ROOT ZONE HEATING SYSTEMS FOR COMMERCIAL GREENHOUSES

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Introduction

Most greenhouse operations use one of two main crop production systems. One is the bench production system that utilizes either fixed or movable benches, and the other is the floor system that utilizes no benches and produces crops directly on the floor. Both of these systems can provide excellent results. In the past, both systems usually relied on unit heaters (forced hot air) or perimeter and overhead heating pipes (steam or forced hot water) as a heating source. Recently, floor production systems have utilized floor heating (using hot water heating pipes embedded in the floor), requiring additional overhead heating during colder outside conditions. Also bench systems are now frequently equipped to operate like floor heating systems. In most such systems, hot water heating pipes are installed under the benches to increase rooting media or pot temperatures.

The well-documented benefits of floor and bench heating have developed a considerable interest in this technology. Many traditional greenhouse production systems used benches to elevate plants above the cooler soil and to allow greenhouse workers a more comfortable working level. However, bedding plant operators traditionally grew their crops in polyethylene glazed plastic film greenhouses and placed the plant material directly on the floor to eliminate the cost of benches. This growing system could have a serious problem during periods with cold soil temperatures. Neither warm air nor overhead hot water heating systems are able to maintain warm root zone temperatures for many crops without operating the greenhouse at ambient temperatures higher than necessary. Using floor and bench heating systems, the temperature of the microclimate surrounding the floor or bench plant canopy can generally be maintained at an optimum level, while the bulk ambient air thermostat setting can be reduced relative to the setting required without root zone heating. Thus, floor or bench heating can significantly reduce the heating costs, with actual savings depending on weather conditions and temperature requirements of the crops being grown.

Types of floor heating systems

Growers have successfully used floor heating systems based on various types of floor construction. These include soil, gravel, sand, and porous and solid concrete. Each of these systems performs well in terms of crop heating and has varying favorable characteristics in terms of crop production. Soil, gravel, and sand floors are the least expensive to install, but offer the least benefits in terms of the ease of materials and personnel movement. Concrete floors are the most expensive to install but provide excellent materials handling characteristics, easier maintenance, long life, and weed control.

Porous concrete (a concrete mix of cement, aggregate, and water, but without sand) became popular as a greenhouse floor material starting in the 1970's. Porous concrete has approximately one fifth the strength of solid concrete; adequate for supporting the weight of greenhouse carts. It provides a solid surface, controls weeds, allows excess irrigation water to drain through, and creates a narrow air space between the bottom of the container and the floor surface that promotes air pruning of any roots exiting the container. Between cropping cycles, the floor surface can be cleaned with an industrial type vacuum cleaner commonly used for cleaning large areas.

Solid concrete has been successfully used, and since it is impervious (except for the inevitable cracks) it should be installed at a gradual slope to provide drainage of excess irrigation water (e.g., using a slope equivalent to a 0.5 inch rise in 6 feet). Allowing water to accumulate under the growing containers (pots, flats, etc.) on the floor can cause root disease and transplanting problems when the roots penetrate the drainage holes located at the bottom of the containers.

A popular application of solid concrete floors with a floor heating system is the ebb and flood irrigation system. This type of system, similar with respect to watering to ebb and flood benching systems, is designed to eliminate runoff from production greenhouses. The floor is alternately flooded and drained in order to water and fertilize the crop growing on the floor. The success of this convenient production system is largely due to the effectiveness of the embedded floor heating system in drying the floor after a watering cycle and keeping the root zone warm.

Pipes for floor heating systems

The floor (bench) is heated by circulating hot water through a piping system embedded in the floor (or under the bench) on top of which the crop is grown. This concept has been used in residential homes and industrial installations for many years, and more recently plastic pipe has been used for these applications. Prior to that copper and steel pipe were used in combination with higher water temperatures. Potential leakage at connections and fittings has been a challenge and caused failures in some of the early systems. The relatively low temperature (90-140°F) system described in this publication utilizes plastic pipe available in long coil lengths, eliminating any connections in the floor and greatly reducing the potential for failure. The use of a relatively low water temperature also minimizes expansion and contraction of the heating pipe and system components.

System design

Two different floor heating systems have been designed, installed, and operated in various commercial greenhouses with concrete floors. These are illustrated in Figures 1 and 2. The wet floor system provides a larger thermal storage capacity. Heat can be added to the stored water either by pumping the water through a solar collector or a heat exchanger coupled to another source such as a cogeneration system or the cooling water from an industrial source such as an electrical power plant. Alternatively an optional plastic piping system can be embedded in the floor for the circulation of warm water as shown in Figure 1. The dry floor system is more often used in commercial greenhouses because of the lower installation cost and the fact that reliable warm water from a source other than a boiler is usually not available.

In either floor system the vertical insulation at the perimeter is useful in maintaining uniform floor temperature near the edges by reducing heat loss to the cold soil adjacent to the greenhouse. Insulation under the liner in the flooded floor is useful for protecting the liner from punctures during loading of the stone as well as insulation. In either case the value of the insulation depends on the heat saved which will be more important when running relatively high floor temperatures and when there is a high water table (i.e., moist soil conditions) under the greenhouse.

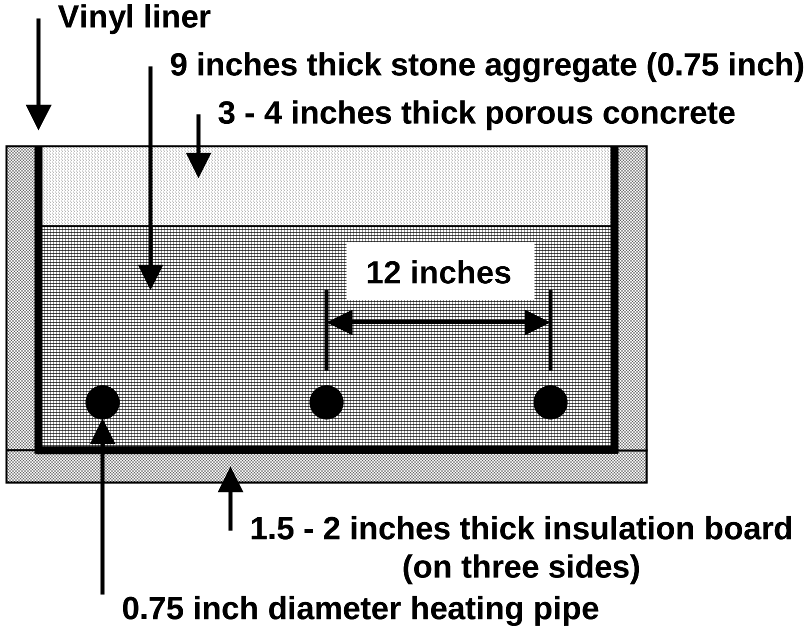

Figure 1. Sketch of a wet floor heating system and its components (not to scale). The recommended thickness of the Vinyl liner is at least 20 mil. The water surrounding the stone aggregate can be directly circulated through a solar collection system, and/or the optional embedded heating pipes can be installed to keep the water surrounding the stone aggregate separate from the heating water that is pumped from a heating source (e.g., a boiler or a waste heat source) through the heating pipes. Heating pipe spacing can be adjusted according to the supply water temperature used (i.e., the higher the temperature, the larger the spacing).

