COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF KENTUCKY • COLLEGE OF AGRICULTURE

# Basics for Heating and Cooling Greenhouses for Tobacco Transplant Production

*George Duncan, Extension Specialist, Agricultural Engineering; Bob Anderson, Extension Horticulturist; and Bob Pearce, Extension Tobacco Specialist*

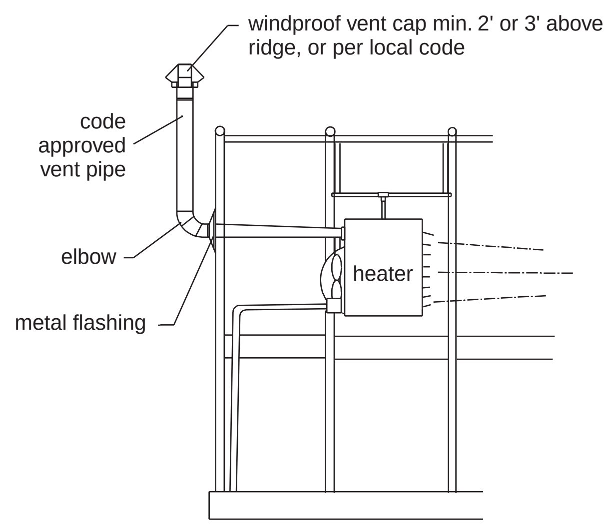
## Introduction

This publication presents basic guidelines for understanding and managing the heating, condensation, air circulation, and ventilation of plastic-covered greenhouses for tobacco transplant production.

## Heating

What conditions are required, or desired, for heating greenhouses? For germination, an optimum soil temperature of 70° to 75°F is preferred. Air temperatures above 90°F often damage or kill germinating seeds and seedlings. For faster transplant growth, daytime temperatures could be above 70° to 80°F. For slower growth, daytime temperatures could be kept in the 60° to 70°F range. At night, temperatures can be lowered to 50° to 65°F after the plants reach the four-leaf stage. This also conserves on heating costs.

*Figure 1. Vented heater installation.*




### How to Heat

Heating equipment depends partially on the fuel source available. The most commonly available fuel on farms is LP gas, although some farms have access to a natural gas line. Other options include fuel oil, diesel, or kerosene. LP and natural gas are the cleanest of the petroleum fuels and the most efficient to use. Electric heat requires excessively large equipment and power requirements, and it is not cost effective at present.

### What Type of Heating Equipment?

Vented and unvented commercial heaters are readily available for greenhouses. Desired features include thermostats for temperature control; aluminized or stainless steel heating chambers for long life in the moist, corrosive atmosphere of greenhouses; fan power to help distribute the heat; and hangers or brackets for ease of mounting in the greenhouse.

Vented heaters are preferred for greenhouses to provide a cleaner, safer environment. They are usually located inside the greenhouse and vented to the outside through the end wall (Figures 1 and 2).

*Figure 2. Commercial vented heater*

Some advantages of vented heaters are:

- They provide safe, clean, dry heat;
- Good heater fans can help distribute heat;
- Vanes can direct heat; and
- Some models of commercial vented heaters can be located outside the greenhouse.

Some limitations of vented heaters are:

- 15 to 20 percent of heat is lost through vent gases (unless modified); and
- They are rather large and heavy to mount to bows.

Unvented heaters are also being offered by some commercial sources and used by producers because all heat is kept inside the greenhouse (Figures 3–6).

