Guidelines for infrared measuring technology

3rd revised edition

Foreword

This “Guidelines for infrared measuring technology” field guide is a compilation of questions raised by our customers on a day-to-day basis on the topic of non-contact temperature measuring technology.

Non-contact measurement of surface temperatures has been technically possible since about 1960, but the expensive sensors and analyser units prevented its widespread use in trade and industry. Thanks to new production techniques and falling component prices for assemblies, the 1990s saw the breakthrough of this technology. A particularly good example of this are the infrared switches, which are used thousandfold in the electrical installation sector. Today, it is possible to use small, inexpensive handheld temperature measuring instruments for non-contact measurement, which cost no more than the sensor component for a comparable unit instrument in the 1970s.

Non-contact temperature measuring instruments are mainly used wherever other measurement methods (e.g. contact thermometer) cannot be used or where their use is restricted. For example, live parts, rough surfaces, objects with a low thermal conductivity and rotating machinery parts or packaged food, which could be damaged if a measurement probe is inserted.

As this measuring technology involves capturing and analysing the IR radiation emitted from the surface of the measurement object, unlike with contact measurement, some basic rules must be observed in order to avoid measurement errors. These tips include examples from everyday measurement applications to provide users with a practical and useful guide.

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Head of Product Management

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1. Thermal radiation

1.1 Basic principles

It is common knowledge that all bodies, depending on their temperature, emit electromagnetic waves, i.e. radiation. Energy is transported along with this radiation, ultimately permitting non-contact measurement of the body's temperature with the help of the radiation.

The radiated energy and its characteristic wavelengths primarily depend on the temperature of the radiating body.

Ideally, a measurement object will take on all the energy (absorption) and convert it into its own heat radiation (emission). In such cases it is referred to as a “black body radiator”. Such behaviour virtually never occurs in nature; rather, additional reflection and transmission of the radiation at or through a body occurs.

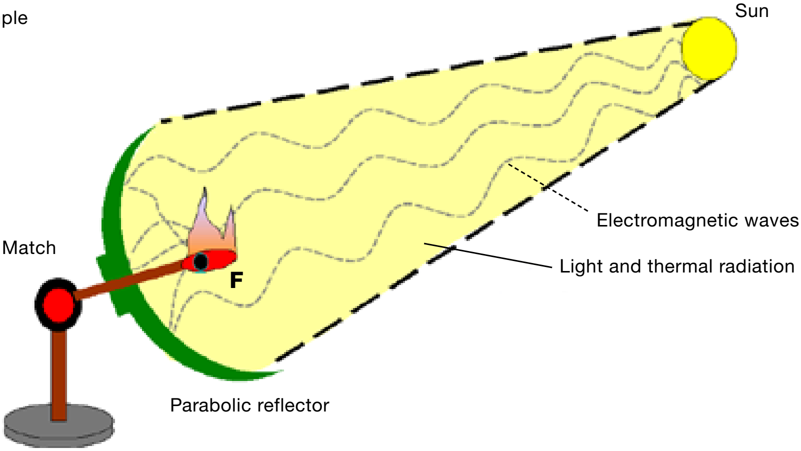
However, in order to nevertheless obtain reliable measurements with infrared measurement systems in practice, it is necessary to identify this emission, reflection and transmission behaviour (also see 1.4) accurately or to eliminate this influence by suitable means.

This can be achieved with the aid of reference measurements using contact thermometers or by deliberately modifying the measuring area to make it suitable for infrared measuring technology, e.g. by applying lacquer coatings, adhesive and glue, plastic coatings or paper stickers.

Whether and how these measures are to be performed depends ultimately on the measurement object and the measurement environment. Classifying applications according to the appearance of the measurement objects and their surface helps when assessing this.

More information on this is given in point 4 “Applications and practical tips”.

Example



If, for instance, a parabolic reflector is directed precisely at the sun with a match positioned at its focal point, the match will soon ignite. This is because of the sun's thermal radiation, which is concentrated by the parabolic reflector at a point **F** (focus).

1.2 Advantages of infrared measuring technology

There has been a huge increase in applications involving infrared measuring systems in recent years. The following factors undoubtedly play an important part in this trend.

- Infrared measuring technology offers easy temperature capture and quick, dynamic processes. This is enhanced by the short response time of the sensors and systems.
- The systems offer sophisticated, modern technology with reliable sensors and modern microprocessor electronics.
- Their absence of interaction, i.e. they do not influence the measurement object, permits online measurements of sensitive surfaces and sterile products, as well as measurements in hazardous or inaccessible areas.

Another factor in this trend that should not be ignored, over and above the technical advantages, is that these systems are attractively priced for customers as a result of cost-optimised production processes, which place the emphasis on high unit totals.

Infrared temperature measuring instruments are particularly suitable for...

...poor thermal conductors, such as ceramic, rubber, plastics, etc. A probe for contact measurement can only display the correct temperature if it can take on the temperature of the measurement body. With poor thermal conductors, this is generally not the case or response times are extremely long.

...for determining the surface temperature of rough surfaces (e.g. plaster, textured wallpaper, etc.). Measurement with probes can only sometimes be carried out due to the poor thermal contact.

...for moving parts,
e.g. running paper webs, rotating tyres, running sheet metal webs, etc.

...for parts that must not be touched, e.g. food, painted parts, sterile parts or aggressive media.

...for live parts, e.g. electrical components, busbars, transformers, etc.

...for small and low-mass parts, e.g. components and all measurement objects where a contact probe draws too much heat, thereby causing incorrect measurements.

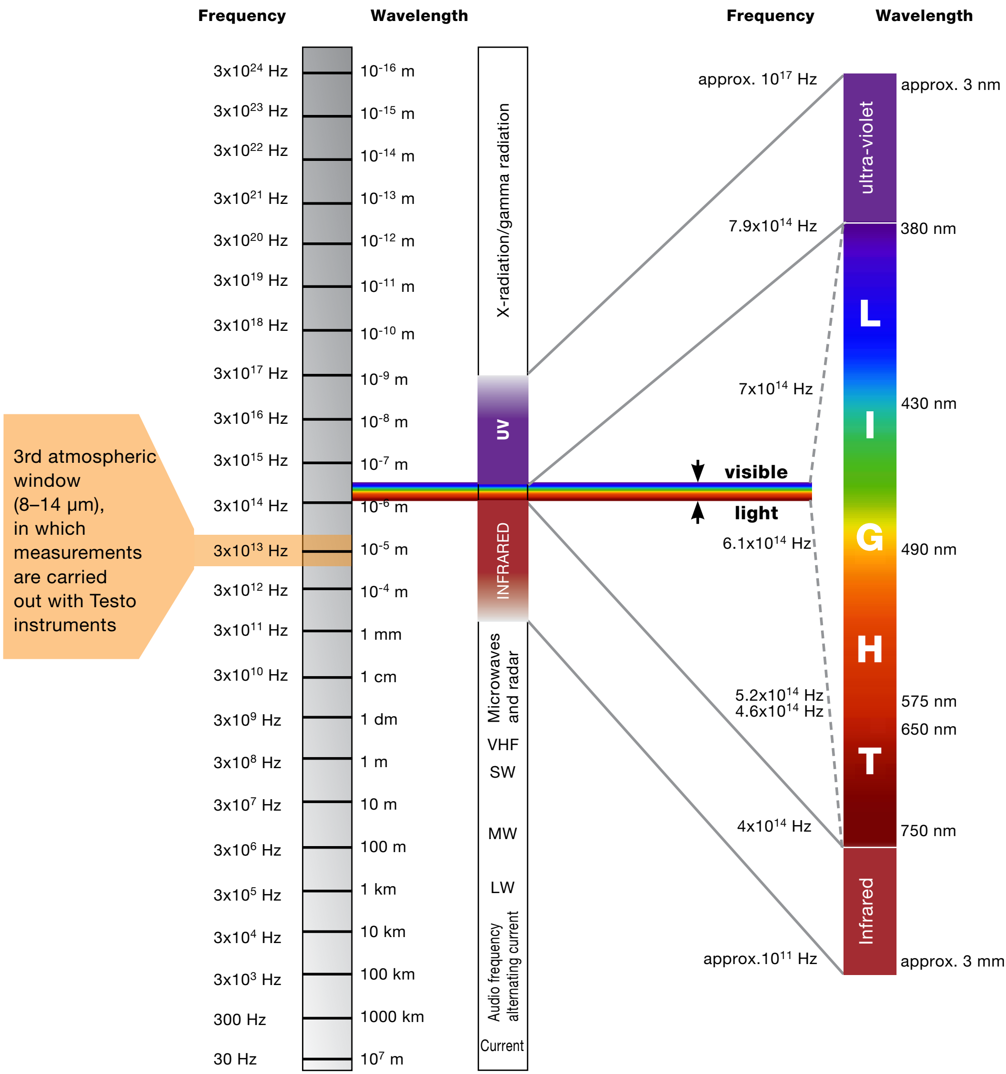
...for the measurement of extremely small or extremely large surfaces through the selection of various lenses.

