Penerbit Akademia Baru

Journal of Advanced Research Design

Journal homepage:
https://akademiabaru.com/submit/index.php/ard
ISSN: 2289-7984

Temperature Effect in the Calibration of NIS Reference Humidity Sensors Using a Two-pressure Humidity Generator

Doaa Mohamed Abd El-Galil[1,*], Ahmed El-Matarawey[1], Essam Mahmoud[1]

[1] Thermal metrology laboratory, National Institute of Standards, Egypt

ARTICLE INFO

Article history:
Received 7 July 2024
Received in revised form 14 November 2024
Accepted 20 December 2024
Available online 31 December 2024

Keywords:
Temperature effect; humidity sensor; two-pressure humidity generator; calibration; correlation

ABSTRACT

Humidity sensors play a vital role in massive production technology and are widely used in industrial processes, medical facilities, museums, agricultural settings, food preservation, meteorology, etc. This paper describes the study of the effect of temperature on different humidity sensors used in practice. The analysis and findings of a study on the role of temperature in the calibration of humidity sensors are presented in this paper using a two-pressure humidity generator (2-P). Relative humidity measurements were performed at different humidity levels: 10, 30, 50 and 80 %. The temperature was adjusted at different setpoints: 25, 35, 45 and 55 °C. The data and associations were assessed using pythonic statistical software. The results show that humidity correction is contingent on the temperature and device used when considering certain conditions. The calibration correction is independent of the temperature for temperatures ranging from 25 to 35 °C, but the calibration correction is strongly dependent on the temperature for conditions above 35 °C in the range from 30 to 80 % relative humidity. The effect of temperature on the calibration of seven hygrometer models was evaluated using the humidity standard in the thermal metrology laboratory at the National Institute for Standards. The results showed that there is a strong correlation between temperature and humidity. The difference in the humidity correction factor shown from the results in this paper was applied during the calibration processes to ensure accuracy and improve measurements in the thermal metrology laboratory at the National Institute for Standards.

1. Introduction

Advancement of humidity standards is the primary objective of the thermal metrology laboratory at the National Institute for Standards (NIS) in Egypt. The NIS also offers services for calibrating all kinds of humidity sensors uniformly and accurately both inside and outside of Egypt. The thermal metrology facility at the NIS has created a number of hygrometer calibration facilities.

To ensure their accuracy and performance, hygrometers that detect temperature and humidity should be calibrated on a regular basis [1]. Calibration ensures that measurements taken with these tools are precise so that product quality can be preserved according to the requirements for the

[*] *Corresponding author.*
E-mail address: m.dody74@yahoo.com

https://doi.org/10.37934/ard.123.1.18

Competence of Testing and Calibration Laboratories ISO/IEC 17025:2017 [2]. When we take medication, ride in an aerial plane, consume food, use chemicals or carry out other routine tasks, we presume that the tools and methods we employ are secure and efficient [3]. However, there are rules to guarantee the standard of the goods and procedures produced by sectors such as pharmaceuticals, semiconductors, chemicals, aerospace and food processing. These regulations generally call for routine measurements of a variety of variables, including humidity and temperature. Calibration is used to ensure that the measurements are precise [4].

To most accurately calibrate a hygrometer or other humidity sensors efficiently, humidity must be generated and measured at a variety of temperatures and humidity levels using a humidity generator. Then, the measurements are compared with the measurements of the device under test (DUT). The difference between the two measurements was calculated by correcting the DUT measurements [5-7].

The reliance of these devices on temperature is one of their drawbacks. The performance of the sensor is inaccurate due to temperature variation. This paper attempts to determine how temperature affects various humidity sensors used in daily life. Python software was used to assess the data, investigate the degree of significance of the temperature effect and evaluate the correlation for each sensor.

2. Methodology

To determine the effect of temperature on humidity, we studied seven different sensors using a (2-P) generator. The temperature effect of the sensor was studied at different temperatures while keeping the humidity constant. The temperature of the chamber was 25, 35, 45 or 55 °C, and the uncertainty was ± 0.3 C. The humidity level in the generator was varied at 10, 30, 50 and 80 % RH, with a measurement uncertainty of ± 0.9 % [8-12].

