INTERNATIONAL SUMMER SCHOOL
on Direct Application of Geothermal Energy

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Division of Earth Sciences

GREENHOUSE AND AQUACULTURE INFORMATION PACKAGES

Compiled by Tonya L. Boyd
Geo-Heat Center, Oregon Institute of Technology
Klamath Falls, OR 97601

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INTRODUCTION

In response to numerous requests for information from prospective developers of greenhouse or aquaculture projects using geothermal energy, the Geo-Heat Center prepared two comprehensive documents to assist these developers (Rafferty and Boyd, 1997; Boyd and Rafferty, 1998). The content of these two documents is outlined below:

GEOTHERMAL GREENHOUSE INFORMATION PACKAGE

Greenhouse heating is one of the most common uses of geothermal resources. Because of the significant heat requirements of greenhouses and their ability to use low-temperature fluids (40 - 50ºC), they are a natural application allowing greenhouse operations to be sited in colder climates where conventional heating may not be economical. Geothermally-heated greenhouses have been in place since the late 1970s, and today there are at least 40 applications in 10 western states in the US and many installations in over 20 countries.

The use of low-temperature geothermal resources for space heating is fairly simple, often using standard, off-the-shelf equipment. If the geothermal fluid is corrosive or causes scaling, a plate heat exchanger can isolate the fluid from the greenhouse heating equipment. Most standard greenhouse heating systems: unit heaters with and without a plastic distribution tube, finned pipes, bare tubes, fan coil units, or a combination of these, are adaptable to geothermal. Fossil fuel peaking can be incorporated with the geothermal heat.

Low to intermediate temperature geothermal resources are widespread throughout the world providing a significant potential for expansion of the geothermal greenhouse industry.

Introduction

This package of information is intended to provide a foundation of background information for developers of geothermal greenhouses. The material is divided into seven sections covering such issues as crop culture and prices, operating costs for greenhouses, heating system design, vendors and a list of other sources for information.

Section 1 - Crop Market Prices

This section contains recent US wholesale price information for some typical vegetable and flower crops grown in greenhouses. Both US national and regional prices are included along with an indication of seasonal variations for some crops. Sources for current price information are provided at the end of the section.

Section 2 - Greenhouse Operating Costs

Information contained in this section outlines ranges of costs for a typical operation such as labor, utilities, plant stock and mortgage components. Market concerns and cost ranges for structure construction are also provided, as outlined below.

It is always a good idea to know your market. Questions to ask yourself before you grow anything are:

1. What is my product?
2. How much can be produced in the greenhouse?
3. Who will be buying my product?
4. How much will they pay for my product?
5. How much will it cost to grow this type of crop?
6. Finally, is this enough to make a profit or break even?

Greenhouse structure capital costs in the US varied with location with the northern climates having increased costs to reflect the need for additional thermal curtains. In west and southwest, evaporative cooling systems were considered. Some of the other variations in prices can be affected by the cost of materials and labor costs. The total greenhouse costs (includes greenhouse and operating equipment in the US) ranged from $122 - 153 /m^2 of greenhouse, with an average price of $136/m^2 of greenhouse. The construction costs alone were in the $79 - 87/m^2 range with an average of $80/m^2. Land costs is a significant portion of the total capital investment.

Depending on the region in the US, the operating budget distribution could look like this:

Labor	40-45%
Plants, supplies and materials	16-25%
Utilities (heating, lights, and water use)	6-16%
Loan payment	17-19%
Other (miscellaneous)	8-10%

Section 3 - Crop Culture Information

This section provides abbreviated culture information for the following crops listed below. Some of the parameters that are covered which can affect the growth in a greenhouse are temperature requirements, relative humidity, CO_2, lighting, dissolved oxygen, pH, electrical conductivity and disease issues. An extensive list of additional information sources is provided at the end of each crop culture section.

Tomatoes are the most common greenhouse vegetable crop. There are some claims by greenhouse growers that 14 or more kgs of marketable fruit can be expected per plant (or plant space) per year. Such production is only possible using quality facilities and cultural practices. Production of about 9 to 11 kgs would be more realistic in some regions. Tomatoes can be grown in a one-crop system (December-to-December) or a two-crop system (August-to-December and January-to-June). In a one-crop system, the crop is started in January and harvest is usually from March through November. The two-crop system is at less risk from crop pests, allows fruit set and harvest when environmental conditions are best, and competition from outdoor productions at its least.

