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# Energy in Agriculture: Energy for Greenhouses Part 1: Energy Conservation

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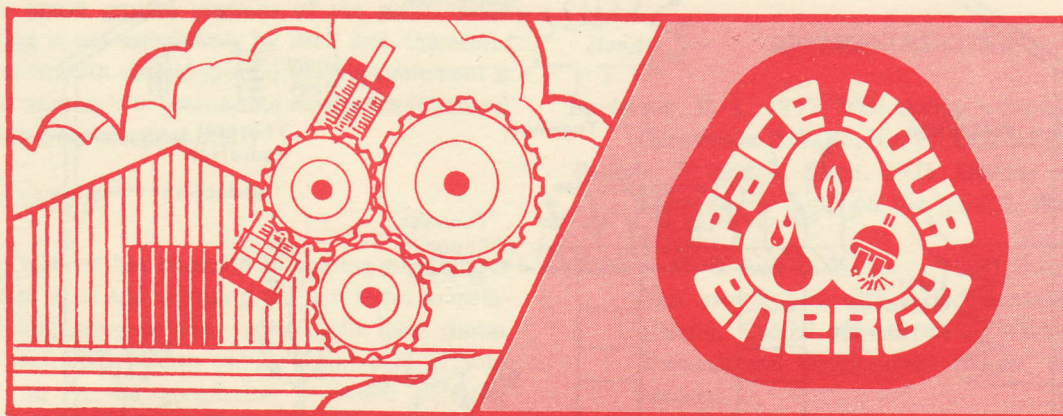
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# ENERGY IN AGRICULTURE

## ENERGY FOR GREENHOUSES Part 1: Energy Conservation

George A. Duncan, John N. Walker, and Larry W. Turner



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ENERGY

# ENERGY FOR GREENHOUSES

## Part 1: Energy Conservation

George A. Duncan, John N. Walker, and Larry W. Turner

The increased cost and scarcity of all fuels have affected the greenhouse owner as badly as any segment of industry. For some, crops have been damaged or lost. For others, it has reduced the margin of profit. Growers, manufacturers, suppliers, horticulturists, engineers and many others have studied the situation thoroughly in order to come up with viable solutions and alternatives for conserving fuel.

The greenhouse itself is merely a structural shell with a transparent covering within which an environment can be created suitable for plant growth when the outside environment is unsuitable. There are several sources of energy gain

and loss in establishing and maintaining this environment (Figure 1). Because of the relatively high losses through the thin transparent covering, the greatest energy requirement is for maintaining an optimum inside temperature during cold weather. Reducing this loss and others can lead to the following items that contribute to energy conservation:

- \*Structural Variations
- \*Thermal Curtain
- \*Infiltration Losses
- \*Proper Thermostat and Day-Night Controls
- \*Scheduled Seasonal Use
- \*Efficient Heating Systems

