Received: 30 August 2018 | Revised: 15 August 2019 | Accepted: 9 September 2019 | Published on: 13 November 2019

DOI: 10.1002/met.1844

RESEARCH ARTICLE

Meteorological Applications RMetS

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

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**Funding information**
European Metrology Research Programme (EMRP), Grant/Award Number: ENV58 "METEOMET"; Kultúrna a edukačná grantová agentúra MŠVVaŠ SR (KEGA), Grant/Award Numbers: KEGA039STU-4/2017, KEGA014STU-4/2015; Slovak Research and Development Agency (APVV), Grant/Award Numbers: APVV-15-0164, APVV-15-0704, APVV 15-0295; Vedecká grantová agentúra MŠVVaŠ SR a SAV (VEGA), Grant/Award Numbers: VEGA 1/0748/15, VEGA 1/0164/15, VEGA 1-0610-17

**Abstract**

Atmospheric air temperature values are fundamental in meteorology and climate studies. To achieve high accuracy in the measurements, the features, characteristics and performances of instruments are of high importance. This study focuses on the most commonly used temperature sensors within automatic weather stations, with a specific focus on evaluating the self-heating effect. Self-heating in automatic weather stations 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. The conducted measurements show the temperature change in the close vicinity of the thermometers over a time period of more than 66 hr with electric current and voltage supply values recommended by the respective sensor manufacturers. Furthermore, the temperature changes after increasing the voltage supply levels up to 80% of the maximum voltage recommended by the manufacturer are 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 use of elevated voltage levels shows a considerably higher temperature increase in the vicinity of the temperature sensors. In the present study, the measured difference from the initial measured temperature can be as high as +0.32°C.

**KEYWORDS**

automatic weather stations, self-heating, temperature sensors

## 1 | INTRODUCTION

Precise and reliable measurements of key meteorological quantities such as 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 characterization, 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 characterized, 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 measurement devices and sensors themselves. This study focuses mainly on the factors that are connected with the overall self-heating effect that occurs within the housing of the automatic weather station (AWS). The work has been done 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 AWSs today measure air temperature using a 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 and 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 the resistance element by the passing current, which can result in an artificial and undesired increase of the 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 and Sukkar, 2014; Sestan and Grgec-bermanec, 2017). Further details of the effect are presented in following sections. Most of the AWS thermometers that are used today house together multiple sensors in a compact space (most commonly humidity sensors). The voltage levels supplied to these temperature and relative humidity (T & RH) sensors have a potential effect on the increase in temperature within the AWS sensor housing. This can cause an artificial increase in 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 AWSs

PRTs are widely used in AWSs. The measurement of temperature with this type of thermometer necessarily implies resistance measurements, entailing the passage of an electric current through the thermometer's sensing element. The resistance of the thermometer is then calculated by observing the generated voltage and using Ohm's law. The electric 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. The self-heating error associated with the resistance thermometer sited in each of the T & RH sensors included in this study was evaluated by García Izquierdo *et al*. (2017), following the procedure described there.

The self-heating error is determined by extrapolating, to zero current, resistance values measured with different electric currents applied in the sensing element, whilst the thermometer is at a stable temperature.

The extrapolated resistance value, to zero current, can be calculated by two methods. In the so-called two-current method, the thermometer resistance is measured at two different currents:

$$R_0 = \frac{I_2^2 R_1 - I_1^2 R_2}{I_2^2 - I_1^2} \tag{1}$$

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

$$R_t = R_0 + aI^2 \tag{2}$$

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

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 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°C.

## 3 | INFLUENCE OF ELECTRONICS WITHIN THE AWS ON AIR TEMPERATURE MEASUREMENTS

Previous research on self-heating in PRTs (which are the most commonly used type of sensors in AWSs) has shown a relatively small effect peaking at 0.064°C when used with 1 mA current supply. Based on these findings a further investigation was 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.