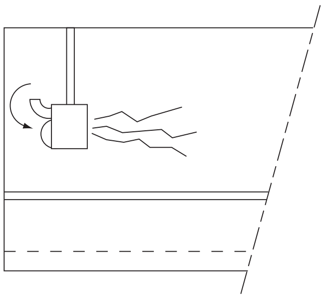


*Figure 3. Inside unvented.*

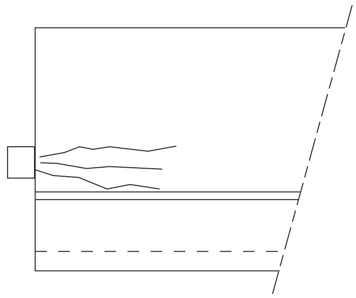


*Figure 4. Outside unvented.*

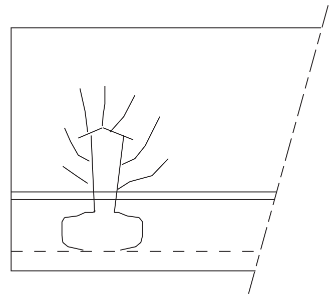


*Figure 5. Kerosene type.*

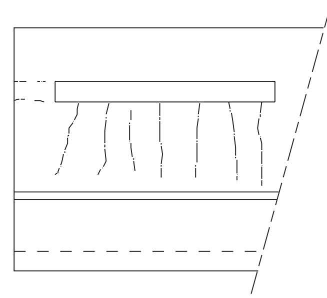


*Figure 6. Radiant type.*

Some advantages of unvented heaters are:

- They can be located inside or outside the house;
- All heat is released inside; and
- They may be simpler to install.

Some limitations of unvented heaters are:

- There is a high risk for plant damage from fumes produced when operated during cold weather;
- They need an oxygen (fresh air) inlet to burn fuel;
- They require an air outlet to allow air to escape the greenhouse due to combustion; and
- Extra moisture is produced, which increases humidity and condensation problems.

The fumes from unvented heaters contain combustion products that can harm tender young seedlings. Ethylene is one product that causes necrotic spots, leaf curl, and yellowing on tomato seedlings. Other products in the flue gases resulting from poor combustion include sulfur dioxide and nitric oxide which cause similar effects. Carbon monoxide is always present in flue gases and is very dangerous to humans working in the greenhouse.

LP and natural gas are the two better sources of fuel for unvented heaters. Fuel oil heaters (and any that use diesel) must be vented to eliminate the fumes from the house.

Some kerosene units (Figure 5) are fairly clean burning in a "clean" room but are considered suitable only for limited emergency heat in a greenhouse as long as some air leaks or sources of positive ventilation are present.

Radiant heaters are normally unvented types that direct the heat to soil and plant surfaces for warmth with less heating of the air (Figure 6). These designs normally have a cleaner combustion and can reduce fuel usage under ideal conditions. Temperature control is more difficult, as the temperature sensor must be selected to measure either the soil/plant surface or the air. Radiant heat will go through plastic if the rays have a direct beam onto the plastic; hence, extra heat loss can occur. Also, moisture is still produced with the unvented types, and there is the need for fresh air to the units. The cost of radiant designs is usually higher than comparable air-heating units.

### The Importance of Fresh Air and Oxygen

An LP gas burner of 200,000 Btu/hour size requires 1,865 cubic feet (a 10 x 10 x 19-foot volume) of 70°F air to burn for an hour. In an airtight 30 x 100-foot house, a 200,000 Btu/hour heater reduces the oxygen content by one-half in 11 hours of burning if no fresh air enters. Fortunately, most greenhouses are not airtight. There is sufficient air leakage to provide oxygen for combustion, but this also results in heat loss. Leakage and infiltration are often enough to provide fresh air and reasonable safety for vented and unvented heaters and to dispel some moisture from the unvented heaters. But there are times under heavy heating loads when vented and unvented heaters located inside the greenhouse do not have enough fresh air and can cause serious combustion problems. For units located outside the house, the continual injection of heat and the combustion products into the house will push out inside air and build up a high concentration of gases that could become harmful to plants and people without adequate fresh-air ventilation.

A standard heating requirement is to have one square inch of fresh air inlet for each 2,000 Btu/hour of heating capacity. A feasible improvement to the standard vented unit heaters is to add extra lengths of single-wall vent pipe to extract more heat from the flue gases (Figure 7). About six feet of pipe length would be adequate, as too much length will cool the flue gases excessively, causing condensation within the pipe and premature corrosion.

## Moisture and Humidity

Moisture is an ongoing problem in most greenhouses. Moisture results from evaporation from the water and soil surface, transpiration from the plants, and the flue gases of any unvented heaters. An unvented 200,000 Btu/hour LP gas heater produces 15 pounds of water vapor per hour. This is one-third as much water vapor as the air in a 30 x 100-foot greenhouse contains at 70°F and 80 percent relative humidity. Thus, the moisture added to the greenhouse by an unvented heater of this size will generate enough moisture to exceed the saturation capacity in 2 to 3 hours unless some method of dissipation or removal of moisture is used. Evaporation and transpiration are also occurring continually and contribute to the moisture buildup.

