

Controlling the Environment in Greenhouses Used for Tomato Production

Michael J. Buschermohle, Professor
George F. Grandle, Associate Professor
Biosystems Engineering and Environmental Science



Introduction

Growing tomatoes in greenhouses allows producers to grow plants at a time when it would be impossible to grow outside because of the weather. The sole purpose of a greenhouse is to maintain an environment that promotes optimum production. Solar energy from the sun provides both sunlight and heat, but growers must provide a system that maintains the optimum growing environment in the greenhouse. To maintain this optimum growing environment, your greenhouse must be equipped with well-designed heating, ventilation and air distribution systems that properly control temperature, carbon dioxide and humidity. This publication explains the importance of carefully managing the heating, cooling, ventilation and air circulation system in plastic-covered greenhouses for tomato production.

Greenhouse Heating

Why Heat?

Both day and night temperatures influence plant vigor, leaf size, leaf expansion rate and time to fruit development. Under low night-time temperatures, the rate of leaf growth is slow and leaf size is reduced in young plants. Day and night temperatures should be carefully monitored. For greenhouse tomato varieties, day temperatures should be maintained in the '70s and no lower than 60 to 64 degrees F at night. High



temperatures in excess of 85 to 90 degrees F will cause many different types of damage, such as inhibition of growth, fruit abortion and

even death. Temperatures lower than the optimum will alter plant metabolic systems to slow growth and again hinder fruit set.

As much as 25 percent of the daily heat requirement may come from the sun; however, a lightly insulated greenhouse will need a great deal of supplemental heat to maintain optimum growing temperatures during cool, cloudy days and cold nights.

Heating Systems

Many types of heating systems are available for use in greenhouses. Selecting the proper heating system is important because of the significant differences between available systems. Some systems cost less to buy or use less expensive fuels. Others may have a higher initial cost, but they are more efficient and cheaper to operate. Features to look for in a heating system include thermostats to control temperature; aluminized or stainless steel heat exchangers for extended life in the humid, corrosive environment of the greenhouse; fans to help distribute the heat throughout the greenhouse; and brackets to mount the heater to the greenhouse structure.

Selecting the appropriate heating equipment depends partially on the type of fuel available. Commonly used fuels in greenhouse heating systems include:

Natural gas is a clean-burning fuel that requires little equipment maintenance. It needs no on-site storage and supplying it to the heater is easy. Natural gas is sold in units called "therms." A therm is the volume of natural gas containing the heat equivalent of 100,000 British Thermal Units (BTUs). The price of natural gas per BTU of heat energy is often competitive with LP gas; however, it is not available in all areas and supplies may be short during periods of extended cold weather.

Liquified Petroleum (LP) is composed primarily of propane and butane, which burn exceptionally clean. Maintenance is minimal, but storage tanks are needed. LP gas is sold by the gallon. One gallon of LP gas contains approximately 95,000 BTUs.

Fuel Oil, Diesel and Kerosene heaters cost more to buy and operate than LP or natural gas heaters. These fuels require on-site tanks with retention systems around them to contain the oil in the event of a spill, and may become difficult to pump when the outside temperature approaches 0 degrees F. Fuel oil heaters, and any that use diesel or kerosene, must be vented to eliminate the resulting fumes from combustion that may build up in the greenhouse.

Compare Fuel Prices and Efficiency

Although availability and heating equipment are important factors in choosing a heating fuel, a key consideration is a fuel's efficiency and BTUs (units of heat) produced per dollar. Fuels burn differently and produce different amounts of heat. For comparative purposes, use these efficiency guidelines:

- Natural gas: 1,000-1,200 BTUs per cubic foot
- Liquid propane: 91,500 BTUs per gallon
- No. 2 diesel: 140,000 BTUs per gallon
- No. 6 fuel oil (used motor oil): 150,000 BTUs per gallon
- Electricity: 3,412 BTUs per kWh (kilowatt hour)

To determine the BTU value per dollar, divide the fuel's BTU per unit by the unit price. Here are examples. Keep in mind that changing fuel prices affect a particular fuel's BTU value per dollar (if the unit price changes, simply substitute the new price).

