# Horticultural Engineering

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**Website: http://aesop.rutgers.edu/~horteng**

**In this Issue:**



Forced air unit heater for greenhouse heating.

## Introduction to Greenhouse Control and Sensors

Adopted from
(1) Remote Measurement Systems, Inc.
Web Site: http://www.measure.com/how2measure.html
(2) NGMA Standard "Greenhouse Environment Control System Considerations"
Web site: http://www.ngma.com

### Introduction

Controlling greenhouse production systems presents unique challenges. For example, temperature changes occur rapidly and vary widely depending on solar radiation levels, outside temperatures and humidity levels, wind speed and direction, the amount of plant material in the greenhouse, irrigation schedules, etc. Proper control of this dynamic environment is indeed challenging, but the benefits of good control usually far exceed the costs.

Ultimately, the objective of any greenhouse control system is to *reduce the input cost per unit of production and maintain or increase the quality of production*. While some investments affect the input cost and/or quality of one or two specific tasks (i.e., transplanters, soil handling equipment, etc.), a well-integrated control system will have a positive effect on virtually every component of the greenhouse production system. Even a small incremental improvement in several areas can yield substantial improvements overall. Growers that own control systems report experiencing many real benefits resulting from improved control:

**Higher Energy Efficiency:** Better equipment coordination and more accurate control can reduce heating fuel and electrical costs. Savings vary depending on how well the environment is already managed and which controls and sensors are purchased.

**Better Labor Efficiency:** Automated controls increase labor productivity by allowing workers to focus on more important tasks. Increased output reduces the need for more labor. Repetitive or physically demanding tasks can be performed by specially designed equipment and controls.

**Improved Management Effectiveness:** Perhaps the most important element of a good control system is the additional information it provides to managers and growers, enabling them to make better management decisions and spend more time managing the production process instead of hands-on involvement in the process.

**Reduced Water Use:** Modern irrigation control systems are capable of applying water and nutrients more precisely and more timely. Growers report reduced overall water use and runoff when using the most effective irrigation controls.

**Reduced Fertilizer Use:** Constant monitoring and control provides higher accuracy that, when combined with efficient water use, can substantially reduce fertilizer application and improve its effectiveness.

**Reduced Chemical Use:** More precise control of temperatures and more effective use of DIF and other growth regulating temperature regimens reduce the need for growth regulators. Better management of humidity, irrigation, and temperature also helps reduce plant stress and diseases and, consequently, the need for fungicides and other chemicals.

**Reduced Pesticide Use:** Greenhouses with better climate control and precise irrigation produce healthier plants. Healthier plants are less susceptible to disease and insect infestation. Growers report noticeable reductions in insect populations and pesticide use in well-controlled greenhouse environments.

**Improved Plant Quality and Uniformity:** Less disease, more effective irrigation and fertilization, improved grower information and management all combine to an increase in health and uniformity of the plants. Uniform crops are easier to handle and market.

**Reduced Equipment Wear and Tear:** Poor control over-taxes equipment by over-cycling and increasing operating hours. Good control allows more precise management of the equipment. Continuous monitoring and alarms alert growers to pending breakdowns and other malfunctions earlier, before more serious problems occur.

**Less Plant Loss from Failures:** Good data logging and graphing of greenhouse conditions and sophisticated early warning alarm systems help reduce losses from catastrophic failures.

### Sensor Basics

Sensors are components of data acquisition systems that convert changes in a physical parameter into electrical signals. Some sensors are strictly electrical like thermocouples, and have no moving parts. Other sensors are electromechanical and translate motion into an electrical signal. Anemometers (wind speed) and tipping bucket rain gauges are good examples of this type. Electro-chemical sensors monitor changing chemical concentrations and are represented by pH probes and ion specific electrodes.

Devices that sense more complex parameters and perform manipulation of the raw data prior to generating an output can be classified in the general category of instrumentation. Mass spectrometers and gas chromatographs are examples of instrumentation that produce an electrical signal suitable for digitization by a data acquisition system. There is a primary sensor in every piece of instrumentation (such as the photomultiplier tube in a spectrometer), but its signal is processed and conditioned before being output from the instrument.