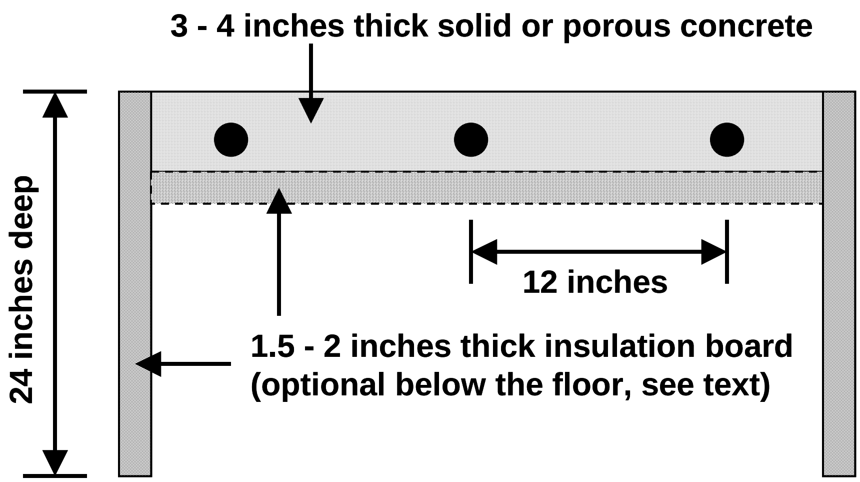

Figure 2. Sketch of a dry floor heating system and its components (not to scale). Heating pipe spacing is commonly 12 inches when using 0.75 inch diameter pipe, and 9 inches when using 0.5 inch diameter pipe.

Wet floor heating system

Figures 1 and 2 show a cross section of both systems that were simultaneously developed at Rutgers University in 1976. The floor design for the wet floor system is an integral and important part of the Rutgers Solar Greenhouse System. It is a composite of a nine-inch stone layer filled with water and capped with three to four inches of porous concrete and contained by a 20-mil PVC liner treated with a biocide. In the solar energy system, the energy is collected by pumping water stored in the floor through the solar collectors, heating it and returning it to the bottom portion of the floor that serves as storage and heat exchanger. The warmed water stored in the floor converts the entire floor area into a radiant heating system. Any time the temperature in the greenhouse is below the floor surface temperature, heat will be transferred from the floor to the greenhouse. Using this flooded floor storage system, the temperature distribution throughout the floor is very uniform.

The wet floor system can also be used when other warm water sources are available. These sources include cogeneration systems, industrial power plants, electrical generation stations, and geothermal sources of energy. Several commercial installations have operated using this floor heating system. The wet floor design is especially suitable for moderate temperature water sources since the entire floor area comprises the heat transfer surface area. Research has shown that the heat transfer coefficient is greater for a wet floor system compared to a dry floor system (Roberts and Mears, 1980)

In contrast with the Rutgers Solar Greenhouse System, the first wet floor system utilizing power plant waste heat used a closed pipe loop for heating the floor as shown in Figure 1. Such a closed-loop design limits any unwanted contamination, by materials used in the greenhouse production system, of the power plant's cooling tower water system. This closed loop system was thought important by the utility providing the warm water to keep the plant cooling water independent from the greenhouse environment, probably an unnecessary precaution. When the primary source of energy was unavailable, for example when the power plant providing 'waste' heat shuts down for scheduled maintenance, the water stored in the floor was circulated through a back-up heat exchanger connected to a boiler. Using the example of a power plant providing warm water for heating: warm water from the cooling tower was delivered to the greenhouse through a large-diameter pipeline and was then circulated throughout the floor of the greenhouse through the plastic pipe loop. The water contained by the liner is used only for increased energy transfer from the heating pipes to the floor system. This heat transfer can be optimized by operating circulation pumps that mix the water contained by the liner, resulting in increased uniformity of the floor temperature.

Dry floor heating system

An early design of a dry floor heating system was implemented in 1976. A warm water plastic pipe distribution system was used to deliver warm water to heat a porous concrete floor in a 144 feet x 210 feet polyethylene covered greenhouse located near Whitney Point, NY. Table 1 illustrates the floor heating system's impact on the temperature stratification observed in greenhouses. The data in the table illustrate the benefits of floor heating. The temperatures shown in Table 1 for the walkway were taken only 6 feet away from where the temperatures were taken for the heated floor section. The grower was very satisfied with his floor heating system, has increased the size of his greenhouse facility, and incorporated floor heating throughout his operation. Few benches were used in this greenhouse and crops of all types, including foliage plants, bedding plants, poinsettias and begonias were grown successfully on the warm floor. The temperature measurements shown in Table 1 indicate that the pot temperatures ranged between 61 and 64°F while the ambient temperature at 6 feet above the floor ranged between 65 and 67°F throughout the night (showing that crop temperatures can be cooler than air temperatures as a result of radiative cooling in a greenhouse covered with polyethylene without an infrared (IR) barrier).

Important temperature differences are shown in Table 1 comparing the temperature under a pot placed in the (paved) walkway, a location without floor heat, with the temperature under a pot placed in the floor-heated area. These plants are within a few feet of each other, yet the media temperature in the pot placed on the unheated floor was 14°F cooler. Crop performance is generally strongly correlated with media temperatures, so this difference in temperature is likely to have an impact on plant growth and development. In addition, it is not uncommon for greenhouses without floor heating to experience a media/canopy temperature for a crop grown on the floor to be at least 10°F lower compared to the temperature recorded at six feet above the floor (a height at which many growers place their thermostats, usually for convenience). This is not necessarily a problem in itself because the temperature at six feet above the floor can be increased by 10°F to provide the desired media/canopy temperature at floor level. In the example shown in Table 1, the greenhouse bulk air temperature would have to be maintained at 84°F to provide the desired media temperature of 65°F (assuming no floor heating system was used). This practice, however, generally results in very high energy costs.

Table 1. Temperatures recorded in a greenhouse near Whitney Point, NY in 1980.

	Floor heated area			Walkway	Foyer	Shop
Temperatures (°F)	18:00	21:00	08:00	08:00	08:00	08:00 (hr)
Outside	30	20	03	03	03	03
Under pot	64	63	67	53	55	39
In pot	62	61	64	51	-	-
12 inch above floor	60	61	65	58	55	45
72 inch above floor	65	65	67	70	68	63

The dry floor heating system, as shown in Figure 2, features plastic pipe embedded in a floor of porous or solid concrete. The floor can also be constructed of sand or gravel. The floor should be insulated around the perimeter of the greenhouse with rigid insulation board, and only under the entire greenhouse floor when a high (less than six feet deep) water table is present at the greenhouse site. The dry floor heating system is easy to install and less costly compared to a wet floor system. It can be used in greenhouses of any size and can be integrated into an ebb and flood irrigation system (Figure 3).

