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Determination of automatic weather station self-heating originating from accompanying electronics

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Key words: automatic weather stations, temperature sensors, self-heating

Abstract

Atmospheric air temperature values are fundamental in meteorology and climate studies. To achieve high accuracy in the measurements, features, characteristics and performances of instruments is of high importance. This paper focuses on the most commonly used temperature sensors within automatic weather stations (AWS), with a specific focus on evaluating the self-heating effect. Self-heating in AWS originates not only from the temperature sensor itself, but also from the electrical components housed together within. This effect introduces extra heating in the system, causing biases and errors in temperature records. Conducted measurements show the temperature change in the close vicinity of the thermometers over a time period of more than 66 hours with an electric current and voltage supply values recommended by the respected sensor manufacturers. Furthermore, the temperature changes after increasing the voltage supply levels up to 80% of the maximum voltage recommended by the manufacturer is presented as well. The results of overall self-heating indicated a +0.07 °C increase in temperature for the tested sensors when using the manufacturers recommended electric current and voltage supply. However, the usage of elevated voltage levels shows a considerably higher temperature increase in the vicinity of the temperature sensors. In the presented study, the measured difference from the initial measured temperature can be high as +0.32 °C.

1. Introduction

Precise and reliable measurements of key meteorological quantities like temperature, humidity, wind speed, precipitation, solar radiation etc. are crucial for accurate weather predictions and to generate reliable data series in climatology. Measurement methods and sensor characterisation, together with the possible influencing factors on the process and sensors, need to be fully understood and evaluated.

Near surface air temperature is a fundamental quantity in meteorology and still represents the main information on climate trends. Although temperature measurements are believed to be well characterised, there are still multiple undefined factors that affect these measurements. Influential factors may originate from the environment the sensors are exposed to or from the used measurement devices and sensors themselves. This paper will focus mainly on the factors that are connected with the overall self-heating effect that occurs within the housing of the AWS. The work has been made within the numerous activities and objectives of the European project "MeteoMet - Metrology for Meteorology", (Merlone *et al.*, 2015, 2018) delivering advances in fundamental and applied metrology for measurements of climate variables. As most automatic weather station (AWS) today measure air temperature using platinum resistance thermometer (PRT), there are multiple effects that may affect the resulting measured air temperature.

As these sensor types rely on the resistance measurement principle of temperature (Siemens, 1870; Callendar, 1887; Harker & Chappuis, 1900), they need to be supplied by a constant and stable source of electric current. This is caused by the need to measure resistance, which is only possible when electric current is present. This measurement principle causes the heating of resistance element by the passing current, which can result in artificial and undesired increase of measured temperature.

This effect commonly called self-heating is well known and has been discussed and analysed in numerous publications (Sutton, 1994; Batagelj *et al.*, 2003; Pearce *et al.*, 2013; Ballico & Sukkar, 2014; Sestan & Grgec-bermanec, 2017). Further details of this effect are presented in following sections. Most of the AWS thermometers that are used today, house together in a compact space multiple sensors (most commonly humidity sensor). The voltage levels supplied to this temperature and relative humidity (T & RH) sensors have a potential effect on the increase of temperature within the AWS sensor housing. This can cause an artificial increase of temperature that is indicated by the temperature sensor. Therefore, it is important to determine the magnitude of this effect.

2. Self-heating of Platinum Resistance Thermometers used in AWS

Platinum Resistance Thermometers are widely used in AWS. The measurement of temperatures with this type of thermometers necessarily implies resistance measurements, entailing the pass of an electrical current through the thermometer's sensing element. The resistance of the thermometer is then calculated by observing the generated voltage and using the Ohm's law. This electrical current heats the thermometer element, by the Joule effect, causing a difference between the temperature of the sensor and the temperature to be measured. This effect is known as the self-heating error. Self-heating error associated to the resistance thermometer sited in each of the T & RH sensors, included in this paper, was evaluated in García Izquierdo C *et al.* (2017), following the procedure there described.

