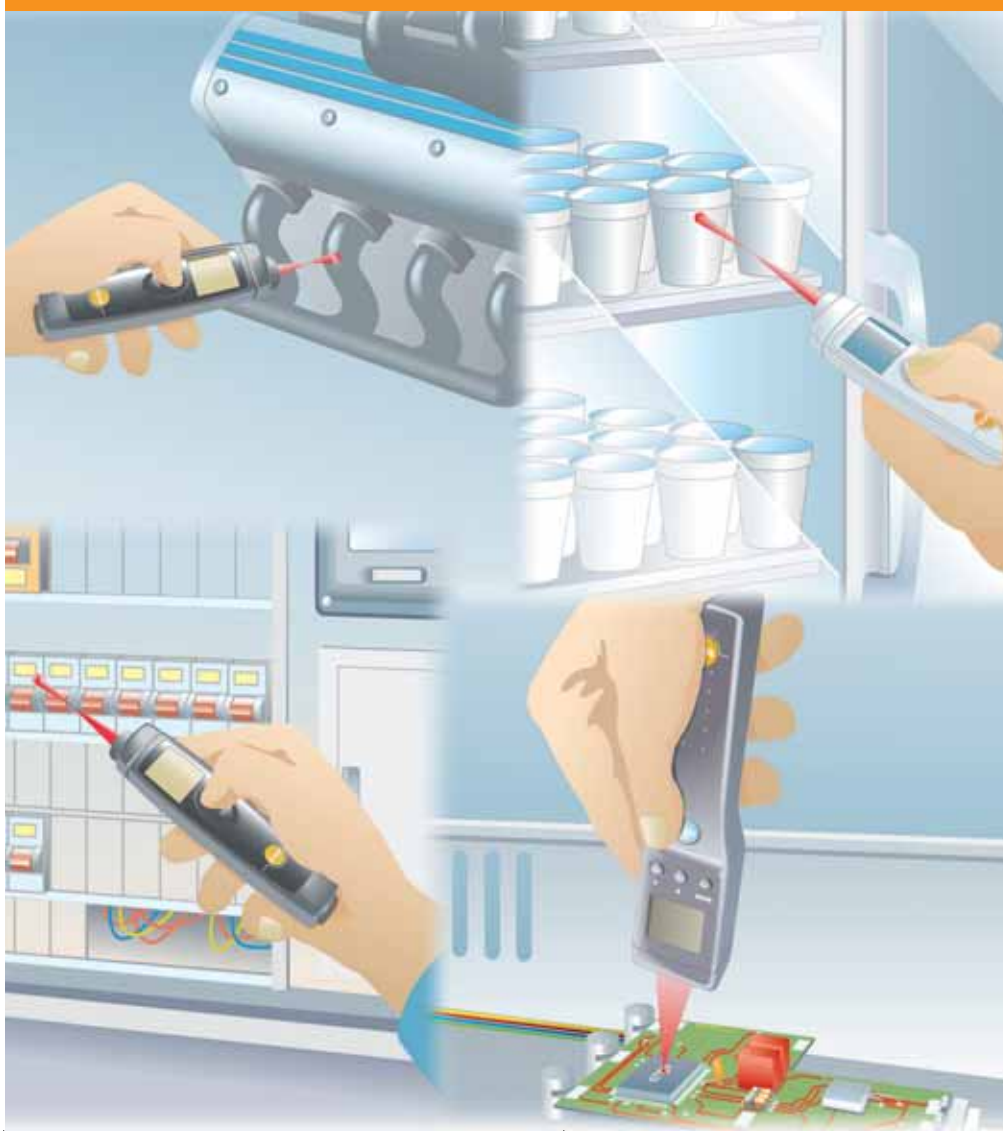




Manual for Infrared Measuring Technology



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Foreword

This handbook, "Manual for Infrared Measuring Technology", is a result of a compilation of questions put by our customers on a daily basis, on the topic of contactless temperature measuring technology.

Contactless measurement of surface temperatures has been technically possible since around 1960, but the expensive sensors and evaluation devices required were a barrier to its widespread use in trade and industry. Due to new production technologies and falling component prices, this technology succeeded in asserting itself in the 90's. This is impressively proven, for example, by the infrared switches used a thousand times over in the electrical installation sector. Thus today small, reasonably-priced hand held temperature measuring devices are available for contactless measurement, which cost no more than the sensor element in a comparable device in the 70's.

The main application of contactlessly temperature measuring devices is in any situation where other measuring methods (e.g. contact thermometers) cannot or can only be conditionally used. Examples of this are live parts, rotating machine parts or packaged foodstuffs, which would be damaged by inserting a probe.

However, as with infrared measuring technology, heat rays which are emitted by the surface of the measuring object are recorded and measured, a few elementary ground rules need to be observed in comparison with contact measurement, in order to avoid measurement errors. These "tips and tricks" have been amplified with examples from everyday measuring practice, in order to provide the user with practical, valuable assistance.

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1. What is heat radiation? - Principles

It is a well-known fact in daily life that all bodies emit electromagnetic waves, or radiation, depending on their temperature. During the dispersion of the radiation, energy is transported, which ultimately allows the temperature of the body to be contactlessly measured with the help of the radiation.

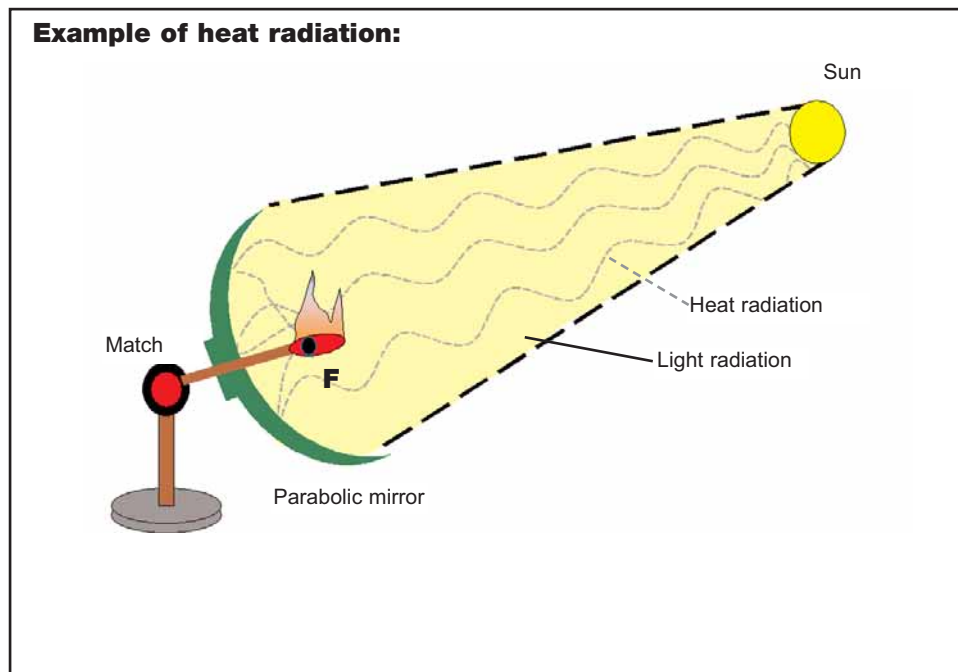
The radiated energy and its characteristic wavelengths are primarily dependent on the temperature of the radiating body.

Ideally, a measuring object absorbs all energy (**absorption**) and converts it into its own heat radiation (**emission**). We refer to such a case as a so-called "Black Body Radiator". In nature, this behaviour as good as never occurs; rather, additional reflection and transmission of the radiation occurs onto or through a body. However, in order to achieve reliable measuring results in practice with infrared measuring systems, it is necessary to accurately identify this emission, reflection and transmission behaviour (see also 1.4) or to eliminate its influence using suitable measures.

This is made possible through reference measurements with contact thermometers or through a deliberate change in the measuring surface, so that the latter can be easily handled by the infrared measuring technology; this can be done, for instance by colour coating with paint, using bonding agent and glue, plastic covers or paper stickers.

If and how measures succeed, is ultimately decided by the measuring object and measuring environment. Assistance with assessment is provided by classifying application cases according to the appearance of the measuring objects and their surfaces.