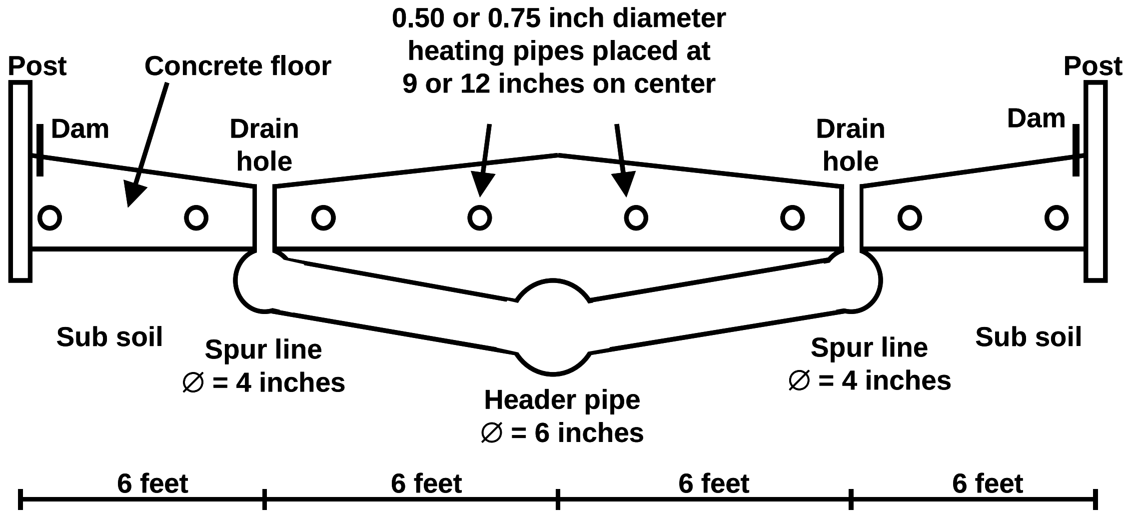

Figure 3. Dry floor heating system with an integrated ebb and flood irrigation system (not to scale). Note the ‘W’ shape of the top of the floor. This shape ensures complete drainage after each irrigation cycle (the recommended slope is 0.5 inch rise in six feet). The header pipe serves as supply and return and drains into a(n) (underground) storage tank.

Which system to select

Each of the floor heating systems has its own advantages. The larger heat storage capacity of the wet floor system is most beneficial for solar heating systems. It also has advantages in managing cogeneration systems, as energy can be stored for cold nights when electricity is generated during the daytime. Greenhouses located adjacent to cooling towers, industrial plants, or manufacturing facilities can be good candidates for this application of using what is otherwise considered ‘waste’ heat. The wet floor system has a slightly larger heat transfer capacity than the dry floor system, and with large quantities of warm water available, the floor can supply a larger percentage of the total heating requirement of a greenhouse. A disadvantage of the wet floor system is the added installation cost. However, a real benefit of the wet floor system is its larger heat storage mass and therefore greater fail-safe capability in the case of power failure or loss of heating capacity. In such cases, compared to a dry floor system, the floor temperature drops slower and the residual heat delivered by the floor can generally maintain the greenhouse temperature through a low-temperature night without crop failure.

The less costly dry floor system can be readily operated using common water heaters or boilers designed for heating water. Generally, pipe spacing in the floor is 9 or 12 inches on centers. Common (inside) pipe diameters are 0.5 and 0.75 inches, respectively.

Additional heating requirements

Each of the floor heating systems discussed can only deliver part of the overall annual heating requirement. Since the floor operates at relatively low temperatures, it cannot deliver all the heat required by the greenhouse during colder periods. The actual percentage of the total that can be supplied by the floor heating system depends on greenhouse location and heating demand. Research has indicated that a warmer root temperature may allow for a lower greenhouse ambient air temperature than normally recommended, particularly for vegetative growth. Therefore, using a floor heating system allows a lowering of nighttime air temperature by 5 -10°F or more depending on crop requirements, thus reducing the maximum capacity of the overall heating system, as well as energy costs. Generally, a well-designed floor heating system can deliver approximately 30 - 40%, or more in some cases, of the annual design heat load. Overhead unit heaters (either the combustion type or hot water to air units) are popular choices to provide the remainder of the annual design heat load for a greenhouse. The uniformity provided by a floor heating system overcomes many of the heat distribution and uniformity challenges associated with hot-air unit heaters. Overhead and perimeter hot-water pipe loops can be used to provide additional heating. Although a hot-water heating system is generally more costly, it can provide excellent temperature uniformity throughout the entire greenhouse.

Pipe materials and water temperatures

Common materials used for the pipes in floor heating systems include polypropylene and cross-linked polyethylene (PEX). Some bench heating systems are designed with EPDM flexible tubing. Most of the tubing materials are available with an integrated oxygen diffusion barrier that significantly reduces the diffusion of oxygen into the heating system water. Entrapped oxygen can form bubbles that impede water flow, and it can promote corrosion in (metal) heating pipes.

Maintaining the proper water temperature is critical for the efficient operation of floor heating systems. Generally, operating temperatures are maintained between 90 and 120°F (when the pipes are spaced 12 inches apart), and the loops are designed to result in a low temperature drop along the entire length of the loop (e.g., 5°F) resulting in a uniform floor surface temperature. When higher floor temperatures are needed, for example in germination areas, the pipes are generally spaced closer (e.g., 9 inches apart) and the temperature of the water in the pipes is sometimes increased to 140°F. This closer pipe spacing generally avoids the problem of uneven heat distribution. Uneven growth in flats of seedlings placed on a heated floor is usually an indication that the temperature of the water in the pipes is too high for the pipe spacing used. Temperatures higher than recommended also increase the amount of energy lost to the soil underneath the floor (when no insulation was installed during construction of the floor) and increase the possibility of damage to fittings and valves (that may not be rated for operation under such high temperatures).

When the greenhouse floor is constructed either of porous or solid concrete, the only connections necessary for the embedded pipe loops can be located along a wall of the greenhouse and either covered with gravel or left exposed so that any potential leak can immediately be detected and repaired without having to remove sections of the concrete floor.

More system design

The amount of heat given off for a given cropping system and floor design can be determined from the heat transfer coefficients reported by Roberts and Mears (1980) and the temperature difference between the water circulating in the pipes and the greenhouse air. A typical example would be for the dry, porous concrete floor system with flat production on the floor and 95°F average water temperature in the plastic pipe loop and a 60°F ambient air temperature. In this case, approximately 20 Btu/hour are given off to the greenhouse from each square foot of floor area. With pots spaced further apart and similar temperatures, approximately 25 Btu/hour for each square foot of floor area would be contributed to the overall greenhouse heating requirement, the remainder of which is provided by the overhead heating system. Tightly spaced flats may limit the rate of heat transfer relative to spaced pots, but usually normal irrigation practices ensure that the heat transfer is adequate. Lower ambient air temperatures and higher pipe water temperatures will increase the rate of heat transfer from the floor. When calculating the total heating requirement for the greenhouse it is good practice to consider that only 20 Btu/hour for each square foot of floor area is provided by the floor and the remainder is provided by the overhead heating system.

Maintaining proper water flow rates in the floor heating loops is very important. A recommended water velocity of 1.5 to 2 feet per second results in adequate heat transfer and helps dislodge pockets of air and small particulate matter (e.g., metal particles) that can accumulate in a horizontal pipe system. This translates to a flow rate of 3.2 to 4.2 GPM per loop when using 0.75-inch inside (nominal) diameter pipe. Pipe loops with 0.75-inch diameter should be no longer than 400 feet to minimize friction losses (or 250 feet when using 0.5-inch diameter pipes). Shorter pipe loops can be used but may require a larger circulation pump, because more loops generally result in more flow through the header pipes as well as more connections and valves, thus increasing the friction losses. Figure 4 shows a sample layout for a 24 by 96 feet double-poly greenhouse. A reverse return header system is used to equalize the distance the water has to travel through every loop. This system eliminates the need for balancing the water flow through every loop. An extra header pipe is required, but the need for (expensive) balancing valves is eliminated.

