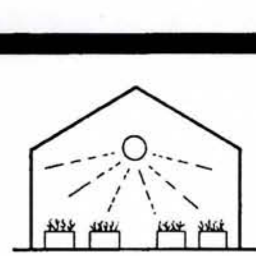
SECTION II



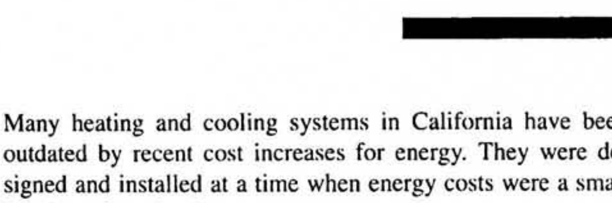
INCREASE EFFICIENCY of HEATING and COOLING SYSTEMS

Many heating and cooling systems in California have been outdated by recent cost increases for energy. They were designed and installed at a time when energy costs were a small fraction of production costs.

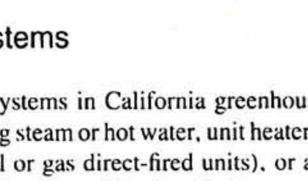
Heating systems

Most heating systems in California greenhouses use a central boiler producing steam or hot water, unit heaters (using steam or hot water or oil or gas direct-fired units), or a combination of these systems. In many older installations, steam or hot water lines, perforated poly tubes, or warm air discharge from unit heaters, will be overhead. Overhead installations do not obstruct the work area of the greenhouse, but increase energy use. The heat distribution system should be lowered near to plant level whenever this will not interfere with greenhouse operations.

LOWER HEAT SOURCE



Under benches—or—near ground level



There are many reasons why heat distribution systems should be located as close to the ground as possible: (1) several recent tests have shown that lowering the heat distribution system is more useful to most plants; (2) less heat is wasted to the upper ridge area of the greenhouse; (3) lowering the heat distribution system is necessary for the installation of thermal blankets or permanent clear poly subroofs; (4) there is increasing experimental evidence that heating the root zone or soil area is beneficial for some crops and permits reduced greenhouse air temperatures, resulting in less energy use for heating; and (5) heating pipes in the top of the greenhouse can transmit as much as one-half of their heat by radiation, and much of this will be lost through the roof.

Infrared heating

(plan for $1.05/ft^2 installed)

• SAVE: 10-30%

There are numerous installations of infrared heaters in California greenhouses. These systems consist of a number of natural gas and propane burners spaced along a connecting steel tube (about 4 inches in diameter). The tube is heated to high temperatures and suspended from the greenhouse roof. Specially designed metal reflectors over the pipes direct heat downward, warming plants and soil directly by radiation. Infrared heating is reported to use less energy because: (1) the burner design provides a higher heat transfer efficiency than most boilers or unit heaters, and (2) air temperature requirements for plants are less, although how much less is unknown.

Growers' reactions are mixed, but generally favorable, depending on the crops grown. Fuel savings of 50 percent, along with better quality plants, have been obtained with infrared heat on geranium cuttings on benches. One rose grower reported savings of 20 percent with infrared heat, but it has not proved beneficial for cucumber production after two seasons of testing.

Infrared systems are still undergoing tests in California, but it appears that this type of heating is best for "short" crops, such as cuttings, transplants, propagation stock, and potted plants such as geraniums and poinsettias. For such crops, infrared heating will probably reduce energy use 35 to 50 percent. Infrared heating should be most effective if the infrared rays can "see" and warm both the leaves and the soil. Where vegetation is thick, or the plants are tall (roses, cucumbers, etc.), some leaves and soil will be shaded from the heat, and the effectiveness of the infrared heat will be reduced.

Costs for such systems vary, but equipment suppliers suggest that costs will average 3½ to 4 cents per square foot of heated area for each degree Fahrenheit of temperature difference between the inside temperature of the greenhouse and the outside design temperature. This suggested cost allowance seems to match the costs for most installations currently in place.

Remember, infrared heating can not be used with thermal curtains unless they are from truss-to-truss and above the infrared heaters.

