Evaporative Cooling

A.J. Both
Associate Extension Specialist
Rutgers University
Bioresource Engineering
Dept. of Plant Biology and Pathology
20 Ag Extension Way
New Brunswick, NJ 08901
both@aesop.rutgers.edu
http://aesop.rutgers.edu/~horteng

Introduction

When regular ventilation and shading (e.g., white wash or movable curtains) are not able to keep the greenhouse temperature at the desired set point, additional cooling is needed. In homes and office buildings, mechanical refrigeration (air conditioning) is often used, but in greenhouses where the quantity of heat to be removed can be very large, air conditioning is often not economical. Fortunately, we can use evaporative cooling as a simple and relatively inexpensive alternative. The process of evaporation requires heat (recall how cold your skin can feel shortly after you get out of the shower or the swimming pool but before you have a change to dry yourself off). This heat (energy) is provided by the surrounding air, causing the air temperature to drop. At the same time, the humidity of the air increases as the evaporated water transitions into water vapor and becomes part of the surrounding air mass. The maximum amount of cooling possible with evaporative cooling systems depends on the humidity of the air you started with (the drier the initial air, the more water can be evaporated into it, the more the final air temperature will drop), as well as the initial temperature of the air (warmer air is able to contain more water vapor compared to colder air). This article will investigate in more detail how evaporative cooling can be used to help maintain target set point temperatures during warm outside conditions when the ventilation system alone is not sufficient to maintain the set point.

Pad-and-Fan System

Two evaporative cooling systems are commonly used in greenhouses: the pad-and-fan and the fog system. Pad-and-fan systems (Figure 1) are part of a greenhouse’s mechanical ventilation system. Note that swamp coolers can be considered stand-alone evaporative cooling systems, but otherwise operate similarly as pad-and-fan systems. For pad-and-fan systems, an evaporative cooling pad is installed in the ventilation opening, ensuring that all incoming ventilation air travels trough the pad before it can enter the greenhouse environment. The pads are typically made of a corrugated material (impregnated paper or plastic) that is glued together in such a way as to allow air to pass through it while ensuring a maximum contact surface between the air and the wet pad material. Water is pumped to the top of the pad and released through small openings along the entire length of the supply pipe. These openings are typically pointed upward to prevent clogging by any debris that might be pumped through the system (installing a filter system is recommended). A cover is used to channel the water downwards onto the top of the pads after it is released from the openings. The opening spacing is designed so that the entire pad area wets evenly without allowing patches to remain dry. At the bottom of the pad, excess water is collected and returned to a sump tank so it can be reused. The sump tank is outfitted with a float valve allowing for make-up water to be added. Since a portion of the recirculating water is lost through evaporation, the salt concentration in the remaining water increases over time. To prevent an excessive salt concentration from creating salt build-up (crystals) on the pad material (reducing pad efficiency), it is a common practice to continuously bleed approximately 10% of the returning water to a designated drain. In addition, during summer operation, it is common to 'run the pads dry' during the nighttime hours to prevent algae build-up that can also reduce pad efficiency. As the cooled (and humidified) air exits the pad and 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. In properly designed systems, this temperature gradient is minimal, providing all plants with similar conditions. However, temperature gradients of 7-10°F are not uncommon.

The required evaporative pad area depends on the pad thickness. For the typical, vertically mounted four-inch thick pads, the required area (in ft^2) can be calculated by dividing the total greenhouse ventilation fan capacity (in cfm) by the number 250 (the recommended air velocity through the pad). For six-inch thick pads, the fan capacity should be divided by the number 350. The recommended minimum pump capacity is 0.5 and 0.8 gpm per linear foot of pad for the four and six-inch thick pads, respectively. The recommended minimum sump tank capacity is 0.8 and 1 gallon per ft^2 of pad area for the four and six-inch pads, respectively. For evaporative cooling pads, the estimated maximum water usage can be as high as 10-12 gpd per ft^2 of pad area.

Fog System

The other evaporative cooling system used in greenhouses is the fog system (Figure 2). This system is often used in greenhouses with natural ventilation systems (i.e., ventilations systems that rely only on opening and closing strategically placed vents and do not use mechanical fans to move air through the greenhouse structure). Natural ventilation systems generally are not able to overcome the additional airflow resistance created by placing an evaporative cooling pad directly in the ventilation inlets. The nozzles of a fog system can be installed throughout the greenhouse, resulting in a more uniform cooling pattern compared to the pad-and-fan system. The recommended spacing is approximately one nozzle for every 50-100 ft^2 of growing area. 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. The water usage per nozzle is small: approximately 1-1.2 gph. In addition, the water needs to be free of any impurities to prevent clogging of the small nozzle openings. As a result, water treatment (filtration and purification) and a high-pressure pump are needed to operate a fog system. The usually small diameter supply lines should be able to withstand the high water pressure. Therefore, fog systems can be more expensive to install compared to pad-and-fan systems. Fog systems, in combination with natural ventilation, produce little noise compared to mechanical ventilations systems outfitted with evaporative cooling pads. This can be an important benefit for workers and visitors staying inside these greenhouses for extended periods of time.

