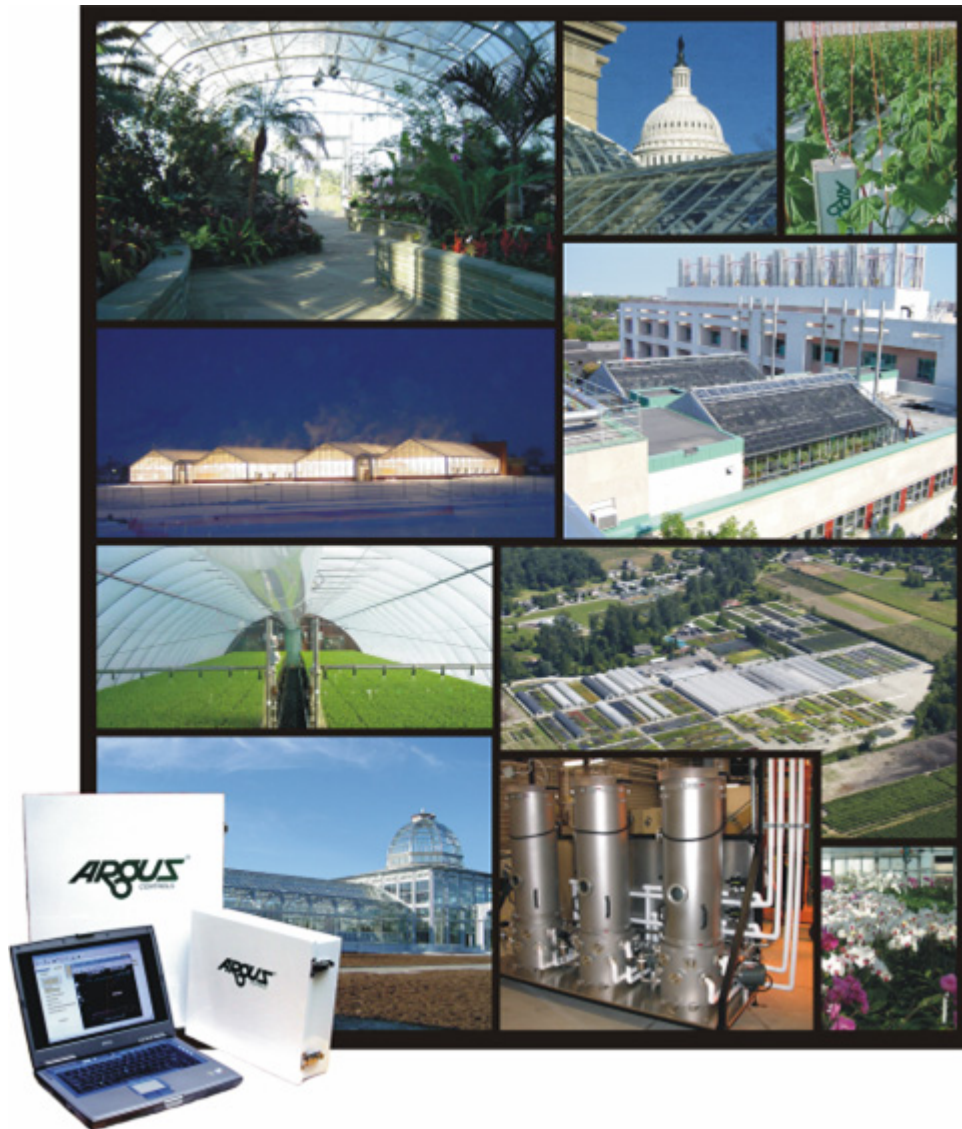




A CONVIRON COMPANY

# Greenhouse Cooling



August 3, 2017

## Greenhouse Cooling Application Note

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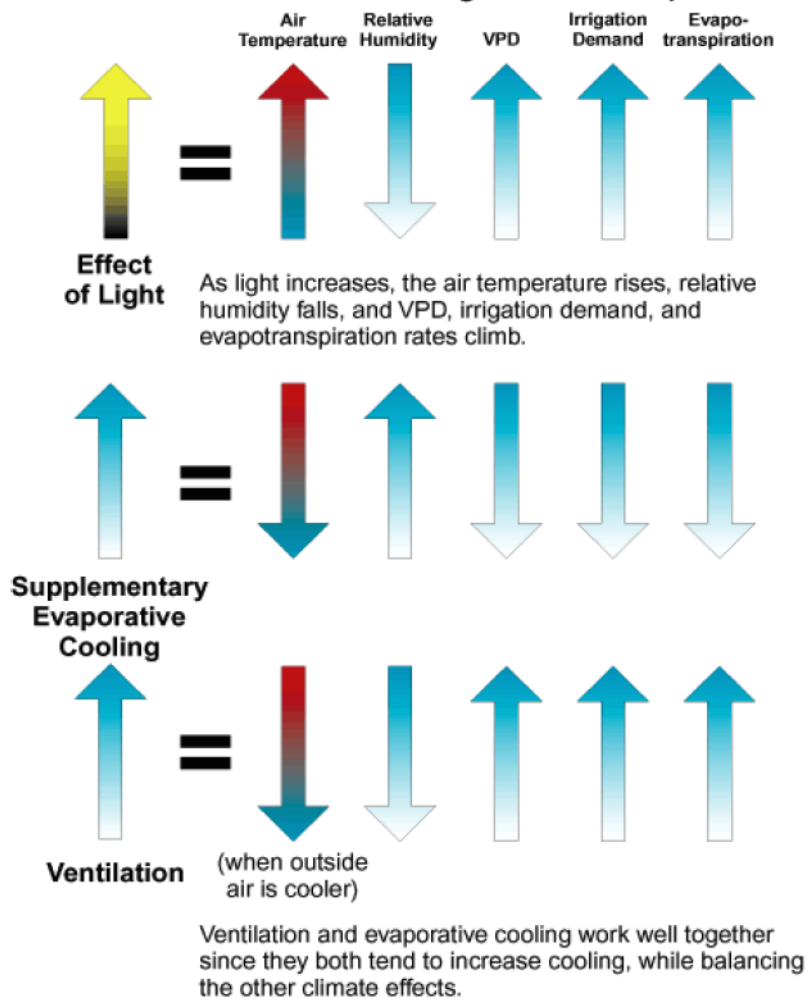
## Greenhouse Cooling Application Note

### GREENHOUSE COOLING

We build greenhouses to gather light and to trap the considerable heat contained in sunshine. They are so efficient at retaining relatively low levels of solar energy, that without specialized ventilation and cooling equipment, they will quickly fry a crop during high light periods.

This article discusses some of the principles, equipment, and cooling strategies required for the active management of greenhouse air temperature and humidity at times when the incoming solar radiation levels exceed the heating needs of your crop.

#### Greenhouse Cooling Relationships



## Greenhouse Cooling Application Note

### *Leaf Temperature and Air Temperature*

The actual temperature of any given leaf in the greenhouse depends upon the surrounding air temperature, the relative moisture content of the air, and whether or not it is in the direct rays of the sun. The cooling effect of evapotranspiration (the water transpired by plants and evaporated from wet substrates) is central to the ability of plants to regulate their tissue temperatures.

When plants evaporate water into the surrounding air, they modify the properties of the air. The surrounding air temperature and the vapor pressure are decreased, while the relative humidity is increased.

Whenever greenhouse air is exchanged with outside air, this also has an effect, due to the change in temperature and the relative moisture content of the exchanged air.

### *Humidity and Vapor Pressure Deficit (VPD)*

Vapor pressure deficit or VPD is a term used to describe how readily water will evaporate into a surrounding air mass. The VPD of a leaf is described as the difference between the humidity at the leaf surface (usually assumed to be saturated or 100% Rh) and the humidity of the surrounding air.