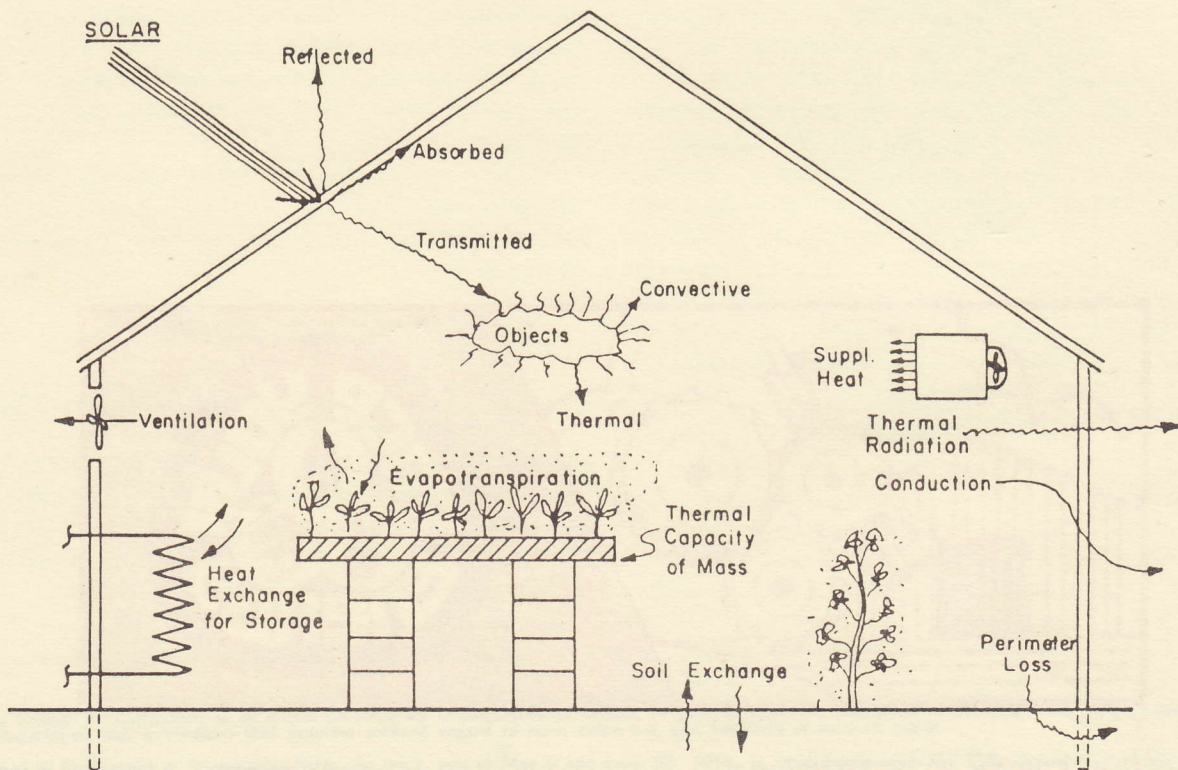


Figure 1.—Schematic of primary energy flows in a greenhouse.

Now to review the application of these energy conservation practices and how they can help you survive the energy crisis.

## COVERINGS

Many greenhouse operators are already familiar with the use of double-layer plastic with a dead-air space between to reduce conductive heat losses in a greenhouse. The double-layer covering saves about 40% of the heat loss compared with a single layer and generally does not seriously reduce light availability for plant growth. If two layers are so good, why not a third? Studies have shown that a third layer provides only about 15% additional heat savings and does begin to seriously affect light transmission. The seriousness of the reduced light depends on the greenhouse geographical location and the plants being grown.

Many owners of glass greenhouses have been reluctant to add plastic film to their house for heat savings due to the possible reduced light, attachment problems and potential snow load buildup. However, the severity of fuel costs is forcing many owners to add the plastic anyway. Several techniques are being used. Since a dead air space needs to be 3/4 to 1 inch for maximum effectiveness, furring strips can be attached to the top side of the framework and a layer of film stretched over the spacer strips. A thin lath strip can be nailed to hold the plastic snugly. These strips should be spaced around all edges and every 4-6 feet across the greenhouse roof.

If the glass panes are glazed tightly enough, a single layer of added film could be pressurized by the small fan inflation technique. Wooden strips or the special aluminum poly attachment channels would be needed primarily at the ends, eave and ridge to firmly hold the edges of the film. For windy locations, additional nail-down strips, netting, or ropes may be needed over the roof at 20-50 foot intervals.

If the glass panes are not tight enough to provide a suitable air seal, then some owners are applying two layers of film to the top of the glass house and pressurizing between the two layers. The bottom layer is pressed flat against the glass and frame bars, thus the surface needs to be free of sharp objects or edges that would cut or rupture the plastic.

