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A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources

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Cover: **Top:** Graphical representation of U.S. geothermal direct-use growth 1975-2000. **Bottom:** Example of geothermal heat pump scaling potential in Pennsylvania.

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GEOTHERMAL PIPELINE

Progress and Development Update
Geothermal Progress Monitor

MEETINGS

Geothermal Resources Council Annual Meeting, San Francisco, September 24-27, 2000

The Geothermal Resources Council will hold their annual meeting at the Hyatt Regency San Francisco Airport Hotel from September 24 to 27, 2000. The conference theme *"Ushering in a Geothermal Millennium"* focuses on issues of special interest to the worldwide geothermal community. In addition to the standard sessions , there will be an innovative Special Session on Commercial Technologies featuring papers by development companies on operations and maintenance, and by vendors on services, equipment and technologies. Other special sessions include Coso Resource Development, Enhanced Geothermal Systems with presentations covering recent Japanese, European and Australian research encouraged, Geysers Resource Development, Long-Term Field Performance, Mexico and Latin America, Plant and Field Enhancements, and Power Marketing. The meeting will also include Workshops and Field Trips. The deadline for the submission of a draft paper is April 28 and the final revision is due by June 16 after review by the Technical Program Committee. Requests for additional information can be obtained from the GRC office, PO Box 1350, Davis, CA 95617-1350, phone: (530) 758-2360, Fax: (530) 758-2839, email: <grc@geothermal.org> or the First Announcement and Call for Papers can be accessed from their web site: <www.geothermal.org>.

World Geothermal Congress 2000, Kyushu - Tohoku, Japan, May 28 - June 10, 2000

The World Geothermal Congress 2000 will be held in Beppu on the island of Kyushu from May 30 to 2 June and in Morioka on northern Honshu from 5 June to 7 June. A transfer program, funded by the Japanese Organizing Committee will be provided for all registered participants between the two venues on June 3 and 4. The main purpose of WGC2000 is to provide a forum for exchange of scientific, technical and economic information on geothermal development. Field trips and Short Courses are planned before and after the meeting. The short courses are: (1) Long-term monitoring of high-and-low-enthalpy fields under exploitation, (2) Project management and financing, (3) Heating with geothermal energy: conventional and new schemes, and (4) Environmental safety and health issues in geothermal development. An extensive social program is also planned. Additional information can be obtained from the official web site: <www.wgc.or.jp> and registration can be made by email at: <wgc2000reg@ics-inc.co.jp>.

Kazuno Geo-Friendship Forum, Kazuno, Tohoku, Japan, June 3-4, 2000

A separate program in conjunction with WGC2000 will be held at the Hotel Kazuno, Kazuno City, Akita Prefecture near Morioka from June 3 to 4. Participants from all over the world will exchange information about the multipurpose uses of geothermal energy, environmental conservation etc., and discuss the direction of geothermal development in the 21st century. They will also have a chance to tour geothermal facilities in the region, and enjoy the natural scenery, history and culture of Kazuno. The Kazuno Carnival will be held the evening of June 3, field trips to Sumikawa and Onuma power plants and Goshogake Hot Springs will take place in the morning of June 4 and the technical session held in the afternoon. Transfer will be provided to Morioka for the start of the second half of the WGC2000 venue on June 5. Additional details can be obtained from the WGC2000 web site.

ENERGEX 2000, Las Vegas, NV, July 23-28, 2000

The ENERGEX 2000, the 8th International Energy Forum will be held at the Riviera Hotel and Convention Center in Las Vegas, NV from July 23 to 28. The conference will give an overview of the most recent developments in energy technologies and commercialization. This program will bring together research scientists, engineers, managers, and manufacturers from a broad range of energy companies, industries, government departments, consulting firms, research institutes, and investment firms. A geothermal session will be held under the Renewable Energies topic. Additional information can be obtain from their web site: <www.GlobeEx.com>.

CALIFORNIA

Mineral Extraction Plant to be Constructed in the Imperial Valley, CA

Construction of a mineral extraction plant by CalEnergy Operating Corporation, a subsidiary of the MidAmercian Energy Holding Company was started in the Imperial Valley last year. The facility will be the first and only facility in the world specifically designed to harvest minerals from high-temperature geothermal brines. The Zinc Recovery Project technology of zinc extraction involves the use of ion exchange, solvent extraction and electrowinning to extract and plate minerals from geothermal fluid used to generate electricity at the existing Imperial Valley facility. The extraction process was first tested on brine in Alaska in 1995. It was then tested on a larger scale through the successful operation of a demonstration project which started in early 1996 and ended in late 1997. The project is projected to recover an estimated 30,000 metric tons (33,000 U.S. tons) of zinc per year. Using 18 to 20 million pounds/hour brine from eight power plants operated by CalEnergy Company (400 MWe), 550 to 600 ppm of zinc will be extracted. Power from the new Unit 5 (55 to 60 MWe gross) will provide 20 to 22 MWe for the extraction process. The current market value of zinc is around 55 cents/pound. In addition to the zinc recovery by the $280 million plant, high grade silica and manganese will also be extracted from the geothermal brine. The project will add 70 to 90 full-time jobs to Imperial Country. To help in the research efforts, the company is receiving a matching grant of $904,340 from the California Energy Commission's geothermal program. Commercial operation is estimated to commence by mid-year. (CalEnergy web site and CEC Media Advisory release).

MEXICO

Mexico to build 100-megawatt Geothermal Plant

Mexico plans to construct a 100-megawatt geothermal power plant in the Mexicali Valley to provide electricity to the Baja California peninsula and the state of Sonora. The Cerro Prieto IV plant will be the second largest in the world, making Mexico as the third-largest producer of geothermal energy by the Federal Electricity Commission (CFE). The new plant will bring Mexico's geothermal electricity capacity to 853 megawatts, according to Dr. Gerardo Hiriart, CFE's chief of Geothermal Projects. The time and cost of completion is not reported. Mexico needs to add an additional 13,000 megawatts of generating power by 2007 to satisfy growing demand. Energy demand is growing by 10 percent a year in some parts of the industry-heavy north and the need for extra megawatts will soon outstrip the government's means to provide them, according to industry analysis. Mexico has a current power capacity of 32,000 megawatts. (Reuters, Feb. 13).

WASHINGTON, DC

GeoPowering the West - National Geothermal Initiative for Western States

On January 24, in an effort to tap the vast geothermal resources of the western United State, Secretary of Energy Bill Richardson and U.S. Senator Harry Reid of Nevada announced a new Department of Energy (DOE) initiative to expand the production and use of energy generated from heat within the earth. The new initiative, known as *GeoPowering the West*, will help bring geothermal electricity and geothermal heat to millions of homes and businesses in the west.

The strategies for *GeoPowering the West* are:

- Increase the use of geothermal for electricity production, through identification and development of new sites, expansion of existing reservoirs, strengthening of technology development efforts, and an effort to tap more-localized resources for small-scale distributed power.
- Use the largely untapped lower temperature resources that are broadly available across the Western states to supply heating for residences and commercial establishments, and for industrial process applications.

The initiative will build on current and future public and private sector efforts to help bring geothermal electricity and geothermal heat to widespread portions of the West and expand its use from Albuquerque to Seattle. *GeoPowering the West* will focus on three major goals:

- Supplying at least 10 percent of the electricity needs of the West by 2020 with 20,000 megawatts of geothermal energy installed.**;**
- Supplying the electric power or heating needs of at least 7 million U.S. homes through geopower by 2010; and
- Doubling the number of states with geothermal electric power facilities to eight by 2006.

New technology under development or now available for geothermal reservoir discovery and recovery will allow for expansion of geopower under development in these states and throughout the entire west.

The initiative supports the DOE plan to have 25,000 megawatts of wind, solar, geothermal and biomass renewable power generating capacity on-line by 2010. On hundred megawatts of geothermal energy provides the residential electricity needs of a city of 200,000 people. In addition, it supports the Western Governor's Association and Western Regional Air Partnership's goal of increasing the contribution of non-hydro power renewable energy to regional electricity needs to 10% by 2005 and 20% by 2015 as a means of reducing pollution in the west.

