H o r t i c u l t u r a l E n g i n e e r i n g

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Providing an optimum growing environment.

Introduction Into Greenhouse Environment Control

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Introduction

Successful greenhouse crop production requires that growers have good control over the greenhouse environment. The most important environmental parameters that need to be controlled include temperature, light, humidity, and the carbon dioxide concentration. Growers use heating, ventilation, and cooling systems to control the greenhouse temperature and humidity levels. In addition, supplemental lighting and shading systems can be used to control light levels. Carbon dioxide enrichment is used to provide a carbon dioxide concentration high enough as not to limit photosynthesis. The control of one parameter, e.g., temperature, can have an impact on the control of other parameters, e.g., humidity and carbon dioxide. Providing optimal environment control under the constantly changing weather conditions is a challenging task that can be made easier with a computerized control system. The discussion in this paper touches on some of the technologies available to growers to help them control their greenhouse environment.

Heating

Many smaller greenhouses are heated with so-called unit heaters. Unit heaters are relatively cheap, easy to install, and can operate on one of several fuel sources (natural gas, propane, fuel oil). However, distributing the heat evenly throughout the greenhouse is a challenge and many growers use poly tubes attached to the exhaust side of the heater for this purpose (check to make sure that the fan in your heater is rated for the additional static pressure resulting from adding the tube). But why heat the entire greenhouse volume when the crop is located in only a small portion of it (e.g., on the floor or bench)? Therefore, floor or bench heating systems may be a better choice and have the potential to reduce the overall greenhouse heating demand.

Boiler systems (steam or hot water) are common in larger greenhouses. For example, heat is produced in the boiler and steam or water is used as a carrier of the heat to cooler locations throughout the greenhouse. Boiler systems generally distribute the heat more evenly compared to unit heaters, but their installation cost is generally higher.

While considering a heating system upgrade (remember that most new systems have considerably higher fuel efficiencies), look for systems that are able to burn multiple fuels (so you can switch depending on price and availability) and seriously consider separated combustion systems. The latter systems only use outside air for the combustion process and do not allow combustion gasses to mix with the greenhouse air (which could result in crop damage). And always make sure you have your heating system thoroughly checked before the start of each heating season.

Ventilation

Greenhouses can be mechanically or naturally ventilated. Mechanical ventilation requires (louvered) inlet openings, exhaust fans, and electricity to operate the fans. When designed properly, such a system is able to provide adequate cooling under most of New Jersey's weather conditions. Based on crop requirements, an evaporative cooling pad or fog system can be incorporated to increase the cooling capacity.

Natural ventilation works based on two physical phenomena: thermal buoyancy (warm air is less dense and rises) and the so-called "wind effect" (wind blowing outside the greenhouse creates small pressure differences between the windward and leeward side of the greenhouse causing air to move towards the leeward side). All that is needed are (strategically located) inlet and outlet openings, vent window motors, and electricity to operate the motors. Compared to mechanical ventilation systems, natural ventilation systems use a lot less electricity and produce (some) noise only when the vent window position is changed. With a natural ventilation system, additional cooling can be provided by a fog system. Unfortunately, natural ventilation doesn't work very well on warm days when the outside wind velocity is low (less than 200 feet per minute).

Due to the long and narrow design of most freestanding hoop houses, mechanical ventilation systems usually move the air along the length of the greenhouse (the exhaust fans and inlet openings are installed in opposite end walls), while natural ventilation systems provide crosswise ventilation (with the help of roll-up side walls and sometimes roof vents).

In gutter-connected greenhouses, mechanical ventilation systems inlets and outlets can be installed in the side- or end walls, while natural ventilation systems usually consist of only roof vents.

Whichever ventilation system is used, uniform air distribution is important because uniform crop production is only possible when every plant experiences the same environmental conditions. Therefore, horizontal airflow fans are frequently installed to ensure proper air mixing.

Humidity control

Healthy plants can transpire a lot of water, resulting in an increase in the humidity of the greenhouse air. A high relative humidity (above 80-85%) should be avoided because it can increase the incidence of disease and reduce plant transpiration. Sufficient venting, or successively heating and venting can prevent condensation on crop surfaces and greenhouse structures. The use of cooling systems (e.g., pad-and-fan or fog) during the warmer summer months increases greenhouse humidity. During periods with warm and humid outdoor conditions, humidity control inside the greenhouse can be a challenge.

