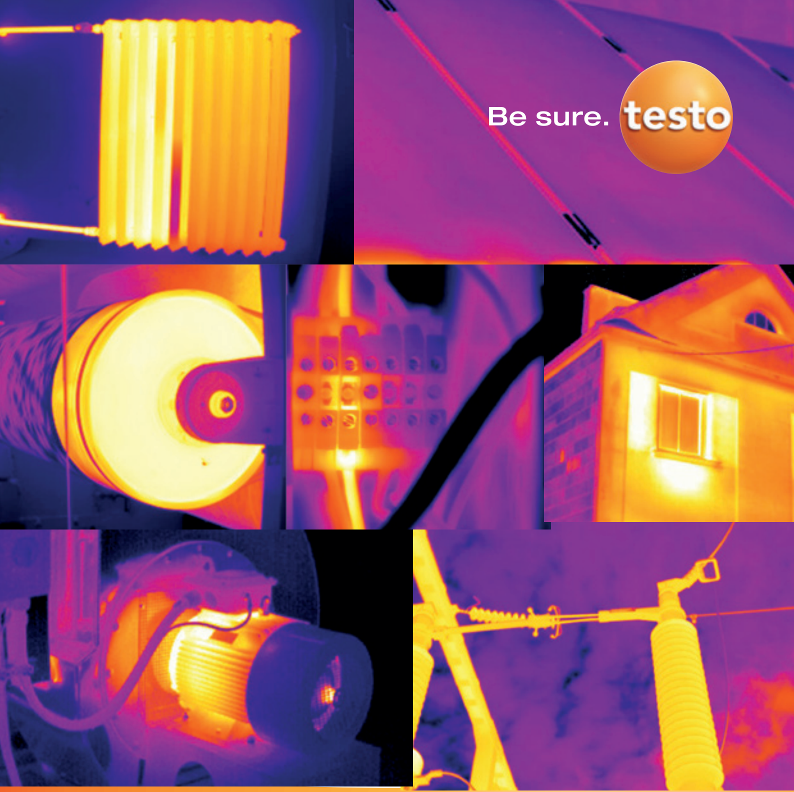


Thermography Pocket Guide

Theory – Practice – Tips & Tricks

Testo SE & Co. KGaA, in December 2017

Foreword

Dear Testo Customer

“A picture says more than a thousand words”.

In times of increasing energy prices and high costs for machine 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 “Thermography Pocket Guide” handbook was created by summarizing the questions raised by our customers on a day-to-day basis. This Pocket Guide is full of lots of interesting information, as well as tips and tricks from practical measurement applications, and is designed to offer you useful, practical help and support you in your daily work.

Have fun reading through it!

B. Knospe

Prof. Burkart Knospe, CEO

Content

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 being measured. The calculation factors in the emissivity (ε) of the surface of the measuring object and the reflected temperature compensation (RTC), with both variables being able to be set manually in the thermal imager. Each pixel of the detector represents a temperature point that is shown on the display as a false colour image (cf. “1.2 Measurement spot and measuring distance”, p. 13).

Thermography (temperature measurement with a thermal imager) is a passive, non-contact measurement method. It involves the thermal image showing the temperature distribution on the surface of an object. This means 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.

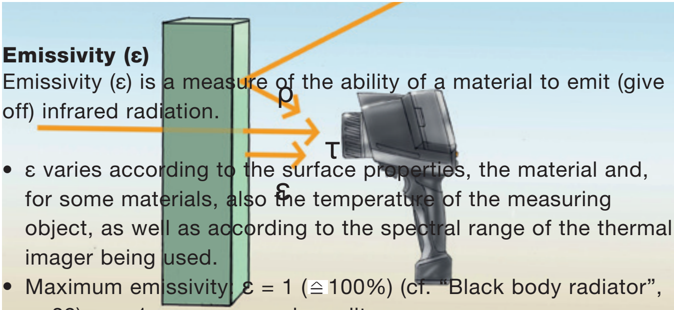
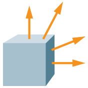


Figure 1.1: Emission, reflection and transmission

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

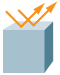
- ε varies according to the surface properties, the material and, for some materials, also the temperature of the measuring object, as well as according to the spectral range of the thermal imager being used.
- Maximum emissivity: ε = 1 (≙ 100%) (cf. "Black body radiator", p. 39). ε = 1 never occurs 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 (ε ≈ 0.8 – 0.95) in the long-wave infrared range that is not dependent on the temperature.
- 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 (ρ) 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).
- RTC corresponds to the ambient temperature in many measurement applications (mainly with indoor thermography). In most cases you can measure this using the testo 810 air thermometer, for example.