- At 80 cents per 100 cubic feet, natural gas gives 125,000 BTUs per dollar.
- At \$1.50 a gallon, liquid propane gives 61,000 BTUs per dollar.
- At \$1.40 a gallon, number 2 diesel fuel gives 100,000 BTUs per dollar.
- At 6 cents per kWh, electricity gives 56,866 BTUs per dollar.

Heaters

Use vented gas heaters because they provide a cleaner, less humid and safer environment for both the growing plants and humans working in the greenhouse. They are usually located inside the greenhouse and the vent pipe, or stack, carries the products of



Vented heater

combustion to the outside.

The use of unvented gas heaters, such as those that burn LP gas or kerosene, is not recommended for tomato greenhouses. These type heaters are located inside the greenhouse and have no vent pipe to carry the products of combustion to the outside. Although they are more efficient than vented gas heaters, the additional buildup of moisture produced from burning the fuel and the potential for air pollution problems inside the greenhouse is too risky.

Sizing Heating Systems

The heating system must be able to supply enough heat to offset the heat lost to the outside. Heater size will depend on the surface area of the greenhouse, the type of covering material, wind speed and the difference between outside temperature and the inside growing temperature. Greenhouse heaters are normally rated on their input capacity in BTUs per hour, not the number of BTUs the unit is capable of putting out. Heater output capacity will vary according to the efficiency of the unit. Input rating and heater efficiency must be taken into consideration when selecting the proper heater size. It is better to use two small heaters, placed in opposite corners of the structure, than one large heater in a single, free-standing greenhouse (i.e. two 100,000 BTU/hr heaters instead of a single 200,000 BTU/hr heater). Although the initial cost will be around 50 percent more to buy two smaller heaters over one larger unit, if one heater fails, the additional heater will provide a backup to prevent the crop from freezing.

Most manufacturers sell a complete greenhouse package that includes properly sized heating equipment. Growers who build their own greenhouses can obtain help in sizing their heating systems from their local county Agricultural Extension Service.

Installing Heating Systems

Heaters are either mounted overhead or on the floor, depending on the type of unit you buy. Overhead-mounted heaters have brackets that easily attach the heater to the greenhouse frame.

Mount the exhaust stack to extend at least 30 inches above the highest part of the house and at least 10 feet away from trees or other obstacles. The height is needed to allow hot exhaust gases to rise up the flue, creating a good upward draft. Vent pipes should be tight to prevent any leaks and supported to prevent any wind from blowing them over.



Vented heater exhaust stack

Providing Air Intake

As previously mentioned, the heater must have a sufficient supply of fresh air to prevent oxygen starvation. Combustion problems caused by the lack of oxygen can be solved by providing an air inlet pipe from the outside to the vicinity of the burner. A good rule of thumb is to have 50 square inches of cross-sectional pipe area for each 100,000 BTUs per hour of heating capacity.

Example: A 200,000 BTU heater requires $2 \times 50 = 100$ square inches of air intake for the burners. Based on the area of circular ducts from Table 1, you would

need to install a 12-inch diameter duct for the air intake to the burners.

Table 1. Cross-sectional Area of Circular Ducts

Duct Diameter (Inches)	Area sq. inches
4	13
6	28
8	50
10	79
12	113
14	154
16	201
18	254
20	314

Heater Maintenance

Keeping the heating system in good repair and operating condition will reduce operating costs and prolong the life of the unit. Before the start of each growing season, remove any soot or other deposits from the combustion chamber and the heat transfer surfaces. A 1/16-inch layer of soot on the heat exchanger surface of a vented gas heater can reduce the efficiency of the heater by as much as 25 percent. During cleaning, also check for cracks in the combustion chamber and heat exchanger surfaces. Cracks allow uncombusted gases to escape into the greenhouse.

All gas lines inside the greenhouse should be periodically checked for leaks. Leaking gas lines not only waste money, they also can be dangerous. A soap solution or a commercial gas detection device can be used to identify leaks.