GeoPowering the West will be a partnership of organizations from both the private and public sectors, representing suppliers, users and the environmental community. The initiative will provide an opportunity for participation to Native Americans, the agricultural community, rural America, and federal facilities. A draft action plan is available at the DOE web site: <www.eren.doe.gov/geopoweringthewest/>. Comments will be taken through April 2000 and incorporated into the initiative's final action plan.

Over $4.8 million will be awarded for geothermal activities in six western states. This includes approximately $4.4 million recently awarded for geothermal reservoir technology research, development and demonstration. The research activities are directed towards the domestic use and development of new technologies for geothermal reservoir exploration, characterization and management. This research will provide developers information on identifying the size of the resource, how good the resource is, and how best to keep the resource viable. Seven awards were made to the following institutions: University of Utah, University of North Dakota, Southern Methodist University, Dr. Denis L. Norton of Idaho and Geomechanics International, Inc. of California.

As much as $400,000 will be awarded for enhancements to geothermal power projects. Two projects have been selected in California for further contract negotiations. These projects will reduce maintenance and operation cost for geothermal power plants and will improve energy production. The selected recipients are Northern California Power Agencies (consisting of 10 municipal power agencies) in Middletown, California and Thermochem, Inc. in Santa Rosa, California. (U.S. Department of Energy News)

New Directions for the DOE Geothermal Program

During the current fiscal year (FY2000) the DOE Geothermal Program is shifting its focus from laboratory based R&D that results in technology improvements to field verification projects that result in the deployment of new technologies. This change in focus will emphasize cost-shared field tests with industry, and the laboratory and computational research that supports field verification. The requested budget for fiscal year 2001 will reflect the change in direction.

A new structure is being used to organize the geothermal program. All aspects of this structure will place strong consideration on cast-shared, joint projects with the geothermal industry. The major components of the new struc-ture along with a tentative proportion of funding is as follows:

- Energy Systems Research and Testing (32% of budget);
- Geoscience and Supporting Technologies (46% of budget); and
- Drilling Research (22% of budget)

This structure of the Geothermal Program takes advantage of previous and continuing research projects while providing flexibility for new initiatives. Emphasis on field verification places a stronger reliance on industry cost-shared joint projects to test new technology under actual operating conditions in geothermal fields. (Marshall J. Reed, Proceedings of the Twenty-Fifth Workshop on Geothermal Reservoir Engineering, Stanford University, Jan. 24, 2000).

Available Now!

Stories from a Heated Earth

Exciting New Publication Details Our Geothermal Heritage Through the Ages and Around the World

A new and exciting book is hot off the press—with a fresh but timeless topic—the history of mankind living on a geothermal planet. Published by the Geothermal Resources Council and the International Geothermal Association, *Stories from a Heated Earth, Our Geothermal Heritage*, is neither a science text nor a technical treatise. Instead, its focus is on people, and how geothermal phenomena have affected cultures around the world.

Stories from a Heated Earth was painstakingly compiled and edited by Raffaele Cataldi (geothermal consultant-Italy), Susan Hodgson (California Division of Oil, Gas & Geothermal Resources) and John Lund (Oregon Institute of Technology Geo-Heat Center). Created to collect, preserve, interpret and distribute global geothermal history prior to the Industrial Revolution, the 588-page volume with 215 photographs and illustrations is a unique amalgamation of both fact and fiction—true and imaginary accounts of our geothermal heritage unlike anything ever published before.

Covering more than 25 countries, this beautifully crafted paperback book is written in an easy, nontechnical style designed for broad appeal. The 47 international authors of *Stories from a Heated Earth* found the historical information presented by this superb volume in the works of archaeologists, historians, geographers, anthropologists, scientists and engineers. Inspiration flowed from artists, photographers, poets, philosophers, and literary figures—with geothermal quotations from Chinese and Japanese poets, Homer, Shakespeare, Pushkin, Herman Melville, Mark Twain and Edgar Allan Poe.

In addition, *Stories from a Heated Earth* derives interesting tales and practices from ancient manuscripts and the oral tradition, never before recorded. And antique quotations in over 30 languages were extracted for the book from pottery, drawings, maps, votive statues, shrines, stelae, myths and legends. All contribute to the fascinating reading offered within the covers of this engrossing, "must have" addition to both geothermal and historical libraries.

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Edited by Raffaele Cataldi, Susan Hodgson and John Lund

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GROUND-SOURCE HEAT PUMP SYSTEMS THE EUROPEAN EXPERIENCE

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ABSTRACT

Ground-source heat pumps play a key role in geothermal development in Central and Northern Europe. With borehole heat exchangers as heat source, they offer de-central geothermal heating at virtually any location, with great flexibility to meet given demands. In the vast majority of systems, no space cooling is included, leaving ground-source heat pumps with some economic constraints. Nevertheless, a promising market development first occurred in Switzerland and Sweden, and now also is obvious in Austria and Germany. Approximately 20 years of R&D focusing on borehole heat exchangers resulted in a well-established concept of sustainability for this technology, as well as in sound design and installation criteria. The market success brought Switzerland to the third rank worldwide in geothermal direct use. The future prospects are good, with an increasing range of applications including large systems with thermal energy storage for heating and cooling, ground-source heat pumps in densely populated development areas, borehole heat exchangers for cooling of telecommunication equipment, etc.

INTRODUCTION

Most European countries do not boast abundant hydrothermal resources that could be tapped for direct use (the notable exceptions are Iceland, Hungary and France). The utilization of low-enthalpy aquifers that enable the supply of a larger number of customers by district heating is limited so far to regions with specific geological settings.

In this situation, the utilization of the ubiquitous shallow geothermal resources by de-central ground-coupled heat pump systems is an obvious option. Correspondingly, a rapidly growing field of applications is emerging and developing in various European countries. A rapid market penetration of such systems is resulting. The number of commercial companies actively working in this field is ever increasing and their products have reached the "yellow pages" stage.

The climatic conditions in Central and Northern Europe, where most of the market development takes place, are such that by far the most demand is for space heating and air conditioning is rarely required. Therefore, unlike the "geothermal heat pumps" in the USA, the heat pumps usually operate in the heating mode only.

The following sections describe the technology, the market situation, future trends and questions in Europe, with special emphasis on the experience in Switzerland where a veritable boom in installing such systems took place in the last couple of years.

DEFINITIONS, TECHNOLOGY

Shallow geothermal resources (<400 m depth by governmental definition in several countries) are omnipresent. Below 15 - 20 m depth, everything is geothermal (Figure 1). The temperature field is governed by terrestrial heat flow and the local ground thermal conductivity structure (± groundwater flow). In some countries, all energy stored in form of heat beneath the earth surface is per definition perceived as geothermal energy (VDI 1998; BFE, 1998). The same approach is used in North America. The ubiquitous heat content of shallow resources can be made accessible either by extraction of groundwater or, more frequent, by artificial circulation like the borehole heat exchanger (BHE) system. This means, the heat extraction occurs–in most cases–by pure conduction, there are no formation fluids required.

The most popular BHE heating system with one of more boreholes typically 50 - 200 m deep is a closed circuit, heat pump coupled system, ideally suited to supply heat to smaller, de-central objects like single family or multi-family dwellings (see Figure 2).

The heat exchangers (mostly double U-tube plastic pipes in grouted boreholes) work efficiently in nearly all kinds of geologic media (except in material with low-thermal conductivity like dry sand or dry gravel).

This means to tap the ground as a shallow heat source comprise:

- Groundwater wells ("open" systems),
- Borehole heat exchangers (BHE),
- Horizontal heat exchanger pipes (including compact systems with trenches, spirals, etc.), and
- "Geostructures" (foundation piles equipped with heat exchangers).

A common feature of these ground-coupled systems is a heat pump, attached to a low-temperature heating system like floor panels/slab heating. They are all termed "ground-source heat pumps" (GSHP) systems. In general, these systems can be tailored in a highly flexible way to meet locally varying demands.