To observe the temperature effect, the humidity was kept constant and the temperature of the chamber was varied from 25 to 55 °C. Measurements were performed under the following conditions:

The laboratory's ambient conditions were set at 25 °C ± 2 °C and 50 % ± 10 % relative humidity. The humidity generator was set to a 20 L/h flow rate to initiate the measuring system, which was stabilized after 30 minutes. The measurements were carried out at four relative humidity points of calibration (10, 30, 50 and 80 %) in the temperature range from 25 to 55 °C, increasing by +10 °C (i.e., 25, 35, 45 and 55 °C).

First, the (2-P) generator was adjusted to a relative humidity of 10 % for temperatures of 25, 35, 45 and 55 °C. The data from the seven humidity sensors were taken at 25 °C for 4 h once the (2-P) generator was stable. This step was subsequently repeated at 35, 45 and 55 °C. The process was repeated for the other humidity levels of 30, 50 and 80 %. The results are the average for each setpoint.

3. Results

The correction is determined as the difference between the (2-P) generator and the humidity sensors as shown in Eq. (1).

$$\text{Correction} = H_{ref} - H_{dut} \quad (1)$$

Where, H_{ref} : Humidity of the reference generator and H_{dut}: Humidity of the device under test. The sensor specifications (range, accuracy and probe location) are shown in Table 1.

Table 1
Specification of the sensors

Device code	Range % RH	Accuracy	Probe location
D 1	0-100	± 1.5 % RH (0 to 90 % RH)	External
D 2	0-100	± 1.5 % RH (0 to 90 % RH)	External
D 3	5-95	± 1.8 % RH	External
D 4	0-100	± 0.8 % RH (10 to 60 % RH) ± 1.3 % RH (60 to 100 % RH)	Internal
D 5	0-100	± 2 % RH (2 to 98 % RH)	External
D 6	0-100	± 2.5 % RH (5 to 95 % RH)	External
D 7	0-100	± 0.8 % RH	External

The effect plots for the seven humidity sensors are shown in Figures 1 to 7.

