Controlled Environment Systems ABE 483/583

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Lecture #8 Heating Systems
Air Heating in the Greenhouse Environment Design, Operation and Expectations

Hannan: **Chapter 4, Temperature,**
pps. 167 - 171 Energy Balance [focus of this first lecture!]
pps. 171 - 186 Effects of Temperature on Plants [minor focus!]
pps. 186 - 199 Temperature Measurement and Its Manipulation
pps. 199 - 223 Heating Systems and Energy Sources
pps. 223 - 236 Energy Conservation
pps. 236 - 260 Ventilation and Cooling

'HeatVent' software by Wei Fang

Others:
ASHRAE 1985 Fundamentals Chapter 6, pps 6.1 – 6.20
The Greenhouse Climate Control Handbook, Engineering Principles and Design Procedures by ACME Engineering & Manufacturing Corp.
A & B Chp 4 Effects of Environment on Plant Growth 4.1-4.5; 4.6 - 4.17
A & B Chp 5, Heating 5.1 - 5.11; 5.15 - 5.20
Roberts, W.J. and D.R. Mears, "Heating and Ventilating Greenhouses" Cooperative Extension Service, Cook College, Extension Publication #E-046, August 1984.

Roberts, W.J., "Soil Heating Systems for Greenhouse Production" Rutgers Cooperative Extension, Cook College, Rutgers University, New Brunswick, NJ. Extension Publication #E-208, April 1996.

ACME controlled environment equipment for greenhouses

Determining the design heat load of the greenhouse. This is the value used for determining the size of the boiler and type(s) of heat distribution system(s).

The heat load is a function of the

- insulative value of the greenhouse glazing
- surface area of the greenhouse
- temperature difference between inside and outside the greenhouse
- radiative properties of the covering
- infiltration through covering

Sizing the Heating System

Maximum greenhouse heat loss (BTU per hour) must equal capacity of heater

$Q = U \times SA \times (T_{in,min} - T_{out,min})$

- minimum outside air temperature
- minimum inside air setpoint temperature
- total surface area of greenhouse
- overall heat transfer coefficient
- heat loss from greenhouse (or heater size)

Overall Heat Transfer Coefficient U

primarily related to greenhouse covering

- single or double layer
- film or rigid plastic
- glass or plastic
- single or multi-span structure

Overall Heat Transfer Coefficient U, (B hr^{-1} ft^{-2} $^{o}F^{-1}$)

single layer glass	1.2
single layer P.E.	1.2
double layer P.E.	0.8
double-walled, structured plastic (acrylic, polycarbonate)	0.6

Temperature Difference

(Tin - Tout,min)
minimum outside air temperature
regional minimum inside air setpoint temperature
desired/required value for plants

Energy Conservation (reduce fuel consumption)

build a smaller greenhouse
select covering
warmer climate
reduce inside air temperature
insulation systems

Types of Air Heating Systems

Hot air

direct fired unit air heater
air heat exchanger unit
(via hot water boiler)

Hot water

water to air heat exchanger
pipe loop system
root zone or floor heat system

Heat Losses

infiltration
evaporation
conduction/convection
radiation

The overall heat transfer coefficient (U) combines all of the heat loss terms into one general term. It consists of conduction, convection and radiation components, as well as, air infiltration (sometimes). Therefore it is important to know its derivation. It is furthermore, an average value for many environmental conditions.

	with infiltration	w/o infiltration
$U_{single\ glazing}$	1.2 B hr^{-1} ft^{-2} $^oF^{-1}$	1.1 B hr^{-1} ft^{-2} $^oF^{-1}$
$U_{double\ glazing}$	0.8 B hr^{-1} ft^{-2} $^oF^{-1}$	0.7 B hr^{-1} ft^{-2} $^oF^{-1}$