Self-heating error is determined by extrapolating, to zero current, resistance values measured with different electrical currents applied in the sensing element, being the thermometer at stable temperature.
The extrapolated resistance value, to zero current, can be calculated by two methods. The so-called two-current method, the thermometer resistance is measured at two different currents (1).

$$R_o = \frac{I_2^2 R_1 - I_1^2 R_2}{I_2^2 - I_1^2} \qquad (1)$$

Other method to calculate the resistance value for zero electrical current is by calculating the independent term of the least-squares straight-line fit (2) of several resistance values when different electrical currents are applied to the sensing element of the resistance thermometer

$$R_t = R_o + aI^2 \qquad (2)$$

$$R_0 = \frac{(\sum_{i=1}^{n} R_i)(\sum_{i=1}^{n} I_i^4) - (\sum_{i=1}^{n} R_i I_i^2)(\sum_{i=1}^{n} I_i^2)}{n(\sum_{i=1}^{n} I_i^4) - (\sum_{i=1}^{n} I_i^2)(\sum_{i=1}^{n} I_i^2)} \qquad (3)$$

The values of self-heating error of the thermometers included in this study are shown in Table 1, using the method of least-squares straight-line fit, for air temperatures of 0 °C and -40 °C, and when 1 mA is applied to the sensing element of the resistance thermometer. Under these conditions, the self-heating errors are lower than 0.1 ºC

Table 1. Tested thermometers self-heating errors.

3. Influence of electronic within the AWS on air temperature measurements

The previous research of self-heating in PRT's (that are the most commonly used type of sensors in AWS) has shown a relatively small effect peaking at 0.064 °C when used with 1mA current supply. Based on these findings a further investigation has been conducted, in order to explore the possible heating of temperature sensors used with humidity sensors in the same enclosure as the PRT sensing element itself.

3.1. Measurement process

The measurement process described in this section was developed and used to determine the self-heating of a selection of T & RH sensors and the accompanying electronic housed within the measurement unit. This developed procedure has the purpose to give guidance on how to measure the influence of electronics associated to the humidity sensor on the readings of the associated thermometer housed within AWS. The measuring process can be divided into the following five sections that need to be dealt with, in order to obtain reliable data on “overall self-heating”:

3.1.1. Thermal insulation of sensor under test

In order to determine the maximal level of “overall self-heating” generated only by the electronics housed within the tested T & RH sensors, it needs to be thermally isolated from the environment that the sensor is going to be exposed to. This is done, in order to see the heating effect only originating from the T & RH sensors electronic. This can be done by covering the tested sensor`s body with an insulation material (used within this study: Class 0 Armaflex plus, Armacell, Maharashtra, India) that will minimise the heat exchange between the body of the sensor and the thermally stable environment. The insulation effectiveness can be tested by monitoring the temperature change by a reference thermometer (in ideal case calibrated) housed together with the tested T & RH sensor. Slower the change of temperature (from a stable state to randomly selected temperature value) is visible by the reference sensor, the better the insulation is. As there are multiple variations of insulation material and its thickness it should be mentioned that the endeavour of achieving the smallest reaction time should be limited. The authors consider a reaction time to a random temperature change from 10 min and more for sufficient. The typical insulation housing used for the presented “overall self-heating” testing is presented in section 3.2 and in Figure 1. The material type used within this study was interlaced foam based on synthetic rubber with a low conductivity λ 0 °C ≤ 0.033(at 0 °C).

Figure 1. The insulation housing proportions together with the placement of the tested and reference senor.

3.1.2. Thermal stability and homogeneity determination of the testing environment

In order to have reliable data that can be used for the “overall self-heating” characterization, the thermal stability and homogeneity of the testing environment is needed for its inclusion in the uncertainty budget. If the environment would have proven to have poor stability the evaluation would be possible, but would result in higher uncertainty making the result of the measurements inconclusive. For the purpose of measuring the testing environment`s thermal stability it is recommended to have calibrated PRT which will be exposed to the same conditions (Tegeler *et al.*, 2017) (position within the environment, temperature, air flow speed etc.) as the tested T & RH sensor housed within the insulation housing. The temperature measurement by the calibrated

PRT sensors have been done continuously until a stable or repeating temperature behaviour has been observed. A thermally stable environment for the purpose of "overall self-heating" testing has been considered one that does not exceed ± 0.04 °C after a period of one hour at a given temperature of testing.

The same reference thermometer requirements should be applied for the temperature homogeneity determination. These measurements have been performed in the same area of the testing environment in which the tested T & RH sensors will be placed. The use of one reference thermometer which is positioned in different vertical and horizontal positions is sufficient to determine the chamber temperature homogeneity (Tegeler *et al.*, 2017). Although to compare the possible temperature difference in the chamber at the same time the use of minimum of three sensors is recommended. These sensors should be placed in several positions of the testing area in vertical axis. The measuring points should be positioned on the bottom and top end of the area and in at least one point in-between these points. This specific procedure was used within the presented study. Subsequently the gathered data were statistically analysed by means of standard deviation calculation and associated to the total length of the measured area.