The higher the VPD, the more readily water will evaporate. High VPD (low air moisture relative to the leaf surface) can lead to plant wilting, desiccation, and injury if plants are unable to evaporate enough water to keep up with the evaporation demand.

When the VPD is too low, the surrounding air is so saturated with moisture that little or no water can be evaporated from leaf surfaces. This can result in inadequate water and nutrient transport within the plant, as well as diminished cooling and the potential for injury under extreme high temperatures (i.e. plants can 'cook' under a propagation tent even though the relative moisture content of the air is high).

## Greenhouse Cooling Application Note

### *Cooling Step 1 - Let Your Plants Cool Themselves*

A greenhouse cooling strategy should always start with the plants. They are excellent air conditioners. On warm days, forests tend to be cooler than deserts because the trees are actively cooling their leaves and the surrounding air through transpiration.

Plants are highly adapted for variable temperatures and humidity conditions, and they attempt to actively regulate their tissue temperatures by evaporating water. They are so good at this, that you can consider your crop to be the primary cooling component in your greenhouse, particularly if it is closely spaced with a lot of leaf surface.

To prove this, just step into an empty greenhouse on a hot summer day and compare it to one filled with plants.

To maximize the ability of your plants to cool themselves, you need to supply plenty of water for transpiration on hot days. This involves extra irrigation and keeping the salinity of the rooting solutions relatively low to make sure that high salts don't interfere with water uptake.