With only a few exceptions, sensors and instrumentation have electrical outputs that vary in either voltage, resistance, or current. The table on the next page lists several sensors that respond to changes in their environment by varying one of these properties.

### Ohm's Law - converting between current, voltage, and resistance

Because Ohm's Law provides an easy way to relate voltage (volts), current (amps), and resistance (ohms), using a data acquisition system to monitor these variables is straightforward. Ohm's Law can be written as follows:

$V = I \times R$

Where, V is voltage (V), I is current (A), and R is resistance (Ω).

If the sensor changes resistance with variation in the sensed parameter, then by applying a constant current, a data acquisition system can monitor the changing voltage. If the sensor responds to changes in its environment by varying its current output, then by running the current through a fixed resistance, a varying voltage is produced. The data acquisition system can then monitor the changing voltage.

| Voltage | Resistance | Current |
|---|---|---|
| Thermocouple | Thermistor (RTD) | 4-20 mA sensors |
| Net radiometer | Wind vane | |
| Anemometer | Pressure transducer | |
| pH probe | Soil Moisture | |
| Most instrumentation | Strain gauge | |

**4 to 20 milliamp sensors**

One of the protocols used for industrial sensors is the "4 to 20 milliamp" protocol. To solve the problem of signal loss over long sensor cables in electrically noisy environments, the sensor signal is transmitted as a current. Current (the number of electrons flowing) is not altered by the resistance of long cables. However, sensor signals sent as a voltage experience a voltage drop due to resistance in the wires. Hence, the 4-20 mA protocol for current loop sensors was developed.

The raw output of a sensor element or transducer is conditioned so that at the low point of its range it limits current output to 4 mA, and at the high end of its range, current output is limited to 20 mA. For example, a temperature sensor might be used for a temperature range of -50°F to 150°F. The electronics of the sensor convert the raw temperature signal into a 4 mA current at -50°F and a 20 mA current at 150°F. The signal is linear in between these two limits. Thus, if the 4-20 mA current signal is run through a 20.5 ohm, 1% resistor, the 4 mA signal will be converted to 82 mV, and the 20 mA signal will be converted to 410 mV. The resistor legs are inserted into the + and - sides of an analog input. The more common 5% tolerance (i.e., less accurate) resistor will work, but will produce slightly less accurate readings.

**Sensor Wire**

Special types of wire are generally not required to interface sensors (other than thermocouples) with a data acquisition and control system. Since sensor cables do not carry much electrical power (usually up to 24 Volt), small gauge wire can be used. Normally, 24-gauge is quite acceptable, but the larger 18-22 gauge may be more available. The 26-gauge wire size is also acceptable, but wire smaller than 26-gauge is probably too fragile for most installations. In most cases, use the stranded rather than solid wire. Stranded has multiple smaller wires within each insulator (plastic shielding) and is more flexible and resistant to breakage. Solid wire will more easily break if it has been crimped, or is bent too often. Usually, the 4- or 6-pair network and 2-pair telephone wire is solid. It is acceptable to use this wire, but only for sensors that are permanently installed where the wire will not be moved or bent frequently.

In many cases, more than one sensor will be installed in the same location (for example, solar radiation, wind speed and direction on the roof). In this case, the use of multiple conductor cable is recommended. Two-pair (four conductor) is very common and will work fine. Some sensors require power supply. With a 4-pair cable, one pair can be used for power supply, and the remaining three for measurements.

Always be sure to check with local authorities (inspection officials) to learn what requirements exist for installing electrical wiring. Wiring that meets the flammability and smoke generation requirements of local electrical codes should be available from local distributors.

In most cases, but especially in electrically noisy environments, it is advisable to use shielded cable. Long unshielded sensor leads may act as antennas and can pick up unwanted signals. Shielded cables also provide mechanical protection of the interior wires from abrasions. In most cases, the shield consists of a foil layer wrapped around the interior wires, and covered with an outer plastic protective jacket. A single "drain" wire - usually bare metal, will also be included. The drain wire should be connected to a

ground, at one end only, to provide shielding from unwanted electrical noise.
Be sure to check wire pricing. Pricing will largely depend on the quantities sold by the distributor.

