GEOTHERMAL RESEARCH AT THE GEO-HEAT CENTER
OREGON INSTITUTE OF TECHNOLOGY

John W. Lund
Geo-Heat Center
Oregon Institute of Technology
Klamath Falls, Oregon 97601

ABSTRACT

The Geo-Heat Center was established in 1975 to provide information and technical services for geothermal energy direct-use and development--mainly utilizing low- and moderate-temperature resources (<150°C). The Center is funded by the Geothermal Division of the U.S. Department of Energy (USDOE). Our main functions are (1) technical assistance, (2) resource information, (3) advising and referrals, (4) speaker's bureau, (5) tours of geothermal systems, (6) publications, (7) research, and (8) stocking a geothermal library. During 1997, the Geo-Heat Center staff provided assistance to 761 individuals, companies and municipalities--up to eight hours of technical assistance can be provided free of charge. Staff members have also participated in numerous international geothermal direct-use projects. The Center has developed a "Geothermal Direct Use Engineering and Design Guidebook" and publishes a free "Quarterly Bulletin" on geothermal direct-use projects and research. The Geo-Heat Center also has a website (http://www.oit.edu/~geoheat). Several of these direct-use research projects are discussed in the paper, including: a) Downhole Heat Exchangers, b) A Cost Comparison of Commercial Ground-Source Heat Pump Systems, c) A Spreadsheet for Geothermal Energy Cost Evaluation, d) Utilization of Silica Waste from Geothermal Power Production, e) Fossil Fuel-Fired Peak Heating for Geothermal Greenhouses, f) Selected Cost Considerations for the Geothermal District Heating in Existing Single-Family Residential Areas, and g) Collocated Resources Inventory of Wells and Hot Springs in the Western U.S.

INTRODUCTION

The beginning of the Geo-Heat Center (GHC) can be traced to an international conference held on geothermal energy at the Oregon Institute of Technology (OIT) campus during October of 1974. The meeting was organized to review nonelectric, multipurpose uses of geothermal energy in Hungary, Iceland, New Zealand, the United States and Russia (USSR). As a result of the conference and interest in the need to exchange and disseminate information on low-to-moderate temperature resources and their utilization, the Geo-Heat Center (first known as the Geo-Heat Utilization Center) was established in 1975. Initial funding was provided by the Pacific Northwest Regional Commission (PNRC), a branch of the Executive Department of the Governors of the states of Oregon, Washington and Idaho. A sum of $3,000 was granted to distribute information to participants of the October 1974 international conference. The proceedings were published in a volume titled "Multipurpose Use of Geothermal Energy--Proceedings of the International Conference on Geothermal Energy for Industrial, Agricultural and Commercial/Residential Uses." The primary functions of the Center were to disseminate information to potential users of geothermal resources, perform applied research on the utilization of low-temperature resources, and to publish a quarterly newsletter on the progress and development of direct-use geothermal energy in the United States and other countries.

Over the years, a number of people were employed by the Center on a full-time basis or for special projects. Many of these individuals started their careers in geothermal with the Center and are still involved with geothermal energy today.

The transfer of technological information to consultants, developers, potential users, and the general public, is an important element in the development of geothermal energy. Through the USDOE, the Geo-Heat Center's resources are available to the public. Information developed through first-hand experience with hundreds of projects and through extensive research is provided to individuals, organizations or companies involved in geothermal development.

SERVICES OFFERED

Technical Assistance

The Geo-Heat Center provides technical/economic analysis for those actively involved in geothermal development. This assistance can be in the area of feasibility at the out-set of a project, equipment and materials selection during the design phase or follow-up troubleshooting for operational systems. Geothermal projects involving direct and heat pump space heating, industrial process, and low-temperature wellhead electric power generation, will be allocated a limited number of man-hours for analysis (based on merit).

Resource Information

Based on recently developed databases for the states of AZ, CA, CO, ID, MT, NV, NM, OR, UT and WA, data can be provided on over 8,000 thermal springs and wells. Data is available for a specific area of a city or county and includes: location, temperature, flow rate, depth, water chemistry, current utilization and source references from which more detailed information can be obtained.

Advising and Referrals

The Geo-Heat Center acts as a clearinghouse providing technical information by meeting with groups and answering telephone inquires, letters and e-mail from individuals, businesses, and local governments on geothermal resources, space heating, district heating, greenhouses, aquaculture projects, equipment, heat pumps, small-scale electric generation systems, and other related items.