Soil or bed heating

(plan for 80¢/ft^2 installed)

Soil or bed heating, also referred to as microclimate or root zone heating, has been shown to improve growth and quality of a number of plants and to reduce energy use. Higher root zone temperatures usually allow greenhouse air temperatures to be reduced 5°F from normal or more. Good plant growth and substantial energy savings have been obtained for such plants as poinsettias, cyclamen, calceolaria, primulas, vegetable tranplants and seedlings, many bulb crops, and most foiliage plants. Not all plants have been fully tested with root zone heating.

Bed or root zone heating generally takes the form of heat supplied by 80° to 140°F water that is distributed to the lower parts of plants through tubes embedded in, or on the surface of, soil, sand, concrete, or other materials used as a greenhouse floor or bench surface. Costs for such systems can vary substantially, depending on growers' needs and design requirements, the degree of sophistication and control required, and on the growers' supplies—labor, water heater. One California nursery has 2½ acres of outdoor propagation area with flats on a heated concrete slab. The slab is warmed with 110°F water flowing through embedded copper tubes at a rate of about 2 gallons per minute. Similar indoor propagation areas are used by some growers with formed concrete benches with embedded copper tubes. Total systems like these, including water heaters, cost about $3.45 per square foot of bench or bed area, a rather high cost, but these bed heating systems successfully meet the requirements of these growers. Another grower distributes 120°F water through 1¼-inch polyvinylchloride (PVC) Schedule 40 pipes spaced along the greenhouse floor. Potted plants are placed on the floor between rows of tubes. This is a relatively inexpensive system.

A more recent type of floor heating system uses EPDM (ethylene propylene diene monomer) tubing that will withstand temperatures of 300°F. A Biotherm system uses small diameter EPDM tubes to distribute 90° to 120°F water along the floor or on benches. Flats and pots can be set directly on the tubes. In one California installation, Easter lilies were successfully grown with energy savings of 35 to 50 percent, using reduced night temperatures and 70° to 75°F root zone heating. Pennsylvania State University reported savings of 42 percent (over a conventional glass greenhouse) for poinsettias with this system. Other advantages of this system: it can use small, efficient, point-of-use water heaters, and the greenhouse microclimate can be easily zoned for different plant temperature requirements.

The suggested *plan for* cost of 80 cents per square foot is based on recent quotations for a Biotherm soil or root zone system completely installed, including water heaters. The distribution system itself, without heaters, would be about 40 cents per square foot.

Fuel cost comparisons

In this time of rapidly fluctuating fuel prices, it is useful to compare various available fuel sources for greenhouse heating. The following formula can be used to compare two different fuel sources (A) and (B) for equal heating costs.

$$\text{Cost/unit A} = \text{Cost/unit B} \times \frac{\text{Efficiency A}}{\text{Efficiency B}} \times \frac{\text{Btu/unit A}}{\text{Btu/unit B}}$$

For example: Determine what the cost of No. 5 fuel oil should be to give the same cost of heating as with natural gas.

Fuel A = No. 5 oil at 148,000 Btu/gal and 70% combustion efficiency

Fuel B = Natural gas at 100,000 Btu/therm and 75% combustion efficiency

$$\text{Cost/gal of No. 5 oil} = \text{Cost/therm of NG} \times \frac{70\%}{75\%} \times \frac{148{,}000 \text{ Btu/gal}}{100{,}000 \text{ Btu/therm}} = 1.38 \times \text{Cost/therm of NG}$$

So: if NG = 65.0¢/therm, then No. 5 oil should cost no more than 1.38 × 65.0¢ = 89.8¢/gal.

Any fuels can be compared this way if the present cost of one is known. The last column in table 6 indicates the maximum price for various fuels to be competitive with natural gas at current costs of 65 cents per therm.