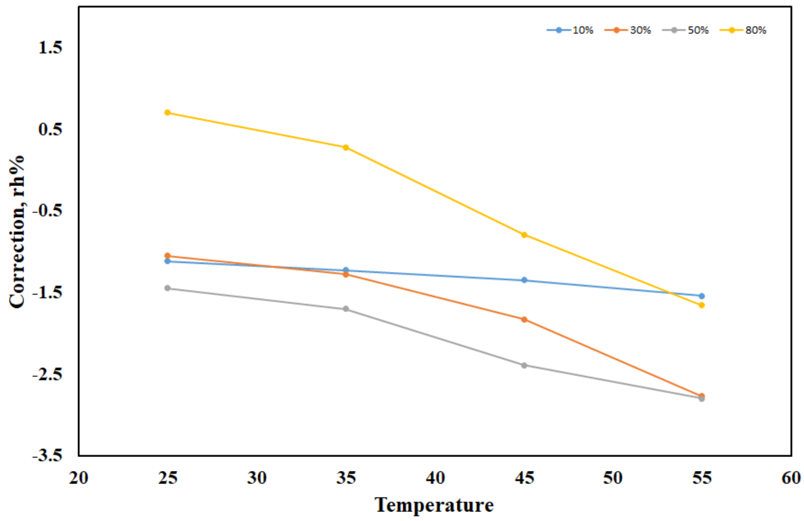

Fig. 1. Temperature effect for device 1 at different humidity levels

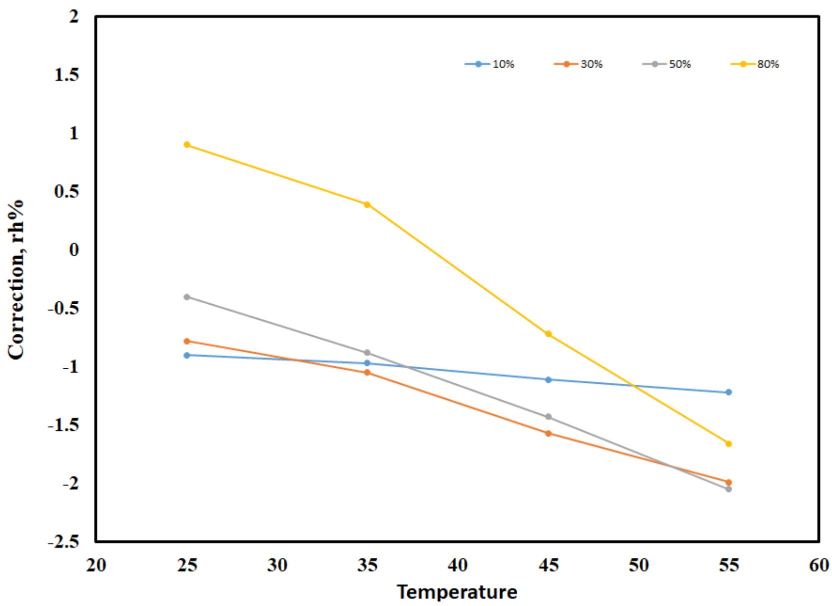

Fig. 2. Effect of temperature on device 2 at different humidity levels

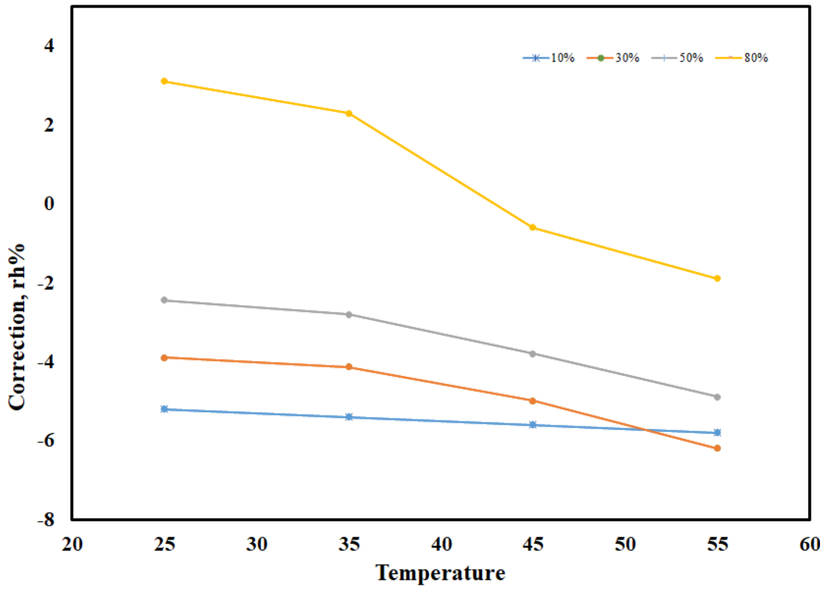

Fig. 3. Effect of temperature on device 3 at different humidity levels

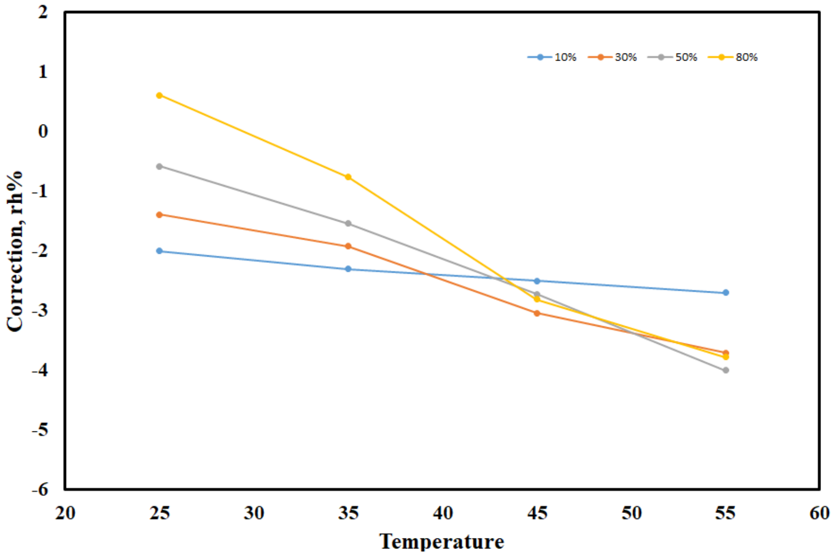

Fig. 4. Effect of temperature on device 4 at different humidity levels

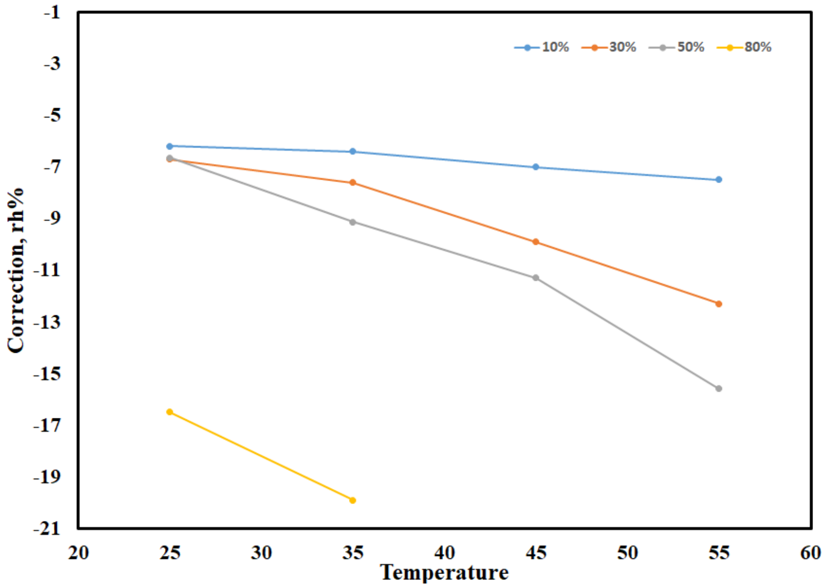

Fig. 5. Effect of temperature on device 5 at different humidity levels

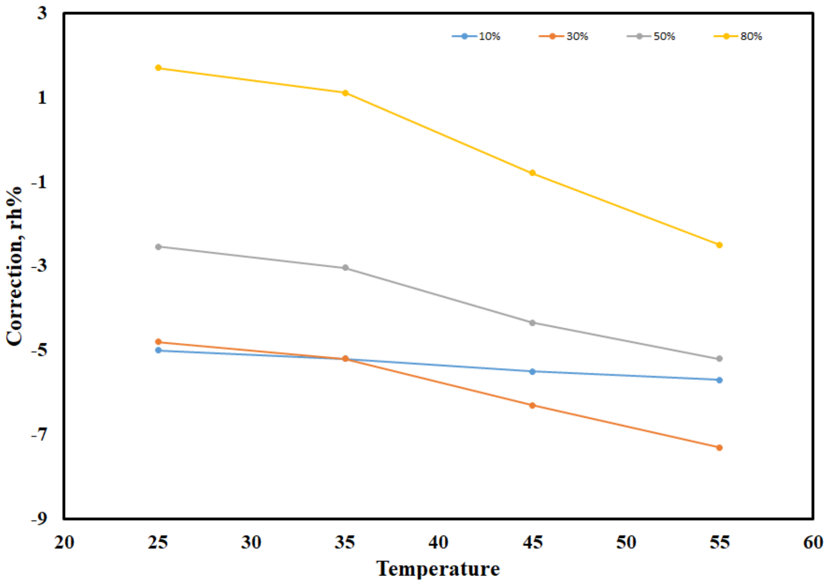

