Greenhouse Production With Lower Fuel Costs

By T. H. Short and W. L. Bauerle

Greenhouse agriculture has existed since transparent materials were first developed. Many solar technologists and hobbyists suggest that a "solar greenhouse" with a massive vertical north wall and a high sloping south transparent roof is the ultimate future commercial greenhouse.

Sketches, however, date this type of structure to at least the early 16th century. Horse manure was usually placed under the ground beds to supply both heat and fertilizer. Even vegetable growers up until the mid part of the 20th century used manure in the base of "hot beds" for heating the small south sloping green houses. Such greenhouses were productive, but not nearly as productive as modern greenhouses with good temperature control.

Most modern commercial greenhouses resemble large factory buildings rather than a "solar greenhouse." Like a factory, productivity for profit is a major goal and the structure must facilitate easy movement of labor, material, and equipment.

A typical tomato greenhouse will produce 110 tons of fruit per acre through the labor of 2.5 people. This sort of productivity is 15 to 20 times that of the best field production in the best climates. The greenhouse grown product is consistently of very high quality while the field grown product quality is a variable dependent on weather conditions.

Estimates of commercial greenhouse acreage in the United Sates range from 6,270 to 20,000 acres. Most of the 6,270 acres are in year-round intensive production while the remaining area is used for seasonal transplant production or as temporary tunnel covers for starting crops in the early spring.

Ohio has traditionally been the leading State in both greenhouse vegetable and flower production. This tradition resulted mostly from Western European immigration patterns and a local need for high quality winter produce before the development of interstate highways. The highest percentage of

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new construction since 1975 has occurred in the Southeast and Western States.

Large gutter-connected glass greenhouses with roof-ridge ventilators were first built in the early 1900's. During the late 1960's, fiberglass glazing became especially popular for connected greenhouses in the West and Southeast. Most new construction since 1970 in cold climates has been in the form of frame supported double-layer (air separated) plastic — a concept developed at the Agricultural Experiment Station of Rutgers State University. Double-layer air separated plastic provides a double glazing with low initial costs and a 30 to 40 percent energy savings over most single glazings.

The ultimate in open construction for good light penetration and machinery movement may be in the form of air-supported greenhouses such as the one-acre commercial bubble near Wooster, Ohio, that is used to grow lettuce and tomatoes.

A greenhouse in year-round intensive cropping will require a night temperature of 55° to 65° F depending on the type of crop being grown. This has resulted in an average annual fuel use of 100,000 gallons per acre of #2 fuel oil or 14 million cubic feet per acres of natural gas (14 billion Btu/acre) for Northeast Ohio glasshouse growers. This heating requirement is lower in warmer climates, but summer ventilation requirements are proportionally higher.

Greenhouses typically have a surplus solar heat supply during the day and excessive heat losses at night. An unventilated, unheated greenhouse in northeastern Ohio, 42° N. latitude, will reach over 85° F on a bright sub-freezing winter day and 120° F on a bright summer day. The following night temperature, however, will drop very rapidly to the outside air temperature if no heat is added.

Night temperature must not be allowed to drop below, or fluctuate from, 60° F for more than a few nights if plant and fruit quality are to be maintained. Day temperatures are allowed to range from 72° to 82° F in proportion to solar radiation. When the greenhouse temperature goes above 82° F, the greenhouse is ventilated with natural or evaporatively cooled air to both cool and minimize plant water stress. Sustained temperatures over 90° F can cause permanent damage to most crops.

Heat loss through greenhouse coverings is mostly affected by the thin boundary layer of stagnated air at the surfaces of each glazing material. Therefore, if one compares a tight double covered greenhouse (double glass, double plastic, double-plastic-over-glass, double fiberglass, glass and a tight internal single-layer-non-porous curtain) to a tight single covered greenhouse such as glass, the average energy savings will be about 40 percent.

If one compares this same tight glass greenhouse to a single layer plastic or fiberglass greenhouse, heat use will be nearly the same, especially after condensation develops on the inner plastic surfaces to minimize thermal radiation losses at night.

