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Fan and Pad Greenhouse Evaporative Cooling Systems[1]

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Without cooling systems, temperatures in Florida greenhouses during the summer can easily exceed 100°F. Temperatures this high reduce the quality of many crops and will greatly reduce worker productivity. Almost all greenhouses cooling systems use some form of evaporative cooling to operate. Air conditioning or refrigeration systems can be used, but their installation and operating costs are usually too high to justify their use.

EVAPORATIVE COOLING

Evaporative cooling is a process that reduces the temperature of air by the evaporation of water into the airstream. As water is evaporated, energy is lost from the air reducing its temperature. Two temperatures are important when dealing with evaporative cooling systems. The first is the dry bulb temperature. The dry bulb temperature of the air is the temperature that we usually think of as air temperature. It is the temperature measured by a regular thermometer exposed to the airstream. A second air temperature is important in evaporative cooling systems. This temperature is referred to as the wet bulb temperature. The wet bulb temperature is the lowest temperature that can be reached by the evaporation of water. The wet bulb temperature is the temperature you feel when your skin is wet and is exposed to moving air. The dry and wet bulb temperatures can be used to calculate the relative humidity. The equipment used to evaporate water, move cooled air through the greenhouse, and exhaust warm air from the greenhouse comprises the fan and pad cooling system.

It is the wet bulb temperature and not the relative humidity that determines to what temperature air can be cooled by evaporation of water. During the heat of the afternoon when the dry bulb temperature is normally at its peak, the difference between the dry bulb and wet bulb temperature is the greatest. Thus the greatest potential for cooling is obtained during the heat of the day when it is needed most. Wet bulb temperatures can be determined by checking with your local weather station or by investing in an aspirated or sling psychrometer. These psychrometers consist of two thermometers. The end of one thermometer is covered by a wetted wick. The other thermometer is a conventional thermometer. These two thermometers are exposed to a moving airstream so that they measure the wet and dry bulb temperatures. The difference between sling psychrometers and aspirated psychrometers is the way the airstream is provided. A sling psychrometer is mounted on a swiveled handle and whirled rapidly, while an aspirated psychrometer uses a small fan to provide air movement.

Weather data collected by the weather bureau for many years indicates that afternoon wet bulbs in Florida are about 79-80°F during hot weather conditions. The most critical time to check wet bulb temperatures is in the afternoon when solar radiation and outside temperatures are highest. With an

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efficient, well managed system, you should be able to reduce the temperature of the air entering the house to within 3-4°F of the wet bulb temperature. Remember, this will not be the temperature in all areas of the house. As the air moves across the house to the exhaust fans, it will pick up solar heat so that the exhausted air will likely be 7-8°F higher than the entering air. In a poorly managed system, the exhausted air could have a much greater temperature differential.

The basis of any evaporative cooling system is the evaporation of water into an airstream. The most common way of accomplishing this is the fan and pad system shown in Figure 1.

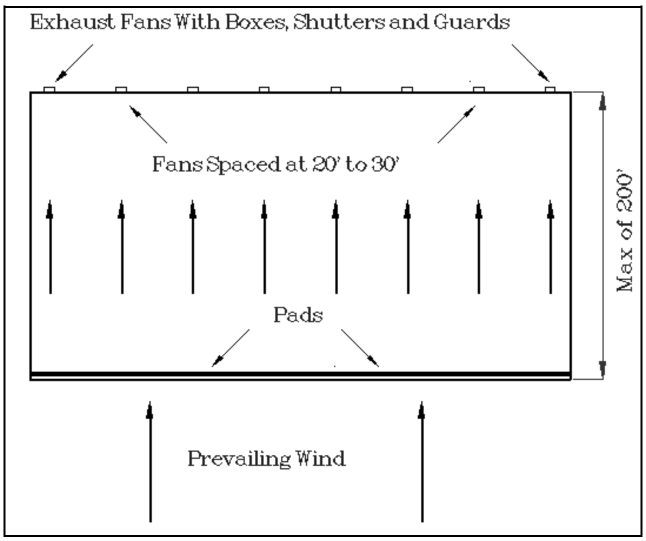

Figure 1. Typical pad-fan greenhouse arrangement.

In recent years, high pressure fog systems have started seeing use in greenhouses. These fog systems can be designed and operated to maintain more uniform temperatures and humidities in greenhouses than are possible with fan and pad systems. Fog systems are more expensive than fan and pad systems but when uniform temperatures and high humidity levels are important they can be the best method of evaporative cooling.