Greenhouse Ventilation

Ventilation is important not only during the warm-season months, but also during the cool season on sunny days. Heat stress can occur even on those days when skies are clear and outside temperatures are quite cool (30 degrees or more below the desired growing temperature). It is not uncommon to have

temperatures well above 100 degrees in a closed greenhouse on a clear day with an outside temperature of only 60 degrees. Without proper ventilation, temperatures inside the greenhouse can easily become hot enough to damage the growing tomato plants. Ventilation is an air-exchange process that replaces the warm, moist air inside the greenhouse with cooler, often less moist, outside air. Proper ventilation not only cools the greenhouse, but also reduces the humidity level inside the greenhouse and replenishes the carbon dioxide that plants consume during daylight hours in the process of photosynthesis. Ventilation can be provided by natural or forced air systems.

Natural Ventilation

Naturally ventilated greenhouses have side walls that can be dropped down or raised like a curtain. Although some curtain systems open up from the bottom, systems that open down from the top are preferred. When ventilation is needed, the curtains are lowered or raised, which allows cool outside air to flow through the greenhouse. The amount of inside air exhausted from the greenhouse is controlled to some degree by how far the curtains are lowered. The curtains can be lowered a few inches when only a small amount of ventilation is needed, or they can be fully opened when maximum ventilation is required. Some advantages and disadvantages of side curtains are:

Advantages

- Lower initial cost;
- Lower operating costs.

Disadvantages

- Manually operated curtains require growers to be nearby at all times.
- Lack of precise control of air flow: natural ventilation depends on the wind, which can change in both speed and direction throughout the day. Growers risk under-ventilating on calm, hot days and over-ventilating on cold windy days.
- There is a possibility of higher heating costs due to air leakage caused by a loose fit between the sidewall curtain and the greenhouse.

The amount of cooling achieved by a naturally ventilated greenhouse will depend on wind velocity and direction, greenhouse orientation, width of the greenhouse, outside air temperature and any air blockage by surrounding trees, buildings or adjacent greenhouses. Naturally ventilated greenhouses should have

at least 3- to 4-foot wide openings along the length of the greenhouse to allow crosswise ventilation by the prevailing wind currents. Curtains should open from the top downward so the first opening for air on cold days will let the cold air mix with the warmer inside air before dropping down onto the plants and causing possible plant injury.

Orientation, as well as location, are critical to naturally ventilated greenhouses. Naturally ventilated greenhouses should be positioned so that prevailing winds blow across the structure, rather than along its length. They should be built away from woods, buildings and any natural obstructions that could inhibit air movement through the greenhouse.

Forced-Air Ventilation

Many tomato production greenhouses rely on ventilation fans to move air into and out of the greenhouse. Forced air ventilation consists of fans on one end of the greenhouse and motorized air inlets, or shutters, at the opposite end. When inside temperatures exceed the desired level, a thermostat opens the shutters and starts the exhaust fan(s). Ventilation is accomplished as outside air is pulled into the greenhouse through the shutters, moved lengthwise through the greenhouse and exhausted out by the fans. When the desired temperature has been reestablished, the thermostat shuts off the exhaust fans and closes the motorized shutters. Some advantages and disadvantages of mechanical ventilation systems:

Advantages

- They minimize drafts and possible chilling injury on plants;
- They provide more precise environmental control;
- They are easier to fully automate.

Disadvantages

- Fans, shutters and wiring materials add to the initial cost of the greenhouse;
- Electricity to operate the fans will incur costs.

The length air must travel from one end of the house to the other should be kept to 150 feet or less. Since plastic film is normally sold in standard lengths of 100 feet, most of the plastic-covered houses that have been built for tomato production are 96 feet or less in length and can be easily ventilated with fans on one end and inlet shutters on the opposite end. It is important to note that undersized fans will not effectively control greenhouse temperatures during warm periods. Furthermore, oversized fans cost more to operate, require a

higher initial investment and create excessive air velocities that have a negative effect on plant growth.

How to Size the Ventilation Fans

Forced-air ventilation systems for tomato production greenhouses in Tennessee are normally designed to exchange the air volume inside the greenhouse with fresh outside air about once every minute. This ventilation rate generally results in a temperature rise of around 9 degrees. This temperature rise is the difference that can be expected between the cooler air entering the greenhouse and the well-mixed warmer air exiting through the fans. Under normal Tennessee conditions, a ventilation rate of one air exchange per minute corresponds to roughly 8 cfm of fan capacity for every square foot of floor area.

