# ANALYSIS OF GREENHOUSE CURTAIN SYSTEMS FOR SHADING, COOLING, AND HEAT RETENTION

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## INTRODUCTION

Curtain systems have been used for environmental control in greenhouses for over 10 years. When they were originally installed, their main function was either:

—to reduce heat loss at night
—for photoperiod control (blackout) of chrysanthemums
—daytime shading of crops

Over the last 10 years, there has been a dramatic improvement in the level of environmental control that can now be achieved in a greenhouse with environmental control curtain systems. This is due mostly to improvements in:

1) the curtain system fabric, which provides better cooling and greater heat savings at night.
2) more dependable curtain system mechanics; i.e. systems that can be automatically controlled so that an operator does not need to be present to monitor the movement of the system.
3) more sophisticated controls for the curtain systems, i.e. computers.
4) growers now having a better understanding of how to use the curtain systems to maximize environmental control and consequently their crop quality.

Now, when growers install an environmental control curtain system, they usually do it to achieve *more than one* of the following:

—shade plants *only* during periods of excessive light levels.
—help cool the greenhouse in the daytime, i.e. reduce both plant and soil temperature.
—reduce nighttime heat losses.
—photoperiod control (blackout)
—control crop height using DIF, (cool days, warm nights, cold shocking the plants in the morning)
—reduce costs associated with watering the plants, i e.
  —reduced water usage
  —reduced cost of hand watering
  —reduced fertilizer usage
—reduce electrical costs associated with using fans.

—control the nighttime escape of stray light from supplemental lighting.
—reduce temperature variations throughout the greenhouse at night.
—increase the quality, color, and shelf life of grown vegetables.
—humidity control for vegetables (i.e. tomatoes, cucumbers) grown hydroponically or in rockwool.

A properly designed environmental control curtain system should by definition "provide the ability to react to changing outside environmental conditions by maintaining *optimal, uniform* conditions inside of the greenhouse, while minimizing the energy inputs spent to provide this control."

In addition to the roof, the sidewalls and gables affect the light and temperature fluctuations that occur in the greenhouse. When we are discussing light and temperature control within a greenhouse using curtain systems, we are not only referring to curtain systems to control the roof of the greenhouse, but we are also referring to rollup curtains to control the sidewalls and gables.

When analysing which curtain system is suitable for your application, the analysis should include the following categories:

1) Fabric selection
   i.e.—should a polyester, polyester and aluminum, acrylic, or polyethylene film be used?
2) System configuration
   i.e.—do covers travel from truss to truss or from gutter to gutter?
3) System design
   i.e.—how is the fabric moved?
   —how does the system support the fabric?
   —is the fabric laying on top of and dragged across nylon wires, or is the fabric suspended from hooks that slide on wires?
4) System controls
   i.e.—is the curtain system controlled manually, by a timeclock, light sensor, or a computer?

Throughout this analysis, we will be referring to what effects the curtain systems can have on the greenhouse environment. All of the examples concerning the use of curtain systems inside greenhouses in this analysis, are based on using aluminized fabrics on the curtain systems. These fabrics are usually made from alternating strips of aluminum and polyester.

Table 1 compares some of the fabrics that can be used on the curtain systems for shading, cooling, and nighttime heat retention.

**Table 1.** Comparison of fabrics available for daytime shading and nighttime heat retention.

| | "LS" Fabric Alum & Clear Strips | White 100% Polyester Fabric | 100% Polyester C W Alum Strips Laminated on | Black Polypropylene Shade Fabric |
|---|---|---|---|---|
| Percent of Range | 22% to 99 9% | 30% to 76% | 60% to 99 9% | 30% to 95% |
| Reflects Light For Better Cooling | Yes | Some | Yes | No |
| Pliability | Good | Average | Average | Poor |
| Resistance to Dirt Adhesion | Good | Very Poor | Very Poor | Good |
| Cleanability | Good | Very Poor | Very Poor | N/A |
| Diffusion | Yes | Some | Some | None |
| Re-Reflection | Yes | Some | Some | None |
| Controls Night-Time Radiant Heat | Yes | Some | Yes | Minimal |
| Heat Retention | Good | Good | Good | Poor |
| Resistance to Mechanical Abrasion | Average | Good | Good | Good |
| Price | High | Low | High | Low |
| Resistance to Algae Growth | Good | Poor | Poor | Very Good |
| Suitable for Nylon Wire Suported Peaked Truss to Truss System | No | Yes | No | Yes |

Due to the custom nature of curtain systems, we will not be addressing the various curtain system designs or curtain system controls. Should you have an interest in the curtain system designs and controls, they should be discussed first hand with the various curtain system manufacturers.