FAN AND PAD EVAPORATIVE COOLING SYSTEMS

Fan and pad systems consist of exhaust fans at one end of the greenhouse and a pump circulating water through and over a porous pad (Figure 2) installed at the opposite end of the greenhouse.

If all vents and doors are closed when the fans operate, air is pulled through the wetted pads and

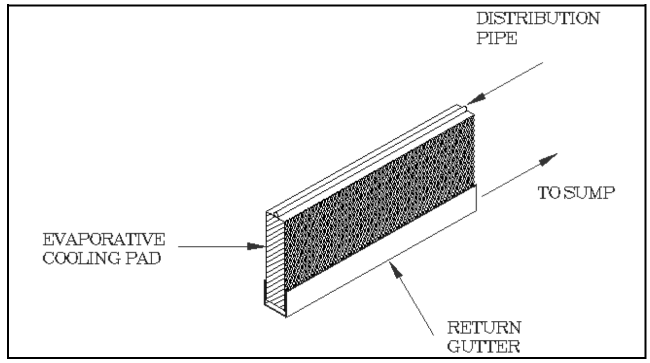

Figure 2. Evaporative cooling pad. The sump should be large enough to hold all run-off when the pump is turned off.

water evaporates. As each gallon of water is evaporated, 8,100 BTUs of heat energy are absorbed from the air by the water in the change from liquid to vapor. Removing energy from the air lowers the temperature of the air being introduced into the greenhouse.

The air will be at its lowest temperature immediately after passing through the pads. As the air moves across the house to the fans, the air picks up heat from plants and soil and the temperature of the air gradually increases. A temperature gradient across the greenhouse results, with the pad side being coolest and the fan side warmest.

TEMPERATURE GRADIENT

The temperature gradient across the greenhouse is hard to predict because many variables affect the gradient. Some of these are bench arrangements, physical obstructions to the movement of air across the house, percentage of floor area covered by plants, or whether the floor is bare soil or covered with concrete. The configuration of the roof can also have an influence on temperature gradient. Experience has shown that air may heat up as rapidly as 1°F for every 10' of movement on sunny summer days. The slower the air movement, the faster the air heats up, and the greater the gradient.

The temperature gradient across the house at plant level is most important. In most systems, the air tends to diverge upward at an angle of about 7° above horizontal, or roughly 1' in 8'. The upper layer of cooled air rises toward the peak of the building above the crop zone and thus does little cooling of the plants. In a cross flow arrangement of gutter connected houses, the gutters serve as baffles and tend to keep the cool air at crop level. In longitudinal flow arrangements where the air flows lengthwise through the house, triangular shaped baffles need to be placed extending from the roof, tapering down to just above the top of the crop level. The baffles should be transparent and spaced about 30' apart. These baffles should be in a fixed position (Figure 3).

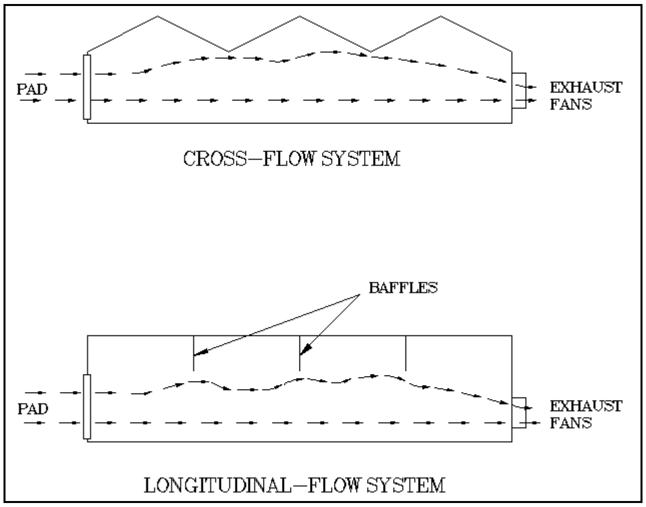

Figure 3. Pad-fan arrangements in greenhouses.

Where plants are grown on raised benches, baffles about two-thirds of the way down the sides of the bench will force most of the cooling air to crop level for more effective cooling.

SYSTEM EFFICIENCY

A well designed, properly installed and operated evaporative cooling system may have an operating efficiency of up to 85% (Figure 4). The difference between dry bulb temperature and wet bulb temperature is referred to as the wet bulb depression. By using a psychrometric chart (Figure 5) with the outdoor temperature and relative humidity, you can calculate the wet bulb temperature that, theoretically, would be the temperature of the entering air.