3.1.3. Reference sensor selection and placement

To be able to measure the "overall self-heating" of the T & RH sensor, a calibrated thermometer with a calibration uncertainty equal or smaller than 0.02 °C (k = 2) needs to be inserted into the near vicinity of sensor under test within the insulation housing described previously in section 3.1.1 and Figure 1. The thermometer type that best meets the uncertainty requirements is a PRT. To minimize the heating of the inside of the insulation housing caused by the PRT, a measurement technique that includes measurements for short periods of time (typically 5 min) needs to be applied. This measurement method will cause that the duration of the current passing through the reference sensor is minimal and the heating of the inside of the insulation housing can be neglected. Based on the performed testing, the authors suggest that an ideal time interval between measurements of temperature within the insulation housing is one hour after which a 5 min continuous measurement of temperature by a reference PRT follows. After this measurement time the current supply to the reference PRT is stopped until the next cycle. The measurement cycle intervals can be extended if there is no repeated increase or decrease in measured temperature by the reference PRT.

This recommendation is valid for the purpose of this study and alternations of used devices may result in different time interval of measurements.

3.1.4. Establishing the zero point

To be able to see the possible "overall self-heating" it is important to measure the temperature in the vicinity of the thermally insulated tested sensor before the current and voltage supply to the sensor is added. This initial measurement will determine the temperature of the equilibrium state (zero point) of the whole measurement setup (the reference PRT and tested sensor housed in an insulation container) and will furthermore give the indication when to start with the testing, by adding the power supply to the sensor under test. Measurements of the zero point should be done with the reference PRT in the same way as described in the previous section. The measurements done for the purpose of this study have been performed in one hour intervals for at least 4 hours. If there was no continuous increase or decrease of measured temperature within this time frame we can assume that the whole system is in stable temperature state and that the zero point has been determined. The typical value that is considered to represent a stable state (zero point) for the presented study is 0.02 °C or better (set limit is presented as a result of standard deviation). The results of zero point measurements can be seen in the following Figure 2.

Figure 2. A measurement example of the zero point stability.

3.1.5. Test measurements of the AWS sensors

After the successful preparatory steps mentioned in sections 3.1.1 to 3.1.4, the T & RH sensor testing can start. This means that the electric current and subsequently the voltage supply to the T & RH sensor can be applied. The level of the current and voltage supply should be selected taking into account the manufacturers recommendations (minimum and maximum levels). Furthermore, the current and voltage supply levels should be identical or as close as possible to the intended real field measurements in order to obtain relevant "overall self-heating" data. The current and voltage supply should work in the same mode as in the real field condition, which means the measuring intervals should be set identically. The reference PRT temperature measurement should start one hour after applying electric current and voltage supply to the tested T & RH sensor. As this time interval was assumed to be sufficiently long enough to see the initial change of temperature from the zero point value. For the presented study the temperature measurement interval with the reference PRT was 5 min and the intervals between these measurements was set for one hour.

3.1.6. Testing duration

The total duration of the test is not strictly defined, but if the measured temperature change after three successive measurements (after 3 hours) shows minimal or no significant change from the initial state then the "overall self-heating" is considered to be negligible. For the presented study the temperature change value under which the "overall self-heating" is considered to be negligible was 0.02 °C, as it is within the expanded measurement uncertainty of the experiments. If the temperature change would be higher, then we can assume that there is an “overall self-heating” effect and the measurement should continue. These measurements were and should be continue until the temperature difference stabilises on the same level and does not show a continuous increase or decrease after a period of three hours.

3.2. Results and findings

The results shown in this section were obtained using the measuring procedure described previously. The purpose of these results is mainly to show the measurement data that can be acquired by the presented method and as well to show the importance of conducting these measurements. As in different scenarios, for example like elevated current and voltage supplies can affect the level of heating produced by the sensors themselves and accompanying electronic within the sheared AWS housing. This effect can affect the measurements of temperature and therefore these undesired effects should be addressed.

A total of three sensors that were designed for the use in AWS temperature and humidity measurements have undergone the described testing procedure. The temperature measurement method used by these sensors was in all cases resistance measurements. The T & RH sensors parameters as their maximum and minimum voltage supply levels, electric current and measurement principles is listed in the Table 2.

Table 2. Tested sensor parameters.

The reference PRT sensor was placed along the body of the sensors under test with both thermometers ends position matching. The detailed parameters of the reference PRT are listed in Table 3. The material type (insulation foam) and thickness of the insulation (2.5 cm) was identical for each tested sensor and was selected based on several preparatory test measurements.

