INTERNATIONAL SUMMER SCHOOL
on Direct Application of Geothermal Energy
Under the auspice of the Division of Earth Sciences

INTRODUCTION TO GEOTHERMAL GREENHOUSE DESIGN

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1. INTRODUCTION

A number of commercial crops can be raised in greenhouses, making geothermal resources in cold climates particularly attractive; however, growth can even be optimized in warmer climates. These include vegetables, flowers (potted and cut), house plants, and tree seedlings. As an example, the optimum growth temperature of cucumbers, tomatoes, and lettuce is shown in Fig. 1 below (Barbier and Fanelli, 1977). Cucumbers grow best in the temperature range 25°- 30°C, tomatoes near 20°C, and lettuce at 15°C and below. The growing time for cucumbers is usually 90 to 100 days; while, the growing cycle for tomatoes is longer, in the range 9 to 12 months. The use of geothermal energy for heating can reduce operating costs (which can amount for up to 35 percent of the product cost) and allows operation in colder climates where commercial greenhouses would not normally be economical. In addition, greenhouses are suited to large quantities of relatively low-grade heat. Furthermore, better humidity control can be derived to prevent condensation (mildew), botritis, and other problems related to disease control. (Schmitt, 1981).

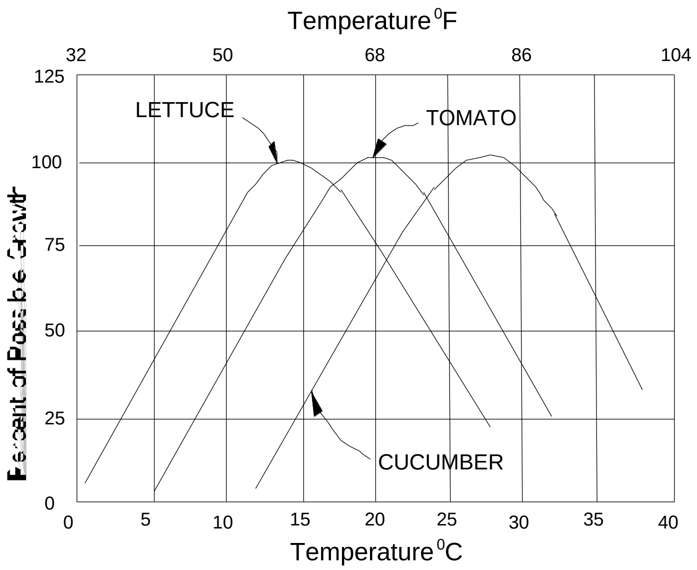

Figure 1. Optimum growing temperature for selected agricultural products.

Greenhouses are one of the largest low-enthalpy energy consumers in agriculture; thus, geothermal energy can provide the necessary heating for greenhouses (Popovski, 1998). Some of the advantages of using geothermal energy are:

* Good correlation between the sites of greenhouse production area and low-enthalpy geothermal resources,
* Low-enthalpy geothermal resources are common in many countries,
* Geothermal energy requires relatively simple heating installations, but advanced computerized installations can later be added for total conditioning of the inside climate in the greenhouses,
* The economic competitiveness of geothermal energy for greenhouse heating, especially in colder climates,
* Strategic importance of energy sources that are locally available for food production, and
* Using a geothermal resource in combination with and existing fossil fuel system for peak heating.

