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Greenhouse COOLING Basics

An associate extension specialist from Rutgers University explains several techniques growers can use to lessen solar radiation's impact on crops cultivated in a greenhouse.

One of the benefits of growing crops in a greenhouse is the ability to control all aspects of the production environment. One of the major factors influencing crop growth is the temperature. Different crop species have different optimum growing temperatures, and these optimum temperatures can vary for the root and the shoot environment, as well as for the distinct growth stages during the life of the crop. Because we are usually interested in rapid crop growth and development, we need to provide these optimum temperatures throughout the entire cropping cycle.

If a greenhouse was like a residential or commercial building, controlling the temperature would be much easier because these buildings are well-insulated, so the impact of outside conditions is significantly reduced. However, greenhouses are designed to allow as much light as possible to enter the growing area. As a result, the insulating properties of the structure are significantly diminished, and the growing environment is influenced by the constantly fluctuating weather conditions. Solar radiation (light and heat) exerts by far the largest impact on the growing environment, resulting in a significant challenge to maintain the optimum growing temperatures. Fortunately, several techniques can be used to reduce the impact of solar radiation on the temperature inside a greenhouse. These techniques are further discussed in this article.

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, mechanical ventilation is able to provide adequate cooling under a variety of weather conditions throughout the US. Typically, for the northern regions of the US, mechanical ventilation systems are designed to provide a maximum ventilation capacity of 8 cubic feet per minute (cfm) per square foot of floor area for greenhouses equipped with a shade curtain, or 10 cfm per square foot of floor area for greenhouses without a shade curtain.

Text and photos
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Naturally ventilated greenhouses use less electricity and produce less noise than mechanically ventilated greenhouses.

Movable shade curtains help reduce the energy load on greenhouse crops during warm and sunny conditions, and they reduce heat radiation losses at night.

Natural ventilation (photo, top) 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 sides of the greenhouse, causing air to move toward the leeward side). All that is needed are strategically located inlet and outlet openings, vent window motors and electricity to operate the motors. In some cases, the vent window positions are changed manually, eliminating the need for motors and electricity, but increasing the amount of labor because frequent adjustments are necessary.

Compared to mechanical ventilation systems, electrically operated natural ventilation systems use a lot less electricity and produce some noise only when the vent window position is changed. When using natural ventilation, additional cooling can be provided by a fog system. Unfortunately, natural ventilation does not work very well on warm days when the outside wind velocity is low (less than 200 feet per minute). Keep in mind that when using either system with no other cooling capabilities, the indoor temperature cannot be lowered below the outdoor temperature.

Due to the long and narrow design of most freestanding greenhouses, 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 (using sidewall and roof vents).

In gutter-connected greenhouses, mechanical ventilation system inlets and outlets can be installed in the side- or end walls, while natural ventilation systems usually consist of only roof vents. Extreme natural ventilation systems include the open-roof greenhouse design, where the very large maximum ventilation opening allows for the indoor temperature to almost never exceed the outdoor temperature. This is often not attainable with mechanically ventilated greenhouses due to the very large amounts of air that these systems would have to move through the greenhouse to accomplish the same results.

When insect screens are installed in ventilation openings, the additional resistance to airflow created by the screen material must be taken into account to ensure proper ventilation rates. Often, the screen area is larger than the inlet area to allow sufficient amounts of air to enter the greenhouse.

Whichever ventilation system is used, uniform air distribution inside the greenhouse 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. The recommended fan capacity is approximately 3 cfm per square foot of growing area.

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 percent to 85 percent) should be avoided because it can increase the incidence of disease and reduce plant transpiration. Sufficient venting can prevent condensation on crop surfaces and on the greenhouse structure. The use of cooling systems (such as pad-and-fan or fog) during the warmer, summer months increases the greenhouse air humidity. During periods of warm and humid weather conditions, humidity control inside the greenhouse can be a challenge. Greenhouses located in dry, desert environments benefit greatly from evaporative cooling systems because large amounts of water can be evaporated into the incoming air, resulting in significant temperature drops.

Because the relative humidity alone does not tell us anything about the absolute water-holding capacity of air (we also need to know the temperature to determine the amount of water the air can hold), a different measurement is sometime used to describe the absolute moisture status of the air: vapor pressure deficit (VPD). VPD measures the difference between the amount of moisture the air contains at a given moment and the amount of moisture it can hold at that temperature when the air would be saturated (such as when condensation would start, also known as the dew-point temperature).

VPD can tell us how easy it is for plants to transpire: higher values stimulate transpiration (but values too high can cause wilting) and lower values inhibit transpiration and can lead to condensation on leaf and greenhouse surfaces. Typical VPD measurements in greenhouses ranges between 0 and 1 pound per square inch (psi; 0 to 7 kilopascals).

Two evaporative cooling systems are commonly used in greenhouses: pad-and-fan (left) and fog (right).

Shading. Investing in movable shade curtains (photo, page 21) is a 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 heat radiation losses at night. Energy savings of up to 30 percent 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 greenhouses can benefit from the installation of a shade system by significantly improving light and temperature control. The curtain materials are available in many different configurations, from low to high shading percentages, depending on the crop requirements and the local solar radiation conditions. Movable shade curtains can be installed inside or outside (on top or above the glazing) of the greenhouse. Make sure you specify the use when you order a curtain material from a manufacturer. When shade systems are located in close proximity to heat sources (such as unit heaters or CO2 burners), 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 when all the curtains are closed.