1.3 History of infrared measuring technology

Up until 1960, radiation thermometers are primarily used to measure high temperatures. However, after that time, various types of radiation detectors that are also receptive to wavelengths larger than 8 µm are developed, enabling reliable and accurate temperature measurement right down to below the freezing point of water.

1800	Herschel discovers the IR spectrum through tests with a liquid thermometer with IR-absorbing ball
1900	Planckian radiation laws
1938	Book “Optical Pyrometry” (measuring technology application)

1.4 The electromagnetic spectrum



Explanation:

Electromagnetic radiation always follows the same fundamental laws of nature, but is perceived completely differently by people. It may be perceived in the form of light or heat; other ranges such as X-rays are not at all perceptible or can only be perceived by their effect (UV light causes sunburn). The electromagnetic radiation spectrum extends over approx. 23 powers of ten.

In other words, light only refers to the visible part of the electromagnetic radiation, or VIS. It includes the wavelength ranges from 380 nm (violet) to 750 nm (red). The limits of this range are dictated by the sensitivity of the human eye.

Next in the short-wave range is ultraviolet (UV).

In the long-wave range, near-infrared (NIR) is the closest to visible light. It ranges from 750 nm to 2.5 µm. This is followed by the spectral range of medium infrared (MIR or simply IR). This ranges from 2.5 µm to 25 µm. Far-infrared (FIR) comprises the wavelength ranges 25 µm to approx. 3 mm.

Atmospheric windows:
What are atmospheric windows and why are measurements carried out in these ranges?

1st atmospheric window
2 µm – 2.5 µm
2nd atmospheric window
3.5 µm – 4.2 µm
3rd atmospheric window
8 µm – 14 µm

In the range of the so-called atmospheric windows, there is very little absorption or emission of (electromagnetic) radiation by the components of the air between the measurement object and the measuring instrument. This is why, particularly at distances of less than 1 m to the measurement object, there are no effects caused by the components usually contained in the air.

Measurements of lower and negative temperatures are only possible in the range of 8 to 14 um, as a wide energy band is used for analysis to generate a usable signal.

1.5 Emission, reflection, transmission

As already mentioned at the beginning, each body emits electromagnetic radiation above the absolute zero point (0 Kelvin = -273.15 °C).

The radiation captured by the measuring head consists of an emission from the measuring body, as well as external radiation through reflection on the measuring body and transmission through the measuring body. The total of this radiation (100% or 1) is analysed by the instrument. As the instrument does not detect the parts of the radiation, it must be given the information about which part is the emission from the measuring body (emission level).

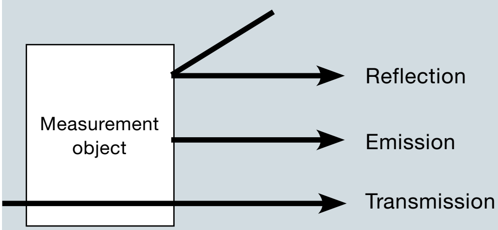
To summarise:

The emission level (ε)
Describes the ability of an object to emit (give off) infrared radiation.

The reflection level (R)
Describes the ability of an object to reflect infrared radiation. It depends on the surface quality and type of the material.

The transmission level (T)
Describes the ability of am object to allow infrared radiation to pass through it. It depends on the thickness and type of material and indicates the permeability of the material to infrared radiation.

These three factors can have values between 0 and 1 (or between 0 and 100%).



Note: To select the correct emission level, see chapter 4.3 "Further practical tips on the emission level".

1.6 The measurement object

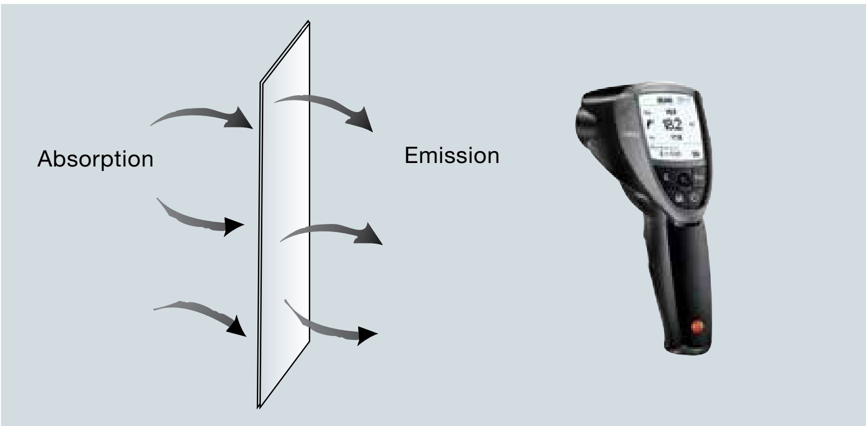
The measurement object is the centre of attention in every application. The task is to determine its temperature exactly and precisely.

Whether it is a solid, liquid or gas, every measurement object represents an individual, specific case for an infrared sensor. This is because its condition is material and surface-specific. Many organic products and liquids can therefore be measured without the need for special measures. Metals, on the other hand, particularly those with reflective surfaces, require special consideration.

If the reflection level and the transmission level are equal to 0, then you have an ideal measuring body, the so-called "black body radiator", which has radiated energy that can be calculated by means of the Planckian law of radiation. An ideal body of this type has an emissive power of ε = 1.

Black body radiator (ideal radiator)

It absorbs and emits 100%. Emission level ε = 1.