Approximations of Thermal Resistance, R, for Different Greenhouse Glazing Methods and Materials

Greenhouse Covering	R Value °F hr ft^2/Btu
Single Glass (Sealed)	0.9
Single plastic	0.8
Single Fiberglass	0.8
Double Plastic, Polyethylene	1.4
Double Wall Acrylic	2.0
Double Glass (Sealed)	2.0
Double Plastic Over Glass	2.0
Single Glass & Thermal Blanket	2.0
Double Plastic & Thermal Blanket	2.5
Double Plastic, Poly-Pellets*	20.0

*A 5 inch thick layer of polystyrene pellets between a double plastic glazing.

Modifying Existing Greenhouses

Existing greenhouses can be modified for energy conservation by changing the exterior glazing or by internal insulation such as curtains. Areas like north walls and foundations can be permanently insulated, but the roof should be of major concern since this is where the major heat losses occur.

Applying a silicone sealant between glass laps can reduce infiltration of cold air into glass greenhouses. The extent of savings depends heavily on previous condition of the greenhouse, windiness of the location, and outside temperature conditions. Older glass greenhouses with wooden frames and in poor repair usually realize the most savings.

Usually it is not profitable to seal new glass greenhouses except during construction. With outside temperatures below 25° F the laps are usually frozen closed because of the large amount of condensate on the inside glass surfaces. At temperatures above 25° F, the heating requirement on a windy night may sometimes equal that for the coldest night conditions.

During the winters of 1978-79 and 1979-80, a lapsealed experimental greenhouse at the Ohio Agricultural Research and Development Center, compared to unsealed glass, had a fuel savings of 9 to 11 percent during freezing temperatures, 20 to 24 percent in above freezing temperatures, and 30 to 35 percent in early fall and late spring. Anticipated annual fuel savings for a similar greenhouse should be 20 to 25 percent after lapsealing.

One internal roof insulating concept is to pull curtain material under the roof at sundown and open the curtains at sunrise. To be effective, the curtain material must be non-porous and tight fitting when closed. The greatest advantage of a curtain system is that it can be used with any type of external glazing such as glass, fiberglass, or double plastic.

There have been numerous developments in closing and opening mechanisms, and of materials — including a series of air-inflated plastic tubes. The most adaptive type of greenhouse for curtains is a modular truss frame type with very few internal support posts. The least adaptive type greenhouse is one with extensive structural framing and one that uses the overhead framing to support trellised crops and hanging baskets. Average annual fuel savings with a good curtain system will be approximately 35 percent.

Older single glass greenhouses are usually best modified externally. The principal technique used commercially has been the application of double plastic over glass (DPOG). This technique was initially researched and developed at the Ohio Agricultural Research and Development Center in 1975. Annual fuel requirements were found to be reduced by 57 percent with a wood frame glasshouse in average repair.

One result of the DPOG research has been renewed awareness of the importance of controlling the night temperature and daytime carbon dioxide (CO_2) levels within the greenhouse. Plastic over glass will always reduce light transmission, with a potential yield reduction of 5 to 10 percent for high light crops such as tomatoes, cucumbers, and roses. For medium and low light crops, yield and quality can be maintained or increased if growing practices are proper.

Some vegetable and rose growers have actually reported yield increases with DPOG over their crops because of better control of night temperature. Also, a tighter sealed greenhouse allows growers who supplement CO_2 to maintain higher than normal levels. If CO_2 is not supplemented, chances are very good of CO_2 deficiency and poor plant growth.

A double wall acrylic glazing can be used to totally replace a single layer of glass for an average 50 to 60 percent fuel saving. Double wall acrylic is manufactured in rigid sheets about 4 feet wide and in standard lengths of 8, 10, 12, 14 and 16 ft.

The acrylic material consists of two layers separated about 0.6 in. with ribs spaced every 0.6 in. It diffuses and transmits 83 percent of the light compared to single glass at 89 to 90 percent, but the total amount of light reaching the plants is about the same because supporting roof bars can be spaced every 4 ft. instead of every 2 ft.

Acrylic is one of the more expensive greenhouse coverings, but it has a very long life and is nearly maintenance free.

Pellets Pumped Between Walls

For most climates, over 75 percent of all supplemental greenhouse heating is required at night. Further, studies in Ohio and Japan indicate that a polystyrene pellet nighttime insulation technique could reduce greenhouse nighttime energy requirements by 80 to 90 percent. Five inches of pellets are pumped between the walls of a double wall greenhouse at sundown and removed at sunrise for a nighttime insulation value of R = 20.

