Broadly speaking, environmental control includes the greenhouse structure, related equipment, and the day-to-day management decisions that characterize greenhouse crop production. In typical greenhouses, controls are a mix of manual adjustments, timed events, and thermostatically regulated actions. In very sophisticated operations, computers are used. Computerized environmental control allows the integration of the different greenhouse components into an efficient and profitable system.

**Crop Environmental Response Characteristics**

Commercially raised plants are predictable. For example, the well understood relationship between day length and flowering in poinsettias is essential information in timing the crop for the Christmas market. Growers fully understand the importance of properly controlling “day length” to obtain the brilliant red leaves that customers want. Growers are also aware of the relationship between temperature and crop development. Foliage plants that take nine weeks to grow to market size in the summer, can take 12 weeks in the winter. Most growers know that the growth rate can be sped up by raising greenhouse temperatures. Certainly, irrigation frequency, fertilization rates, and CO₂ levels all affect crop growth and development.

The success of greenhouse operations hinges on the fact that crop after crop responds consistently to its environment. In recognizing the mechanistic relationship between a crop and its greenhouse environment, growers have increasingly come to rely on automatic control systems to provide consistent, favorable environmental conditions. For example, in the recent past, it was common practice to manually water greenhouse crops. Today, most growers rely on automatic irrigation systems regulated by timers and solenoids. In addition to the labor saving advantages, growers have realized that automated irrigation systems have horticultural advantages. They allow increased precision in regulating the timing of irrigation events and in the amount of water that...
growers apply to their crops. In the same manner, the trend from thermostats to electronic controllers has provided some increased flexibility in regulating heaters, ventilation fans, and wet pads.

The next logical step is a computer greenhouse control system that can link and manage all of the automated control subunits. Generally, computer control strategies can be much more sophisticated than other types of controllers. This provides the grower with more precise management capabilities for more efficient operation of heaters, ventilation fans, and other control equipment. Less obviously, computerized control systems can help the development of a grower's overall management strategy by providing consistent, detailed data about the greenhouse environment. The purpose of this section is to discuss how these capabilities can benefit greenhouse plant production.

Theory

Figure 1 is a schematic representation of a greenhouse and its control system. Temperature, humidity, and CO₂ levels are the primary variables that describe the greenhouse environment as shown in the schematic. The purpose of the control system is to maintain these and other variables within limits specified by the grower. To accomplish its task, the control system must respond to disturbances (such as sunlight and outside weather) acting on the greenhouse environment. Disturbances are processes occurring both inside and outside the greenhouse that alter heat, moisture, and CO₂ balances in the greenhouse. For example, solar radiation or sunlight directly affects a greenhouse's energy balance and consequently, its temperature. Also, solar radiation indirectly affects a greenhouse's CO₂ mass balance (CO₂ concentration) because of its role in photosynthesis.

Control devices or actuators such as heaters, fans, and vents also alter the heat and moisture balance of a greenhouse system. The aim of the control system is to regulate the inputs of the heaters, fans, and other control devices to counteract the disturbances and thereby, maintain the environment of the greenhouse system specified by the grower.

The control system most often uses a feedback loop to regulate the operation of the actuators. A sensor monitors each measurable variable, producing a signal that is a direct indicator of the variable's status. The controller subtracts the measured signal from the setpoint signal (or desired setting) to produce an error signal which indicates the quality of the controls. The controller uses the error signal to drive the actuator. Depending on the particular device, the controller may change a setting in proportion to the error signal or simply turn a piece of equipment on or off when the measured value exceeds a set point.

The feedback scheme is basic to all control systems. Even a grower who relies on manual controls follows the same procedure. When the grower checks a mercury glass thermometer (sensor) for an indication of the greenhouse temperature (a variable), he mentally compares the difference (error) between desired (set point) and existing (measured) conditions. Depending on the direction (sign) and magnitude of the error, the grower can adjust an actuator, for example, he may turn on an exhaust fan when the temperature gets too high. A bithermostat works on the same basic feedback principle and so does a sophisticated computer control system.

For some control problems, a feedforward loop can improve control decisions. If controls are based only on feedback information, then the effect of a disturbance must propagate through the system and drive the variable away from the setpoint before the controller can detect an error and respond. The time
lag between the occurrence of a disturbance and the development of a measurable change in the variable can range from minutes to hours for slow processes. A feedforward loop provides information to the controller about a disturbance as it occurs. If the controller is programmed with a model of the greenhouse system response to the disturbance, then it can anticipate changes in conditions and make adjustments before measurable changes actually occur. Growers frequently use feedforward control techniques in manual controls by recognizing trends and making adjustments. For instance when the weather becomes particularly cloudy, conscientious growers anticipate the possibility of overwatering and adjust their irrigation system timers accordingly. In a similar feedforward fashion, some automated irrigation systems monitor solar light levels and base crop watering decisions on accumulated sunlight. Since computers are readily programmable with models that describe greenhouse and crop interactions with the environment, computer controllers are well suited for implementing feedforward loops.

Sensors

As stated in the sections above, all greenhouse control systems require information on the variables that define the greenhouse environment. Sensors provide the information. Traditionally, the grower has acted as the system's integrated “sensor”, directly feeling greenhouse conditions to which he tried to relate his crop’s growth and development. To supplement the grower's feelings about the greenhouse environment, glass thermometers became one of the earliest sensors regularly used to provide the grower with quantitative information about a variable, dry bulb temperature.