Speaker's Bureau

Center staff are available to make presentations on topics such as system design, economic considerations, and project examples to both lay and technical audiences.

Tours

The Center will arrange individual and group tours of Klamath Falls district heating system, campus geothermal heating/cooling system, residential and local greenhouse applications

Publications

A quarterly bulletin featuring domestic and foreign research, development and utilization is available free of charge. Technical material on resources, direct-use equipment, design schemes, software, and feasibility studies may be obtained by writing or through e-mail for the GHC Publications Request Form.

Library

The Center maintains a geothermal library of over 5,000 volumes for lay and technical readers. Volumes can be reviewed at the Center. Computer reference search is also available.

FUNDING

Research is supported by the Office of Geothermal Technologies, under the Office of Utility Technologies of the U.S. Department of Energy, through a grant.

Since 1975, the GHC has been involved in a number of studies and projects, funded by a variety of sources, but primarily from the Department of Energy, to meet its goals. A summary of these projects and activities are recounted in Lienau and Lund (1995)

TECHNICAL ASSISTANCE PROGRAM

The Geo-Heat Center staff can provide up to eight hours of technical assistance, free of charge, to individuals, public organizations and private companies, in the form of a feasibility study for potential direct use developments. We can also provide "troubleshooting" support for existing systems.

During 1995 over 350 inquiries were handled; in 1996, 583 were responded to (Figure 1); and for 1997, 761 requests completed (Figure 2). The recent increases are due to our home page (http://www.oit.edu/~geoheat) on the World Wide Web. Approximately half of our requests are by e-mail, and our international requests are around 15%.

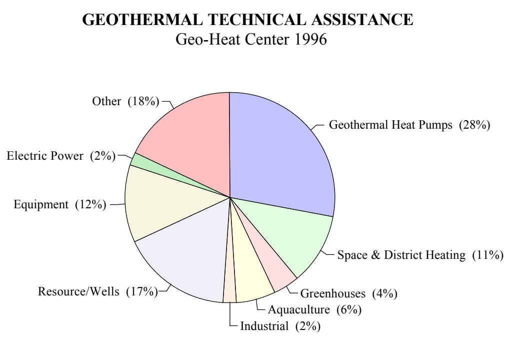

Figure 1. Geothermal technical assistance 1996.

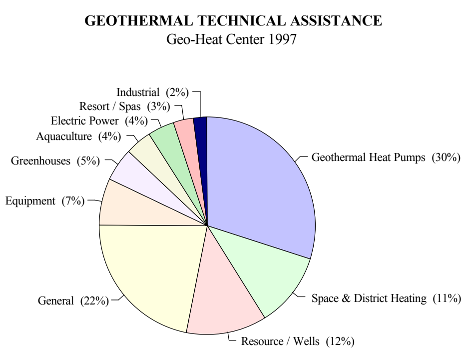

Figure 2. Geothermal technical assistance 1997.

MAJOR PUBLICATIONS

In addition to technical papers and research reports prepared by the staff, the Geo-Heat Center has developed and published a comprehensive "Geothermal Direct Use Engineering and Design Guidebook." This guidebook, revised in 1998 in a 3rd edition, consists of 19 chapters covering all aspect of geothermal direct use, from exploration to greenhouse design to environmental considerations. We have also published a "Quarterly Bulletin" for over 20 years which contains domestic and international articles on direct-use projects and research.

DIRECT-USE PROJECTS

The Geo-Heat Center staff has performed numerous research projects, seven of which are summarized in the following section.

Downhole Heat Exchangers (Lund, et al., 1975; Culver and Reinstad, 1978)

Since Klamath Falls has over 500 downhole heat exchangers in use, research in the area became one of the earliest priorities of the Geo-Heat Center staff.

The downhole heat exchanger (DHE) eliminates the problem of disposal of geothermal fluid, since only heat is taken from the well. The exchanger consists of a system of pipes or tubes suspended in the well through which "clean" secondary water is pumped or allowed to circulate by natural convection. These systems offer substantial economic savings over surface heat exchangers where a single-well system is adequate [typically less than 0.8 MWt (2.73 x 10^6 Btu/hr)] , with well depths up to about 150 m (500 ft) and may be economical under certain conditions at well depths to 450 m (1500 ft) .

