Kamstrup's handbook on

Temperature sensors for heat and cooling meters

Kamstrup A/S · Industrivej 28, Stilling · DK-8660 Skanderborg · T: +45 89 93 10 00 · info@kamstrup.com · kamstrup.com

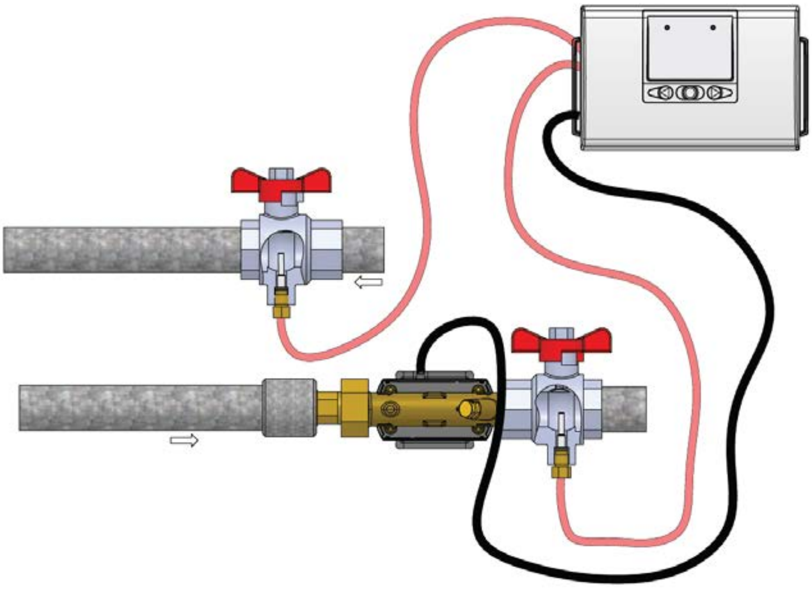
Contents

1 Introduction

For a heat or cooling meter to calculate the amount of energy consumed, it is necessary to measure the temperature difference between the supply pipe and the return pipe. The temperature difference is measured by two temperature sensors and therefore, temperature sensors are an essential part of a heat or cooling meter. Consequently, a number of requirements are imposed on temperature sensors for heat and cooling meters, including type approval, testing for verification and proper installation.

The purpose of this handbook is to provide an introduction to the main topics within temperature sensors for heat and cooling meters. Following an introduction to resistance temperature sensors, the handbook will, among other things, touch topics such as the types of temperature sensors applied, regulatory requirements for temperature sensors, installation of temperature sensors and the special conditions that apply to temperature sensors for cooling meters.

In connection with the standardization work under EN 1434 [1], the term “thermal energy meters” is increasingly used as a general term for both heat and cooling meters. As the terms “heat meters” and “cooling meters” remain widely used, this handbook uses the term “heat and cooling meters” as the unifying term instead of “thermal energy meters”.



2 Resistance temperature sensors

This chapter discusses the basis for the use of resistance temperature sensors, including the correlation between temperature and resistance, measurement principles, temperature sensor designs and resistances applied. The chapter also contains resistance tables for Pt100 and Pt500 temperature sensors.

2.1 The correlation between temperature and electrical resistance

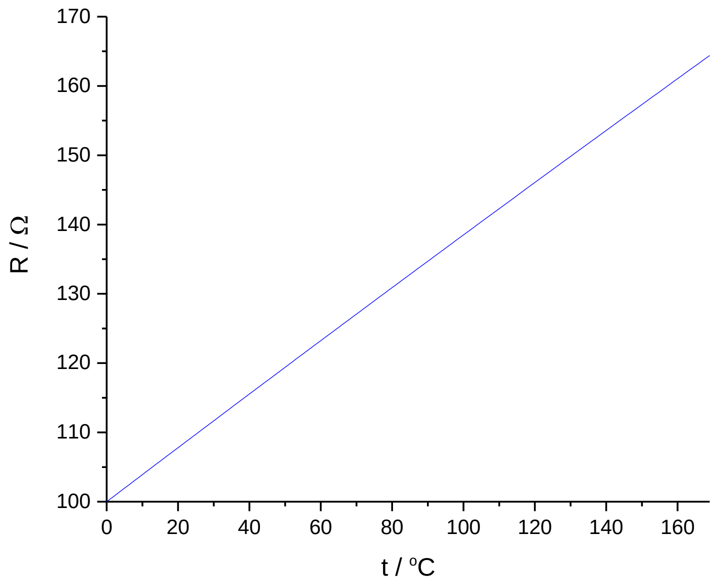


Figure 1: The correlation between temperature, t, and resistance, R, of a platinum-made Pt100 resistance temperature sensor that has a resistance of 100 Ω at 0 °C.

A platinum resistance temperature sensor utilizes that the precious metal platinum has a very well-defined correlation between its electrical resistance and the temperature. An example of this is shown in *Figure 1*. Against this background, an international standard, EN 60751 (DIN/IEC 751) [2], has been established where the correlation between the resistance R_t and the temperature t is defined by

$$R_t = R_0(1 + At + Bt^2)$$

where R_0 indicates the resistance at 0 °C while A and B are constants.

The temperature t can then be determined by the following expression:

$$t = \frac{-R_0A + \sqrt{(R_0A)^2 - 4R_0B(R_0 - R_t)}}{2\,R_0B}$$

The nominal resistance is the expected resistance at 0 °C. The most common nominal resistances within heat and cooling meters are 100 Ω, 500 Ω and 1000 Ω. Based on the nominal resistance and the metal used, resistance temperature sensors are abbreviated as Pt. Platinum resistance temperature sensors with nominal resistances of 100 Ω, 500 Ω and 1000 Ω are thus referred to as Pt100, Pt500 and Pt1000, respectively.

For an ideal Pt100 temperature sensor, it applies that R_0 = 100.00 Ω, A = 3.9083·10^{-3} °C^{-1} and B = -5.775·10^{-7} °C^{-2}, and tables with examples of the correlation between temperature and resistance of ideal Pt100 and Pt500 temperature sensors can be found in paragraph 2.4. The exact true values of R_0, A and B for a temperature sensor vary for each individual temperature sensor and are thus determined as part of the legal verification of a temperature sensor for a heat and cooling meter, see paragraph 5.2.

2.2 Measuring principles and temperature sensor designs

In practice, a resistance temperature sensor works by sending a small constant current through the resistance and then measuring the voltage drop U. The size of the platinum resistance R can then be determined using Ohm's law:

$$R = \frac{U}{I}$$

This is illustrated in *Figure 2*.

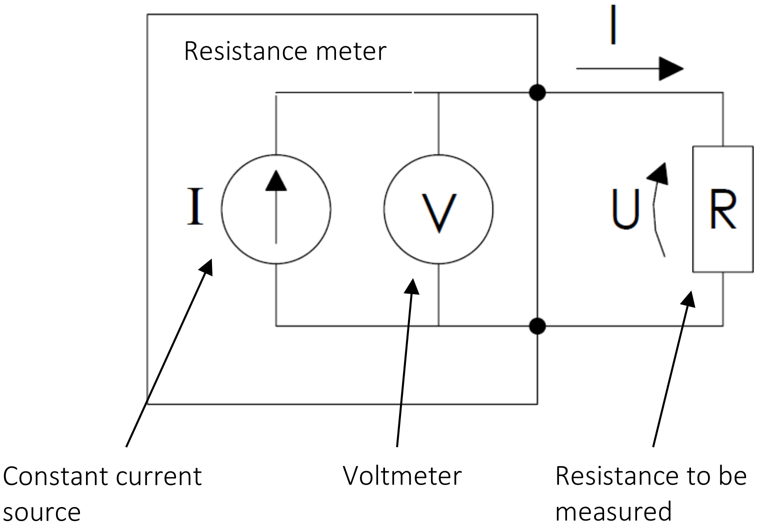


Figure 2: Measurement of a resistance value using a constant current source and a voltmeter.

2.2.1 2-wire temperature measurement

As shown in *Figure 3*, a 2-wire temperature sensor is characterized by the fact that two wires are drawn from the platinum resistance for the current generator and the voltage drop measurement. Therefore, for a 2-wire temperature sensor it applies that the resistance of the wires also contributes to the measured resistance as these are in series connection with the platinum resistance. The measured resistance R_m is thus

$$R_m = R + 2 \cdot R_w$$

where R_w is the resistance of the single wire.

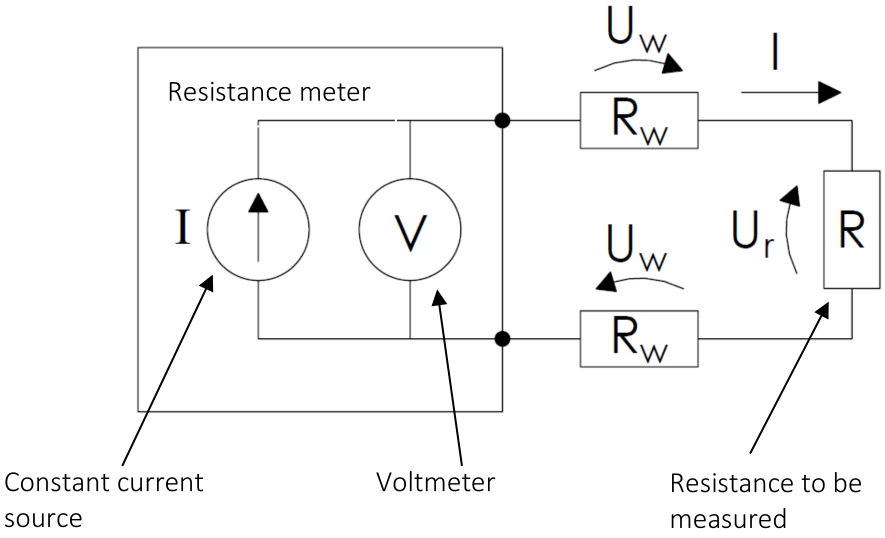


Figure 3: The influence of the cables on the measured resistance value.

As you often want to determine the temperature difference between two temperature sensors with high accuracy, you can compensate for the impact of the cables by requiring all the cables to be equally long, see paragraph 5.4.

2.2.2 4-wire temperature measurement

A 4-wire temperature sensor works in such a way that 4 wires are drawn from the platinum resistance of which 2 wires are connected to the constant current source and 2 wires are connected to the voltage drop measurement, see *Figure 4*. Using a high-impedance voltmeter, the voltage drop *U* above the platinum resistance is measured. As the current is still *I*, the platinum resistance *R* can be determined by:

$$R = \frac{U_r}{I}$$

This allows the resistance of the temperature sensor to be measured only and the temperature measurement to be independent of the resistance of the cables.

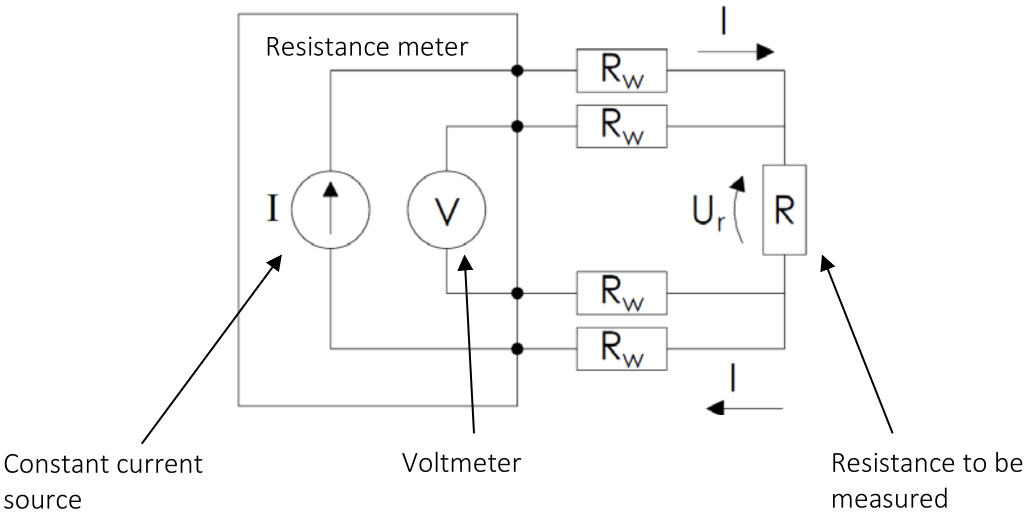


Figure 4: Resistance value measurement using the 4-wire principle where the cables do not affect the resistance measurement.