If the efficiency of your system is 85%, then the entering air temperature would be the wet bulb temperature plus 15% of the wet bulb depression.
Figure 5 shows what happens to air with a dry bulb temperature of 95°F and with a wet bulb temperature of 80°F that is cooled using an evaporative cooling pad. If the pad is 85% efficient, the air is cooled to point A or 82°F. If the pad is 70% efficient, the air is cooled to point B or 84.5°F, and if the pad is 50% efficient, the air is cooled to point C or 87.5°F.

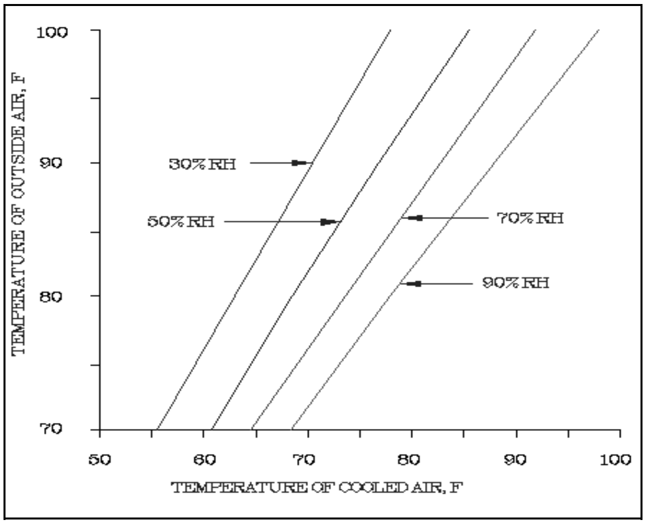

Figure 4. Cooling potential of 85 percent efficient evaporative cooling systems.

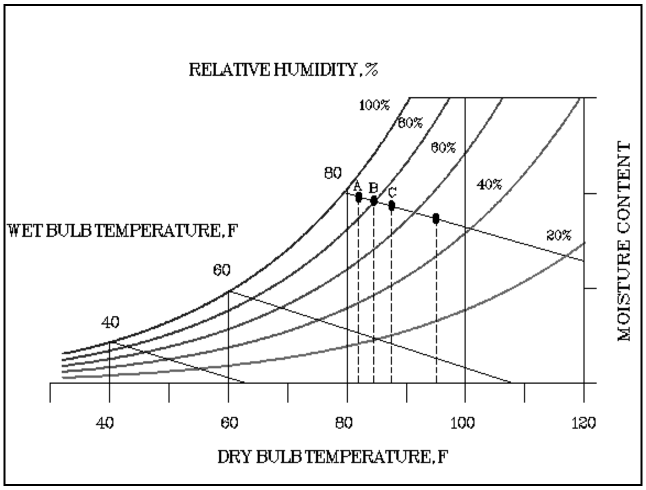

Figure 5. Psychrometic chart showing the effect on operating efficiency of entering air temperatures.

FACTORS THAT INFLUENCE FAN AND PAD EVAPORATIVE COOLING SYSTEMS

House Construction

Managing the house to make sure that it is as tight as possible, and making sure that all doors and other openings are always kept closed except when in use will have a dramatic effect on the success or failure of a fan and pad cooling system. It is very important to keep the building as tight as possible so entering air will be forced to come through the pads. If a door is left open, a vent is unclosed or uncovered, or if excessive cracks are not caulked, it will be easier for the air to take these routes into the building rather than through the cooling pad. An ineffective system will result.

House Location and Orientation

Orientation of the greenhouse in relation to other buildings or structures and in relation to prevailing summer winds has an influence on efficiency of operation and may affect fan arrangements or whether the pad fan will be located on the side or end walls.

Type of Cooling Pad

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 expensive but when properly maintained do an excellent job of cooling air and if properly maintained, should have a lifetime of ten years.

Aspen pads have seen wide use in the past and some are still in service. However, under Florida conditions the life of an aspen pad is usually short. Aspen pads are very susceptible to algae infestation that leads to rotting and compaction. This makes it difficult to maintain an efficiently operating system without frequent and costly pad replacements.

Other pad materials are also on the market, but none has seen wide acceptance. Among these are pads fabricated from aluminum and from plastic fibers. Both these pads types are expensive and have not shown advantages over corrugated cellulose. However, an operator planning to replace an old pad system or install a new one should check out completely all the pad materials available. Then compare costs, life expectancy claims, cooling efficiencies, probability of maintenance problems before selecting the one that appears best for the operation.