Several designs have proven successful; but, the most popular are a simple hairpin loop or multiple loops of iron pipe (similar to the tubes in a U-Tube and shell exchanger) extending near the well bottom (Figure 3). An experimental design consisting of multiple small tubes with "leaders" at each end suspended just below the water surface appears to offer economic and heating capacity advantages.

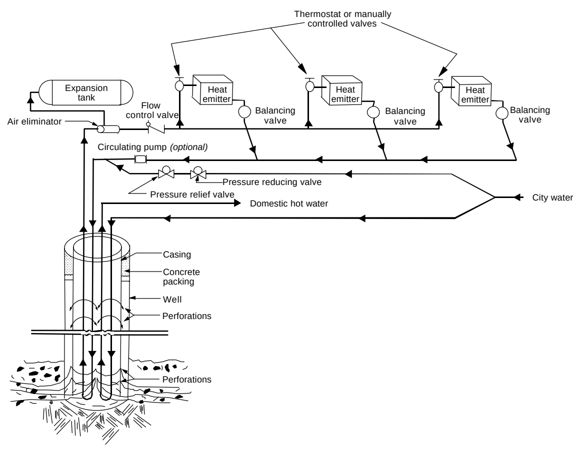

Figure 3. Typical hot-water distribution system using a downhole heat exchanger.

In order to obtain maximum output, the well must be designed to have an open annulus between the wellbore and the casing, and perforations above and below the heat exchanger surface. Natural convection circulates the water down inside the casing, through the lower perforations, up in the annulus and back inside the casing, through the upper perforations. If the design parameters of bore diameter, casing diameter, heat exchanger length, tube diameter, number of loops, flow rate and inlet temperature are carefully selected, the velocity and mass flow of the natural convection cell in the well may approach those of a conventional shell-and-tube heat exchanger.

The interaction between the fluid in the aquifer and that in the well is not fully understood; but, it appears that outputs are higher where there is a high degree of mixing indicating that somewhat permeable formations are preferred.

Considering life and replacement costs, materials should be selected to provide economical protection from corrosion. Attention must be given to the anodic-cathodic relationship between the exchanger and the casing since it is relatively expensive to replace the well casing. Experience in the approximately 500 downhole exchangers in use indicates that corrosion is most severe at the air-water interface at static water level and that stray electrical currents can accelerate corrosion. Insulating unions should be used to isolate the exchanger from stray currents in building and city water lines. Capping the top of the casing will also reduce the air-water interface corrosion.

A Capital Cost Comparison of Commercial Ground-Source Heat Pump Systems (Rafferty, 1995a)

Unitary ground-source heat pump systems for commercial buildings can be installed in a variety of configurations. The oldest and, until recently, most widely used approach was the groundwater system. In this design, groundwater from a well or wells is delivered to a heat exchanger installed in the heat pump loop. After passing through the heat exchanger (where it absorbs heat from or delivers heat to the loop), the groundwater is disposed of on the surface or in an injection well. The use of an injection well is desirable in order to conserve the groundwater resource.

A second and increasingly popular design is the ground-coupled heat pump system. In this approach, a closed loop of buried piping is connected to the building loop. For most larger commercial applications, the buried piping is installed in a grid of vertical boreholes 30 to 90 m (100 to 300 ft) deep. Heat pump loop water is circulated through the buried piping network absorbing heat from or delivering heat to the soil. The quantity of buried piping varies with climate, soil properties and building characteristics, but is generally in the range of 13 to 22 m/kW (150 to 250 ft/ton) of system capacity. Borehole length requirements are almost always dictated by heat rejection (cooling mode) duty for commercial buildings.

A third design for ground-source systems in commercial buildings is the "hybrid" system. This approach may also be considered a variation of the ground-coupled design. Due to the high cost associated with installing a ground loop to meet the peak cooling load, the hybrid system includes a cooling tower. The use of the tower allows the designer to size the ground loop for the heating load and use it in combination with the tower to meet the peak cooling load. The tower preserves some of the energy efficiency of the system, but reduces the capital cost associated with the ground loop installation.

Generally, the hybrid system is attractive in situations where ground loop costs per kW (ton) are high, and where the heating loop length requirement is low relative to the cooling loop length requirement.

