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Geothermal Greenhouse Heating

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Legal Notice

Acknowledgment

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Preface

The primary purpose of this pamphlet is to provide information concerning the use of geothermal water for heating greenhouses. It is not intended to be an all-inclusive reference on greenhouse operation. Important horticultural considerations might be plant spacing and variety, growing media, watering, nutrition, light, temperature, humidity, pollination, soil media aeration, carbon dioxide content in the air, disease control, plant pruning and training, propagation and post harvest handling. If the greenhouse will be operated commercially, other important factors might be labor, production management, grades and standards, packaging, transportation, perishability and costs and profits. Greenhouse heating, as will be discussed here, is just one aspect of a successful greenhouse operation.

While this pamphlet may be used as a guide for greenhouse heating, additional technical assistance may be necessary and can be obtained from the Idaho Department of Water Resources.

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Introduction

Geothermal energy is the natural heat of the earth stored in rocks and in water or steam. It has been used by man for centuries for a wide variety of purposes. Interest in this relatively clean and highly versatile resource has grown in recent years as Americans have become more energy conscious. Geothermal resources are abundant in Idaho and present unique opportunities as alternative energy sources. Low temperature geothermal water and warm discharge water from geothermal applications requiring higher temperatures such as space heating or food processing can provide an ideal source of heat for greenhouses.

Geothermally-heated greenhouse operations range from small hobby greenhouses to large commercial operations occupying up to 100,000 square feet each. Currently there are approximately 10 geothermally-heated commercial greenhouse operations in Idaho occupying over one half million square feet of floor space and utilizing water with temperatures from 99 to 180°F.

Crops requiring high temperatures are best economically, since geothermal heat is cheap. Most potted plants, including both flowering and foliage varieties, can be grown commercially, but bedding plants and cut flowers are also commonly grown in geothermally-heated buildings. A good market also exists for cuttings, small transplants, tropical plants, herbs, medicinal plants and genetically engineered plants. Vegetables such as lettuce, tomatoes and cucumbers can be grown, but they must be able to compete with vegetables imported from southern states or Mexico.

Legal, institutional and environmental factors

Before a project can begin, the access and development rights need to be secured. The first step, whether on state, federal or private land, is to obtain a lease. The Idaho Department of Lands issues geothermal leases for state lands, while the Bureau of Land Management (BLM) issues the leases for all federal lands, including lands managed by the U.S. Forest Service. Leases for private land must be arranged with the land owner. (Figure 1).

The Idaho Department of Water Resources (IDWR) is the regulatory agency for the drilling, operation, maintenance and abandonment of all geothermal wells in the state. Consequently, drilling permits, geothermal permits, and water appropriation permits are obtained through IDWR. The type of permits required may vary depending upon the temperature and proposed use of the geothermal water.

Although geothermal resource projects are usually considered to have relatively minor environmental impacts, there is potential for adverse effects in some situations. These could include the following: the release of airborne effluents, water pollution, land subsidence, induced seismicity, noise, water supply, solid waste, land use, vegetation and wildlife, and economic, social, and cultural factors. The Idaho Departments of Health and Welfare, Fish and Game and other state and local regulatory agencies must be contacted depending upon a project's potential impact.

Figure 1

Permits Required for Geothermal Development

Geothermal Lease:	
State Land	Department of Lands
Federal Land (Both BLM & FS)	Bureau of Land Management
Private Land	Consult with owner and an Attorney
Drilling/Geothermal Permit:	Idaho Department of Water Resources
Environmental:	Idaho Department of Health and Welfare Idaho Department of Fish and Game

Greenhouse construction

Modern greenhouses differ markedly from the wood frame and single pane glass greenhouses of the past. New construction techniques and the availability of new materials have decreased costs and improved energy efficiency. Frames are now normally constructed of steel or aluminum, and coverings may be glass, plastic film, fiberglass or rigid plastics, or combinations of plastic film and fiberglass. Shapes are normally either alpine, quonset or barrel vault as shown in Figure 2, either free standing or interconnected. Many large greenhouse operations use interconnected structures to minimize the exposed surface area and thus reduce heating requirements.

The choice of construction method and materials is often not dictated by energy efficiency concerns, but by cost, grower preference and the horticultural requirements of the crops being grown. For example, frames must be strong enough to support snow loads and the weight of heavy crops, and coverings must be transparent enough to admit adequate light. All construction methods and material have advantages and disadvantages that must be carefully weighed when examining the overall greenhouse operation.