Cooling Pad Area

The amount of pad area needed depends upon several factors, including the type of pad material used. The pads should be continuous along the entire wall. If aspen pads are used, it is recommended that one square foot of pad be provided for each 140 cu. feet per minute (CFM) of air moved by the fans. The fan capacity should be based on total CFM delivered at 1/8″ static water pressure. Cellulose pads can be used with airflows of up to 230 cu. feet per minute per square foot of pad. With the higher airflow rates of cellulose pads, fewer square feet of pad area are needed.

Water Flow Rate

You must have adequate pad surface area and an adequate water supply and distribution system. The amount of water needed will vary with the type of system used, but normally, to assure complete pad surface wetting, about ⅓ gal of water per foot of pad length is recirculated. A valve should be placed in the line from the pump so the flow to the distribution pipe can be adjusted. You do not want a sheet of water flowing down the pad surface. This would increase resistance to air flow and cause transfer of free water into the house. You do want the pad surfaces covered with a water film. If in doubt about the correct quantity of water flow, check with the pad manufacturer. The water collected by the bottom gutter is returned to a sump from which the water is pumped to the upper distribution pipe or gutter. For houses more than 75’ in length, it is usually more efficient to locate the sump near the center of the house. The sump should have a capacity of 1 to 1¼ gal for each linear foot of pad in order to hold the water that drains back to the sump when the system is stopped.

Problems With Cooling Pads

Evaporative cooling pads have severe problems in Florida. They are often subjected to many undesirable factors, such as clogging due to impurities in the water, algae and decay. If the pad material is clogged or decomposed its ability to function as designed is impaired. Air exhausted by the fans will enter the building at the point(s) of least resistance. If a pad area is totally or partially clogged, very little if any air will pass through that portion of the pad. If the pad has holes, the air will take the path of least resistance. This means less contact between air and water and much less cooling. When a pad has decayed, the only alternative is to install a new pad.

Airflow Through Cooling Pads

The required face velocity of the air will depend upon the pad material. Follow manufacturer’s suggestions. This velocity will determine the number of square feet of pad area needed for a house of a given configuration. Regardless of the type of pad material used, the fans should have the capacity to provide a minimum of one air change per minute in the greenhouse. Have automatic shutters on the fans so there will not be back drafts when a fan is not operating (Figure 6).

Construct the pad so that all air entering the house will have to pass through the pad. Provide a method of closing off the pads during the winter when heating, not cooling, is required.

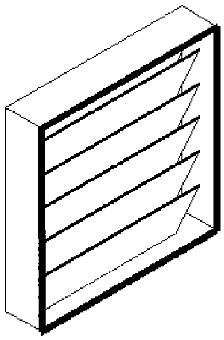

Figure 6. Ventilation and cooling fans should be equipped with anti-backdraft shutters.

Fans

Fans should have the capacity to provide at least one air change per minute. Heat enters the greenhouse through the greenhouse covering and causes the air temperature to rise. Solar heat loads on greenhouses will vary according to latitude location, as well as time of year and day. For example, in central Florida it will vary from a maximum direct normal solar irradiation in BTU per hour per sq. foot of about 280 in June to 300 in September (Table 1).

Table 1. Maximum direct normal solar irradiation.

Date	Maximum direct solar irradiation in BTUs per hour per square foot	
	24°N Latitude	32°N Latitude
June 21	280	280
July 21	279	278
August 21	285	283
September 21	301	296

Location of Fans and Cooling Pads

The best distance between the pads and exhaust fans is influenced by optimum dimensions of the house from an efficiency, functional and operational standpoint and the effective tolerance of plants produced in the house to temperature differences. The greater the crop's tolerance to temperature differences, the greater the distance between pad and fans can be. It is not practical to separate the pad and exhaust fans by more than 200′. A distance of 150' or less is preferred.

Location of pads and fans will be influenced by several factors. Keep in mind:

