Greenhouse production is a year-round operation that requires an optimal indoor growing environment, especially when the outside environment is too cold for plants to survive. For instance, in Alberta during the winter the temperature can drop to -22°F to -40°F (-30°C to -40°C), and the temperature differential between the greenhouse environment and the outdoors can range from 90°F to 108°F (50°C to 60°C). Hence, an adequately sized heating system is necessary for greenhouse production. The system output must be able to maintain optimal temperatures even on the coldest days of the year.

Greenhouse crops can be cultivated on the floor, on benches, or in hanging baskets. Many growers use all three of these production methods at one time or another. Each nurturing method requires its own crop handling procedures and incurs different installation and operating costs. Growers have to weigh the benefits and challenges of these systems before deciding to install them in their greenhouses. The same is true for the heating system. Different heating systems are available to heat greenhouses: from hot-air, to hot-water, and radiant systems. The challenge of all these systems is to provide heat in the right amount at the right location, and as uniformly as possible at a reasonable cost. Generally, hot-water soil/floor heating systems are capable of providing the most uniform heat throughout the crop canopy, especially when floor or bench top heating is employed. To grow a crop successfully on the floor without a floor heating system can be challenging at best. In that case, in order to provide the desired root zone temperature, the greenhouse air temperature has to be increased resulting in significantly higher heating bills.

Because plant containers (e.g. flats, packs, or pots) sit directly on the floor, the root medium is heated by the floor. Listed below are some of the benefits of soil/floor heating in protected cultivation environments.

(1) Improved Plant Growth and Quality

Researchers have confirmed that root-zone heating significantly increased growth and nutrition, compared with no heating. There is a trend in growth and nutrient concentration with timing of root/floor heating: constant (day and night) > day only > night only. In essence, root development is accelerated and the amount of time for root development can be shortened by 20% to 40%.

(2) Energy Savings Due to a Lower Greenhouse Aerial Temperature

Energy savings are a distinct advantage. Researches have indicated that root zone temperatures are more critical to plant growth than leaf temperatures. By maintaining an optimum root zone temperature, greenhouse air temperatures can be lowered by as much as 15°F (8°C). Each degree centigrade spared in the greenhouse air translates to an average saving of about 7% to 10% of the fuel required. Research results have determined that bench-top heating systems used only half the energy required by a perimeter hot water system to produce chrysanthemum and tomato crops.

Floor heating is ideal for crops grown directly on the floor such as bedding plants, containerized ornamentals, and bag-cultured vegetables, as well as greenhouse vegetables grown directly in the soil. With a cool-season crop (lettuce, spinach, Asian leaf vegetables), supplemental air heating may not even be required in a floor-heated greenhouse.

(3) Dryer Floor and Plant Surfaces Reduce Disease Pressures

A drier greenhouse environment is a powerful defense against plant diseases. The first step toward disease prevention in a greenhouse is reducing freestanding water on plant surfaces. A water film on a plant provides an ideal condition for pathogens to grow and infect crops. Condensation (dew) occurs when moisture in the warm air condenses on cool leaf and covering surfaces. Soil/floor heating— when compared to hot water pipe heating near the floor, and forced air heating above the floor—is proven the most efficient and effective heating system in maintaining warm canopy temperatures. Keeping the temperature of leaf surfaces above the dew point is an excellent way to prevent condensation and thus fight common greenhouse diseases.

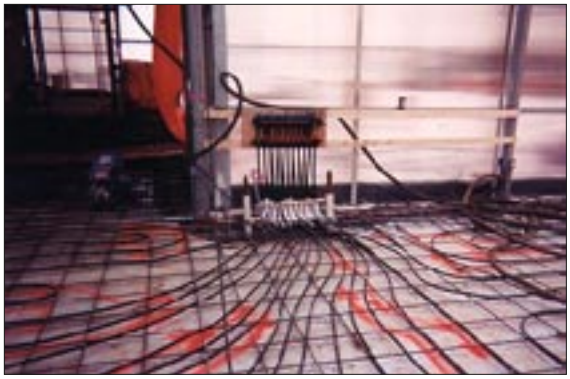
(4) Highly Uniform Distribution of Heat

The large heat transfer surface of the floor delivers heat homogenously throughout the greenhouse. Heating from the bottom of the greenhouse allows warm air to rise through the plant canopy, providing better circulation of the heat. In turn, uniform temperatures can be maintained in the surroundings of the plants. The result is improved uniformity of plant growth and development, and reduced greenhouse aerial temperature. A typical temperature pattern for a two-foot-tall crop in February with an outside temperature of 10°F (-12°C) would be a floor temperature of 74°F (23°C), a canopy temperature of 55°F (13°C), and a temperature of 48°F (9°C) four feet above the ground.