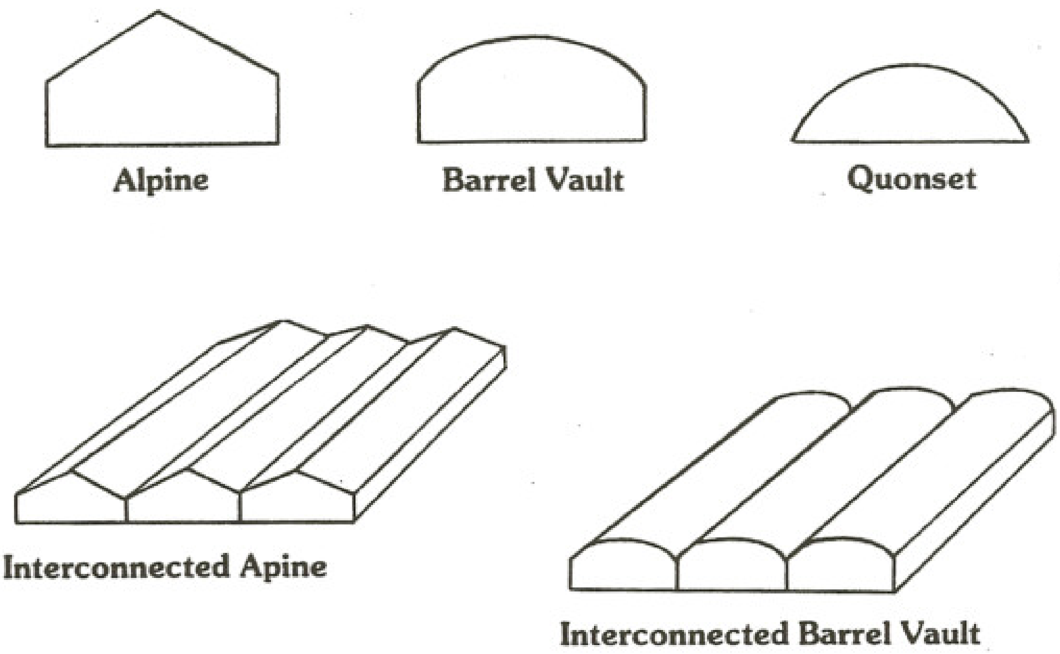

Figure 2 - Common Greenhouse Shapes

Glass

Although it was once used almost exclusively, glass has lost popularity due to its high initial cost and poor energy efficiency. Even though glass may last indefinitely, its cost per year is still greater than other coverings such as plastic. Besides having very poor insulating qualities, glass is very susceptible to cold air infiltration as a result of the many cracks in construction. Double glazed panels have become available in recent years to reduce energy losses; however, energy efficiency is gained at the expense of much higher cost and lower light transmission capability. Glass is also subject to breakage and can be hazardous.

Plastic film

Most new greenhouse construction uses plastic film (polyethylene) as a surface covering. Polyethylene is familiar to almost everyone in the form of plastic bags and food wraps; however, for greenhouse use only polyethylene with an ultraviolet inhibitor should be used. Ultraviolet radiation from the sun causes the plastic to deteriorate more rapidly. "Poly" greenhouses are the least expensive to build and operate, in spite of the periodic labor and cost of replacing the plastic. Films will typically last two summers and one winter.

Plastic film is lightweight; consequently, it requires a minimal structure for support. Its flexibility allows it to be easily adapted to a wide range of shapes and sizes.

The major advantage of plastic film greenhouses is energy efficiency. Since plastic film is attached to the supporting structure in continuous sheets, there is very little opportunity for warm air leakage or cold air infiltration. Further energy efficiency is achieved by installing two layers of plastic film that are separated by a pressurized air space of several inches, maintained by a small electric fan. These greenhouses are commonly referred to as "double poly." The heating requirements of this type of greenhouse are typically 40 percent less than glass. However, due to the tight construction, single and double poly houses sometimes experience humidity and condensation problems which must be addressed through ventilation.

Fiberglass

Fiberglass is sometimes used exclusively as a covering material, but is normally used in conjunction with other materials since its cost is much greater than plastic film and only slightly less than glass. Fiberglass can be applied to nearly any frame, since it is flexible enough to conform to rounded shapes, rigid enough to be applied flat and lightweight enough for nearly all frames.

Depending upon the grade, fiberglass may last from 5 to 25 years. It is quite tough and is resistant to puncture, wind damage, hail, accidental damage and vandalism. The energy efficiency of fiberglass houses is slightly better than glass, but still significantly less than double poly greenhouses. Cooling requirements, however, are typically about 20 percent less for fiberglass than for glass. Since fiberglass is combustible, it can be considered a fire hazard, thus resulting in increased insurance costs.

One of the most important functions of a greenhouse covering is to allow the maximum amount of available light to reach the crop. Insufficient sunlight is an often overlooked "killer" of greenhouse crops. At high intensities fiberglass has light transmission capabilities similar to glass, but at low intensities fiberglass is vastly superior. However, this advantage can be quickly lost as fiberglass panels darken with age. Their light transmission capability can be maintained, however, with periodic surface refinishing.

Besides fiberglass, other plastics such as acrylic and polycarbonate panels are available. They are exceptionally energy efficient, but also exceptionally costly; consequently, they are not widely used.

The advantages and disadvantages of various greenhouse covering materials are summarized in Table 1.

Table 1. Advantages and Disadvantages of Greenhouse Covering Materials

	Glass	Single poly	Double poly	Fiberglass
% Light transmission	90% (Numerous structural members cast shadows)	88%	77%	89-95% (Surface refinishing periodically required to maintain effectiveness)
Cost	High	Very Low	Low	High-initially Low-over its lifetime
Resistance to outside air infiltration	Poor	Excellent	Excellent	Fair
Resistance to conductive heat loss	Poor	Fair	Excellent	Fair
Safety	Poor	Excellent	Excellent	Good
Maintenance	Moderate	High	High	Low
Shape	Alpine	Arched	Arched	Arched or Alpine
Structural requirements	High	Low	Low	Moderate
Life	Indefinite	2-3 years	2-3 years	5-25 years

Heating requirements

In a well-run greenhouse, heating costs can amount to nearly twenty percent of the total operating cost. Heating costs for conventionally-heated systems range from about $0.50 to $1.25 per square foot annually; in Idaho $1.00 per square foot is probably typical.

Greenhouses are designed to collect and store energy using the greenhouse effect. Radiant energy from the sun passes through the greenhouse covering and warms up the plants, soil and other objects in the greenhouse. While some of this energy escapes from the greenhouse, much of it is trapped inside in the form of heat. Consequently, heat that enters the house is largely retained throughout the day and into the night. Unfortunately, solar heating is insufficient in cooler weather, and supplemental heat must be supplied.

The night temperature of greenhouse crops ranges mostly from 45 to 70°F. As a general rule, day temperatures should be maintained 5 to 10°F higher than the night temperature on cloudy days and 15° higher on clear days. When light is limited, such as at night and on cloudy and winter days, temperatures can be kept lower. The reason is that plant growth will be limited by the factor in least supply. Warmer temperatures will not enhance growth if lighting conditions are not optimum. Higher temperatures should be maintained when light intensity is greater.

Heat loss from a greenhouse is composed of three components; 1) conduction - loss of heat through covering materials, which accounts for most of the heat loss, 2) infiltration - the passage of warm air outward and cold air inward through cracks between panes of glass or panels of fiberglass, and around doors and ventilators, and 3) radiation - the emission of energy from warm objects inside through the covering to colder objects outside without significantly warming the air.

In order to select a heating system for a greenhouse, the first step is to determine the peak heating requirements for the structure. Heating requirements will be dependent on several factors including the materials used for construction, the surface area of the walls and roof, the volume of air contained in the greenhouse, the required indoor air temperature, the average temperature for the coldest expected day and the average wind speed during the coldest day.