Ventilation Requirement (cfm) = 8 x (length of greenhouse) x (width of greenhouse)

Example: A 30-foot by 96-foot greenhouse has a floor area of 2,880 square feet (30 x 96). The ventilation requirement can be determined by multiplying 8 x 2,880, or 23,040 cfm. This will give one air exchange per minute for the volume of air in the greenhouse up to a height of 8 feet.

Because ventilation rates will be much less during cool days than during warm days, ventilation systems must be operated in steps or stages to provide the proper amount of incoming air for good temperature control. The first stage of ventilation can be provided by a single fan and the second stage by another fan or a two-speed fan with thermostat control to provide the low-high ventilation rates. Either of these ventilation systems will provide the levels of ventilation needed to maintain the optimum growing environment inside the greenhouse when properly sized and installed. In an effort to cut initial investment costs, some producers have opted to install a large single-speed fan that is designed to supply the necessary ventilation rate of one air exchange per minute. The major drawback with a one fan system is that you run the risk of bringing in large volumes of cool air over a relatively short period of time. This large inrush of cold air can cause chilling injury to the growing plants near the air inlets.

It is important to keep any doors and windows at the fan end of the greenhouse

closed while the fans are operating. If you don't, the fans will pull air through these openings instead of through the shutters at the opposite end of the greenhouse. This "short circuit" effect will result in much hotter temperatures throughout the greenhouse.

Selecting Fans

Fan capacity is measured as the volume of air (cubic feet) moved per unit of time (minute). It is usually expressed as cubic feet per minute (cfm). The amount of air a fan moves depends on the blade diameter, blade shape, fan speed (revolutions per minute, rpm), motor horsepower, the shape of the housing and static pressure (Table 2). The two most common measurements used to describe the characteristics of a fan are blade diameter and motor horsepower. These are useful measurements, but without performance characteristics (airflow and static pressure), these are only general indicators of fan capacity.

Airflow rate (cfm) and static pressure are closely related for fans and ventilation systems. The air-moving capacity of a fan (cfm) is directly affected by the system static pressure. As the resistance to airflow (static pressure) increases, the delivered airflow capacity decreases. Hence, a fan delivers more air against a low static pressure than against a high static pressure. Typically, the system resistance is about 0.1

Table 2. Typical Fan Performance Data

		CFM vs. Static Pressure					
Fan Size	HP	RPM	0"	.05"	.10"	.125"	.15"
24"	1/4	622	5300	4900	4500	4200	3900
	1/3	735	6200	6000	5700	5500	5300
	1/2	820	7000	6700	6500	6300	6100
	3/4	949	8100	7800	7600	7500	7400
30"	1/3	529	8500	8000	7400	7000	6600
	1/2	607	9700	9300	8800	8600	8300
	3/4	686	11000	10600	10200	10000	9800
36"	1/3	421	10300	9600	8800	8300	7700
	1/2	495	11800	11200	10600	10200	9800
	3/4	575	13700	13200	12700	12400	12100
	1	634	15000	14600	14200	14000	13700
42"	1/2	385	14000	13600	12500	11800	11100
	3/4	442	16600	15900	15000	14500	14000
	1	485	18200	17500	16800	16300	16000

to 0.125 inches of water. For this reason, ventilation fans are typically selected to deliver the desired airflow at 0.125 inches of water (1/8") static pressure. When purchasing fans, ask to see a fan performance chart from the manufacturer. The performance chart is needed to determine the airflow capacity (cfm) at various static pressures. Many manufacturers have their fans rated by standard testing procedures certified by the Air Movement and Control Association (AMCA), an independent testing laboratory. A recommended practice is to select fans bearing the AMAC "Certified Rating" seal. Fans with the AMAC seal are more apt to perform in accordance with the information printed in the manufacturer's literature.

Select energy efficient fans that will give long, trouble-free operation. Electric motors should be totally enclosed against dust and moisture, and the outside should be kept clean. See Extension Fact Sheet SP 399-A, **Maintaining Mechanical Ventilation Systems**, for more information on fan maintenance.