## DAYTIME SHADING

If daytime shading is required, a shade factor between 30% and 85% is typically used. The actual shade percentage that you select will depend on:

—maximum daytime light intensity for your area
—maximum foot candles the crop can tolerate
—light transmission of the greenhouse and covering

When needing to shade a greenhouse, there are five basic alternatives:

1) whitewash the greenhouse roof.
2) black shade cloth fastened semi-permanently over the greenhouse roof.
3) black shade cloth fastened semi-permanently inside the greenhouse.
4) automatically controlled curtain system inside of the greenhouse.
5) retractable shading system *above* the greenhouse

The following is a brief summary of the pros and cons of the five alternatives mentioned above.

**1. Whitewash the greenhouse roof**

—is economical to buy
—can be difficult to remove
—may need to be reapplied after a rainstorm
—shades crop even during low light levels (i.e. early morning, late afternoon, overcast days) even though the crop could tolerate all available light at those times, thus *reducing the crop's growth and quality.*
—is a yearly expense to buy, spray on, and wash off.
—can permanently reduce the light transmission of your greenhouse covering.
—can introduce chemicals into your ground water runoff either from the whitewash, or from chemicals used to remove the whitewash.
—cannot be used to reduce heating costs in the winter

**2. Black shade cloth fastened semi-permanently over the greenhouse**

—shades crop
—is economical
—can be dangerous to install
—wind can cause shade cloth to have abrasive effect on poly (may void warranty on poly?)
—shades crop even during low light levels, thereby reducing crop growth, and quality
—stops light from entering the greenhouse, thereby reducing heat build-up inside the greenhouse
—cannot be used to reduce heating costs in the winter

**3. Black shade cloth fastened semi-permanently inside the greenhouse**

—is economical to buy
—is easier to install and remove than black shade cloth fastened over the greenhouse.

—does not affect roof covering
—shades crop even during low light levels
—can shade crop even more during the early morning and late afternoon. Shade cloth can generate a level of shade higher than its rating when the light comes from a low level of incidence, i.e. early morning and late afternoon.
—cannot be used to reduce heating costs in the winter
—Can actually increase crop and soil temperature.

A test was done in southern Florida to determine the effect on plant and soil temperatures of using black shade cloth inside a greenhouse. Plant and soil temperatures were first monitored in a freestanding, 35 ft. wide, double poly covered greenhouse without any black shade in it. The greenhouse had open sidewalls to ensure maximum air movement. After that, 65% black shade cloth was installed in the greenhouse at the bottom cord level. Plant leaf and soil temperatures were again monitored and it was noted that the plant leaf and soil temperature increased by 5° F. instead of decreased. This is contrary to what one would have expected.

**4. Curtain system inside the greenhouse**
—minimum yearly labor cost with respect to shading.
—does not affect the light transmission of, nor have an abrasive effect on the greenhouse covering.
—does not use paint or chemicals.
—can be used to reduce heating costs in the winter
—will positively affect the quality of light that the crop receives, i.e.:
a.—diffusion of light
—using the fabric with the clear strips between the aluminum ones, will create additional diffusion of incoming light.
b.—re-reflection of light
—using the fabric with the aluminum strips will help increase the amount of diffused light that your crop receives. Some of the light that enters the greenhouse is reflected back up off of the plants, benches and walkways. The aluminum underside of the fabric reflects some of this reflected light back down towards the crop. If you had black fabric inside the greenhouse above your crop, this reflected light would be absorbed rather than reflected.
c.—Ensures that you are only shading the crop when it needs to be shaded. Retracting the fabric during low light levels maximizes plant growth by maximizing the light that the plants receive.

**5. Curtain system above the greenhouse**

—provides similar benefits of retractable shade as the curtain system inside the greenhouse

—is not efficient for heat retention

—is better at cooling than a curtain system inside the greenhouse.

Given that the primary difference between a curtain system inside or above the greenhouse is daytime cooling, it will be addressed in more detail in the following section titled "Daytime Cooling."