Evaporative cooling. Two evaporative cooling systems are commonly used in greenhouses: pad-and-fan and fog.

Pad-and-fan system. A pad-and-fan system (photo, above left) is part of a greenhouse's mechanical ventilation system. Note that swamp coolers can be considered stand-alone evaporative cooling systems, but operate similarly to pad-and-fan systems.

An evaporative cooling pad is installed in the ventilation opening, ensuring that all incoming ventilation air travels through the pad before it can enter the greenhouse environment. The pad is 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 downward onto the top of the pad 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 water supply and float valve so water lost through evaporation can be replenished. Because 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 buildup (crystals) on the pad material, which will reduce pad efficiency, it is a common practice to continuously bleed approximately 10 percent 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 buildup that can also reduce pad efficiency.

As the cooled and humidified air exits the pad and moves through the greenhouse toward the exhaust fans, it picks up heat from the greenhouse environment. Therefore, pad-and-fan systems experience a temperature gradient between the inlet (pad) and the outlet (fan) sides of the greenhouse. In properly designed systems, this temperature gradient is minimal, providing all plants with similar conditions. However, temperature gradients of 7° F to 10° F are not uncommon.

The required evaporative pad area depends on the pad thickness. For the typical, vertically mounted, 4-inch-thick pads, the required area (in square feet) can be calculated by dividing the total greenhouse ventilation fan capacity (in cfm) by 250 (the recommended air velocity through the pad). For 6-inch-thick pads, the fan capacity should be divided by 350. The recommended minimum pump capacities are 0.5 and 0.8 gallons per minute per linear foot of pad for the 4- and 6-inch-thick pads, respectively. The recommended minimum sump tank capacities are 0.8 and 1 gallon per square foot of pad area for the 4- and 6-inch-thick pads, respectively. For evaporative cooling pads, the estimated maximum water usage can be as high as 10 to 12 gallons per day per square foot of pad area.

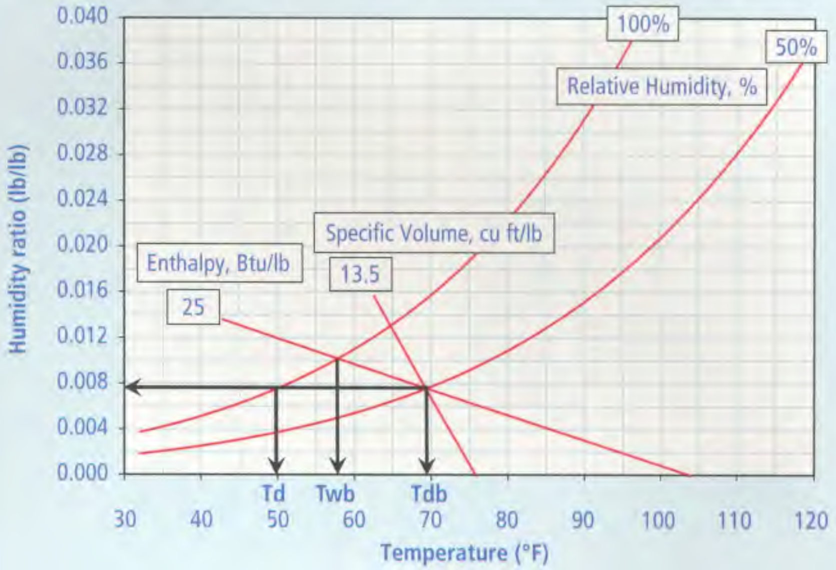
Fogsystem. The other evaporative cooling system used in greenhouses is the fog system (photo, above right). This system is often used in greenhouses with natural ventilation systems that rely only on opening and closing strategically placed vents and do not use mechanical fans to move air through the 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 to 100 square feet of growing area. The water pressure used in 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 to 1.2 gallons per hour. 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 ventilation 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

Simplified psychrometric chart used to visualize the evaporative cooling example.



Psychrometric chart. In order to use a psychrometric chart 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 (with a wick connected to a water reservoir) while the 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; and
- specific volume (cu ft/lb) — indicates the volume of a unit mass of dry air (equivalent to the inverse of the air density).

The maximum amount of cooling provided by evaporative cooling systems depends on the initial temperature and humidity 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 the following example and shown above) to determine the corresponding wet-bulb temperature at the maximum possible relative humidity (100 percent). Once we know the corresponding wet-bulb temperature, we can calculate the difference (known as the wet-bulb depression) that indicates the theoretical temperature drop provided by the evaporative cooling system. Because few engineered systems are 100 percent efficient, the actual temperature drop realized by the evaporative cooling system is more likely to be 80 percent of the theoretical wet-bulb depression.

In the simplified example, 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 percent (look for the intersection of the curved 50 percent relative humidity line with the vertical line for a temperature of 69° F). From this starting point, we can determine all other environmental parameters: the wet-bulb temperature equals 58° F (from the starting point, follow the constant enthalpy line [25 Btu/lb] until it intersects with the 100 percent 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 cu ft/lb (cubic feet per pound). Hence, the wet-bulb depression for this example equals 11°F (69° F - 58° F = 11°F).

Using an overall evaporative cooling system efficiency of 80 percent 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, it may be warmed to its original temperature (but is no longer saturated).

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 can increase. This can become a concern, particularly in areas with water shortages.

In addition, an increase in 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, 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 part of the country.

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