**TABLE 1** Self-heating errors of the tested thermometers

| Sensor | Surrounding temperature 0°C<br>Supply current 1 mA<br>Self-heating error °C | Uncertainty ($k = 2$) mK | Surrounding temperature −40°C<br>Supply current 1 mA<br>Self-heating error °C | Uncertainty ($k = 2$) 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 |

## 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 electronics housed within the measurement unit. This procedure was developed to give guidance on how to measure the influence of electronics associated with the humidity sensor on the readings of the associated thermometer housed within the 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, they need to be thermally isolated from the environment that the sensor is going to be exposed to. This is done in order to identify the heating effect originating only from the T & RH sensor electronics. It can be done by covering the tested sensor's body with an insulation material (Class 0 Armaflex plus was used in this study; Armacell, Maharashtra, India) that will minimize 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 with a reference thermometer (calibrated in the ideal case) housed together with the tested T & RH sensor. The slower the change in temperature (from a stable state to a randomly selected temperature value) visible by the reference sensor, the better the insulation is. As there are multiple variations and thicknesses of insulation material it should be mentioned that the effort of achieving the longest reaction time should be limited. It is considered that a reaction time of 10 min or more to a random temperature change is 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 in this study was interlaced foam based on synthetic rubber with a low conductivity $\lambda$ 0°C ≤ 0.033 (at 0°C).

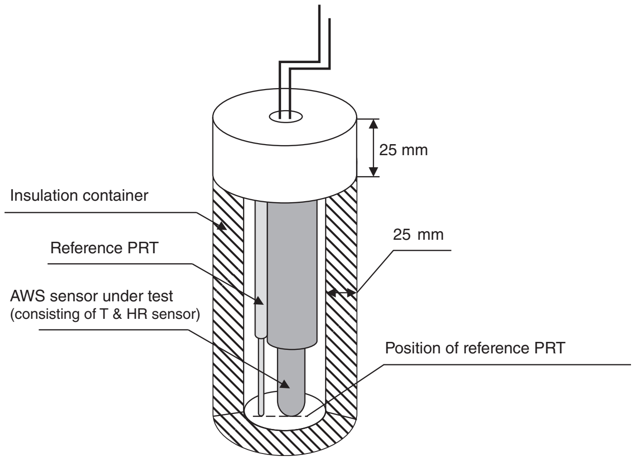


**FIGURE 1** The insulation housing proportions together with the placement of the tested and reference sensor

### 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 proved 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 a 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 measurements by the calibrated PRT sensors were done continuously until a stable or repeating temperature behaviour was observed. A thermally stable environment for the purpose of overall self-heating testing is considered to be an environment that does not exceed ±0.04°C after a period of 1 hr at a given temperature of testing.

The same reference thermometer requirements should be applied for the temperature homogeneity determination. These measurements are 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 a minimum of three sensors is recommended. These sensors should be placed in several positions of the testing area on a vertical axis. The measuring points should be positioned on the bottom and top of the area and in at least one point in-between. This specific procedure was used in the present study. Subsequently the gathered data were statistically analysed by means of a standard deviation calculation and associated with 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 to or smaller than 0.02°C ($k = 2$) needs to be inserted into the near vicinity of the 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 the duration of the current passing through the reference sensor to be minimal and the heating of the inside of the insulation housing can be neglected. Based on the testing, it is suggested that an ideal time interval between measurements of temperature within the insulation housing is 1 hr 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 alterations of used devices may result in different time intervals 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 an indication of when to start 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 were performed in 1 hr intervals for at least 4 hr. If there was no continuous increase or decrease of the measured temperature within this time frame it can be assumed that the whole system is in a 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 present 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 Figure 2.

