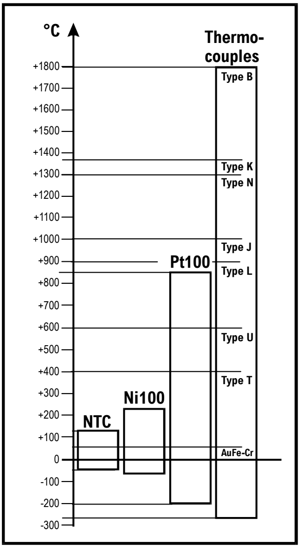
3.1 Temperature Sensors

3.1.1 Selecting the Right Temperature Sensor

Selecting the right type of temperature sensor depends on your measuring task. For example, thermocouples, resistor-based sensors (Pt100 and Ntc) and pyrometers (infrared sensors) are available.

Rule of Thumb:

1. Thermocouples are very fast and provide a large measuring range.
2. Resistor-based sensors are more accurate but slower.
3. Ntc sensors are very fast, accurate, but they have a limited measuring range.
4. Infrared sensors do not contact the device under test and they have very small time constants, but they depend on the emission grade.
5. The larger the measuring range, the more universal the possible range of applications.



Selection Criteria:

Select the temperature sensor that suits your measuring task according to the criteria below:

- Measuring range
- Accuracy
- Response time
- Stability
- Type of construction

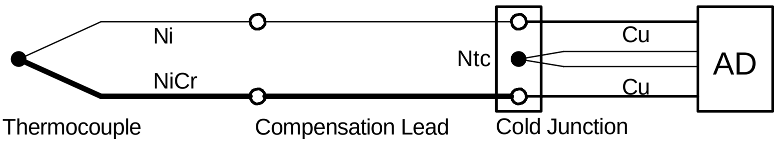
Types:

- Surface sensors for good heat conductors
- Surface sensors for poor heat conductors
- Immersion probes for liquids
- Immersion probes for air and gases
- Insertion probes
- High temperature sensors (note measuring range)
- Infrared sensor for non-contact measurements
- Sword probe for paper, cardboard, tobacco and textiles

3.1.2 Thermocouples

Measuring Principle

Thermocouples consist of two spot-welded wires of different metals or alloys. The thermoelectric effect at the contact surface is used to measure temperatures. It causes a relatively small thermoelectric voltage that depends on the temperature difference between the measuring point and the connecting terminals. A range of thermocouples are available that can be distinguished by their temperature range, sensitivity and particularly the compatibility with the medium of measurement.

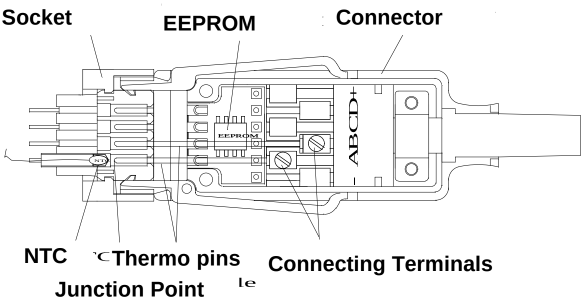


Basic Values IEC 584-1:1995 (ITS90)