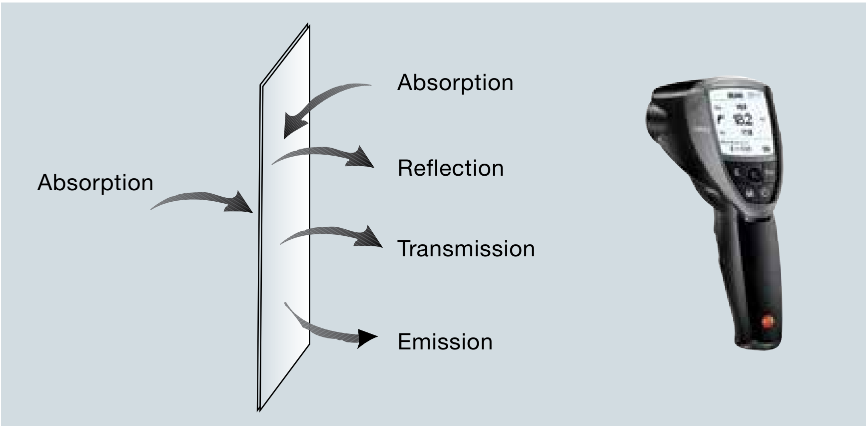


Black body radiator

In reality, however, such ideal conditions do not occur. Transmission and reflection always interfere with the measurement.

Real body

Part of the radiation is reflected or passes through. Emission level ε < 1.



Real body

Grey body radiator (ε less than 1)

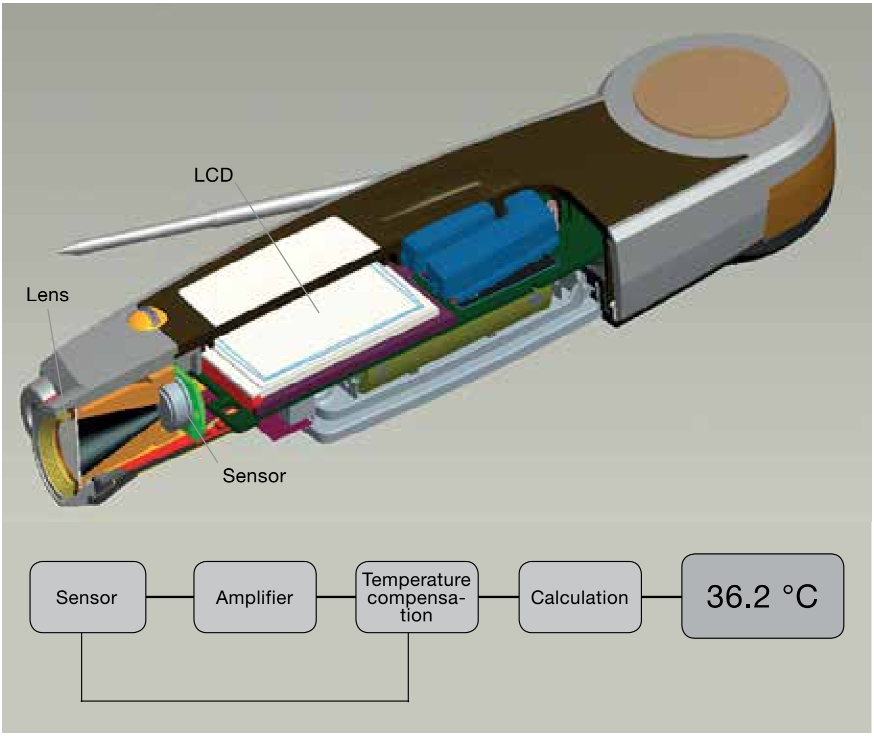
Most naturally occurring bodies are described as “grey body radiators”. They exhibit the same characteristics as black body radiators.. Only the intensity of the emitted radiation is lower. This is corrected by adjusting the emission level.

Coloured body radiator

Coloured body radiators are materials where the emission level depends on the wavelength and therefore the temperature. This means that such a body has a different emission level e.g. at +200 °C than at +600 °C. This applies to most metallic materials. It must be noted here that the emission level ε is determined at the measuring temperature.

2. Setting up an infrared measuring instrument

2.1 Measurement arrangement/measurement system



Cross-section of a testo 104 thermometer

The radiation is concentrated with the help of a lens (in this case a Fresnel lens) and passed on to the sensor. The sensor converts the radiation into an electrical voltage, which is boosted by the amplifier and transferred to the microprocessor. The processor uses the recorded radiation and the ambient radiation (= instrument temperature) to calculate the temperature of the measurement object, taking into account the emission level.

As the measurement method is, in principle, a visual one, the lens must always be kept clean and dust-free.

2.2 What parameters are taken into account in the measurement result?

a) Measurement object
- Temperature of the measurement object
- Emission level of the measurement object

b) Ambient radiation
- Intrinsic temperature of the lens assembly

The measuring instrument calculates the following parameters:

SM = radiation from the measurement object

SU = ambient radiation (is generally equivalent to instrument temperature)

When the emission level ε is known, these parameters are used to calculate the effective signal SW:

$$SW = \frac{SM - SU}{\varepsilon} + SU$$

The measurement object temperature is a function of the effective signal SW calculated in this way:

T measurement object = f (SW)

In the measuring instrument, the effective radiation SW is used to calculate the temperature of the measurement object.

3. Emission level

3.1 Typical emission levels

Food

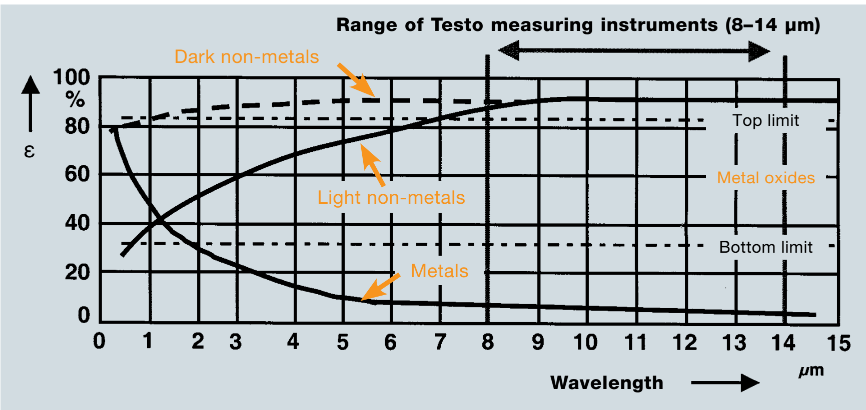
Like all organic materials, food has good emission properties and is relatively unproblematic to measure using IR measurement.

-> Most organic substances (e.g. food) have an emission level of approx. 0.95. That is why this value is fixed in many instruments to avoid measurement errors caused by (undetected) incorrectly set emission levels.

Bare metals

Have very low emission levels in the range 8 to 14 µm and are therefore difficult to measure.

-> Apply coatings that increase the emission level, such as lacquer, oil film or emission tape (e.g. testo order-no. 0554 0051) to the measurement object or measure with contact thermometer.



Emission levels of various materials depending on wavelength (schematic representation)

Metal oxides

Do no present any standard behaviour. Emission levels are between 0.3 and 0.9 and are generally heavily dependent on the wavelength.

-> Determine emission level through comparison measurement with contact thermometer or apply coating with defined emission level.

Light non-metals/dark non-metals/ plastics

E.g. white paper, ceramics, gypsum, wood, rubber, dark wood, stone, dark paints and lacquers, etc. often have an emission level of approx. 0.8 at wavelengths greater than 8 µm.

Effect of colours on the measurement result

Light and dark non-metals hardly differ at all with regard to their emission behaviour in the case of longer wavelengths. For example, it makes no difference whether paints and lacquers are black, blue, red, green or even white. A radiator painted white at a temperature of +40 °C to +70 °C radiates just as effectively as one painted black, as its temperature radiation is mainly emitted at long wavelengths > 6 µm (outside the visible range).

