By Stephanie E. Burnett, Roberto G. Lopez, and Neil S. Mattson

Evaluate your greenhouse to save energy

Now is a good time to evaluate your greenhouse for possible changes or improvements.

Heating costs represent the largest energy input for most greenhouse operations. For this reason, it's vital to heat efficiently. As you prepare for another heating season it's a good time to evaluate your greenhouse and consider changes or improvements you might make for the upcoming winter.

While there are many ways to approach fuel conservation, look at evaluating your overall structure to save energy. In existing structures, proper furnace maintenance, changing the placement of temperature sensors and minimizing temperature gradients using horizontal airflow fans can help conserve fuel. If you are ready to reglaze your greenhouse, glazings that have multiple layers retain more heat, but reduce light transmission. Finally, if you are expanding and plan to build a new greenhouse, you have the opportunity to build the best possible structure for conserving fuel.

Environmental sensors

Proper placement of environmental sensors near the plants can help you effectively monitor, record and manipulate the average daily temperature and light intensity. The rate of plant development (i.e., time to flower or to unfold leaves) is a function of the average daily temperature. In addition, temperature and light can also influence plant quality parameters such as flower number and size, branching and plant mass.

Therefore, it is imperative that sensors are routinely inspected to make sure they are

Heat loss through the roof of high profile greenhouses can be reduced by installing energy curtains.

Horizontal airflow fans circulate air to create uniform temperatures throughout a greenhouse.

clean, level and functioning properly. Air temperature sensors should be shielded and aspirated with a small fan so that they are not influenced by solar radiation.

As crops increase in height, adjust the sensors accordingly so that they are not shaded or covered by foliage. Likewise, a light or temperature sensor that is 3 feet above the plant canopy is not going to provide a representative measurement for the crop. These simple steps will ensure that the heat, ventilated air, shading and light levels in the greenhouse are based on the plants' needs.

Temperature and light variations can occur horizontally and vertically within a greenhouse environment due to internal and external factors. These variations can lead to delayed or accelerated rooting, growth and flowering depending on where in the country a crop is grown. This can pose challenges for most greenhouse crops, which are grown on floors, benches and in overhead hanging baskets. For example, growers often notice a delay in flowering when plants are grown next to non-insulated side walls where the temperature can be several degrees cooler than the rest of the greenhouse.

Horizontal airflow fans

Sustainable crop scheduling that reduces shrinkage and energy consumption can be aided by using horizontal airflow fans that circulate air to create uniform temperatures throughout a greenhouse.

Since HAF fans run continuously, it is important to install the most energy-efficient models you can afford. When configuring HAF fans, 2 cubic feet per minute of fan capacity is required for each square foot of greenhouse space. With this in mind, HAF fans should be placed in the center of the air mass that is being circulated. The location and effectiveness of the fans depends on the structure, but they should be 10-15 feet from one end wall and 30-50 feet apart.

Preliminary research at Michigan State University indicates that the use of HAF fans is most important at night. Research shows that in a glass glazed greenhouse with HAF fans the night time air temperature near the floor is similar to that at bench level and only 1.9°F lower than at 9.5 feet above the ground (where hanging baskets would be located). During the day, temperatures on the ground were 1.2°F cooler than at bench level and 3°F cooler than overhead even with the use of HAF fans. Temperature and light variations within a greenhouse vary depending on the structure, glazing material and age, overhead obstructions, energy curtains, supplemental lighting, humidity and HAF characteristics.

Lock in heat

The glazing material covering a greenhouse can greatly influence both heat retention and light transmission (Table 1). Double-layer polyethylene film or twin-walled rigid plastic panels (polycarbonate and acrylic) can save about 40 percent on heating bills because of their rate of heat loss (U-value) is lower than single layer glazing materials. Newer triple- or quadruple-walled polycarbonate sheets will retain even more heat, but reduce light transmission levels. While polyethylene films are the least expensive, they need to be replaced every few years resulting in substantial labor and waste material. Ultimately you will need to decide on the glazing material that is most sustainable for your operation given your own greenhouse growing situation.

To ensure highest heat retention from a glazing material patch holes before they become too large. Avoid gaps around vents, outside air intakes and where the glazing is secured to the ground. Maximize light penetration into the greenhouse by keeping the glazing material clean. Remove dirt and whitewash off the exterior and control algae inside.

There are several options available for polyethylene films which may enhance their utility. Ultraviolet light-absorbing materials reduce degradation from ultra violet light and extend product life. Infrared reflective films reduce heat loss during the night by allowing less radiated heat to leave the greenhouse. Anti-drip materials reduce condensation that can lower light penetration into the greenhouse by as much as 15 percent. Talk to greenhouse product suppliers to see if the increased costs of these products will improve your bottom line.

Table 1. Properties of typical glazing materials.*

Material	Life expectancy (years)	Light transmission (photosynthetically active radiation, %)	Heat transfer coefficient (U-value, Btu per hour per sq. ft. per °F)
Glass	30+	90	1.1
Polyethylene (single layer)	3-4	88	1.1
Polyethylene (double layer)	3-4	77	0.7
Polycarbonate (twin wall)	10	75	0.6
Acrylic (twin wall)	20	74	0.6

*Modified from Greenhouse Glazings, A.J. Both, Rutgers University, 2008.

A light or temperature sensor that is placed too high above the crop canopy is not going to provide a representative measurement for the crop.