### 3.1.5 | Test measurements of the AWS sensors

After the successful preparatory steps mentioned in Sections 3.1.1–3.1.4, 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,

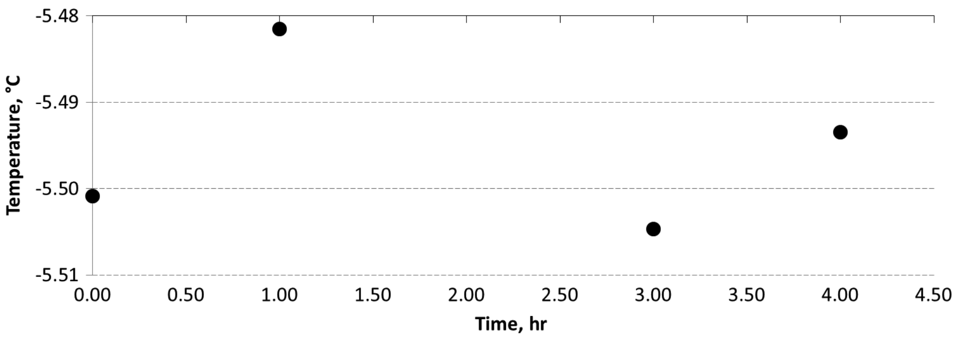


**FIGURE 2** A measurement example of the zero point stability

which means that the measuring intervals should be set identically. The reference PRT temperature measurement should start 1 hr after applying the electric current and voltage supply to the tested T & RH sensor as this time interval was assumed to be sufficiently long to see the initial change in temperature from the zero point value. For the present study the temperature measurement interval with the reference PRT was 5 min and the intervals between these measurements was set for 1 hr.

### 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 hr) shows minimal or no significant change from the initial state then the overall self-heating is considered to be negligible. For the present study the temperature change 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 is higher, then it can be assumed that there is an overall self-heating effect and the measurement should continue. These measurements were and should be continued until the temperature difference stabilizes on the same level and does not show a continuous increase or decrease after a period of 3 hr.

## 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 present method and to show the importance of conducting these measurements. Different scenarios, e.g. elevated current and voltage supplies, can affect the level of heating produced by the sensors themselves and the accompanying electronics within the shared AWS housing. This can affect the measurements of temperature and therefore these undesired effects should be addressed.

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

The reference PRT sensor was placed along the body of the sensors under test with both thermometer ends matched in position. 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 on the basis of several preparatory test measurements.

The prepared insulation housing (containing the tested and reference sensor) was placed in a climatic chamber with specific values of stability and homogeneity listed in Table 4. 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 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 a stable state when the standard deviation of temperature did not exceed ±0.04°C over a period of 15 hr. This stable temperature condition was necessary for measurement of the 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

**TABLE 3** Reference platinum resistance thermometer sensor type parameters as declared by the manufacturer

| Parameter | Value |
|---|---|
| Temperature range | −200 to 300°C |
| Nominal resistance at 0°C | 100 Ω ± 0.10 Ω |
| Sensor length | 28 mm |
| Sheath dimensions | 152 mm × 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<br>±0.012°C at 0°C<br>±0.035°C at 420°C |

**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 4** Uncertainty budget for the overall self-heating 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 |

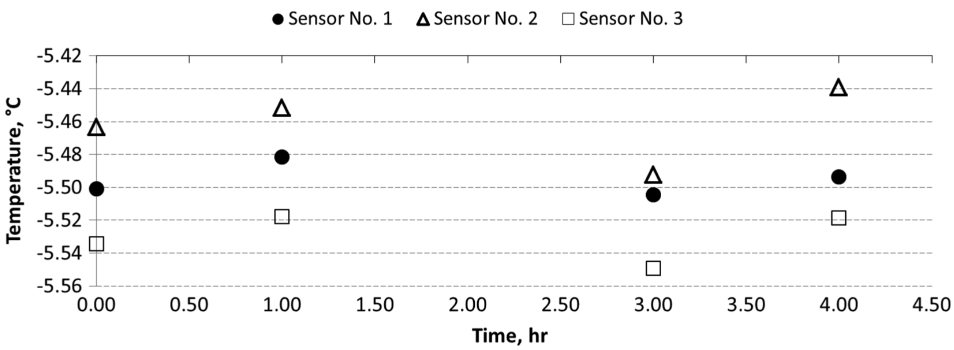


**FIGURE 3** Temperature "zero point" measurement performed on tested sensors 1–3 by the reference platinum resistance thermometer. The temperature inside the insulation container was measured after thermal stabilization of the test chamber and with no power supply to the sensors under test

supply to the T & RH sensor under test in order to determine the temperature zero point. Measurement cycles were done in 1 hr and later 2 hr intervals by the same type of calibrated PRT reference sensor. The measurement time was set to the 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. The temperature zero point value was adopted from four successive (4 hr in total) measurements that showed 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. Typical zero point values for the conducted tests are presented in Figure 3.