Fan and Shutter Installation

As is true in nearly all exhaust ventilation systems, the location and size of the air inlets opposite the fan(s) are important. The air inlet shutters should be motor operated so they can open against the incoming air. These motorized shutters should be 1.25 to 1.5 times larger than the size of the fan frame to provide an adequate opening for the incoming air and not choke the fan's airflow. Size the inlet shutters to provide around 600 feet per minute air inlet velocity. The fans and shutters should be located at least 3 feet above plant level to allow the incoming air to mix with the warmer inside air.

The shutters need to be wired to open when the fans turn on. If the shutters do not open quickly enough when the fans start, a time delay should be used on the fan circuit to give the shutters eight to 10 seconds to open, or the inlet shutters could be wired on a separate thermostat control to open two to three degrees below the thermostat setting for the fan(s) to start.

Controls

Automated controls are recommended for growers who will not always be near the greenhouse to open the curtains or turn on the fans on short notice when the weather changes. Curtains can be operated automatically with thermostatically-controlled motorized equipment. Controllers for these motorized units should move the curtains in small increments to allow the temperature inside the greenhouse to equalize before moving the curtains further. A rapid



Motorized shutters

raising and lowering of the curtains by only a simple thermostat is not recommended because, it causes irregular temperature patterns.

Select accurate thermostats that will withstand the greenhouse environment and maintain their calibration. Locate thermostats near the center of the greenhouse to ensure accurate readings of the temperature around the plants. Keep them away from exterior walls or from direct influence from the heater and shield them from the sun. If the sun is allowed to shine directly on a thermostat, it will read a higher temperature than the air surrounding it.

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 desired temperature. This temperature can be verified with use of the thermometer, regardless of what the thermostat setting reads. Even the best heating and ventilation system has little value if its thermostats do not work properly or if they are incorrectly located.

Evaporative Cooling Systems

Outside air temperatures from late spring through early fall can cause indoor conditions to become much hotter than desired. Evaporative cooling is one way to reduce temperatures inside the greenhouse. Evaporative cooling is a process that reduces the temperature of air by the evaporation of water into the airstream. As water is evaporated, heat energy is lost from the air which reduces its temperature. Cooler indoor temperatures can improve the environment for the fruiting plants, plus significantly improve working conditions for employees.

The most commonly used evaporative cooling system used in greenhouses is the fan and pad system. With this type of system, fans are placed in one wall of the greenhouse and pads are in the opposite wall. The fans exhaust air from the building and draw in fresh air through the pads. The major components of the cooling system are: pad media, water supply, pump, distribution pipe, gutter, sump, and bleed-off line. Water is continuously circulated over and through the pad cells during operation. A pump transports water from a sump through a filter and to a distribution pipe along the top of each pad. A gutter collects unevaporated water that drains from the bottom of each pad. Water can be recycled as long as salt or minerals do not collect noticeably on the pads. As air flows past the moist pad surfaces, some of the moisture evaporates into the air stream. Heat is withdrawn from the air during this process and the air leaves the pad at a lower temperature with higher moisture content.

The drop in temperature depends on how much water the air can absorb (a function of the relative humidity), how evenly the pad media is wetted, and how long the air is exposed to the pad (a factor of turbulence, wetness, and speed of air movement). Evaporative cooling is more effective when the relative humidity of the outside air is low. As the relative humidity of the outside air increases, evaporative cooling becomes less effective. For example, if the outside air conditions are 95 degrees and 50 percent relative humidity, there would be about 13 degrees of effective cooling. However, if the relative humidity is 70 percent, evaporative cooling would only drop the temperature by 8 degrees. With 90 percent relative humidity, only a 2-degree drop in temperature can be expected.



The most widely used type of pad material is corrugated cellulose that has been impregnated with wetting agents and with insoluble salts to help resist rot. These pads are relatively expensive, but when properly maintained, do an excellent job of cooling air and should last around 10 years. Aspen pads have seen wide use, however, they are very susceptible to algae infestation which leads to rotting and compaction. This makes it difficult to maintain an efficiently operating system without frequent and costly pad replacements. A cellulose pad typically needs more air and water flow than does an aspen pad.