Cooling

When the regular ventilation system is unable to provide sufficient cooling for greenhouse temperature control, additional cooling is needed. Two cooling systems are commonly used in greenhouses and both make use of the cooling effect resulting from evaporation of water. These two cooling systems are the pad-and-fan and the fog system. Pad-and-fan systems can only work in combination with mechanical ventilation: an evaporative cooling pad is installed in the ventilation opening, cooling the incoming air. As the air moves through the greenhouse towards the exhaust fans, it picks up heat from the greenhouse environment. Therefore, pad-an-fan systems experience a temperature gradient between the inlet (pad) and the outlet (fan) side of the greenhouse. This temperature gradient should be minimal to provide all plants with similar conditions. However, a gradient of 7-10°F is not uncommon.

Fog nozzles can be installed throughout the greenhouse, resulting in a more uniform cooling pattern compared to the pad-and-fan system. The water pressure used in greenhouse fog systems is very high (500 psi and higher) in order to produce very fine droplets that evaporate before the droplets can reach plant surfaces. In addition, the water needs to be free of impurities to prevent clogging of the small nozzle openings. As a result, water treatment and a high-pressure pump are needed to operate a fog system. Therefore, fog systems can be more expensive to install compared to pad-and-fan systems.

Shading

Investing in movable shade curtains is a very smart idea, particularly with the high energy prices we are experiencing today. Shade curtains help reduce the energy load on your greenhouse crop during warm and sunny conditions and they help reduce radiation losses at night. Energy savings of up to 30% have been reported, ensuring a quick payback period based on today's fuel prices. Movable curtains can be operated automatically with a motorized roll-up system that is controlled by a light sensor. Even low-cost hoop houses can benefit from the installation of a shade system. Where shade systems are located in close proximity to heat sources, it is a good idea to install a curtain material with a low flammability. These low flammable curtain materials can stop fires from rapidly spreading throughout an entire greenhouse.

Supplemental lighting

Supplemental lighting is used in greenhouses to increase crop production during time periods with low levels of solar radiation. These time periods usually occur during the winter months, but cloudy summer days can be as dark as some of the winter days. Thus, if crop production is on a tight schedule, supplemental lighting may be required year-round. Sometimes, photoperiod lighting is also defined as supplemental lighting, but the light intensities required are very low, resulting in a low energy consumption. Despite the installation and operating costs associated with supplemental lighting systems, many growers are discovering their benefits. These systems can help improve crop quality, keep production on schedule, and reduce the length of the growing cycle. Thus, growers produce a higher quality product while keeping their production schedules on target, and they are able to produce more crops per year.

Carbon dioxide enrichment

CO_2 can be supplied (usually up to three times the normal ambient concentration) to the greenhouse environment using different methods. For example, CO_2 gas can be released from compressed CO_2 gas tanks. Since CO_2 is a by-product of many different chemical processes, compressed CO_2 is often readily available for a reasonable price. But a lot of compressed CO_2 tanks are needed to provide a larger sized greenhouse with sufficient CO_2. Therefore, growers that use a lot of CO_2 can opt to install a liquid CO_2 tank that can be purchased or rented through local gas distributors. A refrigeration unit is connected to such a tank to cool the CO_2 to a temperature where it becomes a liquid. The advantage of storing CO_2 as a liquid is that you need less volume, but on the other hand you need a refrigerator (and electricity) to keep the CO_2 cold enough so it will stay in the liquid form. The liquid CO_2 is vaporized (i.e., converted from a liquid to a gas) before it is released into the greenhouse. CO_2 gas is often distributed throughout the greenhouse with small inflatable polyethylene tubes that run the length of the greenhouse and are mounted inside and towards the bottom of the plant canopy (CO_2 gas is heavier than air). Along the length of these inflatable polyethylene tubes are small holes through which the CO_2 can escape, ensuring even distribution throughout the greenhouse.

Another method of CO_2 enrichment uses CO_2 burners (i.e., natural gas burners) to produce CO_2 from the combustion of natural gas.

These burners are usually distributed throughout the greenhouse to increase the uniformity of the gas distribution. Drawbacks of CO_2 burners can be that they produce (some) heat at the same time they produce CO_2 and that improperly installed burners can be a fire hazard. With any of the different CO_2 distribution methods, it is important that no harmful contaminant gasses are released at the same time. For example, ethylene gas is known to cause serious problems for some crop species even at extremely low concentrations. Therefore, a grower using CO_2 enrichment should make sure that the CO_2 gas released in the greenhouse is of the highest purity (check with your gas supplier and/or inspect all CO_2 burners regularly).

Monitoring and data storage

Just because you have a low-tech, low-cost greenhouse, that does not mean you should not be aware of the environmental condition inside your greenhouse. Excellent, and low-cost sensors and data loggers are available these days and you should take advantage of them. Once you get a feel for what is happening with your greenhouse temperature during the course of a day, a crop production cycle, or an entire season, you can make much better decisions about when to start venting, heating, or when to close the shade curtain.

