How Can You Lower
Your Greenhouse Energy Bill?

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The rapidly rising energy prices over the last year have caused a lot of concern among greenhouse growers. Many growers are wondering how they can survive the upcoming heating season, particularly those that grow crops during the coldest months of the year. Greenhouses are typically designed for maximum light transmission. But that often reduces their insulating properties, making them much more expensive to heat compared to well-insulated homes and office buildings. So is there anything you can do to reduce your heating fuel bills? Do you need a new heating system? Can we use any of the lessons learned from the energy crisis in the early '70s? This article attempts to review the issues and provide some guidance.

Before you do anything else...

One of the lessons learned over the years is that it is generally less expensive to consider energy conservation measures first before implementing significant modifications to your heating system. Energy conservation measures range from simple to more complex and include sealing unintended structural leaks and cracks, adding sufficient insulation to structural elements that do not need to transmit light, insulating transportation pipes, adding a properly designed energy curtain, installing high(er) efficiency burner systems, and even lowering the nighttime temperature set point. While the latter approach may reduce energy costs, its impact on plant growth and development should be carefully considered. If in doubt, consult with a crop specialist or try it out on a small number of plants.

Calculating the required heating capacity

The first step in evaluating a heating system is determining the heating capacity needed to heat the particular greenhouse during the coldest conditions expected for the particular site. As long as we match the heating capacity with the heat loss, we can maintain the desired set point temperature. The overall heat loss can be determined by summing the structural heat loss (heat exiting through the structure), the infiltration heat loss (heat exiting through unintended air exchange with the outside environment), and the perimeter heat loss (heat exiting along the lower perimeter wall).

Structural heat loss

The structural heat loss can be calculated for each section of the greenhouse structure (roof, sidewalls, end walls) by multiplying the area of a section with the corresponding heat transfer coefficient and the temperature difference between the inside and outside environment. The area of greenhouse sections can be determined by measurement or by reviewing the construction drawings. The heat transfer coefficient (U-value) is a material specific value. Some values are shown in Table 1. The temperature difference needed is the difference between the inside nighttime temperature set point and the outside design temperature. The outside design temperature is site specific and its value can be found in reference texts (e.g., ASHRAE Handbook of Fundamentals). The value of the design temperature is based on historic data collected for a specific site and it indicates a temperature that is exceeded for only a limited number of hours during the coldest months of the year. If we used the very lowest temperature ever recorded for a site as our design temperature, our heating system would need a very large capacity that would likely be fully utilized for only a very limited number of hours. It is common to use the 99% design temperature for heat loss calculations. This design temperature is thus exceeded only 1% of the time (i.e., the outside temperature is colder than the design temperature for only 1% of the time). For that 1% of the time, a grower can 1) bring in additional temporary heating capacity, or 2) allow for the inside set point temperature to drop. Most growers opt for the drop in set point temperature provided the drop is not too large. Some 99% design temperatures for locations along the northern and central part of the East Coast are shown in Table 2. For other locations the 99% design temperature can be estimated from Figure 1. Once the heat loss for each greenhouse structural section is determined, the overall structural heat loss can be calculated by adding the heat loss values for the various sections.

Infiltration heat loss

The infiltration heat loss can be calculated by multiplying a constant (with a value of 0.02) with the greenhouse volume, an infiltration coefficient, and the temperature difference between the inside nighttime temperature set point and the outside design temperature. The only unknown in this calculation, assuming the greenhouse volume can be determined from measurements or from reviewing the construction drawings, is the infiltration coefficient for which values are shown in Table 3. The infiltration coefficient represents the number of air exchanges per hour.

Perimeter heat loss

The perimeter heat loss can be calculated by multiplying the length of the greenhouse perimeter with a perimeter heat loss factor and the temperature difference between the inside nighttime temperature set point and the outside design temperature. The value of the perimeter heat loss factor depends on whether the greenhouse perimeter is insulated or not (resulting in a value of 0.4 or 0.8 Btu/hr per linear foot, respectively).

In some cases, we need to make final adjustments to our heat loss calculations. In fact, we multiply the overall heat loss by a factor larger than one to ensure that the resulting heating capacity is large enough to accommodate for the additional heat loss under specific conditions. These conditions include: 1. Large differences between the inside set point and outside design temperatures (larger than 70°F), and 2. High average wind speeds (higher than 15 mph). How to determine the multiplication factors for such conditions is described in more detail in the NRAES publications listed at the end of this article.

Heating systems

After determining the required heating capacity for a greenhouse, we can now consider the different heating options.