### Sensor grounding and filtering

When checking sensor installation, it is possible that the values returned by the data acquisition system appear to be very noisy and variable. A likely cause of this condition is that the ground of the sensor is floating relative to the ground of the data acquisition sensor interface. Since voltages are measured relative to a baseline level, commonly called "ground" (GND), it is easy to realize that measurement problems can occur if the ground of the sensor, and the ground of the data acquisition system, are not at the same level.
Usually, the sensor low (ground) should be within a few volts of the data acquisition ground to avoid noisy readings. This can be checked by connecting a short length of wire between the negative side of the sensor input and the data acquisition terminal labeled GND. If the unwanted noise is reduced, the jumper should remain in place. If grounding the input does not reduce the noise to an acceptable level, the input may need to be filtered. By placing a small capacitor (10-100 µF) across the input, high frequency spikes will be eliminated. Keep in mind that, as larger capacitors are used, lower frequencies are filtered and rapid changes in sensor output may be difficult to observe.

### Connecting sensors to a data acquisition system

Most data acquisition systems are equipped with a pair of screw terminals for each of its inputs. Attachment of sensor leads (wires) is easy with the help of a small (flat-head) screwdriver to close the vise-like terminals. The terminal strips are labeled "+" and "-" to denote the polarity sensed by the analog-to-digital (A/D) converter. For example, a negative reading means that the sensor lead attached to the "-" terminal is at a higher potential than the lead attached to the "+" terminal. Most data acquisition systems are capable of bipolar readings, so if the polarity of the sensor leads is reversed, no damage will be done. The reading obtained from that channel will simply be of the opposite sign.
Most data acquisition systems have a maximum input voltage range that should never be exceed. At higher voltages, damage to the internal circuitry may result. Should a moderately excessive voltage be applied accidentally, usually the data acquisition systems can be repaired. However, extensive damage can occur when the system is exposed to regular line voltage (115 VAC) or lightning.

### Sensors

The accuracy and responsiveness of a control system is limited by the accuracy and responsiveness of the sensors it uses. A computer may be able to read a sensor many times per second and resolve the temperatures to within 1/1000$^{th}$ of a degree, but if, for example, the sensor takes 2 minutes to respond to a change, it is of little value to the system. The reliability and accuracy of a sensor, and its construction, are of particular importance in the greenhouse environment, to its ability to withstand the generally unfavorable conditions of the greenhouse environment.

### Temperature

Accurate measurement of the air temperature is best accomplished using an aspirated housing to move an air sample across the sensor and protect the sensor from direct exposure to solar radiation. This ensures a more representative measurement of the greenhouse air temperature.

***Soil Temperature*** probes are typically used to control bottom heat systems. They are also used to monitor soil temperatures and the temperature within the microclimate of the plant. This information can be valuable for determining how and why the plant is responding and what measures the grower may want to take to improve performance or identify problems.

***Pipe Temperature*** sensors are used to monitor the water temperature and pipe surface temperature in hot water heating systems to control mixing valves, minimum pipe temperatures for dehumidification, as well as boiler output and/or transport system temperatures. There are three methods of sensing: (1) surface mount temperature sensors, (2) wet well sensors, and (3) dry well sensors.

*Strap-on surface sensors* are inexpensive and effective since the pipe surface closely follows the water temperature within. Sensing can be as simple as clamping a small thermistor on the pipe covered by a piece of insulation and a hose clamp or tie wrap.

*Wet-well sensors* are actually threaded into a hole (well) in the pipe and sense the temperature of the stream of water. They provide the most accurate temperature reading, and the fastest response, although it is questionable if this accuracy is necessary in most hot water systems. Wet well sensors are more difficult to service since the pipe must usually be drained or at least cooled and depressurized before they can be replaced.

*Dry-well Sensors* are the most expensive but provide the best combination of accuracy and ease of service. A well is threaded into the pipe forming a permanent seal, and the sensor is placed in the well sometimes with thermal grease to ensure good contact and can be easily removed for maintenance or replacement.

*Irrigation Water Temperature* can be monitored with a pipe temperature sensor, as above, or with a simple waterproof sensor dropped into the water volume.

*Other Temperatures* can be monitored for a variety of purposes. For example, equipment operation can often be confirmed with a simple appropriately placed temperature sensor to monitor the operation of e. g., unit heaters, or check for overheating of equipment. Alarms can then be set to alert operators when problems occur.