2.3 Applied types of resistance elements

For temperature sensors for heat and cooling meters, thin-film resistances are most commonly used. Among other things, this is due to the fact that thin-film resistances are affordable to produce, they do not take up much space and they react very quickly to temperature changes. The most common solution is a thin-film resistance mounted on a PCB (printed circuit board). Examples of this type of solution are shown in *Figure 5*. This solution has several advantages. Firstly, it can be mass-produced, thereby reducing costs. Secondly, on the same PCB, two soldering pads are placed on which the 2 wires used for a 2-wire temperature sensor can be soldered directly. This enables the production of 2-wire temperature sensors to be more efficient. Thin-film resistances mounted on a PCB can typically be used at a temperature up to 150 °C, which is sufficient in most installations.

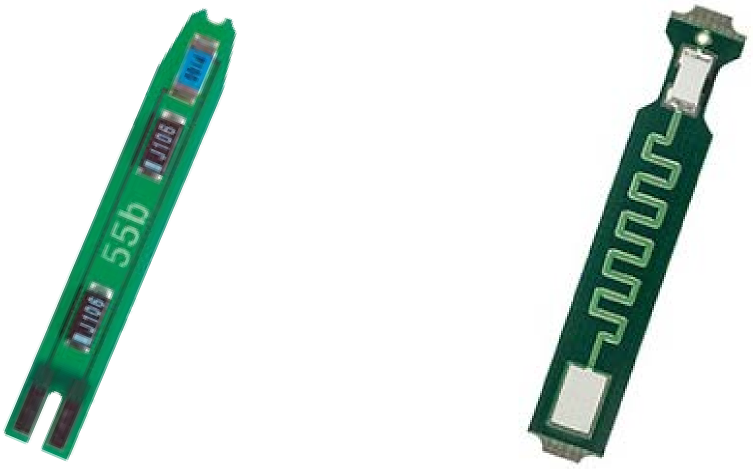


Figure 5: Thin-film resistances mounted on a PCB (printed circuit board) [3,4].

If the temperature sensor is to be used at a higher temperature, e.g. 180 °C, thin-film resistances mounted on a ceramic element are used, see *Figure 6*.

Figure 6: Thin-film resistances mounted on a ceramic element [4,5].

2.4 Resistance tables

Pt100										
°C	0	1	2	3	4	5	6	7	8	9
0	100.000	100.391	100.781	101.172	101.562	101.953	102.343	102.733	103.123	103.513
10	103.903	104.292	104.682	105.071	105.460	105.849	106.238	106.627	107.016	107.405
20	107.794	108.182	108.570	108.959	109.347	109.735	110.123	110.510	110.898	111.286
30	111.673	112.060	112.447	112.835	113.221	113.608	113.995	114.382	114.768	115.155
40	115.541	115.927	116.313	116.699	117.085	117.470	117.856	118.241	118.627	119.012
50	119.397	119.782	120.167	120.552	120.936	121.321	121.705	122.090	122.474	122.858
60	123.242	123.626	124.009	124.393	124.777	125.160	125.543	125.926	126.309	126.692
70	127.075	127.458	127.840	128.223	128.605	128.987	129.370	129.752	130.133	130.515
80	130.897	131.278	131.660	132.041	132.422	132.803	133.184	133.565	133.946	134.326
90	134.707	135.087	135.468	135.848	136.228	136.608	136.987	137.367	137.747	138.126
100	138.506	138.885	139.264	139.643	140.022	140.400	140.779	141.158	141.536	141.914
110	142.293	142.671	143.049	143.426	143.804	144.182	144.559	144.937	145.314	145.691
120	146.068	146.445	146.822	147.198	147.575	147.951	148.328	148.704	149.080	149.456
130	149.832	150.208	150.583	150.959	151.334	151.710	152.085	152.460	152.835	153.210
140	153.584	153.959	154.333	154.708	155.082	155.456	155.830	156.204	156.578	156.952
150	157.325	157.699	158.072	158.445	158.818	159.191	159.564	159.937	160.309	160.682
160	161.054	161.427	161.799	162.171	162.543	162.915	163.286	163.658	164.030	164.401
170	164.772	165.143	165.514	165.885	166.256	166.627	166.997	167.368	167.738	168.108
180	168.478	168.848	169.218	169.588	169.958	170.327	-	-	-	-

Table 1: Pt100, IEC 751 Amendment 2-1995-07

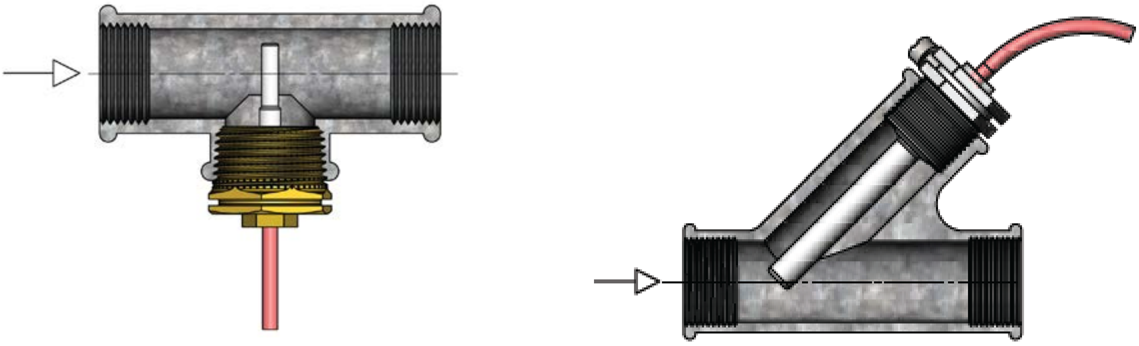
Pt500										
°C	0	1	2	3	4	5	6	7	8	9
0	500.000	501.954	503.907	505.860	507.812	509.764	511.715	513.665	515.615	517.564
10	519.513	521.461	523.408	525.355	527.302	529.247	531.192	533.137	535.081	537.025
20	538.968	540.910	542.852	544.793	546.733	548.673	550.613	552.552	554.490	556.428
30	558.365	560.301	562.237	564.173	566.107	568.042	569.975	571.908	573.841	575.773
40	577.704	579.635	581.565	583.495	585.424	587.352	589.280	591.207	593.134	595.060
50	596.986	598.911	600.835	602.759	604.682	606.605	608.527	610.448	612.369	614.290
60	616.210	618.129	620.047	621.965	623.883	625.800	627.716	629.632	631.547	633.462
70	635.376	637.289	639.202	641.114	643.026	644.937	646.848	648.758	650.667	652.576
80	654.484	656.392	658.299	660.205	662.111	664.017	665.921	667.826	669.729	671.632
90	673.535	675.437	677.338	679.239	681.139	683.038	684.937	686.836	688.734	690.631
100	692.528	694.424	696.319	698.214	700.108	702.002	703.896	705.788	707.680	709.572
110	711.463	713.353	715.243	717.132	719.021	720.909	722.796	724.683	726.569	728.455
120	730.340	732.225	734.109	735.992	737.875	739.757	741.639	743.520	745.400	747.280
130	749.160	751.038	752.917	754.794	756.671	758.548	760.424	762.299	764.174	766.048
140	767.922	769.795	771.667	773.539	775.410	777.281	779.151	781.020	782.889	784.758
150	786.626	788.493	790.360	792.226	794.091	795.956	797.820	799.684	801.547	803.410
160	805.272	807.133	808.994	810.855	812.714	814.574	816.432	818.290	820.148	822.004
170	823.861	825.716	827.571	829.426	831.280	833.133	834.986	836.838	838.690	840.541
180	842.392	844.241	846.091	847.940	849.788	851.635	-	-	-	-

Table 2: Pt500, IEC 751 Amendment 2-1995-07

3 Temperature sensors for heat and cooling meters

In this chapter, the most commonly used temperature sensors for heat and cooling meters will be reviewed. In practice, a wide range of temperature sensors are used for heat and cooling meters, and the choice of temperature sensor is typically depending on the installation in which the heat or cooling meter is to be installed. Basically, a distinction is made between a direct temperature sensor, which is in direct contact with the fluid flow, and a pocket sensor where a pocket, typically of stainless steel, is installed in the fluid flow after which the temperature sensor is installed in the pocket.

Figure 7 shows a direct temperature sensor and a pocket sensor. For clarity purposes, this chapter is divided into a paragraph about the most commonly used 2-wire temperature sensors and a paragraph about 4-wire temperature sensors.



Direct temperature sensor

Pocket sensor

Figure 7: Illustration of a direct temperature sensor and a pocket sensor.

3.1 2-wire temperature sensors

For heat and cooling meters, 2-wire temperature sensors are by far the most common compared with 4-wire temperature sensors. This is due to the lower price for both a 2-wire temperature sensor and the related 2-wire calculator. As a two-wire temperature sensor set must have equally long cables, see paragraph 5.4, there is also the difference that a 2-wire temperature sensor is typically mounted in the calculator at the factory, while a 4-wire temperature sensor is usually first installed in the calculator when the heat or cooling sensor is installed. In the following paragraph, the most common types of 2-wire temperature sensors will be reviewed.

3.1.1 Direct short temperature sensor

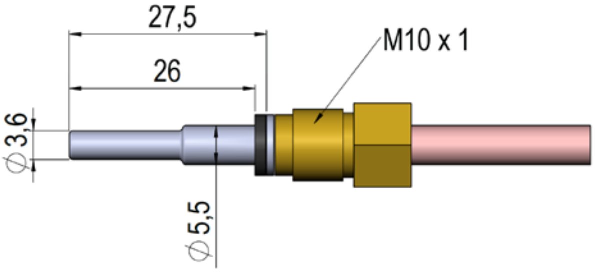


Figure 8: DS 27.5 mm temperature sensor

The direct short temperature sensor has been designed according to the European standard for heat energy meters EN 1434-2 [1]. The most common variant has an immersion depth of 27.5 mm and is therefore called DS 27.5 mm where DS stands for "Direct Short". Similarly, a 38 mm immersion depth variant is available, called DS 38 mm. The DS 27.5 mm temperature sensor is shown in *Figure 8*. The application options for DS 27.5 mm and DS 38 mm temperature sensors are shown in *Table 3*. The direct short temperature sensor is characterized by a very short response time, see paragraph 4.1, due to the fact that the tip of the temperature sensor has a relatively small diameter of 3.6 mm and is in direct contact with the fluid flow. This makes it the preferred temperature sensor for heat and cooling meters used in DN 15 to DN 40 installations. Especially for meters installed in district heating units, the selection of a direct short temperature sensor has a major impact on the correct energy measurement due to the rapid changes in the temperature caused by a district heating unit.

DN	DS 27.5 mm	DS 38 mm
15	X	
20	X	
25	X	
32		X
40		X

Table 3: Application options for DS 27.5 mm and DS 38 mm temperature sensors.

3.1.2 Pocket sensors

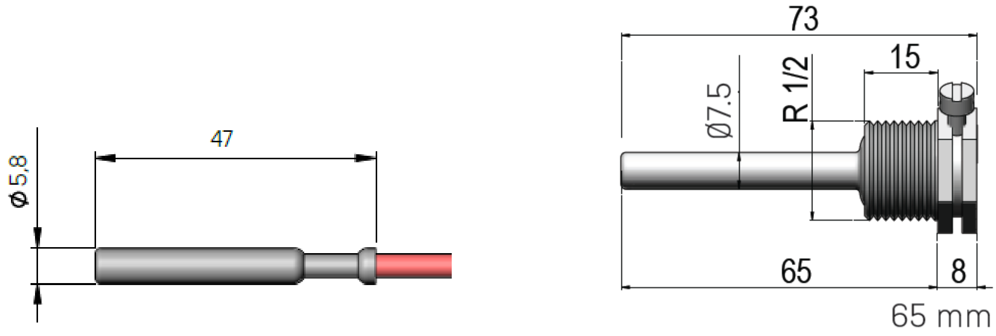


Figure 9: ø5.8 mm pocket sensor with corresponding 65 mm pocket.

In *Figure 9*, an example of a pocket sensor and a corresponding stainless steel pocket is shown. The great advantage of mounting a temperature sensor in a pocket is that the temperature sensor can be replaced afterwards without having to shut off the water. Pocket sensors are thus most often used in conjunction with larger meters, e.g. in a distribution network. A pocket sensor mounted in a pocket has the disadvantage that the total mass is larger and therefore reacts more slowly to temperature changes, which may affect the measured amount of heat energy. For more details on the response time, see paragraph 4.1.