Experimental and theoretical investigations (field measurement campaigns and numerical model simulations) have been conducted over several years to elaborate a solid base for the design and for performance evaluation of BHE systems (Knoblich, et al., 1993; Rybach and Hopkirk, 1995; Rybach and Eugster, 1997). While in the 80s, theoretical thermal analysis of BHE systems prevailed in Sweden (Claesson and Eskilson, 1988; Eskilsson and Claesson,

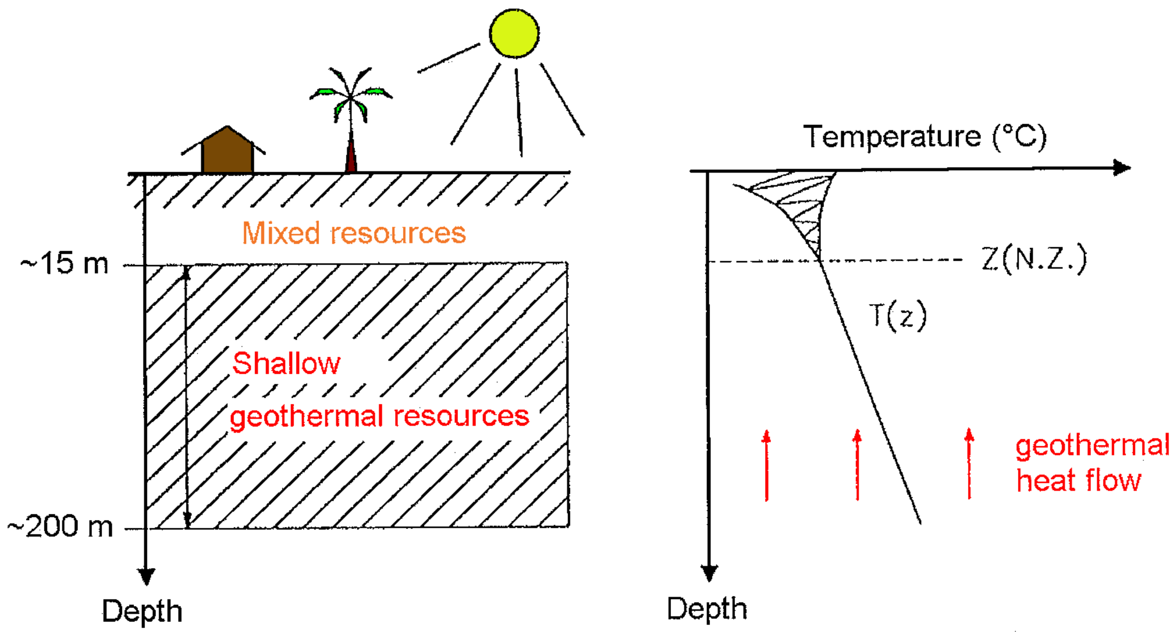

Figure 1. **Geothermal energy, comprising geothermal and mixed resources in the shallow subsurface.**

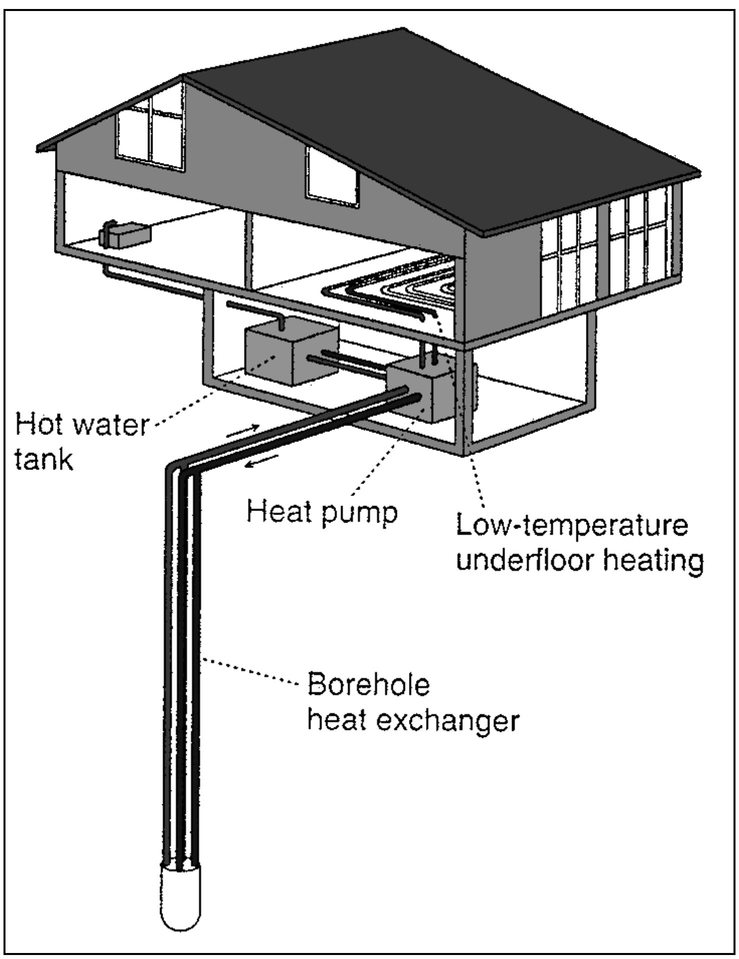

Figure 2. **Typical application of a borehole heat exchanger (BHE) heat pump system in a central European home. Typical BHE length: 100 m.**

1988), monitoring and simulation was done in Switzerland (Gilby and Hopkirk, 1985; Hopkirk, et al., 1988), and measurements of heat transport in the ground were made on a test site in Germany (Sanner, 1986).

In the German test system at Schöffengrund-Schwalbach near Frankfurt/Main, a 50-m BHE was surrounded by a total of 9 monitoring boreholes at 2.5, 5 and 10 m distance, also 50 m deep. Temperatures in each hole and at the BHE itself were measured with 24 sensors at 2 m vertical distance, resulting in a total of 240 observation locations in the underground. This layout allowed to investigate the temperature distribution in the vicinity of the BHE, as shown in Figure 3. The influence from the surface is visible in the uppermost approximately 10 m (see Figure 1), as well as the temperature decrease around the BHE at the end of the heating season. Measurements from this system were used to validate a numerical model for convective and conductive heat transport in the ground (Sanner and Brehm, 1988; Sanner, et al., 1996).

Starting in 1986, an extensive measurement campaign has been performed at a commercially delivered BHE installation in Elgg near Zurich. The object of the campaigns is a single, coaxial, 10- m long BHE in use since its installation in a single family house. The BHE supplies a peak thermal power of about 70 W per m of length.

The ground temperature results are highly informative with respect to the long-term performance (for details see Rybach and Euster, 1998). Atmospheric influences are clearly visible in the depth range 0 - 15 m. Below 15 m, the geothermal heat flux dominates. The results show that in the near field around the BHE, the ground coils down in the first 2 - 3 years of operation. However, the temperature deficit decreases from year to year until a new stable thermal equilibrium is established between BHE and ground, at temperatures that are some 1 - 2 K lower than originally. Thus, a "thermal collapse" (i.e., sudden drop of heat extraction efficiency) will not happen.

After calibration of a numerical model with the data from the Elgg system, the extrapolation for an operation over a 30-year period as well as the thermal recovery for 25 years following the end of the operation period, has been simulated. Figure 4 shows the calculated difference of ground temperature to the initial temperature before start of operation, at various distances from the BHE. Temperature close to the BHE in winter drops quickly in the first years, only to stay more or less stable over the next years. In summertime, initial temperatures are not achieved again, but the temperature drop is decreasing from year to year. After termination of the operation, a rapid thermal recovery can be seen in the first spring, followed by a slowing down of the recovery process due to the decreasing temperature gradients. In the numerical simulation, a complete recovery will occur only after an indefinitely long time period; nevertheless, the remaining temperature deficit 25 years after the operation is stopped, is only in the order of 0.1 K.