Double-layer air-inflated plastic installed over a glass greenhouse compartment at the Ohio Agricultural Research and Development Center showed a 57% heat savings for the four coldest winter months (Dec. '75 to Mar. '76) in comparison to a similar glass greenhouse compartment (Bauerle and Short, 1977). The extra plastic cover was reported to reduce incident radiation 18%, diffuse the light entering the greenhouse, increase the humidity within the house an average of 12%, cause no increase in disease incidence, not affect ventilation with the conventional top vent

system, and reduce test tomato yields an average of 5%. The savings in energy are expected to more than offset any detrimental effects.

The initial installation cost of plastic and fasteners was priced at about \$7,500 per acre covered plus labor. Replacement cost of the plastic was estimated at about \$2,500 and may be needed only every two years if the UV-resistant polyethylene will remain serviceable through two seasons. Considering the cost of heating a greenhouse in Ohio as averaging \$30,000 per acre for No. 2 fuel oil or \$18,000 per acre for natural gas at current prices, a 57% savings yields approximately \$10,260 and \$17,000 per acre per year for natural gas and No. 2 fuel oil, respectively. Obviously the fuel savings are several times the total amortized annual installation and covering costs, thus reducing production costs while at the same time conserving valuable fuel for alternate or future use.

While the Ohio report is recently documented but actually is only one of several known cases of plastic film covering applied over glass greenhouses, the trend is catching on and is likely to increase greatly in the future. The same technique is applicable to single-layer corrugated fiberglass covered houses where the double-layer plastic film can reduce losses. The reduction may not be as great due to less air leakage at the laps compared to glass panes, however, the savings will still be significant. For a rather tight fiberglass roof, one layer of plastic film may be sufficient over the top using the air-inflation technique between the film and fiberglass.

Precautions in applying film over a glass or fiberglass greenhouse include: 1) be sure the structural member where the edge of the plastic film is anchored is strong enough to withstand the pull of the inflated layer; 2) the roof is free of sharp objects, ribs, or protrusions that could puncture either layer during use and lose the inflation capability; and 3) gutters of connected houses are not obstructed in any way to prevent adequate drainage. A good cleaning of the glass or fiberglass surface before covering with the film would air maximum light transmission during use.

In case of heavy snows, the pressurized film will be weighted down against the glass surface which eliminates the insulation effect and the increased heat transfer melts the snow as usual to help clear the roof and avoid structural damage.

The plastic film could be added inside but structural obstructions usually interfere. If the heating equipment is below eave level, a ceiling liner of plastic could be added from eave-to-eave of the house.