2. EXAMPLES OF GEOTHERMALLY-HEATED GREENHOUSES

There are numerous uses of geothermal energy for greenhouse heating throughout the world, estimated at 17,864 TJ/year (4,963 GWh/yr)(Lund & Freeston, 2000). In the USSR, it is reported that over 2,500 ha of agricultural land are heated by geothermal of which 32 ha are covered by greenhouses. In Hungary, over 90 ha of greenhouses are heated geothermally. Many of these greenhouses are built on rollers, so they can be pulled from their location by tractors, the ground cultivated with large equipment, and then the greenhouse returned to its location. In addition, to minimize the cost, much of the building structure pipe supporting system also acts as the supply and radiation system for the geothermal fluid. Greenhouses cover about 40 ha in Japan where a variety of vegetables and flowers are grown. Individual greenhouses, operated by farmers and covering 300 - 1,500 m^2 use 70^o - 100^oC geothermal water. Many large greenhouses totaling about half a hectare, are operated as tropical gardens for sightseeing purposes. New Zealand has numerous greenhouses using geothermal hot water and steam. At the Land Survey Nursery in Taupo, greenhouses are heated by geothermal steam and soil is sterilized (pasteurized) at 60^oC to kill insects, fungus, worms, and some bacteria. In Iceland, over 29 ha are heated, including a greenhouse, restaurant, and horticulture college at Hveragerdi. Everything from bananas, coffee beans, cacti, and tropical flowers to the standard tomatoes and cucumbers are grown in these greenhouses. Studies of the economic feasibility of greenhouses in Iceland have been based on theoretical 33.5-ha facility, which would grow asparagus on 10 ha, flower seedlings on 1 ha, and cucumbers on 0.5 ha. Projected profit on the initial investment would amount to 11 percent before taxes, and the greenhouses would provide jobs for 250 persons (Hansen, 1981).

Based on papers for the WGC2000 and more recent communications, the following estimates are made for the top countries using geothermal energy for greenhouse and soil heating:

*	Tunisia	102 ha
*	Hungary	90 ha
*	China	69 ha
*	Italy	50 ha
*	USA	50 ha
*	Romania	43 ha
*	Japan	40 ha
*	Russia	32 ha + covered ground
*	Iceland	29 ha
*	Bulgaria	22 ha

These numbers are somewhat different than those presented by Popovski (1998); however, in most cases, the actual number of hectars was not reported for WGC2000, and the energy use for some countries (TJ/yr) did not agree with what would be expected for the number of hectars. A total of 27 countries have reported using, geothermal for heating greenhouses and covered ground, totaling about 18,000 TJ/yr, with an installed capacity of 1,246 MWt giving a capacity factor 0.45. Based on what appears to be reliable numbers, the amount of energy use varies from 15 to 23 TJ/yr/ha, and thus, using an average of 19 TJ/yr/ha, this would estimate that there are around 940 ha presently using geothermal energy for heating. Of course, the energy use is a function of location, number of heating days, solar radiation, type of construction, wind, etc.

One of the most successful geothermal greenhouse operations, that has been growing steadily is in Tunisia (see paper by Mohamed and Lund in these proceedings). Starting with 21 ha in 1988, reaching 80 has in 1998 and today, 102 ha are in operation raising cucumbers, tomatoes, watermelons, melons and peppers. By the end of 2002, the area will be

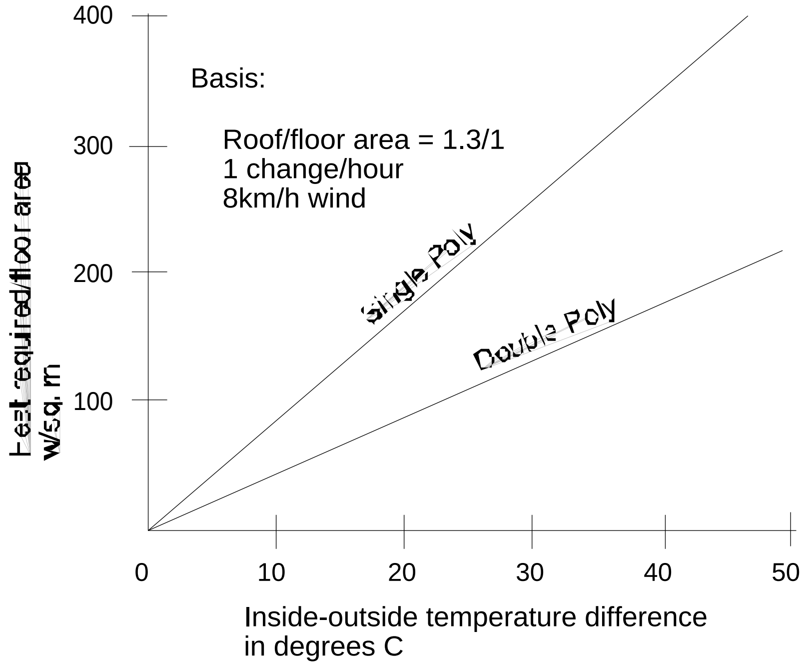

Figure 2. Example of heat requirement for greenhouses in La Grande, Oregon (outside design temperature = -17^{o}C).

increased by 14 ha.