When using a coiled pipe in a 96 ft long greenhouse, the pipe can be looped three times at the end walls so that fittings only have to be used at the connections with the header pipes. Along the end walls, the heating pipe can be curved in an hourglass shape and fastened to the reinforcing wire using plastic electrical ties. The reinforcing wire that covers the entire greenhouse floor area, usually consists of a convenient 6 by 6 inch grid making it easy to secure the heating pipe without crimping or kinking it. Depending on the material, the coiled heating pipe can have 'memory', meaning it wants to return to its coil shape. The use of the reinforcing wires and the wire ties makes it easier to place the pipe until the floor material is added: either sand, gravel, porous or solid concrete.

After the pipe has been laid out and secured to the reinforcing wire, the entire heating system should be connected to a pressurized water supply (e.g., a municipal water system) and filled while minimizing air pockets. If the boiler has not yet been hooked up to the heating system, a temporary hookup should be installed so that all heating pipes are pressurized during the final construction of the floor, particularly during the installation of concrete. This will ensure three things: a leaking pipe or poor joint connection will be very obvious and repairs can be made before the concrete is poured, the water pressure inside the pipes will ensure that they will not be damaged by kinking or crushing during the pouring operation (the pressurized pipe will resemble a bicycle tire and is less likely to be damaged by wheelbarrows or people walking on it during the installation process), and the water filled pipes will not float to the surface of the freshly poured concrete.

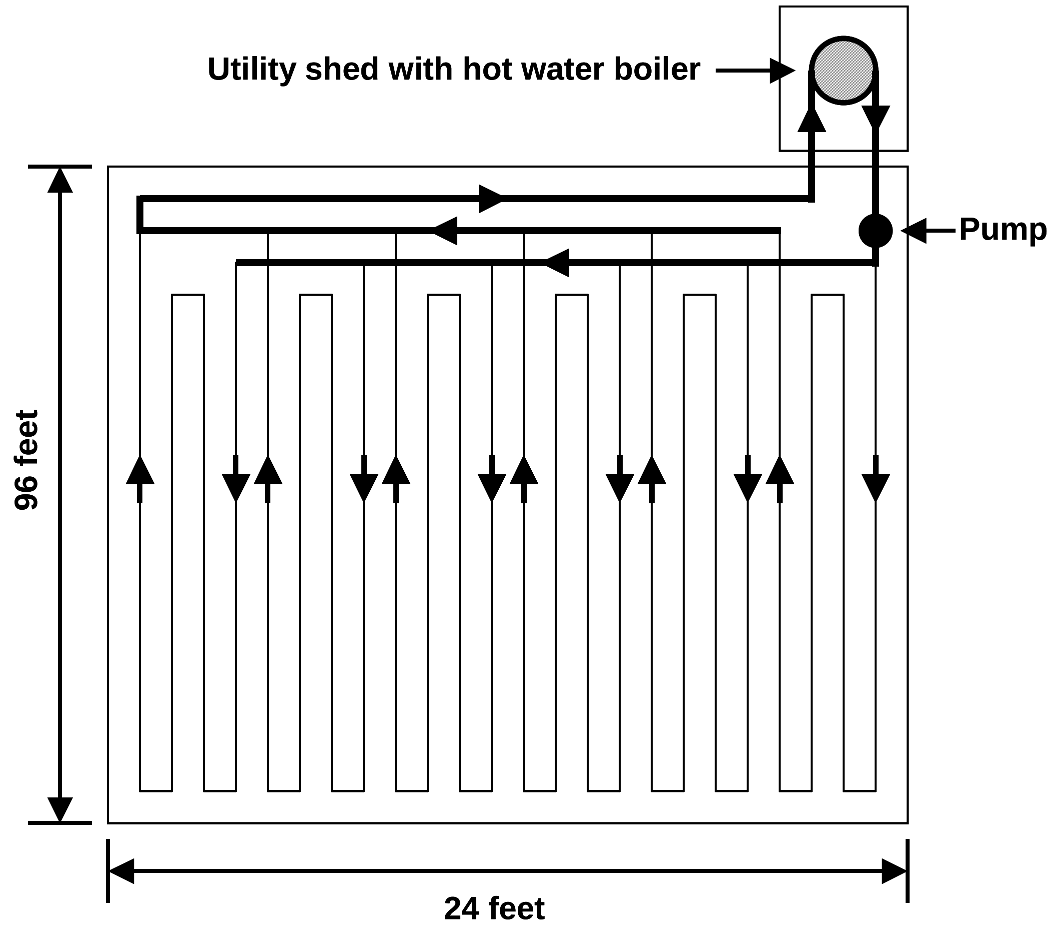

Figure 4. Typical dry floor heating system layout using 0.75-inch diameter heating pipe on 12-inch centers (not to scale).

Floor construction

Some growers who value its drainage characteristics are growing their crops on a porous concrete floor. Porous concrete is similar to traditional concrete, except that it has no sand in the mixture. This feature permits water to pass through it by gravity but, because of the large pore spaces, eliminates water moving up through the floor by capillary action. These unique features make porous concrete a good choice for use as a greenhouse floor, especially for crops that are grown on the floor. The need for additional weed control is practically eliminated. Materials handling equipment can be effectively used throughout the greenhouse. Excess water applied to the crops through hand or automatic irrigation systems drains through the floor and can be contained and collected by a plastic liner installed under the floor. No water accumulates on the floor reducing the occurrence of disease and root damage to flats or potted plants grown on the floor.

The formulation for porous concrete mixes varies but an acceptable mix (for one cubic yard of mix) consists of: 2700 pounds of 3/8" aggregate, 5.5 bags (94 lb each) of cement, 22-23 gallons of water. Research has shown that the working load of this mix is approximately 600 psi. This is approximately one fifth the strength of regular solid concrete of similar thickness. Light vehicle and personnel traffic is appropriate when the material is poured in a 3 –4 inch slab. Main walkways and pathways for carts in the greenhouse should be of solid concrete because of its added load bearing capacity and the surface of a porous floor can be too rough for smooth movement of carts over long distances.

The formulation listed above produces a stiff mix that is more difficult to manage compared to regular concrete. The concrete truck driver needs to be aware of this and refrain from adding water to make the material come down the chute more easily. Porous concrete also sets up quickly so provision should be made to keep it damp, particularly when pouring in high temperatures during the summer. The material can be screeded only with a board but no hand troweling should be used. Troweling tends to work the cement to the surface and create an impervious floor. Even though the porous concrete mix is more difficult to handle and screed, the temptation to add water must be resisted at all cost.

Porous concrete floors can become plugged with media mix and plant debris if potting or media handling operations are carried out on the floor surface. If this is necessary, a plastic liner should be placed on the floor and removed when the media handling operations are completed. Plant and media debris that accumulates during the growing season, can be cleaned between crops by using an industrial vacuum cleaner. Drying the floor and vacuuming it between cropping cycles promotes good sanitation and keeps the floor from becoming plugged so it stays in optimum shape for many years of use.

The cost for porous concrete is about the same as for solid concrete. At the current price of approximately $85-90 per yard, this translates into a cost for a 3" floor of $0.80-0.85 per square foot. Labor and other incidental costs are not included.

