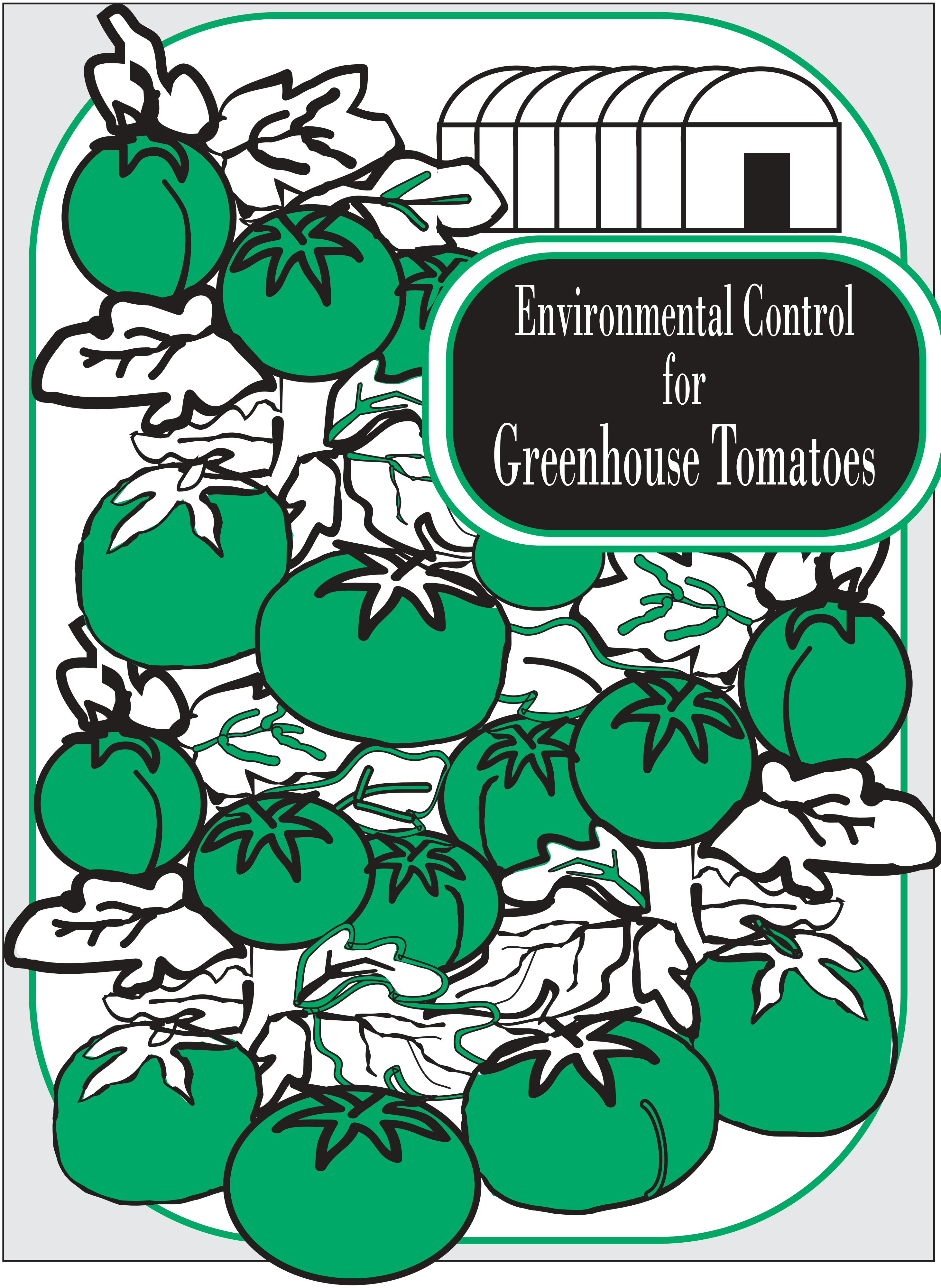
Environmental Control for Greenhouse Tomatoes



The objective of growing greenhouse tomatoes is to set four or five perfect fruit on every cluster of each plant. Proper environmental control will help meet this goal.