This will be discussed in more detail in Point 4 "**Applications and practical tips**"



*If, e.g. you point a parabolic mirror with a match directly towards the sun, then it will ignite after a short period of time. This is because of the heat radiation from the sun, which is concentrated by the parabolic mirror onto a point **F** (Focus).*



1.1 Advantages of IR measuring technology

In the last few years, an overproportional increase can be noted in applications using infrared measuring systems. The following factors undoubtedly play an important role in this development.

- Infrared measuring technology enables simple temperature recording even of fast, dynamic processes. This is assisted by the short reaction time of sensors and systems.
- The systems provide a perfected, modern technology with reliable sensor engineering and modern microprocessor electronics.
- Due to its absence of feedback, i.e. its lack of influence on the measuring object, online measurements can be performed on sensitive surfaces and sterile products, just as well as measurements on hazardous points or points that are difficult to access.

Another aspect of this development that should not be forgotten - in addition to technical advantages - is the customer-friendly pricing of these systems, due to cost-optimised production, which has been specifically designed for large piece quantities.

IR temperature measuring instruments are particularly suitable:

√

...for poor heat conductors, such as ceramics, rubber, plastics etc. A sensing device for contact measurement can only display the correct temperature if it can take on the temperature of the measured body. In the case of poor heat conductors this is usually not the case, and the setting times are very long.

√



...for determining the surface temperature of gears, housings and bearings on large and small motors.

✓



...for moving parts, e.g. moving paper runs, rotating tyres, moving metal runs etc.

- ✓ ...for non-contactable parts, e.g. freshly painted parts, sterilised parts or aggressive media.
- ✓ ...for measurements of small and large areas by selecting different lenses.
- ✓ ...for live parts, e.g. electrical components, busbars, transformers etc.
- ✓ ...for small and low-mass parts, e.g. components and all measuring objects for which a contact probe will remove too much heat, thus causing faulty measurements.

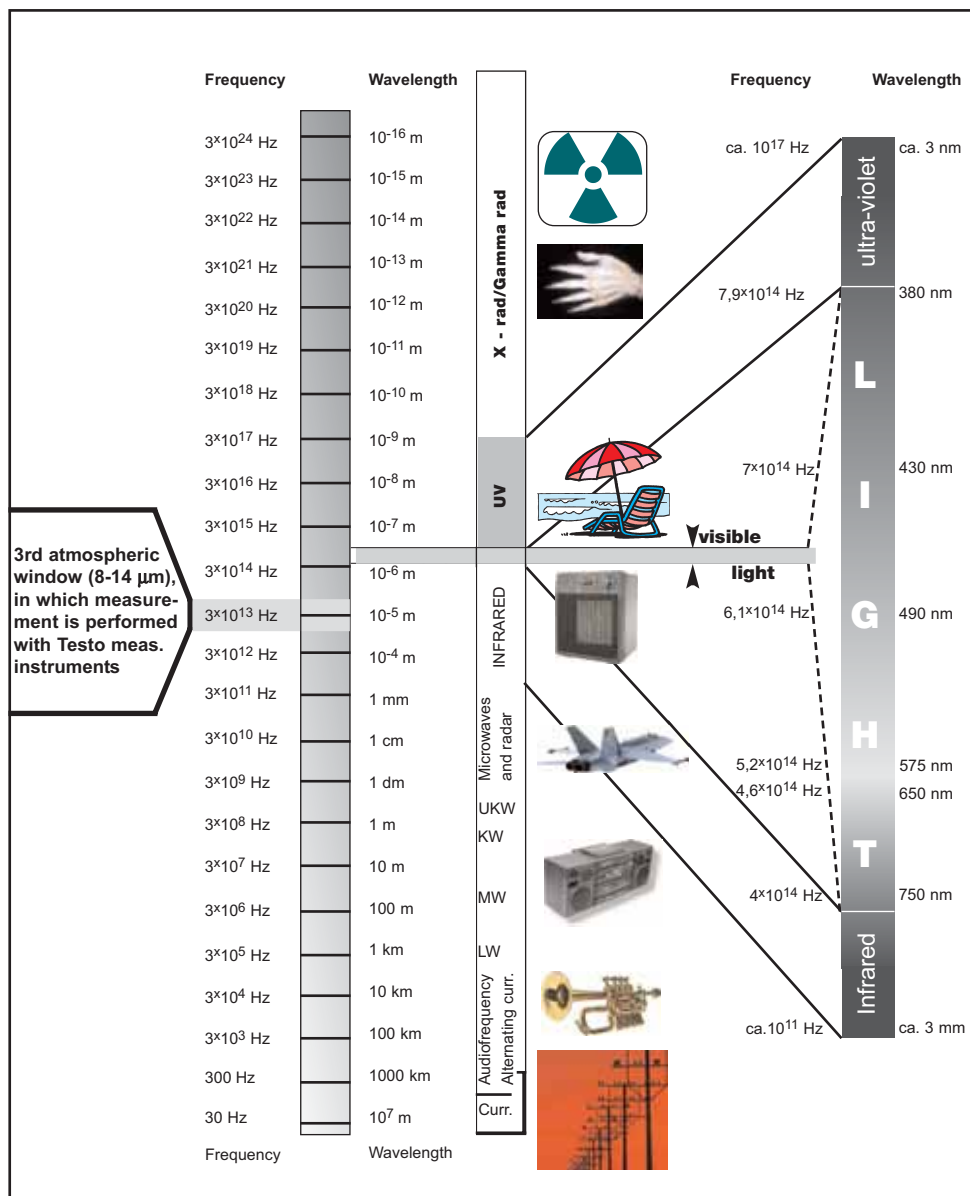
1.2 History

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 technique application)

The measurement of very high temperatures was the fundamental application of radiation thermometers up until 1960. After this, however, different types of radiation receivers were developed, which are also sensitive at wavelengths greater than $5\mu\text{m}$ and thus enable accurate and reliable temperature measurement to far below the freezing point of water.



1.3 Electromagnetic spectrum



Explanation:

Light is an electromagnetic wave, which disperses in a straight line and at the speed of light *. According to the frequency or equivalent of the wavelength, it always follows the same fundamental law of nature, but is perceived completely differently by people. Perceptions are light or heat, other areas, such as e.g. X-radiation, are not perceived at all, or only as a result of their effect (UV light leads to sunburn). The electromagnetic radiation spectrum extends over approx. 23 powers of ten.

Generally light is only the visible part of electromagnetic radiation, which is called VIS (visible), and covers the wavelength ranges of 380 nm (violet) to 750 nm (red). The limits of this area are defined by the sensitivity of the human eye.

Following this with shorter wavelength is ultraviolet light (UV), which at wavelengths under 200 nm is also known as vacuum-ultraviolet (VUV).

In the long-wave range, near-infrared light (NIR) borders on visible light. Its range is between 750 nm and 2.5 μm . Next comes the spectral range of medium infrared (MIR or simply IR). This encompasses the range between 2.5 μm and 25 μm . The far-infrared range (FIR) comprises the wavelength ranges 25 μm to approx. 3 mm.

*the consideration of particles is not taken into account here.



Atmospheric windows:

What are atmospheric windows and why is measurement performed in these areas?

- 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 no or only very little absorption or emission of electromagnetic radiation by the air between the measuring object and measuring instrument. Therefore particularly at distances smaller than 1m from the measuring object, there are no effects due to the gases usually contained in the air.

Suitable spectral ranges are, for example for measurements of temperatures > 1000 °C, the visible and near infrared range, for measurements of average temperatures, the spectral range from 2 to 2.5 μm and 3.5 to 4.2 μm . The energy occurring is correspondingly great in these cases.

For measurements of low temperatures (for which Testo measuring instruments are designed) the wavelength range 8 to 14 μm is suitable, as to generate a usable signal a broad energy band is required for evaluation.



1.4 Emission, reflection, transmission

As already mentioned at the beginning, each body emits electromagnetic radiation above the absolute zero point (0 Kelvin = $-273,15^{\circ}\text{C}$).

The radiation recorded by the measuring head consists of an **emission** from the measuring body, and **reflection** and **transmission** from the external radiation. The sum is always equated to 100% or 1. The intensity of the emitted radiation depends on the **emissivity ϵ** of the material.