Since plants can only evaporate water into air that is not already saturated, you need to provide ventilation to take away moist air and introduce drier (and hopefully cooler) air. Good air circulation will also improve the evaporation efficiency within the crop canopy by moving saturated air away from leaf surfaces and replacing it with dryer air.

## Greenhouse Cooling Application Note

### *Cooling Step 2 - Apply Sun Block*

One of the best ways to avoid heat buildup in the greenhouse is to prevent some of the light energy from getting inside in the first place. Of course, this also blocks light for photosynthesis.

However, you can often strike a balance between the need for sufficient light for plant growth and the need to control potentially damaging temperatures by blocking, filtering, and reflecting incoming light on the outside of the greenhouse covering, or by using fixed or retractable shade materials inside the greenhouse.

Plants are adapted for varying light levels and most species reach their maximum photosynthetic efficiency at rather low light intensities relative to full sunshine.

Extremely high light levels can actually stop or slow down photosynthesis if plants are forced to restrict air and moisture exchange from the leaves to conserve water and avoid wilting. This directly reduces the available carbon dioxide required for photosynthesis.

Therefore, providing some shade can often be beneficial (20-75% depending upon the species and the light intensity), resulting in a net gain in photosynthesis and continued healthy plant growth.

Crops with canopies of dense foliage tend to be more affected by reductions in light levels since the underlying leaves rely upon reflected or filtered light for most of their photosynthetic requirements, and shading will reduce these light levels as well.

Permanent or semi-permanent external shade materials applied as coatings or fixed screens do a good job, but they often can't be easily removed during periods of dull weather. External retractable shade systems are not all that common due to the expense and complexity of deploying them in outdoor environments, but they are an excellent, flexible method of controlling high light levels.

Internal shade systems do not really prevent heat gain inside the structure but they do tend to stratify it as well as blocking the direct rays of the sun from overheating plant tissues. Since most of the heat tends to be trapped above the curtains, roof vents are quite effective at removing it. Sidewall or gable exhaust fans mounted below the curtains are more effective at removing heated air trapped below them.

Open weave type materials will allow some heated air to rise through the curtains towards the roof, but it is often necessary to keep the curtains opened about 10% to allow for sufficient air exchange. Curtains that are pulled east/west tend to create a lighted band that will move with the sun resulting in fewer problems. Some shade systems are designed to provide for good air exchange even when the curtains are completely closed.



## Greenhouse Cooling Application Note

### *Step 3 - Ventilation*

Ventilation is required for greenhouse cooling to remove heated greenhouse air and to introduce drier air for evaporative cooling.

For a moderately shaded greenhouse, the ventilation system should be designed to be capable of exhausting at least 8-10 cubic feet of air per minute for every square foot of greenhouse area.

Solar heat gain is dependent upon greenhouse area, not volume, since no matter how tall your greenhouse is, it receives approximately the same amount of solar energy per square foot.

The ventilation system should be designed to remove heat evenly from all parts of the greenhouse, with no 'hot spots'. Make sure that open doors do not create 'short circuits' in the flow of your ventilation system.

In areas with extremely high temperatures and very dry air, it may be possible to maintain cooler air temperatures than outdoors by taking advantage of the combined effects of evaporative cooling equipment and crop transpiration.

To achieve this, controlled ventilation is required to introduce just the right amount of dry air to sustain the evaporative cooling rate, without causing an unwanted rise in VPD and air temperature.

## Greenhouse Cooling Application Note

### *Step 4 - Active Cooling*

Although plants are capable of controlling their leaf temperatures by evaporating water, this process can at times consume energy that should otherwise be used for active growth. Therefore, greenhouse crops can often benefit from any help that reduces water stress, poor growth, and injury to tissues.

Mechanical cooling (for example, refrigeration-type air conditioning) is possible, but seldom affordable or practical for commercial greenhouses. Evaporative cooling techniques using pads & fans, fogs, mists, sprinklers etc. can be very effective and affordable when used properly. However, their relative efficiency depends upon the amount of moisture already present in the air. Consequently, supplementary evaporative cooling systems are far more effective in desert climates than humid locations.

Pad & fan systems draw outside air through a wet porous pad causing water to evaporate. This results in lowering the VPD, raising the relative humidity, and decreasing the air temperature.

Mist and fog systems operate in much the same way except that they add moisture directly to the greenhouse environment where it then evaporates. In both cases, ventilation is required to exhaust the humidified air and exchange it with drier air so that evaporative cooling can continue.