The temperature sensor illustrated in *Figure 9* has a diameter of 5.8 mm. Pocket sensors with diameters of 5.0 mm, 5.2 mm and 6.0 mm are also used for heat and cooling meters. In this connection, it is worth pointing out that the pocket used must have an inner diameter that fits the diameter of the pocket sensor. In practice, this is clarified by the fact that pocket sensor and pocket must be approved for use together.

Pocket sensors with a diameter of 5.0 mm and 5.2 mm can typically be used as direct temperature sensors when mounting a union, e.g. in a ball valve, see *Figure 10*. This gives a great flexibility in the installation type as the temperature sensor can be installed as both a direct temperature sensor and a pocket sensor.

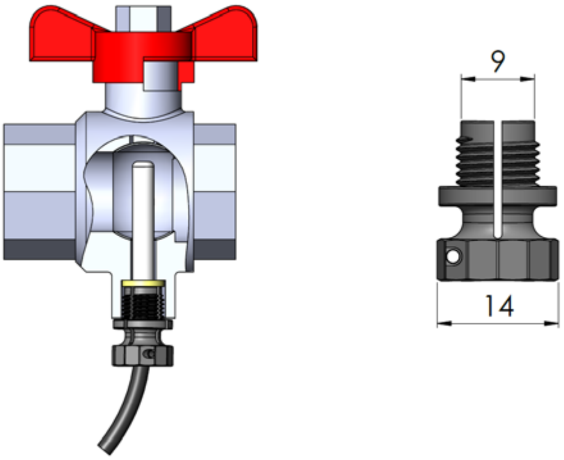


Figure 10: ø5.2 mm temperature sensor with composite union mounted in a ball valve.

3.2 4-wire temperature sensors

Contrary to 2-wire temperature sensors, it applies to 4-wire temperature sensors that the resistance of the cable does not affect the temperature measurement, see paragraph 2.2.2. This means that a more precise temperature measurement is obtained by using 4-wire temperature sensors. Therefore, 4-wire temperature sensors are typically used in large installations where an improved temperature measurement offers greater possibilities to optimize the operating conditions and thus production costs. At the same time, 4-wire temperature sensors also provide great flexibility when it comes to cable routing optimization as it is not required for 4-wire sensors that the cables are equally long. As it in large installations is necessary to be able to replace the temperature sensor without closing the water flow, 4-wire temperature sensors are mainly used as pocket sensors. In the following paragraph, the most common types of 4-wire temperature sensors will be reviewed.

3.2.1 ø5.8 mm pocket sensor with connection head

The ø5.8 mm pocket sensor with connection head is characterized by a replaceable temperature sensor insert on which a 2-wire ø5.8 mm pocket sensor is soldered. The temperature sensor insert is mounted in a stainless steel pocket with connection head, see *Figure 11*. The connection head is deliberately placed outside the insulation of the pipe and is thus easily accessible. Connection of 4-wire cable takes place by inserting the cable through the PG coupling and installing the 4 wires in the screw terminal on the temperature sensor insert.

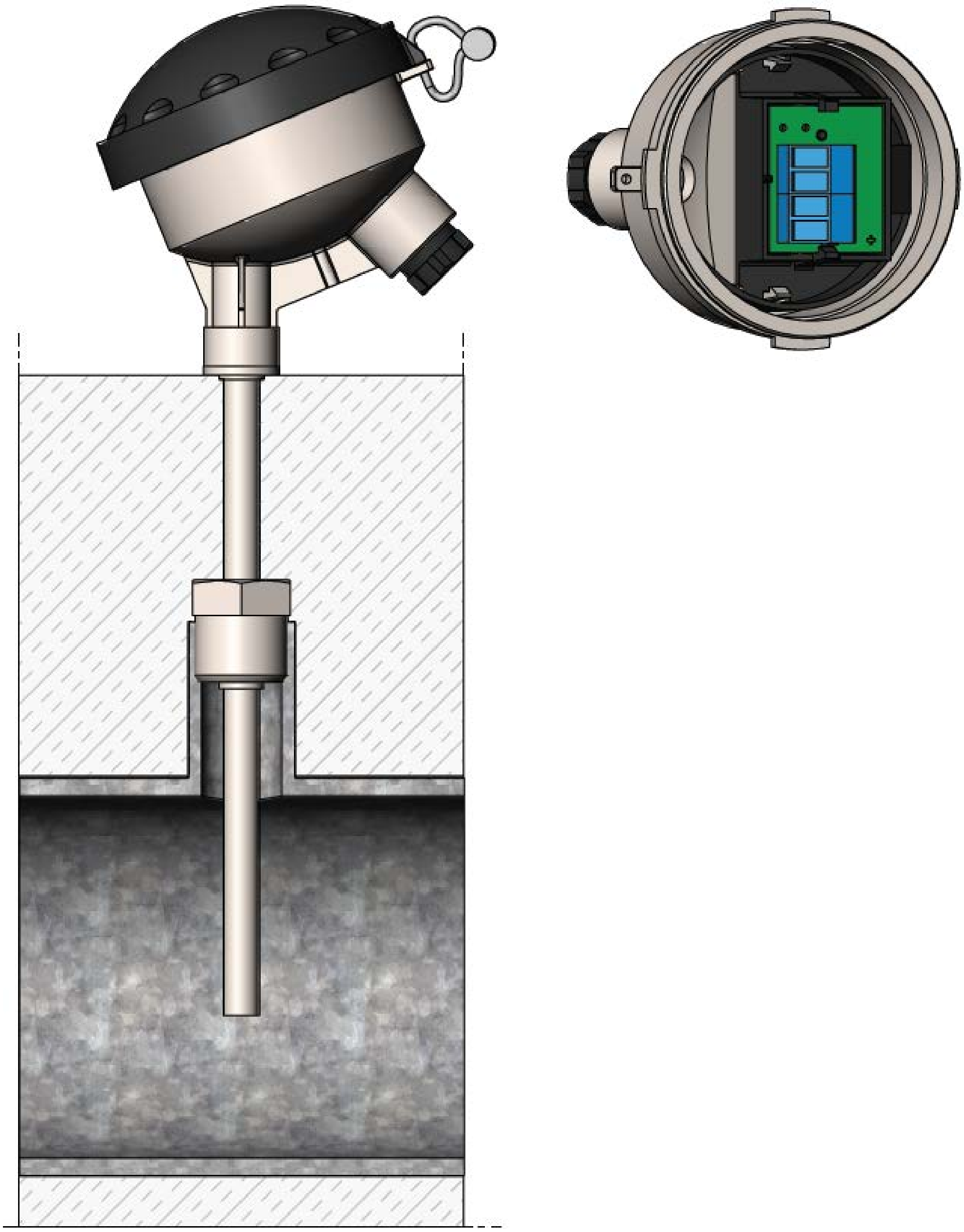


Figure 11: ø5.8 mm pocket sensor with connection head.

3.2.2 ø6 mm pocket sensor with connection head

Contrary to the ø5.8 mm pocket sensor with connection head, it applies to a 6 mm pocket sensor with connection head that the temperature sensor and pocket are be completely separated, as shown in *Figure 12*. For this temperature sensor, both the diameter and the length are defined in the EN 1434-2 standard [1]. The connection head itself is available in several designs and one of the most common designs is the connection head shown in *Figure 12*, which is made of aluminium and of the type DIN Form B. This temperature sensor is also available with a thin-film resistance fitted with a ceramic element, which means that it can be used at temperatures as high as 180 degrees, see paragraph 2.3. For flow rates up to 3 m/s, a welded stainless steel pocket with a diameter of 8 mm at the tip is used. At flow rates above 3 m/s, a stainless steel pocket with a diameter of 10 mm at the tip, see *Figure 12*, and turned out of one piece is used. For more information on selecting pockets at high flow rates and/or high temperatures, see paragraph 6.5.

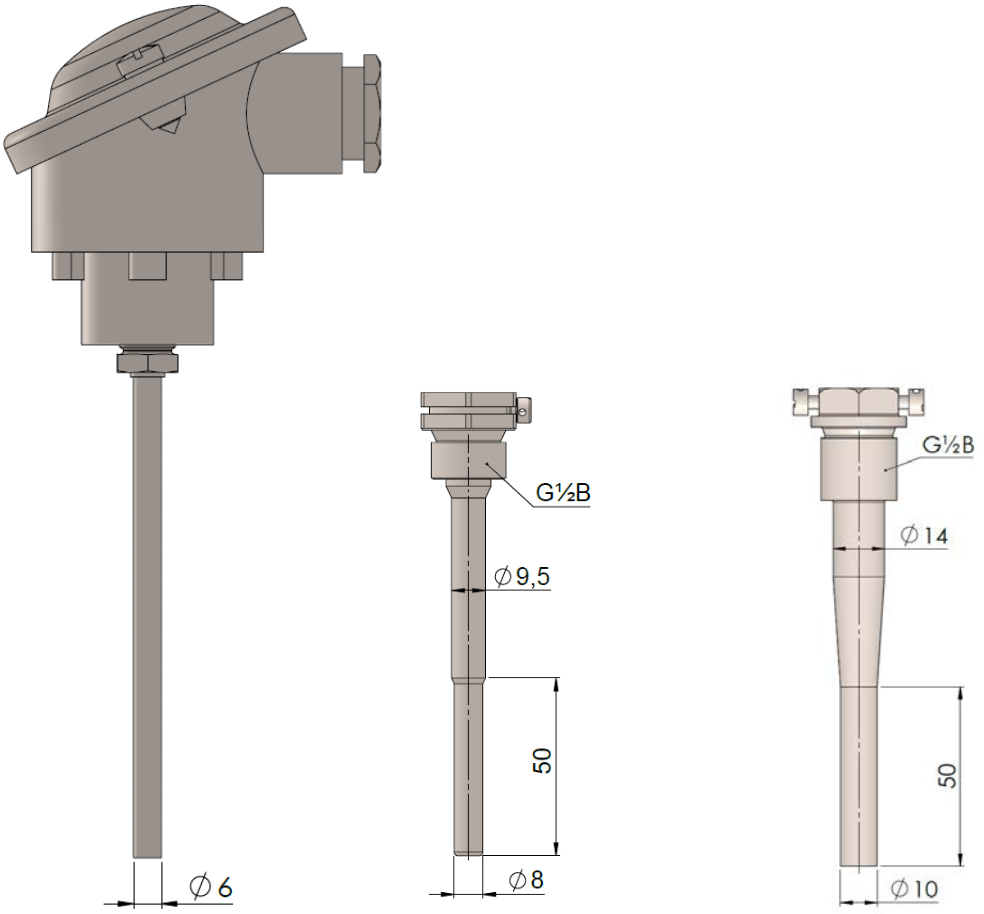


Figure 12: ø6 mm pocket sensor with connection head and corresponding pockets.

4 Terminology for temperature sensors used in energy measurement

This chapter discusses the key terms of temperature sensors used in energy measurement, including the terms response time, heat discharge error and qualifying immersion depth.

4.1 Response time

The response time of a temperature sensor is a measure of how quickly a temperature sensor responds to a given temperature change. Especially for heat meters mounted in district heating units with tap water exchanger, a short response time is important as in this case frequent and short-term temperature changes are occurring. If a temperature sensor with a long response time is used in this application situation, the heat meter will detect a consumption lower than the actual consumption.

The response time $\tau_{0.5}$ is defined as the time it takes for the temperature sensor to detect half of a given temperature change. In *Figure 13*, an example is shown of how a direct short temperature sensor responds to a temperature change from t_1=23 °C to t_2=33 °C. The temperature change starts at the time of τ_1 and at the time of τ_2, half of the temperature change has been detected. The response time $\tau_{0.5}$ may then be determined by the following calculation:

$$\tau_{0.5} = \tau_2 - \tau_1$$

In the example in *Figure 13*, the response time $\tau_{0.5}$ of the direct short temperature sensor concerned is determined to be 1.7 s.

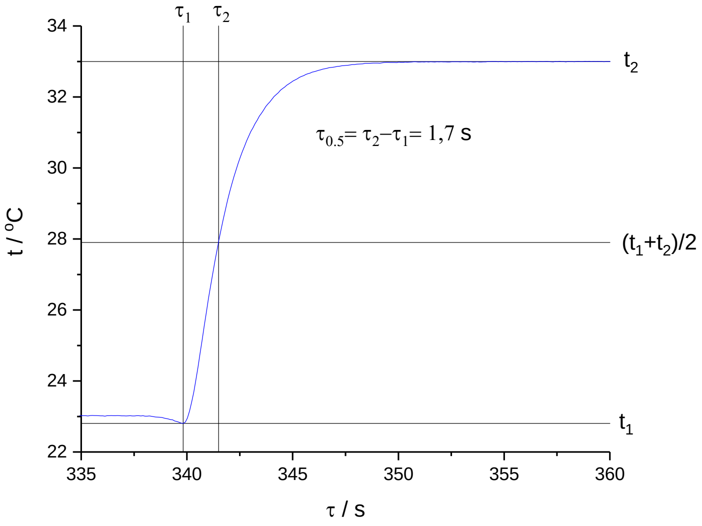


Figure 13: Measurement of the response time of a direct short temperature sensor.