Environmental Control for Greenhouse Tomatoes

The only reason for growing plants in a greenhouse rather than outside is to be able to control the environment. A greenhouse allows the grower to produce plants in a location where they would normally not grow and at a time of year when it would otherwise be impossible because of the weather.

A greenhouse protects plants from extreme temperatures, rain, sleet, snow, winds, hail, insects and diseases, etc. In addition, heat can be added, ventilation can be provided, air can be cooled, humidity can be controlled, carbon dioxide can be added, light level can be altered, and water and fertilizer can be provided at optimum levels.

The purpose of altering the environment is to provide a constantly controlled environment where plants can be grown at their optimum, not just to avoid extremes in the weather.

In summary, the function of a greenhouse is to modify the environment for better plant production.

Site Selection

Select a site that has access to both electricity and fresh water. The water source should be clean – either community water or a well would be best.

Choose an area with no shading from trees or tall buildings. Be sure there are no shadows during the early morning or late afternoon hours. Greenhouse vegetables need full sun. At times when full sun is not needed, plants can be shaded with shade cloth or shade compound.

Choose a site that has room for possible future expansion. You may want to start with only one greenhouse, but locate it so there is ample room to add gutter-connected houses if you need to.

Drainage

Drainage should be one of your first considerations. If the soil is mostly sand, water will percolate directly through the soil under the greenhouse. However, many soils in Mississippi have a large component of clay. In poorly drained soils, water drainage must be designed into the system.

First, level the site. Then put at least a 1 to 2 percent slope from one end of the site to the other. If you plan to plant tomatoes, dig ditches under where the rows will go. These ditches will bring all water to one end of the greenhouse.

Next, cover the floor with heavy black plastic. This will prevent contact between soil-borne organisms and plants within the greenhouse. Fill the ditches with pea gravel 6 inches deep to make the floor level. Finally, cover the pea gravel with a woven plastic, which will allow water to drain through and into the gravel and then travel to ditches to be removed from the greenhouses. The woven floor covering is readily available in black; white floor covering can be found with more effort.

Type of Greenhouse

Greenhouses can be either free standing, single greenhouses, or gutter-connected bays. If you plan to build more than one greenhouse, the gutter-connected formation is more economical. Each side-by-side pair of houses will share a common gutter, reducing the number of sidewalls by two, thereby decreasing construction costs. In addition, there will be less surface area for heat loss, so there is an energy savings as well.

Typical lengths of greenhouses for tomatoes are 96 feet and 130 feet. The 96-foot greenhouse is a convenient size because plastic covering is easily found in 100-foot lengths. This is the longest practicable run from intake vent to exhaust fan that will provide adequate cooling. A greenhouse longer than 150 feet will have too much of a temperature gradient from the intake end to the exhaust end. For greenhouses longer than 150 feet, consider ventillating across the width of the greenhouse.

Side walls need to be vertical for greenhouse tomatoes, rather than the ground-to-ground or quonset styles, which have curved side walls. The vertical side wall should be a minimum of 8 feet high (10 feet preferred), at which point the gutter would be placed in a gutter-connected greenhouse. Above the side wall, an arch-shaped top, with or without trusses, is most common.

Orientation

Face greenhouses north-south rather than east-west. This siting becomes even more important as bays are added in a gutter-connected formation. The shadow caused by the gutter will leave an immobile shadow in an east-west range, whereas in a north-south range, the gutter shadow will move across the crop (from west to east) during the day as the sun moves from east to west.

Locate exhaust fans on the downwind end of the greenhouse so they are not blowing against the wind. Also, place the intake vents on the prevailing wind end (the direction the wind blows from).

Heating

There are several choices for the type of heating system used to heat greenhouses: natural gas (methane), LP gas (propane), number 2 diesel oil, wood, electricity, or even a heat pump. Other than when using a heat pump or an electric heaert, **vent all burners to the outside.**

Never allow gasses to remain inside the greenhouse, as tomato plants are very sensitive to certain pollutants found in fossil fuel exhaust. Especially with kerosene and propane space heaters, the potential exists to poison plants with toxic pollutants. Also, space heaters may consume oxygen and deplete it so that incomplete combustion may result, producing harmful by-products. Or the lack of oxygen may cause the flame to go out and the burner to shut off. In either case, the use of unvented heaters is too risky for the greenhouse grower.