Dry floor heating systems have been installed successfully using sand, soil, gravel, and concrete. When sand or soil is used, it is important it remains moist throughout the heating season in order to maintain good heat transfer from the heating pipes to the surface of the sand or soil. Hence a layer of heavy-duty woven landscape fabric is often placed over the sand or soil. Pots or flats are then placed directly on the landscape fabric. Most of the excess irrigation water will pass through the landscape fabric ensuring moist conditions essential for good heat transfer. The landscape fabric will also inhibit weed growth on the floor. Gravel floors are operated the same as porous concrete floors. Pots and flats can be placed directly on the landscape fabric on top of the gravel surface. In all cases, solid concrete pathways should be used for easy movement of equipment and carts. Most carts will not operate efficiently on rough surfaces.

Warm water supply

Warm water can be supplied to the system in several ways. Most growers use boilers or hot water heaters in conjunction with 3 or 4-way mixing valves to supply high temperature water to the overhead greenhouse heating system and low temperature water to the floor system. Figures 5 and 6 illustrate the operation of these types of valves. There are several options for putting together greenhouse heating systems. Mixing valves allow the boiler to operate within its optimum temperature range, and at the same time provide for the appropriate operating temperature for each of the heating loops. Another advantage of using mixing valves is when the floor heating section is located a significant distance away from the boiler room. In this case, high temperature water at a low flow rate can be delivered to the greenhouse section through a small diameter pipe reducing the installation costs. In the greenhouse section requiring floor heat, the high temperature water is then mixed with water recirculating through the floor loops resulting in the desired floor surface temperature.

In some cases, (residential) hot water heaters are used to supply warm water to a floor heating systems without the use of a mixing valve. Figure 7 illustrates such a system. In this case, the aquastat used to control the water heater must be able to be lowered enough to provide the required moderate temperature water. If this is not possible, a mixing valve will have to be used.

A floor heating control system can be complex or relatively simple. Growers who use only water at one temperature (e.g., 90 or 100°F) can maintain their boiler water temperature with an aquastat and operate the circulation pump with an on-off switch or a thermostat. Growers who use a piped overhead hot water heating system or hot water to air heat exchangers in conjunction with a floor heating system, can use an aquastat to control the boiler water temperature at the desired high temperature based on the needs of the overhead system. Figure 8 shows such a system and includes a 3-way mixing valve to provide the proper temperature for the floor loop. Figure 9 illustrates how a single acting valve can be used to provide two water flows with different temperatures. Generally, operating boilers at higher temperatures increases the life of the boiler or hot water heater. This means that 3-way or 4-way mixing valves are required to control the temperature of the water pumped through the floor heating loops.

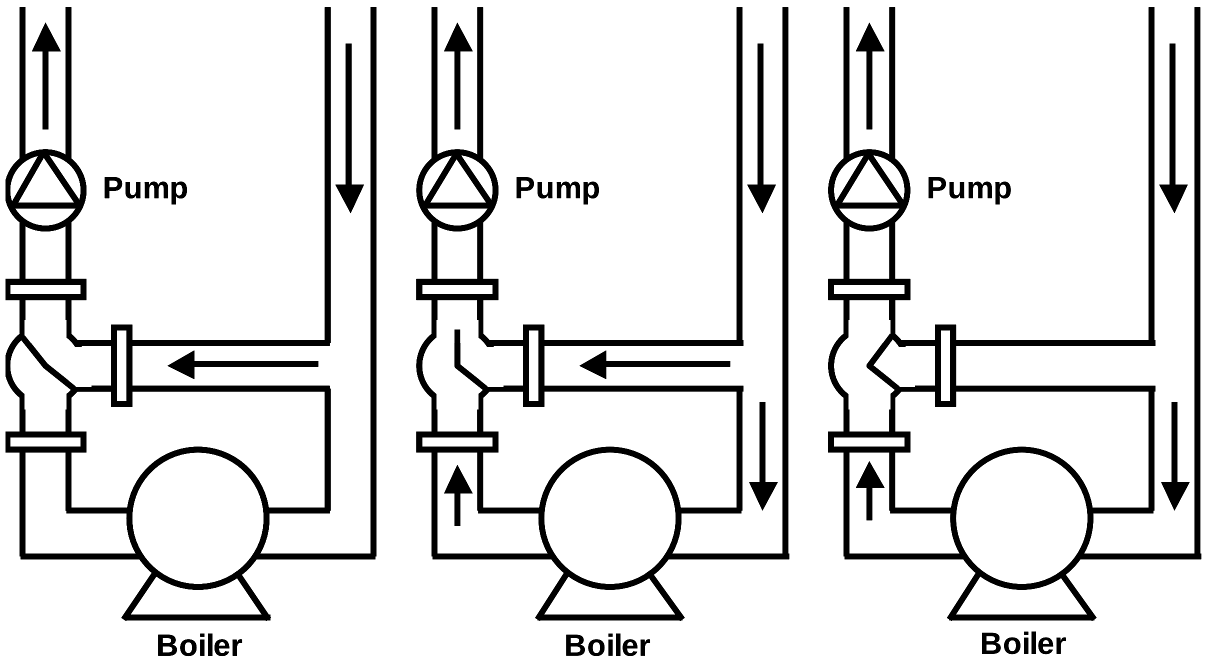

Figure 5. Three positions of a 3-way mixing valve. The diagram on the left shows the valve in the fully closed position. In the middle, the valve is shown in a partial recirculating position. In this position the warm water from the boiler is mixed with the cooler return water. The third position shows the valve in the fully open position with all the return water passing through the boiler.

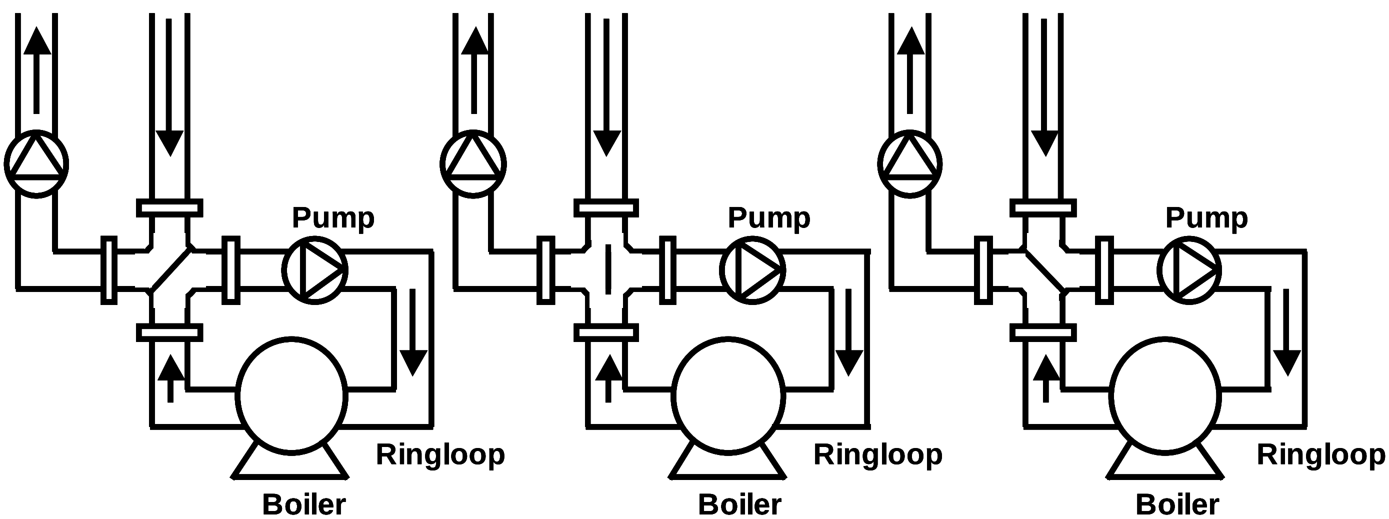

Figure 6. Three positions of a 4-way mixing valve: fully closed, recirculating, and fully open. This valve is used in a ring loop configuration. Greenhouse sections would draw from the main ring line as required depending upon the position of each 4-way mixing valve.