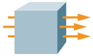


- RTC can be determined using a Lambert radiator (cf. "Measurement of reflected temperature using an (improvised) Lambert radiator", p. 27).
- The angle of reflection of the reflected infrared radiation is always the same as the angle of incidence (cf. "Specular reflection", p. 31).

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, that is permeable, to long-wave infrared radiation.

Conservation of energy principle for radiation 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 through the measuring object.

(cf. Fig. 1.1, p. <?>)

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 proportion of reflected infrared radiation is,
- 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 very accurately measured with a thermal imager

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

3. Measuring objects with low emissivity ($\varepsilon \leq 0.6$):
   - have high reflectance (ρ): $\rho = 1 - \varepsilon$
   - temperature measurement with the thermal imager is possible, however you should critically scrutinize the results
   - correct setting of the reflected temperature compensation is indispensable, as it makes a major contribution to 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 temperatures of the measuring object are higher than the ambient temperature (cf. heater in Fig. 1.2, <?>):
   - excessively high emissivity settings result in excessively low temperature readings (cf. camera 2)
   - excessively low emissivity settings result in excessively high temperature readings (cf. camera 1)

2. Where the temperatures of the measuring object are lower than the ambient temperature (cf. doors in Fig. 1.2, p.<?>):
   - excessively high emissivity settings result in excessively high temperature readings (cf. camera 2)
   - excessively low emissivity settings result in excessively low temperature readings (cf. camera 1)

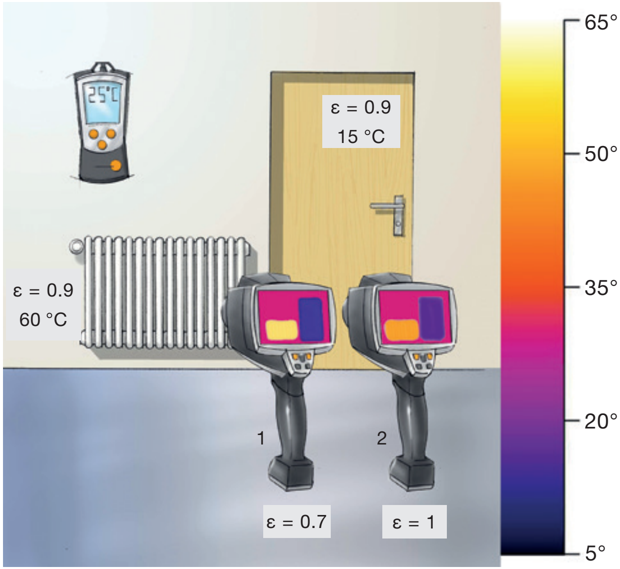


Figure 1.2: Effects of an incorrect emissivity setting on the temperature measurement

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

Please note:

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

Caution: Always observe the operating instructions for the measuring object!

- The small number of 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 which lie under the surface influence the temperature distribution of the measuring object's surface through conduction, structures of the interior of the measuring object can often be identified in 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 Measurement 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 / measurement spot ($IFOV_{meas}$).

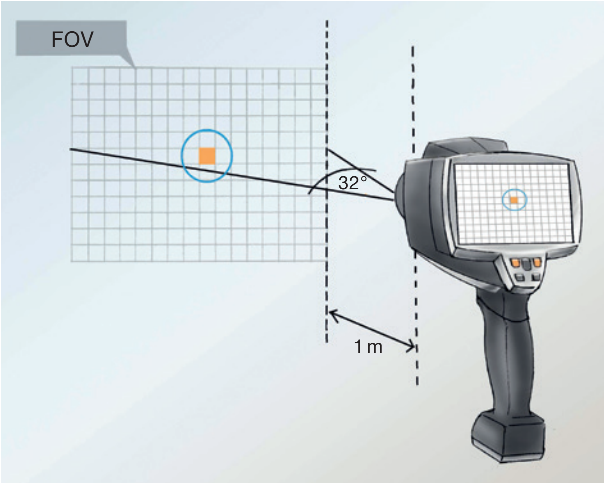


Figure 1.3: The field of view of the thermal imager

The field of view (FOV) of the thermal imager describes the area visible with the thermal imager (cf. Fig. 1.3, p. <?>). It is dependent on the lens used (e.g. 32° wide-angle lens or 9° telephoto lens – this telephoto lens is available as an accessory for the testo 885 and testo 890).