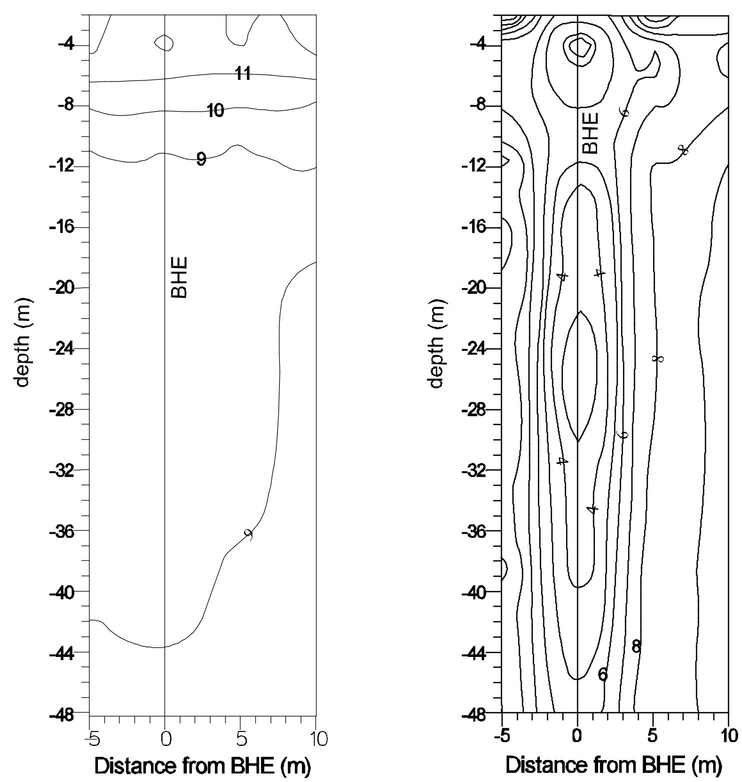

Figure 3. **Measured temperature distribution in the ground at the beginning of the monitoring period (left, on October 10, 1986, after a total of ca. 2 hours of test operation) and at the end of the first heating season (right, on January 5, 1987), Schwallbach GSHP test system, Germany.**

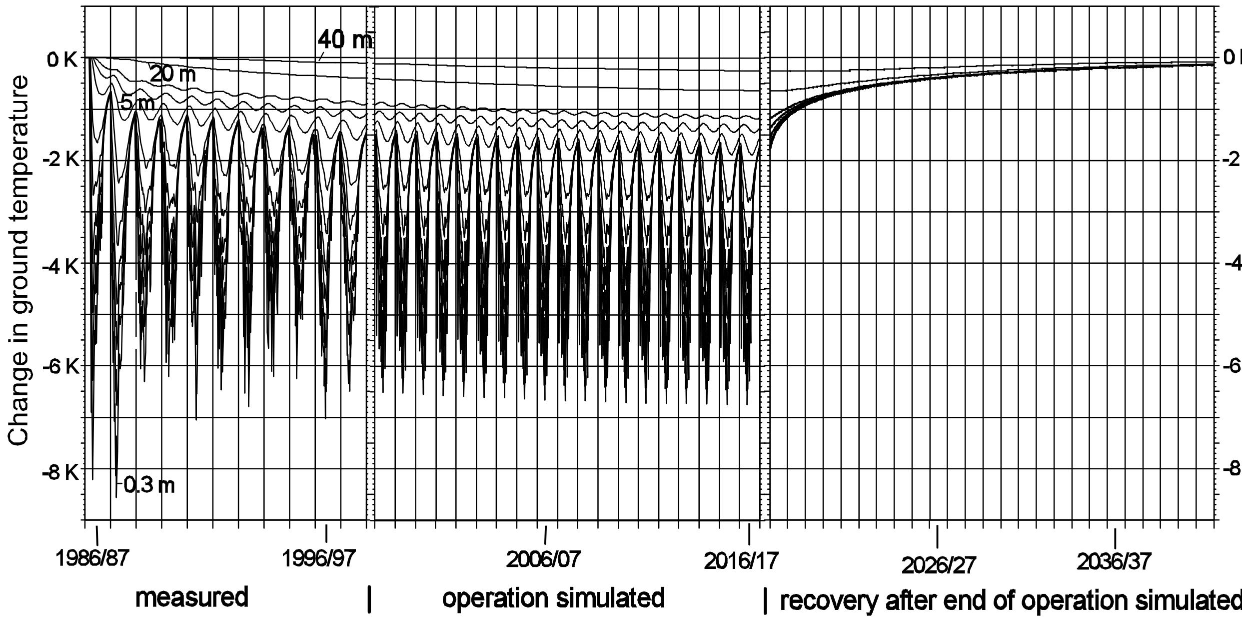

Figure 4. **Changes in ground temperature at various distances from the BHE over many heating seasons, measurement and extrapolation (simulation) for the system in Elgg, Zurich, Switzerland.**

The long-term reliability of BHE-equipped heat pump systems, along with economic and ecological incentives (see below), led to rapid market penetration. This was accomplished by the development of design standards (e.g., VDI 1998) and easy-to-use design tools (Hellstrom, et al., 1997).

MARKET PENETRATION

Within the full swing of heat pump applications in Europe, ground-coupled heat pumps play a significant role. The development started around 1980 when the first BHE-coupled heat pump systems were built in Germany and Switzerland. Following a larger number of new units installed during the oil price crises and a subsequent low (except for Switzerland), the number of new installations is again increasing in the 90s.

Table 1 shows the number of ground-source heat pumps (GSHP) installed in various European countries. The GSHP fraction is especially high in Sweden and Switzerland. In some other countries as Italy, Greece and Spain, there is so far only a negligible number of GSHPs installed.

Table 1. General Heat Pump (Total) and Ground-Source Heat Pump Systems (GSHP) Installed 1993-1996 in Various European Countries (residential sector, in 1000 units, after data from Breembroek and Lazáro, 1999).

Country	All Heat Pumps	Ground-Source Fraction %	GSHP Systems
Austria	22.2	11	2.42
Denmark	3.3	18	0.59
France	25.0	11	2.75
Germany	5.7	4	0.23
Netherlands	0.12	7	0.01
Norway	4.0	8	0.32
Sweden	42.3	28	11.8
Switzerland	15.0	40	6.0
TOTAL			24.12

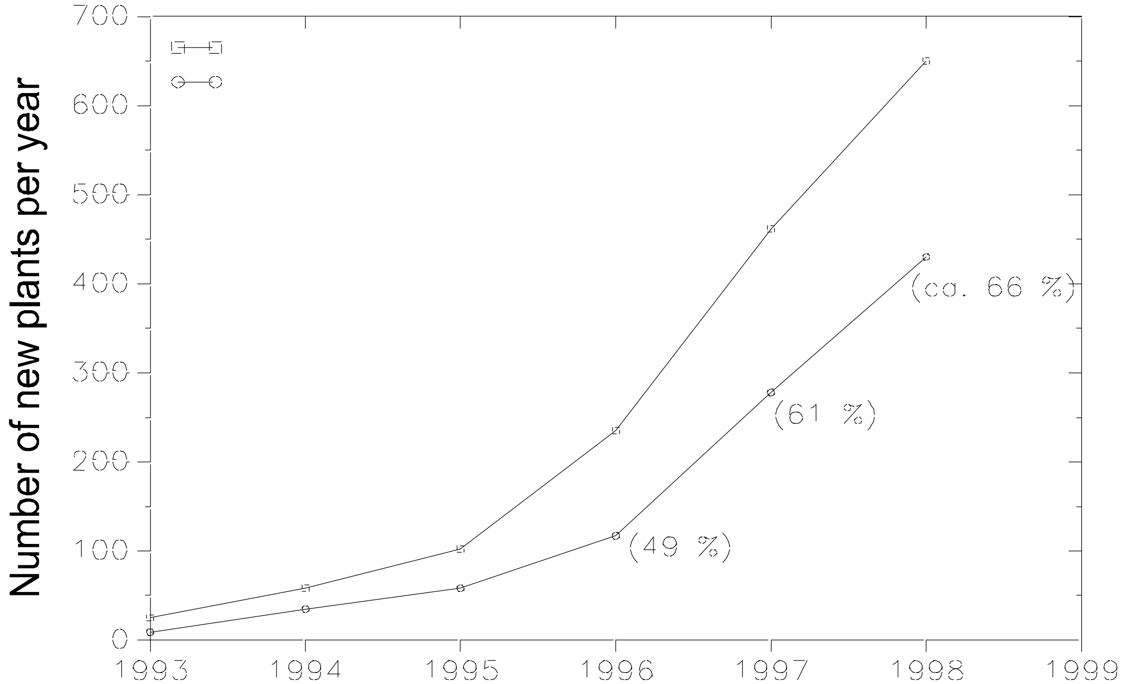

Figure 5. Market development for heat pumps in the RWE-area (data courtsey of RWE).

