Horticultural Engineering
Volume 17 No. 3, May 2002

Website: http://aesop.rutgers.edu/~horteng

Floor Heating in Greenhouses

By A.J. Both , David R. Mears, Eugene Reiss, and William J. Roberts

Introduction

Greenhouse crops can be produced on the floor, on benches, or in hanging baskets. Many growers use all three of these production methods at one time or another. Each 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 greenhouse. The same is true for heating systems. 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 and at the right location, and as uniformly as possible at a reasonable cost. Generally, hot-water 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. In this article, we will focus on hot-water floor heating systems and show how a greenhouse operation can benefit from such a floor heating system.

Floor heating systems are designed to provide uniform heat directly to the soil media 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. Warm water is pumped through a network of pipes installed in the floor and the heat from the pipes keeps the floor at the desired temperature. Because the plant's container (e.g., flats, packs, or pots) sits directly on the floor, the root medium is heated by the floor. The benefits of floor heating are well documented and include (1) improved plant growth and quality, (2) energy savings due to a lower greenhouse aerial temperature, (3) dryer floors, which reduce disease pressures, (4) highly uniform distribution of the heat, (5) eliminates the need for benches, and (6) heat storage capacity of the floor for heat which can be useful during interruptions in power and/or heat supply. However, floor heating adds to the cost of the heating system installation, floor heating requires a hot-water heating system, and floor heating systems respond slowly to changes in the temperature set point. In addition, 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 northerly climates. As a conservative rule of thumb, typical floor heating systems provide around 30% of the total heating requirement of the greenhouse. The remainder is provided with perimeter and overhead heating pipes or with a hot air heating system. However, depending on the outside and desired greenhouse temperatures, a floor heating system can provide a significantly higher percentage of the total heating requirement.

System Design

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-inch insulation board (R = 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 domestic hot water heater 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 provide the additional heat requirement.

These days, concrete floors with floor heating systems are a popular choice for many growers. 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.

System Installation

Preparations before installing the concrete include careful grading of the subsoil and placement of the reinforcing wire. The plastic heating pipes can be secured to the reinforcing wire. Commonly, nominal ¾ inch heating pipes are used, spaced at approximately 12 inches between the pipes. It is best to elevate the reinforcing wire only slightly above the subsoil before installing the concrete. This will increase the strength of the floor and it ensures that the heating pipes end up embedded in the bottom half of the concrete floor.

Usually, the water temperature in the heating loops is maintained around 90-110°F. If the pipe material allows, higher water temperatures can be used, but the spacing between the pipes should be reduced to ensure uniform floor heating. Common materials for the heating pipes are polypropylene or cross-linked polyethylene. Using the 90-110°F water temperature, the maximum length of one pipe loop is 400 ft, while the water flow should be maintained at approximately 2.75 gpm. This requirement is necessary to minimize the temperature drop between the start and the end of the loop. This temperature drop should be not more than approximately 5°F. In addition, the limited length of each pipe loop reduces the total friction losses and ensures adequate water flow. A reverse return header system makes sure that water through each heating loop travels the same distance to and from the boiler, equalizing friction losses and water flows. Heating loop pipe connections should only be installed above ground and any kinks in the heating pipes should be avoided. During the concrete pour, the heating pipes should be pressurized with water, so that any accidental leak during the pour can be quickly discovered and fixed before the concrete hardens. If an ebb and flood irrigation system is installed in combination with a floor heating system, care should be taken so that the heating pipes are not located where holes will be drilled through the concrete floor into the irrigation pipe system underneath.

Control System

Usually, the air temperature in the greenhouse is controlled with an aspirated thermostat. For example, the thermostat controls the position of a mixing valve to allow more or less warm water to be pumped through the heating loops. A similar approach can be used for a floor heating system. A mixing valve is used to maintain the floor heating loop at a fixed temperature, while

Photo 1. The (black) heating pipe is secured onto the reinforcing wire just prior to pouring the concrete. The pipes are spaced 12 inches on center.