Cucumbers grow more rapidly than tomatoes and produce earlier. European variety cucumbers are a popular greenhouse crop, producing fruits that weigh about 450 g and grow 30 to 35 cm long. In contrast to American cucumbers, European varieties set and develop fruit parthenocarpically (without pollination) resulting in fruits that are seedless. They require no bees for pollination and produce higher yields. Before production, you should determine if a suitable market is available in your area; because, they are distinctly different from conventional slicing cucumbers. Since this type is so different from conventional cucumbers, some markets can be found almost all year round.

The process discussed for hydroponic lettuce is for a production-intensive program, where the lighting and electrical power usage is high. Computer technology is also an integral part of this type of production of hydroponic lettuce. For the production of 1000 heads (140 g each) per day, a 660 m^2 growing area is required, which includes spacing of plants at day 21, from 100 plants/m^2 to 40 plants/m^2. To first grow leaf lettuce hydroponically, the growing process is broken into two different areas: the germination area and the pond area. In the germination area, the seeds are started and grown for 11 days; after 11 days they are transplanted to the pond area. The pond area is where the lettuce is grown until harvested on the 35th day.

The carnation is most famous for its use as a cut flower in the florist trade. The carnation is a member of the Caryophyllaceae or pink family. White is still the most popular color, followed by various shades of pink. Carnations are semi-hardy perennials treated as annuals. They grow best in well-drained soil exposed to full sun and cool conditions. The lightly-to-heavily fragrant blooms are excellent for cut flowers and bedding plants, and the miniature types can be used in pot culture. Foliage is slightly-to-light green, linear, and borne on stiff erect stems. Flowers are 5 to 6 cm in diameter, usually fully-double, and exhibit a wide range of colors.

High quality roses can be produced in many areas with the application of new technology in heat shields, high energy lighting, drip irrigation and fertilizer application, high pressure mist for cooling and humidity control, and CO_2 enrichment. The structure of the greenhouse needs to be one that will give full sunlight to all plants. There should be no shading from other greenhouses, buildings or trees. The house should have 7-ft gutters so the roses will not touch the glass when they are at their highest level of production. Rose structures should supply warm humid atmospheres with high light intensity during daytime.

Section 4 - Greenhouse Heating Systems

Greenhouse heating is one of the most common uses of geothermal resources. Because of the significant heating requirements of greenhouses and their ability to use very low- temperature fluids, they are a natural application. The evaluation of a particular greenhouse project involves consideration of the structure heating requirements, and the system to meet those requirements.

The section contains the recently updated *Chapter 15 - Greenhouses* from the Geothermal Direct Use Engineering and Design Guidebook. Which covers greenhouse construction, heating requirements, and greenhouse heating systems. The greenhouse heating systems covered are finned pipe, standard unit heaters, low temp. unit heaters, fan coil units, soil heating and bare tube. The topic of peaking with conventional fuel is also covered.

Section 5 - Greenhouse Heating Equipment Selection Spreadsheet

The Greenhouse Heating Equipment Selection Spreadsheet (GHS) is a tool for evaluating the economics of various types of heating systems for greenhouses. Specifically, six systems are considered: unit heaters (UH), finned pipe (FP), bare tube (BP), fan coil units (FC), combination fan coil/bare tube (FC/BP) and low temperature unit heaters (GLW).

The spreadsheet is comprised of six individual areas, the primary input and output and five additional areas each of which covers one of the system types described above. One screen of the spreadsheet covers both the fan coil and fan coil/bare tube system input output.

The primary input contains 16 individual input items covering supply water temperature, greenhouse size and construction materials, and economics values. The primary output is divided into two areas. The first provides information concerning the peak heat loss of the greenhouse. The second area contains a table that provides information about the economics of the various types of heating systems for the greenhouse under consideration. Values for both capital and operating costs are displayed. The far right hand column of the table indicates total annual costs (owning, maintenance and electrical costs) for each of the systems per square foot of greenhouse floor area. These values can be compared to determine the lowest cost system for the particular application. The remaining five screens cover the details of each of the individual systems and the costs associated with them.