When analysing these alternatives to daytime shading, the analysis ultimately centers on the use of either "fixed" or "movable" shading. One grower in California did a test to monitor the amount of light that plants received in a greenhouse that was shaded with whitewash versus plants located in a house with an automatic shading system. The results were as follows:

—the plants in the whitewashed greenhouse received approximately 6 hours of sunlight at an intensity sufficient for plant growth.

—in the house with the automatic curtain system, the plants received an average of 9 hours of sunlight at an intensity sufficient for plant growth.

—consequently it can be said that the crop under the automatic curtain system received *50% more hours of light sufficient for growth than the crop inside the house that had whitewash on the roof.*

—considering that plants can only process into growth a limited amount of light (if they receive too much light then the plants either burn or "shut down" due to overheating, (heat stall) then it appears that if you want the plants to grow faster, it is better to increase the number of hours in the day that the plants get sufficient light to grow, rather than to try to give them more light than they can tolerate.

To help you understand the concept of fixed and retractable shade, there are three graphs in Figure 1 that show the difference in the amount of light that the plants would receive depending on whether fixed or retractable shade was used.

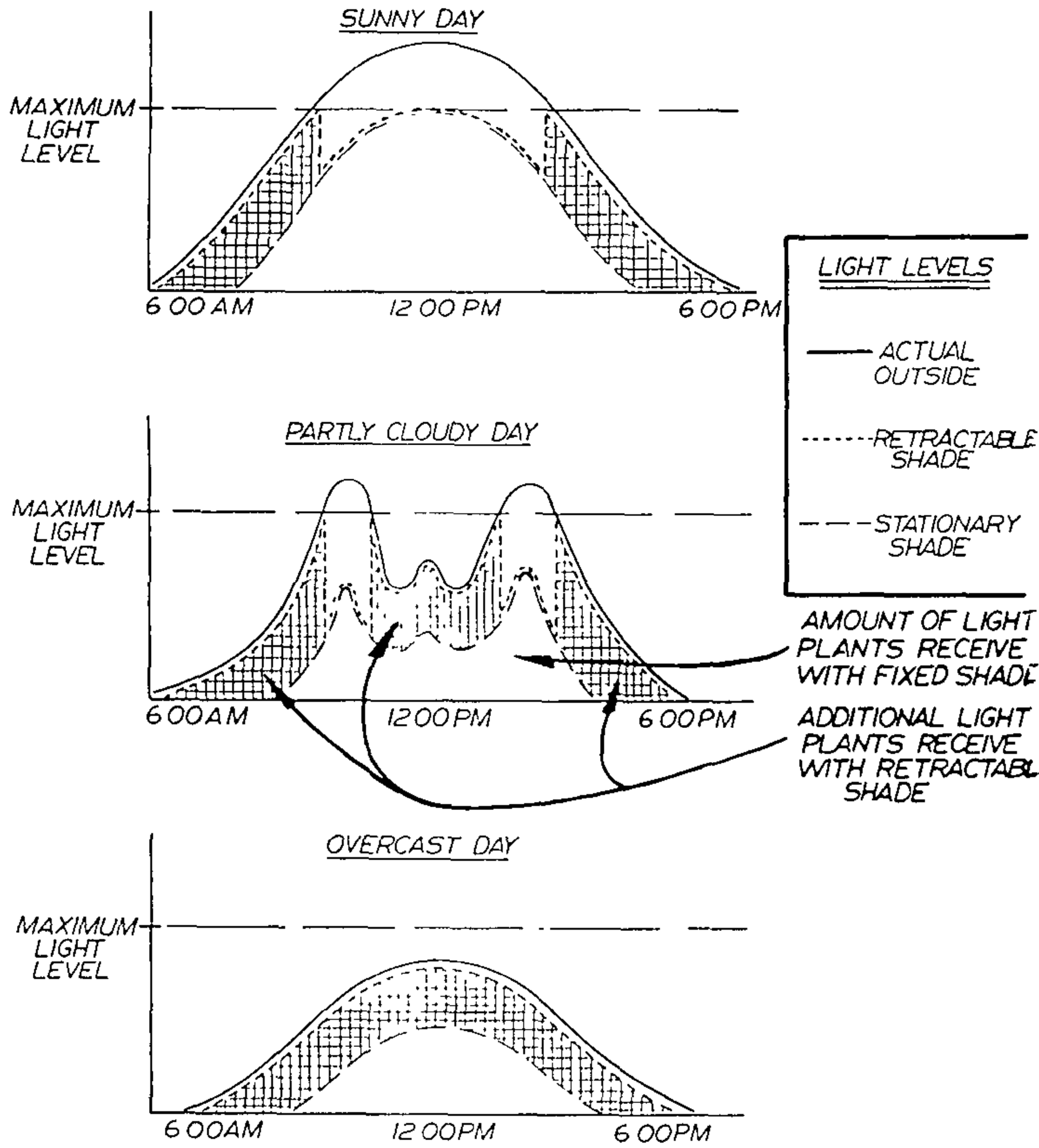


**Figure 1.** Comparison of light levels inside the greenhouse using stationary shade vs a retractable shade/cooling curtain system

## DAYTIME COOLING

When trying to cool a greenhouse, there are five basic alternatives and combinations thereof:

—fans and cooling pads
—fans and side vents
—fog
—roof vents (natural ventilation)
—curtain systems

Normally, a greenhouse already has some sort of ventilation system, either roof vents or side vents. A curtain system is then typically never installed in a greenhouse without some sort of ventilation system already in place. Consequently, it can be said that the curtain system will always be used for cooling in conjunction with a ventilation system.

As mentioned in the ''Daytime Shading'' section, when it comes to cooling, the most important aspect of the curtain system is the fabric selection. The level of cooling that you will achieve with a curtain system is mostly dependent on your selection of fabric. This is comparable to the idea that the greenhouse covering is what primarily determines the environment inside the greenhouse.

Both the greenhouse covering and the fabric used on the curtain system have an effect on:

—light transmission
—light diffusion
—heat retention
—cooling
—humidity