Psychrometric Chart

In order to use a handy tool (the psychrometric chart, Figure 3) to help determine the maximum temperature drop resulting from the operation of an evaporative cooling system, it is important to review a few key physical properties of air:

- Dry bulb temperature (Tdb, °F): Air temperature measured with a regular (mercury) thermometer
- Wet bulb temperature (Twb, °F): Air temperature measured when the sensing tip is kept moist (e.g., with a wick connected to a water reservoir) while the (mercury) thermometer is moved through the air rapidly
- Dew point temperature (Td, °F): Air temperature at which condensation occurs when moist air is cooled
- Relative humidity (RH, %): Indicates the degree of saturation (with water vapor)
- Humidity ratio (lb/lb): Represents the mass of water vapor evaporated into a unit mass of dry air
- Enthalpy (Btu/lb): Indicates the energy content of a unit mass of air.
- Specific volume (ft^3/lb): Indicates the volume of a unit mass of dry air (equivalent to the inverse of the air density).

As mentioned before, the maximum amount of cooling provided by evaporative cooling systems depends on the initial temperature and humidity (moisture content) of the air. We can measure these parameters relatively easily with a standard thermometer (measuring the dry-bulb temperature) and a relative humidity sensor. With these measurements, we can use the psychrometric chart (simplified for following example and shown in Figure 4) to determine the corresponding wet bulb temperature at the maximum possible relative humidity (100%). Once we know the corresponding wet bulb temperature, we can calculate the difference (also called the wet bulb depression) that indicates the theoretical temperature drop provided by the evaporative cooling system. Since few engineered systems are 100% efficient, the actual temperature drop realized by the evaporative cooling system is more likely in the order of 80% of the theoretical wet bulb depression.

In understanding Figure 4, it was assumed that the initial conditions of the outside air were: a dry bulb temperature of 69°F and a relative humidity of 50% (look for the intersection of the curved 50% RH line with the vertical line for a temperature of 69°F). From this starting point, we can determine all other environmental parameters from the list shown above: the wet bulb temperature equals 58°F (from the starting point, follow the constant enthalpy line [25 Btu/lb in this case] until it intersects with the 100% relative humidity curve), the dew point temperature is just shy of 50°F, the humidity ratio equals 0.0075 lb/lb, the enthalpy equals 25 Btu/lb, and the specific volume equals 13.5 ft^3/lb. Hence, the wet bulb depression for this example equals 69 – 58 = 11°F. Using an overall evaporative cooling system efficiency of 80% results in a practical temperature drop of almost 9°F. Of course, this temperature drop occurs as the air passes through the evaporative cooling pad. As the air continues to travel through the greenhouse on its way to the exhaust fans, the exiting air may well be warmed to its original temperature (but is no longer saturated).

In Conclusion

When evaporative cooling pad systems appear to perform below expectation, it is tempting to assume that an increase in the ventilation rate would improve performance. However, increased ventilation rates result in increased air speeds through the cooling pads, reducing the time allowed for evaporation of water. As a result, the overall system efficiency can be reduced while water usage increases. Particularly in areas with water shortages, this can become a concern. In addition, increased ventilation rates may result in a decrease in temperature and humidity uniformity throughout the growing area. A similar situation can occur with fog systems: installing more fog nozzles may not necessarily result in additional cooling capacity, while system inputs (installation cost and water usage) increase. In general however, fog systems are able to provide more uniform cooling throughout the growing area and this may be an important consideration for some greenhouse designs and crops. It should be clear that, like many other greenhouse systems, the design and control strategy for evaporative cooling systems requires some thought and attention. It is recommended to consult with professionals who have experience with greenhouse cooling in your neighborhood.

Figure 1. Evaporative cooling pad installed along the inside of the ventilation inlet opening.

Figure 2. Top-down view of a fog nozzle delivering a small-droplet mist for evaporative cooling.