In summary:

The emissivity (ϵ)

is the ability of a material to emit infrared radiation.

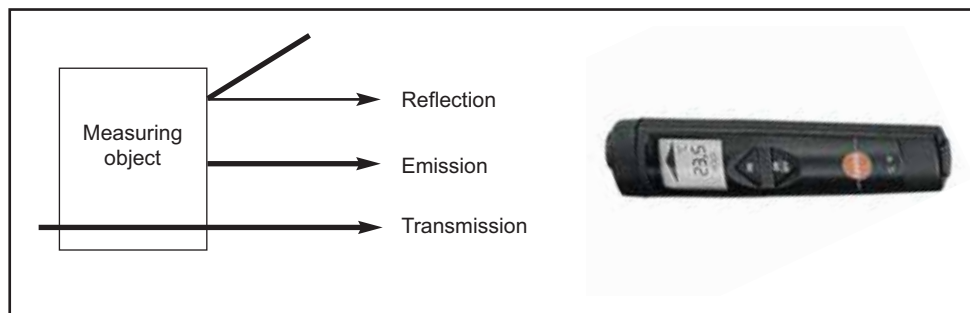
The degree of reflection (R)

is the ability of a material to reflect infrared radiation; it depends on the surface quality and the type of the material.

The transmission factor (T)

is the ability of a material to admit infrared radiation; it depends on the thickness and type of the material. It specifies the permeability of the material for IR radiation.

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



Note:

To select the correct emissivity, see Chapter 4.3 "Further practical tips on emissivity".



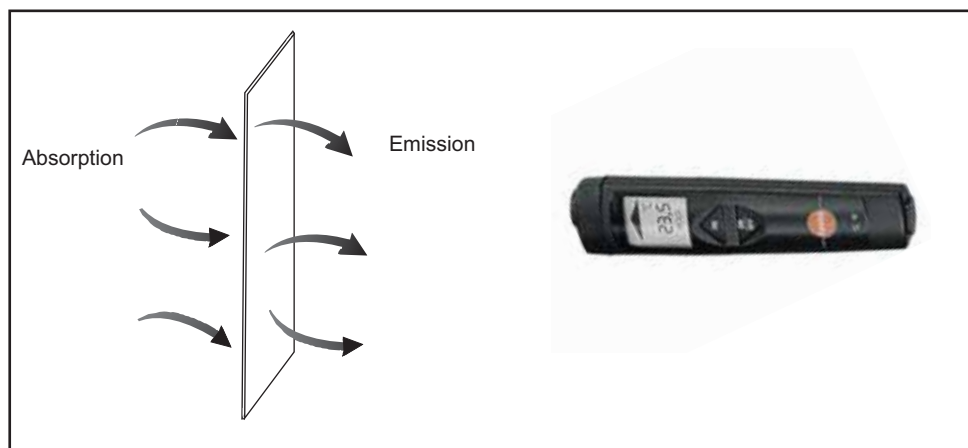
1.5 The measuring object

For each application the measuring object is primarily located in the foreground. The task is to determine the temperature exactly and precisely.

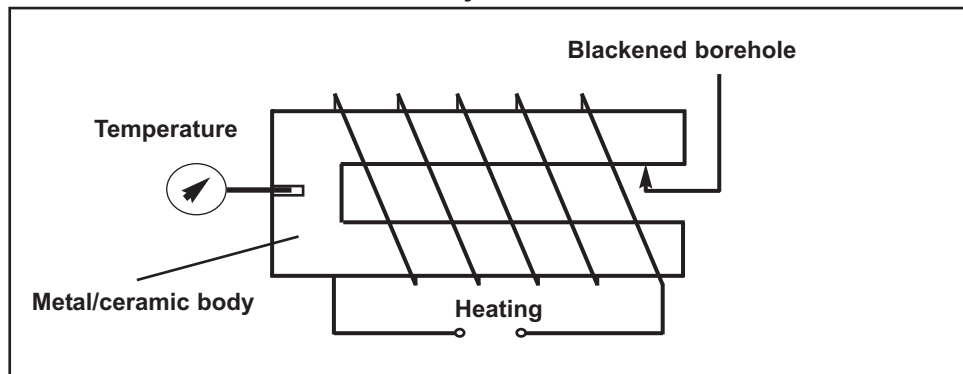
Whether solid bodies, liquids or gases, each measuring object appears individually and specifically for an infrared sensor. This is based on its specific material and surface condition. Thus many organic products and liquids can be measured without taking any special actions. Metals, on the other hand, particularly with reflective surfaces, require special consideration.

If the degree of reflection and the transmission factor are equal to 0, then you have an ideal measuring body, the so-called "Black Body Radiator", whose radiated energy can be calculated by means of the Planckian law of radiation. An ideal body of this type has an emissive power of $\varepsilon = 1$.

- **Black Body Radiator (Ideal Radiator)**



Absorbs and emits 100 %. Emissivity $\varepsilon = 1$.

Schematic structure of a Black Body Radiator:

In reality, however, such ideal conditions do not exist. Transmission and reflection are always considered as disturbances in the measurement. Accordingly, a real body can be schematically represented as follows:

- **Real body**



Part of the radiation is reflected or passes through. Emissivity $\epsilon < 1$.



- **Grey Radiator (ϵ less than 1)**

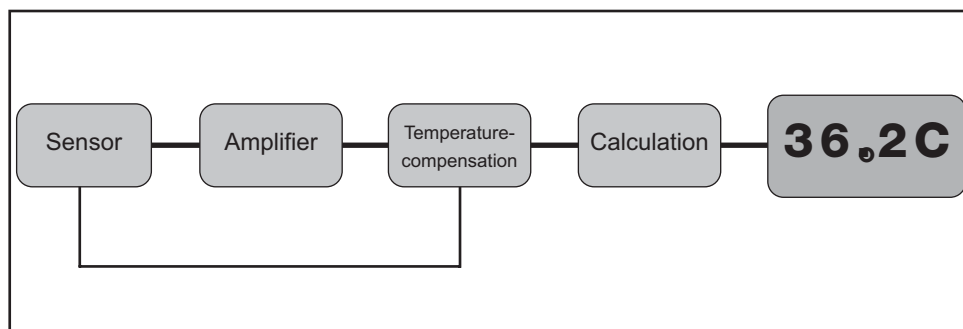
Most bodies occurring in nature are called "Grey Radiators". They present the same characteristics as Black Body Radiators. Only the intensity of the emitted radiation is less. This is corrected by adjusting the emissivity. The emissivity is therefore the ratio between "black" and "grey" radiation intensity.

- **Coloured Radiator**

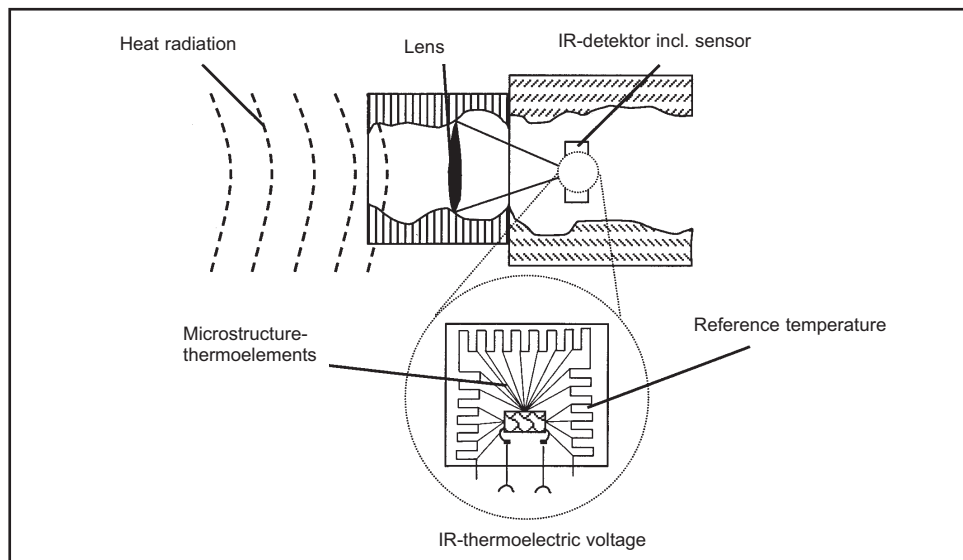
Coloured radiators are materials for which the emissivity is dependent on the wavelength and thus the temperature. This means that such a body has a different emissivity e.g. at 200 °C than at 600 °C. This applies for most metallic materials. In this case it must be ensured that the emissivity ϵ is determined at the correct measuring temperature.