3.2 Effects on the measurement result, with examples

Example 1:

- Measurement object (pizza, frozen, T= -22 °C)
- Emission level = 0.92
- IR measurement at ambient temperature +22 °C
- Permanently set emission level of 0.95
- Display of IR measuring instrument: -21 °C

This means that the measuring instrument display is incorrect by approx. 1 °C.

-> Negligible

Example 2:

- Measurement object (oxidised brass plate, T= +200 °C)
- Emission level = 0.62
- IR measurement at ambient temperature +22 °C
- Set emission level 0.70
- Display of IR measuring instrument: +188 °C

This means that the measuring instrument display is incorrect by approx. 12 °C.

-> Not negligible

Conclusion:
The greater the difference between the temperature of the measurement object and the ambient temperature and the lower the emission level, the bigger the errors if the emission level is incorrectly set.

At temperatures above the ambient temperature

- An emission level set too high will give a temperature display that is too low.
- An emission level set too low will give a temperature display that is too high.

At temperatures below the ambient temperature

- An emission level set too high will give a temperature display that is too high.
- An emission level set too low will give a temperature display that is too low.

4. Applications and practical tips

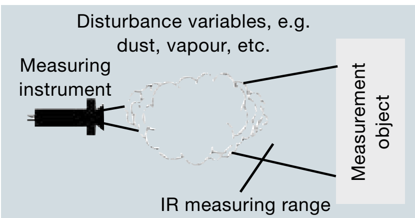
4.1 Sources of error/causes/ compensation with infrared measuring instruments

Influence of intermediate media (disturbance variables) on the measurement result

With non-contact temperature measurement, in addition to material and surface-specific influences, the composition of the transmission path between the instrument and the measurement object can also have an effect on the measurement result. Disturbance variables include, for example:

– Particles of dust and dirt
– Moisture (rain), vapour, gases

Also see "Atmospheric windows" (chapter 1.3).



Incorrectly set emission levels can lead to considerable errors (see 4.2).

After a temperature change, the measuring instrument will not yet have adjusted to the new temperature – see instruction manual for adjustment times. This will lead to considerable measurement errors.

-> If possible, store the instrument in the place where the measurement is to be performed! This will avoid the problem of adjustment time (but: pay attention to the instrument operating temperature!).

IR measurement is a purely visual measurement:

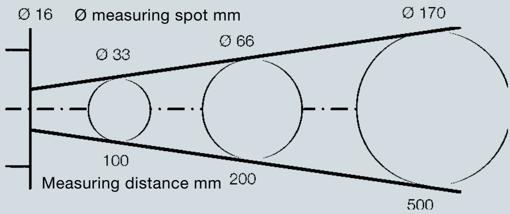
-> A clean lens is essential for accurate measurement.
-> Do not measure with a misted-up lens, e.g. due to water vapour.

IR measurement is a surface measurement:

-> Always keep surfaces clean! If there is dirt, dust, frost, etc. on the surface, only the top layer will be measured, i.e. the dirt.
-> Do not measure at occlusions.

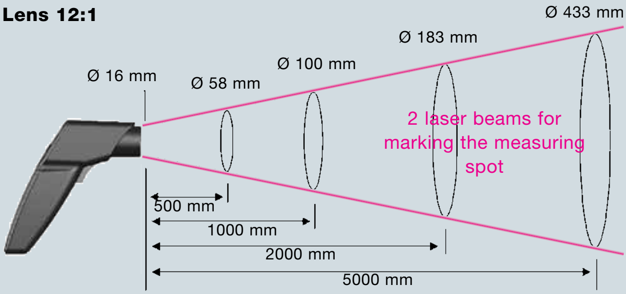
Distance between IR measuring instrument and measurement object is too large, i.e. the measuring spot is larger than the measurement object. In this case, the following measuring spot diagrams, which show that ratio of measuring distance to measuring spot, apply.

Measuring distance to measuring spot 3:1



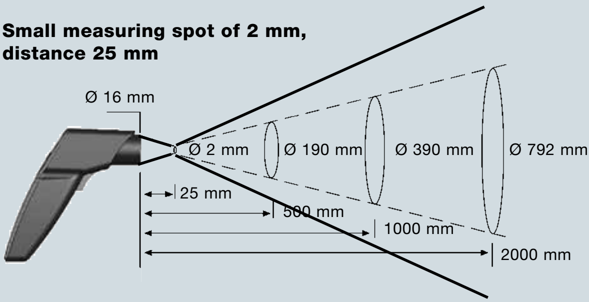
testo 825-T2
testo 825-T4

Lens 12:1



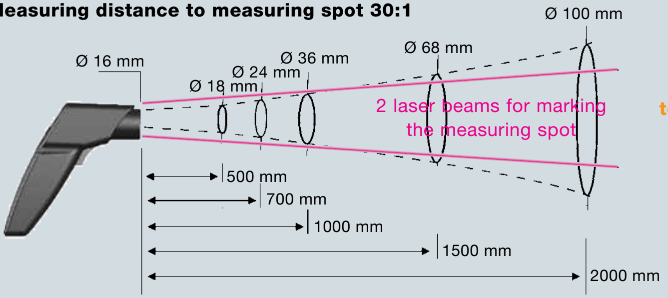
testo 830-T2

Small measuring spot of 2 mm, distance 25 mm

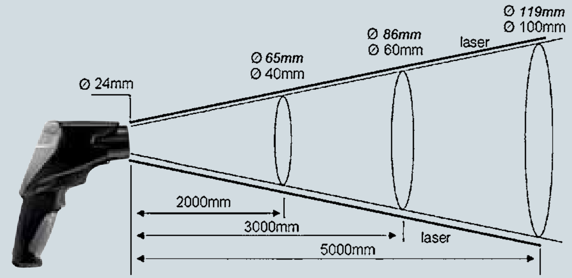


testo 830-T3

Measuring distance to measuring spot 30:1

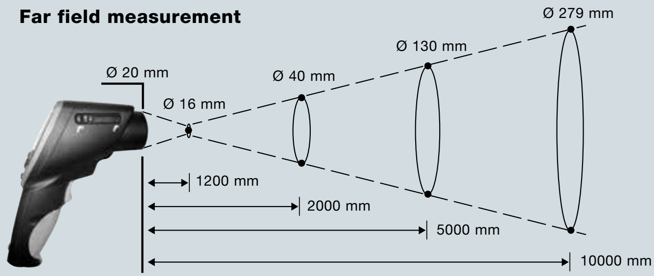


testo 830-T4



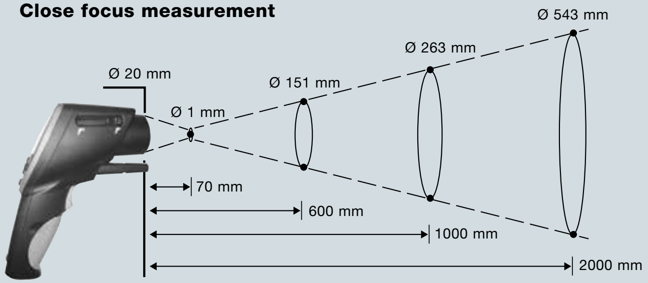
testo 835-T1
testo 835-T2
testo 835-H1

Far field measurement



testo 845

Close focus measurement



Important information about measuring spot size:

The measuring spot diagrams shown in the instrument documentation usually give the so-called 90% measuring spot, which means that 90% of the energy converted in the sensor comes from this range.
However, due to a lack of definition in the illustration, the range that has an influence (even if small) on the measurement result is larger.
Therefore, it is important to ensure that the measurement object is always larger than the measuring spot specified in the documentation in order to prevent undesirable influences from the marginal area.
The greater the temperature difference between the measurement object and the background, the greater the effects on the measurement result.