In practice, the response time is measured by placing the temperature sensor in a cold thermostatic bath, which typically has the same temperature as the surroundings, e.g. 23 °C, and then quickly moving the temperature sensor into a warmer thermostatic bath with a temperature of, for example, 33 °C. In this way, the temperature sensor experiences a temperature change of 10 K. This is illustrated in *Figure 14*.

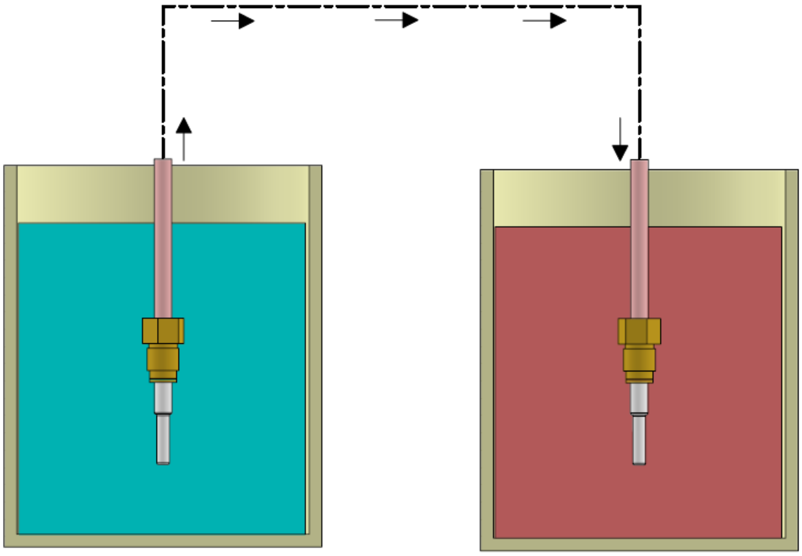


Figure 14: Illustration of the setup for measurement of response time for a temperature sensor where the temperature sensor is moved from one thermostatic bath to another thermostatic bath. The temperature difference between the two baths is typically 10 K.

As a starting point, the response time is assumed to be the same for all temperature changes. If there is a significant heat conduction error, see paragraph 4.2, the response time will be affected by the ambient temperature in such a way that an increased response time will be observed if temperature changes lead to a temperature rise significantly higher than the ambient temperature. Similarly, at a temperature drop from a relatively high temperature to around the ambient temperature, a shortened response time will be observed.

The response time of a temperature sensor depends on its design. In general, direct temperature sensors typically have a short response time as they are in direct contact with the fluid, while the response time is longer for a pocket sensor. In *Table 4*, the typical response times for a number of temperature sensors used for heat and cooling meters are shown.

	Response time
Direct short DS 27.5 mm temperature sensor	2 s
ø5.2 mm direct temperature sensor with fitted union	3 s
ø5.8 mm pocket sensor mounted in a 65 mm pocket	8 s
ø6 mm pocket sensor with connection head mounted in an 85 mm standard pocket	12 s
ø6 mm pocket sensor with connection head mounted in a 120 mm reinforced pocket	16 s

Table 4: Typical response times for both direct temperature sensors and pocket sensors mounted in pockets.

4.2 Heat conduction error

In connection with heat and cooling meters, it is ideal to measure the true temperature of the water in the supply pipe and return pipe, respectively. In heat meters, the temperatures in both the supply and return flows will be higher than the ambient temperature. As shown in *Figure 15*, this temperature difference can lead to a heat conduction into the surroundings, also known as a heat conduction error. The heat conduction into the surroundings causes the temperature sensor to not measure the correct temperature inside the pipe. Basically, the temperature sensor is designed in such a way that the heat condction error is minimized. However, due to its larger mass, a pocket sensor will typically have a greater heat conduction error than a direct temperature sensor. In general, a long temperature sensor has a smaller heat conduction error than a corresponding shorter temperature sensor as a larger proportion of the long temperature sensor is immersed in the fluid, see paragraph 4.3. The greatest heat conduction error is thus seen when using pocket sensors in short pockets with a length of 35 to 50 mm, and these pockets can therefore typically only be approved for use in a temperature range lower than the maximum of 150 degrees for which temperature sensors are normally approved.

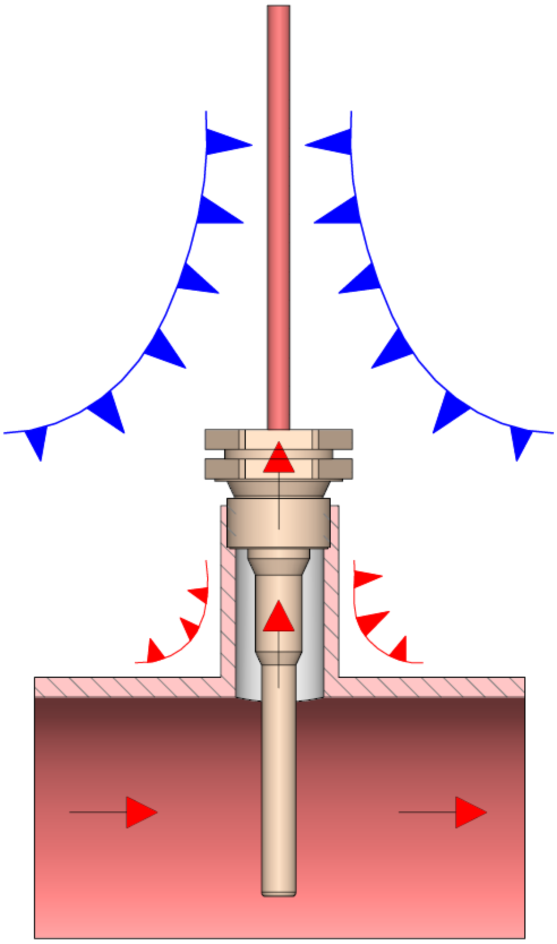


Figure 15: Illustration of heat conduction error in temperature measurement due to heat conduction into the surroundings.

4.3 Qualifying immersion depth

Qualifying immersion depth is a measure of how many millimetres the temperature sensor must be immersed into the fluid to ensure that the heat conduction from the temperature sensor causes a maximum heat conduction error of 0.1 K at 85 °C. The size of the heat conduction error is determined by first immersing two temperature sensors in a thermostatic bath so that they are initially completely immersed in water and thus measure the same temperature. Then one temperature sensor is partially removed from the bath, while the other temperature sensor is still completely immersed in water, see *Figure 16*. Due to the heating conduction error of the partially immersed temperature sensor, the two temperature sensors now measure two different temperatures. The heat conduction error is found by determining the temperature difference between the two temperature sensors. The qualifying immersion depth of a given temperature sensor depends on the design of the temperature sensor. For example, a DS 27.5 mm temperature sensor with an outer diameter of ø3.6 mm will have a smaller qualifying immersion depth than a pocket sensor with a diameter of ø5.8 mm. As further described in paragraph 3.1.1, the EN 1434 standard contains a number of design requirements for a direct short temperature sensor, including that the qualifying immersion depth must not exceed 20 mm.

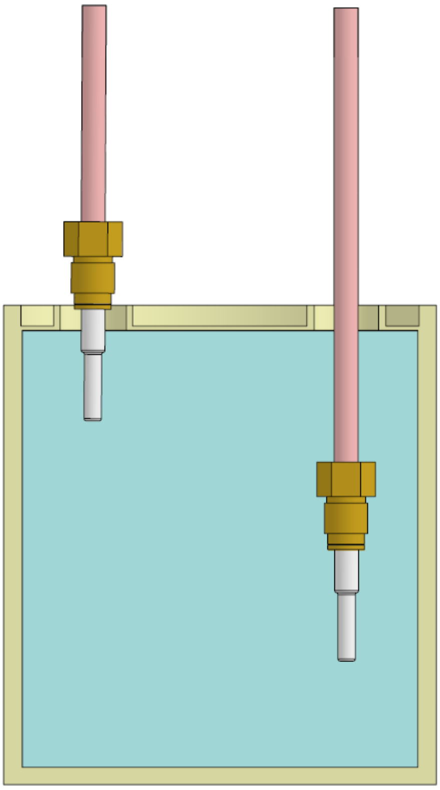


Figure 16: The qualifying immersion depth is determined by comparing the measurements of two temperature sensors that are fully and partially immersed in water, respectively.
The difference between the two temperature sensors must not exceed 0.1 K.

5 Regulatory requirements for marketed temperature sensors

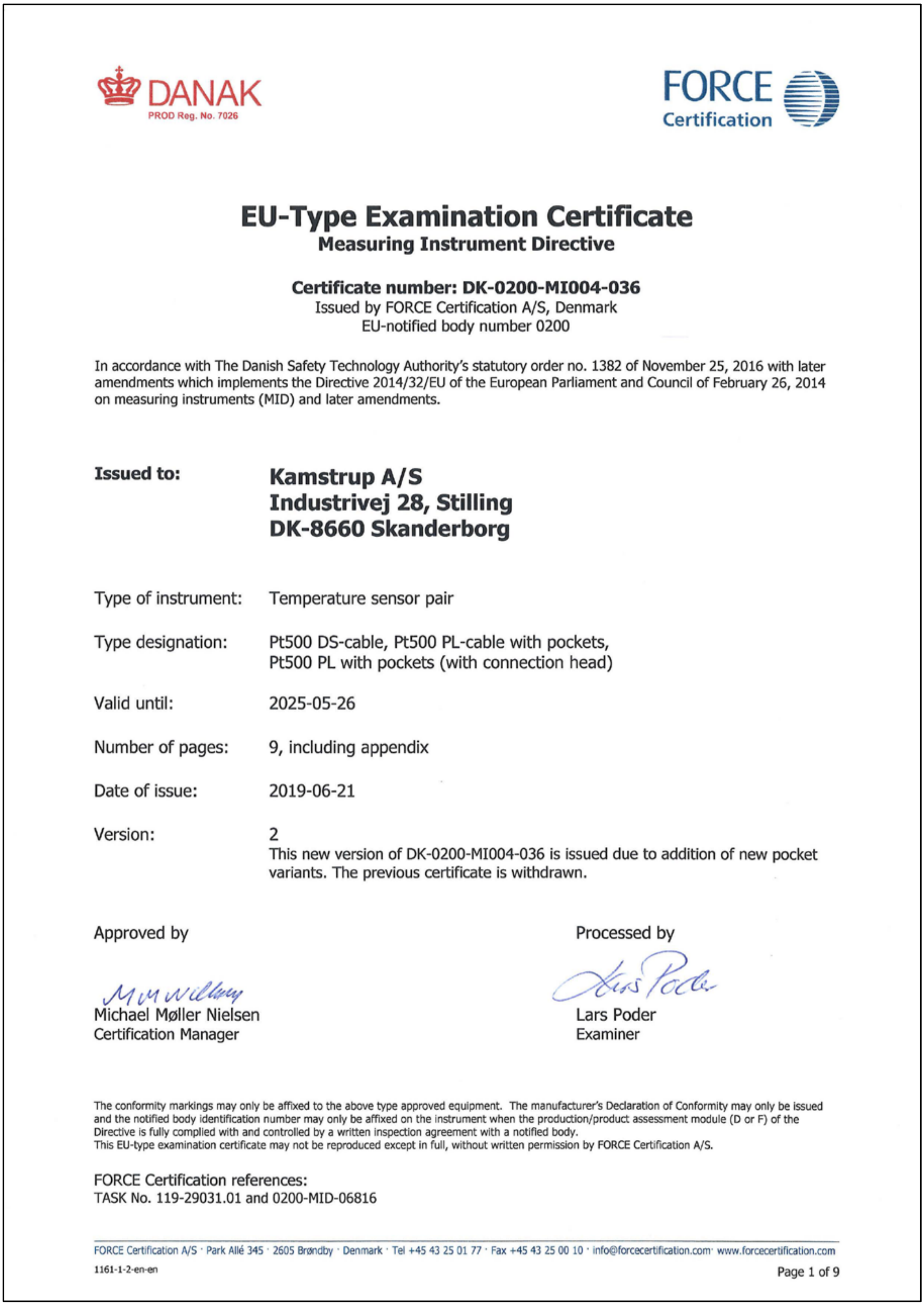
A wide range of regulatory requirements apply to temperature sensors that are marketed for heat and cooling meters. This is because heat and cooling meters are used for billing between two parties. This chapter reviews the main regulatory requirements, including type approval, measurement and verification as well as requirements for temperature sensor sets, cables and marking.