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

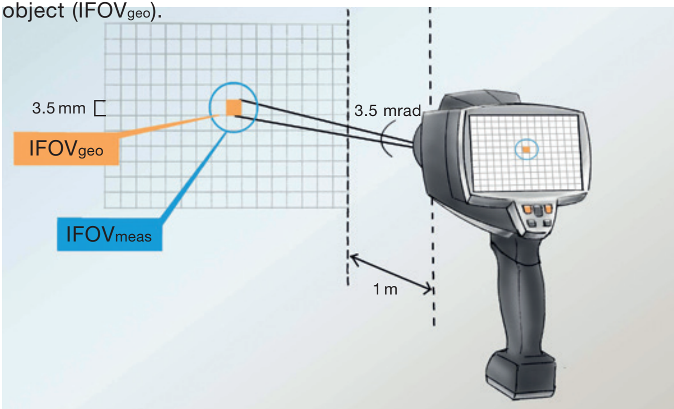


Figure 1.4: Field of view of a single pixel

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

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

2 Thermography in practice

2.1 Measuring object

1. Material and emissivity
The surface of each material has a specific emissivity which is

Please note:
- For a good spatial resolution, you should use a telephoto lens.
- With the testo Thermography App’s FOV calculator, you can calculate the values for FOV, $IFOV_{meas}$ and $IFOV_{geo}$ for different distances.

used to derive how much of the infrared radiation emanating from the material is

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

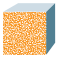
2. Colour

The colour of a material has no noticeable effect on the long-wave infrared radiation emanating from the measuring object 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. For example, a heater which is painted black emits exactly the same amount of long-wave infrared radiation as a heater which is 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 temperature measurement with a thermal imager. Because 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. 31).

Moisture, snow and hoarfrost 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. Because moisture cools the surface of the measuring object when it evaporates and snow has good insulating properties. Hoarfrost does not usually 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. Measuring dirty objects is therefore generally unproblematic. However, your thermal imager always measures the temperature of the surface, i.e. of the dirt, and not the exact temperature of the surface of the measuring object underneath.

Please note:

- The emissivity of a material is heavily dependent on the structure of the surface of the material.
- Pay attention to 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 dirt (falsified temperature due to air pockets).
- Pay attention to possible radiation sources in the surroundings (e.g. sun, heaters, etc.), especially when measuring smooth surfaces.

2.2 Measuring environment

1. Ambient temperature

As well as the emissivity setting (ε), you should also factor in the reflected temperature (RTC) setting, 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. “2. Radiation”, p. 19). You can determine this with an air thermometer, e.g. testo 810. An accurate setting of the emissivity is particularly important where there is a large temperature difference between the measuring object and the measuring environment (cf. Fig. 1.2, p. <?>).

2. Radiation

Every object with a temperature above absolute zero (0 Kelvin = -273.15 °C) emits infrared radiation. In particular, objects with a large temperature difference from the measuring object can disrupt the infrared measurement as a result of their own radiation. You should avoid or deactivate interference of this kind wherever possible. Screening the interference (e.g. with canvas or a cardboard box) enables you to reduce this negative effect on the measurement. If the effect of the interference cannot be removed, the reflected temperature will not correspond to the ambient temperature.

When measuring reflected radiation, a Lambert radiator is for example recommended, in conjunction with your thermal imager (cf. “Determining the temperature of the reflected radiation”, p. 27).

Special features of outdoor thermography

The infrared radiation emanating from the clear sky is colloquially referred to as “cold sky radiation”. In a clear sky, “cold sky radiation” (~ -50 to -60 °C) and warm solar radiation (~ 5500 °C) are reflected all 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.