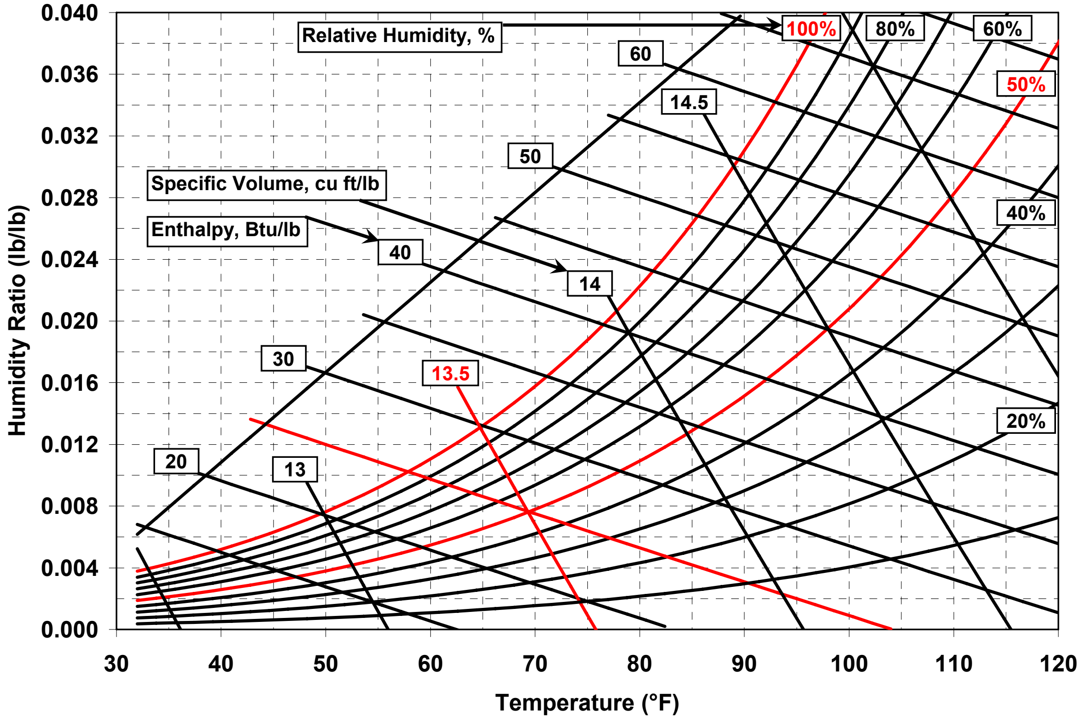

Figure 3. Psychrometric chart used to determine the physical properties air. Note that with values for only two parameters (e.g., dry bulb temperature and relative humidity, or dry and wet bulb temperatures), all others can be found in the chart (some interpolation may be necessary).

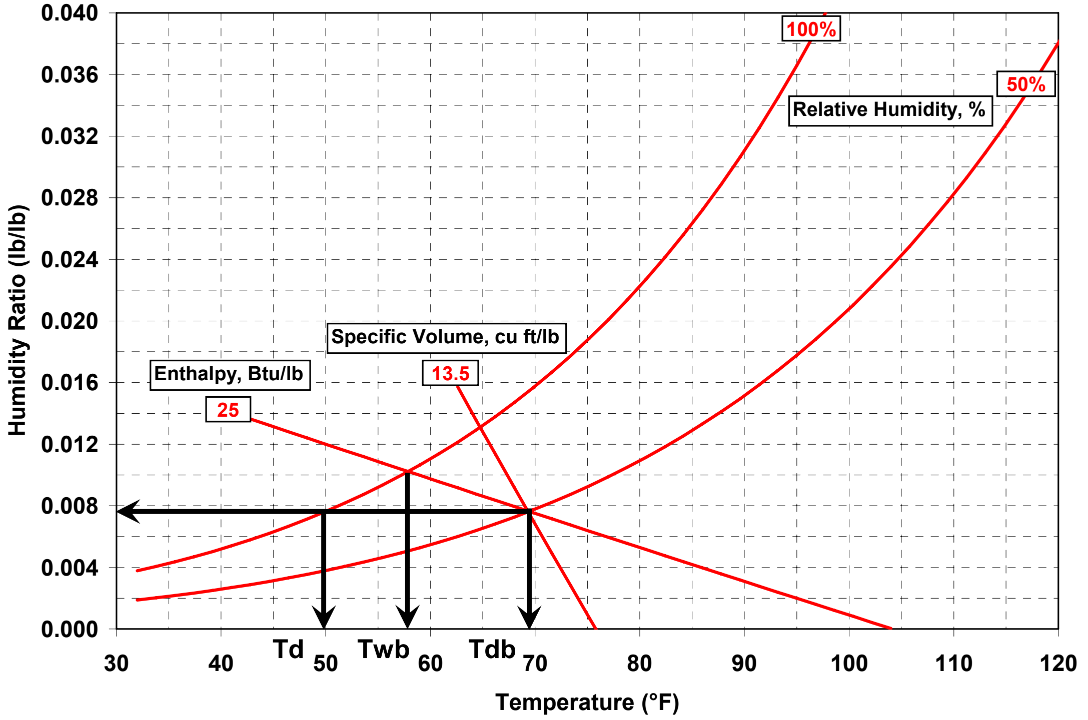

Figure 4. Simplified psychrometric chart used to visualize the evaporative cooling example described in the text.