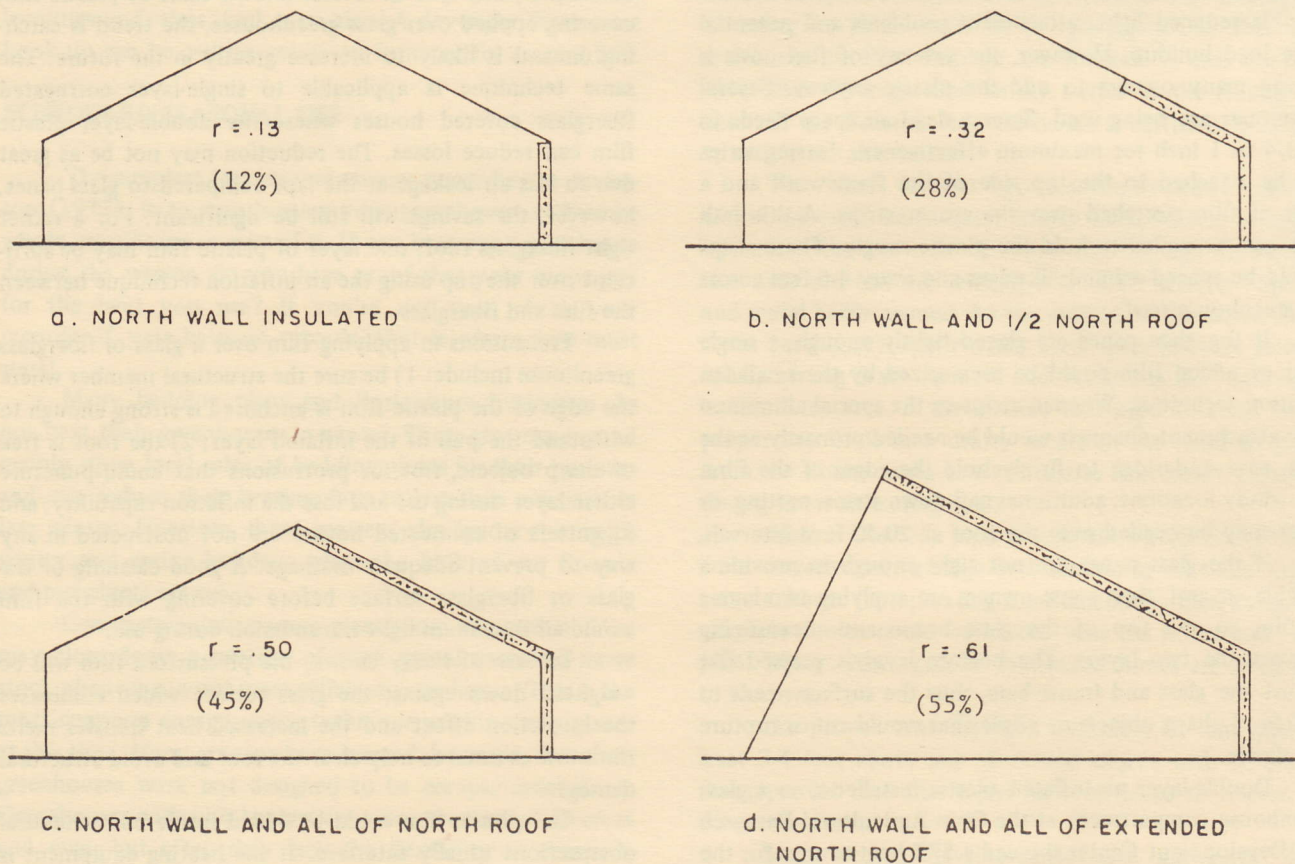
Some newer covering materials are now being tested that transmit light depending on its angle of incidence, thus differentiating between summer and winter sun and partially transmitting or blocking the rays accordingly.

## STRUCTURAL VARIATIONS

Sunlight for plant growth enters the greenhouse primarily as direct radiation from the southern direction but some diffuse radiation from the northern sky has been considered useful for certain plant growth. Thus, how much of the north-facing portions of the greenhouse could be built solid and sealed is debatable. However, for the crops of greenhouse uses that would tolerate this construction, Figure 2 shows some alternative methods of sealing and insulating the northern-facing surfaces and their heat saving effectiveness. For example, insulating the *north wall* of a gable type greenhouse to a magnitude 10 times greater than the normal covering, involves 13% of the surface area (neglecting ends) and reduces the conduction heat loss 12%. Similarly, insulating the north roof and sidewall of such a

house involves essentially 50% of the surface area and reduces heat loss 45%.

Heat loss from the foundation and perimeter of many houses could be reduced with a layer of moisture resistant rigid insulation board or equal method. For example, the heat loss through a 6-inch concrete wall 24 inches high around a 30 x 100 ft. greenhouse for a 70°F temperature differential is about 76,000 Btu/hr. The addition of a 2-inch rigid insulation board would cut this heat loss to about 3,900 Btu/hr. This 72,100 Btu/hr savings represents approximately 16% overall heat savings for a single-layer covered house (glass, fiberglass, or film) and approximately 29% for a double-layer covered house. For the 1/4-inch thick corrugated cement asbestos siding, the comparable savings are even greater at approximately 169,000 Btu/hr which is approximately 38% and 68% respectively for the



$r$  = ratio of insulated area to total above ground area (excluding ends).  
 ( ) = % reduction of conduction heat loss due to added insulation.