Mechanical pad & fan systems depend directly upon a continuous laminar airflow across the greenhouse. They are very effective but there will always be a temperature gradient when they are in use, with the coolest air near the pads and the warmest air near the exhaust fans. Pad & fan systems are not easy to regulate since they are either all 'on' or all 'off'.

Also, since the water in the pads takes a while to completely evaporate it can be difficult to achieve an in-between effect by switching the water supply on and off in a pulsed manner. For these reasons, pad systems are best used to cool and humidify incoming air.

Mists, fogs, and sprinkler systems can be used with or without mechanical ventilation, but they still require controlled air exchange to maintain the correct humidity/air temperature balance. They can usually be pulsed on and off to achieve a fine degree of evaporative cooling control. Problems with fog and mist systems include clogging due to water impurities, continued wetting of foliage from over use, and mineral residues on the crop.

The smaller the particle size, the more even the dispersion of water particles, and the less likely the chance of wetted foliage. However, the amount of cooling depends upon the absolute amount of water that can be evaporated, not just the particle size. All systems must be engineered to deliver a volume of water that when evaporated, will be sufficient to remove a required amount of heat. These systems are best suited to directly cooling or humidifying the air inside greenhouses.

## Greenhouse Cooling Application Note

### *Automated Control for Cooling and Ventilation*

So far, we have described some separate strategies for keeping plants cool that include enabling the plants to do some of the cooling, screening out as much excess light as possible, and using ventilation and evaporative cooling to actively cool the greenhouse environment.

For maximum effect, these strategies should be used in combination.

If there was a constant requirement for greenhouse cooling, you could simply set your equipment and forget it. However, the cooling requirement in your greenhouse is continually changing, requiring constant adjustment of equipment to obtain a stable growing environment.

Automated controls, particularly integrated control systems, can make the job of managing cooling much easier. They can respond to the changing climate cooling needs of your crop by managing irrigation and EC levels, operating retractable shading systems, controlling the ventilation rate, and running evaporative cooling equipment.

A variety of equipment systems can be deployed simultaneously in a responsive, intelligent manner to help keep the relative humidity, VPD, and the maximum temperature within your target settings.

One of the benefits of an automated control system is that it allows you to use sophisticated strategies to operate your cooling equipment.

For example, climate humidity sensors are not a particularly effective way to directly operate fog systems due to lags in sensor feedback. This can result in large cyclical swings in humidity & temperature.

By using more sophisticated strategies to operate your cooling equipment, based on direct sensor information that is then modified by feed forward program equations, you can achieve smoother and more uniform results with less equipment cycling.

## Greenhouse Cooling Application Note

### *Getting the Most from Your Cooling Equipment*

**Use Delays for Retractable Shade Curtains** - partly cloudy days can play havoc with retractable shade systems that are set to respond to specific light levels. Use a sufficient light or temperature proving time delay to avoid excessive curtain movement. Keep in mind that retractable systems can and do break down, and they often have a long movement time. If your crop is particularly sensitive to even a few minutes of full sunshine, use a fixed screen or external shading compounds.

**Don't Over-Ventilate** - too much ventilation, particularly in hot, dry climates where the outside air is sometimes hotter than the greenhouse air can overly desiccate the crop unless active humidification is used.

**Don't Fog without Ventilation** - it's seldom sufficient to simply raise the humidity. While it will reduce the VPD, the greenhouse temperature will eventually rise as the air becomes saturated preventing further evaporative cooling. Plants in a steam bath may not suffer from high VPD problems, but they will eventually cook!

**Pad & Fan Temperature Gradients** - the air temperature at the pads will always be cooler than the temperature near the exhaust outlets. This doesn't matter how long the greenhouse is; it depends upon the ventilation rate. To help compensate for this you can try placing fog or mist lines running at right angles to the air flow at about one third and two thirds of the way down the greenhouse.

**Ventilate under Shade Systems** - allow for sufficient air exchange under shade curtains, even if you have to leave the curtains opened a bit.

**Don't just Dump Air or Water on the Problem** - changing the air affects the moisture balance of the environment and the crop. Continuous evaporative cooling is not possible without sufficient air exchange to introduce drier air into the climate so that additional water can be evaporated, thereby contributing to cooling. Make sure you stop evaporative cooling early enough in the day to avoid problems with excess humidity and wetting of foliage overnight.

**Mineral Residues** – if your cooling water supply contains minerals such as bicarbonates or iron, using roof sprinklers, fogs, and mists may leave deposits on crops and greenhouse surfaces. Mineral deposits may also cause some problems with pad & fan systems although no minerals will be deposited on the crop since the moisture evaporating from the pad leaves the minerals behind. Minerals conveyed in fine water particles may also interfere with the proper operation of electronic humidity sensors.