Each heating fuel has a different energy content as shown in Table 4. In addition to the energy content, the typical conversion efficiency is an important number when determining how much useful heat will be generated by a particular heating system. The inefficiency in fuel conversion often results from incomplete combustion and unused heat contained in the exhaust gasses. By incorporating unit fuel prices in the data presented in Table 4, it is now possible to compare the economics of using different heating fuels. For example, Table 4 shows a gallon of No. 2 fuel oil will generate 105,000 Btu of heat. And 31 kWh of electricity can be converted into approximately the same amount of heat (assuming 100% conversion efficiency). Assuming an electricity price of $0.15 per kWh, the heating oil price would have to rise to $4.65 per gallon before heating with oil becomes equally expensive as heating with electricity (without taking into account the cost of converting heating systems). Note that the rapidly increasing crude oil prices have significantly decreased the difference in fuel prices between electricity and fuel oil, and if this increase continues the idea of heating a greenhouse with electricity may no longer be improbable.

Greenhouses can be heated with a variety of heating systems that deliver heat through steam, hot air, hot water, or radiation. While once common in larger greenhouse operations, steam heating systems are rarely installed today. They are however very efficient in transporting energy over larger distances. Hot air heating systems (furnaces and unit heaters) are very common and are relatively inexpensive and easy to install. They typically produce jets of warm air that may require additional systems (e.g., the poly jet) to ensure proper mixing with the greenhouse air. Hot water systems are more expensive to install and require a carefully designed distribution system. They provide uniformly distributed heat that can be released in specific locations (e.g., floor and bench heating, perimeter and overhead heating). Radiant (infrared) heating systems can provide instantaneous heating of all surfaces in direct view of the radiator. But surfaces shielded from the radiator by for example the upper leaves of the plant canopy will heat up much slower (by re-radiation and convection). Thus, radiant heating can result in uneven canopy heating.

Alternative energy sources

The high oil and gas prices have significant increased the interest in alternative energy sources. These include solar, wind, hydro, geothermal, biomass, as well as energy from waste (e.g., used cooking oil, cooling water from industrial processes, landfill gas, gas from digesters). All of these alternative energy sources have been used for greenhouse applications, with biomass (particularly wood) the largest energy source for heating. System economics often depend on the greenhouse design, operation and location as well as the availability of the energy source. A variety of different systems is available and new technology is being developed constantly. Early adopters have in some cases been able to secure substantial grants, loans, or rebates from federal and state agencies that promote alternative energy technologies. While the level of some of these financial incentives has been reduced over the last few years, they are still worth considering for many greenhouse applications. Growers are encouraged to review these incentive programs that are often advertised through dedicated internet sites.

In addition to alternative energy sources, technology developments can be applied to further increase system efficiencies. Heat pumps (reversible refrigeration units that can provide either heating or cooling) combined with warm and cold water storage tanks can efficiently provide a baseline heating and cooling capacity. Additional capacity can then be provided by conventional heating and cooling systems. Combined heat and power systems convert their fuel source into electricity while the waste heat (largely generated through the combustion process) can be captured and used for greenhouse heating. Some of these systems can also recover the carbon dioxide from the exhaust gasses and use it to enrich the plant growing environment.

Reducing energy costs

After implementing all applicable energy conservation measures, there are various additional options for lowering the greenhouse fuel consumption. The technical options include automated (computer) controls, direct fired unit heaters, condensing boilers, flame retention burners for oil heaters, variable speed motors and pumps, twin (triple) walled covering materials, and performing timely maintenance. Other options include the installation of a wind barrier, reduction of unintended infiltration, installation of perimeter insulation, switching to a different fuel, and perhaps considering dual fuel systems (allowing for fuel selection based on price and availability). Many energy conversion systems (including pumps and motors) operate over a range of efficiencies based on their output and/or their load. Obviously, the higher the system efficiency, the cheaper it is to operate. It would be helpful to monitor the energy consumption of individual greenhouse components so that the efficiency of the operating strategy can be maximized. Special meters may need to be installed to record energy consumption and to help review changes in operating strategies.

Safety

And last but not least, a word of caution. In order to keep energy systems safe, reliable, and efficient, always make sure there is sufficient updraft in the exhaust stacks, provide sufficient make-up air in spaces with operating heating equipment that needs oxygen for the combustion process, locate exhaust stacks at least two feet above the highest point of the structure, clean heat exchangers regularly, and always follow a regular maintenance schedule.

Additional sources of information

The following books published by NRAES (http://www.nraes.org) provide useful information: *'Energy Conservation for Commercial Greenhouses'* and *'Greenhouse Engineering'*. Additional information can be found at: http://www.hrt.msu.edu/Energy/Notebook.htm and http://www.ofa.org/energy.aspx.

Table 1. Heat transfer coefficients (U-values) for various greenhouse covering and construction materials.