- When possible, locate pads on the prevailing summer wind side and locate the fans on the downwind side of the greenhouse. Should the pads be protected by another house within 25', the wind effect is negligible and can be ignored.
- If it is necessary to face fans into the prevailing winds, increase fan CFM capacity 10 to 15% and correspondingly increase fan motor horse power and add shutters or back draft dampers.
- The exhaust fans should not discharge toward the pad of another house unless the houses are separated by at least 50'.
- When fans from two adjacent houses close to each other exhaust into a common area between the houses, they should be offset from each other to avoid the air from one blowing directly against the other (Figure 7). Roof mounted fans should be used if fans do not have at least 1.5 fan diameter clearance between their discharge opening and the nearest obstruction.
- The maximum practical distance from pad to fan should never exceed 200'. Distances of 150' or less are more effective to reduce the temperature gradient. For most houses, about one foot of pad height is required for every 20' of pad to fan distance.
- In very long houses, it is more efficient to locate a pad at each end with the exhaust fans at the center of the house using side wall or roof mounted fans. Cooled air then flows in from each end and is exhausted at the midpoint of the house. All fans should be equipped with automatic shutters for weather protection and to prevent backdrafts when fans are not in use.
- Special motorized roof housings are used for mounting fans on the roof.
- The fans should be properly screened and guarded to safeguard personnel from coming in contact with any moving parts (fan blades, pulleys and belts).

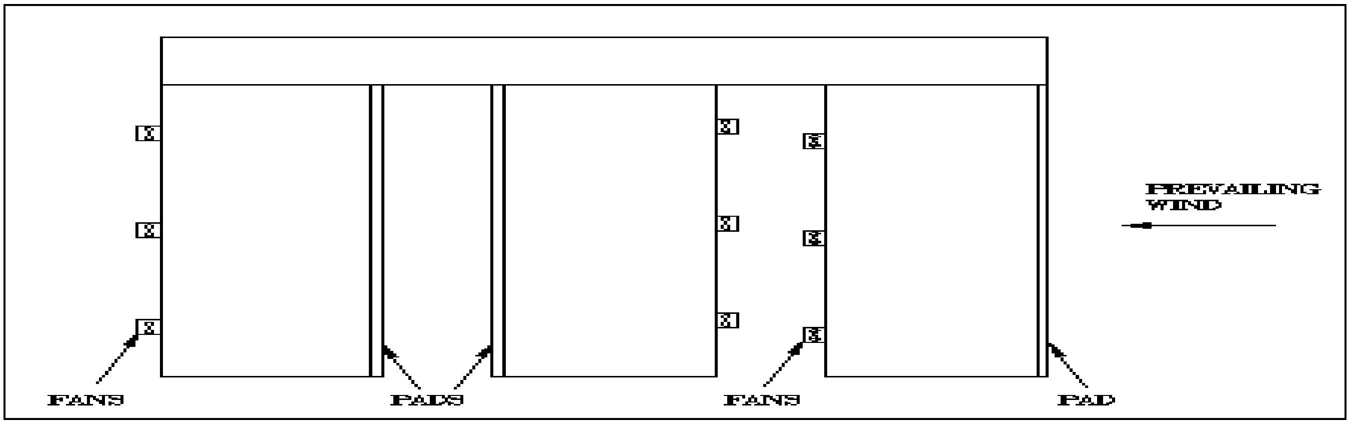

Figure 7. Typical greenhouse range layout.

- A correctly designed pad system is essential to achieve maximum cooling performance. It must be a continuous section along the entire side or end of the greenhouse, be the correct size and thickness. A blank space in the pad, such as a doorway, will cause a hot spot through the house for a distance of 6 to 8 times the width of the blank. Exhaust fans should not be spaced more than 20-30' apart (Figure 1).

- Pads may be built inside the house or in the walls, or they may be built outside the house (Figure 8).

FAN AND PAD COOLING SYSTEM OPERATION

Watch the pad condition carefully. If you notice bare spots or thin areas in the pad, you can be sure that much of the air entering the house is through these areas, which will result in hot spots in the house. To operate efficiently, the pad, pump system, fan system and control systems must be designed to operate as a unit. They must be checked frequently to be sure all parts are functioning properly. Manage the house operations so that doors are never left open and are opened only when necessary to move people or plants and equipment in and out. An open door can reduce the effectiveness of a pad cooling system significantly. The best house equipped with the best possible equipment and sophisticated controls can be a big loser without good management.

Controls

The evaporative pad cooling system must have adequate controls for the operator to be able to adjust the house environment to provide maximum growing conditions for the plants and a comfortable environment for workers. Thermostats are usually used to turn fans and pumps on and off, as required to meet changes in outdoor climate conditions and maintain more uniform greenhouse temperatures with lower operating costs. Thermostats should be checked each spring and fall against an accurate thermometer to insure proper operation.

A humidistat can be used to control pumps and fans of the cooling pad system to help prevent excessive greenhouse humidity. However, humidistats are much less reliable than thermostats. If it is desired to use a humidistat to control humidity, it is recommended that the humidistat be checked at least weekly to make sure that it stays in calibration. Humidistats should be checked against a psychrometer. Thermostats and humidistats must be located at plant level to function properly and should never be located on an outside wall.