Costs were developed for three groundwater/soil temperature 10°, 15.6° and 21.1 °C (50°, 60° and 70 °F) representing northern, central and southern climates. For brevity, only the results for the 15.6°C (60°F) cases are presented in Figures 4 and 5.

Figure 4 presents a comparison of the three types of systems for 15.6°C (60°F soil) (for the most favorable conditions). The ground-coupled system cost line is based upon $16/m ($5/ft) and $284/kW (200 ft/ton = $1000/ton). The two hybrid system curves are based upon loop length ratios (heating ÷ cooling) of 0.30 and 0.40, which is the most favorable for hybrid systems. This figure shows that the groundwater (GW) system has a capital cost advantage over the other systems.

Figure 5 presents additional data for the 15.6°C (60°F) soil case. The ground-coupled line is based on 17 m/kW (200 ft/ton) and $16/m ($5/ft). The two hybrid system curves are based upon loop length ratios of 0.50 (lower) and 0.60 (upper). These are the least favorable conditions for the hybrid systems covered in the paper. The two curves for the groundwater system are based upon a single production/injection well pair at 244 m (800 foot) depth (lower curve) and two production/injection well pairs at a 183 m (600 foot) depth. These are the least favorable conditions for the groundwater system covered in the paper.

At system capacities of 350 - 615 kW (100 - 175 tons) and above, the groundwater system has the capital cost advantage over hybrid and ground-coupled systems. Below this range, the hybrid system is the most attractive. It is only under conditions of less than 350 kW (100 tons) with well depths of 244 m (800 feet) that the groundwater system capital cost exceeds that of the ground-coupled system..

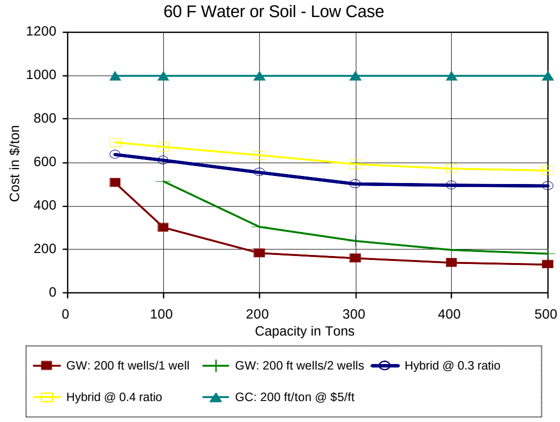

Figure 4. Ground-source system costs - low case.

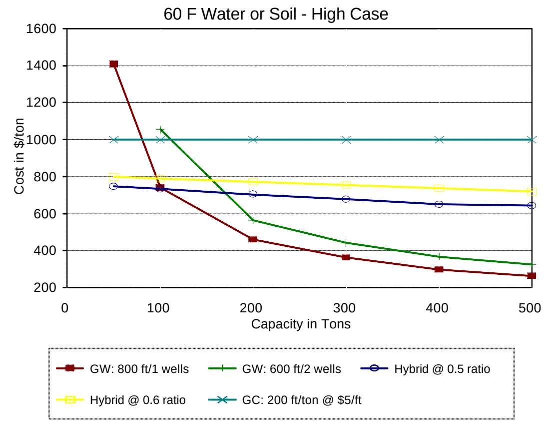

Figure 5. Ground-source system costs - high case.

The article addresses only system capital cost. In the process of system selection, other issues should be considered as well. These would include operating costs such as electricity for pumps and fans, water treatment costs (tower) and regulatory issues with respect to groundwater. As a result, system capital cost provides only a portion of the information required for informed decision making.

A Spreadsheet for Geothermal Energy Cost Evaluation (Rafferty, 1995b)

The Geo-Heat Center developed a spreadsheet which will allow potential users to quickly evaluate the capital cost and unit energy cost of accessing a geothermal resource.

Using resource, financing and operating inputs, the spreadsheet calculates the capital cost for production well(s), well pump(s), well head equipment, injection well(s), and connecting pipelines. These capital costs are used along with the quantity of annual energy to be supplied and financing information to produce a unit cost of energy.