TABLE 6. Cost comparison of various energy sources

Fuel	Heat content (Btu/unit)	Combustion efficiency (%)	Maximum unit cost to equal natural gas at 65¢/therm
Natural gas	100,000/therm	75	65.0¢/therm
No. 2 oil	138,000/gal	70	83.7¢/gal
No. 5 oil	148,000/gal	70	89.8¢/gal
No. 6 oil	150,000/gal	70	91.0¢/gal
Propane	90,000/gal	75	58.5¢/gal
Soft coal	22,800,000/ton	60	$118.56/ton
Hard coal	26,000,000/ton	60	$135.20/ton
Electricity	3,413/kwhr	100	3.0¢/kwhr
Oak wood	24,000,000/cord	60	$124.80/cord

Actions to consider

Replace steam traps. In a steam-heated greenhouse (plan for 4 to 6¢/ft^2 of greenhouse floor area), steam traps perform three important functions. They discharge condensate, prevent escape of steam, and discharge air and other incompressible gases on start up. A malfunctioning steam trap can cause excessive energy losses in a steam-heating system. These losses are difficult to prevent without routine inspection. Most growers have a routine maintenance and inspection program, but it might be advisable to periodically install new traps. New traps cost about 4 to 6 cents per square foot of floor area for a typical California greenhouse. This amount, based on the price of new, high-quality traps, does not include installation labor. The labor to install these would probably be less than the cost of one thorough inspection and repair. The possibility for reducing energy losses from the steam distribution system can be substantial.

Decentralize boilers. Most large steam-heated greenhouses have a central boiler. Such systems usually require a long steam distribution line that must be well insulated to reduce heat losses. High pressures are necessary for good steam distribution. Consider using several small boilers distributed around the greenhouse complex when an older central boiler needs to be replaced, or when planning a new greenhouse or heating system. Smaller boilers can be turned off more easily during the day, require lower steam pressures (sometimes eliminating the need for a certified boiler operator), and will allow better control of different environmental needs in various areas of the complex.

Use hot water for heating. There are several reasons why hot water might be more advantageous than steam for greenhouse heating.

1. Hot water is easy to distribute and control.
2. Distribution heat losses are apt to be less with 100° to 150°F water than with high temperature steam.
3. Root zone heating appears to provide better growth with less energy for many crops and is particularly appropriate for most California climates.
4. Low cost plastic pipe can be used for most warm water distribution systems—more pipe will be required than with a steam system, but the total cost should be less.
5. Most steam boilers can be easily converted to hot water boilers, and the present iron steam pipes can also be used.

Hot water systems will allow easy conversion to a solar heated system in the future if they become economical.

Consider alternate fuels. New furnaces are now on the market that will efficiently utilize wood, coal, biomass, and other renewable energy sources. Investigate these when planning new greenhouses or heating systems. These sources of heating might be quite important to us in the future.

Heating system maintenance. All heating systems and their parts require regular maintenance to maintain high efficiency. Regularly inspect and test boilers, inspect unit heaters and their fan belts and louvers, check for leaking steam traps and valves, water valves, boiler water treatment quality, and so forth.

Cooling systems

Most California greenhouses need some form of cooling during certain periods. Methods of cooling require different levels of energy. Subroofs, shading compounds, or natural ventilation use no energy except for initial installation. An automated shading blanket uses minimal energy for pulling, and misting or fogging for cooling use relatively small amounts of electricity for pump operation. Methods that provide a more positive degree of temperature control do require operational energy, often significant amounts. Forced ventilation and pad-and-fan cooling systems both use large quantities of electricity when operating.

In many areas of California, cooling can be sufficient with one or more of the no-energy or low-energy systems. With good planning, energy use for cooling can be minimized. Such planning might also include allowing for periods of high temperature.

Natural ventilation. Some growers in the San Diego area removed all their ventilation fans and redesigned their polyethylene greenhouses with ridge vents that could be closed at night with inflated poly tubes. By opening side curtains they are able to utilize natural ventilation to exchange the air in the greenhouses.

A reasonably safe ventilation system for cooling should have a capacity equal to about one greenhouse volume of air per minute (about 10 cfm/ft^2 of greenhouse floor area). Natural ventilation rarely produces such recommended air change because it depends on wind movement and heated greenhouse air for its power. Nevertheless, most growers who have been in an area for some time should be able to determine if they could operate with a natural ventilation system. Effective natural ventilation generally requires that some greenhouse sides can be opened easily. For winter energy use, however, such easily opened side vents are a disadvantage because they will not be insulated and will often allow unwanted infiltration. One grower installed a double layer polyethylene roll-up curtain that could be inflated when lowered at night, to provide an insulated wall.

