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By Kurt Parbst

Using shading for greenhouse temperature control

With sufficient ventilation and efficient shading, high quality crops can be produced even in very warm months and climates.

Greenhouse growers know the quality of their crops is strongly related to the production environment. Elevated day temperatures within a greenhouse can impact plant production and quality. Often the temperature elevation is too great and the extra heat must be removed. Ventilation and cooling are of major importance in greenhouse temperature control as well as humidity build up.

The effect of the environment

The greenhouse environment created for plants can be described in terms of temperature, humidity, light and the root environment. The root environment is important, but not discussed here. There are, however, major implications for the root environment in terms of heating efficiency, young plant production and keeping heat stress acceptably low (i.e., plants grown in black pots).

All plants have a minimum, optimum and maximum temperature, or intensity of heat energy, for growth. Most information related to the effect of temperature on plant growth and development refers to air temperature rather than leaf temperature. This is simply because it is easier to measure. Leaf temperature measurement is tricky as a single leaf rarely represents the average of the plant. The greater the radiant energy, the more likely the leaf temperature will exceed the air temperature and this has implications for environmental control.

The plant temperature is based on the energy balance of a leaf and is a function of air temperature, radiant energy, thermal radiation, convective exchange of sensible (air temperature) heat and latent (vapor) heat. This interplay of environmental factors influences photosynthesis, respiration and nutrient and water uptake.

In general it is easier to eliminate extreme conditions rather than trying to create optimum circumstances for a specific plant. This is usually the situation if a general climate is desired for a variety of species sharing the same environment, which is the case for many ornamental plant growers.

Plants lose moisture through the process of transpiration, and the growing medium loses moisture through evaporation. The sum of these two processes is called evapotranspiration. The result of these processes along with the thermal inputs make up the greenhouse humidity level often expressed as a ratio of the water content of the air compared with its full potential to hold water, or the relative humidity. The higher the temperature, the more water the air can hold in vapor form. In this way, evaporative cooling can be employed during the hottest hours of the day even in climates generally considered to be rather humid.

Greenhouse energy balance

A sensible energy balance is generally used to determine a greenhouse's ventilation requirements when an upper temperature limit has been established. Maximum ventilation rates can be sufficiently calculated using energy balances with strictly solar insulation as the gain term and ventilation as the loss term.

Greenhouse overheating

During sunny high light periods it is generally easy for a greenhouse to overheat. Anyone who has ever entered a greenhouse without fans on and the vents closed can attest to that.

With no ventilation a greenhouse could theoretically reach temperatures over 150°F. Because air picks up heat, when indoor air is exchanged for outdoor air a grower can limit the temperature rise. By exchanging the indoor air about once every minute, the temperature rise in the greenhouse can be limited to about 8°F. This is acceptable when the temperature is 75°F but not so good when the outside temperature reaches 95°F. At this point supplemental cooling or reductions of incoming solar radiation are the two strategies for high temperature management.

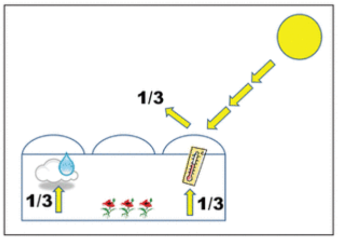


Figure 1: Partitioning of solar insolation

Ventilation systems are sized for temperature control considering that there are not significant heat sources other than the sun. Sensible energy balances are generally used to calculate the maximum required ventilation rate. Solar gain is the major energy source and it is usually safe to assume that the greenhouse temperature is higher than the outside temperature. The fraction of the solar heat load converted to a sensible load must be estimated. Assume that the heat load entering the greenhouse is divided in this way (Figure 1):

- 1/3 of the solar radiation is absorbed by the greenhouse where it is converted to heat and raises the air temperature (sensible heat).
- 1/3 of the solar radiation contributes through evapotranspiration, the sum of crop transpiration and evaporation from the growing medium to latent heat.
- 1/3 of ambient solar insolation is either reflected back to the atmosphere or converted to plant mass via photosynthesis.

Ventilation considerations

The trend in the industry is toward more passive ventilation. This is mainly due to increasing demands for lower energy and capital intensity in greenhouse operations.

Greenhouse designs have improved and multiple crop selections demanding a general climate have permitted more passive ventilation.

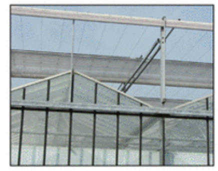
Specialty crops and monoculture growing generally demand narrow operating temperature ranges for high quality productivity. From an engineering or production perspective, when a high level of environmental control is required, mechanical ventilation is usually preferred. Passive ventilation is reliant upon solar and wind energy, both of which are unreliable and always changing.

Shading systems

Ventilation alone is frequently insufficient to control the greenhouse temperature, especially during warm months. Some form of shading is usually used to restrict the solar radiation entry. The shading reduces the rate at which absorbed solar radiation is converted to heat inside the greenhouse.

Where radiation levels are relatively high, shading does not have to have an adverse effect on plant growth during sunny weather. Light charts have been developed that generalize crop quality responses according to daily light integrals. Provided that sufficient daily light is delivered, one can expect to grow a good or high quality plant from a photosynthetic potential perspective.

White wash or black shade panels can be used for shading with the idea that the denser the shading application the less solar radiation enters the greenhouse. Hence the less the heat that needs to be removed to prevent overheating. A disadvantage to these types of shade is they are usually permanent from the time of application in spring or early summer until removal in late summer or autumn. When overcast weather occurs with this shade, light levels in the greenhouse can be low.