2. Structure of an IR measuring device

2.1 Logic diagram

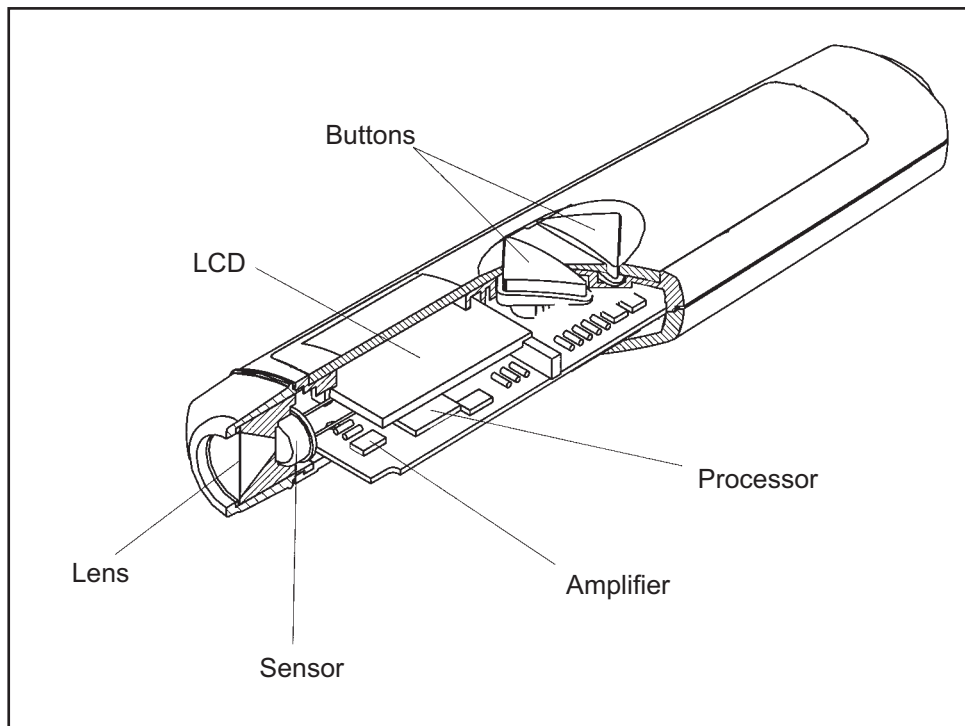


2.2 The sensor





2.3 Measuring layout / Measuring system



Cross-section of a Quicktemp 825 thermometer

The heat radiation is concentrated with the help of a lens (in this case a Fresnel lens) and passed onto the sensor. The sensor transforms the heat radiation into an electrical voltage, which is boosted by the amplifier and transferred to the microprocessor. The processor compares the measured temperature with the ambient temperature and shows the result on the display.

As on principle the measuring method is an optical one, the lens must always be kept dust-free and clean.

2.4 Which parameters are included in the measuring result?

a) Measuring object

- Temperature of the measuring object
- Emissivity of the measuring object

b) Measuring device

- Characteristic temperature (comparison point)

The measuring device determines the following values:

SM = received signal from measuring object

SU = signal from ambient temperature (usually equivalent to the instrument temperature)

From these, if the Emissivity ϵ is known, the effective signal SW is calculated:

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

temperature of the measuring object is a function of the thus determined effective signal SW:

T measuring object = f (SW)

In the measuring device, the temperature of the measuring object is calculated from the effective signal SW via a linearisation function.



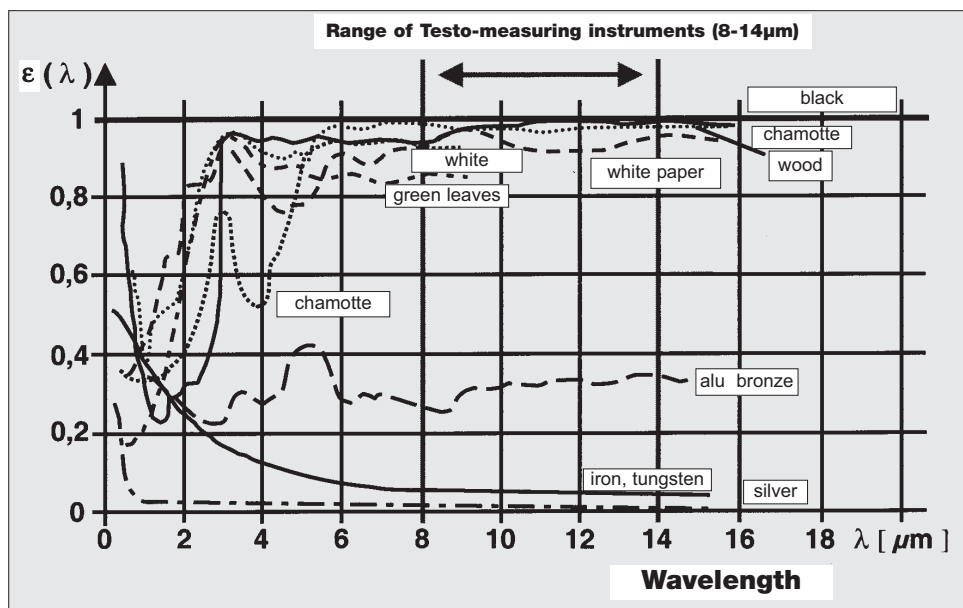
3. Emissivity

3.1 Typical emissivities

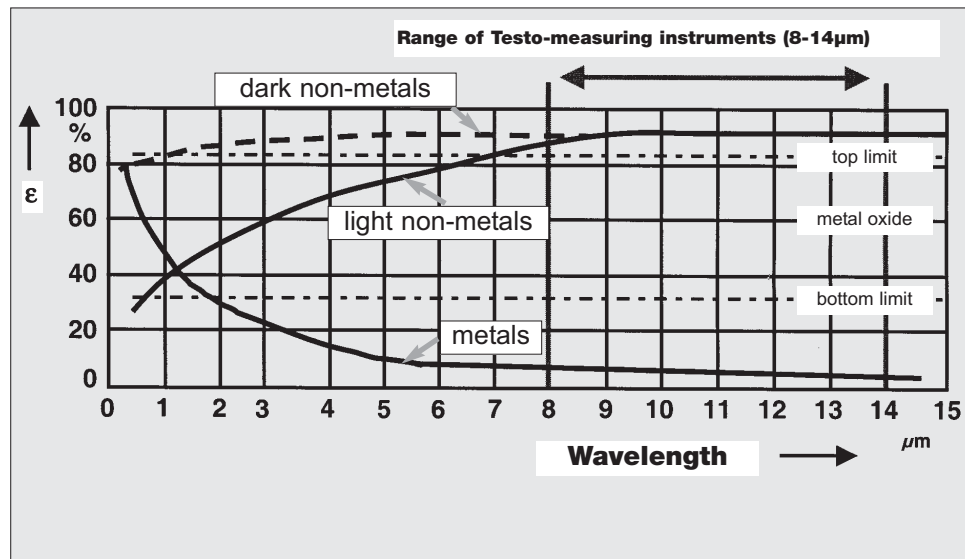
• Foodstuffs

Like all organic materials, foodstuffs have good emission properties and are relatively unproblematic to measure using IR-measurement.

• Industry



Emissivity of various impervious materials depending on the wavelength



Emissivity of various materials depending on the wavelength (schematic representation)

• **Blanc metals**

Have a very small emissivity in the range 8 - 14 μm and are therefore difficult to measure.

⇒ Apply emissivity-increasing coatings, such as e.g. paint, oil film or emission adhesive tape (e.g. testo part no. 0554 0051), to the measuring object or measure with contact thermometer.