Numerous geothermally-heated greenhouses exist in the U.S.; several examples are described as follows. In Salt Lake City, Utah, a 23,000-m^2 greenhouse is using 12.6 L/s of 49^{o}C water for heating. Utah Roses, Inc., is producing cut roses for a national floral market. The 1,200-m geothermal well has replaced a natural gas/oil heating system. Twenty-four kilometer south of Klamath Falls, Oregon, on the Liskey ranch, approximately 4,600 m^2 of greenhouses are heated with 90^{o}C water from a 82-m deep well. One of the greenhouses consists of four 13-m by 46-m buildings connected to form one large complex. Initially, seedlings were raised for federal and private agencies. More recently succulents, cacti, and potted plants are raised. All plants are grown in trays on raised tables, with the heat supplied by pipes under each table (Laskin, 1978; Lund, 1994). A Honey Lake, California, near Susanville, over 30 9-m by 38-m quonset-design greenhouses were used to raise cucumber and tomatoes. The vegetables are raised by hydroponics, with the heat being supplied by forced-air heaters. Production rates were about 680 kg of cucumbers per unit per week and 358 kg of tomatoes per unit per week. The cover of each greenhouse consisted of two layers of 6-mil sheeting (plastic). A small electric air blower continually inflated the area between the two

layers and maintained an air space of about 15 cm, resulted in heat savings of approximately 40 percent over conventional coverings. The savings, using geo-thermal heat as compared to conventional fuel, averages $11,100/ha/year (Boren and Johnson, 1978). A similar analysis has been made for a greenhouse provided in La Grande, Oregon. The double 6-mil polyethylene covering required 45 percent less heating than single layer (Higbee and Ryan, 1981) (Fig. 2).

One of the world's largest geothermally-heated greenhouse operations is near Mt. Amiata, Italy. Approximately 22 ha of greenhouses are used to produce potted plants and flowers. Waste heat is supplied from a 15-MWe power plant. The greenhouse is operated in conjunction with an experimental drier that operates during the summer months when greenhouse heating is low. This combination maximizes the utilization of the geothermal heat as shown in Fig. 3 (Lund, 1987).

Approximately 50 ha of greenhouses are heated geothermally in the United States. The largest single greenhouse operation is at Animas, in southwestern New Mexico, where 13 ha are used for raising cut roses. The three leading greenhouses locations are shown in Table 1. Additional details of geothermal greenhouse development in the U.S. is summarized by Lienau

(1997).

Table 1. The Three Leading Greenhouse Locations in the United States

Location	Annual Energy (TJ/GWh)	Capacity (MWt)	Load Factor	Area (ha)	Product
Animas, NM	220/61.2	32.8	21%	13.0	Cut roses & bedding plants
Newcastle, UT	145/40.3	18.4	25%	8.1	Potted plants
Radium Springs, NM	126/34.9	13.3	30%	5.3	Potted plants

3. GENERAL DESIGN CRITERIA

Greenhouse heating can be accomplished by (1) circulation or air over finned-coil heat exchangers carrying hot water, often with the use of perforated plastic tubes running the length of the greenhouse in order to maintain uniform heat distribution, (2) hot-water circulating pipes or ducts located in (or on) the floor, (3) finned units located along the walls and under benches, or (4) a combination of these methods. A fifth approach is using hot water for surface heating. Surface-heated greenhouses were developed several decades ago in the USSR. The application of a flowing layer of warm water to the outside surface of the greenhouse can provide 80 - 90% of the energy needed. The flowing layers of warm water prevent snow and ice from accumulating. However, this systems does not appear to be practical.

