CHAPTER 13

GREENHOUSE CONTROL SYSTEMS

INTRODUCTION:

*WHY a need for control systems? When you build a greenhouse, the environment inside changes: Light and CO_2 decrease while temperature and humidity increase.

*Therefore, control systems must include those for lighting, heating, cooling, relative humidity and carbon dioxide enrichment.

LIGHT:

***Importance:** Maximum light transmission, of the appropriate quantity and quality (photosynthetically active radiation (PAR) 400-700 nm), through the greenhouse structure to the plants is crucial for optimum photosynthesis, growth and yield.

***Structural considerations:**

Large sections of glazing material (glass, polyethylene, polycarbonate, etc.), held in place by few supports, results in higher light levels and less shading.

Minimize other opaque structures above the crop that would cause shading such as heaters, carbon dioxide generators, opaque vents, etc.

***Too much light:** Occurs in high light regions such as the desert southwest USA (including Arizona), Mexico, Spain, Israel, etc. during the Summer months.

Shade paint/white wash: A mixture sprayed on the outside of the greenhouse. This will either wear off by the end of the Summer or it can be washed off.

External shade cloth: Fabric cloth, placed on the outside of the greenhouse, made of varying degrees of mesh size to exclude specific amounts of light (ex.: 30%, 40%, 50% shade).

Internal shade cloth: Fabric cloth, as above, hung inside the greenhouse.

***Too little light:** Occurs above/below 30^0 north/south latitudes during the “Winter”.

White reflective ground cover: Common in commercial greenhouses in all locations. Can significantly increase light levels to the plant canopy.

Artificial lights:

Used above 30^0 north/south latitudes to extend the Winter growing season.

Provide day length control (photoperiod) that can initiate plant processes.

Provide proper timing of light to control growth (photomorphogenesis).

Typical lamp types include incandescent, fluorescent, mercury vapor, high pressure sodium and low pressure sodium.

Current research on LED’s – use less energy & are more efficient.

Artificial lighting COSTS MONEY! Choose a location that minimizes the need for lights to increase profits. Artificial lighting is most cost effective to start “transplants” early since they require less space.

HEATING:

***Importance:** Each plant species has an optimum temperature range. Heating devices will maintain the temperature within that range during periods of cold weather. IMPORTANT: Do not undersize your heating capacity. You may not need all your heaters much of the year, but if you undersize your system you may loose your entire crop during the coldest nights of Winter!

***Types of heat transfer from or within a greenhouse**

Conduction = Heat transfer either through an object or between objects in contact. Conduction depends on area, path length, temperature differential and physical properties of the object(s).
Ex: Heat loss through glazing material to the outside of the greenhouse.

Convection = Heat transfer by the movement of warm gas or liquid to a colder location. Convection depends on temperature differential.
Ex: Movement of warm air near the plants upward toward the roof.

Radiation = Heat transfer between separated objects. Occurs from all objects. Depends on areas, temps & surface characteristics of all objects involved.
Ex: Heat transfer from objects within the greenhouse or from the warm roof glazing to the immediately surrounding atmosphere.

***Heat loss calculations:** This mainly depends on <u>conduction!</u>

It is important to be able to estimate the heat loss from the greenhouse in order to choose the correct size of heater to replace that heat.

Although radiation and convection transfer heat around the greenhouse, the main <u>type of heat loss from a greenhouse</u> is <u>**conduction**</u> through the glazing.

Conduction heat loss can be estimated: **Q = U A (Ti – To)**

Q = conduction heat loss in Btu's (British thermal units) = size of heater needed

U = heat transfer coefficient: Btu/hr*sq.ft.*deg F temp diff. Typical U values:

1.13 Btu/hr*sq.ft.*deg F		Glass, single layer
0.65	"	Glass, double layer, ¼" space
1.15	"	Polyethylene or other film, single layer
0.7	"	Polyethylene or other film, double layer
1.0	"	Fiberglass reinforced panel
1.2	"	Polycarbonate, single layer, corrugated
0.65	"	Acrylic or polycarbonate, double layer
0.58	"	Polycarbonate, triple layer (also cuts light)

A = surface area (sq. ft.) of greenhouse glazing (does not include the ground)

Ti – To = (temp required inside) – (lowest temp expected outside)

Ex: A gable greenhouse
24' wide, 48' long, 8'to gutter
6' from gutter to peak
Double layer acrylic
15 F – lowest night outside temp
65 F – required night inside temp