(5) Thermal Storage Capacity of Floor is Useful During Interruptions in Power and/or Heat Supply

Soil/floor heating systems offer some protection from short-term power outage or boiler failure due to the stored energy in the huge soil/concrete mass of the floor.

Floor heating has other advantages. Heat can be targeted at specific areas where heat is required, thus creating a number of mini-climates throughout the greenhouse. The entire greenhouse does not necessarily have to be heated at the same temperature. However, floor heating adds to the cost of the heating system installation: as a hot-water heating system is required, and that floor heating systems respond slowly to changes in the temperature set point. Moreover, floor heating systems are generally not able to provide all the necessary heat to keep the greenhouse at the desired temperature during the coldest periods during the winter months in northern climates. As a conservative rule of thumb, typical floor heating systems provide around 30% to 40% of the total heating requirement of a greenhouse. The remainder is to be met by perimeter and overhead heating pipes, or with a hot air heating system. Nevertheless, depending on the outside and desired greenhouse temperatures, a floor heating system can offer a significantly higher percentage of the total heating requirement.



System Consideration

Floor heating systems embedded in gravel, sand, or soil do not require the added cost of installing a concrete floor, but can make materials handling (e.g. moving carts) more of a challenge, and require weed control measures (e.g. through the installation of a landscape fabric). Similar to heated concrete floors, insulation underneath heated loose-fill floors is generally only necessary when the water table is less than six feet below the floor. In that case, installing a continuous layer of 2" insulation board (an equivalent R-Value of 10 hr ft2 °F/BTU) underneath the entire floor area will help significantly reduce heat loss to the subsoil. In colder climates, as a minimum, perimeter insulation is recommended. In small greenhouses, a small heat source (perhaps, a small capacity boiler) can be used to provide warm water to be pumped through the floor heating pipes, while an inexpensive hot air heater can be used to meet the additional heat requirements.

These days, concrete floors with floor heating systems are a popular choice among many greenhouse operators. Concrete floors allow for excellent materials handling, are durable and easy to maintain, and virtually eliminate the need for weed control. There are two types of concrete floors that can be outfitted with a floor heating system: porous or solid. Porous floors are made with a concrete mixture without sand (just gravel and cement). These floors allow for quick drainage of any excess irrigation water, leaving the floor dry most of the time. Porous concrete floors are not as strong as solid concrete floors, but strong enough to support people and light equipment. On the other hand, solid concrete floors are strong enough to support heavier equipment and their floor heating systems can be combined with ebb and flood irrigation systems that allow for recirculation of the nutrient solution.

Installation Design

Floor heating systems are designed to provide uniform heat directly to the soil medium of the crop, which is usually grown directly on top of the floor. The system can be embedded in a layer of fill (e.g. gravel, sand, or even soil), or it is installed in a concrete floor slab typically 4" (100 mm) thick. The PEX heating pipes can be tied to the reinforcing wire mesh. Nominal 3/4" (19 mm) pipe is commonly used, spaced at 12" (300 mm) on centre and positioned in the lower third of the slab.

Hot water at 90°F to 110°F (38°C to 43°C) from gas water heaters, or an alternative fuel source (such as: geothermal water, waste water from power plants and cogeneration facilities, solar or compost-heated water collectors located outside the greenhouse) is circulated through the pipes, heating the concrete slab, growing media, and eventually the greenhouse air. The heat from the pipes essentially keeps the floor at the desired temperature.

Soil/floor heating systems work well with any low temperature between 90°F and 110°F (38°C to 43°C). Higher water temperatures can be considered, but the pipes should be spaced farther apart to ensure uniform floor heating since the purpose of floor heating

system is to use the floor as a large radiator. The combination of pipe spacing and size is dependent upon the supply water temperature. Usually, it can be achieved by either:

(a) placing smaller diameter pipes at close spacing near the surface of the floor, or

(b) placing larger diameter pipes further apart at a greater burial depth.

The theory behind this approach is to reduce the difference between the distance heat must travel vertically (from the tube to the surface directly above it), and laterally (from each tube to the surface between the tubes). Generally, burial depth is more a function of protecting the pipes from surface activity than system design, and a figure of 2" to 6" below the surface (dependent on the thickness of the concrete slab if heating pipes are embedded in the concrete) is common.

Control Strategy

A temperature tempering/mixing valve, utilized to maintain the floor heating loops at a fixed temperature in conjunction with an appropriate number of temperature sensors, should be located either embedded in the floor, or in the root medium of plants growing on the floor. It is essential that these sensors get a representative temperature measurement of either the floor or the root environment. In order to optimize the use of the floor heating system, an outdoor reset controller is recommended that can take changes in the local weather into account in maintaining the floor heating loops at a fixed temperature by controlling how much the temperature tempering valve is to be opened.

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