Subroofs. The 25% heating energy savings of subroofs is described in Section I. A subroof of clear polyethylene or vinyl will substantially reduce summer cooling, in conjunction with forced ventilation or pad-and-fan cooling. Such a subroof seals off the main greenhouse area from the hot ridge area; it also reduces the cooling volume in the greenhouse so that the ventilation system will move a greater amount of air, proportionately, through the greenhouse. Generally, there is ample sun during hot periods so light reduction due to the subroof is not usually a problem. A 6-mil polyethylene subroof will cost about 15 cents per square foot of greenhouse floor area to install and about 7 cents per square foot to replace. This will reduce energy to operate cooling fans by as much as 20 percent.

Shading compounds. Applying shading compounds to the outside of a greenhouse has been a common practice for years. Shading compounds alone can reduce inside air temperatures 6°F or more by reducing light penetration into the greenhouse. Some horticulturists suggest that applications of shading compounds to a greenhouse cover can often be more harmful than a grower realizes. While it might lower the temperature during periods of bright sun, the light intensity might be reduced unnecessarily on cloudy days.

Shading blankets. The subject of thermal blankets was discussed in Section I. Effective in reducing heating energy, thermal blankets are also useful for hot weather shading. Many current blanket installations consist of two layers of blankets, a solid, opaque layer above a porous material. The porous blankets are available in materials that will allow various amounts of light into the greenhouse. They can be pulled on sunny days to reduce light on the plants, eliminating the need for shading compounds. Reducing light also reduces the heat absorbed by plants, soil, and greenhouse structures that result in the temperature rise of air within the greenhouse. A pulled shading blanket acts as a subroof and increases the efficiency of the cooling system. A blanket installation will cost about $1.00 per square foot of greenhouse floor area.

Misting or fogging. With natural ventilation, misting and fogging uses relatively little energy to evaporatively cool the air in a greenhouse. Mist cooling systems utilize low pressure nozzles. Water droplets from low-pressure mist systems are quite large and do not evaporate quickly, so some free water may wet plants and soil leaching nutrients from both. Free water on plants can spread some diseases and fungi.

Fogging uses very high pressure (around 500 psi) nozzles. High-pressure, low-capacity nozzles (1/2 to 3/4 gallon per hour) are used (about one nozzle for 80 ft^2 of floor area) to produce a very fine atomized fog that fills the greenhouse, cooling the air as it evaporates. Most moisture evaporates before reaching plant level. Fogging can reduce air temperature by 10° to 25°F when used with exhaust fans; and can produce the same level of cooling as a pad-and-fan system, but with reported energy savings of 10 to 25 percent. Fogging is reported to produce more uniform temperatures.

Forced ventilation. Although very energy intensive, forced, or mechanical, ventilation provides positive control of air movement and more temperature control than a natural ventilation system. Forced ventilation systems can be made to operate effectively and automatically with use of thermostats for controlling exhaust fans and mechanized roof or side ventilators.

A forced ventilation system should be controlled so that the minimum number of fans are turned on. Exhaust fan use can be greatly reduced by using polyethylene subroofs or shading blankets to reduce the greenhouse cooling volume.

Exhaust fans for a forced, or mechanical, ventilation system should be able to change at least one greenhouse volume of air per minute. For most greenhouses, this represents an air exchange rate of 8 to 10 cfm per square foot, and should limit the increase in greenhouse air temperature to about 10°F. With this commitment to electrical energy, a grower should maintain the best possible system efficiency to minimize energy costs. The following are some suggestions for doing this:

- For new or replacement motors, choose new style, energy efficient motors. Initial costs will be a little higher, but will be made up by energy savings.
- Control fans with a thermostat that is shaded from the sun and with a small blower that circulates greenhouse air across it. Check correctness of thermostat setting often.
- Exhaust fan outlets should be fitted with shutters that open easily when the fan starts, and prevent air exchange when fans are off.
- Use motorized shutters for air inlets and wire these into the fan control system.
- Check fan and motor bearings often for overheating. Lubricate or replace as necessary.