Photo 2. The concrete floor is partially poured. The heating pipes are still visible on the left side of this picture. The floor is 4 inches thick. A special power screed finishes the floor at the correct elevation.

a temperature sensor located either embedded in the floor, or in the root medium of a plant growing on the floor tracks the resulting root zone temperature. In both approaches, it is important to get a representative temperature measurement of either the floor or the root environment. Based on experience, a grower will learn at what floor temperature a particular crop will perform best, and can adjust the position of the mixing valve. Therefore, especially without experience with a floor heating system, it is important to keep adequate records of floor, root, and canopy temperatures, so that set points can be altered based on an evaluation of all these parameters as well as crop responses. As mentioned before, the response time of a floor heating system is slow (in the order of hours). Therefore, to receive the maximum benefits, a control system should be designed to anticipate the changes in heat requirement throughout the day. For example, the floor heating system should be turned on several hours before the outside temperature drop at the end of the day starts influencing the greenhouse temperature. More sophisticated control systems can take changes in the local weather into account and thereby optimize the use of the floor heating system.

Research

At Rutgers University, several floor heating systems have been installed over the years, including a recent installation that combined floor heating with an ebb and flood floor irrigation system. Temperature sensors inside and at several depths underneath the concrete floor are monitoring temperature gradients. Temperature sensors and flow meters in the supply and return pipes to and from the floor heating loops are used to carefully monitor the amount of heat supplied to the floor. Two independent floor sections can be controlled at different set points and crop responses will be evaluated in order to determine the optimum control strategy. Results of these studies will be available after the next heating season.

Summary

Floor heating systems have many advantages, and in general growers are reporting they are well worth the added installation expense. Most significantly, the greenhouse aerial temperature can be lowered while the floor heating system provides warmer temperatures to the root environment. This practice allows for very uniform temperatures to be maintained in the microclimate surrounding the plants. The result is improved uniformity of plant growth and development. In addition, significant energy savings can be accomplished. Finally, the heat stored in a floor heating system can be used to heat the greenhouse during periods of power outage or boiler failure.

Photo 3. The plastic heating pipes are emerging from the concrete floor and are attached to the supply and return lines, which are connected to the hot-water boiler. Two valves are installed in each heating loop in case the loop needs to be isolated for maintenance or repairs.

Photo 4. A floor heating system installation using a porous concrete floor (visible at the bottom of this picture).

Light Conversions for Plant Growth

By A.J. Both

Introduction

Plants use (sun)light as an energy source to convert carbon dioxide (CO_2) and water (H_2O) into sugars ($C_6H_{12}O_6$) and oxygen (O_2), as can be represented by the flowing equation: $6CO_2 + 6H_2O$ + (sun)light —> $C_6H_{12}O_6 + 6O_2$. This process is called photosynthesis. The gaseous carbon dioxide is available in our atmosphere (at a concentration of approximately 0.04%), and the oxygen produced in this reaction is released into the atmosphere allowing many organisms, including humans, to survive and thrive on our planet (the oxygen concentration in our atmosphere is approximately 21%). The sugars produced in this reaction are used by plants for different chemical reactions, allowing them to grow and develop. The required water is taken up by the plant roots and transported to the leaves, where photosynthesis takes place. Since (sun)light is the major energy source for photosynthesis, it is important to measure the amount of light accurately. Generally, the more light is available, the higher the rate of photosynthesis, although this is not a linear relationship: as the light intensity increases, the increase in photosynthesis slowly diminishes until it reaches a maximum and steady rate (Figure 1).