The exhaust flue should extend at least 2 feet, preferably 4 feet, above the ridge (highest point) of the greenhouse. The high temperature of the exhaust gasses helps to draw pollutants out of the greenhouse. In a tight plastic greenhouse, it may be necessary to bring fresh outside air to the burner via a duct to ensure complete combustion. See section "Providing an Air Intake" for information on

Maintaining a temperature of at least 62 °F is important for greenhouse tomatoes. Lower temperatures can result in catfacing and other quality defects.

the correct size.

How To Size the Heating Units

There are four steps needed to calculate the size of the heating system to keep tomato plants at the required temperature (over 62 °F).

1. Figure the greatest difference between inside and outside temperature.

Size your heating systems for the most extreme conditions expected. For example, do not base the BTU rating of the heaters on 40 °F winters because the temperature often drops below this in Mississippi winters. The 99 percent and 97.5 percent Design Temperatures for various cities in Mississippi are shown below. This means for Jackson, for example, 99 percent of recorded hourly temperatures in December, January, and February were 21 °F, and 97.5 percent of recorded temperatures during these months were above 25 °F. Therefore, to be safe, size the heating system to provide adequate heat even when the temperature outside falls as low as 21 °F in Jackson. In northern Mississippi, from Greenville to Tupelo and farther north, the heating system should be designed for 14 °F.

City	99% Design Temperature	97.5% Design Temperature
Biloxi	28	31
Clarksdale	14	19
Columbus	15	20
Greenville	15	20
Greenwood	15	20
Hattiesburg	24	27
Jackson	21	25
Laurel	24	27
McComb	21	26
Meridian	19	23
Natchez	23	27
Tupelo	14	19
Vicksburg	22	26

The inside temperature for greenhouse tomatoes should not go below 62 °F. Therefore, the maximum expected temperature difference = 62 - 21 = 41 °F for Jackson, Mississippi.

2. Know the entire surface area of the greenhouse, including the total area of the side walls, end walls, and roof, expressed in square feet.

3. Use the appropriate U-value (heat flow coefficient). For a single layer of plastic, use U = 1.2; for a double layer, use U = 0.8. If a thermal screen is used, U would be 0.5. The lower the U-value, the better the insulation effect.

4. Next, use the following equation:

Heat Required = U x A x (T_{INSIDE} - $T_{OUTSIDE}$)
U = Heat Flow Efficient
A = Surface Area of Greenhouse
(T_{INSIDE} - $T_{OUTSIDE}$) = maximum difference between inside and outside temperatures

Example:

As an example, assume that a single 24- x 96-foot greenhouse in Jackson, with a double layer of plastic, needs to be sized for a heating system.

If the gutter height is 8 feet, the end walls are each 24 x 8 = 192 square feet. The side walls are each 96 x 8 = 768 square feet. The roof area is the same as the width of plastic over the roof times the length. So, if the top is 30 feet over the curved roof, the roof area is 30 x 96 = 2,880 square feet. The total greenhouse surface area is (2 x 192) + (2 x 768) + 2,880 = 4,800 square feet.

Using the formula above,

Heat Required = U x A x (T_{INSIDE} - $T_{OUTSIDE}$)
= 0.8 x 4,800 x (62 - 21)
= 0.8 x 4,800 x 41
= 157,440 BTUs

A heating system able to supply a total of 158,000 BTUs would be appropriate for a greenhouse of this size located in Jackson, Mississippi.

It is better to use two small heaters (for example, two 80,000 BTU heaters) than one large heater in a single, free-standing greenhouse. Then, if one heater fails, there will be a backup to prevent the crop from freezing.

The best way to distribute the heat is to use 8- or 10-inch poly tubes along the floor. These can run on the floor along side walls and below gutters. By putting the heat distribution tubes on the floor, you deliver heat where it is most needed – at plant level – rather than close to the roof as with traditional fan jet systems. Cut holes in the tubes along the side walls either at "3 o'clock" or "9 o'clock"; cut holes in tubes between gutter-connected bays in both locations to deliver heat in both directions.

Traditional fan jet systems are commonly used to distribute heat produced by heaters and to recirculate inside air when the heating system is not in use.

