Conserving Energy in Greenhouse Operations

INTRODUCTION

Greenhouse operations are a large and significant part of Connecticut agriculture. According to the USDA's 2012 Census of Agriculture, Connecticut ranks 46th among U.S. states for total value of agricultural products, and 17th among U.S. states for value of greenhouse, nursery, floriculture, and sod produced.[1] With the strong desire for season extension for locally grown products, ornamental crop production, seedling production, and year-round marketing, greenhouses fill an important role in the state's agriculture. If not designed and maintained properly, greenhouses can use a lot of energy; therefore, energy conservation can make a large contribution to an operation's profitability and to the overall health of the state.

Greenhouse energy use is primarily heat. However, there are other energy inputs which can have a significant effect including ventilation, pumping, and lighting. Greenhouses typically try to control the indoor air temperature to within a few degrees to optimize plant growth, requiring well-designed systems and accurate, functioning controls. The basic biological needs of plants are the starting point for energy use planning and optimization. Careful planning and detailed monitoring ensure heating systems, cooling equipment, and cultural practices work together to produce the best growing environment with minimal energy use. This publication examines patterns of energy use by greenhouse operations, ways these uses are interrelated, and ways they can be optimized for maximum efficiency.

ENERGY USE IN GREENHOUSE OPERATIONS

Greenhouse facilities intended for year-round plant production – either gutter connected or stand-alone – are generally energy intensive. The energy uses include heating in the winter, cooling in the summer and, in some facilities, sunlight supplements. Simpler stand-alone structures, generally referred to as *high tunnels*, can be an alternative to more sophisticated facilities for some crops. They provide protection from frost, wind, and rain; and can shade, when needed. They rarely have climate control, lighting, or active ventilation systems. High tunnels can be a useful tool for early and late season production of crops which would otherwise be produced outside of a greenhouse.

GREENHOUSE HEATING

The amount of energy required to heat greenhouses depends on the design of the structure and systems, local climate, temperature settings, controls, and growing strategies. There are a variety of techniques for reducing the amount of energy used to heat greenhouses, which fall into several broad categories:

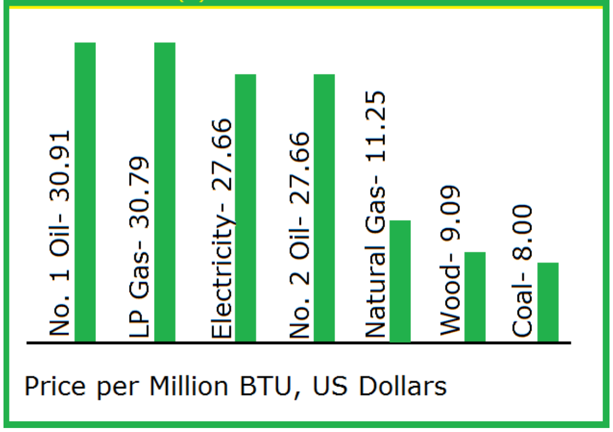
- Fuel supply
- Heating plant
- Heat distribution
- Greenhouse structure and components
- Environmental Controls
- Cultural and operational methods

FUEL SUPPLY

The most common sources of greenhouse heat energy are Liquid Propane Gas (LPG), Natural Gas, and No. 2 fuel oil. Generally, natural gas is the cheapest of these three on a per energy unit basis (Table 1). Determining the lowest cost fuel can be difficult because of the various units of measure and independently fluctuating cost for each fuel. The British Thermal Unit (BTU) is the American standard measure of energy content of a fuel and can be used to compare fuel costs. The efficiency of heating equipment depends, to some extent, on the type of fuel used. Natural gas and propane boilers are typically more efficient than other types of heaters. The efficiency of the heater also has an impact on the final cost per useable unit of energy. Larger heating systems can often use more than one type of fuel, and can switch depending on which has the lowest current cost. In some cases, it may be worthwhile to retrofit existing equipment for dual fuel use to improve efficiency and reduce costs.

Table 1- 2012 Fuel Price Comparison

Source: US-EIA (2)



HEATING PLANT

Greenhouse heaters can either warm the air directly, or generate steam/hot water that is distributed to the greenhouse. Steam/hot water generators are usually located in buildings adjacent to the greenhouse. Hot air heaters--such as unit heaters--are typically located within the greenhouse. All combustion devices should be properly vented, particularly those located within the greenhouse. Inadequate or malfunctioning ventilation and exhaust systems create fire and health hazards.

Hot air heaters tend to change the greenhouse temperature quickly and may require additional air circulation to distribute warm air evenly throughout the greenhouse. Hot water or steam heaters tend to warm the greenhouse air more slowly and evenly, and may also be used in bottom heating systems, which can lead to significant energy savings.