• **Metal oxides**

Do not present any standard behaviour. The emissivity lies between 0.3 and 0.9 and is generally heavily dependent on the wavelength.

⇒ Determine emissivity through comparison measurement with contact thermometer or apply coating with defined emissivity.



• **Light non-metals / dark non-metals / plastics / foodstuffs**

such as white paper, ceramics, gypsum, wood, rubber, dark wood, rock, dark colours and paints etc. have an emissivity of approx. 0.95 at wavelengths greater than 8 μm .

⇒ Most organic materials (e.g. foodstuffs) have an emissivity of approx. 0.95. Therefore, this value is permanently entered in many devices, in order to avoid measuring errors due to (unnoticed) incorrectly set emissivities.

Effect of colours on the measuring result

Light and dark non-metals therefore hardly differ at all with regard to their emission behaviour in the case of longer wavelengths. For example, it makes no difference whether colours and paints are black, blue, red, green or white.

A whitepainted radiator with a temperature of +40 °C to +70 °C radiates just as well as a black-painted radiator, as its temperature radiation is mainly emitted at long wavelengths > 6 μm (outside the visible range).

It can be considered a happy coincidence that non-metals, plastics, rubber etc. at their processing temperature of +50 °C to +300 °C radiate mainly with wavelengths above 5 μm (where the emissivity is very large).

A similar situation applies for metals, particularly for iron alloys, which at a processing temperature above +650 °C radiate with low wavelengths (and very high emissivity).

3.2 Effect on the measuring result in examples

Example 1:

Measuring object (pizza, deep-frozen $T = -22\text{ °C}$)
Emissivity = 0.92

IR measurement at ambient temperature 22 °C
Permanently set emissivity of 0.95
Display of IR measuring instrument: -21 °C

i.e. measuring instrument display is incorrect by approx. 1 °C
⇒ negligible.

Example 2:

Measuring object (oxidised brass plate, $T = +200\text{ °C}$)
Emissivity = 0.62

IR measurement at ambient temperature $+22\text{ °C}$
Set emissivity 0.70
Display of IR measuring instrument: $+188\text{ °C}$

i.e. measuring instrument display is incorrect by approx. 12 °C
⇒ not negligible

Result:



- The greater the difference between the temperature of the measuring object and the ambient temperature and the smaller the emissivity, the larger the errors will be in the case of an incorrect emissivity!



At temperatures above the ambient temperature

- An emissivity set too high will give a temperature display that is too low
- An emissivity set too low will give a temperature display that is too high



At high temperatures below the ambient temperature

- An emissivity set too high will give a temperature display that is too low
- An emissivity set too low will give a temperature display that is too high



3.3 Emissivity tables of important materials

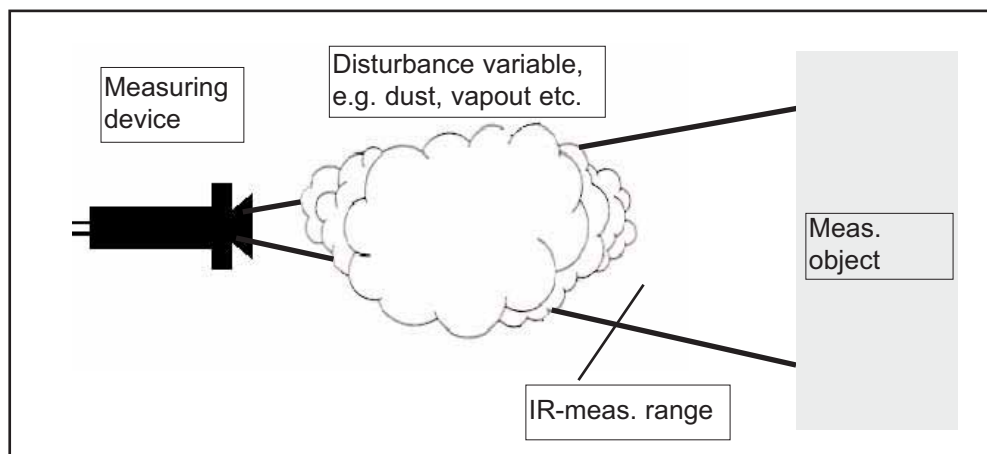
Material	Temperature	ϵ
Aluminium, bright-rolled	170 °C	0,04
Asbestos	20 °C	0,96
Asphalt	20 °C	0,93
Cotton	20 °C	0,77
Concrete	25 °C	0,93
Lead, grey-oxidised	20 °C	0,28
Lead, strongly oxidised	20 °C	0,28
Roofing felt	20 °C	0,93
Ice, smooth	0 °C	0,97
Ice, roughhair-frostcoating	0 °C	0,99
Iron, emiered	20 °C	0,24
Iron bright -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, softgrey	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, lightly 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
Minimum paintcoat	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
Zincwhite (paint)	20 °C	0,95

4. Applications and practical tips

4.1 Error sources/faults/compensation of IR measuring instruments

- **Influence of intermediate media (disturbance variables) on the measuring result**

With contactless temperature measurement, in addition to material and surface-specific influences, the composition of the transmission path between the instrument and the measuring object can also have an effect on the measuring result.



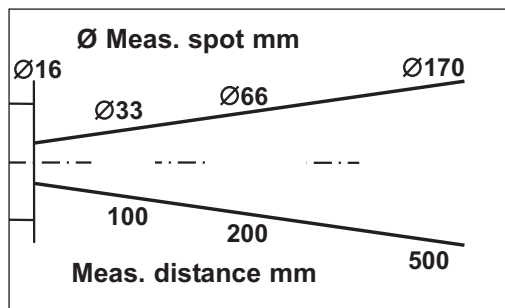
Disturbance variables include, e.g.:

- Particles of dust and dirt
- Moisture (rain), steam, gases

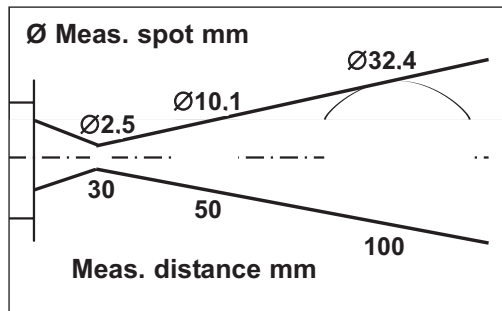
See also atmospheric windows. (see 1.3).



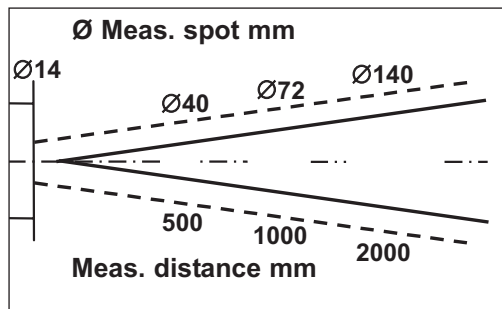
- **Incorrectly set emissivities can lead to considerable errors (see 4.2).**
- **After a temperature change the measuring instrument is not yet adjusted to the new temperature (comparison point) – adjustment times, see Instruction manual. This will lead to considerable measuring errors, problems similar to thermoelement devices.**
 - ⇒ If possible, store the instrument in the place where the measurement is to be performed! This will avoid the problem of adjustment time (but: observe instrument operating temperature!).
- **IR measurement is a purely optical measurement:**
 - ⇒ clean lens is essential for accurate measurement.
 - ⇒ do not measure with misted-up lens, e.g. due to steam.
- **IR measurement is a surface measurement:**
 - ⇒ if there is dirt, dust, rime etc. on the surface, only the top layer will be measured - the dirt, in other words. Therefore, always make sure that the surfaces are clean!
 - ⇒ Do not measure at occlusions.
- **Distance between IR-measuring device and measuring object is too large, i.e. the measuring spot is larger than the measuring object. In this case, the following measuring spot charts, which show the measuring distance-measuring spot ratio, apply:**



Quicktemp 825-T1 /-T2 /-T3 /-T4
826-T1 /-T2 /-T3 /-T4
Meas. distance to meas. spot 3:1

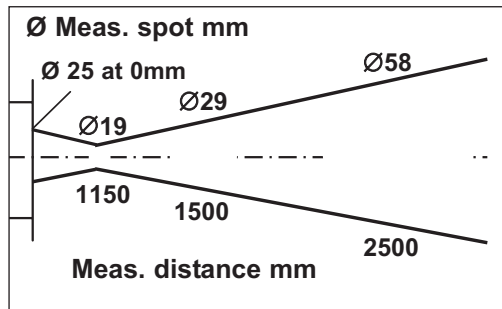


Quicktemp 850-1



Quicktemp 850-2

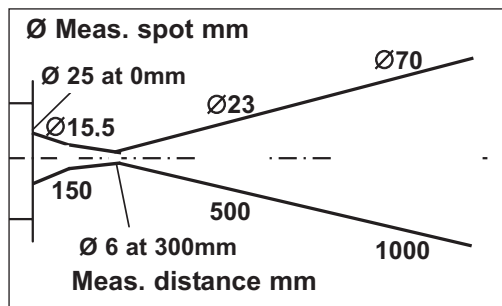
Meas. distance to meas. spot 12:1



Quicktemp 860-T1/T2

Near field 60:1

Far field 35:1



Quicktemp 860-T3

Near field 50:1

Far field 12:1



Important note on measuring spot size!