Temperature sensors and/or thermostats should be mounted at a representative location, close to the crop canopy, and inside an aspirated box. This ensures you get accurate measurements of the conditions experienced by the crop (and not some distance away from the crop). Temperature sensors should be able to respond quickly and accurately to the often rapidly changing conditions inside the greenhouse. Some older sensors take too much time to register changes resulting in a slow response time of the control system.

Storing (logging) environmental data may seem a less useful task. However, retrieving these environmental data at a later time can be very useful and educational. For example, when you discover an equipment problem, it is not always obvious when the problem started. Reviewing the stored data may provide the answer and can help you assess what the impact on your crop might be and what corrective actions can be implemented. In addition, these data archives can be helpful for comparing environmental conditions during a previous period when a similar crop was grown. By comparing the conditions during the two cropping cycles, you may be able to explain some of the differences you observed in crop growth and development. Stored environmental data are very helpful for understanding how your greenhouse system responds to a variety of outside conditions. With this knowledge, you will be able to better anticipate your crop's needs and what you need to do to provide optimum growing conditions throughout the cropping cycle.

Additional References

National Greenhouse Manufacturers Association: http://www.ngma.com

Greenhouse Environment Control System Manufacturers

Argus Control Systems Ltd.
1-800-667-2090
http://www.arguscontrols.com

Bartlett Instrument Company
1-319-372-8366
http://www.bartinst.com

Johnson Controls, Inc.
1-414-524-1200
http://www.jci.com

Micro Grow Greenhouse Systems, Inc.
1-909-296-3340
http://www.microgrow.com

Priva Computers, Inc.
1-905-562-7351
http://www.priva.ca

Q-COM Corporation
1-800-833-9123
http://qcomcorp.com

Wadsworth Control Systems, Inc.
1-800-821-5829
http://www.wadsworthcontrols.com

Ten Ways To Reduce Your Energy Bill

1. Install Energy Curtains

A properly installed curtain system can save a significant amount of energy. With the current high fuel prices, these systems will pay for themselves in a short time period.

2. Reduce Air Leakage From The Greenhouse

Depending on temperature differences between inside and outside air, and wind speed and direction, air will move through cracks or other openings either into or out of the greenhouse. Therefore, it is important to close these openings to prevent this unwanted movement of air. Over time it is not uncommon for louvers on ventilation openings or for ventilation windows to only partially close (e.g., when parts are bent or warped). Therefore, it is important to make sure that these systems close properly and tightly in order to minimize unwanted air movement between the inside and outside of the greenhouse.

3. Provide Heat Only Where It Is Needed

Bench and floor heating systems provide heat close to where you grow your crop. The clear advantage is that you need to use less energy to heat the rest of the greenhouse air volume. Most growers that use bench or floor heating systems report that they are able to successfully grow a crop while maintaining a lower air temperature. As always, it is a good idea to install circulation fans (HAF) inside the greenhouse to provide uniform temperatures throughout the growing areas.

4. Install An Energy Efficient Heating System

Use the highest efficiency units you can afford. In addition, always try to use so-called separated combustion units that use outdoor air for the combustion process and return this air to the outside without it making contact with any indoor greenhouse air.

5. Calibrate Your Temperature Sensors

It is important to use temperature sensors that are regularly calibrated. Every environment control system responds based on temperature readings and if the sensor provides incorrect measurements, the control system will not be able to provide the intended temperature set points. Some growers lower their temperature set points in order to save energy. However, one should be cautious because lower temperatures reduce plant growth rates, and can increase insect and disease problems.

6. (Perimeter) Insulation

It makes a lot of sense to install perimeter insulation (e.g., 2 inch polystyrene board around the entire perimeter to a depth of two feet). This perimeter insulation will reduce the heat loss through the greenhouse floor to the ground directly surrounding the greenhouse. Usually, the heat loss to the ground underneath the greenhouse is relatively small, but if the water table underneath the greenhouse is high (less than 6 feet below the floor), it may be worthwhile to install insulation (e.g., 2 inch polystyrene board) underneath the entire floor.

7. Use A Double Layer Cladding System

Double poly or even double glass will reduce the heat loss by approximately 40% compared to a single layer of glazing material.

8. Install Windbreaks

In areas with high wind speeds, especially during the heating season, it is recommended to install windbreaks (shrubs and trees) around the entire greenhouse or at least in the upwind direction of the prevailing wind.