Determining actual heating costs of an operational greenhouse

The following analogy is used to clarify the difference between the static design (maximum heating load), and the dynamic design considerations for the production capacity and operational interactions of each system. Consider the procedure to determine the design load of a greenhouse heating system (ie. "sizing" the boiler), as compared to determining the projected operational demand“ and subsequent fuel consumption during any given day (or entire heating season). The selection of the size of the boiler is primarily dependent upon the amount of surface area and insulative properties of the greenhouse structure, and the maximum expected difference of the inside setpoint air temperature from the minimum expected outside air temperature. This represents the static or worst case situation design. However the real operating costs to heat the greenhouse are dependent on the difference of the actual inside and outside air temperatures at each and every moment of the heating season, and the length of time each of those temperature conditions is maintained. Thus the design heating load capacity of the boiler may rarely (or never) be reached, but the boiler must provide heat at some level, which is less than the design capacity, nearly all the time during the heating system. Unless the air temperature difference is known on an hourly basis through historical weather data or by real time data acquisition system, the Degree Day Procedure can be used to determine the amount of heat needed over a given period.

Degree Day Procedure

Degree day value is calculated from an arbitrary base temperature, 65 ^oF. The daily average air temperature is subtracted from this base temperature to obtain the degree day value for that day.

Degree Day:

D.D. = (65 - average day air temperature)

The average day air temperature is a simple average between the minimum and the maximum day temperature,

$[T_{min} + T_{max}) /2]$.

This seems to be a very poor indicator of the day temperature but it is reasonably good and regularly utilized.

Given a DD value for any given day then one knows the average day air temperature of that day and thus can use this value in the heat loss equation. For example, if today was 40 degree days, then the average day temperature was 25 ^oF. If the setpoint temperature for the greenhouse is 60 ^oF then the heat, Q needed for today was:

Q = U x A x (60 - 25) B/hr x 24 hr

If a boiler efficiency of 71% is assumed and the low heating value for fuel oil is 140,000 B Gal, then approximately 100,000 B Gal fuel can be assumed available. Dividing the above equation by this value will determine the number of gallons of fuel required for this day.

Daily solar radiative heating was not considered at all. The same delta temperature was assumed to occur for the entire 24 hour period.

A further assumption for energy use can be determined on a monthly basis. Given that the month of December in NJ has historically provided 930 degree-days and knowing that there are 31 days in December, then the average day temperature in December can be calculated as:

(930 DD/Dec) / (31 days/Dec) = 30 DD/day

therefore, the average day air temperature would be D.D. = (65 - average day air temperature), or 30 = 65 - ave day temp = 35^oF

the heating requirements for that month would then be

$Q = U \times A \times (60 - 35)\ B\ hr^{-1} \times 24\ hr \times 31 days$

Each month of the heating season can be determined and added to obtain the yearly energy costs.

The greenhouse energy calculation program included within the Heat&Vent Software will be presented, discussed and utilized.

How to provide and distribute the heat within the greenhouse

Types of Heating Systems

hot water pipes
(overhead and/or at floor),
forced warm air
fanjet, water-to-air heat exchanger
floor heating
bench heating
radiant heating

Forced Warm Air

Unit heater with burner and vented to outside

This is a self-contained unit that requires natural gas or propane as a heating fuel source, and a small amount of electrical power for its convection fan. FAN-JET and Modine are two manufacturers of such heaters.

Mount unit heater of required size [per $Q = U \times SA \times (T_{in,min} - T_{out,min})$] for each section or bay or zone of the greenhouse. Distribute heat by forced convection from unit heater through a convection tube which extends the entire length of the bay. Typically 24 inch in diameter, clear tube with holes spaced along its length.

Example: Sizing the pressurized tube fan (Fan-Jet)

Design as 1st stage ventilation
1/3 Hp 24 inch tube 5400 CFM provides 30% ventilation capacity requires 30 inch by 30 inch inlet and exhaust shutters

see page 15 of ACME GH Climate Control Handbook for details of a FAN-JET system

Heat Exchanger

This is only a heat exchanger that must be connected into a hot water source, and provided electrical power for its convection fan.

Mount heat exchanger of required size [per $Q = U \times SA \times (T_{in,min} - T_{out,min})$] for each section or bay or zone of the greenhouse. Distribute heat by forced convection from unit heater through a convection tube which extends the entire length of the bay. Typically 24 inch in diameter, clear tube with holes spaced along its length.