The measuring spot diagrams shown in the instrument literature usually give the so-called 95% measuring spot, which means that 95% of the energy converted in the sensor comes from this range.

However, due to lack of definition in the illustration, the range which has an influence (even if small) on the measuring result, is larger.

Therefore, it should be ensured that the measuring object is always larger than the measuring spot given in the literature, in order to prevent undesirable influences from the marginal area.

The greater the difference in temperature between the measuring object and the background, the greater the effects on the measuring result.

4.2 Solution of various measuring tasks

• Simple to solve measuring tasks:

All non-metallic parts and surfaces, organic materials such as paints and dyes, paper, plastics and rubber, wood, synthetic materials, foodstuffs, glass, textiles, minerals, stones, etc.

No special measures need to be taken for this group. The emissivity is sufficiently large, usually approx. 0.95 as a rule, and does not change over the temperature range.

• Difficult to solve measuring tasks:

Bright, reflective surfaces of metals, changing surface structures, e.g. due to scales.

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

⇒ If measurement with contact thermometers is not possible here, coatings, such as e.g. paint, oil, or emission adhesive tape with a defined emissivity, must be applied to the measuring object for contactless measurement.

• Conditionally solvable measuring tasks:

Matt appearance metal surfaces and transparent films.

A differentiation must be made in individual cases, as to whether and how the measuring problem must be tackled.

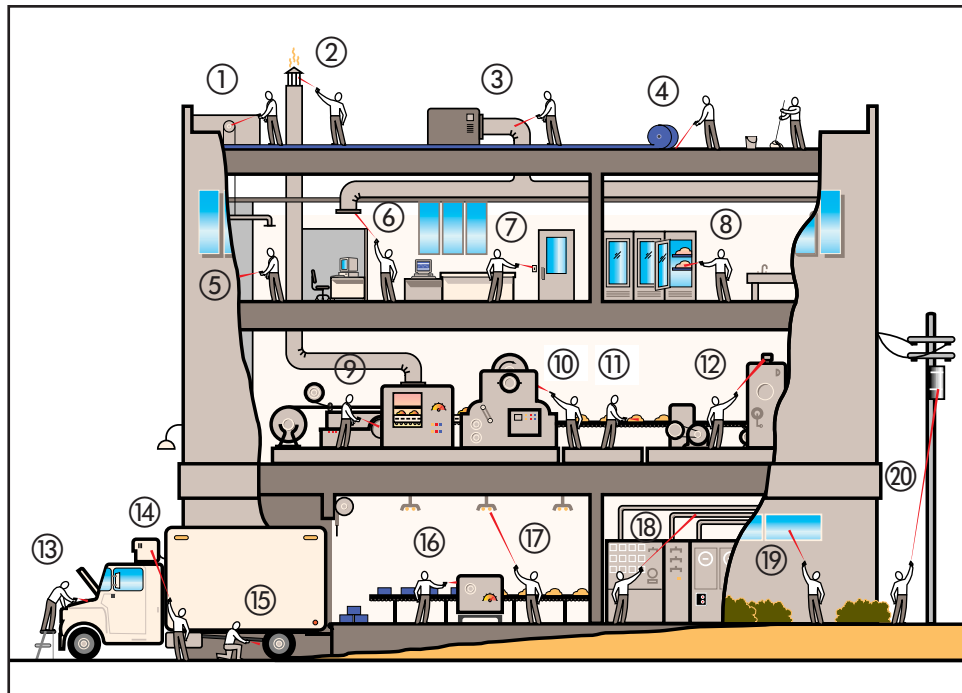
⇒ Determine emissivity through comparison measurement with contact thermometer or again apply coatings with defined emissivity.

Note on emission adhesive tape:

It is important that the adhesive tape can easily absorb the temperature of the measuring object; this is guaranteed in the case of bodies with a good heat capacity (large mass) and good heat conduction, e.g. metals.



Examples of contactless measurement:



① Measurement on PVC pipe systems

- Temperature at approx. +25 °C
 - Emissivity of plastic 0.84.
- Ideal for IR measuring technology.

② Measurement on tinplate hood

- Temperature at approx. +38 °C
- Emissivity of tinplate 0.05

Apply emissivity-increasing coating, e.g. paint or emission adhesive tape, otherwise measure with contact thermometer.

Tip: Use measuring instrument with small measuring spot with large distance and contact thermometer integrated (combi measuring instrument e.g. testo 860 or 825).

③ Measurement on galvanised outgoing air pipe

- Temperature at approx. +24 °C
- Emissivity of zinc 0.23

Apply coating such as paint or emission adhesive tape or comparison measurement with contact thermometer.

Tip: Combi measuring instrument

④ Measurement on asphalt layer

- Temperature at approx. +24 °C
- Emissivity of asphalt 0.93

Can be measured without problem.

⑤ Measurement on brick wall

- Temperature at approx. +21 °C
- Emissivity of brick, (red) 0.93

Can be measured without problem.

⑥ Measurement on ceiling extractor (painted)

- Temperature at approx. +24 °C
- Emissivity of zinc (painted) 0.96

Can be measured without problem.

⑦ Measurement on light switch

- Temperature at approx. +20 °C
- Emissivity 0.85

Can be measured without problem.

⑧ Measurement in electric cabinet (contactor)

- Temperature at approx. +74 °C
- Emissivity of plastic 0.92

Caution : Measure on plastic surface, not on metal!

⑨ Measurement on bearing shell (painted)

- Temperature at approx. +68 °C
- Emissivity of black paint 0.93

Can be measured without problem.

⑩ Measurement on radiator fin of electric motor

- Temperature at approx. +50 °C
- Emissivity of green paint 0.93

Can be measured without problem.

⑪ Measurement of food product on cooling conveyor

- Temperature at approx. +8 °C
- Emissivity of foodstuffs 0.95

Can be measured without problem.



⑫ **Measurement on heat exchanger** Can be measured without problem.

- Temperature at approx. +10 °C
- Emissivity of condensing water 0.93

Note: Measurable through condensation water, otherwise apply coating with high emissivity.

⑬ **Measurement on engine block**

- Temperature at approx. +100 °C
- Emissivity of alu, heavily oxidised 0.2

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

⑭ **Measurement on refrigerating set**

- Temperature at approx. +36 °C
- Emissivity of painted sheet metal 0.92

Can be measured without problem.

⑮ **Measurement on car tyre**

- Temperature at approx. +40 °C
- Emissivity of soft rubber 0.86

Can be measured without problem.

⑯ **Measurement at oven output**

- Temperature at approx. +70 °C
- Emissivity of clay, fired 0.91

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⑰ **Measurement on fluorescent tubes**

- Temperature at +42 °C
- Emissivity of glass, smooth 0.92 - 0.94

Can be measured without problem.

⑱ **Measurement on painted pipes**

- Temperature at approx. +10 °C
- Emissivity of blue paint 0.94

Can be measured without problem.

⑲ **Measurement on galvanised outgoing air pipe**

- Temperature at approx. 38 °C
- Emissivity of zinc 0.23

Apply coating such as paint or emission adhesive tape or comparison measurement with contact thermometer.