Fig. 6. Effect of temperature on device 6 at different humidity levels

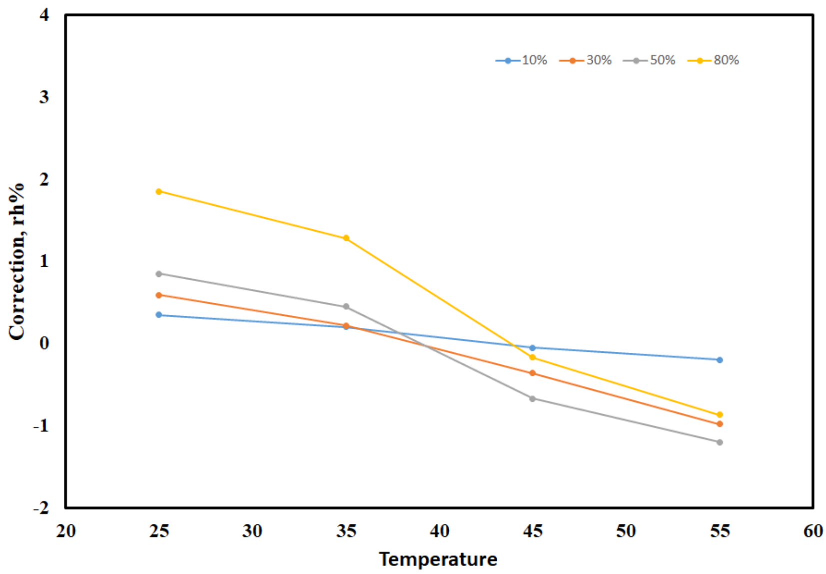

Fig. 7. Effect of temperature on device 7 at different humidity levels

Table 2
Results obtained using Python statistical software

Parameter	sum_sq	Degree of freedom	*p*-value
Humidity level	4.779	3.0	$8.026*10^{-1}$
Device	1343.258	6.0	$5.52*10^{-26}$
Temperature	50.1968	3.0	$1.313*10^{-11}$
Humidity level: device	1717.5599	27.0	$1.162*10^{-50}$
Humidity level: temperature	58.9887	15.0	$6.27*10^{-1}$
Device: temperature	1427.4237	27.0	$2.07*10^{-17}$