Hot water must be pumped from remote boiler to heat exchanger at specification water temperature, water flow rate and pressure flow loss. Calculate pipe size for hot water transport to the heat exchanger based on the required water flow rate, and subsequent pressure loss. This will determine pump size.

See www.bellgossett.com for pump sizing.

Pressure loss will include pipe losses, pipe fittings losses [ells, tees, etc], and losses due to inline components [filters, valves, etc.].

Hot Water Pipe Loop

Already determined total design heat load by Q = U x SA x ($T_{in,min}$ - $T_{out,min}$), now must deliver this amount of energy from the boiler to the greenhouse plant growing space. One approach is to design an array of pipe loops which will carry the warm water to each location within each bay to provide uniform heat distribution and therefore uniform air temperatures.

Assuming that the pipe loses heat at a known rate, say 170 B hr^{-1} ft^{-1}, if the:

water temperature in pipe is 180 F
greenhouse air temperature is 60 F
the pipe is made of unpainted steel
temperature difference from beginning of loop to end is approximately 10 – 15 F.
water flow rate > 1.5 fps but < 2.5 fps

The HEAT&VENT software determines how many linear feet of is required for each bay.

Heat Distribution:
One final comment emphasis about hot water heating systems…..They are more expensive than hot air systems, but they offer the potential to provide a more uniform distribution of heat, and therefore more uniform air temperature throughout the greenhouse.

As we discussed in the design procedure for sizing and locating the hot water pipes......

To achieve uniform heat distribution, the system requires that uniform hot water flow occur throughout the system;
To get uniform water flow you need an equal pressure difference across each pipe loop;
To get uniform pressure difference, size each pipe loop to be equal in length, pipe diameter, and material, and;
Use a double return [reverse return] header to connect to each of the pipe loops, as this combination will assure equal water flow distance, and thus the best chance for equal pressure difference and thus equal water flow throughout the heating system.

Flow:
Water flow rate (fps) in the pipe is determined by velocity limitations.
Water flow capacity (gpm) in the pipe is determine by the velocity and pipe diameter [(since Flow = (velocity) x (cross section area of the pipe)).
Total water flow is determined by the number of pipe loops.

Pressure:
Pressure loss in pipe is function of pipe diameter, water flow rate, length of pipe, roughness of inside of pipe [type of pipe, metal or plastic], number of fittings.
Pressure loss in pipe fittings [ells, tees, etc], filters, valves, etc.
Total system pressure is the maximum sum of the pressure losses of one of the loops, plus the pressure loss within the header.

Use tables to find pressure loss, or Darcy-Weisbach formula to calculate pressure loss.

Given the need for 8 lengths [runs] of plain pipe per bay, then in a 100 foot long greenhouse that is 800 feet of pipe @ 2.5 fps that is 25 gpm, therefore H= head loss = 1.5 ft per 100 ft of pipe

Given the need for 8 lengths [runs] of plain pipe per bay, then in a 100 foot long greenhouse that is 800 feet of pipe @ 2.5 fps that is 25 gpm, therefore:

$H = 3.022\, L\, (V/C)^{1.852} / D^{1.167}$

Where L = 8 (100ft), V= 2.5 fps, C = 140 for steel pipe, D = 2.0/12 feet

H ~ 20 ft, or from chart, H ~ 12 ft of head loss

Once determine the pressure and flow required then select a pump: http://fhs.ittind.com/ or find copy of pump curve.
Compare pump curve (its flow versus system pressure) to the calculated system pressure.

Bottom Heating Systems
See 'Soil Heating systems for Greenhouse Production" William J. Roberts, Extension Publication E208, Rutgers University, April 1996.

Similar design procedure to above, except with ¾ inch diameter plastic pipe, not 2 inch diameter steel pipe.

Describe system (see handout):
- plan view
- cross section view

Wet and Dry floor systems

Design heating calculations for floor heating –
for sizing boiler to supply the energy to the floor heating system, use 30 Btu hr^{-1} ft^{-2}
for expected energy to obtain from the floor for heating the greenhouse, use 20 Btu hr^{-1} ft^{-2}