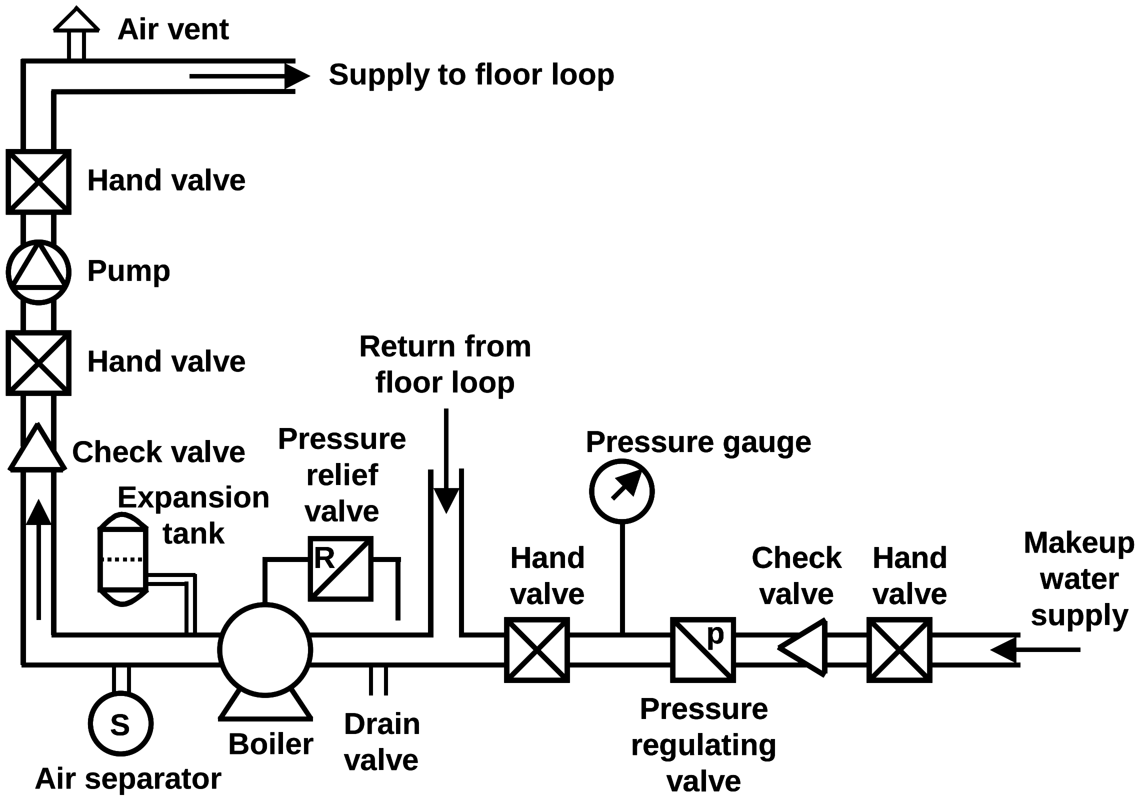

Figure 7. System layout for a single temperature floor heating system (drawing not to scale). In this system, the boiler can be replaced by a (residential) hot water heater.

Control systems

The bulk air temperature in the greenhouse is usually controlled by thermostats that operate overhead unit heaters, or by operating mixing valves and/or pumps in overhead hot water systems. Most floor heating systems are also controlled by thermostats that either sense the water temperature in the floor, or the temperature of the medium in which the crop is grown. Wherever the thermostat is placed, it has to be calibrated with a thermometer recording the floor or media temperature required for the particular crop being grown. After observation and experience, the floor thermostat can be set to provide an accurate floor or media temperature. In all cases, the floor heating system response time is slow and management changes must be anticipated well in advance of the needed temperature change. Computer control can help anticipate the desired floor temperature based on weather conditions, time of day, crop requirements, and energy conservation strategies. The computer control system can activate the floor heating system and anticipate its proper settings early enough to allow temperature fluctuations to be minimized or to occur at desired time periods.

The actual optimum media temperature maintained for a particular crop can vary with crop stage and timing. Optimum media temperature for most crops range from 55 to 75°F, with the most common range between 60 and 70°F. Germination and the rooting of cuttings often requires temperatures in the 70 to 75°F range.

Material costs

The estimated material costs (2005) for a 24 by 96 feet double-layer polyethylene covered greenhouse with a floor heating system, using a hot water heater for the floor loop only, and a porous concrete floor include:

28.5 yards of porous concrete (4 inches thick)	$2,423
480 ft^2 of perimeter insulation (2 inches thick, 2 feet deep)	225
2400 feet of 0.75 inch heating pipe	750
100 feet of 1.25 inch plastic supply pipe	100
1 circulating pump	450
1 thermostat to control the pump	50
miscellaneous fittings and clamps	200
Total	$4,198

This cost of $1.82 per square foot does not include labor, the cost of the hot water heater, and will vary depending on type of equipment and materials selected.

The cost for the equipment needed for a floor heating system will vary depending on the type of system installed. A floor heating loop and an overhead heating loop can be operated from the same hot water boiler by using a standard three-way mixing valve as shown in Figure 8. Figure 9 illustrates the use of a thermostatically controlled, single-action, regulating temperature valve to provide 180°F water to be mixed with the 90°F return water from the floor loop. Check valves are required in these two systems, and the installation of manual valves simplifies future shutdown and maintenance procedures. Since the water pump is likely to require maintenance or replacement, the installation of pipe unions and hand valves on either side of the pump makes repair and maintenance much easier. Shutting these valves isolates the pump from the system and eliminates the need to drain the entire system and/or to bleed off entrapped air. Standard safety features, including an expansion tank, air bleed valves, and low water level shutoff, are required for a hot water boiler system. Galvanized or copper pipe is used in those parts of the system that contain high temperature water.