Table 3. Reference PRT sensor type parameters as declared by manufacturer.

The prepared insulation housing (containing the tested and reference sensor) was placed into a climatic camber with specific values of stability and homogeneity listed in uncertainty section 3.3. The climatic chamber was set to a temperature of -5 °C. This temperature was selected in order to achieve the best possible long-term stability and homogeneity of the used chamber.

The climatic chamber temperature stabilization was monitored and recorded by a calibrated PRT reference sensor within the chamber. The chamber was considered to be in stable state when the standard deviation of temperature did not exceed ± 0.04 °C over a period of 15 hours. This stable temperature condition was necessary for the measurement of temperature change within the insulation container.

When the chamber temperature stability was reached the initial measurements of temperature within the insulation container could begin. This was done with no active power supply to the T & RH sensor under test. This was done in order to determine the temperature zero point. Measurement cycles were done in one hour and later in two-hour intervals by same type of calibrated PRT reference sensor. The measurements time was set to a minimum period that was needed for sensor stabilization. For these specific measurement conditions, the continuous measurement time was set for 5 min. This measurement process was used in order to minimize the potential heating originating from the reference PRT sensor by the electric current supply during temperature measurement. Temperature zero point value was adopted from four successive (4 hours in total) measurements that have shown no significant increasing or decreasing trends. The standard deviation of these measurements was considered only if they did not exceed a value of 0.02 °C. A typical zero point values for the conducted tests are presented in Figure 3.

Figure 3. Temperature "zero point" measurement performed on tested sensors No. 1 – No. 3 by reference PRT. The temperature inside the insulation container has been measured after thermal stabilization of the test chamber and with no power supply to the sensors under test.

After establishing the zero point, only the current supply to the tested sensor was added. The electric current and voltage supplies used for individual tested sensor (No. 1 - No. 3) are presented in Table 2. The temperature change measurements inside the insulation container were separated by a two-hour interval after which a continuous 5 min recording of temperature was performed. The extension of time interval between measurement cycles to two-hours was done as this has shown to be sufficient for the "overall self-heating" determination and the initial one hour measurement intervals were too frequent and no significant change has been observed. The randomly occurring measurement gaps shown in Figure 4 were caused by restricted access to the measurement apparatus. These discontinuous recording did not have any effect on the testing as the temperature generated by climatic chamber and power supply to the tested sensors continued without any changes. The presented result in Figure 4 show the temperature difference in time; from the zero point for each tested sensor.

Figure 4. Temperature evolution in time measured by the reference PRT, shown as a difference from the "zero point" for tested sensors No. 1 to No. 3 only with current supply of 1mA. The temperature change measured indicates the change inside the insulation container.

Test results in Figure 4 shows the change in temperature inside the insulation container measured by the reference PRT from the initial level when the sensors were used without a voltage source to the accompanying electronics and with only 1 mA current supply to the temperature sensors. The maximum positive values of temperature increase after 66 hours were, 0.05 °C from sensor No. 1, 0.07 °C No. 2 and 0.07 °C for sensor No. 3. It is important to note that the overall spread of the data is up to ± 0.06 °C around the initially measured zero point. In conclusion we can state that no clear evidence is presented to state that the usage of 1 mA current results in self-heating surpassing the measurement maximum expanded uncertainty of 0.19 °C (k=2).

After these continuous measurements with 1 mA current supply an additional voltage supply was added to the sensor. The levels of the voltage were up to 80% of the maximum allowed values. Specific voltage levels applied are listed in Table 1. This test was intended to show if the voltage supply levels influences the temperature in the vicinity of temperature sensors.

The test procedure used during the increased voltage supply levels was identical to the previously conducted measurements. The previous measurements continued and the change concerned only the voltage supply levels. The results of these measurements are presented in Figure 5. The results show a temperature difference from the zero point.

Figure 5. Temperature change with time for each individual sensor No. 1-No. 3, shown as a difference from the zero point. The temperature change measured indicates the change inside the insulation container. (Power supply levels: No. 1: 23.86 V, No. 2: 20.31 V, No. 3: 20.44 V)

Measurement results shown in Figure 5 indicate a clear increase in temperature over the investigated time window of 70 hours. This increase can be assigned to the additional voltage supply levels, as this was the only parameter changed since the previous measuring conditions. The maximum temperature difference from zero point recorded after 70 hours since adding the voltage supply were: 0.26 °C, 0.34 °C and 0.32 °C for the sensor No.1 No. 2 and No. 3, respectively.