<u>**Draw the greenhouse here**</u>**:**
Make it <u>3-D</u> to show all surfaces

Area of the greenhouse =	2 Sq ends = 2x8x24 =	384
(surface area)	2 Triangle ends = 24x6 =	144
	2 Sides = 2x8x48 =	768
	2 Sq roofs = 2x48x13.42(*)=	1288.32
	Total square feet =	2584.32

(*) Every length is straightforward… except the roof: use right triangle equation where c = "slanted" roof length: $a^2 + b^2 = c^2$

$c^2 = 6^2 + 12^2 = 36 + 144 = 180 \quad c = 13.42$

Q = (0.65) (A) (65-15)
= (0.65) (2584.32) (50)
= 83,990.4 Btu's/hr

***The basic heating system:**

Consists of a **fuel burner**, **heat exchanger**, **distribution system** and **controls**.
Heat delivery to the crop is by **convection** and **radiation**.
The fuel = usually burn **natural gas**, but also oil, coal, wood, "biofuels", etc.

***Heating by hot water or steam:**

Hot water or steam can be produced using boilers fired by natural gas, etc.
The hot water or steam is then transported throughout the greenhouse in pipes.
The pipes can end in a heat exchanger where a fan distributes heated air.
The pipes can run along the floor and also be used as cart rails between aisles.
Heat will then rise upward through the crop by convection.
Heat pipes can also be positioned within the crop to steer plant growth (Ch. 3).
Heated tubes can create "bottom heat" for propagation or growing.

***Heating by hot air:**

Fuel is burned to heat air that is then distributed by fans around the greenhouse.
Horizontal air flow (HAF) fans circulate warm air above the crop.
Fan jet systems, with unit heaters or heat exchangers and perforated polyethylene tubes, distribute warm air and improve air movement and ventilation throughout the greenhouse.

***Moveable nighttime insulation:** Cloth or film curtains can be positioned above the crop or near the roof to retain heat near the crop. The insulating material used during the night can be the same material used for shading during the day.

***Can have passive heating systems:** but these are not typical; see Chapter 14.

COOLING:

***Importance:**

High temperatures can be detrimental to plant growth.
High temperatures can cause such problems as
Thin, weak stems or, as in tomatoes, stick trusses (thin, weak truss stems)
Reduced flower size or, as in tomatoes, flower fusion and boat formation
Delayed flowering and/or poor pollination/fertilization and fruit set
Flower and bud and/or fruit abortion

***Passive cooling systems:**

Shading: Shade cloth or shade paint/white wash, besides regulating the light intensity, can also help cool the greenhouse.

Ridge Vents: Vents in the roof of a greenhouse that allow hot, interior air to escape. The area of the vents should be 25% of the floor area.

Roll-up Side Walls: Can be used in flexible glazing (polyethelene film) single bay greenhouses where the side walls can be rolled up several feet allowing a natural horizontal flow of air over the plants. As with ridge vents, the area of the side wall vents should be 25% of the floor area.

Cooling Towers: Water cooled pads at the top part of tall towers cool the surrounding air. The cooled air then drops displacing warmer air below.

Removable Roof: Recent greenhouse designs can include a roof that retracts completely for natural ventilation. This would allow for adaptation of greenhouse grown plants to outside conditions prior to movement outside.

***Active cooling systems:**

Fan and Pad: "Evaporative cooling" where air from the outside is pulled through porous, wet pads (usually cellulose paper). Heat from the incoming air evaporates water from the pads, thereby cooling the air. Evaporative cooling will also help to increase the relative humidity in the greenhouse. Expt: moisten a patch on your skin & blow across it → evap. cooling!

Fogging Systems: Uses evaporative cooling like the fan and pad but incorporates a dispersion of water droplets that evaporate and extract heat from the air. This system gives better uniformity since the fog is distributed throughout the greenhouse and not just near one end, as with the fan and pad system. The smaller the droplet size, the faster each droplet evaporates and therefore the faster the cooling. Mist droplets = 1000 microns in diameter.

Air Conditioning: Too expensive for most greenhouses.

***Cooling requirements & calculations: This gives you the proper fan capacity:**

The National Greenhouse Manufacturer's Association 1993 standards =

8 cubic feet per minute/square feet of greenhouse floor area OR…

1 full greenhouse volume exchanged per minute in warm climates.