Unit costs for operation (maintenance and electricity) are added to arrive at a total unit cost in $per million Btu for geothermal heat. To put this value into perspective, similar costs for an equivalently sized gas boiler plant are also calculated. These values can then be compared to determine the relative economic merit of geothermal for any specific set of circumstances.

For the geothermal system, up to three production wells can be specified. Well casing is sized to accommodate a pump capable of supplying the required flow rate. Costs are included for drilling, casing, cementing, packers, bits and drill rig mobilization. An option is provided for open hole completion.

Wells can be equipped with production pumps at the users discretion. Pumps are assumed to be oil lubricated/lineshaft type and can be equipped with electronic variable-speed drives. The spreadsheet calculates the total pump head (including injection pressure if applicable), bowl size, number of stages, lateral requirements, column size and length, and all costs.

Well head equipment includes piping, check valve and shut-off valve along with electrical connections and accessories for the motor. All of these items are assumed to be located in an enclosure.

Injection wells (up to 3) can be included in the system at the users discretion, along with a user defined casing depth. Cost components for the injection wells are similar to those described for the production wells; although, the drilling cost rates used for injection are higher than those used for production. This rate is 20% higher to allow for alternate drilling methods sometimes employed for injection wells.

Finally, piping connecting the production wells and injection wells to the building (or process) are included to complete the geothermal system. A 15% contingency is added to all major cost categories.

For the boiler plant, costs are calculated for a cast iron gas-fired boiler including: boiler and burner, concrete pad, breaching to flue, gas piping, combusing air louvers, expansion tank and air fitting, air separation, relief valve and piping, feed-water assembly, boiler room piping and shut-off valves. The spreadsheet is intended to compare geothermal to other conventional methods of supplying heat. As a result, it focuses upon the heat source only. Costs necessary for interface with a specific use, such as a heat exchanger, fan coil units or distribution system are not included.

Table 1 illustrates the output for a system similar to the one at Oregon Institute of Technology, which consists of three production wells and two injection wells. The system heats over (52,000 m^2 (560,000 ft^2) of buildings.

Table 1. Sample Output for Cost Evaluation

OUTPUT	
1. Required Flow	600 gpm (37.8 L/s)
2. Production Well	$ 281,698
3. Well Pump	$ 117,131
4. Wellhead Equipment	$ 25,913
5. Injection Well	$ 251,487
6. Pipeline	$ 46,182
7. Total Geothermal Cost	$ 722,410
8. Boiler Plant Cost	$ 96,509
9. Unit Capital Cost	2.80 $/MMBtu*
10. Unit Maintenance Cost	0.49 $/MMBtu
11. Unit Electricity Cost	0.42 $/MMBtu
12. Total Unit Cost	3.71 $/MMBtu
13. Boiler Fuel Cost	5.73 $/MMBtu
14. Equipment Unit Cost	0.43 $/MMBtu
15. Maintenance Unit Cost	0.11 $/MMBtu
16. Total Unit Cost	6.27 $/MMBtu
17. Simple Payback	9.28 Years

* 1MMBtu = 293 kWh = 1.05 GJ

Utilization of Silica Waste From Geothermal Power Production (Lund and Boyd, 1996)

The Geo-Heat Center has been investigating the utilization of waste silica from the Cerro Prieto geothermal field for several years. The main objectives of the research were to combine silica with various additives to (1) form bricks for low-cost housing, and (2) to produce a suitable road surfacing material. The various additives that were tested included hydrated lime, portland cement, plastic fibers, asphalt cement and emulsified asphalt. The silica-cement combination produced the strongest bricks and had the best weather resistance; whereas, the silica-lime combination produced the bricks with the lowest thermal conductivity and specific gravity density. The addition of plastic fibers to the silica-lime mixture improved both strength and weather resistance. The combination of asphalt and silica is not suitable as a road surfacing material; however, silica-cement appears promising.

Figures 6 and 7 are test results illustrating the relationships between additive, thermal conductivity and specific gravity.

It is proposed to test several walls constructed of silica-lime and silica-cement mixtures in the Imperial Valley area. This will provide long-term field testing of the various types of bricks and determine if they need protective coatings, reinforcing, etc.

During the course of the investigation, it was determined that a lightweight roofing tile using portland cement, silica and cellulose fibers is presently being manufactured in Mexico City and sold through outlets in the U.S. Their advertised advantage is that they are lighter weight [60 percent lighter than clay or concrete tile at 20 kg/m^2 (4 lbs/ft^2)]. CFE is presently investigating the potential for use of the Cerro Prieto waste silica by this manufacturer.