Temperature changes inside the insulation container presented in Figure 5 shows a link to the heating of the tested sensor by the additional electronic. As the whole T & RH sensors were thermally insulated and any generated heat from within this insulation housing heats primarily the enclosed area which is monitored by a calibrated PRT sensor. This means that any increase of temperature originating from the inside is measured before an interaction between the surrounding environment and the sensor under test happens.

The average increase of temperature within the insulation container for all of the tested sensors after exposure to 1 mA current supply is 0.07 °C after 66 hours with an expanded measurement uncertainty of 0.19 °C (k = 2). By contrast, the average temperature increase when using the 73 % and 80 % additional voltage levels was 0.30 °C after 70 hours with an expanded measurement uncertainty of

0.19 °C (k=2). It is important to note that the measured effects would be smaller than determined when ventilation of the sensors is enabled.

3.3. Measurement uncertainty

In order to deliver relevant and useful information to the users of T & RH sensors, it is mandatory to determine the uncertainty associated to the measurements here performed. This information will enable a clear evaluation of obtained data and possible "overall self-heating" of the sensors. List of influential factors included into the measurement uncertainty budget is given in Table 4, which crucial factors need to be accounted for.

Table 4. Uncertainty budget for the "overall self-heading" measurements.

As can be seen from the provided uncertainty budget the expanded uncertainty for the measurements here performed is 0.19 °C (k=2).

3.4. Including the "overall self-heating" values into measurement uncertainty budget.

The purpose of this study is to show a measurement procedure that can give the users of T & RH sensors guidance on how to determine the possible "overall self-heating" caused by the accompanying electronics and how to integrate the obtained values into the measurement uncertainty budget.

How to select and treat the raw measured values of "overall self-heating" have been presented in detail in section 3.2. This data shows the effect in two different scenarios, with a current supply of 1mA and with an additional voltage supply of 73 % up to 80 % of the maximum allowed levels. The resulting values give the user information about the temperature difference originating from the sensor itself. The obtained values need to be statistically treated with regards to the distribution on base of which the influential factor behaves. Based on the standard deviation, which indicates a stable nature of the effect, we have come to the conclusion that the "overall self-heating" of the sensors behaves according to the uniform or rectangular distribution (BIPM-JCGM - 100:2008, 2008). The standard deviation of the data was in the range from 0.02 °C up to 0.04 °C over a period of more than 142 hours. This is an indication of a uniform distribution of the effect during the measurement. Based on this information it is now possible to include these values into the measurement uncertainty budget. Furthermore, it is important that the tested sensor operate under the same conditions, in terms of current and voltage levels as a strong correlation has been observed between their values and measured sensor "overall self-heating". The examples of calculated uncertainty components from raw measured "overall self-heating" data is presented in Table 5.

Table 5. Examples of calculated uncertainty components originating from the tested sensors (No. 1, No. 2 and No. 3) "overall self-heating".

4. Conclusion

The intention of this publication is to provide the users of AWS, temperature and relative humidity sensors an insight of effects that originate from the current and voltage supply to the T & RH sensors with respect to the manufacturers maximum declared electric current and voltage values. Specifically effects that this study focused on is the “overall self-heating”. This term refers to an increase of temperature within the housing of the T & RH sensors in which all the measuring sensors are housed in. The study investigated heating originating not just from the resistance temperature sensor itself, but also from the accompanying electronics. Measurements with 1 mA current supply have shown a maximum temperature increase of 0.07 °C after 66 hours with an expanded measurement uncertainty of 0.19 °C (k=2). Adding a voltage supply up to 80 % of the maximum recommended levels resulted in a temperature increase in the vicinity of the temperature sensor. Specifically the temperature increases were after 70 hours of continuous voltage supply: 0.26 °C, 0.34 °C and 0.32 °C for the sensor No. 1, No. 2 and No. 3, respectively (the measurement uncertainty of these results was 0.19 °C (k=2)). These values indicate that the accompanying RH sensors and the corresponding electronics housed together with the temperature sensors generate heat by applying elevated voltage levels. Additional voltage supply heating within the AWS housing occurs even when respecting the manufacturers recommended levels. Based on these finding users of T & RH sensors should take into consideration using the lower limits of voltage supply declared by the manufacturer or alternatively minimise the time of exposure to the elevated voltage values. An evaluation of the phenomenon can also be made on existing instrumentation and applied back in time, to correct temperature data series. In this case an accurate uncertainty evaluation must be made, for including in the correction the appropriate uncertainty contributions. This work is part of the wider attempt to complete the uncertainty budget on near surface air temperature records, as requested both within the metrology community, expressed through the 2023-2027 roadmap of the Consultative committee for Thermometry of the BIPM[1], and by the climate science, as prescribed by the GCOS[2] in the creation of the Global Surface Reference Network (GSRN).