IEC 584	NiCr-Ni	NiSil	Fe-CuNi	Cu-CuNi	PtRh10-Pt	PtRh30-Pt	AuFe-Cr
Temperature	Type K	Type N	Type J	Type T	Type S	Type B	
°C	mV	mV	mV	mV	mV	mV	mV
-270	-	- 4.345	-	- 6.258	-	-	- 4.714
-200	- 5.891	- 3.990	- 7.890	- 5.603	-	-	- 3.709
-100	- 3.554	- 2.407	- 4.633	- 3.379	-	-	- 2.039
0	0	0	0	0	0	0	0
100	+ 4.096	+ 2.774	+ 5.269	+ 4.279	+ 0.646	+ 0.033	
200	+ 8.138	+ 5.913	+ 10.779	+ 9.288	+ 1.441	+ 0.178	
300	+ 12.209	+ 9.341	+ 16.327	+ 14.862	+ 2.323	+ 0.431	
400	+ 16.397	+ 12.974	+ 21.848	+ 20.872	+ 3.259	+ 0.787	
500	+ 20.644	+ 16.748	+ 27.393		+ 4.233	+ 1.242	
600	+ 24.905	+ 20.613	+ 33.102		+ 5.239	+ 1.792	
700	+ 29.129	+ 24.527	+ 39.132		+ 6.275	+ 2.431	
800	+ 33.275	+ 28.455	+ 45.494		+ 7.345	+ 3.154	
900	+ 37.326	+ 32.371	+ 51.877		+ 8.449	+ 3.957	
1000	+ 41.276	+ 36.256	+ 57.953		+ 9.587	+ 4.834	
1100	+ 45.119	+ 40.087	+ 63.792		+ 10.757	+ 5.780	
1200	+ 48.838	+ 43.846	+ 69.553		+ 11.951	+ 6.786	
1300	+ 52.410	+ 47.513			+ 13.159	+ 7.848	
1400					+ 14.373	+ 8.956	
1500					+ 15.582	+ 10.099	
1600					+ 16.777	+ 11.263	
1700					+ 17.947	+ 12.433	
1800						+ 13.591	

Cold Junction

Thermocouples only allow for a determination of the absolute temperature when the temperature of the connecting terminals is kept at a known temperature (e.g. using ice water or a thermostat) or when this cold junction temperature is measured continuously. ALMEMO® devices contain a miniature NTC temperature sensor in the contact of the ALMEMO® socket to measure the exact temperature of the junction point from thermocouple to copper. ALMEMO® connectors with thermomaterial pins are available for use with the most popular thermocouple NiCr-Ni, which means that the junction point directly neighbours the temperature sensor. Each temperature difference between junction point and temperature sensor causes an error of measurement. This must be considered with other thermocouples, especially when very hot or cold sensors are inserted into the socket. In copper plugs the junction point is located in the screw terminals. The correct temperature is only measured when the screw terminal and the NTC sensor have the same temperature.



The characteristics of thermocouples are non-linear. Therefore, the temperature of the junction point must not be added to the measured temperature for determining the absolute temperature. The voltage that corresponds to the junction point temperature of the thermocouple used must be added to the voltage that corresponds to the measured value.

Example for NiCrNi thermocouple:

	Voltage		Temperature	
Measured value:	24.902 mV	->	600.0 °C	
Junction point temperature:	+ 1.000 mV	<-	25.0 °C	
Corrected measured value:	25.902 mV	->	**623.5 °C**	not 625 °C!

The user does not need to care about this calculation because it is performed by the ALMEMO® measuring instrument. However, an understanding of the relations is very helpful when measurements with external junction point (see also 6.7.3) are performed.

Compensation Lines

Compensation lines that are lower in costs and easier to handle are often used as an extension for thermocouples. However, the compensation lines can vary with their thermoelectric voltage from the thermocouple. To keep the measuring errors within close tolerances, the contacts for connection to the thermocouple and to the measuring device should be kept at the same temperature.

☞ Even larger errors occur when the type of the compensation line does not fit to the thermocouple or when the compensation line is wrongly poled. This should be avoided at all costs.

Application

Because of their low weight thermocouple sensors provide a high indication speed. Therefore, they especially suit the requirements for reference measurements in production, test fields and laboratories. Jacketed thermocouples with diameters of less than 0.5mm are very beneficial as they are internally isolated and do not provide an electrical connection to the device under test. They are flexible and can even be soldered. However, the bend radius selected must not be too small (at minimum 5x diameter). Generally, too much mechanical stress should be avoided with thermocouples as the characteristics can change due to the structural changes.

