e-GRO Edible Alert

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Are your air temperatures accurate?

Temperature is one of most important environmental variables for plant growth. Temperature measurement may seem easy, but as you learn sensor characteristics, you will know that accurate temperature measurement is one of the most difficult technical tasks in controlled environment agriculture.

Greenhouses and vertical farms are equipped with multiple sensors to monitor temperatures of various locations. Heating and cooling equipment are designed to operate so that temperatures of critical areas affecting crop growth are maintained at or close to the desired temperatures for the crop productivity and health. While there are many types of temperature sensors (thermometers) available at various price ranges in today's market, not all of us as growers or researchers are familiar with the best practices of temperature measurements, especially how to assure accurate measurements of air in the plant growing area.

Figure 1. A commercially available aspirated radiation shield used for temperature and humidity measurements under radiation in greenhouse. The shield has reflective material and an aspiration fan (shown in the inserted photo) to bring air to the sensor at a recommended rate for accurate measurement. (Photos by courtesy of Apogee Instruments Inc.)

Why do temperature sensors need to be shielded and aspirated?

Air temperature measurement is often challenging especially under light (greenhouses and growth chambers). This is because radiation increases the sensor temperature, which is the temperature the sensor gives us, while what we want to know is the air

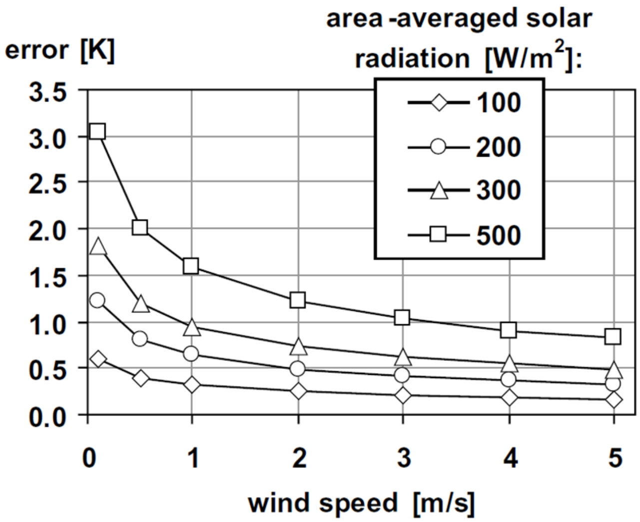

Figure 2. Temperature measurement errors (degrees in Celsius) caused by solar radiation and wind speed around the sensor (Erell et al., 2005; Sensor diameter = 1 mm). 1 degree K = 1 degree C = 1.8 degrees F

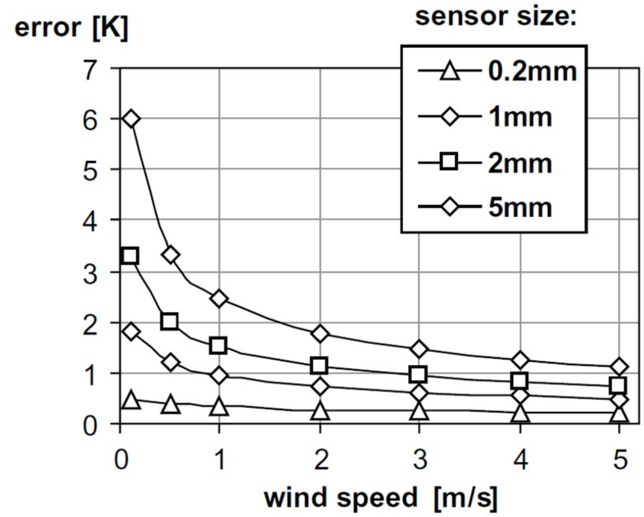

Figure 3. Temperature measurement errors (degrees in Celsius) caused by sensor size and wind speed under 300 W/m solar radiation (Erell et al., 2005). 1 degree K = 1 degree C = 1.8 degrees F