The costs calculated on the individual system screens and finally for the primary output table, consider only the costs of the terminal heating equipment and branch lines. Because all six systems are compared at the same supply water temperature and delta T, the costs for the central equipment and piping would be the same. The only variation in cost for individual systems is for the terminal equipment itself. It is useful to be familiar with greenhouse heating systems and technology before using this spreadsheet.

Section 6 - Vendor Information

This section provides a list of US vendors for components of geothermal systems, and greenhouse structures and equipment such as fiberglass, space heating equipment, well pumps, plate heat exchangers, plant materials (seed and plants) and hydroponic systems.

Section 7 - Other Information Services

An extensive list of sources for information on greenhouse operations including state extension agencies, and USDA state offices is provided in this section.

AQUACULTURE INFORMATION PACKAGE

Aquaculture pond and raceway heating is one of the most common uses of geothermal resources. Because of the signifycant heating requirements of these facilities and their ability to use low-temperature fluids (30ºC), they are the natural application. This use of geothermal resources allows aquaculture operations to be sited in colder climates or closer to markets where conventional heating may not be economical. Geothermally-heated aquaculture ponds have been in place since the 1970s, and today there are at least 30 applications in 12 western states in the US and many installations in 16 countries.

The use of low-temperature geothermal resources for pond and raceway heating is fairly simple, often using standard, off-the-shelf equipment. If the geothermal fluid chemistry is not suitable for direct use, a plate heat exchanger can isolate the fluid from the ponds. Aquatic species such as Tilapia, catfish, Malaysia prawns, tropicals (cichlids), alligators and eels have been successfully raised using geothermal heat. In the Imperial Valley of California, 15 geothermal aquaculture operations produce 3.6 million kgs of catfish, Tilapia and hybrid striped bass annually.

Low temperature geothermal resources are widespread throughout the world providing a significant potential for expansion of the geothermal aquaculture industry.

Introduction

This package of information is intended to provide background information to developers of geothermal aquaculture projects. The material is divided into eight sections and includes information on market and price information for typical species, aquaculture water quality issues, typical species culture information, pond heat loss calculations, an aquaculture glossary, regional and university aquaculture offices and state aquaculture permit requirements.

Section 1 - Market and Price Information

This section contains information on the current status of the catfish and Tilapia markets in the U.S. For the catfish market, information is provided on US production, pond acreage, type of production and end market served. Tilapia data presented in the section includes US production figures, current price data and a brief summary of the international import volume.

Section 2 - Water Quality Issues in Aquaculture

This section contains an listing of some of the major water quality issues for aquaculture in general and explains the importance these factors which are important for fish survival. The water quality factors covered are temperature, dissolved oxygen, nitrogenous wastes, pH, alkalinity, hardness, carbon dioxide salinity, chlorine, and hydrogen sulfide. A summary of the water quality factors, test procedures, and preferred ranges are shown in Table 1.

Table 1. Water Quality Factors, Commonly Used Monitoring Procedures, and Preferred Ranges for Fish Culture

Water Quality Factor	Test Procedure	Preferred Ranges for Fish Culture

Temperature	Thermometer, Telethermister	species dependent
Dissolved Oxygen	Titrimetric (Modified Winkler) Polarographic meter, Calorimetric kits	>4-5 ppm for most species
Total Ammonia-Nitrogen (ionized and un-ionized)	Calorimetric kits (Nesslerization or Salicylate), Ion specific probes	NH_3<0.02
Nitrite	Calorimetric kits (Diazotization) Ion Specific probes	<1ppm; 0.1 ppm in soft water
pH	Calorimetric kits, Electronic meter	6-8
Alkalinity	Titrimetric with pH meter Titrimetric with chemical indicator	50-300 ppm calcium carbonate
Hardness	Titrimetric kit	>50 ppm, preferably >100 ppm calcium carbonate
Carbon dioxide	Titrimetric	<10 ppm
Salinity	Conductivity meter, Reflactometer Titrimetric	species dependent typically <0.5 - 1.0 ppt (For freshwater fish)
Chlorine	Calorimetric kit	<0.02 ppm
Hydrogen Sulfide	Calorimetric kit	No detectable level

Section 3 - Culture Information

Cultural information is provided for the following species of aquaculture: Tilapia, channel catfish, and prawns. The information covered in the Tilapia section includes information on flow-through systems, recirculating systems breeding and a summary of the five most popular cultured species of Tilapia. The catfish section contains information on water quality parameters, brood stock, and spawning. The prawn section has information on breeding, the growth stage from larvae, post larvae, juvenile and adult and feeding rate.