Radiation Spectrum
- Visible Light

What we define as light is part of the radiation spectrum, which includes for example cosmic radiation, X-rays, ultraviolet, infrared, microwave, radar, and radio and TV. Different forms of radiation are usually distinguished by their wavelength, or range of wavelengths. Because the

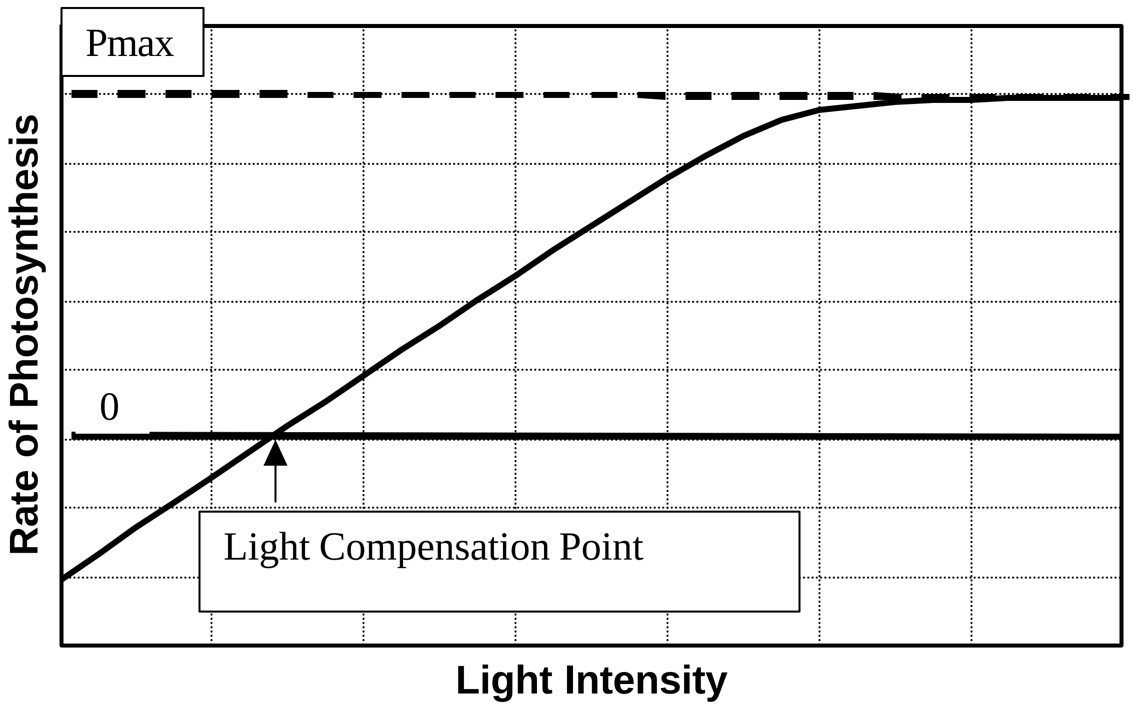


Figure 1. The rate of photosynthesis increases linearly with an increase in light intensity, but at high light intensities this increase diminishes and the rate of photosynthesis reaches a maximum (P_{max}). At very low light intensities, the net rate of photosynthesis is negative because plant respiration (maintenance) consumes more sugars than photosynthesis can produce.

wavelength of the radiation we are interested in is so small, we use the "nanometer" as measurement unit. One nanometer (nm) is one billionth the length of a meter (10^{-9}), and one meter is approximately 3.3 feet. Visible light (the light we can see with our eyes) ranges from approximately 380 nm (violet) to 770 nm (red). In between, we see all the colors of the rainbow: ROYGBIV (red, orange, yellow, green, blue, indigo, and violet). Visible light can be measured with a so-called foot-candle (ft-cd) or lux meter. The foot-candle unit is referenced to the light intensity of a candle at a distance of one foot. The unit of lux represents the light intensity of a candle at a distance of one meter (3.3 feet). Note that one ft-cd equals 10.76 lux, and 1 klux equals 1,000 lux.

- PAR

Plants, however, use a slightly different part of the radiation spectrum for photosynthesis. This part ranges from 400 to 700 nm and is called Photosynthetically Active Radiation (PAR). Because of this (small) difference between visible light and PAR, we need to be careful to measure light with the appropriate sensor. Thus, we can use a foot-candle meter when we are interested in visible light, but we should use a quantum sensor to measure PAR. A quantum sensor measures the photons (light "particles") in the 400-700 nm waveband and, thus, provides an accurate indication of the potential for photosynthesis.