Detailed calculations can be made to obtain an accurate estimate, but as a rough approximation Figure 3 can be used. The design temperature difference should be computed by subtracting the design outside temperature (which is valid for all but 22 hours per year during the heating season) from the temperature that must be maintained indoors. Table 2 lists design outside temperatures for selected Idaho cities. Heat loss in interconnected greenhouses will probably be less since less covering is exposed to outside air. For greenhouses constructed with more than one type of material, heat losses can be estimated using Figure 3 according to the relative surface areas of each material used.

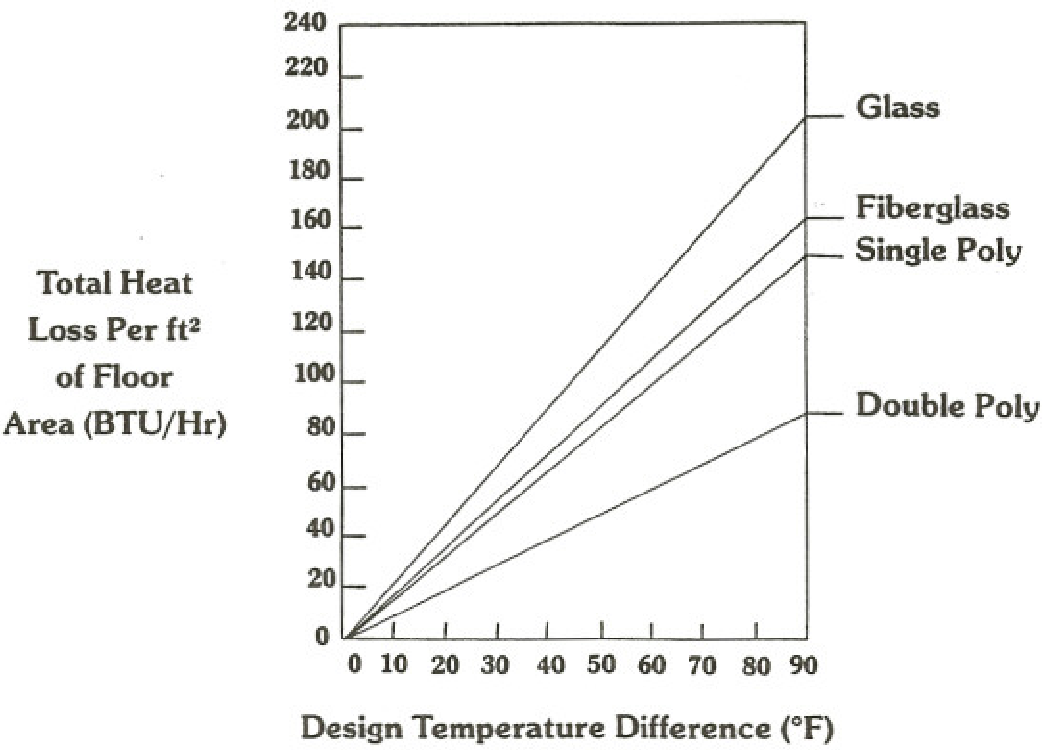

Figure 3 Total Heat Losses in Greenhouses

Table 2. Design Outside Temperatures for Selected Idaho Cities.

Boise	10°F	Moscow	0°F
Burley	2°F	Mountain Home	12°F
Coeur d'Alene	-1°F	Pocatello	-1°F
Idaho Falls	-6°F	Twin Falls	2°F
Lewiston	6°F		

Resource evaluation

The first step in assessing the feasibility of heating with geothermal water should be evaluating the available resource. Knowing the energy content of the resource will determine how big the greenhouse can be and what types of heating systems can be used.

Water temperature and flow rate are the two factors that determine the energy content of the resource. Water temperatures suitable for use in heating can range from about 90°F to more than 200°F. The flow rate that must be maintained is dependent on the heat load of the greenhouse and the degrees of heat extracted from the geothermal water. Typically, a system can extract from 10 to 40°F depending on the supply water temperature. The flow rate that will be required can be computed from the following formula:

$$W = \frac{HL}{500\ \Delta t}$$

where
- W = water flow rate in gallons per minute (gpm)
- HL = heat loss of the greenhouse in BTU/hr
- Δt = heat extracted from water in degrees F

This formula should be used concurrently with heat loss calculations to insure that heating requirements for the size of the proposed greenhouse can be met with the available water.

As an alternative to the formula given above, Figures 4 through 7 can be used to determine required flows per acre of greenhouse area. Each figure shows four curves, corresponding to different degrees of heat extraction from the geothermal water. Once again, the design temperature difference is the difference between the desired indoor temperature and the design outdoor temperature.