5.1 Type approval

In most EU and EEA countries, it is a legal requirement that temperature sensors for heat meters have a type approval before they can be used for legal billing. This type approval is issued on the basis of the EU directive Measuring Instruments Directive (MID), 2014/32/EU, which at EU level determines the rules for measuring equipment to be used for legal billing. Compared to earlier where each country issued a national authorization, today it is only necessary to receive one single MID authorization after which the temperature sensors can be used for legal billing in all EU and EEA countries. In each participating country, a notified body has been designated, which is authorized to issue MID approvals. For temperature sensors, the majority of the MID approvals have been issued by either FORCE Certification in Denmark, PTB in Germany or BEV in Austria.

To obtain a type approval, temperature sensors are required to conform to the harmonized version of the EN 1434 standard, among other things. This is demonstrated by a number of type tests, which are also designed based on the EN 1434-4 standard [1]. Examples of type tests are the determination of response time and the qualifying immersion depth, see the paragraphs 4.1 and 4.3.

Cooling meters are not part of the MID directive and therefore, common European rules do not apply to cooling meters for use in billing. A number of countries have thus introduced national type approvals in this field, including Denmark, Germany, Austria and Switzerland. The requirements for obtaining a national cooling approval vary from country to country, but a general feature is that the temperature sensors for cooling meters must comply with the EN 1434 standard. In some areas, the EN 1434 standard contains extended requirements for temperature sensors to be used with cooling meters. For example, temperature sensors for use with cooling meters must be subjected to an extended type test program to ensure that the temperature sensors are capable of meeting the specific challenges of condensation that may arise in cooling meter installations.



DANAK
PROD Reg. No. 7026

FORCE
Certification

EU-Type Examination Certificate

Measuring Instrument Directive

Certificate number: DK-0200-MI004-036
Issued by FORCE Certification A/S, Denmark
EU-notified body number 0200

In accordance with The Danish Safety Technology Authority's statutory order no. 1382 of November 25, 2016 with later amendments which implements the Directive 2014/32/EU of the European Parliament and Council of February 26, 2014 on measuring instruments (MID) and later amendments.

Issued to: **Kamstrup A/S**
Industrivej 28, Stilling
DK-8660 Skanderborg

Type of instrument:	Temperature sensor pair
Type designation:	Pt500 DS-cable, Pt500 PL-cable with pockets, Pt500 PL with pockets (with connection head)
Valid until:	2025-05-26
Number of pages:	9, including appendix
Date of issue:	2019-06-21
Version:	2 This new version of DK-0200-MI004-036 is issued due to addition of new pocket variants. The previous certificate is withdrawn.

Approved by	Processed by
Michael Møller Nielsen Certification Manager	Lars Poder Examiner

The conformity markings may only be affixed to the above type approved equipment. The manufacturer's Declaration of Conformity may only be issued and the notified body identification number may only be affixed on the instrument when the production/product assessment module (D or F) of the Directive is fully complied with and controlled by a written inspection agreement with a notified body.
This EU-type examination certificate may not be reproduced except in full, without written permission by FORCE Certification A/S.

FORCE Certification references:
TASK No. 119-29031.01 and 0200-MID-06816

FORCE Certification A/S · Park Allé 345 · 2605 Brøndby · Denmark · Tel +45 43 25 01 77 · Fax +45 43 25 00 10 · info@forcecertification.com · www.forcecertification.com
1161-1-2-en-en
Page 1 of 9

Figure 17: An example of a MID approval for temperature sensors issued by FORCE Certification.

5.2 Measurement and verification

A temperature sensor must be measured at three different test temperatures before R_0, A and B (see paragraph 2.1) can be determined. The requirements for the three test temperatures are described in EN 1434. If a temperature sensor is to be used for the temperature range of 2...150 °C, it is typically tested at 10 °C, 75 °C and 140 °C in special thermostatic baths, which have been designed for this purpose. In each thermostatic bath, a reference thermometer is placed, which measures the temperature t_i in the bath. Then the resistance value R_i of the temperature sensor is measured. By measuring in three different baths, the three resistance values R_1, R_2, R_3 and the three corresponding temperatures t_1, t_2, t_3 are obtained. R_0, A and B can then be determined by solving the following 3 equations with 3 unknown quantities:

$$R_1=R_0\cdot(1+A\cdot t_1+B\cdot t_1^2)$$

$$R_2=R_0\cdot(1+A\cdot t_2+B\cdot t_2^2)$$

$$R_3=R_0\cdot(1+A\cdot t_3+B\cdot t_3^2)$$

A temperature sensor for heat or cooling measurement must, as described in EN 1434-5 [1], not deviate more than 2 K from an ideal temperature sensor. When R_0, A and B have been determined for a given temperature sensor, the next step in the verification is to carry out a check calculation to ensure that the temperature sensor complies with this requirement. An example of such a verification calculation is shown in *Figure 18.*

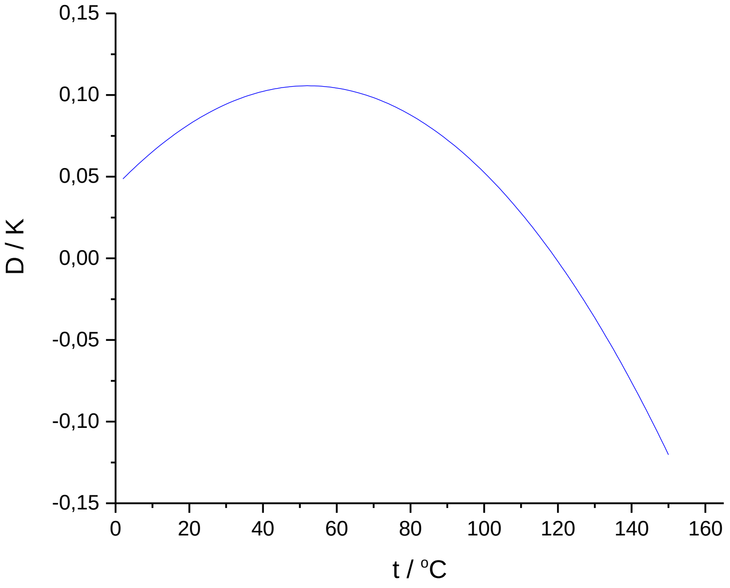


Figure 18: Example of a check calculation of a Pt500 temperature sensor where the deviation D *from an ideal Pt500 temperature sensor is determined for all temperatures* t *in the temperature range 2-150 °C.*

Then, as described in EN 1434, it is checked that the temperature sensor has sufficient insulation resistance. This is to ensure that there is no electrical transition inside the temperature sensor.

5.3 Requirements for temperature sensor set

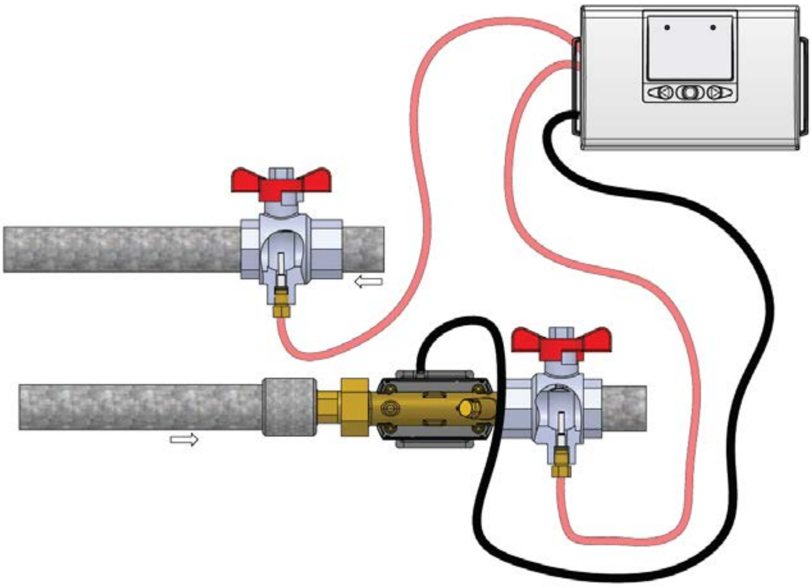


Figure 19: A typical heat or cooling meter installation where two temperature sensors are installed in supply and return, respectively.

As shown in *Figure 19*, a correct energy calculation requires that the temperature difference between the supply temperature and the return temperature is measured. Therefore, very strict requirements are imposed on how much the two temperature sensors in a given temperature sensor set may differ. The deviation in percent of the temperature difference, E_t, is defined in the EN 1434 standard and must be as maximum error:

$$E_t = \pm\left(0.5 + 3\frac{\Delta\Theta_{min}}{\Delta\Theta}\right)$$

where $\Delta\Theta$ is the temperature difference in question and $\Delta\Theta_{min}$ is the smallest temperature difference approved.

The MID directive states that $\Delta\Theta_{min}$ must be at least 3 K, which means that $\Delta\theta_{min}$ is most often 3 K.

In *Table 5*, the maximum allowable deviation between the two temperature sensors is shown for a number of selected temperature differences at $\Delta\Theta_{min}$ = 3 K.

Temperature difference ΔΘ	Maximum allowable deviation %	Maximum allowable deviation K
3 K	3.5 %	0.105 K
6 K	2.0 %	0.120 K
9 K	1.5 %	0.135 K
15 K	1.1 %	0.165 K
30 K	0.8 %	0.24 K
60 K	0.65 %	0.39 K

Table 5: The maximum allowable deviation between the two temperature sensors for a number of temperature differences.

When pairing a given temperature sensor set, a number of calculations are made to ensure that any temperature sensor set complies with the limits set in the EN 1434 standard for the deviation between the two temperature sensors. For the Kamstrup Pt500 temperature sensors, the maximum deviation between the two temperature sensors in percent is typically:

$$E_t = \pm\left(0.4 + \frac{4}{\Delta\Theta}\right)$$

This gives the following maximum typical deviation for the Kamstrup Pt500 temperature sensors:

Temperature difference ΔΘ	Maximum typical deviation %	Maximum typical deviation K
3 K	1.7 %	0.052 K
6 K	1.1 %	0.064 K
9 K	0.84 %	0.076 K
15 K	0.67 %	0.10 K
30 K	0.53 %	0.16 K
60 K	0.47 %	0.28 K

Table 6: Maximum typical deviation between two Kamstrup Pt500 temperature sensors for a number of temperature differences.

5.4 Requirements for temperature sensor cables

As shown in paragraph 2.2.1, it applies to two-wire temperature sensors that the resistance of the cable affects the measured temperature. The EN 1434 standard therefore describes a number of sensor cable requirements used for 2-wire temperature sensors to ensure a correct energy calculation as possible. Firstly, the cables must be equal in length as different cable lengths will cause an error in the calculation of the temperature difference. In continuation of this, EN 1434 also describes that the lengths of the sensor cables must not be subsequently changed.

The resistance of the temperature sensor cables changes with the temperature, which can cause a serious error in measuring the temperature difference if certain conditions are present in the form of long cables and small cable cross sections. In practice, the wires in the sensors cable are designed as stranded wires and therefore the cable cross section is the area of the copper wires. Therefore, requirements for the maximum cable length for a given combination of the cable cross section and the nominal resistance have been introduced in EN 1434, as shown in *Table 7*.

Cable cross section	Max cable length for Pt100	Max cable length for Pt500
0.22 mm^2 / 0.25 mm^2	2.5 m	12.5 m
0.50 mm^2	5.0 m	25.0 m
0.75 mm^2	7.5 m	37.5 m
1.50 mm^2	15.0 m	75.0 m

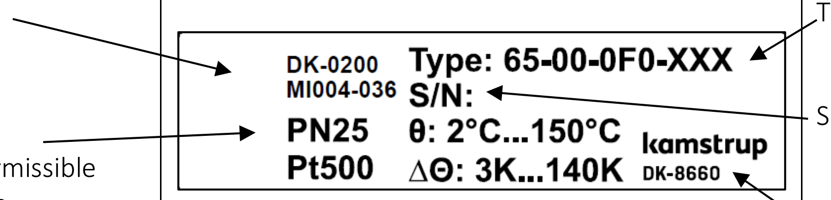
Table 7: Requirements in the EN 1434 standard for temperature sensor cables to be used for 2-wire temperature sensors.