Payback time

During the past few years, many more growers have installed thermal curtains in their operations to reduce night time heat loss. Thermal curtains save energy by adding an insulation layer, reducing the volume of air that needs to be heated, and reflecting radiated heat back into the greenhouse. Virtual Grower software, which is available for free from USDA (http://www.ars.usda.gov/services/software/download.htm?softwareid=108), to determine the payback time for thermal curtains in your operation. The software allows users to design a virtual greenhouse and then calculate the cost to heat a structure given a specific geographic location and greenhouse specific parameters.

Virtual Grower can be used to calculate the payback time to install a thermal curtain in Albany, N.Y., compared to Raleigh, N.C. In Albany, if the cost of the curtain is $1 per square foot and fuel oil is $4 a gallon, payback time is less than a year. If the curtain cost in Raleigh is $2 per square foot and fuel oil is $2 a gallon, the payback time would be more than four years (Table 2).

The payback time for each operation depends on location, fuel source, efficiency of the heating system, the insulation properties of the greenhouse and the months it will be heated. The above scenario assumes heating is needed during the two coldest winter months, January and February. If heating only occurred from March through May, the payback time under these conditions would take

Table 2. The payback time (in years) of installing a thermal curtain*

Albany, N.Y.			
Cost of No. 2 fuel oil	Cost of thermal curtain		
	$1 per sq. ft.	$1.50 per sq. ft.	$2 per sq. ft.
$2 per gallon	1.2 years	1.8 years	2.4 years
$3 per gallon	0.8 years	1.2 years	1.6 years
$4 per gallon	0.6 years	0.9 years	1.2 years
Raleigh, N.C.			
Cost of No. 2 fuel oil	Cost of thermal curtain		
	$1 per sq. ft.	$1.50 per sq. ft.	$2 per sq. ft.
$2 per gallon	2.2 years	3.3 years	4.4 years
$3 per gallon	1.5 years	2.2 years	3 years
$4 per gallon	1.1 years	1.7 years	2.2 years

*Scenario assumes a 24,000 square foot, gutter-connected greenhouse with double polyethylene film covering and concrete curtain walls heated from Jan. 1 to May 31 with forced air unit heaters at a 68°F day temperature and 60°F night temperature. The thermal curtain is an aluminum fabric with a U-value of 0.40.

two to three times longer.

A federal grant program offers 25 percent matching funds to growing operations that install energy efficient devices such as thermal curtains. More information is available at Cornell's commercial greenhouse Web site http://www.greenhouse.cornell.edu/structures/energy_grants.htm.

Recycling greenhouse films

Because polyethylene films used to cover greenhouses must be replaced every few years, a large volume of plastic is collected. In the past growers have discarded this plastic resulting in a significant amount of waste and costly landfill tipping fees. For example, a 6 mil polyethylene film that measures 40- by 100-feet produces about 115 pounds of waste plastic.

These films have recyclable value, particularly if they are kept fairly clean and baled so they are less bulky and can be conveniently transported. Contact your local extension office to see if a plastic film recycling program is available in your state (New Jersey and Michigan currently have recycle programs). Extension personnel may also be able to assist you in locating a baler and finding a local source to accept the discarded plastic.

Greenhouses structures

If you are planning to build a new greenhouse, you have the opportunity to purchase the best possible structure for efficient fuel use. The selection of greenhouse design may greatly impact future heating costs. One way to improve fuel efficiency is to build a multi-span structure that meets your growing needs rather than building several single span greenhouses. The same growing area in a single span house will have many more walls exposed to cold, outside air than one large multi-span house.

For example, if you have 18,000 square feet of growing area, this can be split into three single span houses that are 30- by 200-foot or one 90- by 200-foot multi-span house. A single-span house would have 1,380 feet of walls exposed to outside air, while the multi-span house would have only 580 feet of walls exposed to outside air. Walls exposed to outdoor winter temperatures lose heat very quickly. Minimizing the area of outdoor walls reduces heat loss.

When planning greenhouse design, it's also important to evaluate how much space you will use in a new structure each winter. If you only use half of the growing space during the peak winter heating season, it makes sense to have two multi-span houses. For cooler temperature crops, consider separating a greenhouse into sections that may be heated at different temperatures. While one large multi-span is less expensive to heat than several single-span greenhouses, this heat savings is minimal compared to the savings that result from only heating space where plants are grown.

Reducing the volume of head space in the roof will also conserve fuel. High profile greenhouses have a much greater volume of air in the roof compared to low profile or Venlo style greenhouses. For this reason, Venlo houses are ideal, particularly in cold climates. One drawback to growing in a Venlo house, though, is that high profile greenhouses tend to have a more uniform growing environment. Heat loss through the roof can be further reduced with the installation of energy curtains.

Heating pipe placement can impact the amount of heat distributed in a greenhouse. Pipe placement along the perimeter curtain walls or overhead takes heat away from the plants. The heat must then be forced towards the plants using HAF fans. A considerable amount of heat is lost in this process.

In the case of overhead pipes, the natural buoyancy of hot air causes it to rise toward the greenhouse roof. In-ground heating or under bench heating are more efficient systems. The heat rises from the floor or beneath the benches to the growing space around the plants and less heat is lost through the roof or side walls. With in-ground heating, you may save more fuel by insulating the greenhouse against heat loss to the ground. Under bench heat retention may be improved by attaching skirts of insulating materials to the benches.

Stephanie E. Burnett is assistant professor, University of Maine, (207) 581-2937; sburnett@maine.edu, Roberto G. Lopez is assistant professor and floriculture extension specialist, Purdue University, (765) 496-3425; rglopez@purdue.edu and Neil S. Mattson is assistant professor and floriculture extension specialist, Cornell University, (607) 255-0621; nsm47@cornell.edu. The authors are members of the Floriculture Sustainability Research Coalition.