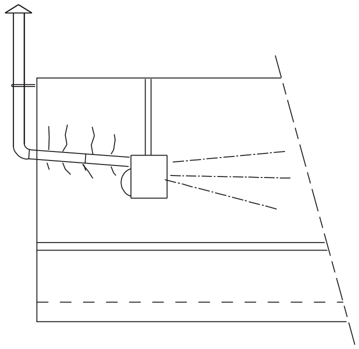


*Figure 7. Extra vent pipe to extract more heat.*

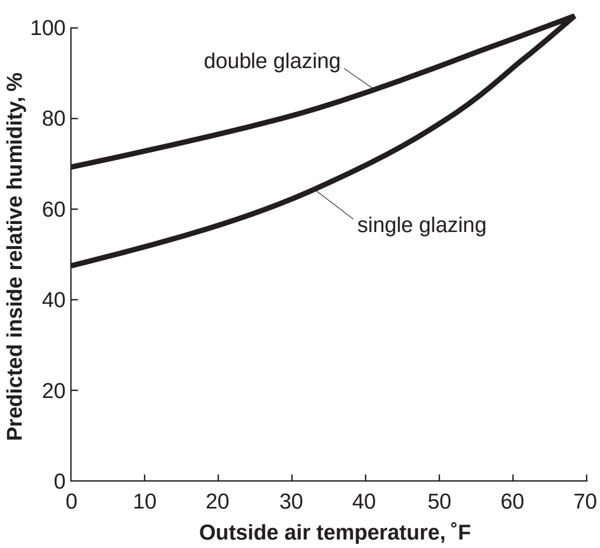
Extra moisture causes high humidity, which is a significant factor in plant disease. Past studies on greenhouse production of tomatoes has shown that periods of several hours with more than 90 percent relative humidity favor rapid development of leaf diseases. Foliar leaf diseases can begin around 80 percent relative humidity, while humidity below 70 percent effectively curtails disease development (as far as humidity is concerned). Tobacco plants can be expected to respond similarly. The most visible effect of high humidity is the condensation on plastic or structural surfaces and the resulting drip, which erodes seedlings from tray cells and causes disease problems and corrosion of structures and equipment.

## Managing High Humidity and Condensation

Condensation occurs when the inside plastic surface cools to the dew point temperature of the inside air, just as dew forms on cool surfaces at night or condensation forms on windows. Single-layer plastic will condense moisture more quickly because of the greater heat loss and cooling of the air at the single-layer surface. Double-layer plastic covering insulates better, has a warmer inside surface temperature, and has less condensation potential.

A greenhouse covered with double-layer material (plastic or other) on the roof, with single-layer end walls and vent curtains, can effectively condense the excess moisture in the house on the single-layer materials when the outside temperatures are below 45° to 50°F. This condensation of the excess moisture lowers the humidity enough that condensation may not occur on the overhead double layer, thus preventing the drip problems. However, when outside temperatures are above 50° to 55°F, this condensation situation does not occur sufficiently to lower the humidity and control condensation (Figure 8). For these conditions, some form of ventilation and heating is necessary to remove the excess moisture.

*Figure 8. Temperatures and humidities for condensation to occur with single- and double-layer coverings.*



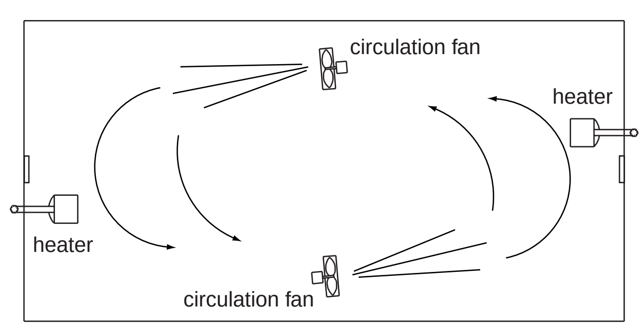

In a 30 x 100-foot greenhouse, leakage of one-half air change per hour can dispel 22 pounds of moisture (assuming 70°F, 90 percent relative humidity air out and 40°F, 50 percent air in, heated up to 70°F). This air exchange is equivalent to approximately 400 to 500 cubic feet per minute (cfm) of steady fan capacity. “Flushing” the air from the greenhouse each evening and morning (by opening the side curtains or operating the ventilation fans for several minutes) will help ventilate excess moisture but may not be sufficient to keep the humidity low enough throughout the night to prevent condensation.