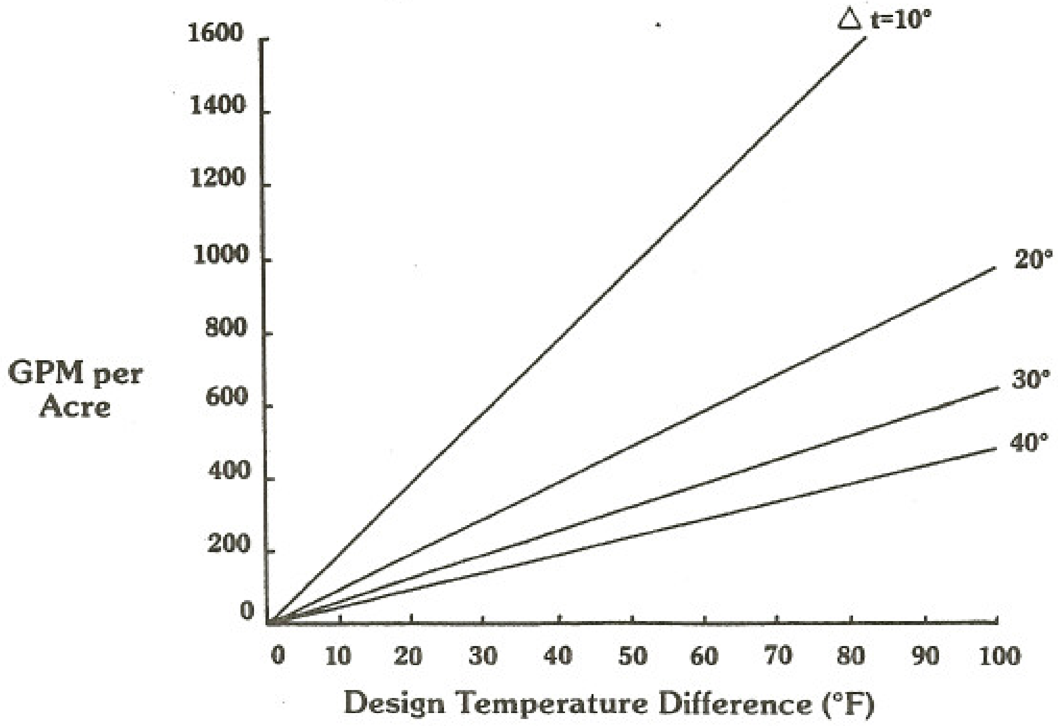

Figure 4 Required Water Flows per Acre of Glass Greenhouse

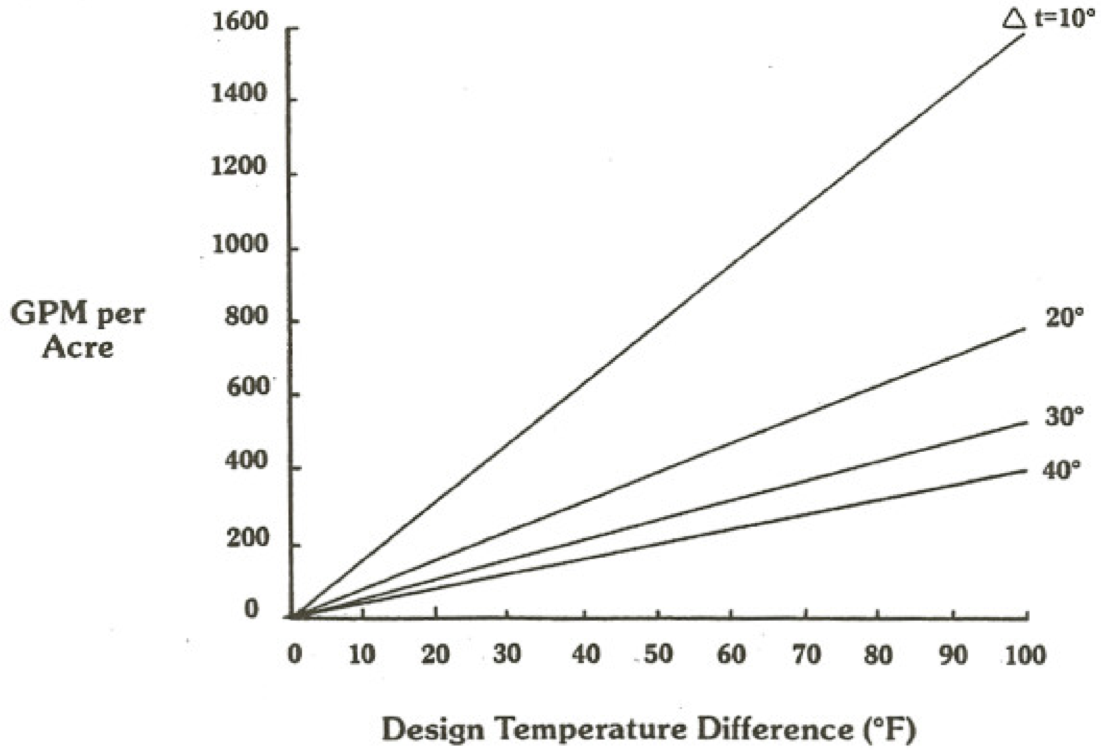

Figure 5 Required Water Flows per Acre of Fiberglass Greenhouse

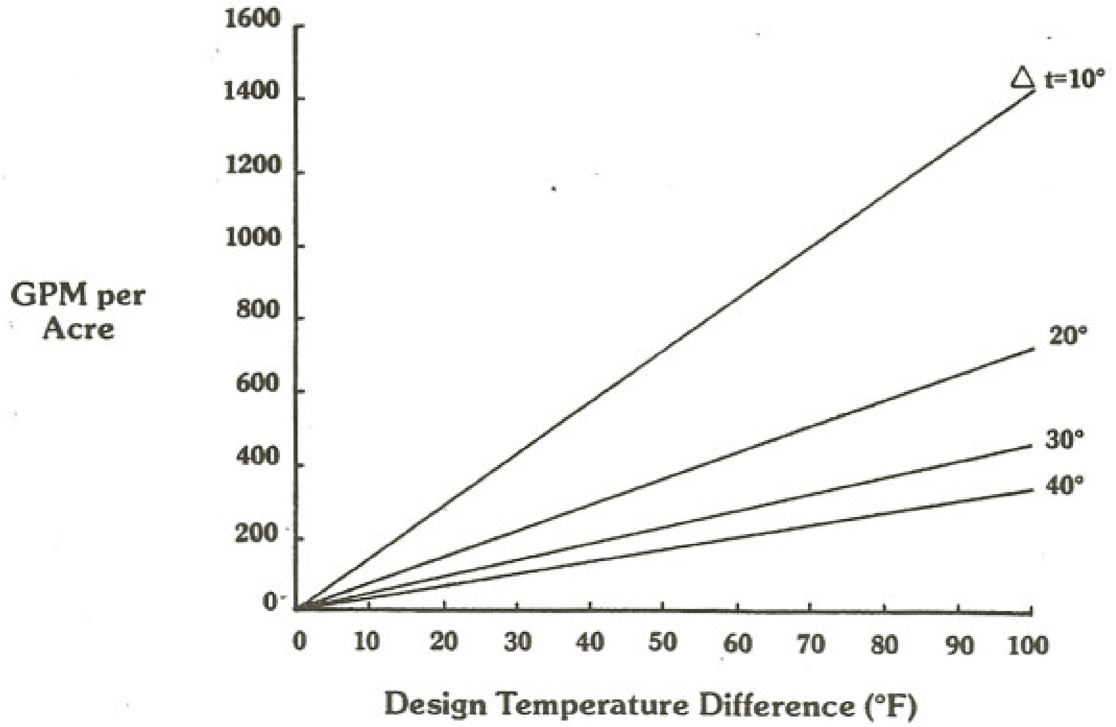

Figure 6 Required Water Flows per Acre of Single Poly Greenhouse

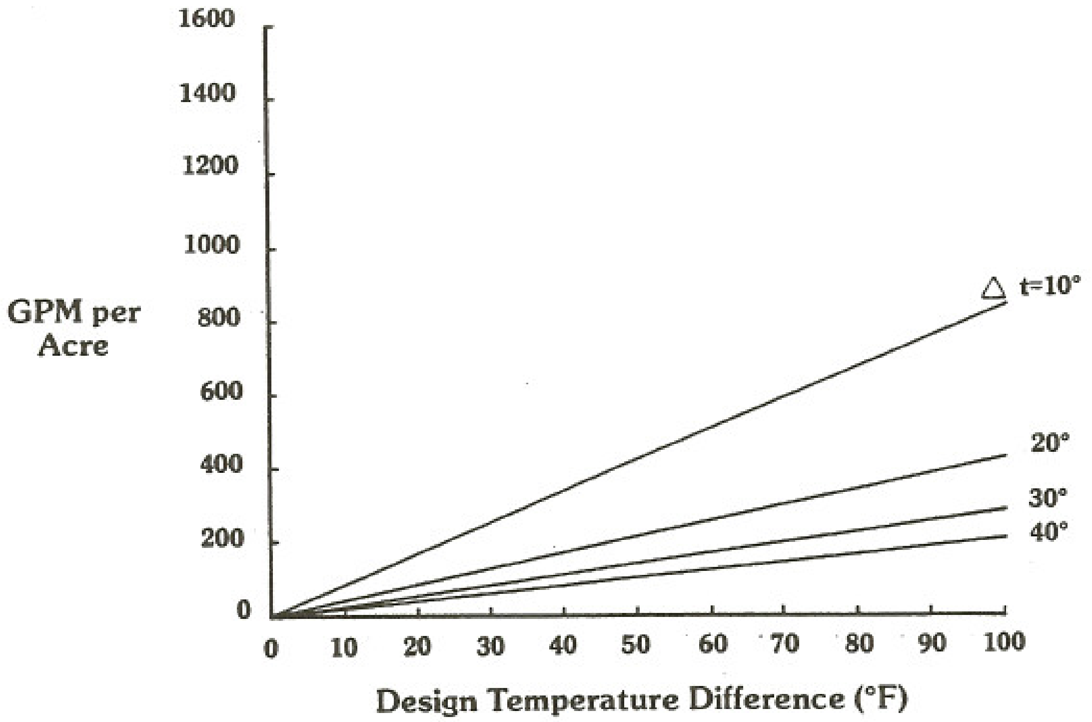

Figure 7 Required Water Flows per Acre of Double Poly Greenhouse

Heating systems

In the selection of a greenhouse heating system, the engineering and economic advantages of various heating methods should be carefully considered, although horticultural considerations and grower preference may dictate the final selection. Personal experience with a particular system and with specific crops may convince a grower to forego some energy efficiency in exchange for decreased risk, increased convenience or better crop yields. Backup heating should also be considered since as little as one hour of cold temperatures can destroy an entire greenhouse crop.

Horticultural considerations can also be extremely important in selecting a heating system. As a general rule, heating devices should be placed either on or below benches for crops grown on bench tops, while crops grown on the ground do best with heating systems placed in the floor. Put another way, plants like warm roots.

Crops susceptible to leaf mildew, such as roses and mums, require closely controlled humidity and adequate air circulation. Systems employing fans, tubes and air deflectors could be required to distribute warm air evenly and to maintain circulation. Some plants, such as tropical and subtropical potted plants, may grow better with higher soil temperatures. This could be accomplished by growing the plants directly on a heated floor or on benches warmed by small radiant tubes attached to the bench tops. In cold, wet climates overhead heating systems could be preferred to keep snow from accumulating on the roof and inhibiting light entry in the winter. Since some plants may require shading at times during the growing cycle to promote blooming, shades may restrict the type of air handling equipment employed, and consequently the type of heating system installed. Shadows caused by overhead heating and air handling equipment may also have some influence on the system selected.