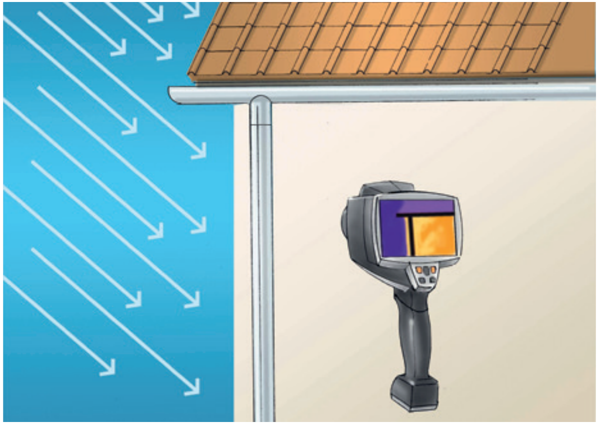


Figure 2.1: Reflection in measurements outdoors

In Figure 2.1, you can see that the gutter is shown as colder than the house wall on the thermal image. However, both are nearly the same temperature. The image must therefore be interpreted.
Let us assume that the surface of the gutter is galvanized and has extremely low emissivity (ε = 0.1). Only 10% of the long-wave infrared radiation emanating from the gutter is therefore emitted inherent radiation and 90% is reflected ambient radiation (RTC). If the sky is clear, "cold sky radiation" (~ -50 to -60 °C), amongst other things, is reflected on the gutter. The thermal imager is set to ε = 0.95 and RTC = -55 °C to ensure correct measurement of the house wall. Due to the extremely low emissivity and extremely high reflectance, the gutter is shown as too cold on the thermal image. To show the temperatures of both materials correctly on the thermal image, you can change the emissivity of specific areas retrospectively using analysis software (e.g. IRSoft or testo Thermography App). To determine the correct RTC, we recommend a Lambert radiator (cf. "2.3 Practical determination of ε and RTC", p. 25).

Please note:

- Never disregard 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 angle of view changes.
- Avoid measurements close to very hot or very cold objects, or screen them off.
- Avoid direct solar radiation, even several hours before the measurement. Take measurements in the early morning.
- Wherever possible, carry out outdoor measurements under a thickly clouded sky.

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. "2. 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 lead to measurement errors, as the surface of the measuring object cools down with evaporation (cf. "3. Surface of the measuring object", p. 16).

Sun

(cf. "2. Radiation", p. 19)

4. Air

Air humidity

The relative air humidity in the measuring environment should be low enough for there to be no condensation in the air (mist), on the measuring object, on the protective glass or on 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 will fail to fully penetrate through the water onto the lens.

Please note:
- Ideally, carry out measurements under a thickly clouded sky.
- Take cloud cover into consideration several hours before the measurement as well.
- Avoid heavy precipitation during the measurement.

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 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 heat exchange effect increases with 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, along with some vapours, have high emissivity and are barely transmissive. This means they can impair the measurement, as they themselves emit infrared radiation which 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.

Please note:

- Do not carry out measurements in thick mist or above water vapour.
- Do not measure if there is air humidity condensing on the thermal imager (cf. “Moisture, snow and hoarfrost 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 these data into your analysis of the thermal images.
- Do not measure in heavily contaminated air (e.g. when dust has been freshly disturbed).
- Always measure with the smallest possible measuring distance for your measurement application in order to minimize the effect of any possible suspended particles in the air.

5. Light

Neither light nor illumination play a significant role in 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 when there is direct solar radiation 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 Practical determination of ε and RTC

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

- read off the emissivity from a table (cf. “3.2 Emissivity table”, p. <?>).
  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 comparative measurement with a contact thermometer (e.g. with the testo 905-T2 or testo 925) (cf. “1. Method using a contact thermometer”, p. 25).
- Determine the emissivity by means of a comparative measurement with the thermal imager (cf. “2. Method using the thermal imager”, p. 26).

Determining the emissivity by means of a comparative 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 using the thermal imager

First stick a piece of emission tape (e.g. heat-resistant emission tape from Testo) onto 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 adjust 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 emission 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 ($\varepsilon \approx 0.95$).
- determine the emissivity and the RTC with the ε-Assist function (testo 868/868s, testo 871/871s, testo 872/872s).

Please note:

- 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 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 accordingly. However, if sources of infrared 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. For this purpose, a piece of aluminium foil which has been crumpled and then unfolded again is a suitable substitute for a Lambert radiator. 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-hand side of the aluminium foil, p. <?>).