If condensation plagues your greenhouse, operating a small fan continuously, operating a larger fan on an interval timer, or opening the side curtain on the downwind side 1 to 2 inches could remove the moisture required. This causes some extra heat to be used, but that is the cost of reducing high humidity and condensation.

# Air Circulation

Forced air circulation inside the greenhouse is essential to provide a more uniform environment for improved plant growth. The simplest and most common means of internal air circulation is the horizontal air flow system produced by 16- to 24-inch fans suspended in the greenhouse. These fans should be spaced 40 to 50 feet apart, one-fourth of the house width from each sidewall, at a height about halfway between plant level and the roof, and turned about 10 to 15 degrees inward and downward to direct the air for a good circulation pattern (Figure 9).

*Figure 9. Fans produce horizontal air circulation.*



It is important to determine whether air is moving at plant level and providing the proper micro-environment for the plant. An airflow meter is very useful to determine the air movement at plant level, but in the absence of such devices, small strips of thin plastic on a short stick can be held steady near plant level to see if air currents exist (Figure 10).

Another simple way to detect air movement is to shake a container of very fine powder, such as baby powder, and see how the air currents move (Figure 11). Some commercially available smoke devices that are safe to use around plants can detect the same air movement patterns.

*Figure 10. A simple air movement detector.*

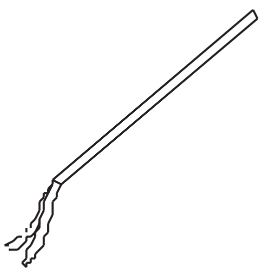
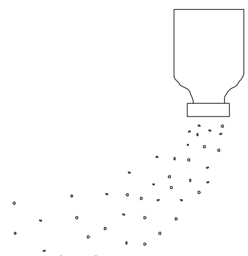


*Figure 11. Powder to detect air movement.*

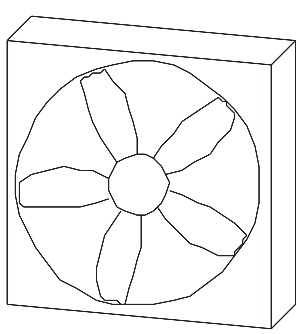


## Ventilation

The objectives of ventilation are primarily to:

- Maintain the inside air and soil temperature below 85° to 90°F for germination,
- Maintain the inside air temperature below 95°F for plant growth,
- Remove excess moisture, and
- Provide fresh air for heater fuel combustion.

*Figure 12. Fans for forced ventilation.*



Ventilation can be provided by passive or forced methods. Passive ventilation is achieved by opening side curtains or vent panels to allow natural air exchange due to wind and thermal currents; forced ventilation is achieved by motorized fans (Figure 12).

### Sidewall Curtains

Some advantages of side curtains (Figure 13):

- Can cost less than all fans; and
- Can be automated to reduce labor and provide more precise control.

Automated sidewall curtain mechanisms can be installed to automatically regulate the curtains in response to inside temperature, provided a proper controller is used to move the curtains in small increments and allow the inside temperature to equalize before the next movement. A rapid raising and lowering of the curtains by only a simple thermostat device is not desired since it causes irregular temperature patterns.

*Figure 13. Sidewall curtains.*

Some limitations of curtains:

- Manual operation requires human presence;
- They generally provide nonuniformity of temperature throughout day and night, many times with cold drafts;
- Heaters are likely to operate when curtains are open unless manually turned off;
- There is a possibility of air leakage due to a nontight fit, leading to added heat costs; and
- They work best on a straight sidewall greenhouse.

To determine the width of the opening needed for curtains, the producer needs to consider wind velocity and direction, greenhouse orientation, width of the greenhouse, outside air temperature, and any air blockage by surrounding vegetation or buildings (such as two or more greenhouses side by side). A longtime rule of thumb for glass houses has been 1 foot of sidewall opening for each 10 feet of house width. This arrangement assumes ridge vents are also used, as is typical of older glass houses.

For plastic-covered greenhouses, this rule of thumb would require at least 3- to 4-foot-wide openings for the popular 30- to 36-foot-wide houses. Some earlier plastic-covered Quonset greenhouses with bows all the way to the ground or short vertical sidewalls with 3 feet or less of sidewall curtains seemed to get rather hot at times in May and June. Many of the current commercial greenhouses have 4-foot or higher straight sidewalls which can accommodate 4-foot or wider curtains and should be better able to provide adequate ventilation on hot, calm days.