4.2 How to solve various measuring tasks

Simple to solve measuring tasks:
All non-metallic parts and surfaces, organic materials such as lacquers and paints, paper, plastics and rubber, wood, synthetic materials, food, glass, textiles, minerals, stone, etc. No special measures need to be taken for this group. The emission level is sufficiently high, often around 0.95, and does not change over the temperature image.

Conditionally solvable measuring tasks:
Matt, corroded metal surfaces and transparent films. A differentiation must be made in individual cases as to whether and how the measuring problem must be tackled.

-> Determine emission level through comparison measurement with contact thermometer or apply coatings with defined emission level.

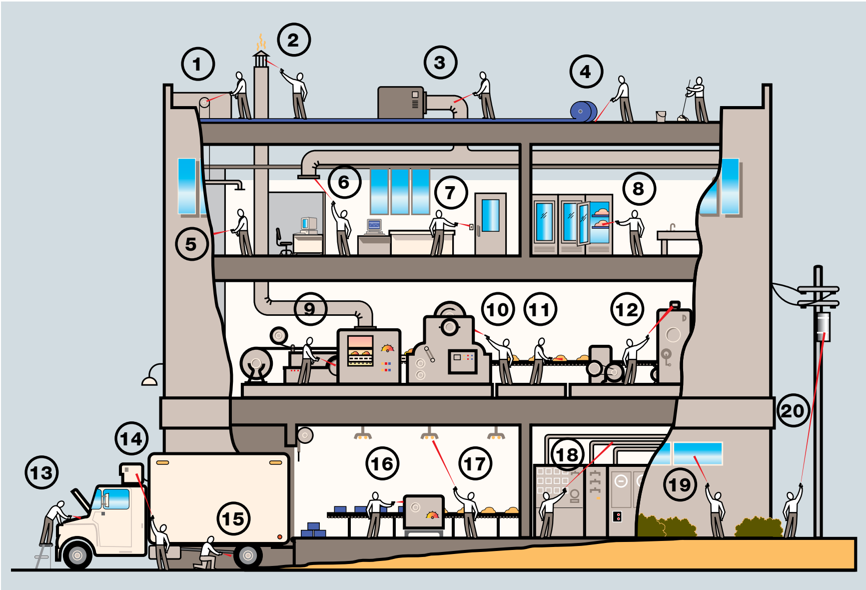
Difficult to solve measuring tasks:
Bare, reflective surfaces of metals, changing surface structures, e.g. due to scaling.

Applications for this group can only be solved with difficulty and only under special conditions. Emission level is only known for a certain bandwidth. The values are small and fluctuate over the temperature interval.

-> If a measurement with contact thermometers is not possible here, coatings such as paint or oil, or emission tape with a defined emission level, must be applied to the measurement object for non-contact measurement.

Note about emission tape:
It is important that the adhesive tape effectively absorbs the temperature of the measurement object. This will be the case for bodies with good thermal capacity (large mass) and good thermal conductivity (metal bodies).

Examples of non-contact measurement



1 Measurement on PVC pipe systems
· Temperature at approx. +25 °C
· Emission level of plastic 0.84.
Ideal for infrared measuring technology.

2 Measurement on tin-plate hood
· Temperature at approx. +38 °C
· Emission level of tin-plate 0.05
Apply coating that increases the emission level, e.g. paint or emission tape, otherwise measure with contact thermometer.
Tip: Use measuring instrument with small measuring spot with large distance and integrated contact thermometer (e.g. testo 845 or testo 835).

3 Measurement on galvanised outgoing air pipe
· Temperature at approx. +24 °C
· Emission level of zinc 0.23
Apply coating such as lacquer or emission tape or carry out comparison measurement with contact thermometer.

4 Measurement on asphalt layer
· Temperature at approx. +24 °C
· Emission level of asphalt 0.93
Can be measured without any problem.

5 Measurement on brick wall
· Temperature at approx. +21 °C
· Emission level of brick (red) 0.93
Can be measured without any problem.

6 Measurement on ceiling extractor (painted)
· Temperature at approx. +24 °C
· Emission level of zinc (painted) 0.96
Can be measured without any problem.
Tip: Use measuring instrument with small measuring spot with large distance and integrated contact thermometer (e.g. testo 845 or testo 835).

7 Measurement on light switch
· Temperature at approx. +20 °C
· Emission level 0.85
Can be measured without any problem.

8 Measurement in electrical cabinet (contactor)

· Temperature at approx. +74 °C
· Emission level of plastic 0.92

Caution: Measure on the plastic surface, not on metal!

Tip: Use testo 845 with close focus measurement

9 Measurement on bearing shell (painted)

· Temperature at approx. +68 °C
· Emission level of black paint 0.93

Can be measured without any problem.

Tip: Use measuring instrument with small measuring spot with large distance and integrated contact thermometer (e.g. testo 845 or 835).

10 Measurement on radiator fin of electric motor

· Temperature at approx. +50 °C
· Emission level of green paint 0.93

Can be measured without any problem.

11 Measurement of food product on cooling conveyor

· Temperature at approx. +8 °C
· Emission level of food 0.95

Can be measured without any problem.

12 Measurement on heat exchanger

· Temperature at approx. +10 °C
· Emission level of condensing water 0.93

Note: Measurable through condensing water, otherwise apply coating with high emission level.

Tip: Use measuring instrument with small measuring spot with large distance and integrated contact thermometer (e.g. testo 845 or testo 835).

13 Measurement on engine block

· Temperature at approx. +100 °C
· Emission level of aluminium (heavily oxidised) 0.2

Apply coating with oil or emission tape, so that $\varepsilon > 0.9$.

14 Measurement on cooling unit

· Temperature at approx. +36 °C
· Emission level of painted sheet metal 0.92

Can be measured without any problem.

Tip: Use small measuring spot, testo 845.

15 Measurement on car tyres

· Temperature at approx. +40 °C
· Emission level of soft rubber 0.86

Can be measured without any problem.

16 Measurement at furnace output

· Temperature at approx. +70 °C
· Emission level of clay (fired) 0.91

Can be measured without any problem.

17 Measurement on fluorescent tubes

· Temperature at +42 °C
· Emission level of glass (smooth) 0.92–0.94

Can be measured without any problem.

18 Measurement on painted pipes

· Temperature at approx. +10 °C
· Emission level of blue paint 0.94

Can be measured without any problem.

Tip: Use measuring instrument with small measuring spot.

19 Measurement on galvanised outgoing air pipe

· Temperature at approx. 38 °C
· Emission level of zinc 0.23

Apply coating such as lacquer or emission tape or carry out a comparison measurement with contact thermometer.

Tip: Use combi measuring instrument.

20 Measurement on transformer (painted)

· Temperature at approx. +70 °C
· Emission level of trans. paint 0.94

Can be measured without any problem.

Tip: Use a measuring instrument with a small measuring spot at a large distance.

Application examples

Industrial applications

Detection of excessively high temperatures on switch cabinets, measurement on electrical circuits, such as resistors, transistors in printed circuits, etc.

Points to watch out for:

- Measuring spot/measuring distance
- Measurement not on bare surfaces (they reflect the ambient temperature), but on plastic with ε setting 0.95.

Tip: Use an IR measuring instrument with a small measuring spot (e.g. testo 845, testo 830-T3)

Temperature measurement on refrigeration unit

Points to watch out for:

- Measuring spot/measuring distance
- Measurement on surface with a high emission level (e.g. painted surface)

Tip: Use a measuring instrument that has a small measuring spot at a large distance and permits a comparison measurement using a contact thermometer (e.g. testo 845 or 835 set).