Types of heating systems

There are five basic types of heating systems commonly used for heating greenhouses. Of course, there are also many hybrid systems and adaptations depending on the crops being grown and on the grower. Only five basic methods will be discussed here.

Forced Air

Forced air systems consist of a fan which forces air across a finned coil through which hot water circulates (Figure 8). Some systems, called unit heaters, use a propeller-type fan and can discharge air in a vertical or horizontal pattern. High performance unit heaters use a centrifugal or "squirrel cage" fan and deeper coils (more rows of tubes). Both types of equipment are generally hung from the ceiling and discharge air directly into the greenhouse or into a perforated plastic distribution tube running the length of the greenhouse. Standard unit heaters are available as off-the-shelf units, while high performance unit heaters are more often custom designed. Coil thickness, number of rows of coils, and fin spacings can all be adjusted to achieve more effective heat transfer. Extracting more heat from each gallon of water is more costly in terms of both equipment and electrical power, but pumping costs are less due to reduced water requirements. Also, more greenhouse area can be maintained with the same resource.

Most coil systems are constructed with small diameter copper tubes having very long flow paths. Copper is extremely susceptible to corrosion if small concentrations of hydrogen sulfide (indicated by a rotten egg odor) or ammonia are present. Scaling (deposition of mineral compounds on the pipe surfaces) can also be a problem in some waters. Consequently, if coil-type heaters are used, an isolation heat exchanger is recommended.

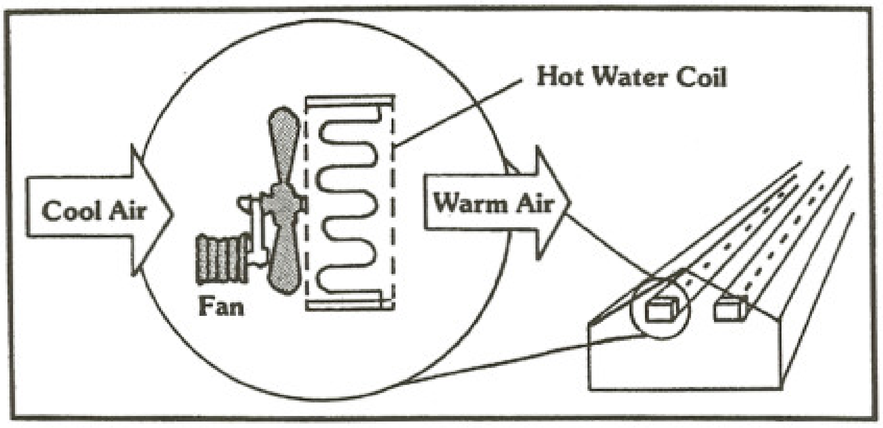

Figure 8 Forced Air Heating System (adapted from: EG & G Idaho, Inc.)