temperature, not the sensor temperature. Therefore, the success of our measurement depends on how we can make the sensor temperature equal to (or as close as) the true air temperature. Placing the sensor inside radiation shield would avoid directly radiating and therefore increasing sensor temperature; however, bulky shield often prevents air circulation around the sensor. Therefore, a combination of radiation shield and mechanical aspiration is almost always necessary to assure more accurate measurements of air temperature. Figure 1 is a commercially available aspirated shield for temperature sensors as an example. To better understand the importance of radiation shield and aspiration, a research group in Portugal simulated temperature measurement errors under various hypothetical conditions (Erell et al., 2005). Figure 2 is some of their results showing the measurement errors as affected by solar radiation and wind speed received around the sensor. Note that a low light level of 100 $W \cdot m^{-2}$ solar radiation (~200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ in PAR) can cause 0.5-degree Celsius error (0.9 degrees Fahrenheit) without aspiration (0 $m \cdot s^{-1}$). Under moderate radiation of 500 $W \cdot m^{-2}$, errors can be greater than 3 degrees (5.4 degrees Fahrenheit) without adequate aspiration. Even with adequate aspiration, without blocking the light, error can be as large as 1 degree Celsius (1.8 degrees Fahrenheit). Recommended type of shields should have highly reflective materials outside for at least shortwave radiation (300-3000 nm) and aspiration fans that would achieve an airflow speed around the sensor at 2.5 $m \cdot s^{-1}$ or greater.

Fine thermocouples can be placed without the need of shield or aspiration.

For some cases, bulky sensor housings for radiation shield and aspiration can be problematic as they are too large to install in a small head space (e.g., vertical farms) or creating significant shadow over the plants. For such a situation, we recommend considering using a fine thermocouple without having radiation shield or aspiration. Figure 3 shows the impact of sensor size (diameter) on the measurement errors under radiation. Extremely small sensors (e.g., 0.2 mm diameter) show an error of only 0.3-0.5 K (0.3-0.5 degrees Celsius, or 0.5-0.9 degrees Fahrenheit) even under moderate level of solar radiation. In our greenhouses and growth rooms, we use aspirated radiation shield for main temperature and humidity probe (~1 cm diameter), and fine thermocouples (Gauge 36, 0.13 mm diameter) when a bulky set up can cause problems. It is recommendable to use extension thermocouples of 0.5 or 1 mm diameter (e.g., Gauge 20, 0.81 mm) to connect the short length of fine thermocouples of the same 'type' as measurement end. This approach reduces the material costs as fine thermocouples are many times more expensive.

Thermocouples consist of a pair of different metals joined to form two junctions in a circuit. A voltage is generated according to the difference in temperature between two junctions and the metals used. Discovered by the German physicist Thomas Seebeck (1770–1831), it is also called the thermoelectric effect, and is the basis of the thermocouple. Knowing this relationship and measuring voltage, one can tell the temperature difference created between the two junctions. If one junction is held at a known (reference) temperature, then the temperature of the unknown (measurement) junction can be computed. The accuracy of thermocouples is generally 0.1 degree Celsius. Type T thermocouple consisting of copper-constantan wires is the most common thermocouple type used in CEA application. Type K thermocouple consists chromel-alumel wires and sometimes is preferred due to its lower thermal conductivity (Hicklenton and Heins, 1997).

Water is the best media for air temperature sensor calibration.

Any electric sensors can experience increasing errors caused by sensor decay or drift over time being used in various conditions. Therefore, having a capacity to test the sensor used for climate control is highly recommended. However, temperature calibration in air is almost impossible as air can never be isothermal. For that reason, well-stirred water bath is almost always used for temperature sensor calibration. Having a calibrated sensor or certified liquid-in-glass thermometer is highly recommended for calibration use. It is recommended to check the sensor accuracy at least once a year. For calibrating thermocouples, *in-situ* calibration using the exact setup is recommended as reference sensor (e.g., thermistor), connectors, extension cables, and recording device (e.g., datalogger) can cause additional errors. Two-point linear calibrations are common including zero degree Celsius (32 degrees Fahrenheit) created by mix of crush ice and water at around 1:1 volumetric ratio.

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