EXTENSION PUBLICATIONS

COLLEGE OF TROPICAL AGRICULTURE AND HUMAN RESOURCES
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Calibration of Humidity Sensors for Agriculture

At A Glance: Humidity is an important environmental factor affecting not only plant growth, but also the propagation of microbial pathogens, mildew, or mold. Inexpensive and simple-to-operate sensors are available to monitor humidity, but the accuracy of these devices must be evaluated through calibration to ensure that the data is reliable for use when making decisions to control humidity.

Measuring Humidity

Absolute humidity is a measure of the actual moisture content of air, while relative humidity (RH) is the absolute humidity of air divided by the maximum amount of moisture that air can hold at a specific temperature and pressure. Relative humidity is more relevant to plant growth since it impacts the plant's ability to regulate transpiration, or water loss through stomata on the leaves. Low RH can lead to the browning and drying of leaves. Elevated RH can lower transpiration and reduce nutrient uptake and plant growth. Other negative issues associated with high RH include the growth of plant pathogens like mildew and mold.

Several low-cost humidity sensors, or hygrometers, were examined for this study. A single representative of each sensor was tested except for the "Mini Digital" sensor, for which the entire pack of 12 was evaluated. The BME280 and SHT40 sensors require a separate programmable microcontroller to operate, but this device also adds many additional and helpful features, such as the ability to make a calibration or correction, save data, and communicate wirelessly.

Testing

The accuracy of these sensors was determined by comparing the measured values to a reference relative humidity. This reference humidity was created using a wet or saturated salt, which regulates the RH within a small airtight enclosure by absorbing or releasing moisture. Over time, each salt will reach a different equilibrium relative humidity with the enclosed air, which is also affected by temperature (Table 2). The three salts included in this procedure are available as food-grade products, with sodium chloride (non-iodized table salt) being a common cooking ingredient.

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Table 1. Relative humidity sensor attributes. *Use of these sensors requires an additional microcontroller, i2c cable, and USB-C cable purchased from Adafruit, which adds at least $19 to the total cost.

Sensor	Cost	Wireless	Datalogging	Calibration	Rated accuracy
Mini Digital	$2	N	N	N	±5%
Thermo Pro TP50	$11	N	Max / Min	N	±3%
Vivosun T21	$21	Pairs with packaged receiver	Max / Min	N	±5%
BME 280	$15 ($34)*	Bluetooth and WIFI	Y	Y	±3%
SHT 40	$6 ($25)*	Bluetooth and WIFI	Y	Y	±1.5%

The sensors were placed in a sealed 2-liter plastic food container, with one of the reference salts weighed into a dish. The amount of salt used can be varied (10 -20 grams), but generally, more salt should be used when the reference relative humidity will be significantly lower than the ambient relative humidity.

A maximum of 0.25g of water per 1g salt was added to the salt dish to avoid completely dissolving the salt, which will diminish the capacity of the salt to absorb moisture from the air. Similarly, if not enough water is added, the salt cannot release water to the air. The relative humidity was allowed to reach an equilibrium over a 24-hour duration in an air-conditioned room at 25 °C.

No modifications are necessary to the container, although a clear lid is recommended to enable observation. The lid pictured (Figure 1), contains two modifications to allow airtight fittings for the wires to the BME280 and SHT40 sensors, as well as a calibrated Omega RHXL3SD hygrometer, which was used to verify the relative humidity in the enclosure.

Table 2. Equilibrium relative humidity of wet salts (Greenspan, 1976).

Salt	15°C	20°C	25°C	30°C
Magnesium Chloride	33.30	33.07	32.78	32.44
Potassium Iodide	70.98	69.90	68.86	67.89
Sodium Chloride	75.61	75.47	75.29	75.09

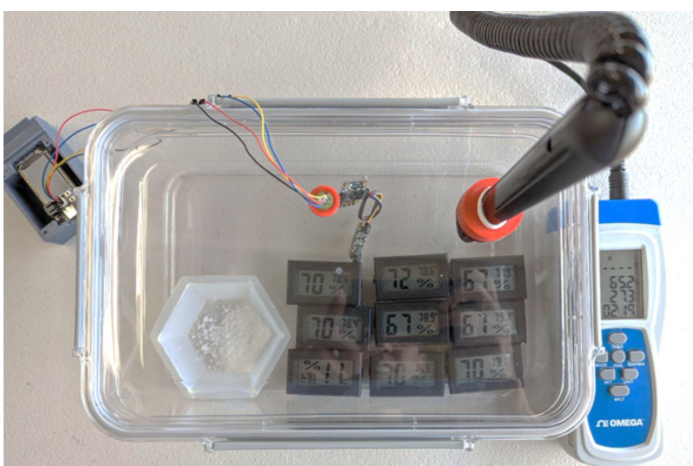


Figure 1. Wet salt enclosure

Performance

The sensor measurements were compared to each of the reference RH values associated with the three salts (Table 3). All sensors except for the BME280 and SHT40 were able to measure the correct RH within the rated accuracies without a calibration performed by the user. Two calibration processes were explored using either a single or two reference points, with sodium chloride (NaCl) and/or magnesium chloride (MgCl). Potassium iodide (PI) was used to evaluate the calibrated values.

Table 3. Observed sensor accuracy prior to user calibration. Lower is better.