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

The test results in Figure 4 show 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 hr were 0.05°C from sensor 1, 0.07°C from sensor 2 and 0.07°C for sensor 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 it can be stated that no clear evidence that the use of 1 mA current results in self-heating surpassing the measurement maximum expanded uncertainty of 0.19°C ($k$ = 2) is presented.

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 2. This test was intended to show whether the voltage supply levels influence the temperature in the vicinity of the 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

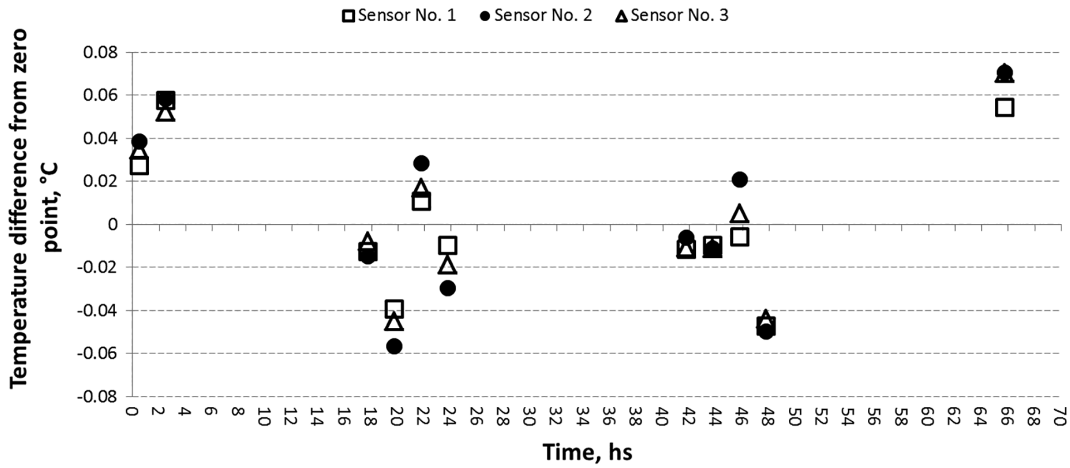


**FIGURE 4** Temperature evolution in time measured by the reference platinum resistance thermometer, shown as a difference from the "zero point" for tested sensors 1–3 only with a current supply of 1 mA. The temperature change measured indicates the change inside the insulation container

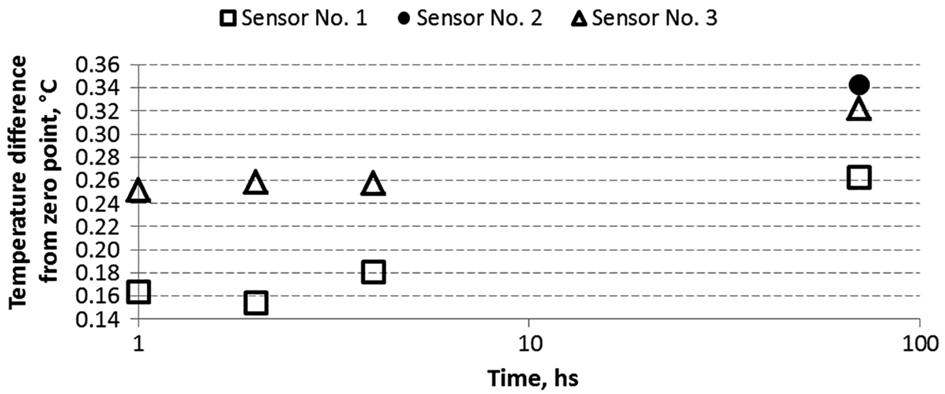


**FIGURE 5** Temperature change with time for each individual sensor 1–3, shown as a difference from the zero point. The temperature change measured indicates the change inside the insulation container (power supply levels: no. 1, 23.86 V; no. 2, 20.31 V; no. 3, 20.44 V)

of these measurements are presented in Figure 5 and show a temperature difference from the zero point.