☞ Measuring operations using bare, non-insulated thermo-wire sensors can only be recommended in air or in / on electrically insulating materials (e.g. plastics). For measuring operations on electrically conductive materials with (high) electrical potential, insulated jacket thermocouple sensors should preferably be used. Alternatively, thermo-wire sensors can be connected, electrically isolated, via the NiCr-Ni measuring module ZA9920AB; (see 4.2.8.3).

Accuracy of Measurement

The thermocouple sensors are available in two tolerance classes, according to DIN/IEC 584-2. The following limits are applicable for type K (larger value of each):

Class 1:	±1.5 °C	or ±0.004 x l t l	(-40...1000°C)
Class 2:	±2.5 °C	or ±0.0075 x l t l	(-40...1200°C)

The T_{max} values given in the technical data refer to the tip of the sensor. The sensor grips and cables are stable for temperatures up to 80°C. Heat-resistant silicon or teflon cables are available for use at higher ambient temperatures.

3.1.3 Resistor-based Sensors

Measuring Principle

The increase in resistance at increasing temperatures is utilised at the **Pt100 sensors**. The measuring resistor is fed with a constant current and the voltage drop at the resistor is measured as a function of the temperature. Due to the small resistance variation (0.3 to 0.4Ω/°C) the 4-conductor circuit should always be used to exclude any influences from the lead wires.

In contrast **NTC sensors** (thermistors) have a significant higher resistance and a negative temperature coefficient, i.e. the resistance decreases when the temperature increases.

Accuracy of Measurement

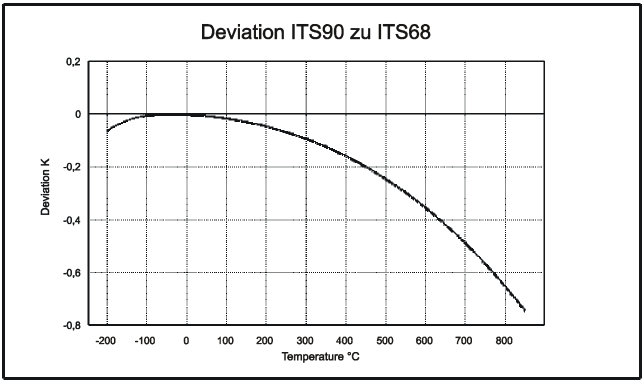
Pt100 sensors are, as standard, used with class B (DIN/IEC 751) measuring resistors (surcharge for class A or 1/5DIN accuracy). The accuracy data of the normalised NTC sensors are based on manufacturer specifications. The T_{max} values given in the technical data refer to the tip of the sensor. The sensor grips and cables are stable for temperatures up to 80°C. Heat-resistant silicon or teflon cables are available for use at higher ambient temperatures.

Description	Range	Maximum Deviation		
Meas. resistances		Class B	Class A	1/5 DIN
Pt 100	at -200°C and +200°C	±1.3°C	±0.55°C	
(100Ω at 0°C)	at -100°C and +100°C	±0.8°C	±0.35°C	
	at 0°C	±0.3°C	±0.15°C	±0.06°C
	at +300°C	±1.8°C	±0.75°C	
	at +400°C	±2.3°C	±0.95°C	
NTC element	-20 to 0°C		±0.4°C	
(10KΩ at 25°C)	0 to 70°C		±0.1°C	
	70 to 125°C		±0.6°C	

Pt100 sensors FP Axxx are, as standard, provided with the measuring range Pt100-1 (resolution 0.1°C). The range Pt100-2 (resolution 0.01°C) or Pt100-3 (resolution 0.001°C) can, alternatively, be programmed on the first or, in addition, on the second channel.

International Temperature Scale ITS 90

With the implementation of the new international temperature scale 1990 into German law, the previous temperature scale IPTS-68 is no longer valid and the new standards of ITS-90 (DIN/IEC) must be applied. The characteristics of the Pt100 sensors show the deviations below that must be considered at calibrations and comparisons.