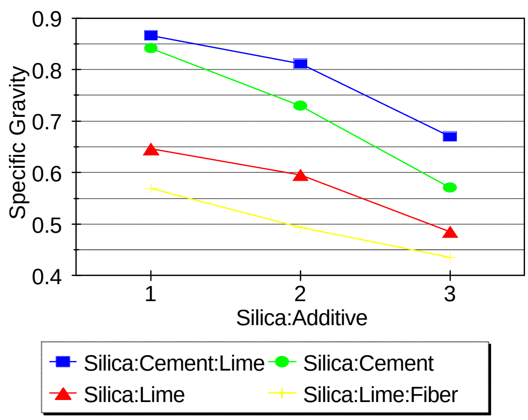

Figure 6. Silica additive vs. specific gravity.

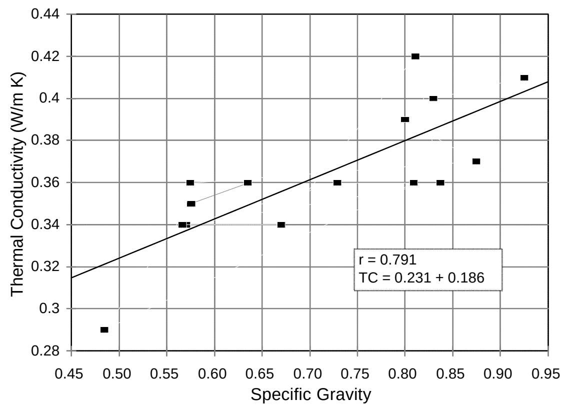

Figure 7. Specific gravity vs. thermal conductivity.

Fossil Fuel-Fired Peak Heating for Geothermal Greenhouses (Rafferty, 1997)

Increasingly, greenhouse operations will encounter limitations in available geothermal resource flow due either to production or disposal considerations. As a result, it will be necessary to operate additions at reduced water temperatures reflective of the effluent from the existing operations. Water temperature has a strong influence on heating system design.

Due to temperature occurrences in most western geothermal locations, a base load system (geothermal) designed for approximately 60% of the peak load can actually meet 95+% of the annual heating requirement. As a result, a facility with limited geothermal flow can expand to provide a portion of the heating requirements with a conventionally-fueled peak heating system. Thus, they can use the heating system of choice and still achieve substantial energy savings with a base load/peak load heating system design. In addition, the fossil-fueled peak load system offers a no-cost emergency backup in the event of a failure in the geothermal system.

The report examines the economics of fossil-fuel peaking for three different climates (Helena, MT; Klamath Falls, OR and San Bernardino, CA) representing very cold, moderate and warm climates. Figure 8 presents the results for Klamath Falls. Cost shown are expressed in $\$/ft^2$ of greenhouse floor area and include capitalization of the equipment, fuel costs and maintenance for the fossil-fuel peaking system.

As indicated, the propane boiler (BLR prop) is the least expensive peaking system for a wide range of conditions, with the propane unit heaters (UH prop), and oil boiler system (BLR oil) competitive up to the 65% base load level. These results are similar to the other climates with the exception that in the coldest climate, the oil unit heater system (UH oil) is the least cost design at less than 60% base load sizing.

In cases where there is limited geothermal flow available and the grower wishes to use a system which is difficult to apply at low water temperatures, the use of fossil fuel peaking permits the use of the growers preferred system for a reasonable increment in operating costs.

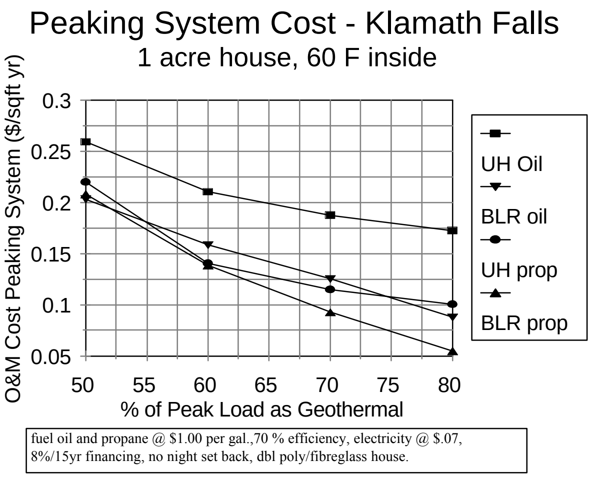

Figure 8. Peaking system cost - Klamath Falls.