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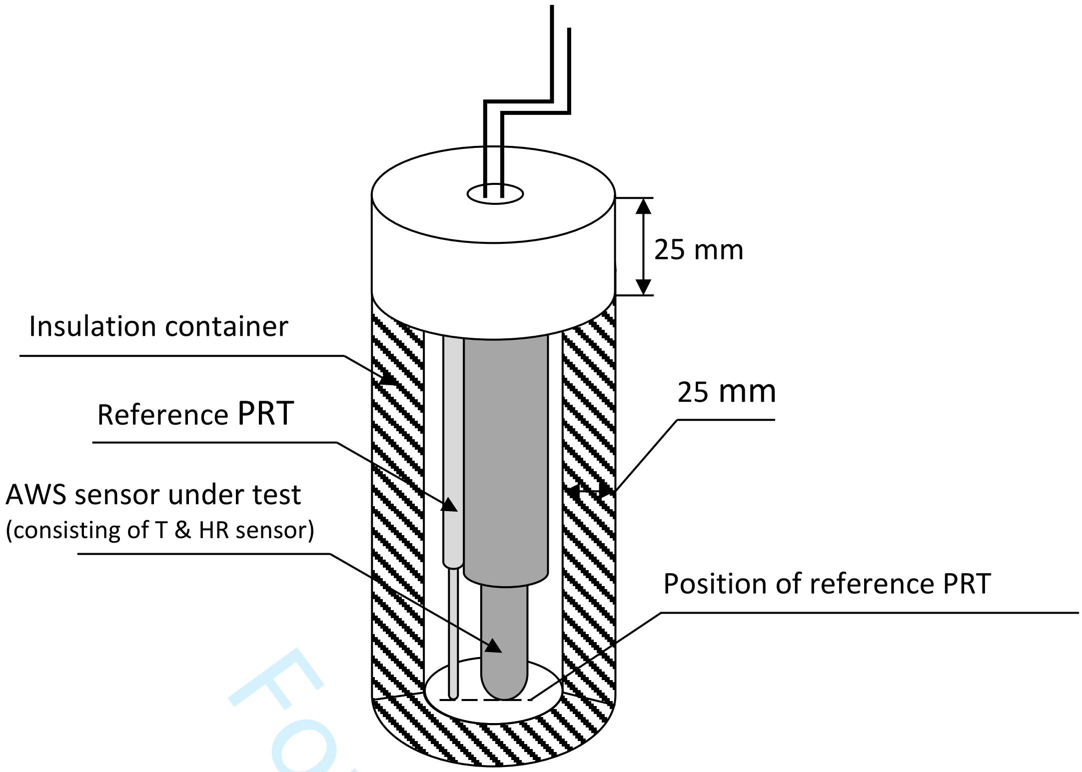


Figure 1. The insulation housing proportions together with the placement of the tested and reference senor.