Providing an Air Intake

Now that you know the size of the heating system, you can size the air intake for the heating unit. Calculate this by using this formula: Use 50 square inches of intake for each 100,000 BTUs of the heating system.

If 160,000 BTUs are needed, as in the example above, use 1.6 x 50 = 80 square inches (or about half a square foot) of air intake for the burners.

Thermostat

Each environmental control device needs a thermostat to control when it is activated. This includes any or all of the following: heater, exhaust fan, fan jet louver, poly vent, evaporative cool pads, and/or mist system. The location of these thermostats is very important.

Do not put thermostats on an outside wall; put them somewhere in the interior of the greenhouse where the temperature they monitor will be representative of most of the plant space.

Locate thermostats near the center of the house or range to get good temperature control. Also, enclose the thermostat in an aspirated box, or shade it so that it indicates the air temperature correctly. If the sun is allowed to shine directly on the thermostat, it will read a higher temperature than the air surrounding it.

Do not put thermostats where hot air from the heater or cool air from the fans will blow directly on them.

Never trust a thermostat to be 100 percent accurate. It is wise to install a high/low thermometer in the greenhouse near the thermostat. It will record the highest and lowest temperature that occurred since the last reset of these values. The important point is to maintain the actual temperature that is desired. This temperature can be verified with use of the thermometer, regardless of what the thermostat setting reads.

Ventilation

Ventilation is important not only during the warm-season months, but also during the cool season on sunny days. Fresh air is primarily needed to lower the humidity and air temperature, but it also replenishes carbon dioxide (CO_2) that plants consume during the daylight hours in the process of photosynthesis.

Design the ventilation system to provide one air exchange per minute, 8 cubic feet per minute (CFM) per square foot. For a 24- x 96-foot greenhouse, two 36-inch or 48-inch fans are usually required. Even with proper ventilation in the warm season, the inside temperature will always be higher than the outside temperature.

How To Size the Exhaust Fans

Exhaust Fan CFM = 8 x (Length of Greenhouse) x (Width of Greenhouse)

Example: In a 24- x 96-foot greenhouse, the square footage of the floor is 2,304 square feet. Therefore, calculate the CFM of the fans by multiplying 8 x 2,304, or 18,432 CFM. This will give one air exchange per minute for the volume of air in the greenhouse up to a height of 8 feet.

Proper sizing of the exhaust fams is important to ensure adequate temperature control during warm periods. Refer to the text for the simple calculations.

If you use variable speed fans or two-speed fans, you can have better temperature control. Be sure to keep any doors and windows at the fan end of the greenhouse closed while the fan is operating. Otherwise, air currents will short circuit the greenhouse interior. Fit plastic coverings and poly vents tightly to prevent air leaks.

Be sure not to exhaust hot air from one greenhouse into the intake vent of another. This only compounds the cooling problem. Have shutters on fans that close automatically when they stop blowing.

How To Size the Intake Vent

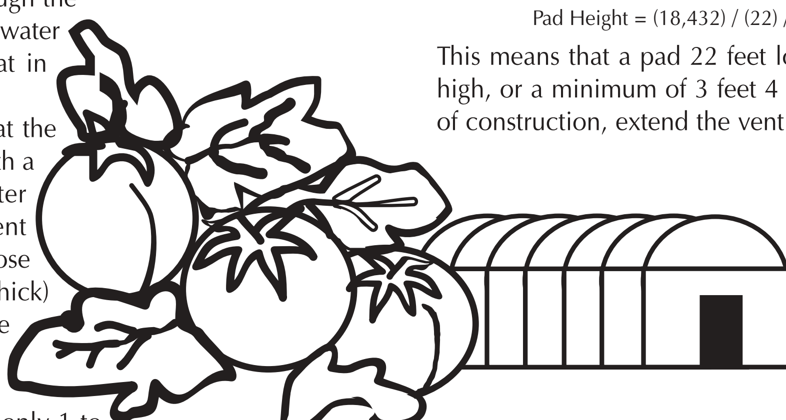
Vent (sq ft) = 8 x (Length of Greenhouse) x (Width of Greenhouse) / 700

Example: With a 24- x 96-foot greenhouse, the square footage of the floor is 2,304 square feet. To know the volume of air that must be moved, multiply this number by a height of 8 feet. Therefore, 2,304 x 8 = 18,432 cubic feet. Have adequate ventilation to achieve approximately one air exchange per minute, or, in this case, 18,432 cubic feet per minute (CFM). Wind velocity needed at the intake vent is 700 feet per minute. Divide the cubic feet per minute by 700 feet per minute to get the square feet of the intake vent. To find the answer, divide 18,432 by 700. This equals 26.3. So, a minimum of 27 square feet of intake vent is required. For greenhouses with an insect barrier over the intake vent, increase the vent size to compensate for reduced air flow. Contact the manufacturer for information.