Tip: Combi measuring instrument.

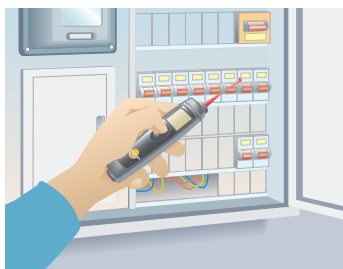
⑳ **Measurement on transformer (painted)**

- Temperature at approx. +70 °C
- Emissivity of trans. paint 0.94

Can be measured without problem.

Application examples:

- from the sector of "Industrial applications"



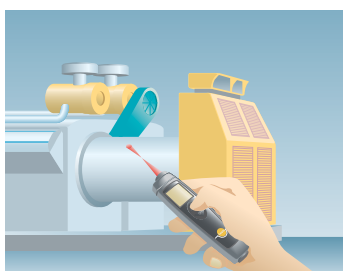
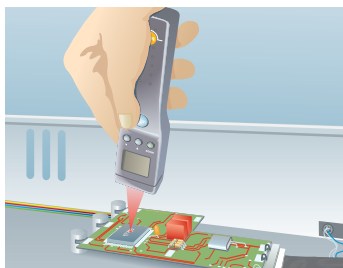
- **Detection of excessively high temperatures on switch cabinets, measurement on electrical circuits, such as, e.g. resistors, transistors in printed circuits etc.**

Points to watch out for:

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

Tip:

IR measuring instrument with small measuring spot (e.g. testo 850-1, testo 860-T3).



- **Temperature measurement on refrigeration unit**

Points to watch out for:

- Measuring spot / Measuring distance
- Measurement on surface with high emissivity (e.g. painted surface)

Tip:

Measuring instrument which has a small measuring spot at a large distance and has the facility for comparison measurement with contact thermometer (e.g. set testo 860-T2 or 825-T4).



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

Points to watch out for:

- Measuring spot / Measuring distance
- Measurement on surface with high emissivity or e.g. moisten surface with oil.

Tip:

Measuring instrument which has a small measuring spot at a large distance and has the facility for comparison measurement with contact thermometer.

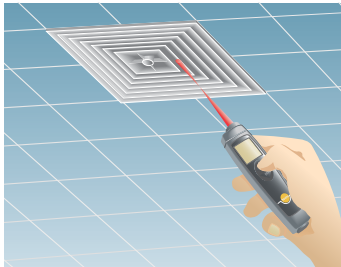


- **Temperature control on rail vehicles, e. g. "Hot-box determination" on railway carriage through measurement of axle cover temperatures.**

Points to watch out for:

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

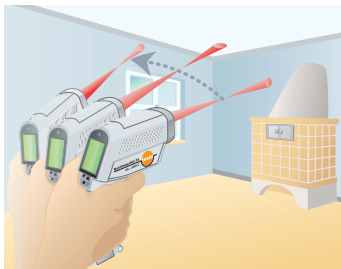
- from the "Heating, ventilation and cooling plant" sector:



● **Temperature control of ventilation ducts.**

Points to watch out for:

- The air is not measured, but the temperature of the grilles.
- Do not measure blank metals.
- Do not measure too close to the measuring point.



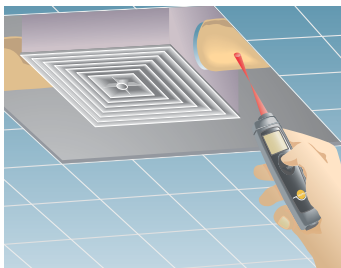
● **Control of heat paths in buildings.**

Points to watch out for:

- Measurement of materials such as wallpaper, wood, plaster, painted window frames and glass are easy to measure, due to their high emissivity between 0.9 and 0.95.
- Measure bare metal frames either with a contact thermometer or apply a coating which increases the emissivity.

Tip:

Measuring instrument with small measuring spot at a large distance. In addition, contact measurement should be performed, e.g. with combi measuring instrument (e.g. testo 860-T3).



● **Control of thermal insulation in buildings.**

Points to watch out for:

- Do not measure bare metals.
- Note different emissivities.



- from the "General applications" sector



● **For fire protection**

Points to watch out for:

- do not perform measurements on bare metal doors.

Tip:

Combi measuring instrument (e.g. set testo 860-T2 or 825-T4).



● **Quick temperature measurement during road construction in the open-air.**

Points to watch out for:

- Permissible operating temp. of measuring instrument
- Measuring spot / Measuring distance
- Measuring instrument must be adjusted to ambient temperature.
- Only measurement of materials with high emissivity, as "cold diffuse celestial radiation" at -50...-60°C present a disturbance variable. Possible screening of the sky by e.g. an umbrella over the measuring point.

Tip:

Measuring instrument with small measuring spot at 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!

- Measuring spot / Measuring distance
- Measuring instrument must be adjusted to the ambient temperature.
- Ideal distance between measuring instrument and goods / packaging is 1 - 2 cm (with 3:1optics).
- If the goods are enclosed in cardboard boxes, open the box and measure into the packaging.
- With film-sealed foodstuffs, only the temperature of the film is measured. Therefore, only measure at points at which the film is directly in contact with the goods
- Do not measure at occlusions.

Tip:

Combi measuring instrument (e.g. set testo 860-T3 or 826-T4)



Further applications in short:

- Setting the switching point of bimetals by measuring the temperature of the moving inner tongue in a heat current.
- Temperature monitoring in heat-setting, drying and laminating processes.
- Measurement of temperature on running rubber tyres under load. Detection of material errors through uneven heating.
- Temperature measurement in drying and deformation processes in the plastics industry.
- Temperature measurements in medicine, during diagnosis and for therapy control.
- Leak indication in distant heat lines through measurement of the increase in temperature occurring at the earth surface.

4.3 Further practical tips:

• IR-measuring instruments:

- Plastic fibres and wires

are pyrometrically difficult to measure, because they are usually very thin - smaller than the measuring field - and because they can drift out of the measuring field due to inaccurate guidance.

⇒ Measurable with: Partially fixed instruments, otherwise only resolvable with special instruments, not resolvable with Testo IR measuring instruments.

- Natural objects in the open air

such as water, stones, earth, sand, plants, wood etc. have emissivities between 0.8 and 0.95 in the spectral range between 8 and 14µm. If measurement is to be performed in the open air, it may be necessary to take "cold diffuse celestial radiation" into account in the case of small emissivities. 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 an "umbrella" over the measuring point.

⇒ Measurable with testo IR measuring instruments

- Glass and quartz

have high emissivities between approx. 0.95 and 0.98 in the wavelength range over $8\mu\text{m}$. Not pervious for IR, i.e. the glass pane is measured.

⇒ Measurable with: Testo IR measuring instruments.

- Plastics

are measured in the temperature range between $+20\text{ }^{\circ}\text{C}$ and $+300\text{ }^{\circ}\text{C}$ during drying and deformation processes, during extrusion, calendering, deep-drawing etc.. The emissivity 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

certain wavelengths have a characteristic absorption band, in which the transmission factor is really small. As the degree of reflection is small (0.05...0.20), the emissivity is very large. However, the degree of transmission and thus the emissivity are dependent on the thickness of the film. The thinner the film, the smaller the emissivity will be. Thin films are often pervious in the IR-range, so take account of the background.

⇒ Measurable with Testo IR measuring instruments

- Hot gases and flames

are "volume radiators with selective emission properties". The measuring point is no longer punctiform. The average temperature value is taken from a section inside the flame. This value is also frequently influenced by oven walls located behind the flame or the gases.

Similarly as with transparent materials, flames and gases radiate primarily in certain spectral ranges, for example in the range around $4.3\mu\text{m}$ (CO_2 band).

⇒ Measurable with: special instruments.

⇒ Not 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 must be ensured 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 emissivity (e.g. 0.95), the display must be converted to $\varepsilon = 1$.

• Emissivity

Even if the emissivity is correctly set, measuring errors may occur!