Figure 2.—Effect of structural shape and opaque insulation on greenhouse heat loss.

cited conditions. At an insulation cost of 20 cents per board foot plus the same amount for installation (\$416 total cost) and fuel oil costs of 40 cents per gallon, the added insulation would have a pay back period of approximately 4130 and 1750 degree-days for the two foundations, or 1/2 to 1 year for the middle latitudes of the U.S. Gutter connected houses would have less perimeter foundation area relative to the covering surface area, thus the losses and savings would be proportionally less.

Also, reflective materials should be added to the inside walls behind hot water or steam heating pipes to block similar radiant heat losses.

### THERMAL NIGHT CURTAINS

Since a third layer of permanent transparent covering is not often practical, several studies have shown that a third layer in the form of an opaque and reflective thermal curtain pulled at night can reduce heat losses significantly.

Studies at Penn State and Colorado State Universities (Rebuck, *et al.*, 1976) found that internal curtains such as the photoperiod type or new materials with reflective surfaces could reduce heat losses up to 57% during single night test conditions for a glass greenhouse and approximately 25% on a seasonal basis.

The principal effect of the thermal curtains concept is mainly the addition of two additional surface "air film" resistances to reduce conductive heat transfer and the barrier to reduce convective air currents near the outer greenhouse surfaces. The curtains would have limited effect on thermal radiation losses for fiberglass or glass glazings, which are mostly opaque to thermal (long wave) radiation anyway. However, for polyethylene covered houses where the poly has a rather high thermal radiation passage, an opaque curtain could have greater effects on savings than above. The effectiveness of the thermal curtains depends on how well the edges lap together and seal to stop convective air currents.

Some precautions with interior curtains in houses, especially smaller houses not built for curtain systems include: 1) the problem with storage of curtains when open and possible shading or interference with personnel and equipment movement; 2) greenhouse structural interference with installing and closing of the curtains; 3) location of the heating system to provide heat underneath the curtains for night-time heating; 4) problem of snow loads accumulating on the roof due to reduced heat loss (could leave curtains open to melt such snow accumulation, etc.); and 5) long term repay for thermal use only.

An estimate by the authors indicated the initial cost of an automatic curtain system for a 100 x 300 foot greenhouse would be approximately 68 cents per square foot of *external* surface area. Heating costs were estimated at

approximately 21.1 cents per square foot of exposed glass surface area. At a 50% seasonal heat savings, it would take at least seven years to regain the cost of the system not counting interest, installation and maintenance expenses, which might easily double the amortized cost and repay period. Of course, the additional benefits of a curtain for photoperiod control in certain types of production and other benefits were cited to possibly reduce the repay period and future savings.

### BETWEEN-LAYER INSULATION

Studies are underway in Arizona and elsewhere testing the injection of a liquid foam or lightweight foam beads between two layers of covering. The theory of the liquid foam is that it is generated and injected during the night to reduce heat losses. The foam condenses to a liquid after a short period of exposure and is drained for reuse. The styrofoam beads are being "blown" between the layers similarly and then "blown" out. Both methods are still under study and not yet available for general use.

Another insulation type material being used by producers is the plastic film formed "air-bubble" material. It is applied as a layer on the inside surface of glass or flat fiberglass. Some data on the heat reduction potential of this bubble material indicates up to a 50% heat savings when applied to a single layer covering with an 8% reduction in light.

### INFILTRATION LOSSES

Infiltration losses through shutters, doors, covering laps, etc., can be sizable, especially on cold windy days. As winter comes, most of the ventilation fans and shutters should be electrically switched off to prevent automatic operation and then plastic sealed over the openings. Leave one or two smaller vent fans and shutters operational to provide required ventilation on sunny winter days.

Where gas or oil furnaces are located inside the house, too tight an air seal could reduce air for combustion causing poor combustion, wasted fuel, toxic fumes, and/or flame extinguishing with loss of heat completely. To maintain a tight house but ensure combustion air, you could provide a special vent opening and duct to the combustion area of the furnace sized for one square inch of cross sectional area for each 5,000 Btu's of combustion ratings.