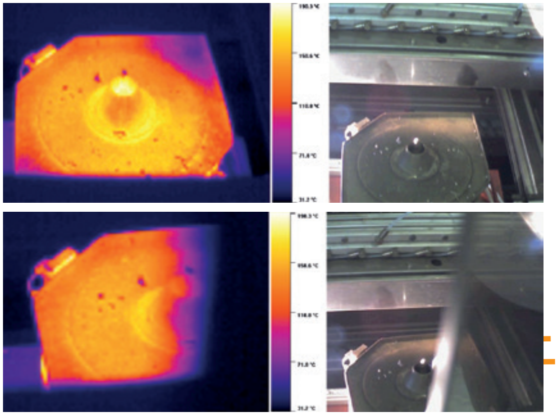
To measure the temperature of the reflected radiation, place the Lambert radiator near the measuring object or ideally on the surface of the measuring object. Then measure the temperature on the radiator with the emissivity set to one. The camera will now calculate the temperature of the incident radiation. You can now input this value as the RTC in your thermal imager and measure the temperature on 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 falsify the result of your infrared measurement:

- Incorrect emissivity setting
  - → Determine and set the correct emissivity (cf. “Determining the emissivity by means of a comparative 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 image has been taken.
- Measuring distance is too long or too short
- Measurement taken with unsuitable lens
- Measurement spot too large
  - → When taking the measurement, pay attention to the minimum focus distance of your thermal imager.
  - → As when taking an ordinary photograph, make an appropriate choice between telephoto and wide-angle lenses.
  - → 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 is interference.
  - → Deactivate or screen interference wherever possible, or factor its 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-stabilized 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). However, glass is transmissive for short-wave radiation, such as solar radiation. You should therefore note that sunlight shining through the window could, for example, 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).



Glass pane slid in front of the measuring object

Figure 2.2: Measurement on glass

Measurements on metal
Metals, particularly those with a shiny surface, are strong reflectors of long-wave infrared radiation. They have very low emissivity, which can become temperature-dependent at higher temperatures. Measuring the temperature of these with a thermal imager is therefore problematic. 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 here (cf. “Specular reflection”, p. 31).
If metals are painted measurement is unproblematic, as paint generally has high emissivity. However, you must again be aware of reflections of 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, being highly specular for the human eye in the visible range does not always mean being highly reflective in the infrared range as well. 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 measurement), even though paint generally has high emissivity ($\varepsilon \approx 0.95$). Equally, 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 does not therefore depend primarily on the emissivity, but on the structure of the

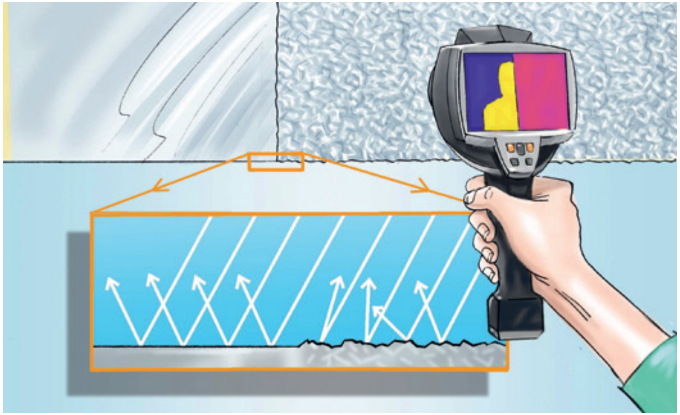


Figure 2.3: Specular and diffuse reflection

surface.
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 recognizable 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 measurement is reflected in the same form in which it hit the surface (specular reflection).
Of course the angle of incidence = angle of reflection rule also applies to the infrared radiation hitting the crumpled aluminium foil (right-hand side). Here, however, the infrared rays fall on partial areas with different gradients 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 measurement and background behind the person taking

Please note:

- Being highly specular in the visible range does not always mean being highly reflective in the infrared range as well.
- 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 identify which of the irregularities in the temperature distribution are attributable to reflection and which to the measuring object.

the measurement).

2.5 The optimum conditions for infrared measurement

Stable environmental conditions are particularly important for infrared measurement. This means that the ambient conditions, objects in the measuring environment and any other influencing factors should not change during the measurement. This is the only way to assess possible interference and document it 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 interference in the measuring environment or transmission path
- A measuring object surface with high emissivity that is known exactly

For building thermography, a difference of at least 10 °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 image section, and
- focussing the thermal image correctly on the area relevant to the measurement.