The measurement results shown in Figure 5 indicate a clear increase in temperature over the investigated time window of 70 hr. 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 the zero point recorded after 70 hr since adding the voltage supply were 0.26, 0.34 and 0.32°C for sensors 1, 2 and 3, respectively.

Temperature changes inside the insulation container presented in Figure 5 show a link to the heating of the tested sensor by the additional electronics. The whole of the T & RH sensors was 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 in temperature originating from the inside is measured before an interaction between the surrounding environment and the sensor under test happens.

The average increase in temperature within the insulation container for all of the tested sensors after exposure to 1 mA current supply is 0.07°C after 66 hr 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 hr with an expanded measurement uncertainty of 0.19°C ($k = 2$). It is important to note that the measured effects would be smaller than those 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 with the measurements performed here. This information will enable a clear evaluation of the obtained data and possible overall self-heating of the sensors. A list of influential factors included in the measurement uncertainty budget is given in Table 4, which gives the crucial factors that need to be accounted for.

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

**TABLE 5** Examples of calculated uncertainty components originating from the tested sensors (nos. 1, 2 and 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 |

### 3.4 | Including the overall self-heating values into the measurement uncertainty budget

The purpose of this study was 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 values obtained into the measurement uncertainty budget.

How to select and treat the raw measured values of overall self-heating has been presented in detail in Section 3.2. These data show the effect in two different scenarios, with a current supply of 1 mA 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 regard to the distribution on the basis of which the influential factor behaves. Based on the standard deviation, which indicates the stable nature of the effect, it is concluded that the overall self-heating of the sensors behaves according to a uniform or rectangular distribution (BIPM-JCGM – 100:2008, 2008). The standard deviation of the data was in the range from 0.02 up to 0.04°C over a period of more than 142 hr. This is an indication of the 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 operates under the same conditions, in terms of current and voltage levels, as a strong correlation has been observed between their values and the measured sensor overall self-heating. Examples of calculated uncertainty components from raw measured overall self-heating data are presented in Table 5.

## 4 | CONCLUSION

The intention of this study was to provide the users of automatic weather station (AWS) temperature and relative humidity (T & RH) sensors an insight into 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 the effect that this study focused on was the overall self-heating. This term refers to the increase in temperature within the housing of the T & RH sensors in which all the measuring sensors are housed. 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 hr 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 after 70 hr of continuous voltage supply were 0.26, 0.34 and 0.32°C for sensors 1, 2 and 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 on applying elevated voltage levels. Additional voltage supply heating within the AWS housing occurs even when the manufacturers' recommended levels are respected. Based on these findings users of T & RH sensors should consider using the lower limits of voltage supply declared by the manufacturer or alternatively minimize the time of exposure to 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, including in the correction the appropriate uncertainty contributions. This work is part of a 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 Bureau International des Poids et Mesures (BIPM),[1] and by climate science, as prescribed by the Global Climate

Observing System (GCOS)[2] in the creation of the Global Surface Reference Network (GSRN).

## ACKNOWLEDGEMENTS

This work is being developed within the framework of the European Metrology Research Programme (EMRP) joint research project ENV58 "MeteoMet". The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union. The authors would like to thank the Slovak University of Technology in Bratislava and the Slovak Institute of Metrology, the grant agency VEGA (project numbers VEGA 1/0748/15, VEGA 1/0164/15, VEGA 1-0610-17), the agency APVV (project number APVV-15-0164, APVV-15-0704, APVV 15-0295) and the agency KEGA (project numbers KEGA039STU-4/2017, KEGA014STU-4/2015) for their support.

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## ENDNOTES

[1] xxx.

[2] xxx.

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**How to cite this article:** Pavlasek P, Merlone A, Sanna F, *et al.* Determination of automatic weather station self-heating originating from accompanying electronics. *Meteorol Appl*. 2020;27:e1844. https://doi.org/10.1002/met.1844