The share of GSHPs in supplying the residential heat demand also varies from country to country (Table 2). The fraction is still small but steadily growing. In Switzerland, about every fourth new one- or two-family house is now being equipped with a GSHP system.

Table 2. Share of Ground-Coupled Heat Pumps in Total Residential Heating Demand (after data from Van Deven, 1999)

Country	
Austria	0.38
Denmark	0.27
Germany	0.01
Norway	0.25
Sweden	1.09
Switzerland	0.96

The development can also be seen in individual regions. In Figure 5, the number of installations realized within an incentive program of the German utility RWE is depicted. Not only the total number of heat pumps installed in the RWE-area is rapidly increasing, but also the share of BHE-equipped heat pumps. For all heat pumps installed in this area until 1982, the ground (mainly with horizontal coils) was the heat source for 5% and groundwater for another 30%. In 1998, the BHE alone encountered for about 66% of the heat sources.

THE SWISS SHOWCASE

With a total of 50,000 presently installed heat pumps for space heating/warm water supply, Switzerland is, per capita, the world leader in this environmentally friendly technology. The general popularity of heat pumps in Switzerland lead also to a real boom of heat pump coupled BHE systems. Today, every third newly built single-family house is equipped with a heat pump system. Although air-source heat pumps are significantly lower in installation cost (there are no drilling costs as for a BHE system), nearly 40% of the heat pumps installed today have a geothermal (BHE) source. The generally lower seasonal performance coefficient of air-source heat pumps (due to the low source temperature in winter) is the main reason for this high percentage.

The share of heat delivered by BHE/heat pump systems in the Swiss geothermal mix is overwhelming (75% of a total of 439 GWh in 1997, Rybach and Wilhelm, 1999).

The boom resulted in the installation of over 20,000 BHE systems to date, with a total of about 4,000 km of BHE length. At present, 1 m of BHE costs (drilling and installation included) about 40 US $. Figure 6 shows the spatial distribution of BHE installations, delivered by just one commercial company (GRUNDAG, Gossau/SG: 7,900 BHEs with 695 km total length; status in mid-1997). The pattern of BHE system locations corresponds roughly to the population density. The widespread BHE installations secure Switzerland a leading position. Areal BHE density in Switzerland is the highest worldwide (1 BHE installation every 2 km^2). The number of installations increases yearly by >10%, as well as the heat production.

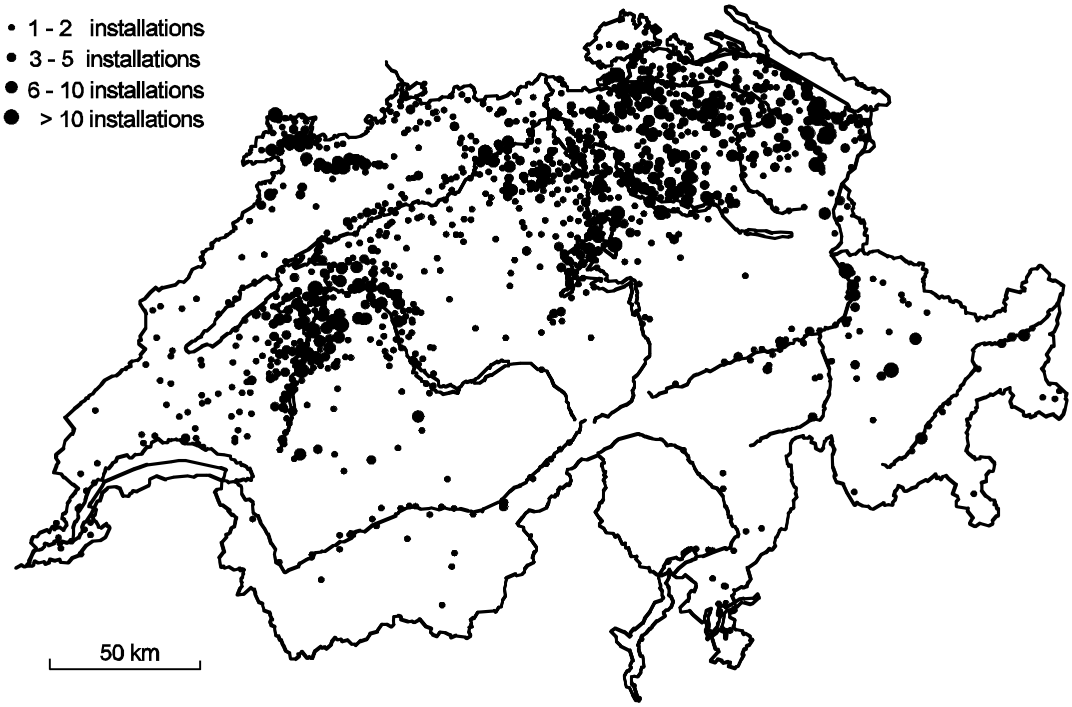

Figure 6. **Location of BHE systems in Switzerland, delivered by a single company (GRUNDAG AG, Gossau/SG; from Rybach and Engster).**

Technical and economic factors lead to the BHE systems boom in Switzerland. Their synergy is responsible for the rapid market penetration (annual growth rate is exceeding 10%).

There is a number of technical factors which are favorable for BHE-coupled heat pump systems:

- Appropriate climatic conditions of the Swiss Plateau (where most of the population lives);
- The BHE systems are installed in a de-central manner, to fit individual needs. Costly heat distribution (like with district heating systems) is superfluous;
- Relatively free choice of position next to buildings (or even underneath);
- No need, at least for smaller units, of thermal recharge of the ground; and
- The systems operate emission free and help to reduce greenhouse gas emissions like CO_2.

As main economic incentives can be listed:

- No transportation risks and costs as with oil/gas solutions;
- No need for groundwater protection (as with oil boilers/tanks);
- Low areal demand of a few m^2 only (in a country where ground property prices are high);
- Less space demand (several m^3) than for conventional systems;
- Low operating costs (no oil or gas purchases, burner controls, etc., like with fossil-fueled heating systems);
- Local utility subsides/rebates for environmentally-favorable options like electric heat pumps;
- BHEs provide CO_2-free heating, and
- Current parliamentary discussions show that a CO_2 tax is in sight.

Of all countries, China has, with 2.1 GW_{th}, the largest figure in installed geothermal capacity for direct use, followed by the USA with 1.8 GW_{th}(Fridleifsson, 1997). China and the USA are huge countries. So some normalization is needed to account for the country size. When normalized on the basis of the installed capacity and the country population, Switzerland occupies the prominent world rank 3, thanks to the large number of BHE/heat pump installations.

RECENT DEVELOPMENT IN CENTRAL AND NORTHERN EUROPE

The total number of GSHP in Europe can only be estimated; in Table 3 such an effort is made. In the following, some developments in individual countries are characterized.

A relatively new trend in Germany and even more in the Netherlands is using GSHP in residential development projects. 50,100 or more houses are built in a limited area,

Table 3. Estimation of GSHP Numbers in Europe, Using Published Information (with year) and Extrapolation According to Published Rates of Increase (after Sanner, 1999).