A similar system is used on a small scale in commercial Japanese glass greenhouses where snow is not a problem. The Japanese form a double wall by installing rigid plastic sheeting material approximately 3 in. behind the glass.

In most cold climates, however, especially with gutter-connected houses, snow can accumulate in localized areas and damage or break brittle materials such as glass. Snow also interferes with light transmission the following day if not melted off. Because snow load forces are better distributed over the supporting framework of air-inflated double plastic covers than with glass, the Ohio approach has been to use conventional double-plastic covers that are air inflated during the day and filled with pellets at night.

Polystyrene pellets should have a minimum diameter of 1 in. and should be treated with a fire retardant. Pellets are pumped directly through blowers with an air/pellet ratio of approximately 25:1. A 1 horsepower blower rated at 1,000 cfm at 3,450 rpm and 1 in. water column pressure will pump about 0.75 cu. ft. of pellets per second.

The mixture must be pumped into the plastic layers at pressure less than 1 in. water column pressure to prevent rupturing the plastic. This is accomplished by evacuating air from between the plastic sheets with a similar-sized blower while filling. The evacuation procedure can also control the thickness of fill and maintain film tension on the insulated system at night.

Static electric cling of the pellets to the plastic and each other can be controlled by such chemicals as glycerine. Approximately 1 gallon of glycerine (mixed with an equal amount of water) added to each 1,000 cu. ft. of pellets prevents static problems for many months. Other antistatic chemicals recommended for garments have also been effective. The precise life of the antistatic agents is unknown.

Moisture in the pellets and between the plastic must be minimized during sub-freezing weather. A thin layer of pellets can freeze on the inside surface of the outside cover. Likewise, moisture in the pellets can reduce the insulation effect. Therefore, all air inlets to blowers are designed to be outside the humid greenhouse. On dry days, the pellet storage can be air-dried with one of the blowers.

Pellets should be stored ouside the greenhouse growing area in a dark, dry location to prevent any slow deterioration of the polystyrene by sunlight. Large thin wall plastic tubes can be used horizontally or vertically for storage as the pellets weigh only 1 lb/ft^3. The life of the pellet is indefinite since proper handling causes no apparent deterioration.

Modifying Heating and Ventilation

Almost every conservation practice requires some modification of an existing heating and ventilating system. A tighter single glazing tends to require more ventilation to reduce condensate dripping on plants. A double glazed structure will have less condensation even at higher humidities because of a warmer inner surface. These changes in humidity and condensation can have a great effect on the grower's ability to properly control plant growth and quality.

All heating systems should discharge the heat as low and as close to the plants as possible. Steam or hot water pipes are usually placed low and between the rows of a trellised vegetable crop or beneath the benches of most potted crops.

Root zone heating is an important concept being developed and studied along with energy conservation systems. There is evidence that many plant tops will tolerate lower night temperatures if the roots are maintained at 70° to 80° F.

One system for potted crops is to install 3/4 inch plastic pipe on 2 to 4 ft. spacings within a 4 inch layer of porous concrete (concrete without sand). For soil grown crops such as lettuce, the plastic pipes are placed directly in the soil (sand preferred) to heat the root zone. Water temperature within the pipes is usually maintained at 100° F.

For conventional double plastic greenhouse structures, root zone or floor heating will take care of 15 to 25 percent of the heat requirement during the coolest periods. For polystyrene pellet insulated greenhouses, the soil heating is predicted to provide all of the heat necessary for high production and optimum temperature control.

Cultural practices that growers use for optimum plant growth are often related to some of the unique features of the greenhouse itself. Much of a successful greenhouse grower's production is based on his ability to control plant growth under different light conditions by controlling fertilizer, water, and carbon dioxide rates, and temperature and humidity levels. For each control variable, too much and too high, or too little and too low can have a very adverse effect on yield and quality of any crop.

Plants always need less water as the humidity rises and after tightly sealing a greenhouse. A tight seal often increases condensation and dripping from a single glazed greenhouse even though the humdity remains the same. Therefore, a tight greenhouse should preferably be a double glazed greenhouse to prevent inside water condensation that will drip on the plants. Double glazing will result in higher winter humidities for better plant growth and drier ceilings as long as the greenhouse is properly managed with a trickle irrigation system.