Today, there are many sophisticated electronic sensors available to the grower for monitoring greenhouse conditions and providing input data for automatically making increasingly subtle and efficient control decisions. Many greenhouse operations in Florida have electronic sensors for measuring dry bulb temperature (thermistors), wet bulb temperature (psychrometers), and light level (pyranometers) linked to specific control sub-systems. Other sensors include conductivity and pH probes used in fertigation systems, gas analyzers used in CO₂ injection systems, and wind speed and direction sensors used to control vent positions.

In most Florida greenhouses, sensors link directly to specific control actions such as fan and pad operations. Often the sensor is part of a control subsystem or may be a handdevice for making localized or diagnostic measurements. For these reasons, growers typically do not record sensor data.

Control Sub-Systems

The other essential components in the computer-based environmental control system shown in Figure 1 are the actuators or automated control sub-system. Once the computer evaluates the sensor data and makes a controls decision, a computer device must be available to carry out the decision. In recent years, the number and sophistication of control devices regularly used in commercial greenhouses has steadily increased. In the area of cooling systems, inflatable walls, high pressure fog systems, and automated shade curtains are a few recent innovations now available in addition to vents and ventilation fans.

Other control sub-systems commonly used in Europe are also finding their way into Florida greenhouses. Fertilizer injection systems are fairly common and a few growers have installed CO₂ injection equipment. Some growers are also using horizontal air flow fans or their polysystems for mixing the greenhouse air to create a more homogeneous environment when the ventilation fans are not being used.

All of these sub-systems are compatible with computer controls. By linking the component subsystems through a computer, one set of sensors can regulate all of the equipment. More importantly, each control component is not in isolation, but operates in coordination with the other equipment in the system. For example, when the ventilation fans are operating, CO₂ injections can be stopped.

Data Acquisition

Aside from alarms, more efficient equipment control, and flexibility, the foremost advantage of computer controls is the computer’s secondary role
as a data acquisition system. The advantages of having data were directly apparent in an Apopka grower’s experience with the heating system described above. The rose grower’s strategy of cooling the plants to slow development of the rose buds indirectly suggests the advantages of data acquisition. In that case it should be obvious that the grower probably did not get the temperatures exactly right the first time he tried manipulating the roses. Furthermore, as the seasons changed the strategy probably required adjustments to account for changing average daily temperatures and accumulated light levels. The ready availability of reliable data from the computer provided the rose grower with the information he needed for quick recognition of his crop’s response patterns.

On an even more basic level, data from computer control systems train growers about the actual daily environmental patterns that exist in their greenhouses. Once growers become familiar with the data provided by the system, they can become very sophisticated in its use.

**Future Control Systems**

There are several trends in computer control systems that deserve consideration. The most current commercially developed products are distributed systems, which means that the processing (computing) is not centrally located in a single dedicated computer. Instead, there can be many stand-alone programmable controllers (subprocessors) located in the greenhouse units that they control. Each subprocessor has a serial connection to a central monitoring computer (hostprocessor). The subprocessors handle data acquisition and real controls while the hostprocessor saves and displays data passed to it from the subprocessors. The hostprocessor can pass down setpoints and other control parameters to any of the connected subprocessors.

Computers continue to become less expensive and more powerful. The increasing capabilities of commercial computers coupled to centralized data acquisition offers new possibilities for greenhouse controls. One successful idea already applied to industrial control problems is the concept of adaptive controls. Essentially, the hostprocessor evaluates the quality of the controls by inspecting data as it is taken. If any of the controlled variables begin to fluctuate more than expected (based on previous behavior), then the system re-evaluates the appropriate control constants, generates new values, and passes them down to the subprocessor.

A major advantage of these systems is that they provide the grower with data on greenhouse conditions as related to outside conditions and the operating characteristics of the control sub-system. The combination of these features gives growers the flexibility and data required to fine tune their production systems. The bottom line is that consistent, efficiently managed, automatically controlled environments maintained by a fine tuned control system repeatedly produce high quality crops.

**More Information**

For more information on greenhouse crop production, please visit our website at http://nfrc-sv.ifas.ufl.edu.

For the other chapters in the Greenhouse Vegetable Production Handbook, see the documents listed below:

**Florida Greenhouse Vegetable Production Handbook, Vol 1**

- Introduction, HS 766
- Financial Considerations, HS767
- Pre-Construction Considerations, HS768
- Crop Production, HS769
- Considerations for Managing Greenhouse Pests, HS770
- Harvest and Handling Considerations, HS771
- Marketing Considerations, HS772
- Summary, HS773
Florida Greenhouse Vegetable Production
Handbook, Vol 2

General Considerations, HS774
Site Selection, HS775
Physical Greenhouse Design Considerations, HS776
Production Systems, HS777
Greenhouse Environmental Design Considerations, HS778
Environmental Controls, HS779
Materials Handling, HS780
Other Design Information Resources, HS781

Florida Greenhouse Vegetable Production
Handbook, Vol 3

Preface, HS783
General Aspects of Plant Growth, HS784
Production Systems, HS785
Irrigation of Greenhouse Vegetables, HS786
Fertilizer Management for Greenhouse Vegetables, HS787
Production of Greenhouse Tomatoes, HS788
Generalized Sequence of Operations for Tomato Culture, HS789
Greenhouse Cucumber Production, HS790
Alternative Greenhouse Crops, HS791
Operational Considerations for Harvest, HS792
Enterprise Budget and Cash Flow for Greenhouse Tomato Production, HS793
Vegetable Disease Recognition and Control, HS797
Vegetable Insect Identification and Control, HS798