As with a normal digital picture, you cannot change either the image section or the sharpness 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 analysis software (e.g. testo IRSoft or testo Thermography App):
- Change the emissivity and the reflected temperature compensation (RTC) setting. This can also be done point-by-point or via ranges with professional analysis software, such as testo IRSoft or testo Thermography App for example.
- Choose an appropriate colour palette (e.g. iron, rainbow, etc.). Depending on the colour palette, you will get a high-contrast,

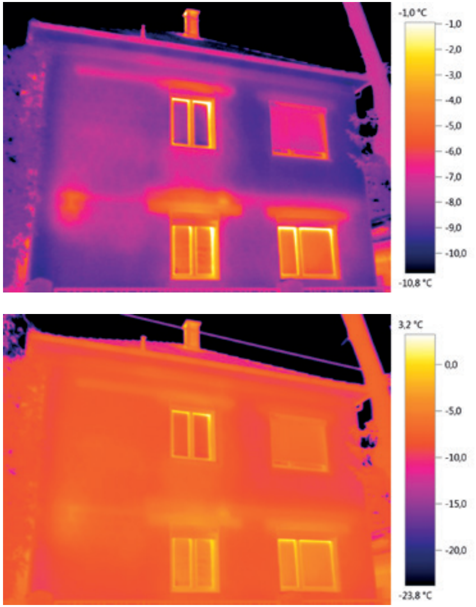


Figure 2.4: Adjusting the temperature scale

easy to interpret thermal image.

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

Observe the following tips for taking the thermal image:

- Factor in, prevent or screen all 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 angle of view changes.
- Your measurement 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.
- The use of a stand is recommended for the exact measurement of details.
- The design of your measuring object should be known in order to enable the correct identification of thermal features.
- Use a thermal imager with a built-in digital camera, so that you can consult visual images for later analysis.
- Note all environmental conditions. Measure and document these where necessary for the later 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 absolute zero 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).

Acclimatization time
The acclimatization time is the time which the thermal imager needs to adjust to the ambient temperature of the measuring location in order to measure within the specification. Take the acclimatization time of your thermal imager from the instruction manual.

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 practice.
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 measuring values of an instrument (actual values) and the measuring values of a reference instrument (nominal values) are determined and compared. The result allows conclusions to be drawn about whether the actual measuring values of the instrument are still within a permitted 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 depend 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 the “coldspot”, and the hottest spot is referred to as the “hotspot”.Using the “Auto Hot/Cold Spot Recognition” function, you can display these two spots directly on your thermal image in the camera display. This function is also available in many of the analysis software packages, e.g. with testo IRSoft or testo Thermography App. There you can also display these two spots for any areas of the thermal image you wish to define.

Colour palette
Selection of the colour display for the thermal image in the camera (e.g. “rainbow”, “iron”, “grey scale” colour palette). 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 analysis software (e.g. with testo IRSoft or testo Thermography App) after the thermal image has been saved. Also pay attention to the interpretability of your thermal image when choosing the colour palette. In most cases, red and yellow colours are intuitively associated by the viewer with heat, green and blue colours with cold.

Coloured body radiator
Coloured body radiators are materials whose emissivity depends on the wavelength. If you look at the same object using a thermal imager in the long-wave infrared range (LWIR, 8 – 14 µm) and a thermal imager in the medium-wave infrared range (MWIR, 3 – 5 µm), it may be necessary to set different emissivities in the thermal imager.

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, which involves thermal energy moving 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 shown in pixels and the thermal resolution with the NETD.

Dew point/dew point temperature
Temperature at which water condenses. At dew point tempera-

ture, 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 (Field Of View)", p. 42.

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. With the same detector, wide-angle lenses have a large field of view, whereas telephoto lenses (e.g. Testo 9° telephoto lens) and super-telephoto lenses have a small field of view.

G

Grey body radiator
As nature has no ideal black body radiator (ε = 1), we make do with the concept of the grey body radiator (ε < 1). Many building or organic materials can be approximately described as grey body radiators in a narrow spectral range. This involves disregarding the wave length dependency of the emissivity (cf. "Coloured body radiator"), because the spectral sensitivity of common thermal imagers only covers a small spectral section of the infrared spectrum. This therefore represents a permissible approximation.
In contrast to black body radiators, grey body radiators never absorb 100% of the radiation which hits them, which means the intensity of the radiation they emit is also 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 $IFOV_{geo}$ indicates the resolution of the camera system. It indicates which details the camera system can resolve depending on the detector and the lens. The resolution of the camera system ($IFOV_{geo}$) is given in mrad (= milliradian) and describes the smallest object that can still be depicted on the thermal image, depending

on the measuring distance. 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: $IFOV_{meas} \approx 3 \times IFOV_{geo}$.
$IFOV_{meas}$ is also referred to as the smallest measurement spot to be measured.