Finned pipe

Finned pipe, as illustrated in Figure 9, consists of a steel or copper pipe to which steel or aluminum fins have been attached. Finned pipes can be found inside hot water baseboard radiators in homes, although they are probably smaller in diameter since heating requirements are not as great as in a greenhouse.

The heating capacity of finned pipe is dependent on fin size, pipe diameter and water flow velocity. Since most hot water heating equipment is rated based on a standard average water temperature of 190°F and an entering air temperature of 65°F, de-rating factors must be applied for different water and air temperatures as may occur in geothermal applications. For resource temperatures below about 150°F, or in very cold climates, finned pipe is not a particularly effective heating system because the lengths of pipe required become impractical.

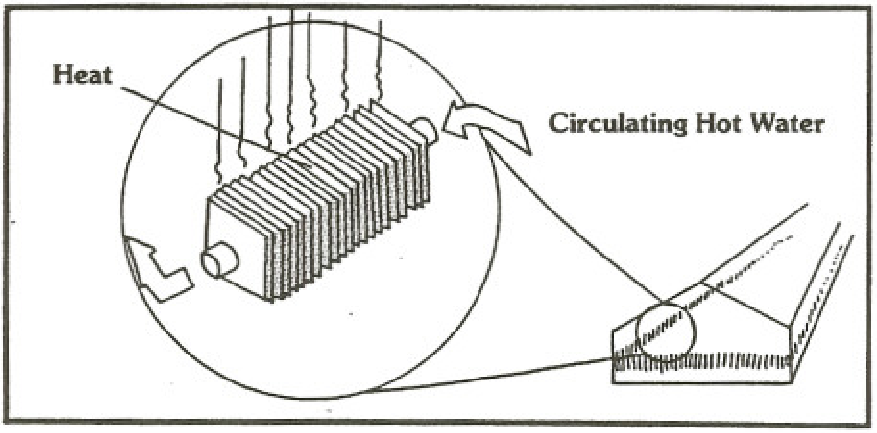

Figure 9 Finned Tube Convective Heating System (adapted from: EG & G Idaho, Inc.)

Soil heating

Air inside a greenhouse can be heated by passing hot water through tubes buried in the floor to warm the soil, which in turn, radiates its heat to the air (Figure 10). Normally, a plastic tubing such as polybutylene is used since it can withstand high temperatures, is not susceptible to corrosion as are steel or copper; it also is flexible, making installation easy. PVC is also sometimes used, but not as frequently because of its temperature limitations and its rigid form. Polyethylene and other flexible plastics are used infrequently due to temperature restrictions.

A soil heating system offers several advantages over other systems, including an even temperature distribution from floor to ceiling, free floor and overhead space, and no shadows due to overhead equipment.

One disadvantage, however, is that in order to maintain adequate air temperatures the floor must be kept quite warm. A high floor temperature can be uncomfortable to workers over long periods and can be too warm for plants grown on or near the floor. In addition, a great deal of piping material may be required. This type of system can be used in mild climates, or where inside design temperatures are low, but in many cases a secondary system is used to meet high heat demands.

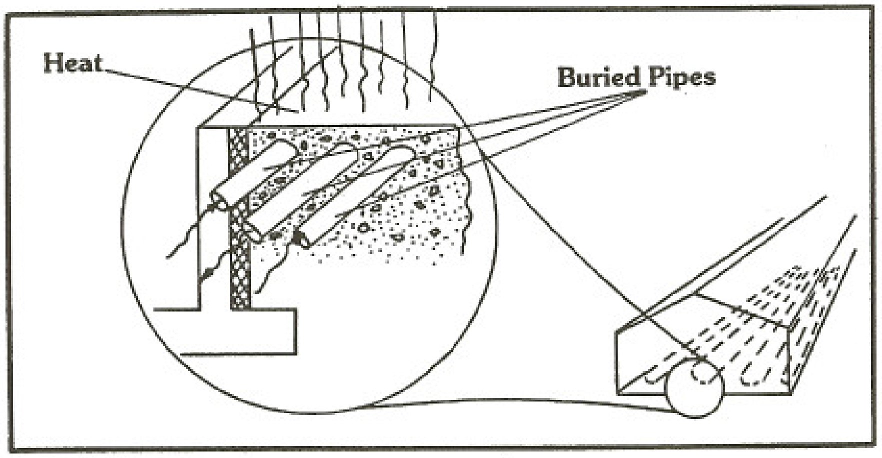

Figure 10 Buried Soil Heating System

Bare tube systems

A bare tube system (Figure 11) operates similarly to a soil heating system, except that the tubes are not buried and are usually much smaller in diameter. Several small tubes, each separated from one another, make up a heating element. Heating elements are usually placed on the floor or under benches, while some can be placed overhead. A disadvantage of this system, as with a soil heating system, is that large amounts of tube may be required, especially in cold climates.

Temperatures are most effectively controlled with this system by regulating the temperature of water entering the tubes using a heat exchanger, but can be controlled by regulating the amount of water entering the system.