Curtains should open from the top downward so the first opening for air on cold days will let the cold air mix with the inside air before dropping down onto the plants and causing possible “shock” and injury.

## Automated Curtains

There are motorized units for operating the curtains by thermostatic control. These units can reduce the need for human presence but must be reliable and not overreact to the changing temperature inside and open too wide, producing harmful drafts.

Experience with automated inflated sidewall tubes at the University of Kentucky indicates that only one wall (the side away from prevailing wind) should work during the cool spring weather of March and early April. Both sides should operate during the warm weather of late April and May.

## Fan Ventilation

Fan ventilation can be an asset with curtains or can provide fully automated ventilation requirements (Figure 14).

*Figure 14. Vent fans in end wall.*

Some advantages of fans are:
- They provide automatic and consistent ventilation; and
- They minimize drafts and cold effects on plants.

Some limitations of fans are:
- Costs of equipment, installation, and operation can be high.

## Combining Fans and Curtains

Some fan ventilation in conjunction with curtains can automate the first stages of fresh air ventilation and reduce the demand for human presence, the irregularity of curtain opening on drafts, potential for cold injury, and wasteful heater operation (if not turned off) when the curtains are first opened.

Some advantages of fans and curtains in combination are:
- They provide a first stage of ventilation to reduce critical human presence; and
- They minimize drafts and cold effects on plants.

Some limitations of these combinations are:
- Curtains still have to be checked and opened or closed as required; and
- There is a tradeoff between costs and better temperature control.

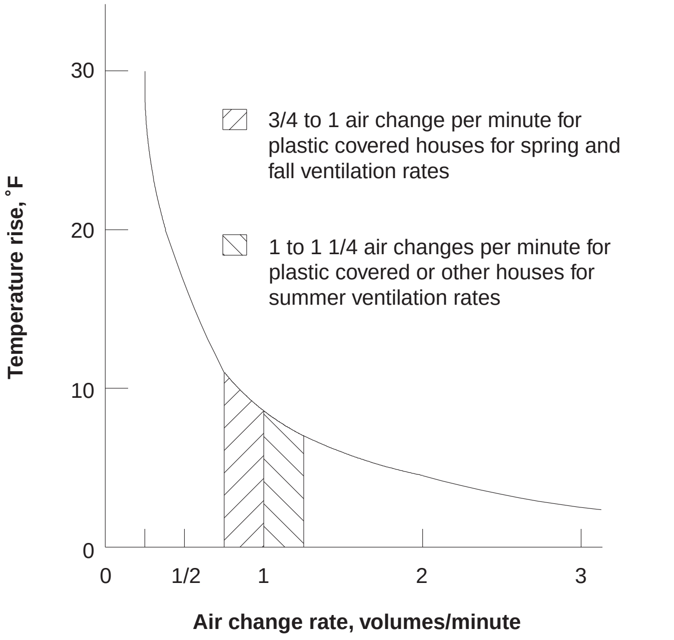
For any fan ventilation system, ventilation must be operated in steps or stages to provide the amount of air needed for temperature control. Typically, the steps or stages of fan ventilation for a greenhouse are established as:

1st stage—20 percent of requirement
2nd stage—40 percent of requirement
3rd stage—40 percent of requirement

Determining how much fan ventilation is required or recommended will depend on the outside temperature and the control of inside temperature desired. Calculations show the following guidelines for ventilation under high temperature conditions (Figure 15):

| air change/minute | temperature rise |
|---|---|
| 0.75 air change/minute | 11°F |
| 1.0 air change/minute | 9°F |
| 1.25 air change/minute | 7° to 8° |

*Figure 15. Temperatures and air change rates.*



An air change/min is the equivalent of removing and replacing all the air in the greenhouse once each minute. The temperature rise is the temperature difference that can be expected between the cool (or cold) air entering the house and the well-mixed warm (or hot) air exiting through the fans (for an exhaust system). For spring and fall use of a greenhouse, such as tobacco transplants in the spring, the three-fourths air change/minute can be used. Thus, based on three-fourths air change/minute, the following quantities of airflow in cubic feet per minute (cfm) are suggested for a 30 x 100-foot or 36 x 150-foot Quonset with 4-foot high sidewalls.

| Quonset Size | Stage 1 20 percent | Stage 2 40 percent | Stage 3 |
|---|---|---|---|
| | cfm | cfm | |
| 30 x 100 x 4-foot | 7,000 | 14,000 | Sidewalls |
| 36 x 150 x 4-foot | 14,000 | 28,000 | Open, fans off |

The stage one air flow can be provided by a single fan and stage two by another fan, or sometimes a two-speed fan motor with proper thermostat control can provide the low-high ventilation rates fairly closely.