Temperature	Pt100 (ITS90)	Pt100 (IPTS68)	Temperature	NTC
°C	R(T) [Ω]	R(T) [Ω]	°C	R(T) [Ω]
-200	18,52	18,49	-50	670100
-150	40	39,71	-40	336500
-100	60,26	60,25	-30	177000
-50	80,31	80,31	-20	97080
0	100,00	100,00	-10	55330
50	119,40	119,40	0	32650
100	138,51	138,50	10	19900
150	157,33	157,32	20	12490
200	175,86	175,84	25	10000
250	194,10	194,07	30	8057
300	212,05	212,02	40	5327
350	229,72	229,67	50	3603
400	247,09	247,04	60	2488
450	264,18	264,11	70	1752
500	280,98	280,90	80	1255
550	297,49	297,39	90	915,3
600	313,71	313,59	100	678,3
650	329,64	329,51	110	510,3
700	345,28	345,13	120	389,3
750	360,64	360,47	130	300,93
800	375,70	375,51	140	235,27
850	390,48	390,26	150	185,97

3.1.4 Wet Bulb Globe Temperature Measurement

The wet bulb globe temperature (WBGT) is the decisive parameter for evaluating the work stress at heat-exposed working places and the operation and cool-off times involved. Temperature, radiation, relative humidity and air velocity are determined by measuring the dry temperature TT, the natural humid temperature HTN of a psychrometer and the globe temperature GT of a globe thermometer. These are all combined as WBGT.

For measuring TT and HTN a psychrometer with disengageable ventilator (FN A846-WB) must be connected to the input socket M00 and programmed with the measuring ranges `Ntc` and `P HT`. To obtain the natural humid temperature HTN the plexiglass cap of the psychrometer must be removed during the measurement and the ventilator must be switched off using the slide switch.

A globe thermometer (Pt100) (FP A805-GTS) with the measuring ranges `P204` and `WBGT` is required at the socket M01.

For calculating the wet bulb globe temperature (WBGT) the function channel WBGT indicates the wet bulb globe temperature when the correct sensors are connected.

☞ The factor 0.2 for the globe temperature must be programmed as slope correction at the measuring point $M01_2$ (WBGT).
No longer included in V6 (ALMEMO 2390-5, 2690-8) !

Arrangement and programming of the WBGT sensors:

Sensor	Mst	Range	Size	Note
Psychrometer	$M00_1$	Ntc	TT	Dry temperature of the air, in °C
	$M00_2$	P HT	HTN	Natural humid temperature of the air
Pt100 Globe	$M01_1$	P204	GT	Globe temperature in °C
Thermometer	$M01_2$	WBGT	WBGT	0.1 TT + 0.7 HT + 0.2 GT

A continuous or a cyclic measuring point scan must be run to obtain up-to-date values.

Printout sample:

```
01:23:40 00: +070.00 °C Ntc  TT
         01: +075.00 °C P204 GT
         10: +030.00 °C P HT HT
         11: +043.00 °C WBGT
```

3.1.5 Infrared Sensors

Measuring Principle

Infrared sensors are used for a non-contact measurement of the heat radiation of objects and for indication of the temperature in °C. This measuring method also allows for a scan of temperature measuring points that would not be possible with conventional contact thermometers. Surfaces with a low thermal conduction and body portions with low thermal capacity can be measured with the same high speed of response as moving, inaccessible or live parts without affecting the device under test.

To obtain satisfactory results when using infrared measuring technology it is important to consider the basic relations and influences of the total emissivity, environmental radiation and the beam path.

Fundamentals of Thermal Radiation

Every substance, when above absolute zero, provides an electromagnetic radiation. According to Planck's radiation laws a relation exists between the emitted radiation and the temperature of a body.