Since an aluminized fabric is one of the best fabrics for reflection, (and the higher the reflection, the better the cooling), the following discussion concerning the use of curtain systems *inside* greenhouses for cooling is based on the using of an aluminized fabric.

When new, white fabrics can also have a high degree of reflection, but they tend to get dirty faster and, consequently, they become less effective in cooling a greenhouse the longer that they have been installed.

See ''Daytime Shading'' section for a discussion of why black shade fabric should not be used inside a greenhouse for shading and cooling.

One of the major benefits of using a retractable curtain system for cooling instead of fixed shade is as follows. When you install fixed shade for shading and cooling, whether it be whitewash or shade cloth, the right shade factor must be selected. If, for example, you choose 50% shade, the problem arises that 50% may not be quite enough for proper daytime cooling. However, 50% shade *is too much shade* in the early morning, late afternoon, and during overcast conditions. To select a 65% shade for the sake of better

cooling would definitely slow the plant growth down too much, so one would probably stick with the 50% shade. With fixed shade, one could say that the plant is never getting the right amount of light. Not enough in the morning, too much in the middle of the day, and not enough in the late afternoon.

With a retractable curtain system for shading and cooling, a fabric with a 65% shade could safely be used. The system is retracted during the early morning, the late afternoon, and during all overcast conditions. Finally, when the sunlight is excessive, the curtain system is closed, shading the plants with a 65% shade thus cooling the plants sufficiently to maintain growth.

## CURTAIN SYSTEM INSIDE GREENHOUSE

*The following is a summary of the benefits of what some* greenhouse operations have achieved by using an interior curtain system for daytime cooling.

**Increases cooling efficiency of ventilation system.**

A curtain system reflects a high percentage of incoming light back up, thereby minimizing the amount of light that accesses the plant level. This reduces the amount of heat at the plant level that the ventilation system has to expel from the greenhouse.

At one greenhouse operation in San Antonio, Texas, the following was observed on a summer day (in a double poly gutter connected range, with and without a 50% shade aluminized curtain system), when the outside air temperature was 100° F.

Air temperature:

—inside air temperature, using pad and fan cooling, WITHOUT curtain system: 95° F.

—inside air temperature, using pad and fan cooling, WITH curtain system: 83° F.

Soil temperature:

—soil temperature WITHOUT curtain: 90° F.

—soil temperature WITH curtain: 85° F.

Consequently, an air temperature drop of 12° F and a soil temperature drop of 5° F was realized simply by closing the curtain system.