### PROPER THERMOSTATS AND DAY-NIGHT CONTROLS

A thermostat can be a source of excess heating cost and loss. How? One that is located poorly, such as against an outside wall or in an unrepresentative crop zone, can

give false operation and not provide the desired temperature control.

Have you checked your thermostats to see how accurate they are? A two or three degree error can cause several dollars of wasted fuel. Also, a large on-off differential (peak to peak temperature) can cause greater heat losses and extra fuel consumption. A more sensitive thermostat or use of a small fan to blow air past the sensing element can smooth out the on-off cycle and provide more uniform operation and temperature control. Some of the newer multi-stage controllers have the aspirated sensor and other features to provide smooth response and control of environment equipment.

A day-night thermostat control can save fuel by providing the desired daytime temperature for photosynthesis while lowering the temperature at night when the plants are "at rest" and the outside temperature drops also. As much as a 10°F lower night temperature can mean a 50% or more reduction of heating degree-days in some localities and, thus, fuel costs also. A day-night thermostat hook up can be put on gas or oil furnaces for around \$50.

### SCHEDULED SEASONAL USE

The simplest idea to save energy, according to Anderson (1977), is to stop heating your greenhouse, either the whole greenhouse or part of it. If you heat your greenhouse during the winter, do you have proof that your crops pay for the heat you use? If you're not sure, check your records; if you have no records, that is where you must start!

Many bedding plant and floriculture businesses do not heat their greenhouses in winter. These growers depend mainly upon local sales of bedding plants for their business and can reduce their heating days to less than a month in late winter. However, these growers also ignore the major winter and spring holidays when the bulk of cut flowers and pot plants are so!

Compartmentalize your greenhouse if possible. You may close down a portion of your greenhouse and move stock plants into your most efficient greenhouse. This is the most common energy saving technique used in many places at this time. Many growers have learned, however, that their greenhouses were not designed to be compartmentalized. Greenhouses with unit heaters are more economical to erect and own, but often they lack the flexibility to compartmentalize easily. The same is true with houses that have steam or hot water pipes passing through.

If you don't have small greenhouses or a compartmentalized greenhouse, don't heat the whole greenhouse for seed germination! Many growers use simply built germination chambers that allow them to keep the greenhouse cooler while the bedding plant crop is beginning. The

chamber can be simply a large wooden or pipe frame with a clear polyethylene covering to let in the sun. A small household electric heater can be mounted in one of the end walls to provide supplemental heat for the flats. Some trials may be necessary to become familiar with the moisture needs of the germination media and with the best thermostat setting on the heater. Be sure good electrical practices and a safe heater are used to make the set-up safe.

### EFFICIENT HEATING SYSTEMS

What can be done to make your heating system more efficient? Several things. Proper gas flame adjustment is a good start. A strong blue flame with some white tips is recommended.

A clean combustion chamber and surface will aid maximum heat transfer. Dust accumulation on the metal surfaces and fins reduces the heat transfer capacity and causes the unit to operate longer just to heat the facility. Cleaning fan blades monthly is a good practice. This allows maximum air flow through the furnace. A unit can be so dirty that the high limit safety switch in the furnace will shut off the flame before the house is sufficiently warmed to satisfy the thermostat.

The "draft diverter" portion of unit heaters can be a source of extra heat losses and/or toxic fumes. In normal operation, the hot exhaust fumes rise through the combustion area and out the vent pipe. A "draft diverter" opening and metal baffle around the top section of the heater allows room (or house) air to freely flow into the vent pipes to satisfy strong draft currents and not affect the combustion in the flame area. If the outside vent pipe does not have a proper cap or is in a drafty location, the extra air pulled from the house could cause excessive heat losses, especially during the non-heating cycle.

Also, if the vent pipe is subject to back drafts due to wind currents over a ridge or a suction in the house due to some exhaust fan operating simultaneously, then dangerous ethylene fumes could be leaked into the house and cause plant injury. Also, carbon monoxide fumes are dangerous to workers.