However, for 4-wire temperature sensors, cables need not be of equal lengths as the resistance of the cables does not affect the temperature measurement. Similarly, the same requirements regarding a maximum cable length for a given combination of the cable cross section and nominal resistance are not demanded. The maximum cable length, however, depends on the calculator used (e.g. for EMC reasons). The MULTICAL® 603 and MULTICAL® 803 calculators are approved for use with up to 100 m 4-wire cable, e.g. of the type 4 x 0.25 mm^2.

5.5 Labelling of temperature sensors and pockets

As the temperature sensors and their pockets are used for legal billing, there are a number of requirements for proper labelling. Depending on the approval, there will be different labelling requirements and the correct labelling thus always depends on the exact approval. The following examples of temperature sensor and pocket labelling are thus only to be seen as examples explaining the most commonly used labels in the labelling of temperature sensors and pockets.

Example of labelling of a direct short temperature sensor



Approval

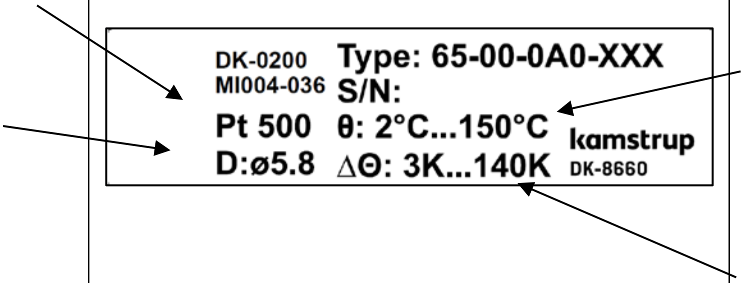
Maximum permissible pressure stage

Type number

Serial number

Manufacturer logo and postal address

Example of labelling of a pocket sensor



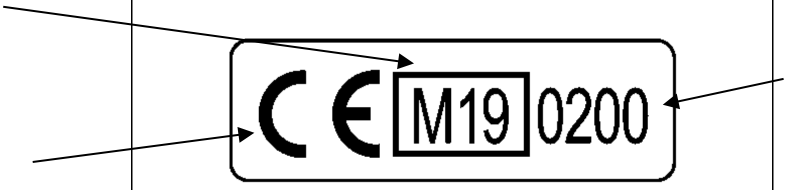
Nominal resistance

Nominal diameter

Permissible temperature range

Permissible differential temperature range

Example of MID Module D verification mark

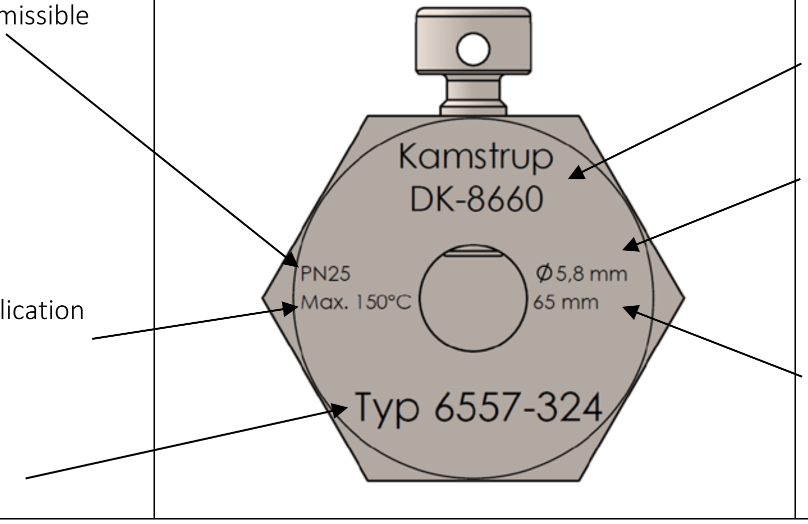


Verification year

Verification type

Registration number of the notified body that has approved the verification site

Example of labelling of sensor pocket



Maximum permissible pressure stage

Maximum application temperature

Type number

Postal address

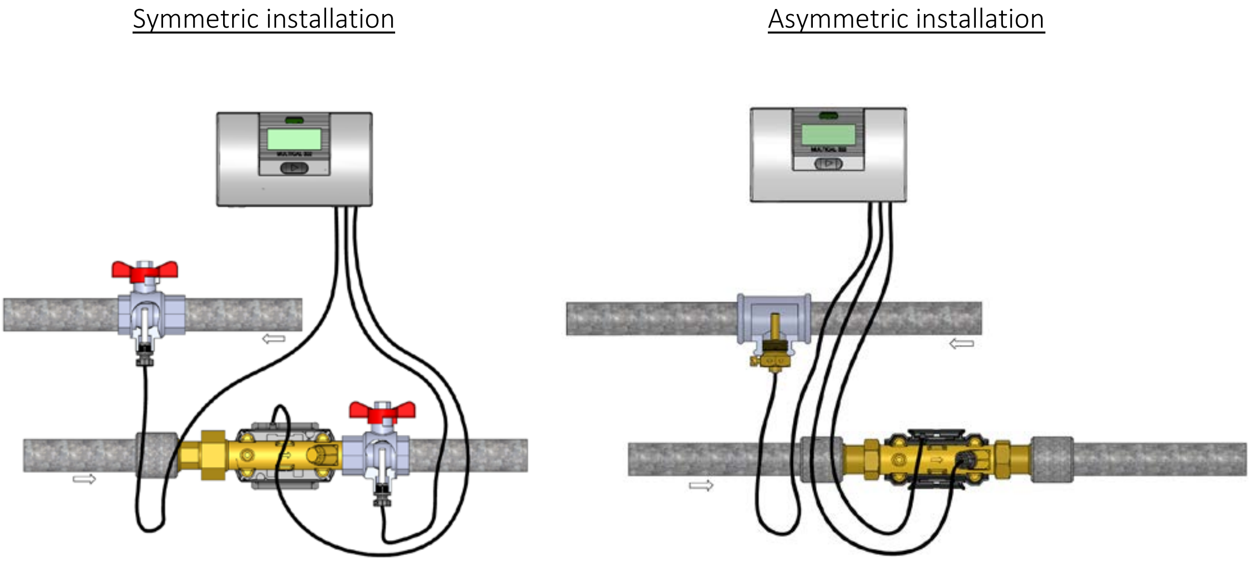
Nominal inner diameter

Length of pocket

6 Installation of temperature sensors

This chapter discusses the main conditions of installing temperature sensors, primarily focusing on the installation conditions that ensure correct temperature measurement.

6.1 Symmetric installation


Symmetric installation

Asymmetric installation

Figure 20: Examples of an symmetric installation and an asymmetric installation, respectively.

When installing temperature sensors, it is very important that the temperature sensors are installed in the same way in both the supply and return. This is referred to as the symmetric installation. An example of this is shown in *Figure 20* where ø5.2 mm temperature sensors with composite unions are installed in two ball valves. An example of an asymmetric installation, however, is that one temperature sensor is installed as a direct temperature sensor, for example in the flow sensor, while the other temperature sensor is installed in a pocket. In a symmetric installation, it is ensured that there is no difference between the measurement characteristics of the two temperature sensors and that a correct temperature difference is thus calculated.

In case of the asymmetric installation, such an installation will introduce two different errors, each affecting the measurement properties. Firstly, if installed in a pocket rather than as a direct temperature sensor, the response time of a given temperature sensor will be significantly increased, and in case of the asymmetric installation, there will be a significant difference in response time of the two temperature sensors, which will lead to errors in determining the temperature difference. Secondly, a temperature sensor installed in a pocket will have a significantly increased heat conduction error compared with a direct temperature sensor. This will affect the temperature measured by the temperature sensor. If both temperature sensors are installed in a pocket, the error on both temperature sensors will be comparable and within the limits set for the correct measurement of the temperature difference. However, if one temperature sensor is installed in a pocket and the other temperature sensor as a direct temperature sensor, there will be a significant heat conduction error on one temperature sensor and a limited heat conduction error on the direct temperature sensor, and this will typically lead to the deviation of the measured temperature difference being greater than the specified limits, see paragraph 5.3.

A widely used installation method is to install one temperature sensor in the flow sensor and the other temperature sensor in either a ball valve or nipple. As both temperature sensors are installed as direct temperature sensors, this installation method is also considered to be a metrologically correct installation, see *Figure 21.*

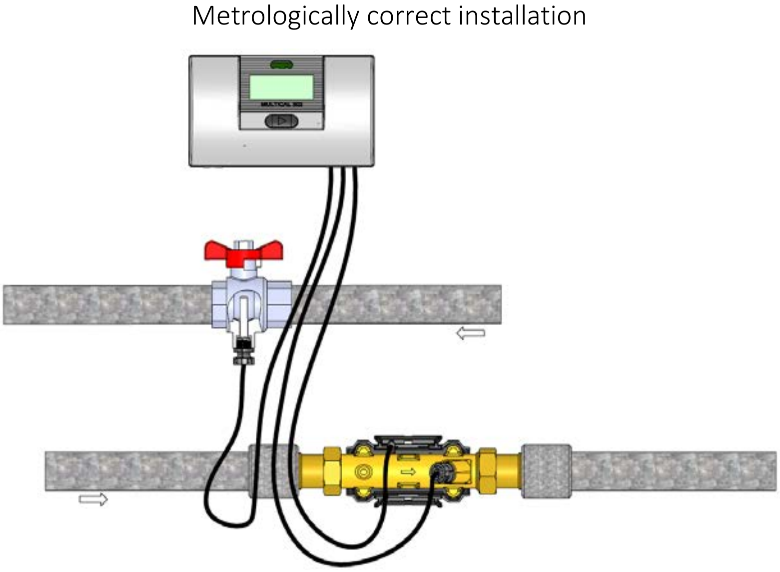


Figure 21: An example of a metrologically correct installation.

6.2 Installation length

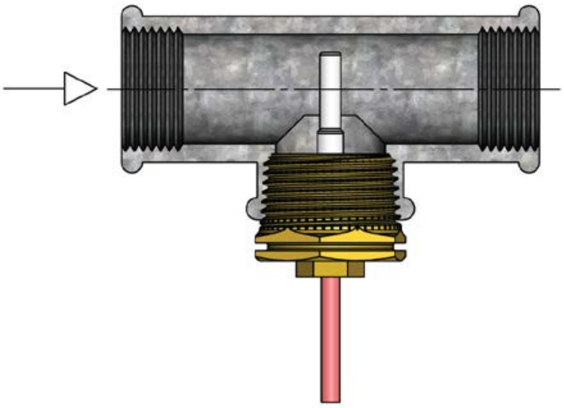


Figure 22: Example of correct installation of direct short temperature sensor.

Based on the paragraph about the qualifying immersion depth, it is important to consider that the temperature sensor is correctly positioned in the pipe for the best possible measurement. When installing a DS 27.5 mm temperature sensor in small pipes such as DN15 and DN20, be aware that the temperature sensor must be placed as far into the pipe as possible to comply with the qualifying immersion depth requirement as stated in the approval. An example of this is shown in *Figure 22*.

For larger pipe dimensions, there will be a greater risk of stratification inside the pipe, and it is recommended to position the temperature sensor as far as possible in the centre of the pipe. When installing in, for example, a 90° angle, be aware that the temperature sensor must be placed relatively far into the pipe before you can be sure that the temperature sensor is measuring the correct temperature. An example of correct installation in a 90° angle is shown in *Figure 23.*

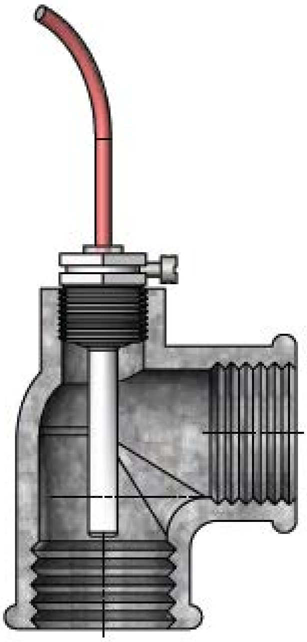


Figure 23: Example of correct installation of pocket sensor in a 90° angle.