Correlation is a statistical measure that expresses the extent to which two variables are linearly related and the degree to which two variables move in relation to each other. The correlation coefficient shows the strength of the link and its direction (direct or inverse) for each device to determine whether a relationship between temperature and humidity occurs for temperatures between 25 and 55 °C and for humidity's between 10 and 80 % of the rh. Figure 8 shows an example at 80 % relative humidity. The results showed that there was a strong correlation between temperature and humidity.

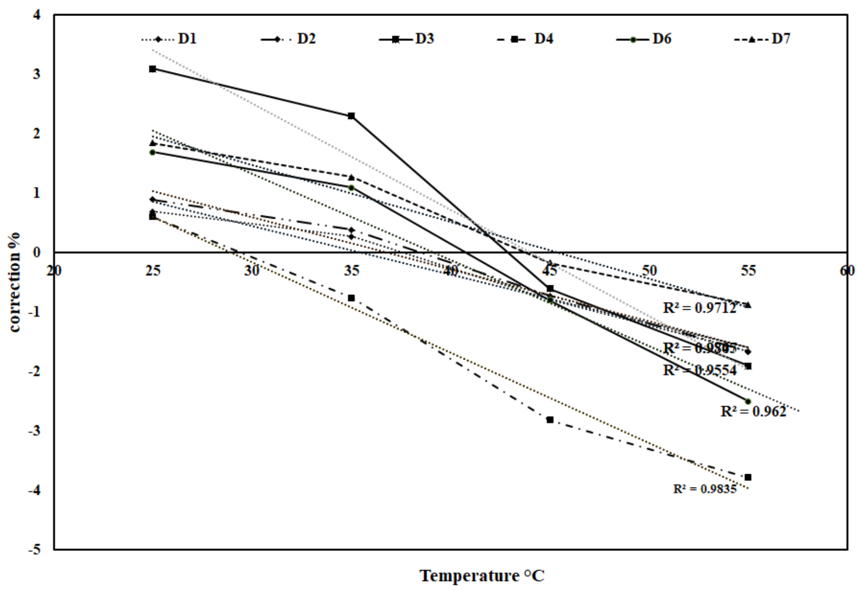

Fig. 8. The correlation coefficient (R2) at 80 %

Table 3 shows the calculation of the coefficient of determination, $R^{2,}$ for the devices under test.

Table 3
Correlation between temperature and humidity

Device Code	@ 10 % rh	@ 30 % rh	@ 50 % rh	@ 80 % rh
D 1	0.99	0.98	0.99	0.98
D 2	0.99	0.99	0.98	0.98
D 3	0.99	0.99	0.98	0.98
D 4	0.99	0.98	0.99	0.98
D 6	0.99	0.97	0.98	0.96
D 7	0.99	0.99	0.95	0.97

4. Discussion

Figures 1-7 show that the device and humidity strongly affect the calibration correction, which is predictable based on the specifications in Table 1. As seen, there is not much difference in the calibration correction between the 25 and 35 °C plots, meaning that the temperature is not a significant factor in this temperature range. Additionally, temperature is not a significant factor at a humidity level of 10 %, and there is not much difference in the calibration correction at different temperatures. However, above 35 °C, the calibration correction increases by increasing the temperature in the range from 30 to 80 % relative humidity, meaning that the temperature is a significant factor in this range [13-15].

As shown in Table 2, we used pythonic statistical software to determine whether the effect of temperature was significant. A null hypothesis was considered that neither the difference between the variance between groups (σ_1^2.= σ_2^2.=…) nor the temperature effect existed. The alternative hypothesis is considered to be that there is a difference between variances within groups (σ_1^2.≠ σ_2^2.≠…) or that a temperature effect occurs. A p value less than 0.05, which indicates that the results of three-way ANOVA using Python software are typically considered to be statistically significant, in which case the null hypothesis should be rejected. The temperature has a significant effect on the relative humidity shows that the humidity level, device and temperature interactions are significant. As shown in Figure 8 and Table 3, there is a strong correlation between temperature and humidity.