With emissivities 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, then emissivity correction by the instrument will be incorrect. I.e. if the instrument temperature is lower, then the measuring result is too high and if the instrument temperature is higher, then the measuring result is too low.
- If individual heat or cold radiators (e.g. heating elements, lamps, refrigerating units etc.) are reflected on the surface of the measuring object, then this radiation does not correspond to the ambient temperature = instrument temperature, and thus also in this case the emissivity correction performed by the instrument will be incorrect.

Remedy: Screen such radiators e.g. with a cardboard box. This will absorb the perturbing rays and emit its own radiation = ambient temperature.

4.4 Summary: Contactless measurement or contact measurement? - Testo's recommendation

Contactless infrared temperature measurement

1) Ideally suited to the measurement of the surface temperatures of:

- a) Poor heat conductors such as ceramic, plastic, rubber, wood, paper, wallpaper, plaster, textiles, organic materials, foodstuffs.

The measuring instrument measures reactionlessly, i.e. without influencing the measuring object. The infrared radiation of the measuring object is thus always at the same speed and independent of the heat radiation.

- b) Materials with a high emissivity, for example poor heat conductors (see a), varnishes, paints, glass, minerals, tiles, stones, tar and all non-metallic materials.

In this case, an emissivity setting of 0.95 (i.e. only 5 % of the ambient radiation is reflected on the measuring surface) is usually correct. Errors due to radiation from other sources being reflected on the surface are only slight.

- c) Moving parts (provided that the material has a high emissivity or a material with a defined emissivity can be applied) e.g. moving paper runs, rotating tyres, oxidised steel parts on a conveyor line.
- d) Non-contactable parts, such as e.g. freshly painted parts, sterilised parts or aggressive media, live parts such as electronic elements, busbars, transformers.
- e) Small and low-mass parts, e.g. components and all measuring objects for which a contact probe would remove too much heat and thus cause faulty measurements.

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

2) Only conditionally suitable for:

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

In this case you should either apply a coating with a defined emissivity (e.g. testo emission adhesive tape part-no. 0554 0051, paint or oil) or determine the emissivity by means of a comparison measurement with a contact thermometer.



3) Not suitable:

For bare metals (emissivity less than 0.1; i.e. more than 90 % of the ambient radiation is reflected on the measuring surface), to which no emissivity-increasing materials such as e.g. adhesive tape, paint or oils can be applied. Here a high error rate can be expected, caused by the high level of reflection on the measuring object surface.

Typical temperature control measurements using infrared in the industry:

- Generators, drives, aggregates
- Bearing shells
- Switch cabinets
- Electronic circuits
- Bimetal shift point setting
- Heat setting, drying and laminating processes
- Rotating rubber tyres
- Plastics in drying and deformation process.

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

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

Typical infrared applications in heating installation construction:

Surface measurements on:

- Radiators, painted heating pipes
- Floor coverings, wood, cork, tiles, granite as well as unfinished wall surface for the localisation of heating paper.

Typical infrared applications in foodstuffs inspection:

- Quick test in goods-in or in the freezer chest.

Contact temperature measurement

1) Ideally suitable for:

- a) Measurement of smooth surfaces with good heat conduction such as e.g. all metals. In this case, contact measurement is usually also more accurate than infrared measurement.
- b) Determination of core temperatures in liquids and foodstuffs.

2) Conditionally suitable for:

- a) Measurements of poor heat 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 measured body. In the case of poor heat conductors, this will mean faulty measurements and very long setting times, until the probe has taken on the temperature of the measuring object.
- b) For small, low-mass parts.

Here the contact probe removes heat from the measuring object, consequently influencing the measuring result.

3) Not suitable for:

- Non-contactable parts (see above)
- Moving parts.

Typical contact measurements in the industry on:

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

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

Typical contact meas. applications in building-air conditioning technology on:

- Ventilation ducts
- Wall surfaces.



Typical contact measurement applications in heating installation construction:

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

Typical contact measurement applications in foodstuffs inspection:

- Measurement of core temperature at critical product temperatures

Result:

Testo does not recommend contact or contactless measurement, but rather the use of a non-contact infrared thermometer and a contact thermometer in one compact device. This combination allows almost all measuring tasks to be solved quickly and precisely.

Ideally, the emissivity can be set to infrared in industrial, air conditioning and heating applications.

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

In the case of surface measurements, a quick-actuating spring-mounted measuring head, which enables reliable and precise measurement even on convex metal surfaces, should be integrated on the contact side. Thus exact determinations are possible even on surfaces whose emissivity is not known, and the advantages of contactless measurement can be exploited.

In the case of insertion or plunge measurements the finest possible measuring point should be used when making a contact measurement to determine the core temperature, so that even in the case of small insertion depths, the measured value can be determined quickly and reliably.

Appendix: Emissivity table

The following tables serve as guidelines for setting the emission factor during infrared temperature measurement. They give the emission factor ϵ of some common metals and non-metals. As the emission factor changes with the temperature and the surface quality, the values listed here should be regarded only as a guiding principle for measuring temperature ratios or differences. If the absolute value of the temperature is to be measured, the emission factor must be exactly defined.

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	0.06-0.08
	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
	Rusty	25	0.65
Gold	Lacquering	100	0.37
	Polished	38 to 260	0.02
Cast iron	Oxidised	200	0.64
	Oxidised	600	0.78
	Non-oxidised	100	0.21
	Heavily oxidised	40 to 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
	Copper rolled	40	0.64
	Natural	40	0.74
	Molten	540	0.15



Metals			
Material	Type/Quality/Element	Temperature (°C)	ϵ
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 to 260	0,07 to 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 to 260	0.31 to 0.46
	Non-oxidised	25	0.05
	Non-oxidised	100	0.06
	Non-oxidised	500	0.12
	Electrolytic	40	0.04
Platinum	Platinum	40 to 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 to 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
	Steel, non-oxidised	100	0.08
	Steel, oxidised	25	0.80
Steel alloy	Type 301, polished	25	0.27
	Type 316, polished	25	0.28
	Type 321, polished	150 to 815	0.18 to 0.49
Stellite	Polished	20	0.18
Tantalum	Non-oxidised	727	0,14

Metals			
Material	Type/Quality/Element	Temperature (°C)	ϵ
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 to 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

Non-metals			
Material	Type/Quality/Element	Temperature (°C)	ϵ
Aluminium paint	Aluminium paint	40	0.27 to 0.67
	10 % al	40	0.52
	26 % al	40	0.30
Asbestos	Asphalt, road topping	20	0.93
	Asphalt, tarred board	20	0.72
	-tissue	93	0.90
	-paperboard	38 to 370	0.93
	-plates	40	0.96
	-cement	0 to 200	0.96
Basalt	Basalt	20	0.72
Cotton Cloth	Cotton cloth	20	0.77
Minium	Minium	100	0.93
Bronze paint	Bronze paint	low	0.34 to 0.80
Ice	Smooth	0	0.97
	Rough	0	0.98
Earth	General	40	0.38
	Dark loamy ground	20	0.66
	Ploughed field	20	0.38
Paints	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 to 0.90
Glass	Flat plate glass	0 to 90	0.92 to 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 to 0.90
	Beech, planed	70	0.94
	Oak, planed	40	0.91
	Spruce, polished	40	0.89
Lime mortar	Lime mortar	40 to 260	0.90 to 0.92
Lime sand brick	Lime sand brick	40	0.95



Non-metals			
Material	Type/Quality/Element	Temperature (°C)	ϵ
Ceramics	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
Paint	Blue on aluminium film	40	0.78
	yellow, 2 coats on alu-film	40	0.79
	Clear, 2 coats on alu-film	90	0.09
	Clear, on bright copper	90	0.65
	Clear, on tarnished copper	90	0.64
	Red, 2 coats on alu-film	40	0.74
	Black, CuO	90	0.96
	White	90	0.95
	White, 2 coats on alu-film	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 0.10mm	22	0.72
Oil paints	All paints	90	0.92 to 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	Azetylene	25	0.97
	Camphor	25	0.94
	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

Non-metals			
Material	Type/Quality/Element	Temperature (°C)	ϵ
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 to 650	0.83 to 0.96
Water	Water	40	0.67
Water glass	Water glass	20	0.96
Pulp cement	2 layers	20	0.34
Brick	Air-dried	20	0.90
	Red. Rough	20	0.93



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