The most efficient and economical greenhouse development consists of large structures covering 0.2 - 0.4 ha (Fig. 4). A typical size would be 36 by 110 m constructed of fiberglass with furrow-connected gables. Heating would be from a combination of fan coils connected in series with a network of horizontal pipes installed on outside walls and under benches. A storage tank would be required to meet peak demand and for recirculation of the geothermal water to obtain the maximum temperature drop. Approximately 6.3 L/s of 60^{o} - 82^{o}C water will be required for peak heating. The average is much less. Fortunately, most crops require lower nighttime than daytime temperatures. Greenhouse construction and outfitting will run from \$54 to \$108 per m^2.

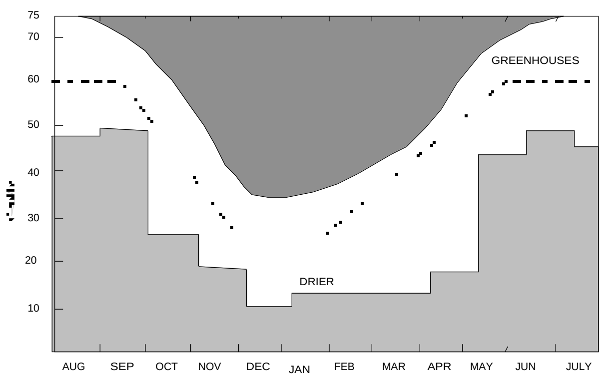

Figure 3. Geothermal energy consumed by greenhouses and drier at Mt. Amiata, Italy.

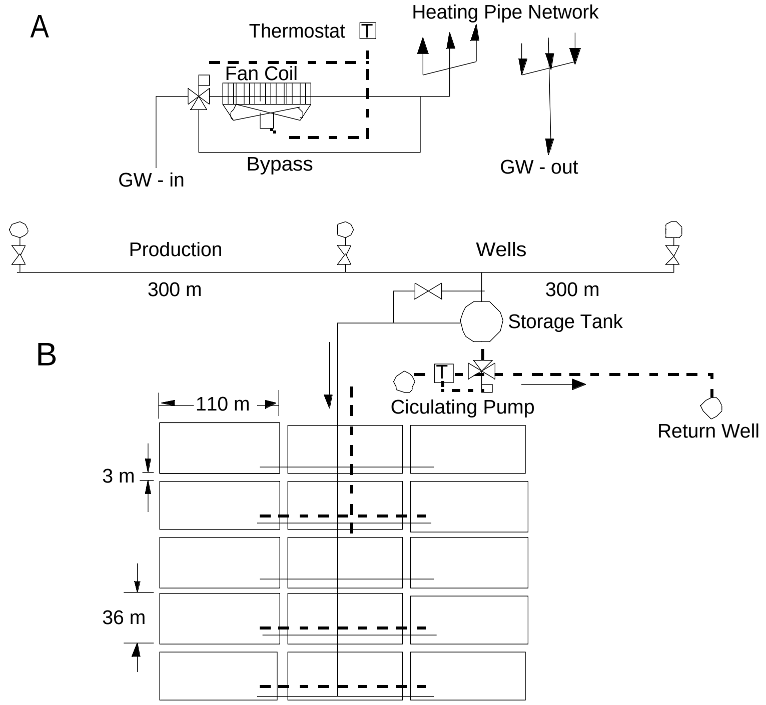

Figure 4. a) Unit heating system design (three per house); b) six-hectar greenhouse complex.

4. ADDITIONAL INFORMATION

An engineering design guide is available to determine the heating requirements along with designing various heating systems for a greenhouse (Rafferty, 1998 - using U.S. units) and (Rafferty, 2000 - using metric units). This design guide calculates heat losses for various types of greenhouse construction materials, and then determines the transmission and infiltration losses. It also provides information for the design of various heating systems, such a finned pipes, unit heaters, soil heating, bare tubes and combinations of these.

A "Geothermal Greenhouse Information Package" (Rafferty and Boyd, 1997) is also available from the Geo-Heat Center and will be described in a presentation by Boyd published in these proceedings. This package includes crop market prices, greenhouse operating costs, crop culture information, greenhouse heating systems, greenhouse heating equipment selection spreadsheet, vendor information, and other information services. This package is available from the Geo-Heat Center website: http://geoheat.oit.edu/pdf/green.pdf.

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