Total radiation: $S = \sigma \bullet T^4$ (Stefan-Boltzmann law) (1)

However, this law is only applicable for 'black body radiators' that emit their whole radiation. Real bodies are also called 'grey radiators' that emit only a part of the radiation and that reflect or let through the other part of the radiation. The ratio between the individual emission S_O of a temperature radiator to the emission of a black body radiator S_B is called the total emissivity of a thermal radiator:

Emissivity: $\varepsilon = S_O / S_B$ (2)

The emissivity plays an important role in non-contact temperature measurements. As the infrared instruments are calibrated with 'black body radiators' it is necessary to consider the emissivity during measurement. The radiation thermometer measures a radiation S_M that is composed of the characteristic radiation of the device under test S_O and of the radiation S_U that is reflected by the background. The radiation S_O of the object is multiplied with the emissivity factor ε and the ambient radiation S_A is multiplied with the reflection coefficient ρ :

Measuring radiation: $S_M = \varepsilon \bullet S_O + \rho \bullet S_A$ (3)

Using the relation $\varepsilon + \rho = 1$ the object radiation can finally be determined as:

Object radiation: $S_O = \frac{1}{\varepsilon}(S_M - S_A) + S_A$ (4)

particularly: $S_O \approx \frac{1}{\varepsilon} S_M$ if object temp. much higher than ambient

$S_O \approx S_A$ if object temp. = ambient temperature

The latter relations explain that the emissivity factor is only playing a secondary role in closed rooms and with objects with a low temperature. For objects that have a temperature, which is much higher than the ambient temperature, the influence of the background temperature can be neglected.

Application

Infrared probes are suitable for non-contact temperature measurements on surface in numerous industrial applications. Typical fields of application are, for example, measurements on paper or textile webs, on lacquering lines, coatings and drying processes. Special applications in the electric/electronic field include, for example, finding hot spots on PCBs and contacts. Cold junction measurements on surfaces using thermocouples allow for a determination of the emissivity factor.

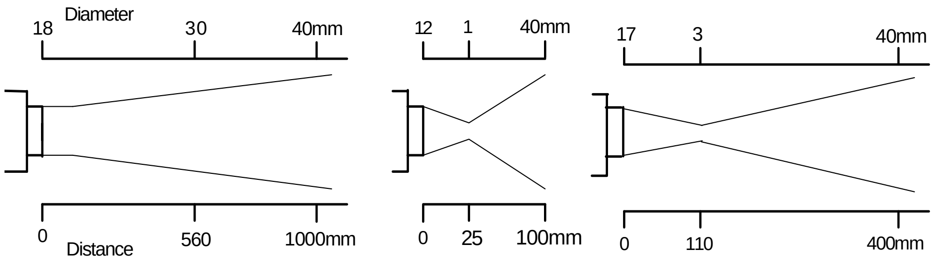
Sensor

Photoelectric radiation receivers with high sensitivity and very short response times, as well as thermal detectors with a slightly slower response are available as transducers. The ALMEMO® measuring system provides the infrared transducers FI A628 as photoelectric radiation receivers. All transducers include a chopper setup for the compensation of the ambient temperature.

Sensor:	**FI A628-4**	**FI A628-5**	**FI A628-6**
Measuring range:	-30 ... +100 °C	0 ... +200 °C	0 ... +500 °C
Accuracy:	1°C ± 1.5% of measured value		
Spectral sensitivity:	7 ... 16µm		
Total emissivity:	0.5 ... 1.0		
Response time:	50/320/720/1000 ms		
Output:	0 ... 1V not linear		
Supply voltage:	8 ... 12V through device		

Beam Paths and Measuring Spot

The emissivity and also the beam path of the sensor must be considered to obtain correct measured values. The optics and the distance lead to a certain measuring spot diameter that must always be smaller than the object to be measured or the measuring point under test.



Standard Optics FI A628-xK Optics -xM Optics -xL

Sensor Programming

The infrared sensors are, like all other ALMEMO® sensors, configured ready to be connected. They can be easily connected to all ALMEMO® measuring instruments for a read-out of the measured values. Special measuring ranges are available for the linearisation of the 6 sensors FI A628 (types 1-3 no longer available).