	Relative Humidity Accuracy (±%)		
Sensor	NaCl 75.29%	PI 68.86%	MgCl 32.78%
Mini Digital	1.6	1.4	3.7
TP50	2.0	2.1	1.0
T21	0.0	0.1	4.0
BME280	5.9	5.8	1.4
SHT40	5.6	6.8	7.3

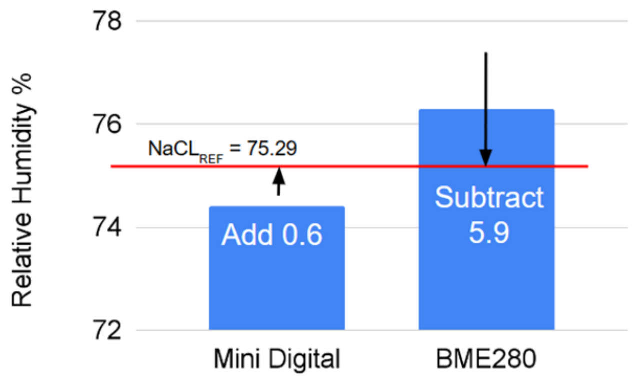
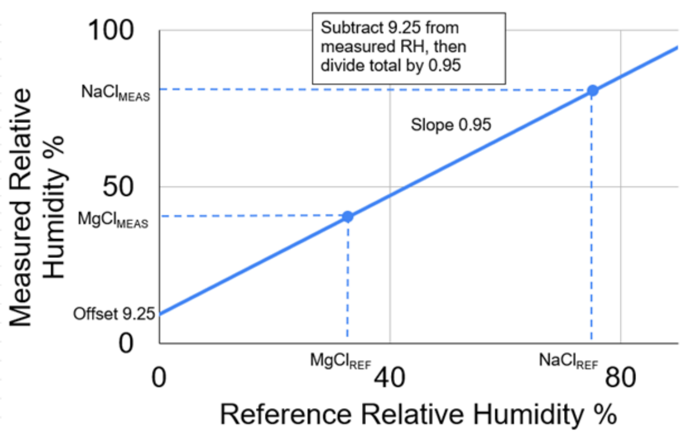


Figure 2. Single-point correction using sodium chloride or table salt as a reference.



$$\text{Slope} = \frac{\text{NaCl}_{\text{MEAS}} - \text{MgCl}_{\text{MEAS}}}{\text{NaCl}_{\text{REF}} - \text{MgCl}_{\text{REF}}} \quad (1)$$

$$\text{Offset} = \text{NaCl}_{\text{MEAS}} - \text{Slope} \cdot \text{NaCL}_{\text{REF}} \quad (2)$$

$$\text{RH}_{\text{Corrected}} = \frac{(\text{RH}_{\text{MEAS}} - \text{Offset})}{\text{Slope}} \quad (3)$$

Figure 3. Two-point calibration with sodium chloride and magnesium chloride as relative humidity references.

Single Point Calibration

For the single-point calibration, the sensor measurement was compared to one reference RH to determine if any offset should be added or subtracted to the measured value in order to obtain a more accurate reading (Figure 2). This is the simplest correction technique, however, as seen in Table 4, the accuracy does not stay constant over the range of RH tested. This method works best when the device is used at or near the single reference humidity. If the single-point calibration is applied to an RH measurement of air significantly different in the reference point used, the results will be less accurate.

Two Point Calibration

When measuring the RH over a wider range, a two-point calibration will generally provide more accurate measurements. The two-point calibration implemented in this study used NaCl and MgCl as references. An example plot was created of the measured and reference relative humidities for the SHT40 sensor (Figure 3). The calibration was applied by subtracting the 9.25 offset from the measured value and then dividing the total by the slope of 0.95, which was calculated using the two reference points (Equations 1-3). The accuracy of the measurement using PI was vastly improved with a two-point calibration when compared to a single-point calibration using magnesium chloride, which has an equilibrium RH (32.78%) – significantly different from the sample (68.86%) (Table 4). However, the single-point calibration using sodium chloride is at least as accurate, or even more accurate, than the two-point calibration, since its equilibrium RH (75.29%) is closer to that of potassium iodide (68.86%).

Table 4. Accuracy of sensors measuring air in a potassium iodide (RH 68.86%) wet salt-controlled container after single-point corrections with sodium chloride and magnesium chloride, and a two-point calibration using both salts.

	Relative Humidity Accuracy (±%)		
Sensor	Single Pt with NaCl	Single Pt with MgCl	Two Point
Mini Digital	0.3	4.5	1.7
TP50	0.1	1.1	0.5
T21	0.1	3.9	0.3
BME280	0.1	4.4	0.7
SHT40	1.2	0.5	1.2

Summary

The wet or saturated salt method is an inexpensive method using food-grade salts to calibrate or verify humidity sensors. All sensors except for the BME680 and SHT40 returned measurements within their rated accuracies over a range from 33-75% RH, without the need for calibration. Once calibrated, BME680 and SHT40 sensors performed within their rated accuracies, and these devices were the only two evaluated that could be programmed to incorporate a calibration into the displayed readings. Furthermore, these two sensors, when paired with a microcontroller, have datalogging and wireless communication capabilities and can be integrated into a humidity controller.

Resources

Arduino programming code SHT40 and BME280 for the microcontroller and 3D printer part files are available for download from **Github**.

References

Greenspan, Lewis. (1976) Humidity Fixed Point of Binary Saturated Aqueous Solutions. J*ournal of Research of the National Bureau of Standards*, 81A(1), 89-96.

Disclaimer

Names of products and companies are provided by the authors to document the materials used in the testing of the sensors described in this publication, as well as for the convenience of readers. The mention of these product and company names should not be considered a recommendation in preference to alternatives that may also be suitable.

The results obtained with these sensors may not be achieved under all conditions and may be affected by variations between units. Persons following the procedures suggested in this publication should be prepared to modify them to reflect their different conditions, including the sensors selected and environmental factors, such as ambient relative humidity.