Cooling Pad Area

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

$$\text{Pad Height (ft)} = (\text{air flow rate, cfm}) / (\text{pad length, ft} \times \text{design velocity, ft/min})$$

The desired air flow rate is the same one air exchange per minute we used in selecting the fans for forced-air ventilation systems. With our 30- x 96- foot greenhouse, we again use 30 x 96 x 8 to give us 23,040 cfm. The pad length will be about two feet less than the width of the greenhouse, or 28 feet for this size greenhouse. A good rule of thumb for the design velocity is to have 250 ft/min of air flow through a 4-inch cellulose pad, 380 ft/min through a 6-inch pad and 165 ft/min through an aspen pad. If we are using 4-inch cellulose, the above equation becomes:

$$\text{Pad Height (ft)} = 23,040 / (28 \times 250) = 3.29 \text{ feet or } 3 \text{ ft } 4 \text{ inches.}$$

Since pads come in 2, 3, 4, 5 and 6 foot heights, use a 4-foot tall pad.

Air Distribution

Air distribution within the greenhouse is important if near-optimal levels of temperature and humidity and normal or above-normal levels of carbon dioxide are to be maintained near the growing plants. Since there is very little natural air movement in a closed greenhouse, temperature variations between the roof and plant surfaces will exist as warm, lighter air rises toward the roof while cool, heavier air is pushed toward the growing plants. Moving or stirring the air with fans reduces these temperature variations

by distributing the heat more uniformly throughout the greenhouse. Uniform heat distribution causes the temperature near the growing plants to be more stable, which reduces growing stress. Uniform distribution also reduces heating costs, because warm air is placed near the plants where it is needed and not along the greenhouse roof. Moving air through the plant canopy also keeps the leaf surfaces dryer, reducing the risk of disease. The two most commonly used methods for circulating air in a greenhouse are horizontal air flow and poly-tube systems.

Horizontal Air Flow Fans

The horizontal air flow (HAF) system uses 16- to 24-inch diameter fans suspended about halfway between the roof and plant level to continuously move air throughout the greenhouse. Fans should be spaced 40 to 50 feet apart along the length of the greenhouse, about one-fourth of the house width from each side wall. With this configuration, the fans on each side of the greenhouse blow in opposite directions, which causes the air to flow down one side of the greenhouse, across the end and back up the along the other side. Fans should be turned 10 to 15 degrees toward the center and slightly downward to direct the air for a good circulation pattern throughout the greenhouse. It is highly recommended to run these fans continuously. The fan motors are very energy efficient and the benefits of having good air circulation throughout the greenhouse far outweigh the cost of operating the fans.



Horizontal airflow fans

Poly-tube Systems

The overhead perforated sleeve system, more commonly called a poly-tube, combines a heating, air circulation and partial ventilation system in one package. Its main function is to convey and distribute air, as uniformly as possible, from a high-velocity fan at one end of the ventilated or heated space through a pressurized tube with holes along its length. The high-velocity air exiting through these holes mixes or stirs the large volume of air inside the greenhouse, thus creating more uniform temperatures throughout. The fan can be part of the heating system or separate from it. If the fan is used as part of the heating system, it must be wired to operate even when the heater is off so it can continuously circulate the inside air. One advantage of the poly-tube system over the HAF system is that it has the capability of bringing in fresh air from the outside and distributing it through the perforated tube for the first stages of cooling and humidity control.

The size of the poly-tube and the number and location of the holes are functions of the capacity of the fan and the length of the greenhouse. Tubes that are too short or have too small or too few holes will restrict airflow, which can damage certain type fans or cause inadequate air distribution in the greenhouse. Conversely, excessively large holes or long tubes on undersized fans will also cause inadequate air distribution. Positioning of the tube within the greenhouse is also important to achieve proper air distribution. Poly-tubes are generally suspended overhead with the discharge holes in the 4 o'clock and 8 o'clock positions. These hole positions provide a slight downward direction for the discharge air to achieve better air mixing at the plant level.



Poly-tube

There are some disadvantages of the poly-tube system over the HAF system. Installation, maintenance and energy costs of a poly-tube system are more than for a HAF system. The poly-tube must be replaced every few years and the hangers used to suspend the tube can be expensive.