9. Use The Cheapest Fuel

It is not always easy to determine which is the cheapest fuel (prices fluctuate depending on many different factors), but you should be able to get a good idea by talking to other growers and your local fuel suppliers.

10. Alternative Energy Sources

Consider alternative energy sources (e.g., wind, water, solar). Significant improvements in conversion efficiencies have been demonstrated and in some areas it is possible to sell any excess power (electricity) back to the local utility. In addition, co-generation units may become a more attractive alternative making growers less dependent on local power companies.

2004 Greenhouse Engineering Short Course
Design of Greenhouse Systems
Cook College, Rutgers University

Program

Thursday January 8, 2004

8:00 am Arrival and Registration

8:30 am Introduction and Overview of Greenhouse Systems
A.J. Both

9:15 am Things to Consider when Designing and Building your Own Greenhouse
Dave Mears

10:15 am Break

10:30 am Greenhouse Heating
A.J. Both

11:15 am Soil Heating
Bill Roberts

12:15 pm Lunch

1:00 pm Important Greenhouse Crops and Their Production Systems
George Wulster

2:00 pm Greenhouse Ventilation and Cooling
A.J. Both

2:45 pm Break

3:00 pm Greenhouse Glazing
Bill Roberts

4:00 pm Open-Roof Greenhouse with Subirrigation and Floor Heating
Eugene Reiss

5:00 pm Adjourn

Friday January 9, 2004

8:30 am Greenhouse Supplemental Lighting and Shading
A.J. Both

9:15 am Financial Aspects of the Greenhouse Business
Robin Brumfield

10:15 am Break

10:30 am Greenhouse Environment Control Systems
A.J. Both

11:15 am Low Tech: High Tunnels
A.J. Both

12:00 pm Lunch

12:30 pm Tour of Commercial and Research Greenhouses

5:00 pm Tour returns, **Adjourn**

Registration information is available from the Office of Continuing Professional Education at Cook College: (732) 932-9271, or on the web: *http://cook.rutgers.edu/*

Greenhouse Engineering Workshop
January 21-22, 2004
Ohio State University
Wooster, OH 44691

The Ohio State University will host its 6th Greenhouse Engineering Workshop at the Ohio Agricultural Research and Development Center (OARDC) in Wooster, Ohio from January 21-22, 2004. This workshop will focus on energy management and is designed to provide the latest information on energy management for efficient greenhouse heating operations. Major topics covered are: energy conservation, heat delivery, alternative fuels, and management strategies to increase greenhouse profitability. Information will be delivered through presentations and interactive "Ask the experts" sessions to address general and specific needs of the workshop participants.

For more information contact:
Dr. Peter Ling
Food, Agricultural, and Biological Engineering Department
1680 Madison Avenue, Wooster, OH 44691
Phone: (330) 263-3854
E-mail: ling.23@osu.edu
Visit **http://www.oardc.ohio-state.edu/ling/announce.html**
for online information

Greenhouse Crop Production and Engineering Design Short Course
January 18-21, 2004
The University of Arizona
Controlled Environment Agriculture Center
Tucson, Arizona

Designed specifically for
Controlled Environment Agriculture
in the Southwest

Topics include:
Crop Production
Engineering
Marketing
Pest Management
Environmental Control

Organized and sponsored by the
Controlled Environment Agriculture Center
and Cooperative Extension in the
College of Agriculture and Life Sciences,
The University of Arizona, Tucson, Arizona

Contact Dr. Gene Giacomelli
giacomel@ag.arizona.edu;
(520) 621-1412 Voice;
(520) 621-3691 FAX

Visit **http://www.ag.arizona.edu/CEAC**
for online information

Research greenhouses of the OARDC in Wooster, OH.

Research greenhouses of the CEAC in Tucson, AZ.

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Greenhouse heating system.

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

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Upcoming Meetings, Shows, etc.

NJ Vegetable Growers Association Annual Meeting
Atlantic City, NJ
January 13-15, 2004
http://www.njveggies.org/

Mid-Atlantic Fruit and Vegetable Convention
Hershey, PA
January 28-30, 2004
Info: wt.pvga@tricountyi.net

Empire State Fruit and Vegetable Expo
Rochester, NY
February 9-12, 2004
Info: Jeff Kubecka, (315) 687-5734

Ohio Short Course
Columbus, OH
July 10-14, 2004
http://www.ofa.org

HortiFair (NTV)
Amsterdam, the Netherlands
November 3-6, 2004
http://www.hortifair.nl

For more information on greenhouse crop insurance, please visit the following web site: http://aesop.rutgers.edu/~farmmgmt