Evaporative Cooling

In addition to cooling by using exhaust fans, often you will need to take additional measures. One of the most common measures is to add evaporative cooling, also referred to as "wet pads" or "cooling pads." The principle is simple. As the exhaust fans blow air out of one end of the greenhouse, they draw in moist air from the other end. As the moist air moves through the greenhouse, some of the water vaporizes, absorbing heat in the process.

Moisture is supplied at the end opposite the fans with a system that drips water through an absorbent material, such as cellulose (typically 4 or 6 inches thick) or aspen pads. These are commonly called cool pads. Because aspen pads last a maximum of only 1 to 2 years in the Southern climate, they are not recommended. All incoming air passes through this wet fiber. Any water that drips through the fiber is collected in a gutter at the bottom and drains into a small holding tank. Water is recirculated from the holding tank back to the top of the cool pads.



Take care to replace water that is absorbed by the air's passing through the cool pads. This is usually done with a toilet tank type float-valve controller.

Evaporative cooling is more effective when the air outside the greenhouse has a low relative humidity. As the relative humidity of the outside air increases, this technique becomes less effective. For example, if the outside air is 95 °F and the relative humidity is 50 percent, there would be about 13 degrees of effective cooling. But if the relative humidity is 70 percent, there would be only an 8-degree drop. With 90 percent relative humidity, only a 2-degree drop can be expected. So long as the relative humidity is less than 100 percent, this method will have some cooling effect on the air.

Choosing the correct pad size is important so that adequate cooling will be achieved. The length of pad is limited by the greenhouse width, so it is the height that must be calculated.

How To Size the Cool Pads

Pad Height (feet) = (Air Flow Rate) / (Pad Length) / (Design Velocity)

The air flow rate is the same as the cubic footage of the greenhouse. With a 24- x 96-foot greenhouse, use 24 x 96 x 8, because the useable height for cooling is 8 feet. This equals 18,432 cubic feet. Because you need one air exchange per minute, 18,432 CFM is the air flow rate. The pad length is probably about 2 feet less than the greenhouse width, or 22 feet, in this example.

The design velocity is the speed with which air can pass through the cool pad, in feet per minute. For 4-inch cellulose, use 250; for 6-inch cellulose, use 380; and for aspen pads, use 165. If you are using 4-inch cellulose, as in this example, divide by 250.

So, the equation above becomes as follows:

Pad Height = (18,432) / (22) / (250) or 3.35

This means that a pad 22 feet long needs to be 3.35 feet high, or a minimum of 3 feet 4 inches in height. For ease of construction, extend the vent height to 4 feet.

Horizontal Air Flow

Horizontal air flow refers to movement of air within the greenhouse, as opposed to drawing fresh air in from outside. This inside air movement is important to the health and productivity of greenhouse crops.

It is necessary to have air movement within the greenhouse at all times, whether the exhaust fans are on or not. When exhaust fans are not in use, make some other provision to create air movement within the greenhouse.

Constant air movement is important for the following reasons:

- A more uniform environment is maintained throughout the greenhouse, avoiding "pockets" of high or low temperature or humidity.
- Air movement helps to keep leaf surfaces dry so that diseases are not so likely to develop.
- The air will also help to dry the inside surface of the plastic covering. Any condensation on the plastic film will reflect some light rather than transmitting it to plants; in effect, it causes shading.
- Carbon dioxide is brought to the leaf surfaces. In the absence of air movement, carbon dioxide, essential for photosynthesis, can actually be depleted adjacent to leaves even though it is more available in other parts of the greenhouse. Air movement keeps carbon dioxide mixed throughout the greenhouse.