Plant temperature at night is one of the more important control factors for the greenhouse grower to manage. The optimum plant temperature may actually be different for roots and tops even though one temperature for both has typically been recommended. For the fruiting of a crop such as tomatoes, night temperature of the plants must be maintained above 58° F to have significant fruit set. Vegetative growth of the same tomato or other totally vegetative crops, however, may be more affected by proper root temperature (65° to 75° F) than top temperature.

Plant temperatures during the day are controlled in proportion to solar radiation. This control function is usually allowed to occur naturally since any rise in solar radiation also increases the greenhouse temperature above a daytime base of 65° to 70° F. If the daytime temperature is set too high when light intensity is low, excessive respiration can result in plants that are elongated and weakened. This results in poor quality and low production. If the temperature is too low, limited growth occurs.

Carbon dioxide must be available at ambient (330 parts per million), or above, levels for good production. Vegetable and rose growers usually supplement CO_2 to 1,000 to 1,500 ppm. It requires approximately 75 pounds of CO_2 per acre per hour to achieve 1,500 ppm. Without supplemental CO_2, it has been demonstrated that CO_2 levels in commercial greenhouses can drop to 200 ppm in 20 minutes on a bright sunny day. This makes enrichment increasingly important as infiltration is reduced with energy conservation systems. CO_2 can be provided from different burner sources, including a boiler stack if a clean fuel is burned efficiently.

Alternate Energy

The relatively large amount of low temperature heat required in greenhouses makes them good candidates for using waste heat from electric power plants and other industrial sources. Greenhouses can also be heated with active solar collectors or solar ponds.

For all alternate energy considerations, an energy conserving greenhouse design will be much more feasible than any conventional design. Conventional designs require large, expensive heat exchangers for low temperature waste heat applications. Further, a conventional greenhouse has too high a heating requirement for any active solar collector system. Floor or soil heating with nighttime insulation tends to be as good an application for alternate energy systems as it is for fossil fuel heated greenhouses.

There is every reason to believe the greenhouse industry has a greater potential for the future than ever before. The consistent quality horticultural product comes from the greenhouse, not the field. Field production has relied on expensive mobile fuels and the interstate highway systems, while the greenhouse can use local low-grade fuels such as coal or waste heat being generated close to population centers.

The energy dilemma of the 70's can shape a future for the greenhouse industry that will be brighter than ever before. The industry, however, will need to make major technological changes to conserve energy. And the supporting energy industries must develop energy systems compatible with commercial greenhouse production.

The most crucial problem of the early 1980's will be to continue reducing the energy consumption and operating costs of the existing greenhouse growers. One economical alternative has been the use of double plastic-over-glass (DPOG).

DPOG reduces heat requirements 50 to 60 percent and has received wide adaptation by the industry since 1977. New greenhouses and the existing double plastic greenhouses must be designed to adapt to some highly insulative nighttime insulation system.

Night curtain systems are an intermediate step in the right direction. A major step will be the polystyrene pellet system under development in Ohio which shows promise of reducing night heating by 90 percent. More research and development of the handling and control systems is expected to bring the pellet system into commercial use.

Further Reading:

Building Hobby Greenhouses, Agriculture Information Bulletin No. 357, U.S. Department of Agriculture, #001-000-03692-1, for sale from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. $1.

Conserving Energy In Ohio Greenhouses, Special Circular 102, Ohio Agricultural Research and Development Center, Mailroom, Wooster, OH 44691. Free.

Conserving Heat In Glass Greenhouses With Surface-Mounted Air-Inflated Plastic, Special Circular 101, Ohio Agricultural Research and Development Center, Mailroom, Wooster, OH 44691. Free.

Energy Conservation and Solar Heating for Greenhouses, NRAES-3, Northeast Regional Agricultural Engineering Service, Distribution Center, Cornell University, 7 Research Park, Ithaca, NY 14850. $1.50.

Hobby Greenhouses and Other Gardening Structures, NE-77, Northeast Regional Agricultural Engineering Service, Distribution Center, Cornell University, 7 Research Park, Ithaca, NY 14850. $2.