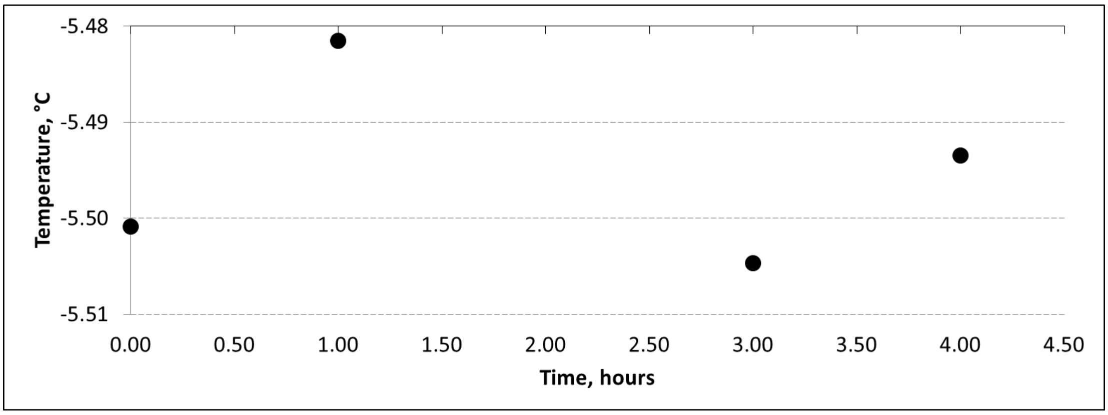
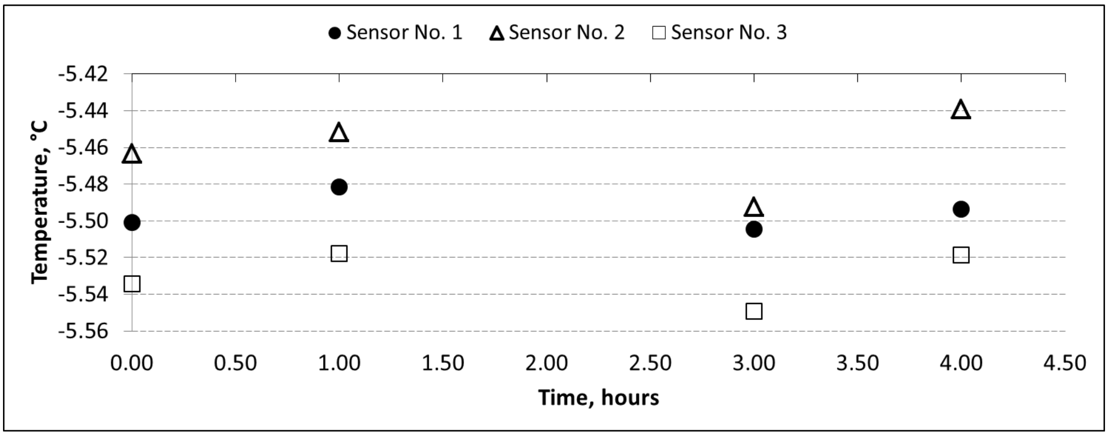


Figure 2. A measurement example of the zero point stability.



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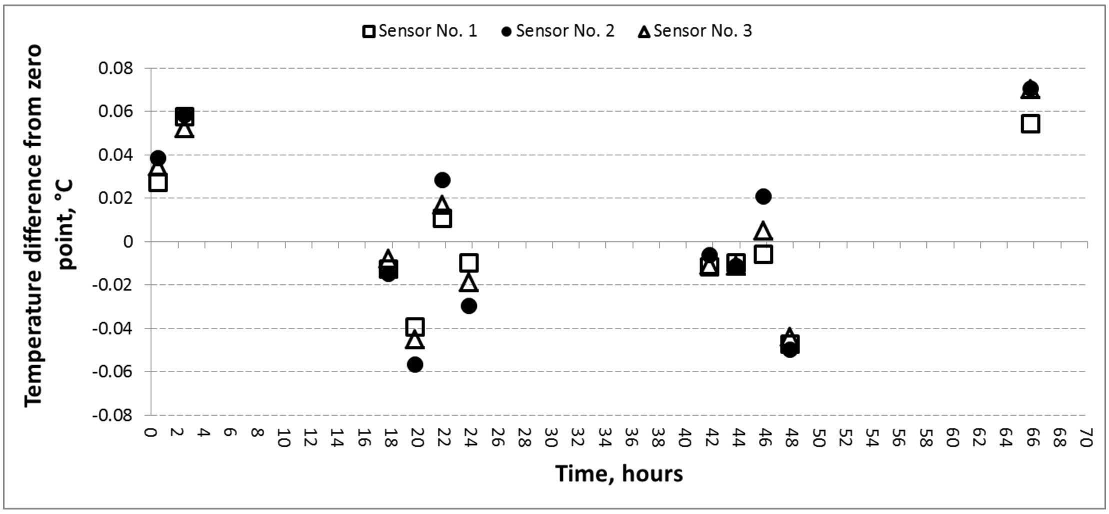