CFM = height x width x length = volume of air to be moved

Note: Dr. Nadia Sabeh (Ph.D. UA/ABE 2007), testing cooling in Tucson, found that, under hot dry conditions, if you go above ½ a greenhouse volume or 0.5 air exchanges/min, you don't cool any more effectively:

Air exchanges/min	Water Use gm-2s-1	T oC	T oF
0.1	--		
0.2	0.1	26	79
0.4	0.2	23	74
0.5	0.28	21	69
0.7	0.34	21	69

In fact, one full greenhouse volume exchange per minute produced slight warming (personal communication from Dr. Giacomelli – 2007).
Therefore: in hot, dry conditions, having all fans on may work against you.
However: in humid conditions, you may need all fans…

Therefore: <u>Don't ever undersize your fan capacity!</u>

Ex: Using the greenhouse dimensions in the heat calculation example AND the 1 full greenhouse volume exchange per minute criteria:

CFM = volume lower section + volume triangular top (1/2HtxWxL)
= (8 x 24 x 48) + (6/2 x 24 x 48)
= 9216 + 3456
= 12,672 cubic feet per minute

Therefore, for this example, you would purchase fans that will give you this amount of air flow and size your pads accordingly.

$$\% \text{ RELATIVE HUMIDITY} = \frac{\text{Amount of water in the air}}{\text{Amt. of water possible at a given temp.}} \times 100$$

***Importance:**

High or low relative humidity can be detrimental to plant growth.

Effects on transpiration – When RH is too high, transpiration is reduced along with movement of mineral nutrients through the plant. When RH is too low, transpiration may be significantly increased, resulting in plant wilt.

Effects on pollination – When RH is too high, the pollen can clump on the stigma causing cat facing or the pollen may not be released from the anthers at all. When RH is too low, the normally sticky stigma can dry out and the pollen may not stick to it's surface, decreasing pollination.

Many greenhouse crops are bred for higher humidity. If grown outside, in lower humidity environments, they usually perform poorly.

***Ways of controlling RH in the greenhouse:**

Relative humidity can be increased by running the cooling pads or by fogging.
Relative humidity can be decreased by running the heaters or simply venting.
Problem with either method: will these actions adversely change temperature?

CARBON DIOXIDE (CO_2) ENRICHMENT:

***Importance:**

The rate of photosynthesis is dependent upon the availability of carbon dioxide.

Carbon dioxide (CO_2) enrichment is most important during the Winter months in the morning (or evening) when it is cold outside and fans are not on.

The sun drives photosynthesis. When sunny, plants can reduce CO_2 levels from ambient, 390-400 ppm (higher in cities – industry/vehicles) to ~ 220 ppm.

Lowered carbon dioxide levels reduces growth and can cause flower and fruit drop reducing overall yields.

***Ways of controlling carbon dioxide levels in the greenhouse:**

Ventilating (bringing air in from the outside) may provide sufficient carbon dioxide during the Spring, Summer and Fall months. Venting in Winter, or other cold times, will, however, result in cold outside air coming into the greenhouse and heating may be needed; may become uneconomical.

CO_2 generation is typical and effective. CO_2 generators can burn natural gas (most economical) or propane. CO_2 levels of 800 - 1200 ppm, have been shown to be beneficial to plant growth (but use will depend on gas prices).

AIR CIRCULATION:

***Importance:**

One reason for having a greenhouse is to create a "controlled environment" for all of the plants. And each plant within the greenhouse should receive the same conditions. However, especially during times when the heating and cooling systems are not in operation, pockets of high or low temperature, relative humidity or carbon dioxide may develop which can be less than optimal for plant growth or flower/fruit development.

***Ways of improving air circulation:**

Horizontal air flow (HAF) fans can be placed in the rafters of the greenhouse to circulate air above the crop. This helps to minimize pockets of warm or cold air, high or low humidity and carbon dioxide in the greenhouse.

HAF fans can be used in conjunction with hot air heating systems (see above) to circulate warm air throughout the greenhouse.

HAF fans can also be used at anytime to enhance air mixing in the greenhouse.

ENVIRONMENTAL CONTROL SYSTEMS:

***Control systems can be very simple or very complex. Examples include:**

The "original" environmental control systems were manual:

- Manually rolling up a side vent.
- Manually opening a roof vent or door.
- Manually turning on a heater or cooler.

Simple controllers operate using thermostats in the greenhouse and:

- Automatically maintain day and night temperature ranges.
- Automatically open and close vents (side, roof, etc.).
- Automatically turn on or off heaters and fans/pads.

Step controllers operate using a temperature sensor in the middle of the greenhouse (for tomatoes, placed at the level of the flowers) and:

- Automatically maintain day and night temperature ranges.
- Automatically control 1 or 2 heating stages (depends on # of heaters).
- Automatically control cooling stages using vents, fans and pads.

Sophisticated computers operate using a temperature sensor in the middle of the greenhouse (for tomatoes, placed at the level of the flowers) and:

- Automatically maintain day and night temperature ranges.