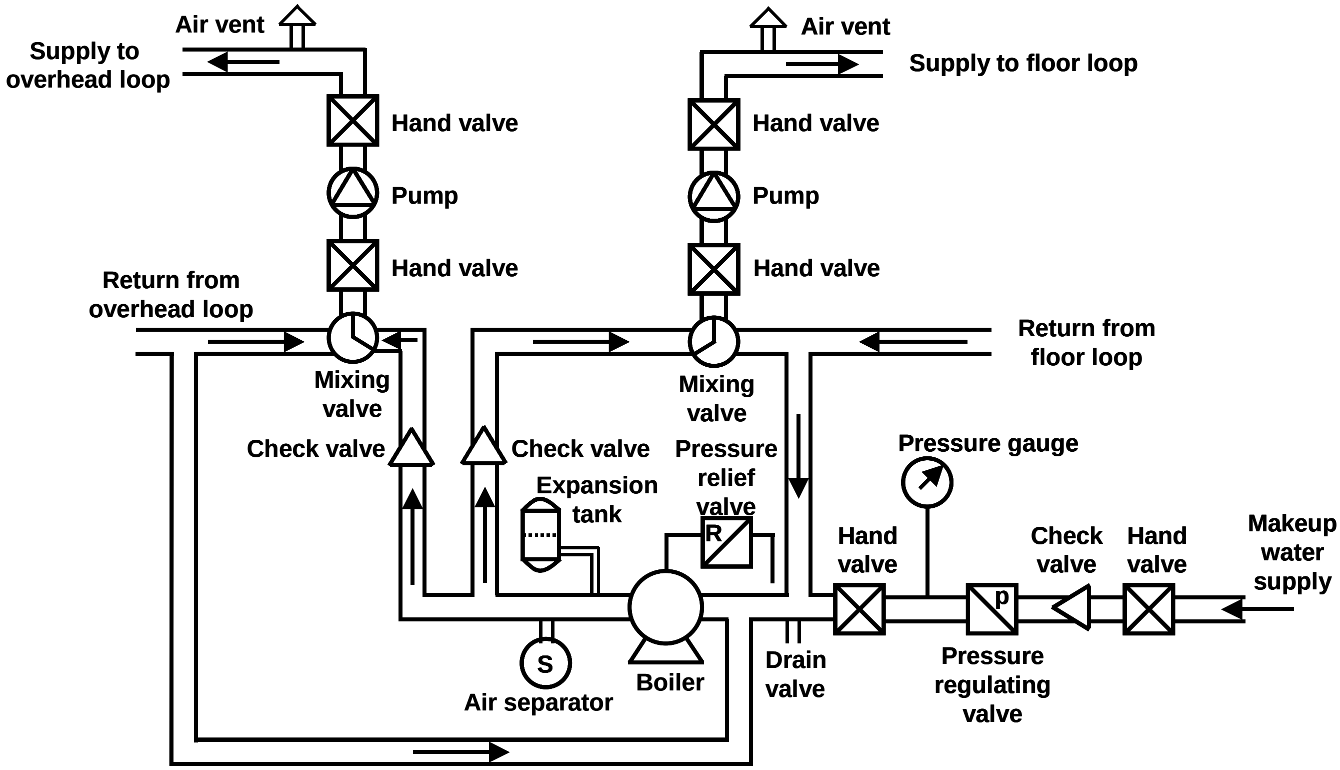

Figure 8. Typical layout for a dual temperature heating system using three-way mixing valves (drawing not to scale).

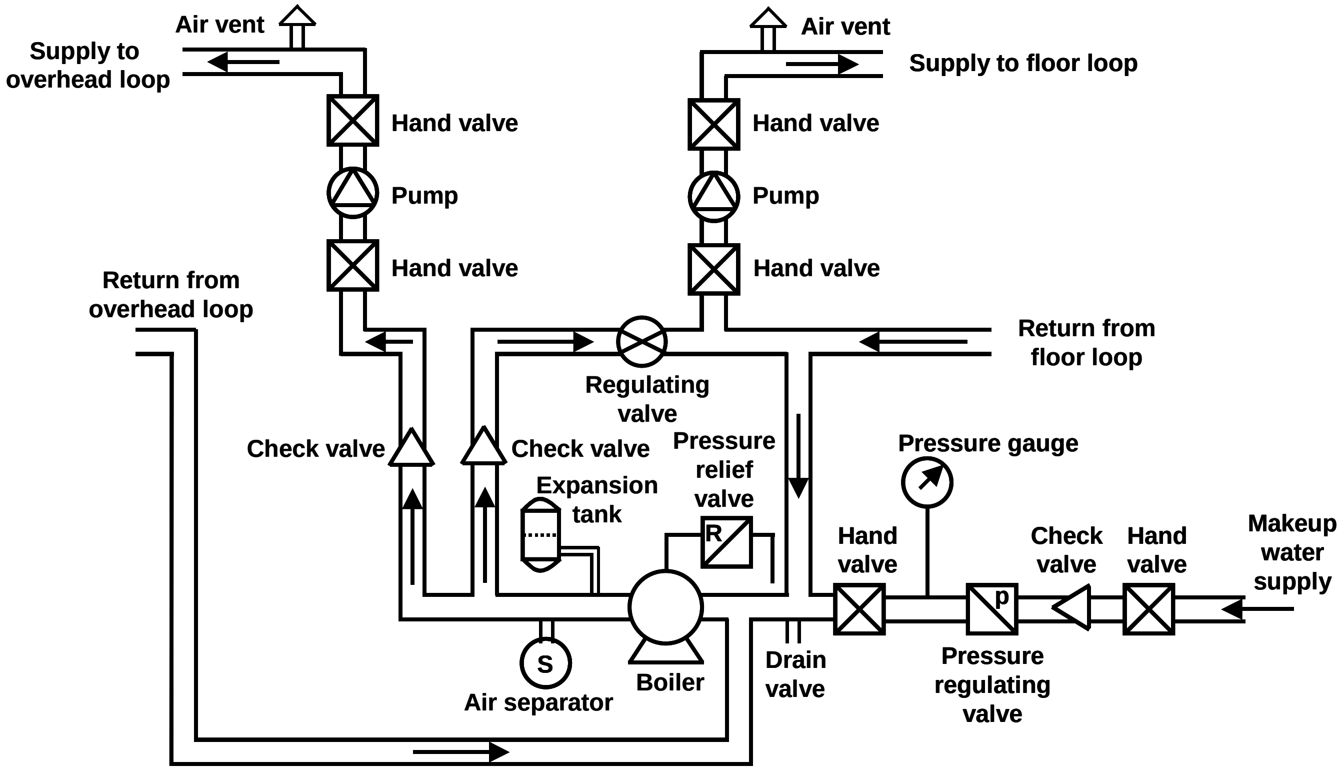

Figure 9. Typical layout for a dual temperature heating system using a single temperature regulating valve in the floor heating loop (drawing not to scale).

Important points to remember:

- A floor heating system has a slow response time. Allow up to 24 hours for a system to stabilize after the system is first turned on.

- The floor heating system usually provides only 30-40% of the annual heat requirement of a double-layered greenhouse structure. The additional heat must be provided by an overhead heating system.

- The water temperature in a floor heating pipe loop (using 0.75 inch heating pipes on 12 inch centers) should rarely exceed 120°F in order to maintain uniform floor temperatures (140°F when using 0.5 inch heating pipes on 9 inch centers). Such high water temperatures can cause uneven growth in crops grown directly on the floor.

- Typically only the perimeter of the floor needs to be insulated (e.g., 2 inch thick board to a depth of 2 feet). Insulation should be installed under the entire floor when the average water table is within six feet below the soil surface, and/or when heat loss to the sub-soil increases as a result of higher water temperatures in the heating pipes.

- A reduction in the bulk ambient air temperature may be possible for some crops grown under conditions with warmer root temperatures. Always test such strategies carefully (e.g., in 2-3°F increments) and observe the impact on the crop over a period of time.

Root media heating for crops grown on benches

Traditional bench heating systems use steel or specially extruded aluminum finned piping under the bench to deliver heat to the rooting media and to the crop (Figure 10). Growers using hot air heating systems for their houses have successfully used EPDM tubing systems as an excellent way to supply heat to the media and provide for proper root temperatures. These systems have produced excellent plant growth and in some cases have reduced energy usage because, as a result, lower ambient bulk air temperatures could be maintained. Many of the principles previously discussed for floor heating apply to bench heating as well.