Checking and recording temperature values on generators and drives, on diesel units and on exhaust manifolds.

Points to watch out for:

- Measuring spot/measuring distance
- Measurement on surface with a high emission level or moisten surface, e.g. with oil.

Tip: Use a measuring instrument that has a small measuring spot at a large distance and permits a comparison measurement using a contact thermometer (testo 845 and 835).

Temperature check on output cables of an electricity generator.

Temperature check on rail vehicles, e.g. "hot box detection" on railway carriages through measurement of axle cover temperatures.

Points to watch out for:

- Use a measuring instrument that has a small measuring spot at a large distance.

Heating, ventilation and air conditioning systems

Temperature check on ventilation ducts.

Points to watch out for:
- The air is not measured, but rather the temperature of the grilles.
- Do not take measurement on bare metals.
- Do not take measurement too close to the measuring point.

Checking heat profiles or detecting critical points in buildings.

Points to watch out for:
- Materials such as wallpaper, wood, plaster, painted window frames and glass are easy to measure due to their high emission level of between 0.9 and 0.95.
- Either measure bare metal frames with a contact thermometer or apply a coating that increases the emission level.

Monitoring the thermal insulation in buildings.

Points to watch out for:
- Do not take measurement on bare metals.
- Note differences in emission levels.

General applications

Quick temperature measurement for road construction.

Points to watch out for:

- Permissible operating temperatures of measuring instrument
- Measuring spot/measuring distance
- Measuring instrument must have adjusted to ambient temperature.
- Only measure materials with a high emission level, as “cold sky radiation” at -50 to -60 °C present a disturbance variable. If necessary, screen the sky e.g. with an umbrella over the measuring point.

Tip: Use a measuring instrument with a small measuring spot at a large distance.

In food inspection

Points to watch out for:

- Only surface temperature is determined contactlessly.

=> In the case of critical values, always verify with contact thermometer!

- Observe measuring spot/measuring distance
- Measuring instrument must have adjusted to ambient temperature.
- The ideal distance between measuring instrument and cooled product/packaging is 1 to 2 cm. Outer cardboard packaging should be opened and the measurement taken inside the packaging.
- With film-sealed food, only the temperature of the film is measured. Therefore only measure at points at which the film is in direct contact with the product.
- Do not measure at occlusions.

Tip: Use combi measuring instrument (e.g. testo 104 IR)

Other applications in brief

- Temperature monitoring of heat-setting, drying and laminating processes.
- Temperature measurement on running rubber tyres under load to detect material defects through uneven heating.
- Temperature measurement in drying and forming processes in the plastics industry.
- Leak detection in district heating pipes by measurement of the rise in temperature at ground level.

4.3 Further practical tips

Infrared measuring instruments

Natural objects in open air such as water, stone, earth, sand, plants, wood, etc. have emission levels between 0.8 and 0.95 in the spectral range 8 and 14 µm. If measurement is to be performed in the open air, it may be necessary to take “cold sky radiation” into account in the case of small emission levels. Wherever possible, however, this “ambient radiation” should lie in the proximity of the air temperature. This is achieved by screening the interfering radiation, e.g. with a box or an umbrella over the measuring point.
-> Measurable with Testo IR measuring instruments

Glass and quartz
Have high emission levels of approx. 0.90 in the wavelength range over 8 µm. Non-transmissive to IR, i.e. the glass pane is measured.
-> Measurable with Testo IR measuring instruments

Plastics

Are measured in the temperature range between +20 °C and +300 °C during drying and forming processes, extrusion, calendering, deep-drawing, etc. The emission level of almost all plastics is between 0.8 and 0.95, and is therefore easy to measure.

-> Measurable with Testo IR measuring instruments

Transparent films

Have, at certain wavelengths, a characteristic absorption band, which means that the emission level is, however, dependent on the thickness of the film. The thinner the film, the lower the emission level. Thin films are often transmissive in the IR range. Take the background into account.

-> Conditionally measurable with Testo IR measuring instruments

Hot gases and flames

Are “volumetric radiators with selective emission characteristics”. The measuring point is no longer planar. The average temperature value is taken from a section inside the flame. This value is also frequently influenced by furnace walls behind the flame or gases.

As with transparent materials, flames and gases radiate primarily in certain spectral ranges, for example in the range around 4.3 µm (CO_2 band).

-> Measurable with special instruments

-> No measurable with Testo IR measuring instruments

Testing and calibration

To test and calibrate the display of radiation pyrometers, a black body radiator is required. During calibration, it is important to ensure that the respective measuring field of the radiation thermometer to be tested is smaller than the opening of the black body radiator.

In the case of a permanently set emission level (e.g. 0.95), the display must be converted to $\varepsilon = 1$.

Emission level

Even if the emission level is correctly set, measurement errors may occur!

With emission levels less than 1, the measuring value is extrapolated on the basis of instrument temperature = ambient temperature.

- If the instrument temperature does not correspond to the ambient temperature, the instrument's emission level correction will be incorrect. In other words: if the instrument temperature is lower, then the measurement result is too high, and if the instrument temperature is higher, then the measurement result is too low.

- If individual heat or cold radiators (e.g. heating elements, lamps, refrigeration units, etc.) are reflected on the surface of the measurement object, then this radiation does not correspond to ambient temperature = instrument temperature. In this case too, the emission level correction performed by the instrument will be incorrect.

Remedy: Screen off such radiators, e.g. with a cardboard box. This will absorb any stray radiation and emit its own radiation = ambient temperature.

4.4 Comparison of an infrared thermometer and thermal imager

Particularly with multi-point temperature measurement on large objects, IR measuring technology with an IR thermometer (pyrometer) is, also thanks to its comparably low price, seen as a simple non-contact measuring solution. For the measuring tasks described here, these instruments are more than adequate.

In contrast, however, the testo 870 thermal imager, for example, has 19,200 individual temperature values, which are used to create an IR image. In practice, this means the following advantages:

- Detection of critical temperatures even on extremely small objects, e.g. a hot cable.
- Large surfaces or measurement objects (e.g. floors, buildings, switch cabinets, etc.) are shown on one image. There is no longer any need to carry out time-consuming “scanning” of a surface with an IR thermometer.
- Documentation of measurement result as an IR image and real image at the touch of a button

These features may be decisive in industrial maintenance, for example, where faulty machinery parts such as an overheated motor have to be quickly detected to enable them to be replaced immediately in order to avoid downtime. Most available thermal imagers now also have a digital camera. This means that both a thermal image and a visual image of the measurement object are captured, ensuring better orientation during analysis. Tip: Essentially, if you have found the point at which you want to take a measurement, i.e. you know where to measure and are not dependent on the ambient temperature, then a single-point pyrometer is adequate. For example, to measure fruit or the temperature in refrigerated displays, it is not necessary to use a thermal imager. However, if you need to detect danger spots without knowing beforehand where they are, a thermal imager can bring considerable advantages.

4.5 Summary: non-contact measurement or contact measurement – Testo's recommendation

Non-contact infrared temperature measurement is...