Selected Cost Considerations for Geothermal District Heating in Existing Single-Family Residential Areas (Rafferty, 1996)

District heating in existing single-family residential areas has long been considered to be uneconomical due to the low-heating load density. In comparison to the typical downtown business districts load density is low; however, there are some characteristics of residential areas which could serve to enhance the economics of district heating.

Among these are: (1) wide variety of heating fuels (and costs) which can result in a range of conventional heating costs of 3 or more to 1 for the same heating load density; (2) availability of unpaved areas for installation of the distribution system; (3) fewer utilities in the pipeline corridor; (4) less traffic control requirements during construction; (5) potential for the use of uninsulated piping, and (6) older, poorly insulated structures with high energy use.

The report explores some of the issues related to costs involved in the installation of geothermal district heating (GDH) in existing single-family residential areas. A summary of construction cost percentages for a 6-in. preinsulated ductile iron pipe installation is shown in Figure 9.

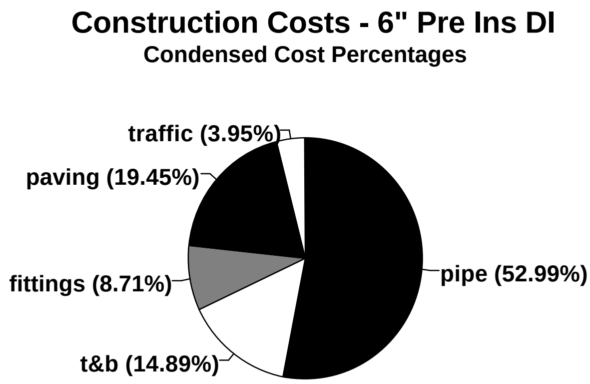

Figure 9. Sample construction costs.

Based on the example residential area evaluated in the paper, it appears that geothermal district heating in existing single-family residential areas could be feasible in situations where: (1) propane, fuel oil and electricity (or combination of these fuels with wood) dominate the conventional heating used; (2) small lot sizes (465 m^2) (<5,000 ft^2); (3) subdivisions where unpaved areas are available for installation of some or all of the distribution system, and (4) customer penetration rate is high (\$75%).

Collocated Resources Inventory of Wells and Hot Springs in the Western U.S. (Boyd, 1996)

Low- and moderate-temperature geothermal resources are widely distributed throughout the western and central United States. Since the last major effort in assessing the national potential of these resources in the early 1980s, there has been a substantial increase in direct-heat utilization. However, the large resource base is greatly under-utilized. To help expand utilization of the direct-heat resource base, a current inventory of these resources has been developed.

A further breakdown of the current inventory, identifies 271 collocated communities with wells or springs 50ºC (\$122ºF) within 8 km (5 miles). These communities could benefit by utilizing the geothermal resource. The Geo-Heat Center has sent out information about the resources to the Economic Development Centers for the collocated communities in hopes of promoting geothermal use.

Figure 10 is the map of the 70 collocated communities in California, and Table 2 is an example database for five of these locations.

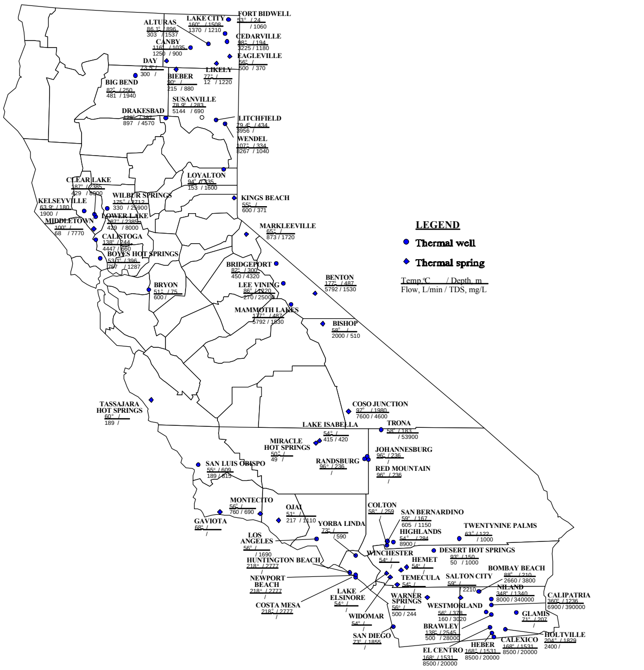

Figure 10. The 70 collocated communities located within California.