Manufacturers are required to report the efficiency of their equipment using standard testing procedures. This information allows the grower to determine how much of the energy going into the heating equipment actually comes out as productive heat. Some energy will always be lost in the exhaust of combustion heaters, but many new natural gas and propane heaters are over 90% efficient. Oil heaters tend to be less efficient, but the cost per unit of input energy may be less than for propane or natural gas, offsetting the difference in efficiency. Electric heat is efficient and sometimes appropriate on a small scale, but the cost per unit of energy is typically much higher than other sources. Electric heating is often limited to germination and propagation applications.

Heating equipment should be serviced regularly to ensure it is operating at peak efficiency. Improperly adjusted or poorly vented heating systems can consume more energy than necessary and potentially produce an unsafe greenhouse environment.

HEAT DISTRIBUTION

Maintaining a uniform temperature at the crop level is important for energy efficiency and uniform crop growth. Bottom heating, below the crop either in the floor or below benches, helps to warm the soil and improve crop growth. Bottom heat can often allow for cooler air temperatures without sacrificing crop growth. The low temperature requirements of bottom heat (typically 120°F) makes waste heat generated by industrial operations an option for greenhouse heating, which can help create sustainability synergies between agriculture and other local activities.

Overhead heating systems are often used to supplement bottom heat or to meet all of the greenhouse heating requirements. These systems should be designed to provide uniform temperature conditions at the crop level. Overhead heating may be achieved with metal piping, finned pipe, or forced air systems (which are typically less expensive, but generally provide less uniform conditions). The simplest air heaters typically blow warm air into the greenhouse through one or more short ducts. Heat distribution with these heaters tends to be highly non-uniform, which generally leads to higher energy requirements. Air heaters are often connected to large diameter polyethylene film tubes that run the length of the greenhouse. Perforations in the tubing help distribute the warm air throughout the greenhouse.

Greenhouses heated with forced air will often have higher temperatures near the greenhouse roof, resulting in greater heat loss. Horizontal Airflow Fans (HAF) can be useful in improving temperature uniformity throughout the greenhouse, as well as help with humidity control. HAF is not a substitute for good design of heating and cooling systems, and the layout should be in accordance with manufacturer's recommendations or other guidelines. Fans should only operate when needed; variable speed fans may improve energy performance, in some situations.

GREENHOUSE STRUCTURES AND CONSTRUCTION

Greenhouse coverings vary greatly in their ability to transmit light and retain heat. Table 2 shows the comparative heat retention efficiency of a selection of materials commonly used in greenhouse construction. Greenhouse geometry affects energy performance, and structures with lower ratios of wall area to roof area are more efficient. Larger greenhouses and gutter-connected structures typically use less energy per square foot than standalone hoop and gable frame greenhouses. Where light quality won't adversely be affected, knee walls and other areas of the greenhouse perimeter should be insulated.

Glazing selection affects energy use and crop production. Growers will often need to choose between glazing that is transparent but doesn't retain heat, or a covering that has reduced light transmission and a better ability to retain heat. As a rule, single layer coverings will use 50% more energy for heating than double layer materials. Double-layer acrylic or polycarbonates or double-layer polyethylene films transmit light fairly well and retain heat better than single layer glass or polyethylene. Lexan is polycarbonate, the U value for twin-wall is listed in the table; single wall is the same as glass. The rigid materials (acrylics and polycarbonates) tend to be much more expensive. Single layer glass provides the highest light transmission level, requires less maintenance, and is more durable but is less energy efficient, and can be much more expensive. The performance of polyethylene films with infrared opaque (IR) and anti-condensate (AC) coatings depends on the specifics of the greenhouse structure. Energy savings can be 20% or greater, with the greatest savings typically seen in low temperature greenhouses with forced air heating systems. It is important to know the needs of specific crops for light, heat, and humidity than base glazing selection on these factors.

Table 2- Insulation Value of Common Greenhouse Materials

Source: Both (3)

Material	U-Value (1/R-Value)
Single (Double) Layer Glass	1.1 (0.7)
Single (Double) Layer Polyethylene	1.1 (0.7)
Single Layer + Energy Curtain	0.5-0.8
Double Layer + Energy Curtain	0.3-0.5
Twin-Wall Layer Acrylic	0.6
Twin-Wall Polycarbonate	0.6
1/2" Plywood	0.7
8" Concrete Block	0.5
2" Polystyrene Board	0.1

Use of insulation in walls, floors, and around heat plumbing can offer significant energy savings. Walls should be insulated to just above the height of benches, with aluminum faced between plumbing and walls to reduce heat loss from pipes to walls. A thermal-imaging camera is useful for finding heat leaks. Using retractable energy curtains can reduce heat loss by approximately 1/3 with all glazings, as well as function as a shade curtain in the warmer seasons to reduce cooling energy needs. To be effective at reducing heat losses, energy curtains should seal tightly at all edges when closed, be in good operating condition, and free from rips and holes. In many greenhouses, adding energy curtains is often the most effective measure from achieving significant savings on energy costs.

Minimizing the amount of air leaks is important to improve energy efficiency. Common areas are around fan louvers, doorways, corners, where the walls meet the roof, where the roof meets the gutters, and around the base of the walls. Any penetrations through exterior walls and roofs should be well sealed and inspected regularly.