EPDM tubing is easy to handle, can withstand moderately high temperatures, and can provide uniform media temperatures when used for bench heating. Various system designs are used. Some manufacturers extrude the tubing in a counter flow configuration. An advantage of this type of system is that two adjoining tubes are operated in counter flow resulting in more uniform temperatures. If the design temperature drop along the loop is 20°F and water enters the loop at 120°F, it will return at 100°F. Because of the counter flow design, the average temperature at any one point along the entire loop will be approximately 110°F. Frequently, this twin tube counter flow system is installed on 4 inch centers, while a single tube system is installed on 2 inch centers, making the total length of tubing the same. A common layout is shown in Figure 11.

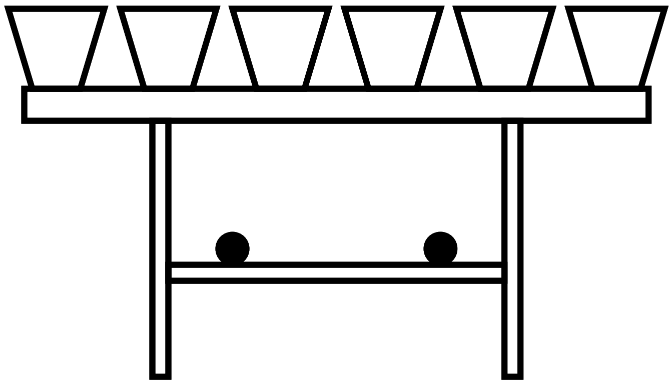

Figure 10. Typical under-bench heating system with steel or extruded aluminum pipe (drawing not to scale).

Since the diameter of the EPDM tubing is so small, it is important to properly lay out the header and tubing system to ensure equal flow through each loop. EPDM tubing can safely withstand moderately high water temperatures and various systems can be used to control this temperature. Mixing valves are the most commonly used control method, although a simple (residential) hot-water heater with an aquastat set at the appropriate temperature can also be used. Tankless water heaters can also be used for this type of installation.

EPDM tubing can be laid on top of an open bench, embedded in the top of thermal insulation board, or placed near the top of a sand or soil bed. In each case, the operating temperatures need to be controlled so that the desired media temperature can be achieved. Multiple bench installations are common and separate pumps and/or solenoid valves can be used to vary the time of operation. If different temperatures are needed, mixing valves are required for each separate zone.

Figure 12 shows a bench heating system using 0.75-inch plastic heating pipes as a substitute for EPDM tubing when the bench design is not suitable for the small tubing or when small diameter pots are used which tend to tip over if not handled in flats. The pipe is installed 8 inches on centers, passes through notches in the bench supports, and can be secured to the bench top with e.g., electrical wire ties. PVC pipe works well for this application when the benches are short and when coiling plastic pipe would make installation cumbersome. When using rolling benches, flexible supply and return lines are required to allow the bench to move without interfering with the heating system. When transportable benches are used, fixed steel or aluminum piping is the only option since each bench needs to be able to move independently of the bench heating system.

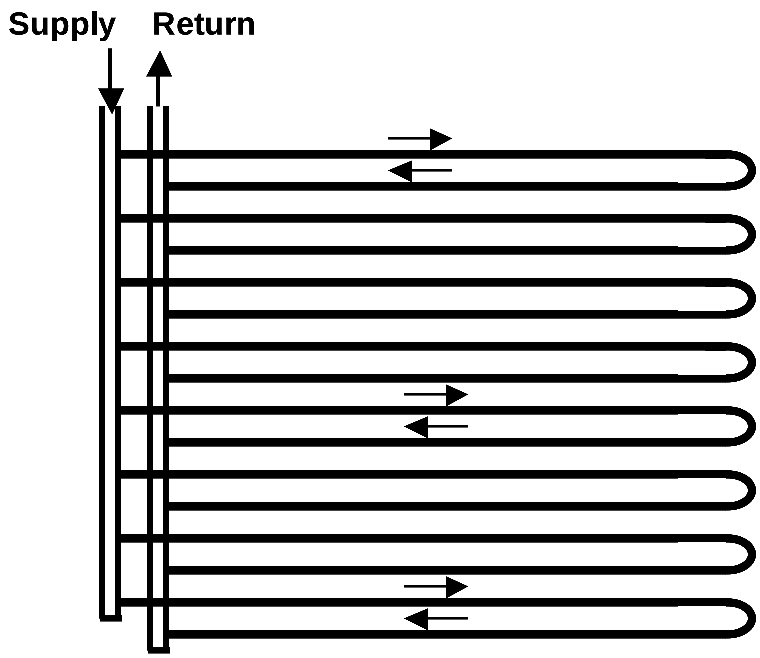

Figure 11. Typical bench top heating system with EPDM tubing placed 2 inches on center (drawing not to scale).

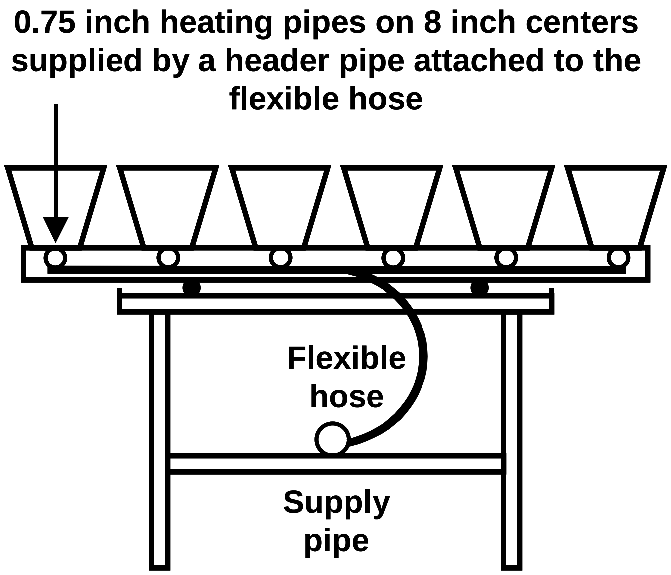

Figure 12. Typical bench top heating system with 0.75-inch diameter heating pipes placed 8 inches on center on a rolling bench (not to scale). The warm water supply is drawn at this end of the bench, while the return is located at the opposite end (not visible). Main supply and return lines could also be located at one end of the bench allowing neighboring bench heating pipes to alternate as supply and return lines (similar to the layout shown in Figure 11).

Summary

Floor heating systems have several fringe benefits. It may be possible to eliminate benches for some crops that require little or no hand labor throughout the growing season. Better materials handling techniques are possible throughout the season. An additional benefit is the heat storage capacity of the floor. In the event of a heating system failure, the warm floor can help carry the greenhouse through a cold night without significant crop damage.

Bench heating systems have provided opportunities for growers to maintain proper rooting media temperatures while reducing ambient bulk air temperatures.

Floor heating systems have enabled the increase in popularity of the ebb and flood floor irrigation system, a system that was developed to eliminate potential runoff from greenhouses and to reuse excess irrigation water. The incorporation of floor heating has made this system highly successful.

Note: This extension publication is based on a version previously developed by Professor Emeritus William J. Roberts.

Additional reading

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