6.3 Installation in large pipes

Normally, only one temperature sensor is used in each pipe and this is done assuming that the temperature in the pipe is relatively homogeneous. In large pipes, e.g. above DN100, stratification may occur inside the pipe. The stratification is caused by hot water searching upwards. Stratification becomes more critical at high temperatures and low flow rates. In case of stratification, the temperature in the pipe is no longer homogeneous and therefore, a single temperature sensor is not necessarily representative of the average temperature in the pipe. In such cases, the temperature measurement can be improved, as shown in *Figure 24*, by using four temperature sensors connected in a combination of series and parallel connections. The combination of series and parallel connections means that the four temperature sensors together have the same nominal resistance as if only one temperature sensors had been used. If the four temperature sensors are positioned as shown in *Figure 24*, they will measure four different temperatures due to the stratification that, due to the combination of series and parallel connections, will result in a more representative average temperature.

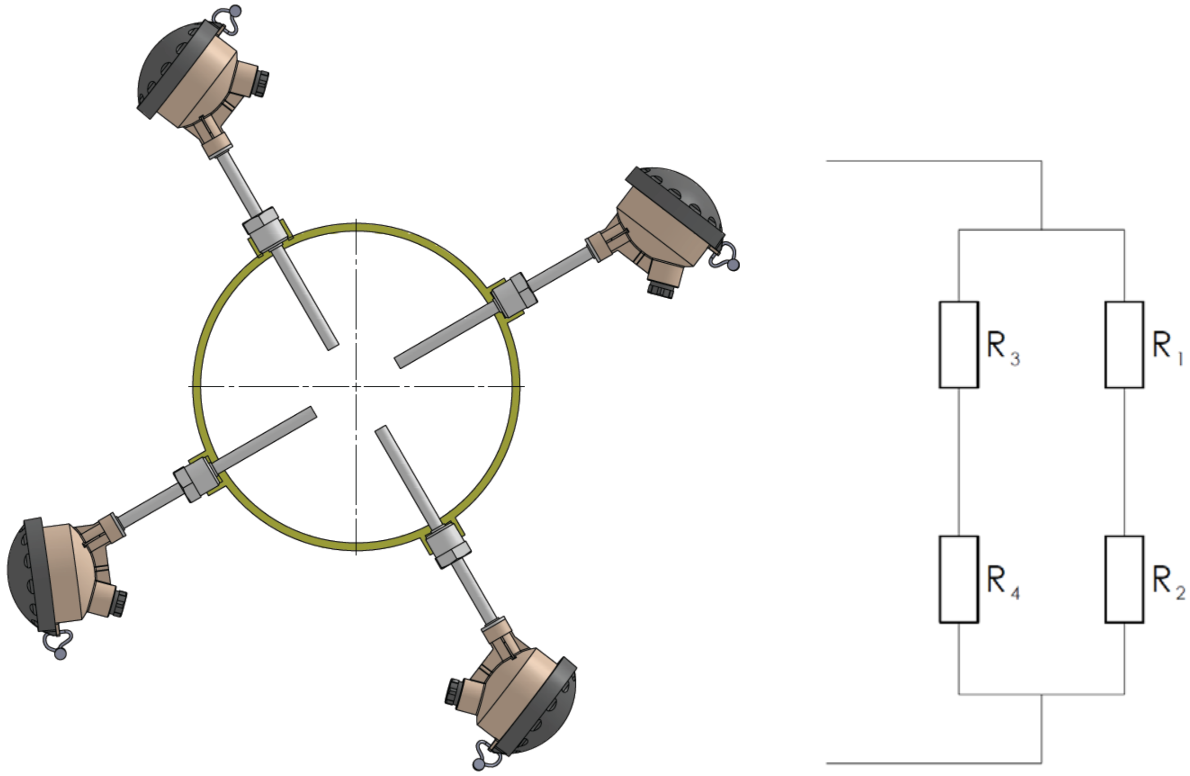


Figure 24: An example of an installation where a more representative average temperature is obtained by using four different temperature sensors connected by a combination of series and parallel connection.

6.4 Other installation conditions affecting the temperature measurement

A more correct temperature measurement is achieved by limiting the heat conduction into the surroundings as the heat conduction will cause a temperature measurement error. The heat conduction into the surroundings can be limited by insulating the temperature sensors. If you choose to insulate the temperature sensors, you should be aware that both temperature sensors are similarly insulated as the insulation of a single temperature sensor may conversely help to introduce an additional error in the measurement of the temperature difference. For pocket sensors, the response time can be reduced by using heat-conducting paste in the pocket. As heat-conducting paste results in a significant reduction in response time, it is also important that the same amount of heat-conducting paste is used in both pockets. Over time, most heat-conducting pastes tend to dry out. Therefore, the use of heat-conducting paste may mean that the temperature sensor cannot be removed from the pocket at a later time due to the solidified heat-conducting paste. At the same time, it should be borne in mind that the use of heat-conducting paste may be regulated by national legislation due to its high impact on the temperature measurement. It has, for example, been experienced that heat-conducting paste is not allowed in some countries.

6.5 Installations with high flow rates and/or a high combination of pressure and temperature

For temperature sensor pockets, welded pockets may only be used at flow rates up to 3 m/s. At higher flow rates, there are examples of welded pockets breaking, probably due to the pocket being exposed to its characteristic resonance frequency. For flow rates higher than 3 m/s, a reinforced pocket turned out of one piece is recommended, see paragraph 3.2.2. In *Table 8*, the flow corresponding to a flow rate of 3 m/s is shown for selected pipe diameters. If a higher flow is used than the number in the table, it is recommended to use a reinforced pocket turned out of one piece. Similarly, it is also recommended to use reinforced pockets turned out of one piece for installations with a high combination of pressure and temperature, e.g. PN40 installations, and where a broken pocket will cause a high risk of injury.

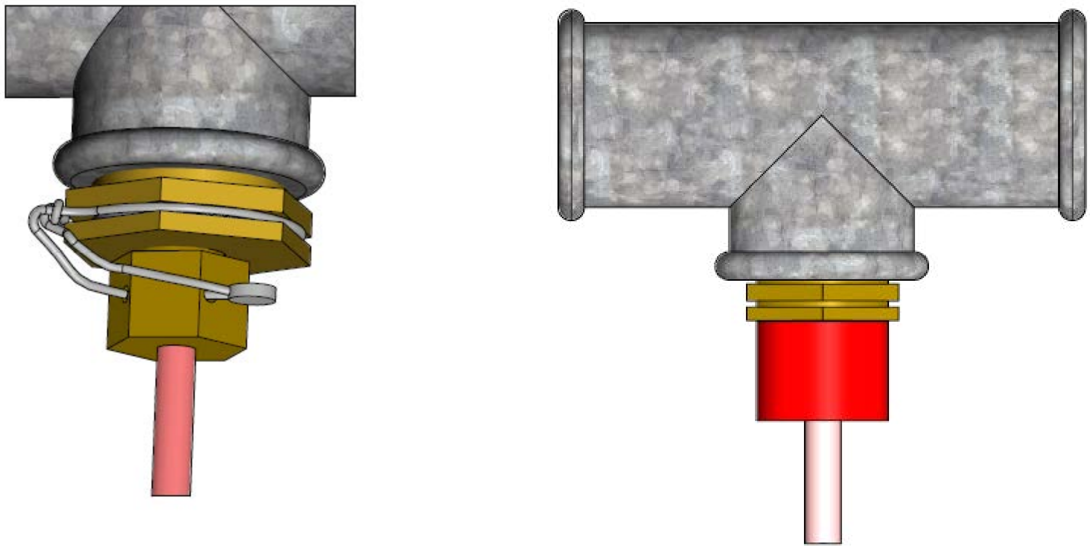
Nominal pipe diameter [DN]	Flow [m^3/h]	Flow [L/h]
50	21	21195
65	36	35820
80	54	54259
100	85	84780
125	132	132469
150	191	190755
200	339	339120
250	530	529875
300	763	763020

Table 8: Flow for selected pipe diameters corresponding to a flow rate of 3 m/s.

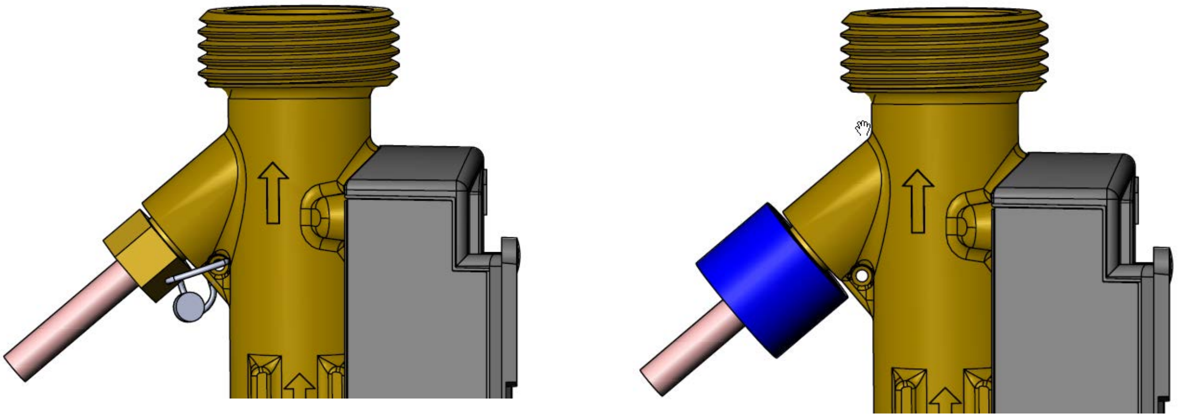
6.6 Sealing of temperature sensors

As described in paragraph 6.2, a correct temperature measurement depends on a satisfactory installation length of the temperature sensor. To ensure that no subsequent changes are made to the installation after proper installation, the installation is often sealed. This is usually done using a wire that is finally sealed, called a sealing wire. For direct short temperature sensors, so-called sealing shells that surround the brass union can also be used. The sealing shells are available in both a red version, which is used to seal a temperature sensor mounted in the supply, and a blue version, which is used to seal a temperature sensor mounted in the return. A number of examples of sealing both with sealing wire and sealing shells are shown in *Figure 25.*

Examples of sealing of direct short temperature sensor mounted in a nipple



Examples of sealing of direct short temperature sensor mounted in a flow sensor



Examples of sealing of pocket sensor

Figure 25: A number of examples of sealing of temperature sensors, either with sealing wire or sealing shells.

7 Accessories for the installation of temperature sensors

This chapter describes some of the most commonly used types of accessories for installing direct short temperature sensors, including ball valves, nipples, tee and 11 mm adapter for DS 38 mm temperature sensor.

7.1 Ball valve

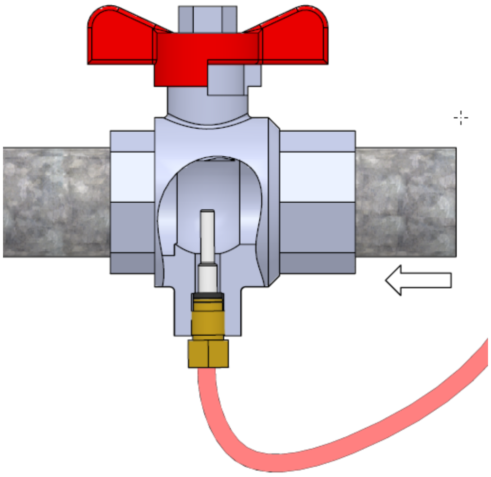


Figure 26: Direct short DS 27.5 mm temperature sensor mounted in a ball valve.

By installing a ball valve with M10x1 insert for a temperature sensor, it is possible to install a direct short temperature sensor without draining the installation of water. The ball valve operates by turning the handle, temporarily blocking the water flow during installation by a ball-shaped valve. The installation of temperature sensors in a ball valve also has the advantage of allowing the temperature sensor to, as far as possible, be placed optimally within the fluid flow.

7.2 Nipple

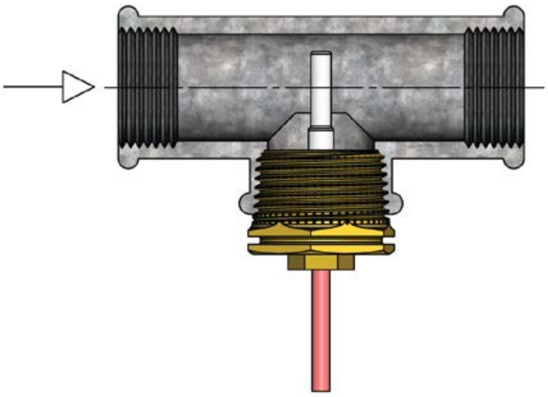


Figure 27: Direct short DS 27.5 mm temperature sensor mounted with nipple in a T-piece.