Material	U-value (Btu/hr per ft^2 per °F)
Single (double) layer glass	1.1 (0.7)
Single (double) layer plastic film	1.1 (0.7)
Double layer plus energy curtain	0.3 - 0.5
Double layer acrylic panel	0.6
Double layer polycarbonate panel	0.6
1/2" Plywood	0.7
8" Concrete block	0.5
2" Polystyrene (R = 10)	0.1

Table 2. Ninety-nine percent outdoor design temperatures for various locations along the East Coast.

Location	99% design temperature (°F)
Portland, ME	-6
Worcester, MA	0
New Haven, CT	3
New Brunswick, NJ	7
Washington, DC	14

Table 3. Infiltration coefficients (representing the number of unintended air exchanges per hour) for various greenhouse covering materials and ages.

Construction	Infiltration coefficient
New, covered with glass	0.75 - 1.5
New, covered with two layers of plastic film	0.5 - 1.0
Old, glass covered and good condition	1.0 - 2.0
Old, glass covered and poor condition	2.0 - 4.0

Table 4. Typical conversion efficiency and unit heat value for various heating fuels.

Fuel	Efficiency (%)	Unit heat value
Electricity	95 - 100	3,413 Btu/kWh
Natural gas*	80	1,000 Btu/ft^3
Propane	80	91,000 Btu/gal
No. 2 fuel oil	75	140,000 Btu/gal
No. 6 fuel oil	75	150,000 Btu/gal
Hard coal (anthracite)	65	13,000 Btu/lb
Soft coal (bituminous)	65	12,000 Btu/lb
Hard wood (dry)**	65	7,000 Btu/lb
Wood chips	60	3,800 Btu/lb

***100 ft^3 of natural gas equals 1 therm**

****For example: oak produces approximately 26,000,000 Btu/cord (8 by 4 by 4 feet)**

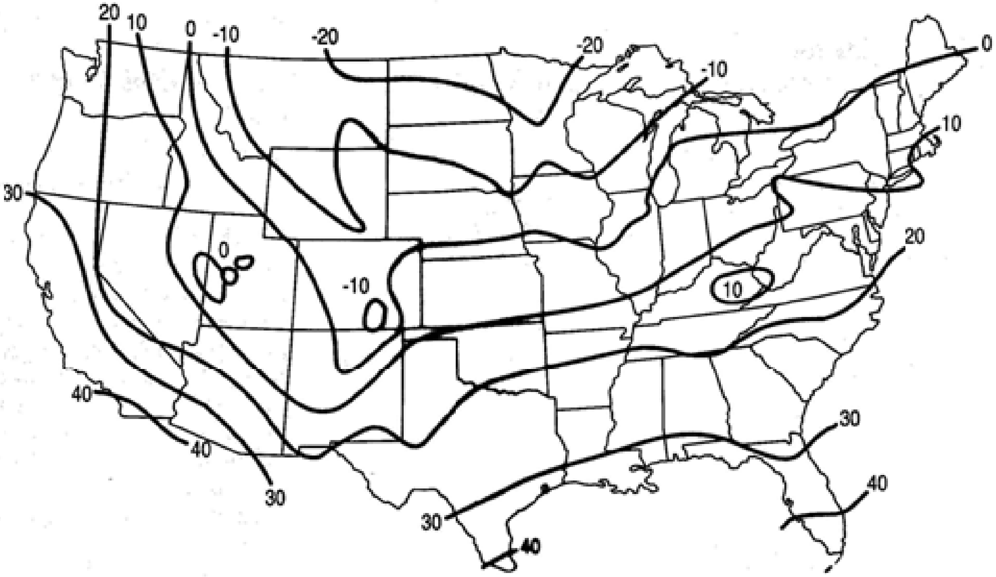

Figure 1. Contour lines showing the approximate location of selected values of the ninety-nine percent outdoor design temperatures (°F) for the continental US.

Photo 1. Unit heater at Lucas Greenhouses, Monroeville, NJ.

Photo 3. Wood boiler at Weaver's Farm Market, Pittsgrove, NJ.

Photo 2. Hot water boiler at Cromwell Growers, Cromwell, CT.

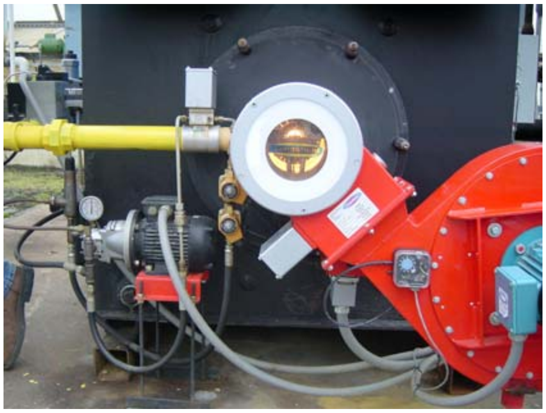

Photo 4. Dual fuel boiler at Kube Pak, Allentown, NJ.