ENVIRONMENTAL CONTROLS

Environmental controls for greenhouses can be quite simple—using thermostats, switches, and time clocks; or very complex—using computerized equipment to monitor and regulate the greenhouse environment. Any temperature sensor used to control heating or ventilation should be located so that it accurately reflects the conditions the crop experiences. Temperature sensors should be shaded from direct sunlight, placed in the center of the growing space, and ideally, aspirated with a small fan.

Computerized environmental controls can be one of the most effective tools in reducing energy use. They typically provide more accurate control, which tends to reduce swings in indoor conditions that lead to higher energy requirements.

Use the largest fan with the smallest motor possible, or use a larger motor equipped with variable speed controls to provide better control over energy use.

VENTILATION AND AIR CIRCULATION

Greenhouse ventilation systems are used to cool, and in some cases dehumidify, the greenhouse environment. Without ventilation, greenhouses, can reach temperatures that will damage crops, even in colder months. Ventilation systems range from manually operated louvers, to automated roof vents with natural ventilation, to forced air cooling with fans and vents. Automated cooling systems will typically reduce air temperature fluctuations. Understanding how much fluctuation in air temperature your crop can tolerate is important for selecting the most efficient ventilation system. Cool season vegetable transplants and nursery stock can tolerate wide temperature ranges, whereas tomatoes generally perform poorly in widely fluctuating temperatures.

Automatic and manual ventilation systems that rely on natural ventilation through the sides and/or roof of the greenhouse are very energy efficient, but may not cool adequately when wind speeds are low. Fan and vent systems will use more electricity to operate, but often provide better temperature control. Fan and vent systems can also utilize cooling pad or high pressure mist systems for additional cooling, but are not effective with naturally ventilated houses. Fan and vent systems should be designed with sufficient vent openings to maintain static pressures within the optimal operating range of the exhaust fans.

Evaporative cooling is frequently used to lower greenhouse temperatures below the range possible with ventilation alone. Common evaporative cooling methods include fogging systems and cooling pads along inlet walls. In both systems, regular maintenance and inspection of pumps, as well as plumbing, piping, and fixtures, will help ensure efficient operation. Optimal performance of evaporative cooling systems requires appropriate control strategies, calibrated sensors, and functional controls. Inlets with insect screening should be sufficiently large to maintain static pressures within the operating ranges of exhaust fans; inlet vents may need to be modified to accommodate insect screens. The area of screening required depends on mesh size and geometry.

The National Greenhouse Manufacturers Association provides guidelines for designing greenhouse ventilation systems, as do some fan manufacturers. Poorly designed ventilation systems that do not perform within recommended rates can reduce energy efficiency and result in poor crop performance. Multiple stages of ventilation generally provide more accurate cooling, reduce energy use, and improve crop quality.

Ventilation equipment must be maintained regularly. Fans must be kept clean; fan belts appropriately tightened; and worn belts replaced. Adjust louvers and vents to prevent air leakage and replace damaged or missing weather stripping and gaskets. Smoke generators can be used to detect leaks and undesirable airflow patterns.

LIGHTING SYSTEMS

Artificial lighting can improve plant yield and quality in some crops and climates. In addition to substantial initial costs, supplemental lighting is often expensive to operate. Although fluorescent bulbs may be appropriate for smaller growing areas such as germination benches, most fixtures use high pressure sodium bulbs and, when a more balanced spectrum is needed, metal halide lamps. LED lamps can be efficient and produce light in wavelengths most useful to many plants. LEDs have potential for use in greenhouse production, but current costs and limited performance data discourage widespread adoption in commercial operations.

Supplemental lighting installations should be laid out in accordance with manufacturers' recommendations and designed to supply light levels appropriate for crops. Computerized controls and weather-driven, crop-specific lighting strategies can optimize the use of supplemental light and minimize the associated electrical use. Supplemental lighting may affect greenhouse heating and cooling requirements, but the actual impact depends on many factors, including crop type and maturity, lighting system design, control strategies, and the specifics of the greenhouse itself.

IRRIGATION

Greenhouse irrigation is usually a relatively small portion of total greenhouse energy expenditure. Nonetheless, differences in efficiency between different irrigation system designs can account for up to 300% variation in water consumption. Irrigation system efficiency also affects pesticide use and ventilation systems. Effective systems deliver irrigation water directly to the plants roots. Water accumulation on floors, benches, and leaf surfaces typically indicates inefficient irrigation and can contribute to a variety of crop problems and increased use of fungicides and other pesticides. Drip irrigation is often the most effective system in greenhouse settings. Sensors to monitor and control water application minimize energy use, particularly in larger operations where manual valve operation is not feasible. Irrigation pumps should be sized to match the flow and pressure characteristics of the irrigation system.

SUMMARY

A well-designed greenhouse with efficient equipment and devices is important as a base, but maintenance and efficient utilization are also significant keys to lower cost of energy per production unit.

REFERENCES

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ADDITIONAL READING

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