Exhaust fans should be uniformly spaced not more than 20 to 30' apart. The fans may be wired so that the thermostats will turn on alternate banks of fans in sequence as the temperature demands. Some greenhouses are equipped with 2-speed fans which should be controlled with 2-stage thermostats. This arrangement will permit the first stage to turn the fan on low speed and off as required while the second stage will run the fan on high speed according to demand. It is important that, during the time of year a thermostat controls the heating system, the cooling thermostat which controls the first stage fans should be set 5-10°F above the setting of the heating thermostat to avoid having the heating and cooling systems on at the same time.

If evaporative cooling water pumps are controlled by humidistats and thermostats, they should be wired in series. This will help maintain more uniform temperatures and avoid excessive humidities. It will

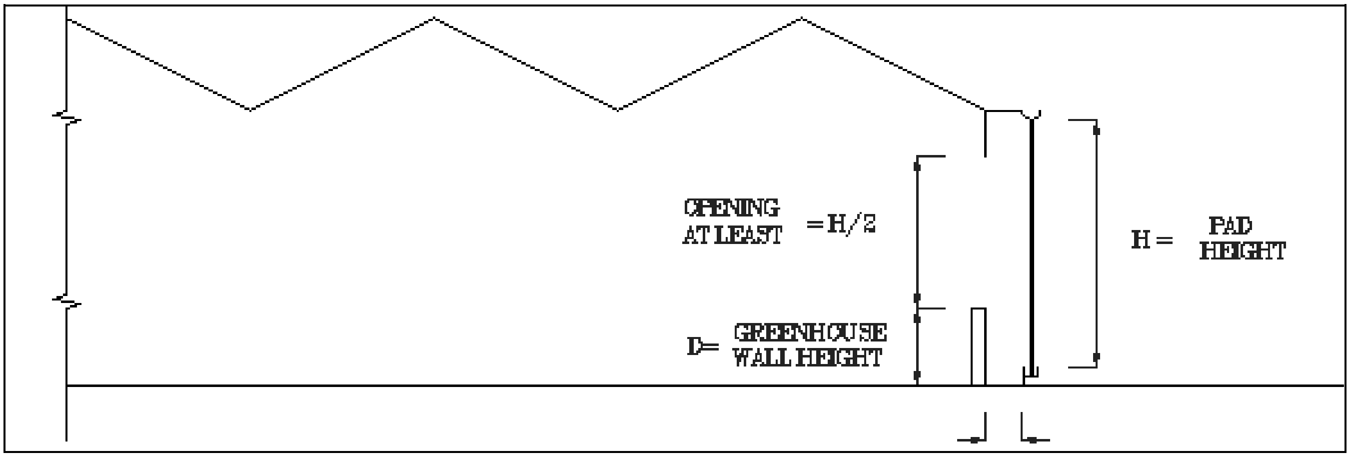

Figure 8. Typical section showing pad located outside building.

also help conserve power and water. In all cases, however, a thermostat should be used as the main pump control. The thermostat should be set to stop the pump before all the fans go off so that the pad can dry out.

Each thermostat and humidistat should have a manual control switch wired in parallel with it so that manual control can be used when desired. A safety disconnect switch should be located near each fan and pump. All controls and instruments including thermostats, humidistats and thermometers should be shielded from the direct rays of the sun to avoid being influenced by solar radiation and to provide more correct readings and control settings. They should also be mounted so that air can circulate freely around the sensing elements and be located where they represent the average greenhouse condition at plant level. Aspirated thermostats at plant level are the best choice. Do not locate near heating lines or near an air inlet opening. This will distort the readings from the true environmental conditions for plants in the greenhouse.

Computers and Microcontrols

Thermostats and humidistats are reliable and inexpensive, but are limited to simply turning pieces of equipment on or off in response to a change in temperature or relative humidity. Simple on-off controls cannot regulate environmental conditions exactly because they cannot sense how far the temperature or relative humidity is from the set point, or how rapidly the temperature or humidity is changing. Computers and microcontrollers can use software or hardwired circuits that incorporate logic to make decisions about the exact amount of heat or airflow required to produce desired environmental conditions. The higher degree of control provided by these devices results in more constant conditions that provide a better environment for crop growth.

Computers and microcontrollers are rapidly decreasing in cost at the same time that they are increasing in reliability and sophistication. They are now important tools that growers can use to increase crop quality and increase profits.