## Humidity

Controlling the humidity in the greenhouse can yield powerful benefits in disease reduction, improved water and nutrient uptake, and improved plant growth. It is too often under utilized and not well understood. Humidity control is a standard function of nearly all greenhouse control systems.

Humidity measurement is expressed as a percentage (i.e., relative humidity). It is the actual amount of moisture in the air, relative to the maximum capacity the air can hold. Accurate humidity sensing can be a challenge, even with the most expensive sensors, which are typically not suitable or practical for the commercial greenhouse industry.

There are three common types of humidity sensors: capacitive, resistive, and wet/dry bulb. Both *capacitive and resistive solid-state sensors* are fairly common in the U.S. because they offer reasonable accuracy and, in the humidity range typical of most horticultural applications, maintenance is generally limited to cleaning once or twice per year. However, solid-state sensors are susceptible to chemical contamination and high humidity conditions (i.e., over 90%), which may require more frequent recalibration or replacement.

*Wet/dry bulb sensors* offer the best accuracy if maintained properly, particularly in environments with humidity levels consistently above 90%, such as germination chambers and fog houses. These sensors do require frequent but simple maintenance. Water reservoirs must be refilled and wicks trimmed and replaced regularly. The drier the climate, the more frequent maintenance is required. These sensors are more common in Europe and Canada, due to a number of factors, including tradition, more crops requiring closer humidity control, and climates more appropriate for this type of sensor.

## Light

There are three commonly used measurements of light: solar radiation, PAR, and visible light. *Solar radiation* is often used for greenhouse control because it measures the total amount of energy contained in sunlight. Solar radiation is measured with a pyranometer, and is generally expressed in units of Watts/$m^2$. Solar radiation includes radiation in approximately the 280-2,800 nanometer (nm) waveband.

*Photosynthetically Active Radiation* (PAR) measures the amount of light used by plants for photosynthesis.
PAR is expressed in units of $\mu mol/(m^2 s)$, and is the preferred unit of measurement when one is interested in the potential for photosynthesis. PAR includes radiation in the 400-700 nm waveband. PAR sensors should be located at the top of the plant canopy and kept free of any shading by plant parts.

*Visible light* meters measure light intensity as seen with the human eye. Visible light includes radiation between approximately 380 and 770 nm. Because these sensors measure a different part of the radiation spectrum (compared to PAR and solar radiation sensors), they are not recommended for use in horticultural production facilities. Visible light is expressed in units of foot-candle or lux. Conversion of a visible light measurement into a PAR measurement is possible, but the conversion factor depends on the light source.

### $CO_2$

Carbon dioxide sensors are typically used in $CO_2$ enrichment applications. The most common types of sensors employ an infrared sensing element. A separate sensor may be used in each zone, or to reduce costs, samples from several zones can be multiplexed (i.e., directed consecutively) to a single sensor. Control systems can initiate $CO_2$ injection from boiler stacks, $CO_2$ burners, or liquid $CO_2$ tanks based on light and temperature conditions and $CO_2$ target levels.

#### Wind Speed and Direction

Mounted on the outdoor weather station, an anemometer measures wind speed and the vane measures wind direction. The controller uses this information to close or limit the opening of vents, roofs, and sidewalls during high wind conditions, or winds from a specific direction. This information can also be used to optimize the operation and effectiveness of windward/leeward vent systems, and even to make or modify irrigation and heating decisions.

### Precipitation

These are sensors are mounted on outdoor weather stations to measure precipitation. Simple rain “grids” indicate either the presence or absence of precipitation but not the volume. These simple sensors are commonly used to close or limit roof vents or retractable roofs when it is raining. They are the most appropriate sensors for this purpose because they allow a fast response. Heated rain grids enable snow sensing and differentiation between dew and rain.

Rain volume is normally measured using a tipping bucket rain gauge. This device collects the water in a small cup or spoon that tips when it is full, triggering a small switch. The number of tips are counted to determine the amount and rate of rain fall, generally as accurately as 1/00$^{th}$ to 1/10$^{th}$ of an inch. These gauges can also be used to measure propagation misting, and irrigation application and leachate rates. Rain volume measurements are not used for closing or limiting vents and roofs due to their slow response rate.