5. Conclusions

The effect of temperature on the calibration of the seven hygrometer models was evaluated using the humidity standard established in the thermal metrology laboratory at the NIS in Egypt at 25, 35, 45 and 55 °C for humidity's of 10, 30, 50 and 80 %, respectively. The results showed that humidity correction is contingent on the temperature and device used when considering certain conditions. According to the results, the calibration correction is independent of the temperature for temperatures ranging from 25 to 35 °C, but the calibration correction is strongly dependent on the temperature for conditions above 35 °C, for which there is a strong correlation between the temperature and humidity. The difference in the correction that appeared from the results in this paper was applied during the calibration processes in the thermal metrology laboratory at the National Institute for Standards to ensure accuracy and improve measurements.

References

[1] Islam, Tarikul, Zaheer Uddin, and Amit Gangopadhyay. "Temperature effect on capacitive humidity sensors and its compensation using artificial neural networks." *Sensors & Transducers* 191, no. 8 (2015): 126.

[2] ISO/IEC 17025:2005, General Requirements for the Competence of Testing and Calibration Laboratories, 2005.

[3] Abd El-Galil, Doaa Mohamed, and Essam Mahmoud. "NIS two-pressure humidity generator." *International Journal of Metrology and Quality Engineering* 7, no. 3 (2016): 303. https://doi.org/10.1051/ijmqe/2016012

[4] Fernicola, Vito, Mauro Banfo, Lucia Rosso, and Denis Smorgon. "Investigation of capacitive-based relative humidity sensors and their stability at high temperature." *International Journal of Thermophysics* 29 (2008): 1668-1677. https://doi.org/10.1007/s10765-008-0457-2

[5] Abd El Galil, Doaa M., A. El-Matarawey, and Essam Mahmoud. "The effect of temperature on NIS reference humidity sensor calibration."

[6] BIPM IEC IFCC ILAC IUPAC OIML, Guide to the expression of uncertainty in measurement, JCGM 100:2008 (GUM), 2008. Available at http//www.bipm.org/ [Google Scholar]

[7] El-Matarawey, A., Doaa M. Abd-ElGalil, and Eman M. El-Dien. "Testing the reliability of new developed firmware for controlling NIS climatic chamber." *Measurement* 199 (2022): 111366. https://doi.org/10.1016/j.measurement.2022.111366

[8] M. Heinonen, Uncertainty in humidity measurements, EUROMET Workshop P758, 2006 [Google Scholar]

[9] Fernicola, Vito, Mauro Banfo, Lucia Rosso, and Denis Smorgon. "Investigation of capacitive-based relative humidity sensors and their stability at high temperature." *International Journal of Thermophysics* 29 (2008): 1668-1677. https://doi.org/10.1007/s10765-008-0457-2

[10] S. Ugur, A. Uttum, Characterization of UME two-pressure humidity generator, Tubitak. UME Gebze, Turkey, ISHM, 2002.

[11] Garcia Skabar, J. "Uncertainty estimations for standard humidity generator of INTI." *International Journal of Thermophysics* 36 (2015): 2172-2184. https://doi.org/10.1007/s10765-015-1905-4

[12] Hardy, Bob. "Uncertainty Analysis of the Thunder Scientific Model 2500 Two-PressureHumidity Generator." *Thunder Scientific Corporation, Albuquerque* (2006).

[13] Abd El-Galil, Doaa, and M. G. Ahmed. "Consistency of the national realization of dew-point temperature using NIS standard humidity generators." *International Journal of Metrology and Quality Engineering* 8 (2017): 1. https://doi.org/10.1051/ijmqe/2016028

[14] Abd El-Galil, Doaa Mohamed, and Essam Mahmoud. "Testing the reliability of humidity generator through measurements traceable to calibration standards." *Measurement* 124 (2018): 159-162. https://doi.org/10.1016/j.measurement.2018.04.028

[15] Smit, Herman, Rigel Kivi, Holger Vömel, and Ari Paukkunen. "Thin film capacitive sensors." In *Monitoring atmospheric water vapour: ground-based remote sensing and in-situ methods*, pp. 11-38. New York, NY: Springer New York, 2012. https://doi.org/10.1007/978-1-4614-3909-7_2