Automatically control heating equipment including boilers, root zone heating, heat retention curtains (i.e., thermal blankets), etc.
Automatically control other equipment including HAF fans, exhaust fans, vents, pad pumps, fogger systems, etc.
Automatically control relative humidity (in some systems; difficult).
Automatically control shade curtains and artificial lighting.

Sophisticated computers can also monitor an external weather station and use data from that station to control internal conditions in the greenhouse.
Data monitored includes: outside light, temperature, RH, rain and wind.
Examples of systems that can be controlled:
Shade curtain: deployed or stowed depending on light availability
Vents: can be closed during rain or high wind events
Rain can wet plants promoting fungal infections
Wind can blow in pathogen spores or blow out roof!

Sophisticated computers can also operate the fertigator system (see Chapter 10)
Automatically using light quantity (e.g., X ml of solution/Y amt. of light)
Automatically controlling timing of watering, duration of watering, nutrient solution pH and EC, misting, watering booms, etc.

What is the basic information you will need to program?
Environment: Set points for temperature (to activate fans, pads, vents & heaters will), carbon dioxide (CO_2 generator), light (shading if too bright, artificial lights if too dark)
Fertigator: Set points for pH, EC, duration of irrigation (to give 60-120 ml per watering), number of irrigations (will need to be adjusted as the plants grow and the seasons change, see page 10-5, input/output calculations) and on/off times (since we only fertigate during the day, on/off times will change throughout the year as days decrease in length in the Fall and then increase in length in the Spring). NOTE: Some systems change on/off times automatically.

.

A NEW DESIGN: CLOSED/SEMI-CLOSED GREENHOUSES

*Pioneered in The Netherlands, the closed & semi-closed greenhouse design reduces the release of CO_2 into the atmosphere and loss of warm or cool air and moisture.
In Summer, a heat exchanger transfers heat from the air in the greenhouse to water which is then pumped into an aquifer below. Cool water from the aquifer is pumped up to cool the greenhouse. In Winter, the reverse occurs.
In other designs a heat exchanger in a tower above the greenhouse is used.

*A semi-closed greenhouse has been built by Village Farms in Texas, with great success.
The GATES design greenhouse has surpassed 100 kg/m_2 of tomato production.
GATES = Greenhouse Advanced Technology Expert System

*EuroFresh in Willcox Arizona was experimenting with semi-closed greenhouses

*Wholesum Family Farms in Amado AZ built a semi-closed greenhouse and is organic.

*Problems/Pleasures: With no release of humidity, moisture from plant transpiration and other sources must be dealt with. With closure comes less problems with pests.

VIRTUAL GROWER 3
*A program developed by the USDA / Agricultural Research Service (ARS).
*Free to everyone; downloadable from the internet.
*Can create a virtual greenhouse with plants and predict energy requirements, lighting needs and more.
*Weather databases are preloaded for 785 locations in the United States. If your location is not in the "location" list, you can use a city close to your location.

REFERENCE MATERIALS:

1. **Conserving Energy In Ohio Greenhouses.** 1979. P.C. Badger and H.A. Poole. Ohio State University, Cooperative Extension Service Bulletin No. 651.
2. **Energy Conservation For Commercial Greenhouses.** 1989. W.J. Roberts, J.W. Bartok, E.E. Fabian and J. Simpkins. NE Regional Agricultural Engineering Service, NRARS-3, Cornell University, 152 Riley-Robb Hall, Ithaca, NY, 14853.
3. **Protected Agriculture: A Global Review. Part 2: Protecting materials and structures.** 1995. M.H. Jensen and A.J. Malter. The International Bank For Reconstruction and Development/The World Bank. 1818 H Street, N.W., Washington, D.C., 20433. ISBN 0-8213-2930-8.
4. **"Google"** your favorite topic or the following companies (for example): Crop King, Hummert International, Micro Grow, Wadsworth, Argus, Priva, TrueLeaf, Fan Jet, Modine, Schaffer, Bartlett, Agra Tech, Delta T Solutions, etc.

Concerning closed and semi-closed greenhouses:
http://blog.maripositas.org/page/9
https://kb.osu.edu/dspace/bitstream/handle/1811/36591/weefong?sequence=1
http://www.crophouse.co.nz/files/Gr_G01-Greenhouse_matters-view.pdf
http://www.villagefarms.com/AppliedResearchDivision/Default.aspx
http://www.bomgroep.nl/files/file/Hortifair%20Seminar.pdf

Concerning Virtual Grower 3
http://www.ars.usda.gov/services/software/download.htm?softwareid=309