#### Shutter Installations

Gravity-type shutters the size of the fan frame are used on the outlet side of the fan to open when the fan is running and close when the fan stops to keep cold air from entering the greenhouse. Comparable air inlet shutters are required at the opposite end of the greenhouse (Figure 16). These shutters must be motorized so the shutter will open against the incoming air flow. The shutters need to be wired to open when the fan operates to let the air into the house. If the shutters do not open quickly enough at the start-up of the fan, a time delay should be used on the fan circuit to give the shutters 8 to 10 seconds to open, or the inlet shutters should be wired on a separate thermostat control to open 2 to 3 degrees temperature setting before the fan(s).

These motorized air inlet shutters should be at least equal to the size of the fan frame or 1.25 to 1.5 times larger, depending on whether the fan operates against resistance to airflow (static pressure rating) to provide adequate inlet air opening and not choke the fan's airflow. The fans and shutters should be located at least 3 feet above the plant level to minimize air drafts directly on the plants. For inlet shutters, a baffle can be added to deflect the air upward and provide mixing before the air contacts the plants (Figure 17).

*Figure 16. Motorized inlet shutter.*

## Wiring for Heaters, Fans, and Shutters

Wiring in the greenhouse is necessary to provide power for the equipment and proper manual or thermostatic control. Wiring should be done for proper operation of the equipment and for safe working conditions. See *Notes on Wiring Greenhouses for Tobacco Float Plants* (AEU-70) for guidelines on wiring.

Greenhouse wiring should:
- Provide circuit overload protection;
- Open a shutter (or shutters) when a fan (or fans) operate;
- Prevent heaters and fans from operating at the same time;
- Stage fans if two or more are used; and
- Generally cut off fans when curtains are fully open to save electricity.

#### Thermostat Location and Mounting

Because thermostats are the sensors and "brains" of the greenhouse environmental system, they should be located where the important temperature conditions are needed—near plant level. Two "don'ts" for thermostats are:
- Do not locate them on end walls and/or near cracks of doors, fans, or shutters, where cold air drafts will distort the temperature sensor; and
- Do not locate them where direct sun will strike the thermostat and heat it above air temperature, which will distort the ventilation control (fans can operate while heating is still occurring).

To properly sense air temperature and avoid the effects of solar heating, thermostats should be mounted on a board with sides and a top to shade them from direct sun but allow free air circulation around the thermostat (Figure 18). An alternative is to use an "aspirated" chamber or enclosure, in which a small fan moves air by the thermostats (Figure 19). These mountings should be located near plant level out in the house. If in-house clipping systems are used, mount the thermostats such that the mounting can be swung up out of the way for equipment to pass.

Commercial control panels with attached temperature sensors and easy hook-up of heaters, fans, and shutters can provide integrated control of all equipment and allow easy night-time set-back conditions.