Humidity Control

Tomato plants must be allowed to transpire freely during photosynthesis for the plant to actively grow. This means the plant must have plenty of water available, it must be growing in a low to moderate humid environment and must be exposed to good air circulation. High humidity coupled with low air movement reduces transpirational cooling, which can lead to heat overload for the plant.

Managing humidity levels inside greenhouses is critical for optimum plant growth. The ideal humidity level for tomato plants should be between 65 to 75 percent during the night and 80 to 90 percent during the day. Tomato yields and fruit quality are lower at higher humidity levels. Leaf size can also be reduced and flower and fruit abortion can be significantly increased under high humidity conditions. Glassiness and “gold fleck” in tomato fruit is also attributed to high humidity levels.

Unfortunately, moisture buildup can be a major problem in greenhouses used for tomato production. Moisture results from the evaporation of water from the soil or potting media and the transpiration from the plants. Moisture problems generally don't occur during periods when ventilation is used to control excess temperatures. However, during cooler cloudy periods, when ventilation is not needed to control temperature, moisture buildup can become a serious problem. Excessive moisture causes high humidity levels inside the greenhouse. The most visible effect of high humidity is the condensation that forms on the plastic or structural surfaces inside the greenhouse. Leaf surfaces of the plant will also feel damp to the touch, which can lead to increased disease problems.

The easiest way to control moisture buildup is to ventilate the greenhouse by operating a small fan continuously, operating a larger fan manually or on an interval timer, or opening the side curtain on the downwind side 1 to 2 inches, even when the outside temperatures are cooler than the desired growing temperature. The relative humidity of outside air is generally lower than that of the air inside the greenhouse. When heating the air to the desired growing temperature, a drying effect takes place that further



Condensation problems caused by excessive humidity levels.



Disease problems brought on by high humidity levels.

reduces the relative humidity inside the greenhouse. The benefits obtained from keeping condensation problems to a minimum and the plants dry far outweigh the cost of heating the air. The drier and warmer the greenhouse, the less likely that disease problems will exist.

Energy Conservation

Rising fuel costs have made energy the second largest cost, behind labor, in greenhouse operations. Combined fuel and labor costs often exceed half the total production costs and energy costs alone can exceed 20 percent of the total greenhouse production costs.

Double Plastic Cover

Heating costs are among the largest variable costs in operating a greenhouse. Greenhouse covering materials do very little to resist the flow of heat. While the exterior walls of your house may have a R-value of 19 (the resistance to heat flow), the R-value of two layers of plastic with an air space between the two sheets has a R-value of roughly 1.4. For a single layer of plastic, the R-value drops to around 0.9. Growers can reduce the size of heating equipment and save up to 40 percent on their heating bill by covering the greenhouse with two layers of plastic with an air space between the layers.

In general, the larger the greenhouse, the less it costs to heat per square foot of growing area. Heat loss is primarily a function of the outside surface area of the greenhouse. Small greenhouses have more surface area relative to the floor area and are more difficult to heat. Keeping the outside exposed surface area to a minimum reduces the greenhouse heat requirement per square foot of floor area. For instance, a range with six individual freestanding greenhouses 30' x 96' with 10' sidewalls, has a 37 percent greater surface area than a gutter connected house providing the same area for growing. Regardless of the size of the greenhouse, maximizing the number of plants per square foot of floor space will get you the most from your heating dollars.



Insulating North Wall

Greenhouse covering materials, especially single and double layers of plastic, have little resistance to heat flow. Since very little light enters the greenhouse through the north end wall of north-south oriented greenhouses, the north wall can be insulated more thoroughly than with a standard double layer of plastic. A solid wall can be constructed and insulated with polystyrene boards, fiberglass batts or similar insulation materials. Any insulation must be waterproofed or protected from water with a vapor barrier. The wall can be finished with plywood or any other material.

The Agricultural Extension Service offers its programs to all eligible persons regardless of race, color, national origin, sex, age, disability, religion or veteran status and is an Equal Opportunity Employer.

COOPERATIVE EXTENSION WORK IN AGRICULTURE AND HOME ECONOMICS

The University of Tennessee Institute of Agriculture, U.S. Department of Agriculture, and county governments cooperating in furtherance of Acts of May 8 and June 30, 1914.

Agricultural Extension Service Charles L. Norman, Dean