Sensors

Designation	Meas. Range	Meas. Range
FI A628-1/5	0.0 to +200.0 °C	Ir 1
FI A628-4	-30.0 to +100.0 °C	Ir 4
FI A628-6	0.0 to +500.0 °C	Ir 6

Emission Factor and Ambient Temperature

Both functions, emission factor EF and ambient temperature Ta are provided in infrared sensors with all ALMEMO® instruments. The functions allow to process the measured value T_M according to formula (4) for the object radiation:

Object temperature: $T_O = \frac{1}{\varepsilon}(T_M - T_A) + T_A$

If an infrared sensor is connected and the corresponding measuring channel is selected the functions zero point correction ´NK´ and slope correction ´SK´ are replaced by the functions ´Tu´ for ambient temperature and ´EF´ for emission factor for ALMEMO® instruments. For instruments with a rotary switch, the functions can be accessed under the function BASE and FACTOR using the key F. For instruments that do not provide any input capabilities, the once programmed emissivity will also be considered.

A detailed description of the input of parameters is provided in the manual of the specific instrument. The value of the emission factor can, for example, be taken from the table below. With polished or glossy metal surfaces and translucent devices under test, the emission factor is too small for an accurate measurement. However, a blackened measuring point provides an emission factor of 0.9 to 1.0 and can be measured without problems.

☞ We recommend to treat the measuring point with matt black varnish or similar.

The ambient temperature T_A can usually be determined with one 'look' of the sensor into the environment (e.g. room ceiling, oven wall, etc.). This measured value within function MEAS. VALUE can, with a zero point correction (keys ENTER, ±), be copied into the function ambient temperature Tu.

Table of Emission Factors

The following table provides a guideline for estimating the emissivity of various materials.

☞ Please note that the emissivity, especially with metals, can largely vary depending on the surface quality, oxidation, rust or presence of dirt, water or oil.

Material	Emission	Material	Emission	Material	Emission
Aluminium		Spring steel	0,87	Nickel	
bright	0,10	Gypsum	0,8 - 0,9	not oxidated	0,15
oxidated	0,2 - 0,4	Glass	0,85 - 0,95	oxidated	0,2 - 0,5
Alumin. oxide	0,42 - 0,26	Rubber	0,95	Paper	0,95
Asbestos	0,96	Graphite	0,7 - 0,8	Plaster	0,91
Asphalt	0,95	Cast iron		Mercury	0,1 - 0,12
Basalt	0,70	not oxidated	0,20	Soot	1,00
Concrete	0,95	oxidated	0,6 - 0,95	Sand	0,90
Lead oxidated	0,2 - 0,6	turned	0,45	Fireproof clay	0,75
Bitumen	1,00	Skin	0,99	Snow	0,90
Bread	0,88	Hard board	0,95	Steel	
Tar paper	0,94	Radiator	0,80	sheet with	
Iron		Wood	0,9 - 0,95	rolling skin	0,75
not oxidated	0,1 - 0,2	Limestone	0,95	sheet, bright	0,65
oxidated	0,5 - 0,9	Ceramics	0,95	Turn. parts, bright	0,30
rusted	0,5 - 0,7	Coal	0,8 - 0,9	Textiles	0,95
Stainless steel	0,1 - 0,8	Copper oxidated	0,4 - 0,9	Clay	0,95
Ice	0,98	Plastics	0,90	Water	0,93
Enamel	0,90	Leather	0,94	Cement	0,90
Colour		Marble	0,93	Brick	
mat	0,95	Brass oxidated	0,50	rough	0,93
glossy	0,90	Monel oxidated	0,40	glazed	0,75
Alu colour	0,52			Zinc oxidated	0,10

Spectral Emissivity of some Materials

The infrared measurement is limited mainly on wavelengths between approximately 0.5 and 20µm. However, even in this range the emissivity, in certain areas, strongly depends on the wavelength. Therefore, filters are required in some cases.