Table 2 taken from the Aquaculture Information Packet shows the temperature requirement and growth periods for selected aquaculture species.

Table 2 Temperature Requirements and Growth Periods for Selected Aquaculture Species[a]

Species	Extremes (°C)	Growth (oCF)	to Market Size (mos)
Oysters	0 to 36 typ	24 to 26 typ	24
Lobsters	0 to 31	22 to 24	24
Penaeid Shrimp			
Kuruma	4 to ?	25 to 31	6 to 8 typ
Pink	11 to 40	24 to 29	6 to 8
Salmon (Pacific)	4 to 25	15	6 to 12
Freshwater Prawns	24 to 32	28 to 31	6 to 12
Catfish	2 to 35	28 to 31	6
Eels	0 to 36	23 to 30	12 to 24

Tilapia	8 to 41	22 to 30	--	
Carp	4 to 38	20 to 32	--	
Trout	0 to 32	17		6 to 8
Yellow Perch	0 to 30	22 to 28	10	
Striped Bass	? to 30	16 to 19	6 to 8	

a. Behrends, 1978

Section 4 - Pond and Raceway Heat Loss Calculations

This section consists of the recently updated *Chapter 16 - Aquaculture* from the Geothermal Direct Use Engineering and Design Guidebook. One of the most common areas of interest in geothermal direct use is that of aquaculture. For those involved with the initial planning of such a project, one of the first questions to be addressed relates to project size. In most geothermal applications, the maximum pond area which can be developed is restricted by the maximum heat available from the resource. The purpose of this section is to present a brief introduction to the subject of heat loss from ponds (or pools) so that developers can make an informed evaluation of geothermal resources for this purpose. The heat losses to take into consideration are evaporation, convection, radiation and conduction. Some ways to reduce heat losses are discussed such as surface covers, pond enclosure and thermal mass.

Section 5 - Aquaculture Bibliography

The bibliography section provides a list of useful aquaculture references in the areas of general aquaculture, economics, culture systems (ponds), broodstock, American eel, American lobster, channel catfish, freshwater prawns, lake trout, shrimp, striped bass and Tilapia. Information is also provided on where to obtain these publications and how to order them.

Section 6 - Aquaculture Glossary

The glossary defines typical terms used in the aquaculture industry such as broodfish, fingerlings and seine.

Section 7 - State/Regional/University/Extension Aquaculture Offices

Contact information is provided in this sec-tion for a variety of technical experts in the US who may be of use to the aquaculture developer. Some of the technical experts include ex-tension contacts in aquaculture, Federal fishery assistance offices, Department of Fish and Wildlife offices, Regional and State Aquaculture associations, state aquaculture coordinators, diagnostic services and Sea grant programs.

Section 8 - State Aquaculture Permit Requirements

This section summarizes the permits and regulations impacting the aquaculture industry for the following states, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, South Dakota, Utah, and Washington. The four main issues covered are water use, effluent discharge, production and marketing. For each permit, license, or act required information is provided on the issuing agency, statutory reference, regulatory reference, activities covered, process, fees and other information is provided.

CONCLUSIONS

The Geo-Heat Center has a technical assistance program to provide advice and preliminary engineering and economic analysis of projects for potential greenhouse and aquaculture developers. The program is funded by the Office of Geothermal and Wind Technologies, U.S. Department of Energy.

REFERENCES

Boyd, T. L., and K. Rafferty, 1998. Aquaculture Information Package, Geo-Heat Center, Klamath Falls, OR, 106 p.

Rafferty, K., and T. L. Boyd, 1997. Geothermal Greenhouse Information Package, Geo-Heat Center, Klamath Falls, OR, 80 p.

Rafferty, K. 1998a. Greenhouses, Geothermal Direct-Use Engineering and Design Guidebook, Geo-Heat Center, Klamath Falls, OR, pp. 307-326

Rafferty, K., 1998b. Aquaculture, Geothermal Direct-Use Engineering and Design Guidebook, Geo-Heat Center, Klamath Falls, OR, pp. 327-332.