- Short and Long Wave Radiation

Some of the instruments used to measure radiation intensity measure the so-called short wave radiation. These instruments cover the waveband between 280 and 2,800 nm. The units for short wave radiation are energy units: W m^{-2}. Instruments measuring short wave radiation are called pyranometers. Short wave radiation is also called solar radiation because it represents the radiation plants receive from the sun. In contrast, long wave radiation is radiation received by plants from objects with a (much) lower surface temperature (e.g., all surfaces on Earth that surround the plant). Long wave radiation approximately covers the waveband between 2,800 and 100,000 nm.

Common Conversions
It is possible to convert units of visible light into units of PAR or short wave radiation, and vise versa, but the conversion depends on the light source (e.g., sunlight, or electric light). When a mixture of light sources are used, e.g., when supplemental lighting is operated during sunlight hours, this conversion becomes much more difficult. Therefore, it is recommended to use the appropriate sensor for the particular waveband (visible light or PAR) you are interested in. In doing so, conversion between the different units is not necessary and potential errors will be prevented. Nevertheless, many growers are still using foot-candle (and lux) meters to measure light intensities. Therefore, Table 1 shows conversion factors for several common light sources.

Table 1. Converting light units for several different light sources.

Light Source	PAR 400-700 nm µmol m^{-2} s^{-1}	Visible 380-770 nm ft-cd	Visible 380-770 nm lux	Solar Radiation 280-2,800 nm W m^{-2}
Sunlight	100	520	5,600	48.3
High Pressure Sodium (HPS)	100	790	8,500	44.4
Metal Halide (MH)	100	660	7,100	48.3
Incandescent (INC)	100	465	5,000	48.3
Fluorescent, Cool White (FCW)	100	688	7,400	44.4

Note: For example, for sunlight: 100 µmol m^{-2} s^{-1} (PAR) = 520 ft-cd (visible radiation) = 5,600 lux (visible radiation) = 48.3 W m^{-2} (solar radiation). For simplicity, this last conversion assumes that 45% of the solar radiation occurs in the PAR waveband.

Other Conversions
In addition to the units described above, several (older) light units are still being used. Table 2 lists several of these units and shows their appropriate conversion factors.

Converting Light Integrals
Besides instantaneous light measurements, growers can use integrated (i.e., daily accumulated) light measurements. Table 3 list conversion factors for several common light sources that are useful when evaluating integrated (accumulated) light levels.

Table 2. Additional useful light conversion factors.

Short wave radiation (280-2,800 nm)
1 Langley (Ly) = 1 cal cm^{-2}
1 cal cm^{-2} = 4.184 J cm^{-2}
1 MJ m^{-2} = 2.08 mol m^{-2} (PAR, from Ting and Giacomelli, 1987)
100 Ly d^{-1} = 8.70 mol m^{-2} d^{-1} (PAR)
PAR (400-700 nm)
1 Einstein m^{-2} = 1 mol m^{-2}
1 µEinstein m^{-2} s^{-1} = 1 µmol m^{-2} s^{-1}
Visible radiation (380-770 nm)
1 ft-cd = 10.76 lux

Table 3. Conversions of integrated (accumulated) light measurements.

Light Source	Conversion Factors (short wave —> PAR —> visible radiation)
Sunlight	1 MJ m^{-2} = 2.08 mol m^{-2} = 32.4 klux h = 3,004 ft-cd h
High Pressure Sodium (HPS)	1 MJ m^{-2} = 2.25 mol m^{-2} = 53.1 klux h = 4,937 ft-cd h
Metal Halide (MH)	1 MJ m^{-2} = 2.08 mol m^{-2} = 41.0 klux h = 3,813 ft-cd h
Incandescent (INC)	1 MJ m^{-2} = 2.25 mol m^{-2} = 31.3 klux h = 2,906 ft-cd h
Fluorescent, Cool White (FCW)	1 MJ m^{-2} = 2.08 mol m^{-2} = 42.8 klux h = 3,975 ft-cd h

Note: It is assumed that 45% of the solar radiation occurs in the PAR waveband.