Table 2. Section of the Collocated Resource Database for California.

	Bombay Beach	Boyes Hot Springs	Brawley	Bridgeport	Byron
County	Imperial	Sonoma	Imperial	Mono	Contra Costa
Latitude	33.35	38.317	32.9833	38.25	37.8472
Longitude	115.7167	122.4833	115.5333	119.2333	121.63
Population	500	5937	19450	900	1100
Resource Temp. ^oC	88	53.1	138	82	51
Number of Wells	11	2	5	3	1
Typical Depth m	201	396	2545	300	75
Flow L/min	2660	757	500	450	600
TDS	3800	1287	28000	4320	
Current Use	Aquaculture	Baths/ pools & space Heating		Power Plant	
HDD	925	3311	925	6022	2806
Design Temp.	38	30	38	10	30
Remarks	11 wells, located within 5 miles of Bombay Beach	1 spring/ well, located within 0.5 miles of Boyes Hot Springs, and 2 miles of Sonoma	5 wells, located within 2 miles of Brawley	2 springs/ 1 well, located within 3 miles of Bridgeport	1 well, located within 1 mile of Byron

CONCLUSION

The Geo-Heat Center has been in operation for over 20 years, providing information and technical assistance for geothermal direct utilization projects. Research activities are intended to improve the design and cost effectiveness of geothermal direct-heat projects

Additional information and details on the direct-use research projects discussed in this paper can be obtained through our home page (http://www.oit.edu/~geoheat). Most of this information is available free of charge, including the Geo-Heat Center Quarterly Bulletin.

REFERENCES

Boyd, T. L., 1996, "Collocated Resources," Geothermal Resources Council, *Transactions*, Vol. 20, Davis, CA, pp. 43-50.

Culver, G. G. and Reistad, G. M., 1978, "Evaluation and Design of Downhole Heat Exchangers for Direct Application," Geo Heat Center, Klamath Falls, OR.

Lienau, P. J. and Lund, J. W., 1995, "20th Anniversary of the Geo-Heat Center," *Geo-Heat Center Quarterly Bulletin*, Vol. 16, No. 4 (October), Klamath Falls, OR, pp. 1-6.

Lund, J. W.; Culver, G. G. and Svanevik, L. S., 1975, "Utilization of Intermediate-Temperature Geothermal Water in Klamath Falls, Oregon," *Proc. Of the 2nd U.N. Symposium in the Development and Use of Geothermal Resources*, San Francisco, CA, 2, pp. 2147-2154.

Lund, J. W. and Boyd, T. L., 1996, "Research on the Use of Waste Silica from the Cerro Prieto Geothermal Field, Mexico," *Geothermal Resources Council Transactions*, Vol. 20, Davis, CA, pp. 227-233.

Rafferty, K., 1995a, "A Capital Cost Comparison of Commercial Ground-Source Heat Pump Systems," *Geo-Heat Center Quarterly Bulletin*, Vol. 16, No. 2 (February), Klamath Falls, OR, pp. 7-10.

Rafferty, K., 1995b, "A Spreadsheet for Geothermal Energy Cost Evaluation," *Geo-Heat Center Quarterly Bulletin*, Vol. 16, No. 2 (February), Klamath Falls, OR, pp. 11-14.

Rafferty, K., 1996, "Selected Cost Considerations for Geothermal District Heating in Existing Single-Family Residential Area," *Geo-Heat Center Quarterly Bulletin*, Vol. 17, No. 3 (August), Klamath Falls, OR, pp. 10-15.

Rafferty, K., 1977, "Fossil Fuel-Fired Peak Heating for Geothermal Greenhouses," *Geo-Heat Center Quarterly Bulletin*, vol. 18, No. 1 (January), Klamath Falls, OR. pp. 1-4.