...ideal for measuring the surface temperatures of:

a) Poor thermal conductors such as ceramic, plastic, rubber, wood, paper, wallpaper, plaster, textiles, organic materials, food.
The measuring instrument measures without any retroactive effect, i.e. without any influence on the measurement object. The IR radiation of the measurement object is therefore always at the same speed, irrespective of thermal conductance.

b) Materials with a high emission level, e.g. lacquer, paints, glass, minerals, tiles, stone, tar and all non-metallic materials. In this case, an emission level setting of 0.95 is usually correct. Errors due to external radiation reflected on the surface are only slight.

c) Moving parts (provided that the material has a high emission level or a material with a defined emission level can be applied) e.g. running paper webs, rotating tyres or oxidised steel parts on a conveyor.

d) Parts that must not be touched such as freshly painted parts, sterilised parts or aggressive media or live parts such as electronic components, busbars and transformers.

e) Small and low-mass parts, e.g. components and all measurement objects where a contact probe draws too much heat, thereby causing incorrect measurements.

However, you must always ensure that the measuring spot of the measuring instrument is smaller than the measurement object!

...only conditionally suitable for:

Metal oxides, as these have an emission level that is mainly dependent on the temperature (between 0.3 and 0.9).

In this case, you should either apply a substance with a defined emission level (e.g. testo emission tape order-no. 0554 0051, lacquer or oil) or determine the emission level by means of a comparison measurement with a contact thermometer.

...not suitable:

For bare metals to which no materials that increase emission level such as tape, lacquer or oils can be applied. Here, a high error rate can be expected due to the high level of reflection on the measurement object surface.

Typical temperature control measurements using infrared in industry:

- Generators, drives, power units
- Bearing shells
- Switch cabinets
- Electronic circuits
- Bimetal shift point setting
- Heat setting, drying and laminating processes
- Running rubber tyres
- Plastics in drying and forming processes.

Typical temperature control measurements using infrared in building/air conditioning technology:

- Ventilation ducts
- Heat profiles and thermal insulation in buildings
- Localisation of cold bridges and insulation weak points.

Typical infrared applications in heating engineering:
Surface measurements on:

- Radiators, painted heating pipes
- Floor coverings, wood, cork, tiles, granite and unfinished wall surfaces for the localisation of heating pipes.

Typical infrared applications in food inspection:

- Quick test in Incoming Goods or in a chest freezer.

Contact temperature measurement is...

...ideal for:

a) Measurement of smooth surfaces with good thermal conductance such as all metals. In this case, contact measurement is usually also more accurate than infrared measurement.

b) Determination of core temperatures in liquids and food.

...conditionally suitable for:

a) Measurements of poor thermal conductors (for examples, see IR measurement)
   A probe for contact measurement can only display correct temperatures if it can take on the temperature of the measurement body. With poor thermal conductors, this will mean faulty measurements or very long adjustment times until the probe has taken on the temperature of the measurement object.

b) For small, low-mass parts.
   Here, the contact probe draws heat from the measurement object, which influences the measurement result.

...not suitable for:

- Parts that must not be touched (see above)
- Moving parts.

Typical contact measurement applications in industry on:

- Tools for forming processes
- Drives, gearboxes, bearings
- All metal surfaces

and for comparison measurement with the IR measurement, in order to be able to establish the emission level of the surface.

Typical contact measurement applications in building/air conditioning technology on:

- Ventilation ducts
- Wall surfaces.

Typical contact measurement applications in heating engineering:

- Measurement of flow/return temperature on bare copper pipes
- Radiator inspection
- Localisation of heating pipes in the floor and in walls

Typical contact measurement applications in food inspection:

- Measurement of core temperature at critical product temperatures

Conclusion

Testo does not recommend contact or non-contact measurement, but rather the use of a non-contact infrared thermometer and a contact thermometer in one compact device. This combination enables virtually any measuring task to be solved quickly and precisely.

The emission level can be set on the infrared side for industrial, air conditioning and heating applications.

In the case of food inspection, a fixed set value of 0.95 is usually adequate.

For surface measurements, a quick-actuating spring-mounted measuring head, which enables reliable and precise measurement even on curved metal surfaces, should be integrated on the contact side. This means that accurate determination is possible even on surfaces for which the emission level is unknown, enabling the advantages of non-contact measurement to be exploited.

In the case of insertion or immersion measurements, the finest possible measuring tip should be used to determine the core temperature on the contact side, so that even in the case of small insertion depths, the measuring value is determined quickly and reliably.

Appendix: Emission level tables

The emission level tables serve as a guide for adjusting the emission factor for infrared temperature measurement. They indicate the emission factor ε of certain common metals and non-metals. As the emission factor changes depending on the temperature and particularly on the surface quality, the values given here should be regarded only as a rough guide for the measurement of temperature ratios or differences. In order to measure the absolute temperature value, the exact emission level of the material must be determined.

Emission level table for important materials

Material	Temperature	ε
Aluminium, rolled blank	170 °C	0.04
Asbestos	20 °C	0.96
Asphalt	20 °C	0.93
Cotton	20 °C	0.77
Concrete	25 °C	0.93
Lead, grey oxidised	20 °C	0.28
Lead, heavily oxidised	20 °C	0.63
Roofing felt	20 °C	0.93
Ice, smooth	0 °C	0.97
Ice, rough frost coating	0 °C	0.99
Iron, emery-ground	20 °C	0.24
Iron, bare etched	150 °C	0.13
Iron with cast skin	100 °C	0.80
Iron with rolled skin	20 °C	0.77
Iron, slightly rusted	20 °C	0.61
Iron, heavily rusted	20 °C	0.85
Earth, cultivated arable land	20 °C	0.38
Earth, black clay	20 °C	0.66
Tiles	25 °C	0.93
Gypsum	20 °C	0.90
Glass	90 °C	0.94
Gold, polished	130 °C	0.02
Rubber, hard	23 °C	0.94
Rubber, soft grey	23 °C	0.86
Wood	70 °C	0.94
Pebbles	90 °C	0.95
Cork	20 °C	0.70
Corundum, emery (rough)	80 °C	0.86
Heat sink, black anodised	50 °C	0.98
Copper, slightly tarnished	20 °C	0.04
Copper, oxidised	130 °C	0.76
Copper, polished	20 °C	0.03
Copper, black oxidised	20 °C	0.78
Plastics (PE, PP, PVC)	20 °C	0.94
Leaves	20 °C	0.84
Marble, white	20 °C	0.95
Minium coating	100 °C	0.93
Brass, oxidised	200 °C	0.61
NATO-green	50 °C	0.85
Paper	20 °C	0.97
Porcelain	20 °C	0.92
Slate	25 °C	0.95
Black paint (matt)	80 °C	0.97
Silk	20 °C	0.78
Silver	20 °C	0.02
Steel (heat-treated surface)	200 °C	0.52
Steel, oxidised	200 °C	0.79
Clay, fired	70 °C	0.91
Transformer paint	70 °C	0.94
Water	38 °C	0.67
Brick, mortar, plaster	20 °C	0.93
Zinc white (paint)	20 °C	0.95