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 µm up to 1000 µm (= 1 mm) and therefore borders on the wavelength range for light (0.38 to 0.78 µm). Thermal imagers often measure the long-wave infrared radiation in the range from 8 µm to 14 µm (testo 865/865s, testo 872/872s, testo 883, testo 890), 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. This involves all measuring points in the thermal image with temperature values within a pre-defined range being 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 marking 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 872/872s, testo 883 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 marking and the centre of the image of the measuring surface do not correspond exactly, as they are on different optical axes. It serves as a guide.
Caution:
Laser class 2: Never direct the laser at people 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 also the size of the measurement spot, change according to the lens used. A wide-angle lens (e.g. 32°) is particularly suitable if you want to get 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 greater distance. For the measurement of the smallest details from a great distance, there is also a super telephoto lens (for the testo 883 and testo 890 cameras).

M

Measurement spot
Cf. "IFOVmeas (Measurement Instantaneous Field Of View)", 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 or thermal sensitivity of the thermal imager is.

R

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, temperature and type of material.

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 therefore 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.

RTC (Reflected Temperature Compensation)
Some of the thermal radiation is reflected with real bodies. This reflected temperature must be taken into account in the measurement of objects with low emissivity. An offset factor in the camera enables the reflection to be 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 (especially with indoor thermography). If the infrared radiation from interferences 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.

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.

Thermogram
Cf. “Thermal image”, p. 48.

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

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.

Two-point measurement
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 provides the emissivity ε of some common materials. As the emissivity changes with the temperature and surface properties, the values shown here should be regarded merely as guidelines for the measurement of temperature conditions or differences. In order to measure the absolute temperature value, the exact emissivity of the material must be determined.

Material (material temperature)	Emissivity
Aluminium, rolled blank (170 °C)	0.04
Aluminium, not oxidized (25 °C)	0.02
Aluminium, not oxidized (100 °C)	0.03
Aluminium, heavily oxidized (93 °C)	0.20
Aluminium, highly polished (100 °C)	0.09
Brass, oxidized (200 °C)	0.61
Brick, mortar, plaster (20 °C)	0.93
Brickwork (40 °C)	0.93
Cast iron, oxidized (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, slightly tarnished (20 °C)	0.04
Copper, oxidized (130 °C)	0.76
Copper, polished (40 °C)	0.03
Copper, rolled (40 °C)	0.64
Cork (20 °C)	0.70
Cotton (20 °C)	0.77

Material (material temperature)	Emissivity
Glass (90 °C)	0.94
Granite (20 °C)	0.45
Gypsum (20 °C)	0.90
Human being (36 °C)	0.98
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, oxidized (40 °C)	0.43
Lead, grey oxidized (40 °C)	0.28
Marble, white (40 °C)	0.95
Oil paints (all colours) (90 °C)	0.92-0.96
Paint, blue on aluminium foil (40 °C)	0.78
Paint, black, matt (80 °C)	0.97
Paint, yellow, 2 coats on aluminium foil (40 °C)	0.79
Paint, white (90 °C)	0.95
Paper (20 °C)	0.97
Plastics: PE, PP, PVC (20 °C)	0.94
Porcelain (20 °C)	0.92
Radiator, black, anodized (50 °C)	0.98
Rubber, hard (23 °C)	0.94
Rubber, soft, grey (23 °C)	0.89
Sandstone (40 °C)	0.67
Steel, heat-treated surface (200 °C)	0.52
Steel, oxidized (200 °C)	0.79
Steel, cold-rolled (93 °C)	0.75-0.85
Transformer paint (70 °C)	0.94
Wood (70 °C)	0.94
Zinc, oxidized	0.1

3.3 Testo recommends

Calibrating your thermal imager
Testo SE & Co. KGaA recommends that you have your thermal imager calibrated regularly. The intervals at which this should be done depend 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 SE & Co. KGaA 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/thermography

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 at lightning speed, even in the dark.

Pit vipers, a subspecies of vipers, perceive even the tiniest temperature differences of around 0.0003 degrees Celsius really quickly. It is the highly sensitive "pit organ" that enables them to do this. This sensory organ allows pit vipers to see images which are very similar to those of modern thermal imagers …

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