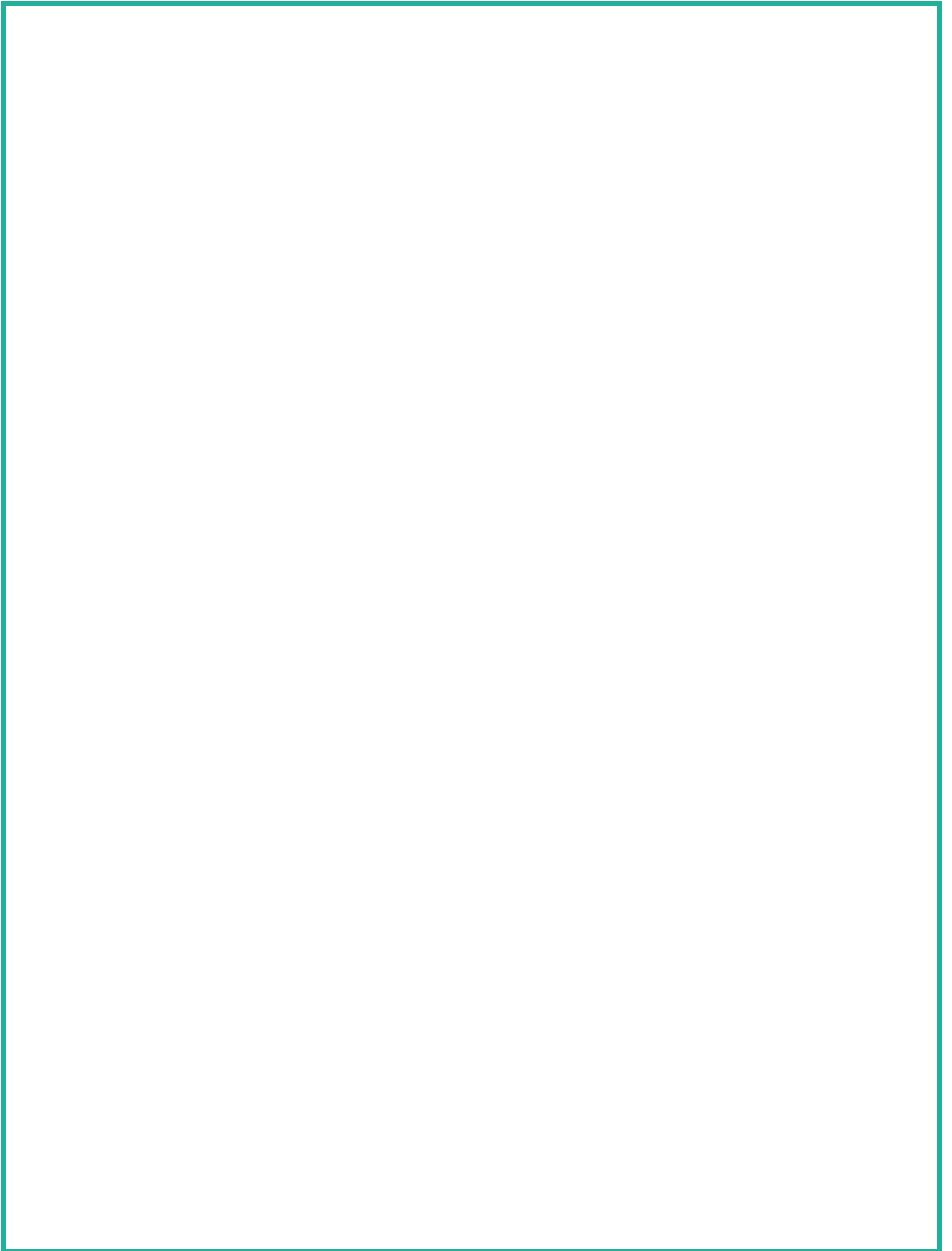
**Humidity & Temperature Sensors** – try to locate humidity and temperature sensors in an area that is representative of the average crop conditions, while avoiding the direct path of fog or mist nozzles. For pad & fan systems, take your measurements halfway between the inlet pads & the fan exhaust.

## Greenhouse Cooling Application Note

**Roof Sprinklers** – while moderately effective at raising the humidity on roof-ventilated greenhouses and providing some cooling through evaporation and conduction, you may need to limit roof vent opening angles to avoid dripping and overspray onto your crop.

Mineral deposits can stain the greenhouse covering, requiring expensive chemical removal. Roof sprinklers are best used on greenhouses with natural ventilation and low evaporative cooling needs.

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