Use proper vent caps and terminate all vent pipes at least 3-4 feet above any structural object with 10 feet of the pipe. Be sure flue pipes have no leaks to release the dangerous fumes.

Some recent developments with automatic draft control devices on residential furnaces indicate these devices can save fuel and heat but no reports are known on greenhouse installations. The same principles and savings should apply to greenhouse heaters but further tests should be conducted to verify the savings and determine if there are any unforeseen problems.

When two unit heaters are mounted opposite each

other and discharge into a polytube fan, be sure the heaters don't hinder each other's operation. Some reports indicate that one heater can blow the heated air right through the fan jet housing and possibly push some heated air out the vent of the opposite heater or interfere with proper combustion. A metal baffle is being mounted in the center of some fan jet housings to block such air pass-through. In others, draft diverter baffles are mounted over the draft openings.

Maintenance of boilers is particularly important since the efficiency of these units is closely related to their condition. A poorly maintained boiler with high stack temperatures can have efficiencies of 55% or less; whereas, a boiler in excellent shape may operate at 85% efficiency. In one study of small boilers, the efficiency ranged between 45 and 75%. Even gas fired equipment such as unit heaters can vary widely in efficiency with efficiencies between 70 and 90% being observed. Deposition of soot on the heater exchange surfaces is particularly detrimental with 1 mm (approximately 1/25 inch) of soot reducing heat exchange efficiency by 3%. Thus, 1/8 inch layer of soot would be nearly a 10% loss. Periodic maintenance should be scheduled to flush the residue from the water lines and to scrape the soot and other deposits from the combustion area.

In addition to these maintenance procedures, efforts are being made to improve the energy efficiency of greenhouses by developing practical systems for zone heating. These efforts have included an investigation of the warming of the ground more than the aerial temperatures such as presently being used under various benches. Some techniques use plastic tubes or pipes on the ground around bedding plants or other crops. Though these techniques may aid root development for selected plants, a system must be provided for aerial heating as well, since the level of heating from the soil surface to the air is not sufficient to heat the air to a temperature satisfactory for development of the above ground portions of the plant. Since ground heating is not satisfactory by itself and, therefore, an investment in both air and ground heating equipment is required, this approach to greenhouse environment control appears to have only marginal utility.

## RADIANT HEATING

Similar interest has occurred in heating greenhouses by radiant heat units and adjusting the heat input to maintain desired leaf temperatures. Experiments have shown that desired leaf temperatures can be maintained without heating the air in the greenhouse to levels generally considered desirable. This would result in a reduced heat requirement; however, in some of these studies the soil was not sufficiently warmed for effective root development and

poor growth was achieved. Either of these techniques which separately heats the above ground or below ground portion of the plants may have application for a restricted number of plants; however, either technique must be carefully planned and designed to have value for general greenhouse use. Such factors as the ratio of radiant heat to convective heat output for the heater, height above the plants, thermostatic control, supplemental air circulation for dense foliage crops, removal of combustion products, fresh air supply and shading are a few of the features requiring consideration.

## SUMMARY

The high cost of heating greenhouses due to escalating fuel costs has created a crisis situation in the greenhouse industry. As a result, interest in methods of energy conservation, in alternate and less costly sources of energy and in plants which grow satisfactorily in cooler environments has become intense. The engineer has been looked to by the grower and the plant researcher to develop the hardware and methods of achieving solutions to these problems.

Much effort has been directed to energy conservation by use of night curtains. Most commonly these curtains are quite similar to photoperiod control curtains. If the curtains are pulled tightly over the crop, they have been shown to be highly effective in reducing the heat requirement. The use of heavy insulation in the north wall of greenhouses and the increase in the number of layers of glazing on the south side and end walls has also been shown to be very beneficial. Polyethylene bubble liners, bead walls and foam between two layers of glazing have also been studied.

As a result of the activities of engineers and innovative greenhouse operators, a number of viable alternatives are now available to greenhouse operators for reducing their energy costs.

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