References

Both, A.J. 1994. HID lighting in horticulture: a short review. Natural Resource, Agriculture, and Engineering Service (NRAES) Publication No. 72. Ithaca, NY, USA. pp. 208-222.

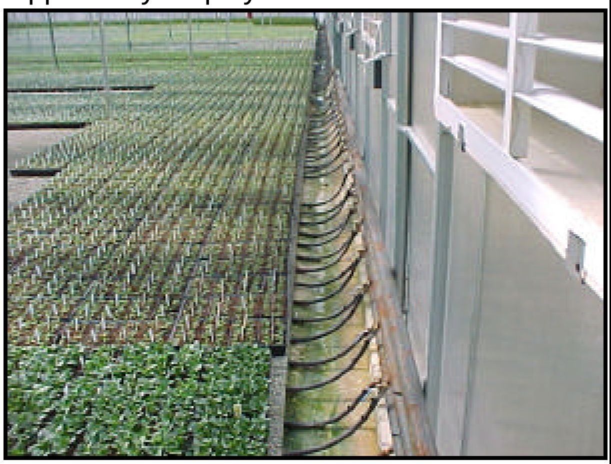
IESNA. 2000. *Lighting Handbook, 9th Edition*. Illuminating Engineering Society of North Amercia. New York, NY, USA. 989 pp.

Ting, K.C. and G.A. Giacomelli. 1987. Availability of solar photosynthetically active radiation. Transactions of the ASAE 30(5):1453-1457.

Spaargaren, J.J. 2001. *Supplemental Lighting for Greenhouse Crops*. P.L. Light Systems, Inc., Beamsville, Ontario, Canada. 178 pp.

Thimijan, R.W. and R.D. Heins. 1983. Photometric, radiometric, and quantum light units of measure: a review of procedures for interconversion. HortScience 18(6):818-822.

RUTGERS COOPERATIVE EXTENSION
COOK COLLEGE
RUTGERS, THE STATE UNIVERSITY
NEW BRUNSWICK, NJ 08901



HORTICULTURAL ENGINEERING

Dr. A.J. Both
Assistant Extension Specialist
Director of CCEA
Bioresource Engineering
Rutgers, The State University of NJ
George H. Cook College
20 Ag Extension Way
New Brunswick, NJ 08901-8500
Your comments, questions, and suggestions are always welcomed.
Phone (732) 932-9534
email: both@aesop.rutgers.edu
Web: http://aesop.rutgers.edu/~horteng

Horticultural Engineering Web Site
This issue of Horticultural Engineering, like previous ones, will soon be available on the internet at:

http://aesop.rutgers.edu/~horteng

If you provide us with you e-mail address, we will send an e-mail announcing each Horticultural Engineering Newsletter as it is posted on our web site. Thanks to those of you who have elected to receive this newsletter via the Web. We appreciate your help in reducing the duplicating, postage, and handling costs.

Upcoming meetings/shows in 2002

Ohio Short Course
Columbus, OH
July 13-17, 2002
http://www.ofa.org

26th International Horticultural Congress
Toronto, Canada
August 11-17, 2002
http://www.ihc2002.org/ihc2002/cgi.html

New England Greenhouse Conference
Worcester, MA
October 21-23, 2002
http://www.uvm.edu/~pass/greenhouse/negc.html

HortiFair (NTV)
Amsterdam, the Netherlands
November 6-9, 2002
http://www.hortifair.nl

Floriade (once every 10 years)
Near Amsterdam, the Netherlands
April 6-October 20, 2002
http://www.floriade.nl