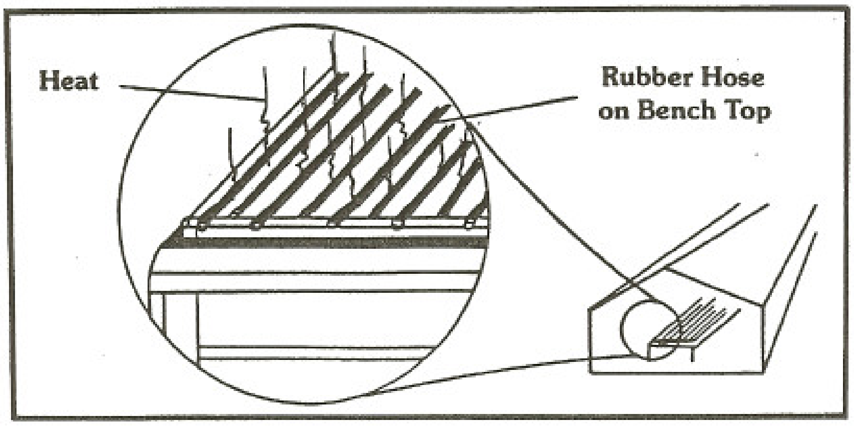

Figure 11 Bench Top Heating System

Heat pumps

For geothermal waters less than about 90°F, but greater than 40°F, a heat pump system may be possible (Figure 12). Heat pumps tend to be expensive initially; therefore, a careful comparison should be made with the cost of alternative heating methods.

A heat pump extracts heat from the geothermal water and transfers the heat to air inside the greenhouse. It differs from a heat exchanger and forced air system in that a refrigerant, usually freon, is used as an intermediate fluid. Energy is released as the intermediate fluid condenses from a gas to a liquid, allowing the temperature of air exiting the heat pump to exceed the incoming geothermal water temperature. In the summer, heat pumps can be used for cooling. A heat pump is manufactured as a self-contained unit, but requires an air distribution system such as a perforated tube.

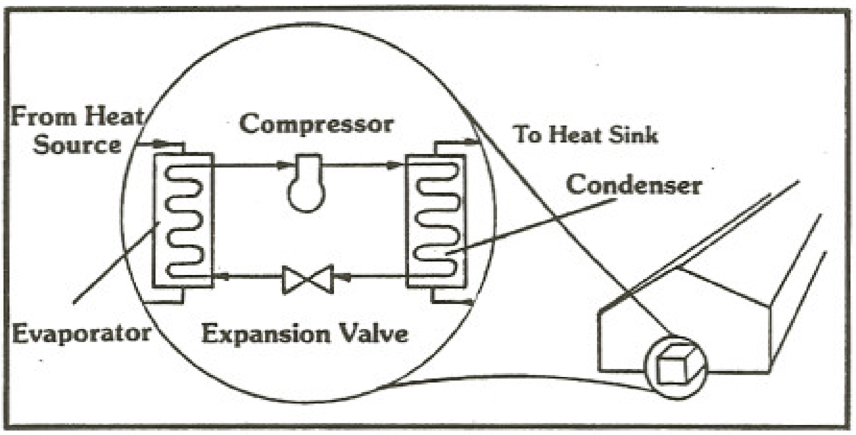

Figure 12 Heat Pump System (adapted from: EG & G Idaho, Inc.)

Cooling and ventilation

Nearly all greenhouses require some cooling or ventilation at various times during the year. Cooling can be as important as heating, since one hour of overheating can be disastrous. Ventilation is important to control humidity, insects, disease and carbon dioxide content in the air. When outside air temperatures are low enough, simply introducing a small volume of already cool air to the inside can provide adequate cooling. Cool air must be introduced to a turbulent flow, high in the greenhouse gable so that it thoroughly mixes with the interior air before reaching the plant zone; otherwise cold spots occur. Typically the same fan-tube system used for forced air heating is used for ventilation. The system consists of a fan that draws air into the greenhouse through a louvered air inlet in the gable, and a polyethylene tube with holes along the sides for turbulent air emission that runs from the inlet along the length of the greenhouse. A typical arrangement is shown in Figure 13.

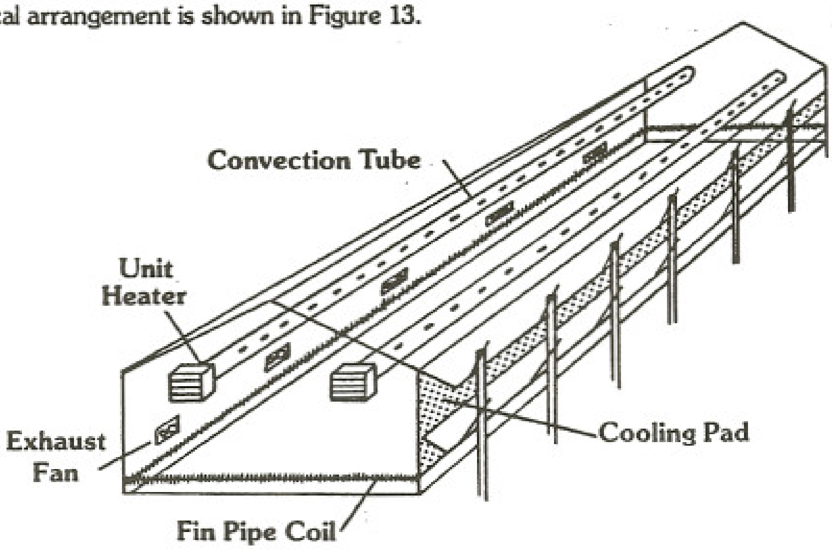

Figure 13 Typical Greenhouse Heating and Ventilation System

(source: Paul V. Nelson, GREENHOUSE OPERATION AND MANAGEMENT, 3/E, ©1985, p. 161. Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, New Jersey.)

In the warmest months, simple ventilation is not enough to sufficiently cool a greenhouse. Most greenhouses use evaporative cooling systems in which heat is absorbed during the evaporation of water. An evaporative cooling system consists of pads on one wall through which water is circulated, and exhaust fans on the opposite wall. Air entering through the pads is cooled and then drawn across the greenhouse to exhaust fans. Pads may be mounted horizontally or vertically, and are composed of crossfluted cellulose material similar in appearance to corrugated cardboard. Cooling depends on the surface area of the pads and the rate of air exchange. It is best if pads are placed on the windward side of the greenhouse, and fans are placed on the leeward side.

Temperature control

Temperature control in modern greenhouses is handled by a multi-stage thermostat that regulates heating, evaporative cooling and ventilation. Some systems can also control humidity.

In large greenhouses several thermostats may be used to regulate heating and cooling of zones, so that temperatures can be kept more uniform throughout the greenhouse. Depending on the particular situation, certain areas will almost inevitably be more prone to being either too warm or too cold. Thermostats are normally placed at about the same level as the plant crop.