Country	No. of GSHP Systems	Remarks
Austria (1996)	ca. 13,000	Annual increase ca. 1,600.
Germany (1995)	14,000 - 22,000	240 - 450 MW thermal capacity, annual increase ca. 2,000.
Netherlands (1997)	ca. 900	Market development is about to begin.
Sweden (1998)	ca. 55,000	ca. 330 MW thermal capacity
Switzerland (1998)	More than 20,000	ca. 300 MW thermal capacity, annual increase ca. 15%.
Other Countries	??	France, Italy, UK, Denmark, Norway, etc.
Total Europe (extrapolated to end of 1998)	100,000 - 120,000	Almost 1,300 MW thermal capacity, ca. 1,950 GWh heat per year.

and all are equipped with GSHP. Several studies have been made mainly for sites in the Ruhr region and the Rhein-Main area.. Here the limits of natural thermal recharge may be reached for heating only operation. According to the heat load of the houses and the distance between houses, the length of BHE has to be increased, to tap more ground volume. An example is shown in Figure 7, based upon a calculation for 60 houses. Each house has a supposed heat load of 7 kW and 2 BHE to supply heat to the heat pump. A distance of 15 m between BHE means a total area for the house, garden, street, etc., of 450 m^2, which is not uncommon in condensed building areas. The necessary increment of BHE length with 15 m distance over a single, isolated system is about 60% for the 30-year operation, and for 20 m distance (800 m^2) it is still around 25%.

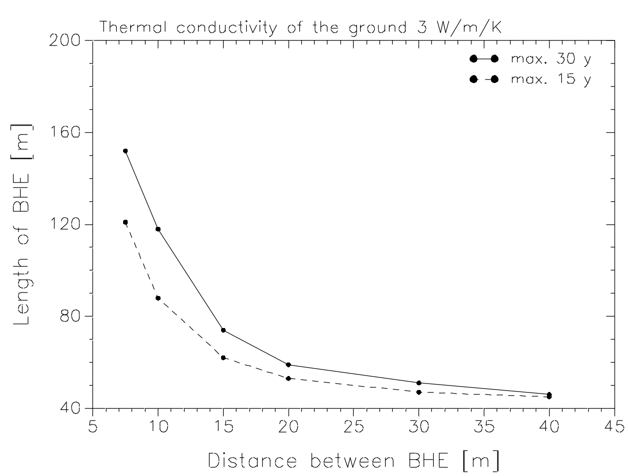

Figure 7. Influence of distance between borehole heat exchangers (BHE) on the necessary BHE length for operation in a 15-year or 30-year time frame. Field of 60 houses (7 kW heat load each) with 2 borehole heat exchangers for each house. No groundwater flow, no artificial thermal recharge (after Sanner, 1999).

The calculation was done without considering the influence of moving groundwater. However, in a large field of houses, the impact of the groundwater is good for the houses upstream, and bad for those in the flow direction. In the end, for a large enough area, there is virtually no advantage in groundwater flow. One method to avoid increase BHE length is to provide artificial thermal recovery in summertime. This may be from waste heat, warm surface water, excess heat from solar collectors, etc. For the group of 60 houses with 450 m^2 area each, recharging of a total of 300 MWh of heat in the period from May to September will allow for only 14% increase over the single system.

Austria

In Austria, ground-source heat pumps had a market share of 95% in 1996 (Figure 8). Most systems have less than 15 kW_{th} heating output, and with ground as heat source, direct expansion systems are predominant. In 1996, emission of 335,000 tonnes CO_2 compared to fuel oil burner was saved (Faninger, 1997). A survey of the Austrian Research Center Seibersdorf in co-operation with heat pump manufacturers and utilities revealed seasonal performance factors (spf) in realized systems from spf = 2.1 to spf = 4.0. The theoretical values for spf are not always achieved in practice.

Ground-coupling with "energy piles" started in the late-80s in Austria. Meanwhile, also other parts of the building in contact with the ground are used, beside foundation piles. Two extraordinary examples are described below:

- 320 cast concrete piles, each 18 m deep, with a total of about 65 km of polyethylene pipe support the multi-purpose convention center of Dornbirn. The building may house fairs, congresses, an indoor ice rink, etc. The energy piles are part of the complex energy system of the building, including the refrigerator for the skating rink, and they can supply up to about 800 kW for heating or cooling.

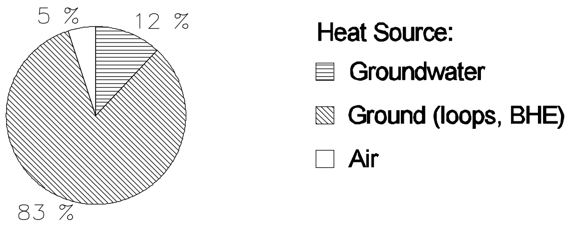

Figure 8. Distribution of heat sources for heat pumps (for space heating) in Austria, new systems 1996 (after data from Faninger, 1997).

- In the Kunsthaus (house of arts) in Bregenz, there is no heating or cooling in the traditional way. Instead. A total of about 24,000 m of polyethylene pipe, embedded in the 120 m long and 28 m deep trench walls surrounding the excavation pit during construction, control the room temperature. Within the building, concrete ceilings, floors and walls are equipped as heat exchangers. The system is aided by an optimum insulation of the exterior walls.

Like in Germany, the combination of solar heat and shallow geothermal energy is tested again in Austria. In the ESG-Ökopark in Linz, an ecological housing area, a multi-family house is equipped with "trench-type" ground collector and 35 m^2 of solar collectors (Faninger). The solar collectors are used for ground thermal recharge at temperatures not otherwise usable in the building. The spf of the system is 3.3. In 1996, a total of 50.8 MWh was supplied to the building, 55% of which were from the earth and 19% from directly the sun.

Netherlands

As environmentally-friendly alternative to the prevailing natural gas burners, GSHP are considered in the Netherlands over the last years. After some development in the 80s (Bourna and Koppenol, 1984), the use of heat pumps became almost non-existent over several years. In the second half of the 90s, a kind of revival could be seen. Table 4 shows the various sectors of heat pump use.

With the development of new housing areas, the natural gas distribution may be omitted, and heating could be done through electricity supply and heat pumps. GSHP together with the notoriously dense construction in the Netherlands may result in mutual thermal influence of the BHE and requires specific care. Nevertheless, the first larger systems have been built:

- In 1997, 36 residential houses were equipped with BHE in Nijmegen/Grootstal. Each house has a heat pump with about 5 kW evaporator capacity and 4 single-U-BHE made from polyethylene, 30 m deep (Snjders and Wennekes, 1997/98);
- Each unit of a row of houses in Reeuwijk has 8 energy piles 15 m deep supplying heat to a heat pump with 5.5 kW evaporator capacity, and
- The next plans are the conversion of a hole residential quarter of Gouda, were fuel oil and propane are used. Natural gas pipes are not suitable at this site due to the very high groundwater level.

While the GSHP technology is restarting after several years in the Netherlands, the country is one of the leaders of aquifer thermal energy storage (ATES), mainly for space cooling. About 70 systems exist, with an annual increase of 10 - 20 systems. A very interesting example is described by Bakema an Snkjders, 1997: The multi-purpose sports stadium "Geldredôme" in Arnhem uses ATES for heating the lawn in winter with a heat pump, and for cooling of office area in summertime. Other systems comprise:

- The Rijksmuseum in Amsterdam,
- The headquarters of IBM Nederlands in Zoetermeer,
- The Prins-von-Oranje building of the Utrecht trade fair,
- The new operating center of KLM airline on Schiphol airport,
- The European headquarters of Nike in Hilversum, and
- An IKEA center in Deuven.

and many more.

Belgium

The first ATES cold storage systems are operational in Belgium, following Dutch prototypes (e.g., CERA Bank headquarters in Leuven). Other are under construction or in planning, so for a pharmaceutical industry, a hospital, a sausage factory, etc.

France

The French utility EdF launched a campaign to develop a market for GSHP in France. In a research center, seven identical single-family houses are equipped with four types of horizontal ground loops and three different types of BHE. Due to the identical geological and climatic conditions of the houses, a practical comparison between systems can be made. In co-operation with the Swiss and German geothermal associations, a guideline for GSHP use for the EU is planned.