A highly used solution for installing direct short temperature sensors is to use a brass nipple with, for example, R½ or R¾ thread, which is installed in a corresponding T-piece. For nipples with cone-shaped threads, use packing cord or Teflon tape to obtain the required seal, while straight-threaded nipples typically use a copper gasket.

7.3 Tee with M10x1 thread

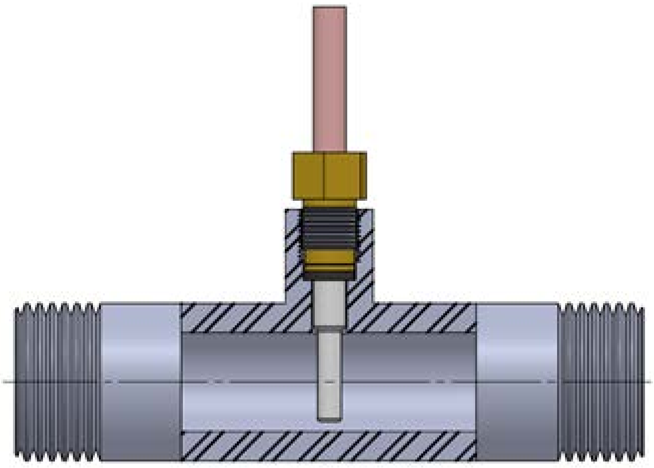


Figure 28: Direct short DS 27.5 mm temperature sensor mounted in tee with M10x1 thread.

Installing a direct short temperature sensor in a tee with M10x1 thread is typically used if you want to reposition the flow sensor so that it is then, for example, placed in the supply instead of in the return. In this case, a tee with M10x1 thread is a good and practical choice for establishing a new location for installing the temperature sensor that is not installed in the flow sensor.

7.4 11 mm adapter for DS 38 mm temperature sensor

As can be seen from *Table 3*, a DS 27.5 mm temperature sensor can be used in DN15 to DN25 installations and a DS 38 mm temperature sensor can be used in DN32 and DN40 installations. By mounting an 11 mm adapter on a DS 38 mm temperature sensor, a DS 38 mm temperature sensor can also be used in small installations from DN15 to DN25, see *Table 9*. This may be particularly relevant in old installations where subsequent reconstruction/re-insulation have resulted in the supply pipe being DN40 and the return pipe being DN25.

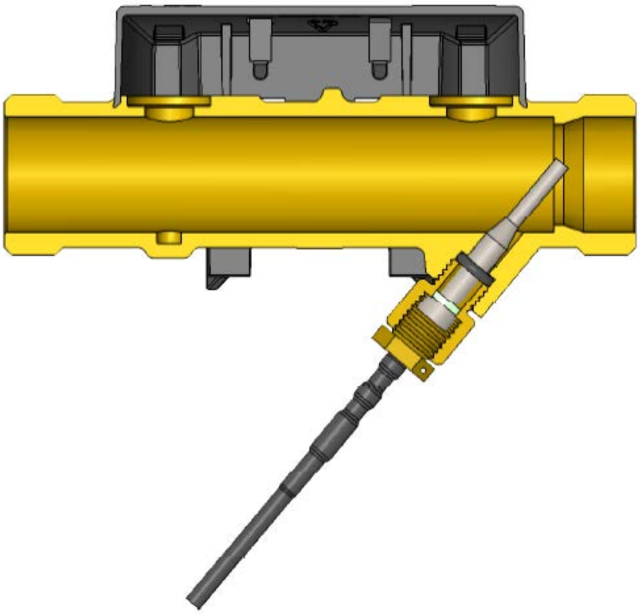


Figure 29: Direct short DS 38 mm temperature sensor mounted with 11 mm adapter in a flow sensor.

Temperature sensors

DN	DS 27.5 mm	DS 38 mm	DS 38 mm with 11 mm adapter
15	X		X
20	X		X
25	X		X
32		X	
40		X	

Table 9: Overview of the use of direct short temperature sensors, both with and without 11 mm adapter.

8 Application of temperature sensors for cooling meters

Basically, the same temperature sensors are used for both heat and cooling meters. In this chapter, we look at some of the special conditions that should be observed when using temperature sensors for cooling meters.

8.1 Correct measurement of the supply temperature

In the field of remote cooling, the customer is often guaranteed a given supply temperature of, for example, 6 °C. As the temperature difference between the supply and the return is used to calculate the energy consumption, the two temperature sensors in a pair of temperature sensors are basically produced to obtain a correct measurement of the temperature difference, see paragraph 5.3.

However, the absolute temperature, i.e. the temperature measured by the individual temperature sensor, used to determine whether the requirement of the 6 °C for the supply temperature is complied with, is specified in the EN 1434 standard to deviate up to 2 K. If this deviation on the temperature sensor results in the actual temperature of the supplied district cooling water being in practice above 6 °C, even if the cooling meter displays 6 °C, the customer is not receiving the promised product. Conversely, if the actual temperature of the supplied district cooling water is below 6 °C, even if the meter displays 6 °C, unnecessary resources are used to supply district cooling water that is colder than the required 6 °C. Therefore, if the customer is guaranteed a given supply temperature of, for example, 6 °C, it should be ensured that the deviation of the measured supply temperature is as small as possible.

The deviation of the absolute temperature is caused by several factors. Firstly, the platinum resistance used in the temperature sensor will have a deviation from a perfect platinum resistance as defined in EN 60751. Typically, a class B platinum resistance is used, which is specified to have the following deviation:

$$\pm (0.3 + 0.005xT) \text{ K}$$

where *T* is the temperature.

	Class B
Requirement for max deviation	± (0.3 + 0.005xT) K
Deviation at T=0 °C	± 0.3 K
Deviation at T=20 °C	± 0.4 K

Table 10: Calculation of permissible deviation for a class B temperature sensor according to EN 60 751.

As can be seen from *Table 10*, the maximum deviation of the platinum element will be up to ±0.4 K when used in district cooling applications. In addition to the platinum element, the calculator itself also has uncertainty about the temperature measurement and it is typically ±0.2 K.

The last factor that can affect the absolute temperature measurement is the cable of the temperature sensor. This is because the cable has a resistance that increases the total resistance of the entire temperature sensor. For a Pt500 temperature sensor, the measured absolute temperature is increased by max 0.08 K per running metre of cable using a 0.25 mm^2 cable. This means that the measured temperature of a Pt500 temperature sensor with 5 m cable will be increased by 0.4 K. For 4-wire temperature sensors, the cable does not increase the measured resistance, see paragraph 2.2.2. This difference helps to make more use of 4-wire sensors in the case of cooling meters. For Pt100 temperature sensors, however, the cable increases the measured absolute temperature by 0.4 K per running metre of cable using a 0.25 mm^2 cable. Therefore, it is not recommended to use Pt100 temperature sensors for cooling measurements.

If the above factors are combined, the result is that the absolute deviation will typically be between +1.0 K and -0.2 K for 2-wire Pt500 temperature sensors with 5 m cable, while it for 4-wire Pt500 temperature sensors typically will be between -0.6 K and +0.6 K.

The MULTICAL® 403, MULTICAL® 603 and MULTICAL® 803 calculators are available with an offset adjustment function that allows for an absolute temperature adjustment of up to ±0.99 K in the calculator. As the above deviations in the absolute temperature are determined during the temperature sensor calibration, the use of the offset adjustment function will result in a reduction of the absolute deviation to typically less than ±0.1 K. As both the supply and return temperatures are adjusted by the same value, the offset adjustment does not affect the calculation of the amount of energy consumed.

8.2 Condensation problems

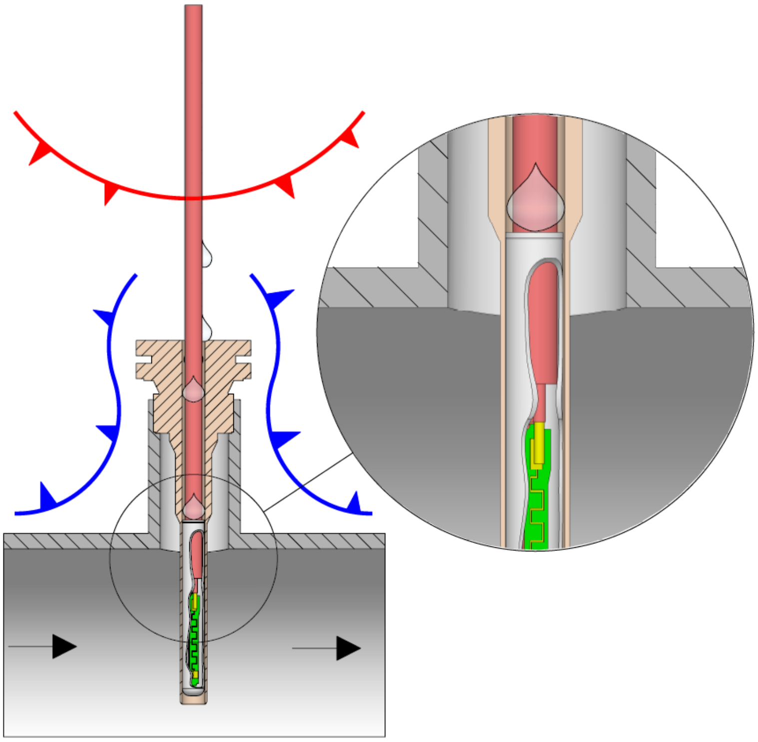


Figure 30: Penetration of condensation into a pocket sensor.

When hot air with relatively high humidity comes into contact with a cold surface, the air is cooled down and the moisture in the hot air forms condensation on the cold surface. In connection with district cooling where water is typically circulated in the district cooling pipes, which are for example 5 to 15 °C and thus significantly colder than the surroundings, it is therefore well-known within the field of cooling meters that problems may occur due to condensation. This also applies to temperature sensors where the penetration of water into the temperature sensor may cause the temperature sensor to fail. This issue is illustrated in *Figure 30*.

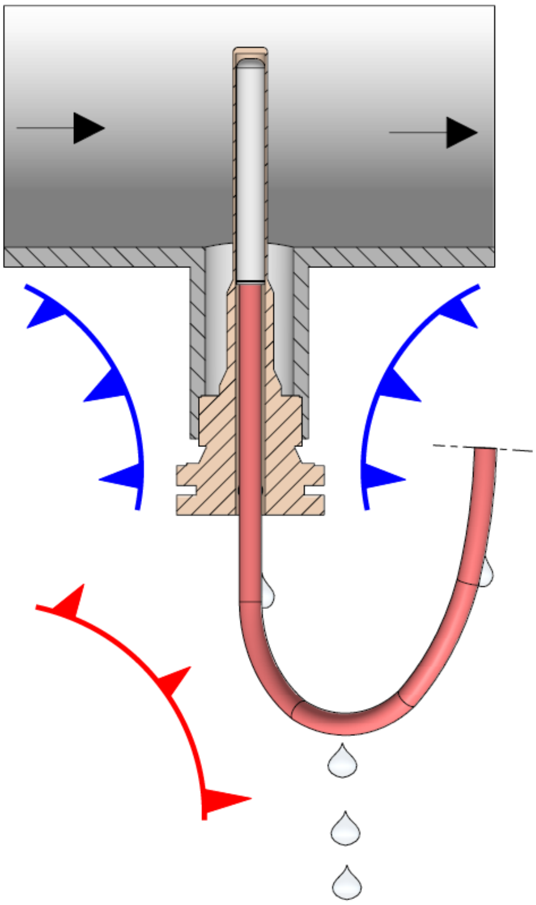


Figure 31: Correct installation of a temperature sensor for use in cooling measurements by which gravity prevents the penetration of condensation.

Condensation issues can be minimized by mounting the temperature sensors from below, causing gravity to drain the water formed, for example, inside a pocket. This solution to the problem of condensation is illustrated in *Figure 31*.

9 References

[1] https://webshop.ds.dk/Default.aspx?ID=120&q=Varmem%C3%A5lere

[2] https://standards.globalspec.com/std/1199183/en-60751

[3]https://www.jumo.de/products/temperature/temperature-sensors/thin-layer/906122/platinum-chip-temperature-sensors-of-smd-design-type-on-epoxy-pcb-according-to-din-en-60751-pcse---pcsm-design-type-906122.html?parentId=2917

[4] https://www.heraeus.com/en/hne/sensor_products/sensors.aspx

[5]https://www.jumo.de/products/temperature/temperature-sensors/thin-layer/906121/platinum-chip-temperature-sensors-with-connection-wires-according-to-din-en-60751-pca-design-type-906121.html?parentId=2917