Water quality considerations

The chemical quality of geothermal water is an important factor to be considered in evaluating its usefulness for greenhouse operations. Water suitable for heating may not be suitable for irrigation, and a secondary source of water may be required. Chemical composition is very site specific and can vary widely; however, many geothermal waters have characteristically high levels of some constituents. It is strongly recommended that a chemical analysis be performed on any water being considered for use. The water should be evaluated in terms of its usefulness for irrigation and its corrosivity.

Irrigation

Whether or not a given water is suitable for irrigation in the greenhouse is a very complex question and may depend on many factors not directly associated with chemical composition. Similarly, some indicators of chemical quality are interdependent and when considered alone may not give a good indication of a water's suitability. Generally, however, features of the chemical composition that need to be considered include concentration of dissolved matter in the water, the concentrations of certain potentially toxic constituents and the relative proportions of some of the constituents present. Table 3 gives some permissible limits for important water characteristics.

Table 3. Permissible Limits of Selected Characteristic for Irrigation Water

	Specific conductance (micromhos per centimeter @ 77°F)	Total dissolved solids (parts per million)	Sodium absorption ratio	Boron (parts per million)
Excellent	<25	<175	<10	<0.33
Good	25-75	175-525	10-18	0.33-067
Permissible	75-200	525-1400	18-26	0.67-1.00
Doubtful	200-300	1400-2100	26-100	1.00-1.25
Unsuitable	>300	>2100	>100	>1.25

Flouride, a constituent that is often present in high concentrations in geothermal waters, can be injurious to some green plants at levels of 0.5 to 1.0 parts per million. Sensitivity depends upon the plant and may be lessened by modifying watering methods.

Proper fertilizer application or periodic replacement of the growing media may compensate for some of the limitations given here or may increase plant tolerance for less than ideal conditions. Because various species have different tolerance limits, water quality must be evaluated for a particular greenhouse operation.

Corrosion

Although most geothermal waters in Idaho are relatively "clean" in comparison to other geothermal waters in the U.S., corrosion of piping and equipment can still be a problem unless good design practices are followed and proper materials are selected. Ideally, the design philosophy should be to transfer heat using heat exchangers to another medium so that the kind and number of components contacting the geothermal fluid are minimized, and to make those components contacting the fluid of corrosion resistant materials. Figure 14 illustrates this philosophy.

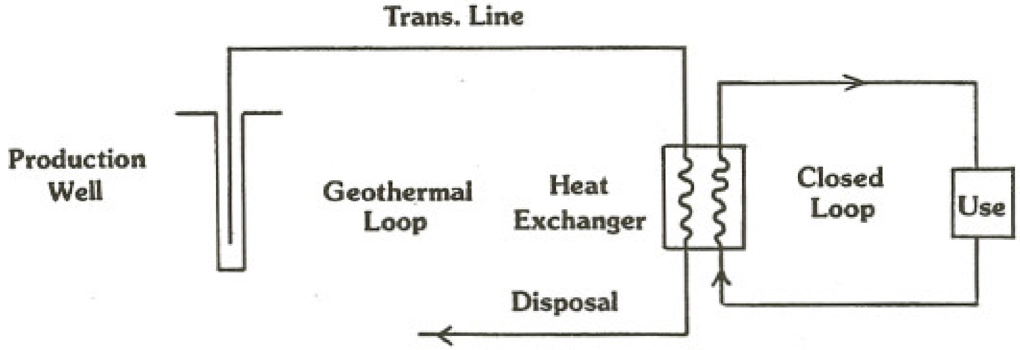

Figure 14 Closed Loop Heating System Using a Heat Exchanger

One advantage of this type of system is that it is simple to operate. Another advantage is that maintenance requirements are less, since less of the system is in contact with geothermal fluids. Finally, oxygen intrusion into the geothermal fluid - one of the primary causes of extreme corrosion in carbon and low-alloy steels - is not as critical.

A summary of several corrosive constituents commonly found in geothermal waters is shown below.

Oxygen - very low concentrations cause significant increases in the rate of corrosion of carbon and low-alloy steels.

Hydrogen sulfide - indicated by a rotten egg odor, commonly occurs at low levels in geothermal fluids above 120°F; in combination with oxygen it is extremely corrosive to susceptible alloys including copper.

Ammonia - corrosive to some copper alloys.

Carbon dioxide species - accelerates corrosion rates in steels.

Chloride - corrodes carbon and stainless steel alloys.

Sulfate - corrodes cements.

A summary of the corrosive characteristics of some materials commonly used in geothermal systems is shown below.

Carbon and low-alloy steel - oxygen must be rigorously excluded and exterior surfaces must be protected from groundwater.

Copper - commonly found in some fan-coil units and tube heat exchangers, corrodes rapidly in the presence of hydrogen sulfide in combination with oxygen, corrodes in the presence of sulfide species. Solders used in copper systems are also extremely corrosion prone.

Stainless steels - used primarily in plate-type heat exchangers because of cost are not affected by hydrogen sulfide. Some types corrode in the presence of chloride at high temperatures.

Aluminum alloys - unacceptable in nearly all geothermal waters.

Titanium alloys - highly corrosion resistant, used only in plate-type heat exchangers due to high cost.

Plastics (chlorinated polyvinyl chloride and fiber reinforced plastic) - not affected by oxygen intrusion, easily fabricated, low cost, subject to creep and rupture at high temperatures.

Disposal of geothermal fluids

After the useful heat has been extracted, the geothermal water must be discharged in an economical and environmentally acceptable manner. Subsurface disposal (injection) is the preferred method, although surface disposal may be acceptable in some instances. State and federal laws strictly govern the disposal of geothermal waste water, and they should be thoroughly researched before proceeding with any project.

Summary

One of the most expensive items in a greenhouse is the operation of the heating system. Geothermal water, where available, can be utilized as a source of heat to significantly reduce costs. When contemplating the construction of a greenhouse a careful evaluation should first be made of the available resource and of the necessary permits required. With this information in hand, design of the greenhouse, including size, construction materials, and heating system can then proceed. Along with the energy aspects, horticultural factors will play an important role in the greenhouse design and operation.

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