Table 4. Number of Heat Pumps for Space Heating in the Netherlands, 1997 (most with groundwater or ground heat exchangers), According to Ecofys-Study.

Agricultural	Industry	Commercial	Residential	Total 97	Total 94	Increase 94-97
143	43	150	567	903	220	310%

In some regions of France, in particular in Alsace, groundwater heat pumps are operational for a long time. The Palais d'Europe in Strasbourg is the site of a large groundwater heat pump system. Horizontal ground loops, including those with direct expansion, have been used at various places. Several GSHP with BHE have been built in Alsace in recent time, and at least two of them are documented.

Poland

One of the first GSHP in Poland was built in 1993 for the hotel "Ornak" in Zakopane, with horizontal ground loops. On the most recent horizontal loop installations is for heating of a block of flats in Lomza. This system will be enlarged for neighboring multi-family houses, and BHE will be used due to space restrictions. There are also groundwater heat pumps, as for heating apartments and administration buildings in the Slowinski National Park in Smlodzin with 150 kW. Some recent examples of GSHP in Poland are listed in Table 4. Polish manufacturers of heat pumps exist, meanwhile, offering a range of thermal capacity from 4 - 200 kW.

Sweden

Sweden is one of the classic countries of heat pump use. Around 55,000 BHE systems are operational, with a total installed capacity of about 330 MW_{th}. GSHP are a generally accepted form of heating, and due to the high share of hydropower in the electric power supply, heat pumps always offer an opportunity for reduction of emissions.

Besides in GSHP use, Sweden is also leading in underground thermal energy storage technology. Here often BHE are used, and in areas with glacio-fluviatil sediments or, in the southern part of the country, with fractured limestone, groundwater is used directly (aquifer storage; see Andersson, 1998). In Stockholm, the first district cooling system based on aquifer cold storage is operational.

Cooling of telecommunication systems is done using BHE. The first systems were built in 1995 in Boromma (Ängby, 6 BHE each 154 m deep, 27 kW cooling power) and Skogås (Drevikstrand, 4 BHE each 155 m deep, 20 kW cooling power), to cool telephone switching stations. The largest system so far is located within a tunnel in the center of Stockholm, offering 220 kW of cooling from 30 BHE. There is now cold storage in the ground associated with these systems. The aim is to keep the return temperature from BHE below 20°C after 10 years of operation. A specific capacity of about 25 W/m secures this requirement in granite (? = 3.5 - 3.9 W/m/K). During the 10-year period, a saving of 40% of costs compared to conventional alternatives is expected.

Equipment and procedures for in-situ tests of thermal properties in installed BHE was developed at the Technical University of Luleå (Eklöf and Gehlin, 1996). These tests allow better accuracy of simulations and design by supplying reliable data on the actual thermal properties of the ground.

Similar equipment now is used in other countries as USA or the Netherlands.

A particular success story can be told of Strömstad, a town of 6,000 about 200 km to the north of Gothenburg. The rocky subsoil is not suited for district heating, and thus, 140 GSHP with a total of 400 BHE have been installed for heating of houses and apartments for 3,000 people (Sanner and Hellström, 1998) the improvement of air quality in winter was reported to be visible.

FUTURE TRENDS AND QUESTIONS

The European experience with GSHP systems so far is excellent. It is expected that the market will further expand, in the leading countries like Sweden and Switzerland as well as in other countries to follow. The growth can be exponential as the Swiss example shows (Figure 9).

An important factor, related to the further development of electric heat pump systems in general and the GSHPs in particular, is the current process of deregulation in Europe. The energy sector and, especially the electric utility companies, is currently under deregulation and privatization. This affects not only the producers but also the customers. The deregulation process may affect the heat pump market in two ways: 1) heat pump economy might be influenced by changes in the energy price structure, and 2) the heat pump market might be stimulated or hindered, depending on changing utility market strategies (Breembroek, 1998).

Table 4. Recent GSHP Systems in Poland (after Chwieduk, 1999).

Location	Purpose	Thermal Capacity (kW)
Warsaw	Diplomatic Service Company	36
Warsaw-Bemowo	Municipal block of flats	72
Jasionna (near Bialobrzegi Radomskie)	Church	16
Lichen	Church administration	36
Szamotuly	Sports hall	260
Olecko	Bank PBK (heating and cooling)	220
Gostynin-Kruk	Hospital, medical care office	970

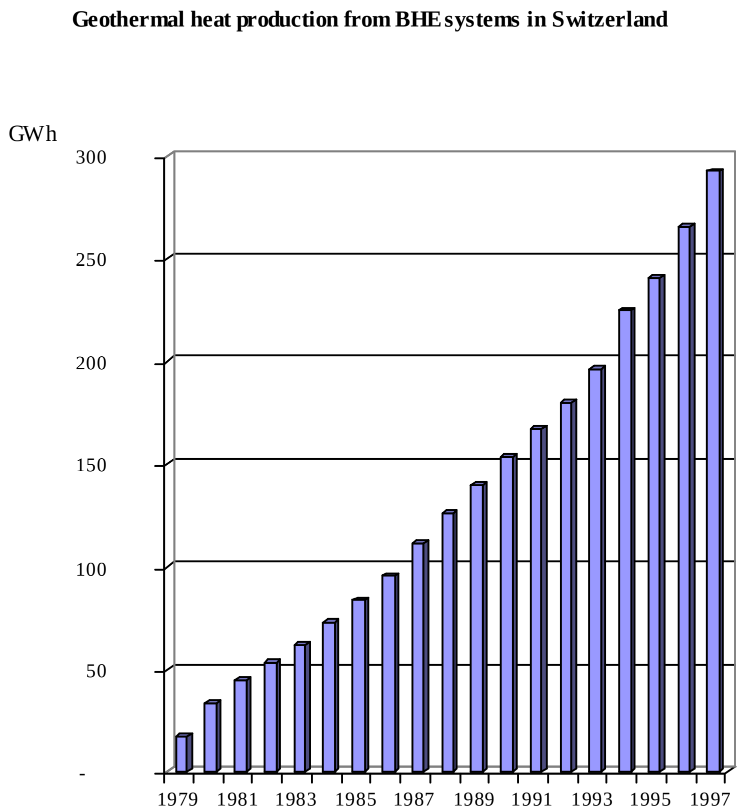

Figure 9. **Compilation of geothermal heat production (before the heat pump) by BHE systems in Switzerland. The values are based on AWP sales statistics (AWP = Arbeitsgemeinschaft Wärmepumpen Schweiz). The compilation has been commissioned by the Swiss Federal Office of Energy, Bern (see Wilhelm and Rybach, 1999).**

So far, in the regulated market, some utilities have clearly supported heat pumps, in line with governmental energy-efficiency programs (e.g., by offering grants or special electricity tariffs). However, in a deregulated energy market, the market strategies of utilities will change. Only when the market matures and energy prices drop to a stable level will utilities offer incentives such as products/bonuses or energy-efficiency services.

Nevertheless, the ecological incentives like avoiding greenhouse gas emissions will further support GSHP development. The CO_2 tax in sight is a further (financial) incentive. Of course, there will be considerable differences in this respect from country to country.

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SCALING IN GEOTHERMAL HEAT PUMP SYSTEMS

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INTRODUCTION

Water quality is a frequently overlooked issue in the application of geothermal heat pump (GHP) systems. When considered at all, is often viewed as a problem unique to open loop systems. In residential open loop applications water is supplied directly to the heat pump's refrigerant-to-water heat exchanger. If the water has a tendency to be scale forming, fouling of the heat exchanger may occur. This fouling reduces the effectiveness of the heat exchanger and compromises the performance of the heat pump. Water quality is also a consideration for closed loop systems. In the closed loop system, the concern is not the main refrigerant to water heat exchanger but the desuperheater. Water is circulated through the desuperheater and back to the main hot water heater to provide a portion of the domestic hot water heating needs. Again scale formation in this heat exchanger will reduce the contribution of the desuperheater makes to the domestic hot water heating load. In large commercial systems, the groundwater is isolated from the building loop using a plate-and-frame heat exchanger. This eliminates the potential for scaling in the heat pump units. In addition, it reduces the maximum temperature to which the groundwater is exposed, thus reducing scaling potential.