One way to provide continuous air flow is to set the fan on the heater so that it remains on constantly. Or, a separate thermostat can be wired to the heater fan so that it can be set to turn on when exhaust fans are off and heat is not needed. The heater thermostat will still control when the burner comes on, but the fan will stay on more of the time. When exhaust fans are on, they will provide all the air mixing needed.

Another technique is to install low-volume fans above the crop to push air through the greenhouse. These are left on all the time, or they are wired so they turn off when the exhaust fans come on.

The reason for horizontal air flow is to keep air moving among the plants at all times. You must be able to see the slight movement of the leaves and any loosely hanging strings in all parts of the greenhouse.

Plastic Film

The plastic film used to cover greenhouses comes in various formulations that affect its longevity. Generally, it is sold as 2-year, 3-year, 4-year, or unspecified length films. Film rated 2-year or higher has UV (ultraviolet) inhibitor in it to prevent rapid breakdown from the sun. A film with an unspecified life span will probably last less than a year with the strong Mississippi light, so it would not be worth the cost. The longer the life of a film, the more expensive it is. But, although costlier, the longer life films require less frequent replacement.

The recommended film to use for the greenhouse is a 3-year film, the best compromise between longevity and price. Be certain that it says "UV-resistant" and is the correct size to cover the greenhouse with a little left over to

Small squirre-cage blowers (¼ or ½ HP) can be used to inflate between the two layers of plastic covering the greenhouse. It is important to use outside air for this purpose so that condensation does not collect between the layers.

fasten around the edges.

Energy Conservation

Double Plastic Cover

One technique used to reduce heat loss is to apply two layers of film to the surface of the greenhouse rather than one layer of film or glass. This double layer is often referred to as "double poly." A single layer has a U-value (heat flow) of about 1.2, while two layers bring the U-value down to 0.8 (remember: the lower the U-value, the better the insulation). Also, the air space between the two layers serves as an excellent insulation to heat flow. An energy savings of 30 percent is attainable by using this simple method. However, there are two important points:

- **Do not allow the two layers of plastic to touch each other except where fastened.** Any point where the two layers come in contact is reduced to an insulating value of one layer. To avoid this, a small blower is used to inflate the space between the two layers of plastic. A 1/3 or 1/4 horsepower squirrel-cage fan (100 to 200 watts) is usually adequate for this purpose. This blower should run constantly to maintain inflation.
- **It is important to use outside air for this purpose.** Although inside air is warmer and will use less energy to heat, it holds more moisture than the cooler outside air.

Often, greenhouses that use inside air will have water collect between the layers, making small pools of water. If this happens, puncture the lower layer to let the water drain; then patch the hole. Otherwise, the weight of the water can tear the plastic.

Water collects because the warm, humid air blown between the layers from inside the greenhouse comes in contact with the outside layer of plastic. This outside layer is cooler. If the temperature of the outside layer is below the dew point, as it usually is in the winter, it causes water to condense from the air onto the cool surface. This water collects between the layers into pools that grow with time.

Insulation of North Wall

The primary form of insulation for a greenhouse is the double layer of plastic on the top, side walls, and end walls. However, the north wall can be insulated more thoroughly than with double poly (on a north-south oriented greenhouse). Not enough light enters the greenhouse through the north end wall to supplement light from the other walls and top. Therefore, construct a solid wall. This can be insulated with polystyrene boards, fiberglass batting, or any other means. The wall can be finished with plywood or with any other suitable material.

More Information

For additional information on greenhouse tomatoes, refer to the following publications:

Pat Harris, Frank Killebrew, and Herbert Willcutt, 1993. *Greenhouse Tomatoes – Pest Management in Mississippi.* Mississippi State University Extension Service. Publication No. 1861. 11 pp.

William Roberts and David Mears, 1984. *Heating and Ventilating Greenhouses*. Rutgers University Cooperative Extension Service, New Brunswick, NJ 08903. Publication E-046. 19 pp.

Mississippi State University Extension Service

MSUcares.com

By **Dr. Richard G. Snyder**, Professor and Extension Vegetable Specialist

Publication 1879
Extension Service of Mississippi State University, cooperating with U.S. Department of Agriculture. Published in furtherance of Acts of Congress, May 8 and June 30, 1914. JOE H. MCGILBERRY, Director. (rev-1M-7-03)