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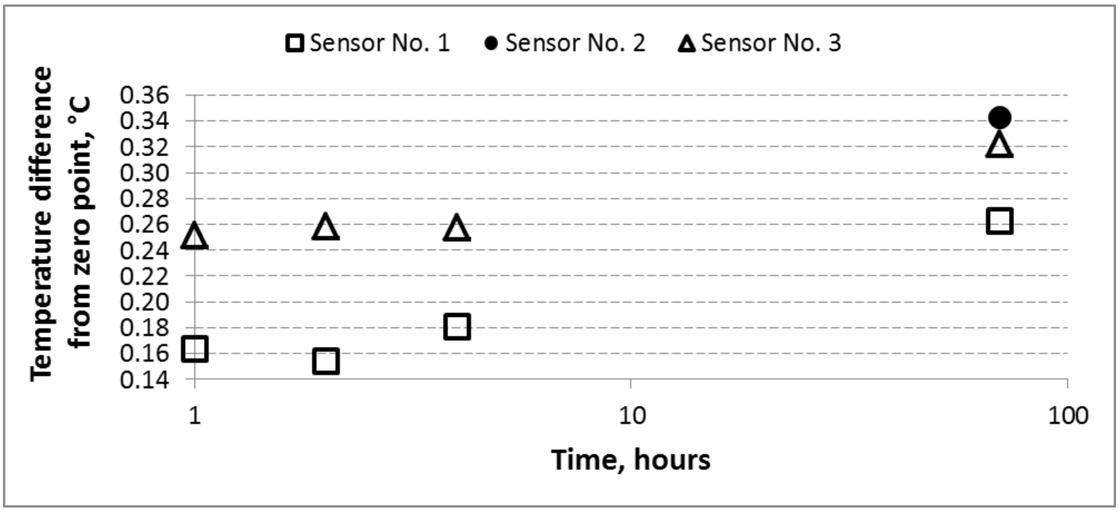

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Table 1. Tested thermometers self-heating errors.

Sensor	Surrounding temperature: 0 °C		Surrounding temperature: -40 °C	
	Supply current: 1 mA		Supply current: 1 mA	
	Self-heating error	Uncertainty (*k* = 2)	Self-heating error	Uncertainty (*k* = 2)
	°C	mK	°C	mK
No. 1	0.064	34	0.052	7.1
No. 2	0.055	4.6	0.042	32
No. 3	0.054	15	0.028	6.8

Table 2. Tested sensor parameters.

Sensor	Minimum voltage supply	Maximum voltage supply	Maximum voltage supply levels used during tests	Electric current supply
No. 1	6 VDC	30 VDC	80 % of max.	1 mA
No. 2	10 VDC	28 VDC	73 % of max.	1 mA
No. 3	7 VDC	28 VDC	73 % of max.	1 mA

Table 3. Reference PRT sensor type parameters as declared by manufacturer.

Parameter	Value
Temperature range	–200 °C to 300 °C
Nominal resistance at 0 °C	100 Ω ± 0.10 Ω
Sensor length	28 mm
Sheath dimensions	152 mm x 4.76 mm
Sheath material	Inconel™ 600
Short-term repeatability	±0.009 °C at 0.010 °C
Drift	±0.007 °C at 0.010 °C
Accuracy	±0.024 °C at –200 °C ±0.012 °C at 0 °C ±0.035 °C at 420 °C

Table 4. Uncertainty budget for the "overall self-heading" measurements.

Source	**Value (°C)**	**Distribution**	**Value with included distribution (°C)**
Test chamber stability	0.067	Rectangular	0.039
Test chamber homogeneity	0.084	Rectangular	0.05
Reference PRT calibration uncertainty	0.02	Normal	0.01
Measuring device uncertainty (DC resistance bridge)	0.0002	Normal	0.0001
Reproducibility of measurement	0.12	Rectangular	0.069
Resulting expanded uncertainty (*k* = 2)			**0.19 °C**

Table 5. Examples of calculated uncertainty components originating from the tested sensors (No. 1, No. 2 and No. 3) "overall self-heating".

	Sensor		
	No. 1	**No. 2**	**No. 3**
Measured raw value with 1 mA current supply	0.06 °C	0.07 °C	0.07 °C
Resulting measurement uncertainty contribution with 1 mA power supply, considering rectangular distribution ($\sqrt{3}$).	0.03 °C	0.04 °C	0.04 °C
Increase voltage supply levels from minimum value	80 %	73 %	73 %
Measured raw value with additional voltage supply levels	0.26 °C	0.34 °C	0.32 °C
Resulting measurement uncertainty contribution with additional voltage supply levels, considering rectangular distribution ($\sqrt{3}$).	0.15 °C	0.19 °C	0.23 °C

Determination of automatic weather station self-heating originating from accompanying electronics

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This paper focuses on the most commonly used temperature sensors within automatic weather stations, with a specific focus on evaluating the self-heating effect, which originates not only from the temperature sensor itself, but also from the electrical components housed together within. The results of overall self-heating indicated a 0.07 °C increase in temperature for the tested sensors when using the manufacturers minimum recommended electric current supply. The usage of elevated voltage levels up to 80% of recommended values shows a temperature increase high as 0.32 °C.