*Figure 17. Inlet shutter and deflector baffle.*

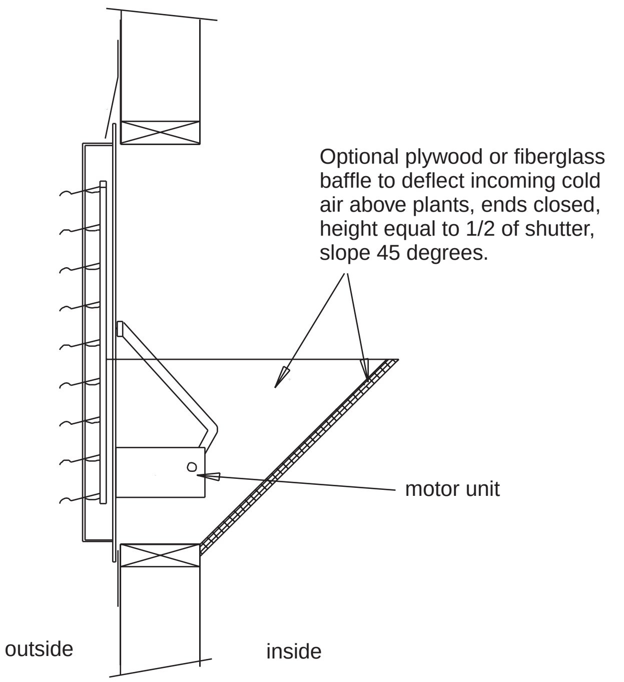



*Figure 18. Shielded thermostat mountings.*

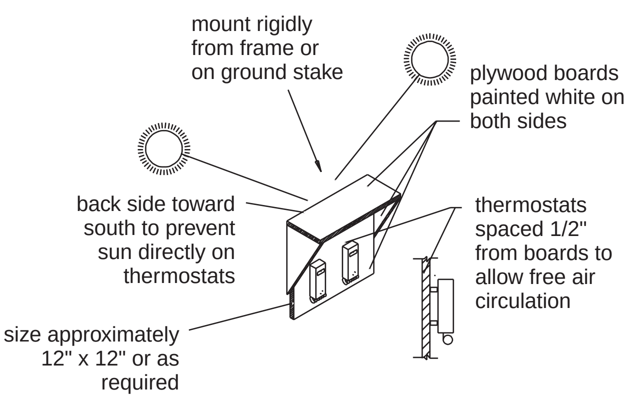
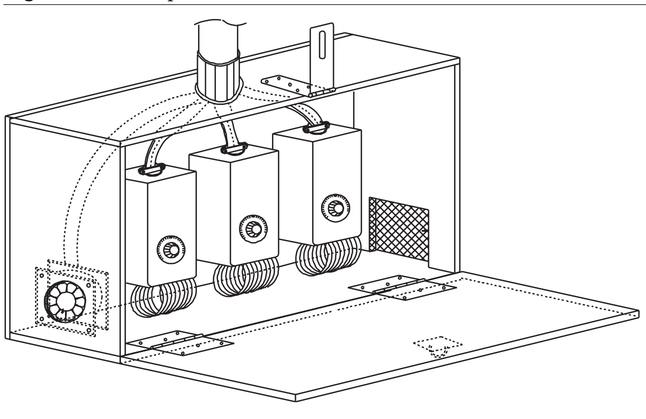



*Figure 19. An aspirated thermostat enclosure.*



## Emergency Power

As growers become more dependent on large greenhouses for producing transplants, the threat of power outages and the damage that could result in plant losses creates the need for standby power generators. See *Standby Electric Generators for the Farm* (AEN-51) for guidance on selecting and installing standby generators.

## Summary

Basic considerations for greenhouse heating and cooling include:

- Using vented heaters or adequate fresh air inlet with unvented heaters;
- Providing good air circulation at plant level;
- Managing the environment to reduce humidity and condensation;
- Operating curtains in cool and cold weather with small increments of openings to reduce cold drafts. Be alert on hot, sunny days to open curtains enough to prevent high temperatures;
- Ensuring curtains open from the top downward to minimize cold drafts directly onto plants;
- Using fans and shutters with sufficient capacity to provide first- or second-stage ventilation needs and reduce critical human operation of curtains; and
- Using shielded and properly located thermostats to control heaters, fans, and shutters, and providing day-night settings to conserve fuel.

## References

Fehr, R.L., and G.A. Duncan. 1983. *Standby Electric Generators for the Farm* (AEN-51). Kentucky Cooperative Extension Service, College of Agriculture, University of Kentucky, Lexington, Kentucky.

Overhults, D.O. 1994. *Notes on Wiring Greenhouses for Tobacco Float Plants* (AEU-70). Biosystems and Agricultural Engineering Department, College of Agriculture, University of Kentucky, Lexington, Kentucky.

Walker, J.N., and G.A. Duncan. 1982. *Air Circulation in Greenhouses (*AEN-18). Kentucky Cooperative Extension Service, College of Agriculture, University of Kentucky, Lexington, Kentucky.

Walker, J.N., and G.A. Duncan. 1987. *Greenhouse Humidity Control* (AEN-19). Kentucky Cooperative Extension Service, College of Agriculture, University of Kentucky, Lexington, Kentucky.

Issued 10-98, 2000 copies.