### Irrigation

Measuring the use and/or presence of water for irrigation purposes can be accomplished with a number of sensors depending on the purpose, growing culture, and required accuracy. Soil tensiometers are used to indicate approximately how much moisture is available in the media. Evaporation trays are used to indicate the approximate evaporation rate of water in a particular environment. Flow meters can measure the amount of water being fed to the plants. Accumulation gauges, such as tipping bucket rain gauges, can be used to measure how much water is leached out of the media and, consequently, how much water the media absorbs.

### Nutrition

pH sensors are used to determine the acidity of liquid solutions. EC sensors are used to determine the amount of salts in nutrient solutions. Both types of sensors are used for nutrient control and availability, and for monitoring and alarm information in irrigation systems.

### Miscellaneous Sensors

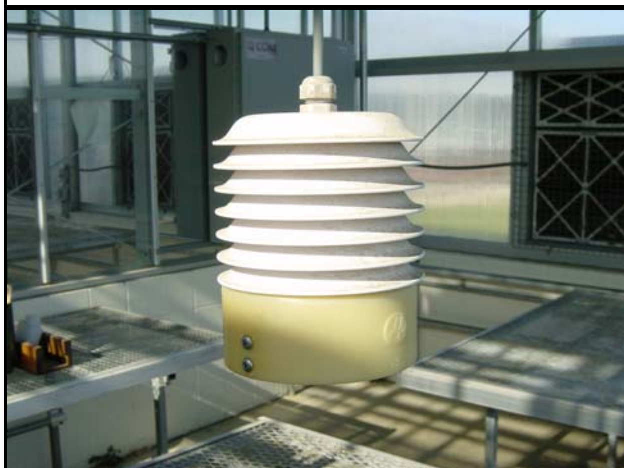
There are many sensors available to monitor and record a wide variety of conditions. Many control systems can use these sensors to improve control, set alarm conditions, activate equipment, or simply report occurrences. Certain safety or alarm related sensors can be incorporated into computerized control systems as well. An example may include smoke or heat sensors to detect fire. In some systems, particularly computer control systems, the system could be programmed to, for example, open/retract the shade or blackout curtain systems and close vents to minimize the spread of fire.

Other sensors include:

- Flow switches *to confirm proper pump operation, detect clogged filters and line breaks, etc.*
- *Pressure transducers* to monitor water pressures, greenhouse air pressures, fan output, etc.
- *Potentiometers* to monitor vent positions, mixing valve positions, etc.
- *Micro-Switches* to monitor closure of vents and doors, the position of watering booms, curtain systems, retractable roofs, etc.

## Sensor Calibration

Sensor calibration is very important and should be performed regularly (check the recommendations provided by the manufacturer). Without careful calibration, the measurements collected with the data acquisition system will have little value. Sensors that are out of calibration can cause significant problems for greenhouse growers. For example, the heating system can use more energy than needed to maintain the temperature set point, or the pH of the nutrient solution can be maintained incorrectly resulting in nutritional problems for the crop.



An aspirated box with temperature and humidity sensors located inside shield the sensors from direct solar radiation and ensures a representative measurement of the greenhouse environment.

Various greenhouse radiation sensors used to determine solar radiation and PAR.

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Poinsettia trials in the open-roof greenhouse.

**HORTICULTURAL ENGINEERING**

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**Upcoming Meetings, Shows, etc.**

HortiFair (NTV)
Amsterdam, the Netherlands
November 6-9, 2002
http://www.hortifair.nl

Important Dates

*January 13 – 14, 2003*

**Greenhouse Engineering Short Course at Rutgers University**

This 2-day course, coordinated by your editor, features timely topics for greenhouse operators and those interested in learning more about greenhouse engineering or perhaps thinking about getting started in the greenhouse business. Registration information is available for the Office of Continuing Professional Education at Cook College,
Phone: (732) 932-9271, or on the web:
http://cook.rutgers.edu/~ocpe
It is not too early to plan to attend this program! Topics include heating, ventilation, supplemental lighting, environment control, insect screening, open-roof greenhouses, simple greenhouses (high-tunnels), planning, crop production, and more.