Greenhouse Cooling

*Why is Cooling Needed?*

- Solar radiation is the “heat input” for the earth
  - can radiate as much as 277 Btu/ft\(^2\)/hr onto the surface of the earth on summer’s day
  - in coastal and industrial areas, may only be 200 Btu/ft\(^2\)/hr
- Up 85% of this radiation may enter the greenhouse
  - most of the IR heat becomes trapped inside
  - greatly increases the greenhouse temperature
- Mechanism is needed to remove this trapped heat
Greenhouse Cooling

*Types of Cooling Systems*

- Summer cooling
- Winter cooling
Summer Cooling

Passive Cooling Systems

• Open ridge and side wall vents
  — temperatures can still rise 20 °F above outdoor in old-style greenhouses
    • ridge vent area is only about 10% of the total roof area
  — newer passive cooling greenhouses have ridge vent areas equal to 20 to 40% of the total roof area
    • can maintain temperatures closer to outdoor temperatures
Summer Cooling

Passive Cooling Systems

• Other modifications include
  – roll-up side walls for ventilation
  – roof ventilators on plastic film-covered greenhouses
  – retractable roof greenhouses for almost 100% ventilation area
Summer Cooling

Passive Cooling Systems

- Passive cooling is cheaper to operate than active cooling
- Initial construction cost = $1.25/ft\(^2\) of greenhouse floor area to add ventilators to a polyethylene film covered greenhouse
Summer Cooling

Active Cooling Systems

- Takes advantage of heat absorption from air during the evaporation of water

- Two major types:
  - fan and pad
  - fog cooling

- Accurately designed fan and pad system should be able to lower the temperature of incoming air by 80% of difference between the dry and wet bulb temperatures
Summer Cooling

Active Cooling Systems

- Dry bulb temperature--actual air temperature measured with an ordinary thermometer
- Wet bulb temperature--the air temperature if enough water were to be evaporated into it to saturate the air
  - measured with a psychrometer
  - wet “sock” is placed over the bulb of a thermometer
  - air is drawn across the moistened sock to allow for evaporative cooling
Summer Cooling

Active Cooling Systems

• Wet bulb temperature is what the air can be cooled to if 100% efficient evaporative cooling system

• Fan and pad systems only reach about 80% efficiency; fog systems about 95%

• Fan and pad cooling systems = $0.75 to $1.25/ft^2 of greenhouse floor area
Summer Cooling

*Physics of Evaporative Cooling*

- Use evaporation of water to convert sensible heat into latent heat, thus reducing the temperature of the air.
- About 1,060 Btu’s of heat are “absorbed” out of the air for every pound of water evaporated.
- Conversion of energy from sensible heat into latent heat does not change total energy content of the air.
  - Lowers the temperature of the air and increases the water vapor content (transfers energy to water vapor).
  - Increases the relative humidity.
Summer Cooling

Physics of Evaporative Cooling

• Process of cooling air through the evaporation of water is called adiabatic cooling
  – adiabatic--pertaining to, or designating a reversible thermodynamic process executed at constant entropy; loosely, occurring without gain or loss of heat

• Ability to reduce sensible heat of air depends on how much water we can evaporate into the air
Summer Cooling

*Physics of Evaporative Cooling*

- Amount of water that can be evaporated into air depends on:
  - the original temperature of the air
    - sensible heat measured with a dry bulb thermometer
  - the warmer the air, the more water it is capable of “holding”
  - note the grains of moisture per pound of dry air along the right axis of the psychrometric chart; 7,000 grains of water = 1 lb of water
PSYCHROMETRIC CHART

DRIY BULB TEMPERATURE °F
Summer Cooling

Physics of Evaporative Cooling

- Amount of water that can be evaporated into air depends on:
  - how much water is already in the air (the moisture content)
  - the grains of water difference between the original RH and 100% RH is the evaporative cooling capacity, if we could achieve 100% efficiency
Summer Cooling

Physics of Evaporative Cooling

- Amount of water that can be evaporated into air depends on:
  - the density of the air
  - water-holding capacity of air is based on lbs of water per lb of air, not per ft$^3$ of air
  - related to the barometric pressure and thus the elevation
  - under normal greenhouse temperatures and given a BP of 29.92”, 1 lb of air occupies about 13.5 ft$^3$
Summer Cooling

Physics of Evaporative Cooling

• Amount of water that can be evaporated into air depends on:
  – the density of the air

• systems designed based on this density to pull enough air through the greenhouse

• less dense air (air at higher altitudes) = greater volume per pound of air = greater volumes of air must be pulled through to achieve design levels of cooling
Summer Cooling

**Physics of Evaporative Cooling**

- Amount of water that can be evaporated into air depends on:
  - the efficiency of the evaporative system
    - fan and pad systems = 80%
    - fog systems perhaps closer to 95%
Summer Cooling

Evaporative Cooling Examples

• Tucson, Arizona
  – dry bulb temperature = 100 °F
  – wet bulb temperature = 70 °F
  – elevation = 2,400 feet above sea level

• Raleigh, NC
  – dry bulb temperature = 94 °F
  – wet bulb temperature = 77 °F
  – elevation = 360 feet
PSYCHROMETRIC CHART

Tucson = 22% RH
Need 48 grains/lb

Raleigh = 47% RH
Need 28 grains/lb

Tucson = 22% RH
Summer Cooling

Evaporative Cooling Examples

- Tucson
  - 80% efficiency = 80% of the wet bulb:
    - \(100 \, ^\circ F - (0.8 \times (100 \, ^\circ F - 70 \, ^\circ F)) = 76 \, ^\circ F\)
  - since elevation is 2,400 feet, we need to increase the flow of air through system to account for the lesser density of the air 14.8 ft\(^3\)/lb rather than 13.5 ft\(^3\)/lb
  - need a flow rate about 1.096x greater than if our elevation were under 1,000 feet
Summer Cooling

**Evaporative Cooling Examples**

- Raleigh
  - 80% efficiency = 80% of the wet bulb:
    - $94^\circ F - (0.8 \times (94^\circ F - 77^\circ F)) = 80.4^\circ F$
  - Since our elevation is 360 feet, which is below 1,000 feet, we do not need to increase the flow of air through our system ($F_{ELEV} = 1.0$)