Shading and cooling of crops are not only required in the south. There are greenhouse operations in the northern U.S. States, and Canadian Provinces, where soil temperatures of 100° F. have been observed. In Ontario, Canada, a glasshouse with pot mums dropped the soil temperature 5° F. when the curtain system with a 50% shade aluminized fabric was closed.

The monitoring of the soil temperature is becoming even more critical with the number of crops being grown in flats and 4 in. pots. The less soil in a container, the faster the soil temperature will rise,

the faster the plant will shut down from overheating, and consequently the greater the need for proper cooling.

**Reduces power consumption.**

Using a curtain system to assist in daytime cooling can also help reduce your electric bills by reducing the number of fans that need to be operated to attain a certain level of cooling. During periods of maximum heat loading, the curtain system will help maintain cooler temperatures while the fans are running at maximum capacity. As the temperature drops, the cooling system will drop to a lower stage of cooling, thus shutting off several banks of fans. This not only will reduce electrical costs but also extend the life of the fans.

**Reduces water consumption.**

From the greenhouse operation in San Antonio to a greenhouse in Michigan, operators have experienced between a 40 to 50% drop in water consumption in the houses where they installed a curtain system and used it for daytime shading and cooling.

This not only reduces the cost to buy water, but it also:

—reduces the amount of fertilizer that is used

—reduces the potential for groundwater contamination

—reduces the cost associated with hand watering

—can allow for expansion if on a limited water supply

**Increased employee comfort and productivity.**

Employees tend to be happier and more productive in an environment where there are cooler temperatures (by greenhouse standards) and where the lighting conditions are less intense, i.e. diffused light. Greenhouse owners in the southern states can now have their employees work for a full day in the greenhouse without excessive fatigue. As the labor force continues to get smaller and more expensive, it is becoming even more important to provide better working conditions.

## CURTAIN SYSTEM ABOVE THE GREENHOUSE

In the southern climates, it has been apparent that most growers have a bigger problem trying to cool their greenhouses rather than heat them. In these cases, a curtain system above the greenhouse usually makes more sense than a curtain system inside.

The primary benefits of a curtain system above the greenhouse instead of inside are as follows:

1) **Maximum cooling.** Sun is prevented from getting access to the greenhouse roof covering, consequently the solar gain is minimized.

   The air space between the curtain and the roof covering minimizes the radiant heat transfer. When black shade cloth is fastened on top of the roof covering, the radiant heat transfer into the greenhouse can be very substantial.

Fabric is porous to the air so that the heat that does build up underneath the fabric can pass through and escape.

Reduces cooling problems created by bug screening vents. Bug screening drastically reduces air movement necessary for cooling. The curtain system above the greenhouse stops a large percentage of heat from entering the greenhouse. This will reduce the amount of air flow required to maintain a given level of cooling.

Due to the air space between the shade system and the greenhouse roof, black shade cloth can be used on the curtain system while still maintaining adequate cooling. If required, an aluminized fabric can still be used for even better cooling. This is especially effective in high heat, high humidity locations where pad and fan, and fog are not as effective.

The distance between the shade and the plants is maximized, (it could be 2× greater than a curtain system inside a greenhouse.) This allows for twice as much air volume that must be heated up before the air at the plant level heats up.

2) **Reduces humidity.** This method reduces reliance on evaporative cooling. During periods of marginal cooling the cooling pads or fog can be run at a lower stage of cooling since the curtain system above the greenhouse is reducing the amount of heat that enters the greenhouse, and consequently the amount of heat that needs to be removed.
3) **Extends the life of the roof covering.** The curtain system above the greenhouse shades the roof covering everytime there is high U.V. exposure, which is when you need the curtain system closed for cooling. The fabric from a curtain system never touches the roof covering so that the roof covering will never suffer any mechanical abrasion, unlike when shade cloth is fixed on top of the roof covering.

Unfortunately, the existing greenhouse designs only allow for the curtain system to be installed above two types of greenhouse structures, gutter connected sawtooth style greenhouses, and free standing quonset greenhouses. This is due to the fact that the curtain system needs a member above the greenhouse. As the greenhouse structure designs develop over time, there may be designs of gutter connected greenhouses that are not sawtooth that may accommodate these curtain systems. In any event, if you are planning to build a greenhouse with a curtain system above it, clear the structural design with the curtain system supplier before you build the greenhouse.