The main benefit to an exterior shade system is that light is intercepted before it enters the greenhouse.

An alternative shading method is the use of retractable systems either inside or outside the greenhouse. The main benefit to an exterior system is that light is intercepted before it enters the greenhouse enhancing the cooling effect. Although exterior systems are very effective, they can be costly since they have substantial structural and mechanical requirements. Growers who place a high value on cooling and light transmission control install these systems and accept the investment and maintenance requirements.

A dark shade cloth mounted inside a greenhouse intercepts some of the radiation entering the structure.

Interior shading systems originally intended for energy conservation and creating blackout conditions can also be made with suitable materials to provide shade. These interior systems are not as effective at excluding solar radiation as exterior shading. There are shading options with an interior system, but in general the material used is porous and selected according to its light transmitting properties. It is important to select a material that reflects rather than absorbs the radiation that it intercepts.

A dark shade cloth mounted inside a greenhouse intercepts some of the radiation entering the structure. This intercepted radiation is absorbed rather than reflected and the absorbed energy is converted into heat.

Gapping an energy shade curtain and ventilating around it can provide additional ventilation.

Shading efficiency

The ability to retract a shade curtain during periods of overcast weather is important. Some growers invest in a retractable system or incremental system if one retractable system is already installed, perhaps to save energy. The reason for installing a second retractable system solely for shading is to provide a greater level of cooling and greater light uniformity at plant level to prevent uneven drying out of the growing medium.

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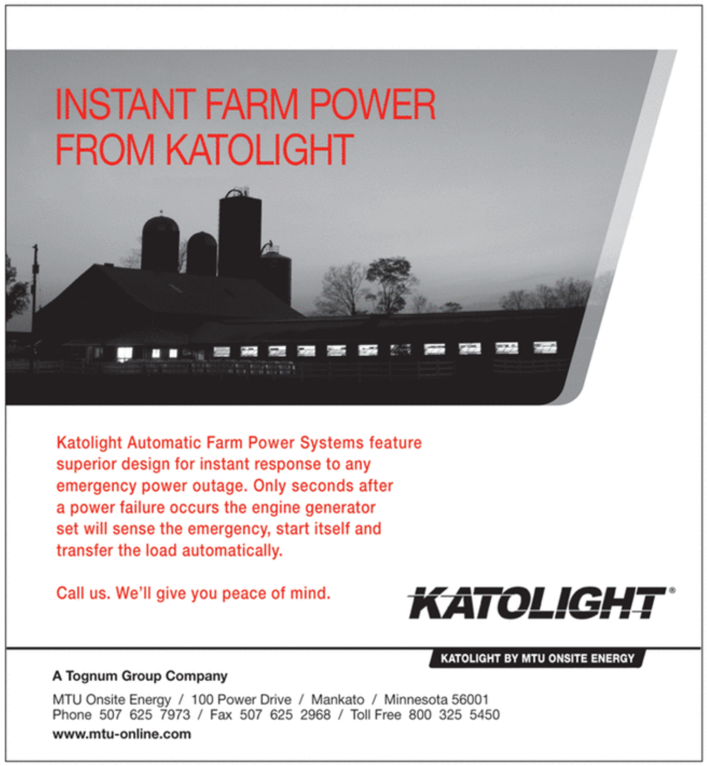

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Studies indicate that having a second, porous shade curtain provides 4°F-7°F of additional cooling than is possible by gapping an energy shade curtain and ventilating around it.

If an exterior fixed shade material is used in place of a retractable shade system, the type of material selected is important. The material can absorb, transmit or reflect solar radiation. Using absorbing shade materials can effectively reduce light transmission, but has minimal impact on temperature reduction. The shade becomes a radiator and, ignoring wind losses, sends about half of the heat energy back into the sky, but the other half toward the crop.

Results of studies by Daniel Willits, professor of biological and agricultural engineering at North Carolina State University, suggest that the cooling efficiency of external shade cloth on greenhouses is significantly affected by the energy balance of the cloth. Absorption of solar energy by the cloth raises the cloth's temperature. The cloth then effectively becomes a radiator and increases the radiation load on the environment below. Heat is transmitted without the benefit of the useful photosynthetic active radiation light, leading to hot and dark conditions in the greenhouse. Reducing the temperature of the shade cloth improves the cooling efficiency of the cloth.

The term shading efficiency is used to describe the fraction of the shading that occurs as a result of reflection rather than absorption. Increasing the shading efficiency of the cloth can have implications for growing practices.

By maintaining a typical level of shading but selecting a more efficient shade cloth, the energy load is reduced along with the temperature of the greenhouse and the plants. It is likely that a grower has established through trial and error a crop's tolerance to local warm weather conditions and selected a suitable shading level. By using a more efficient shade cloth, a grower can instead choose more light transmission with the goal of gaining production or crop quality improvements associated with being able to handle more light at higher temperatures as a result of the reduced heat load.

Further studies at North Carolina State indicate that using reflective shade materials can reduce the heat gain (the sum of sensible and latent heat) by approximately half of the shading value compared to absorbing materials. A black shade cloth cannot be expected to perform better than 40-50 percent effectiveness. For example, at a 60 percent shade level the reduction in greenhouse heat gain is about 30 percent.

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