Emission level tables, typical values of metals

Material	Type/quality/element	Temperature (°C)	ε
Aluminium	Non-oxidised	25	0.02
	Non-oxidised	100	0.03
	Non-oxidised	500	0.06
	Oxidised	200	0.11
	Oxidised	600	0.19
	Heavily oxidised	93	0.20
	Heavily oxidised	500	0.31
	Highly polished	100	0.09
	Lightly polished	100	0.18
Lead	Polished	38 - 260	0.060 - 08
	Rough	40	0.43
	Oxidised	40	0.43
	Grey oxidised	40	0.28
Chromium	Chromium	40	0.08
	Chromium	540	0.26
	Chromium, polished	150	0.06
Iron	Oxidised	100	0.74
	Oxidised	500	0.84
	Non-oxidised	100	0.05
	Rust film	25	0.70
	Heavily rusted	25	0.65
Gold	Lacquering	100	0.37
	Polished	38 - 260	0.02
Cast iron	Oxidised	200	0.64
	Oxidised	600	0.78
	Non-oxidised	100	0.21
	Heavily oxidised	40 - 250	0.95
Inconel sheet	Inconel sheet	540	0.28
	Inconel sheet	650	0.42
Cadmium	Cadmium	25	0.02
Cobalt	Non-oxidised	500	0.31
Copper	Copper oxide	100	0.87
	Copper oxide	260	0.83
	Copper oxide	540	0.77
	Black, oxidised	40	0.78
	Etched	40	0.09
	Polished	40	0.03
	Rolled	40	0.64
	Natural	40	0.74
	Molten	540	0.15
Alloys	Ni-20, Cr-24, Fe-55, oxidised	200	0.90
	Ni-60, Cr-12, Fe-28, oxidised	270	0.89
	Ni-80, Cr-20, oxidised	100	0.87
Magnesium	Magnesium	40 - 260	0.07 - 0.13
Brass	73% Cu, 27% Zn, polished	250	0.03
	62% Cu, 37% Zn, polished	260	0.03
	Matted	20	0.07
	Burnished	20	0.40
	Oxidised	200	0.61
	Non-oxidised	25	0.04

Molybdenum	Molybdenum	40	0.06
	Molybdenum	250	0.08
	Molybdenum	540	0.11
Monel	Ni-Cu	200	0.41
	Monel	400	0.44
	Monel	600	0.46
	Oxidised	20	0.43
Nickel	Polished	40	0.05
	Oxidised	40 - 260	0.31 - 0.46
	Non-oxidised	25	0.05
	Non-oxidised	100	0.06
	Non-oxidised	500	0.12
	Electrolytic	40	0.04
Platinum	Platinum	40 - 260	0.05
	Platinum	540	0.10
	Black	40	0.93
	Black	260	0.96
	Oxidised at 600 °C	260	0.07
	Oxidised at 600 °C	540	0.11
Mercury	Mercury	0	0.09
	Mercury	25	0.10
	Mercury	100	0.12
Silver	Polished	40	0.01
	Polished	260	0.02
	Polished	540	0.03
Wrought iron	Dull	25	0.94
	Dull	350	0.94
	Smooth	40	0.35
	Polished	40	0.28
Steel	Cold-rolled	93	0.75 - 0.85
	Polished sheet	40	0.07
	Polished sheet	260	0.00
	Polished sheet	540	0.14
	Soft, unalloyed steel, polished	25	0.10
	Soft, unalloyed steel, polished	25	0.12
	Non-oxidised	100	0.08
	Oxidised	25	0.80
Steel alloy	Type 301, polished	25	0.27
	Type 316, polished	25	0.28
	Type 321, polished	150 - 815	0.18 - 0.49
Stellite	Polished	20	0.18
Tantalum	Non-oxidised	727	0.14
Bismuth	Bright	80	0.34
	Non-oxidised	25	0.05
	Non-oxidised	100	0.06
Zinc	Usual commercial purity (99.1%)	260	0.05
	Galvanised	40	0.28
	Polished	260 - 540	0.11
	Polished	38	0.02
	Polished	260	0.03
	Polished	540	0.04
Tin	Non-oxidised	25	0.04
	Non-oxidised	100	0.05

Emission level tables, typical values of non-metals

Material	**Type/quality/element**	**Temperature (°C)**	**ε**
Aluminium paint	Aluminium paint	40	0.27 - 0.67
	10% Al	40	0.52
	26 % Al	40	0.30
Asbestos	Asphalt, road surface	20	0.93
	Asphalt, tarred board	20	0.72
	-tissue	93	0.90
	-cardboard	38 - 370	0.93
	-plates	40	0.96
	-cement	0 to 200	0.96
Basalt	Basalt	20	0.72
Cotton fabric	Cotton fabric	20	0.77
Minium	Minium	100	0.93
Bronze paint	Bronze paint	Low	0.34 - 0.80
Ice	Smooth	0	0.97
	Rough	0	0.98
Earth	General	40	0.38
	Dark loamy ground	20	0.66
	Cultivated field	20	0.38
Paint	Blue, Cu 203	25	0.94
	Black, CuO	25	0.96
	Green, Cu 203	25	0.92
	Red, Fe 203	25	0.91
	White, Al 203	25	0.94
Gypsum	Gypsum	20	0.80 - 0.90
Glass	Flat plate glass	0 - 90	0.92 - 0.94
	Convex D	100	0.80
	Convex D	500	0.76
	Nonex	100	0.82
Granite	Granite	20	0.45
Rubber	Hard rubber	25	0.94
	Soft, grey	25	0.86
Wood	Wood	Low	0.80 - 0.90
	Beech, planed	70	0.94
	Oak, planed	40	0.91
	Spruce, polished	40	0.89
Lime mortar	Lime mortar	40 - 260	0.90 - 0.92
Lime sand brick	Lime sand brick	40	0.95
Ceramic	Porcelain	20	0.92
	Earthenware, glazed	20	0.90
	Earthenware, matt	20	0.93
Gravel	Gravel	40	0.28
Carbon	Flame soot	25	0.95
	Non-oxidised	25	0.81
	Non-oxidised	100	0.81
	Non-oxidised	500	0.79
	Candle soot	120	0.95
	Fibres	260	0.95
	Graphitised	100	0.76
	Graphitised	300	0.75
	Graphitised	500	0.71

Lacquer	Blue, on aluminium foil	40	0.78
	Yellow, 2 coats on Al foil	40	0.79
	Clear, 2 coats on Al foil	90	0.09
	Clear, on bright copper	90	0.65
	Clear, on tarnished copper	90	0.64
	Red, 2 coats on Al foil	40	0.74
	Black, CuO	90	0.96
	White	90	0.95
	White, 2 coats on Al foil	40	0.88
Clay	Clay	20	0.39
	Fired	70	0.91
	Slate	20	0.69
Marble	White	40	0.95
	Smooth, white	40	0.56
	Polished, grey	40	0.75
Masonry	Masonry	40	0.93
Oil, on nickel	Coat thickness 0.02 mm	22	0.27
	Coat thickness 0.05 mm	22	0.46
	Coat thickness 0.10 mm	22	0.72
Oil paints	All paints	90	0.92 - 0.96
	Grey-green	20	0.95
	Green, Cu 203	90	0.95
	Red	90	0.95
	Black, CuO	90	0.92
	Black, glossy	20	0.90
	Camouflage paint, green	50	0.85
	White	90	0.94
Quartz glass	1.98 mm	280	0.90
	6.88 mm	280	0.93
	Opaque glass	300	0.92
Soot	Acetylene	25	0.97
	Camphor	25	0.94
	Carbon black	95	0.96
	Candle soot	120	0.95
	Coal	20	0.95
Sand	Sand	20	0.76
Sandstone	Sandstone	40	0.67
Sawdust	Sawdust	20	0.75
Slate	Slate	20	0.69
Snow	Fine	-7	0.82
	Large flakes	-8	0.89
Emery	Emery	80	0.86
Silk	Silk	20	0.78
Silicon carbide	Silicon carbide	150 - 650	0.83 - 0.96
Water	Water	40	0.67
Sodium silicate	Sodium silicate	20	0.96
Cellulose adhesive	2 coats	20	0.34
Brick	Air-dried	20	0.90
	Red, rough	20	0.93

Notes

Notes

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