In most cases, the formation of scale is a slow process occurring over months or years. As a result the impact of the reduced heat pump or desuperheater performance on the utility bill is gradual. This slow erosion of the savings the system would otherwise produce may be imperceptible to the system owner. The object of the work reported here was to identify areas of the country where water quality is such that scale may occur. With this information installers and system owners can plan for the regular maintenance that may be necessary to address the scaling and preserve system performance.

In the residential sector, closed loop GHP's tend to be installed in homes in the upper cost end of the market. Since these homes would likely be equipped with a water softener in hard water areas, the potential for scaling in these instances would be substantially eliminated.

WATER CHEMISTRY AND SCALING

Depending upon it's specific chemistry, water can promote scaling, corrosion or both. Scaling, according to the Water Quality Association, is the number one water quality issue in the US. Scale can be formed from a variety of dissolved chemical species but two reliable indicators are hardness and alkalinity. Calcium carbonate is the most common form of scale deposition attributable to groundwater used in residential GHP systems.

Total hardness is primarily a measure of the calcium and magnesium salts in water. In addition, other minor contributing components to hardness can be aluminum, manganese, iron and zinc (Carrier, 1965). Two types of hardness are generally recognized: carbonate (sometimes referred to as temporary hardness) and non-carbonate hardness. Carbonate hardness, depending upon the nature of the water is composed of calcium or magnesium carbonates and bicarbonates. It is this form of hardness that contributes most to scale formation. Non-carbonate hardness is normally a small component of the total hardness and is characterized by much higher solubility. As a result it's role in scale formation is generally negligible.

Water hardness is classified according to a somewhat subjective criteria that varies from reference to reference. Table 1 provides a common interpretation. Scaling problems typically occur above levels of 100 ppm hardness.

Table 1. Water Hardness Classification (Carrier, 1965)

Hardness (as ppm $CaCO_3$)[1]	Classification
<15	Very soft
15 to 50	Soft
50 to 100	Medium hard
100 to 200	Hard
>200	Very Hard

1. Hardness is sometimes expressed in units of grains per gallon(gpg). To convert gpg to ppm as $CaCO_3$ multiply by 17.1.

Calcium hardness is a key parameter in evaluating scale formation. It generally constitutes 70% or more of the total hardness in water. For worst case evaluations or in the absence of sufficient information, calcium hardness can be considered equal to total hardness. If a calcium ion value is available from a water chemistry analysis, calcium hardness (as $CaCO_3$) can be calculated by multiplying the calcium ion value by 2.5.

Alkalinity is a measure of a water's ability to neutralize acid. Like hardness it is usually expressed as ppm $CaCO_3$. In the range of normal groundwater chemistry, alkalinity is the result primarily of the bicarbonate content of the water. At pH values of greater than 8.3 carbonate and hydroxide can also contribute to alkalinity. Two measures of alkalinity are of interest: Methyl Orange ("M" alkalinity or total alkalinity) and Phenolphtalien ("P"alkalinity). Since P alkalinity measures that portion of the alkalinity effective at very high pH, the M alkalinity is the value of interest in evaluating scale potential.

A relationship between hardness and alkalinity exists as follows:

> If M alkalinity is greater than total hardness, all hardness is due to carbonates and bicarbonates.
>
> If M alkalinity is less than total hardness, carbonate hardness = M alkalinity non-carbonate hardness = total hardness-M alkalinity.

In order to evaluate the general character (scale forming or corrosive) of a particular water sample it is necessary to know the total dissolved solids (TDS), pH and temperature in addition to the calcium hardness and the M alkalinity.

Total dissolved solids is a general indication of the quality of a water source. As TDS increases water quality problems are more likely to occur. Whether these problems are on the corrosion or scaling end of the spectrum is dependant upon other indicators. Federal drinking water standards call for a limit of 1000 ppm in waters used for municipal water supplies though this is not directly health related.

The pH value of most groundwaters is in the range of 5.0 on the acid end of the spectrum to 9.0 on the alkaline end. Scaling problems are common at pH value above 7.5.

Two indices commonly used in the water treatment industry to evaluate the nature of a water source are the Langelier Saturation Index (LSI or Saturation index) and the Ryznar Stability Index (RSI or Stability index). In both cases these indices are based upon a calculated pH of saturation for calcium carbonate (pH_s). The pHs value is then used in conjunction with the water's actual pH to calculate the value of the index as follows:

$$LSI = pH - pH_s$$
$$RSI = 2pH_s - pH$$

Evaluation of the saturation index is as indicated in Table 2. The stability index (table 3) produces a slightly different value numerically but is interpreted in a similar fashion.

Table 2. Interpretation of the Langelier Saturation Index (Carrier, 1965)

LSI Index Value	Indication
2.0	Scale forming but non corrosive
0.5	Slightly scale forming and corrosive
0.02	Balanced but pitting corrosion possible
-0.5	Slightly corrosive but non-scale forming
-2.0	Serious corrosion

Table 3. Interpretation of the Ryznar Stability Index (Carrier, 1965)

RSI Index Value	Indication
4.0 - 5.0	Heavy scale
5.0 - 6.0	Light scale
6.0 - 7.0	Little scale or corrosion
7.0 - 7.5	Corrosion significant
7.5 - 9.0	Heavy corrosion
> 9.0	Corrosion intolerable

It is important to point out that the accuracy of the RSI and LSI is much greater as a predictor of scaling than of corrosion. This results from the fact that both methods are based upon the saturation of calcium carbonate. The assumption implicit in the calculations is that if the calcium carbonate content exceeds the level that can be maintained in solution, scale will occur. At lower pH corrosion will occur. In terms of general corrosion in systems constructed of primarily ferrous materials, this is a valid assumption for corrosion. In heat pump systems where the materials are more likely to be copper or cupro-nickel there are other chemical species that can cause serious corrosion that are not accounted for in the RSI/LSI calculations. These would include hydrogen sulphide (H_2S) and ammonia (NH_4) among others. As a result for GHP systems, the RSI/LSI indices should be used as scaling rather than corrosion predictors.

Calculation of the value for pHs can be done using the nomograph found in various references (ASHRAE, 1995; Carrier, 1965) or through the use of the following equation:

$$pHs = (9.3 + A + B) - (C + D) \qquad \text{(Edstrom, 1998)}$$

where:

$A = (\log(TDS) - 1)/10$	TDS in ppm
$B = (-13.12 \ \log(^{\circ}C + 273)) + 34.55$	Temperature in ºC
$C = (\log(\text{calcium hardness})) - 0.4$	Ca hardness in ppm (as $CaCO_3$)
$D = \log(\text{M alkalinity})$	M Alk in ppm as ($CaCO_3$)

Example:

> pH = 8.2, TDS = 500 ppm, calcium hardness = 165 ppm as $CaCO_3$, Alkalinity = 100 ppm as Ca CO_3, temperature = 55 ºF (12.8 ºC)
>
> $A = (\log(500) - 1)/10 = 0.17$
> $B = (-13.12 \log(12.8+273)) + 34.55 = 2.33$
> $C = \log 165 - 0.4 = 1.82$
> $D = \log 100 = 2.0$
>
> $pHs = (9.3 + 0.17 + 2.33) - (1.82 + 2.0) = 7.98$

LSI = 8.2 - 7.98 = 0.202 (balanced)
RSI = 2(7.98) - 8.2 = 7.76 (heavy corrosion)

Same water at 150°F

LSI = 1.2 (scale forming)
RSI = 5.8 (light scale)

It is apparent from this example that the temperature at which the calculation is made has considerable impact upon the results. The water chemistry above is non-scaling to corrosive at the temperature at which it would be delivered from the well. If exposed to higher temperature, it would deposit scale. For heat pump applications this is an important consideration.

Figure 1 is a plot of scale deposit at various temperatures for a water containing 170 ppm hardness. The relationship between temperature and scaling is clearly demonstrated.

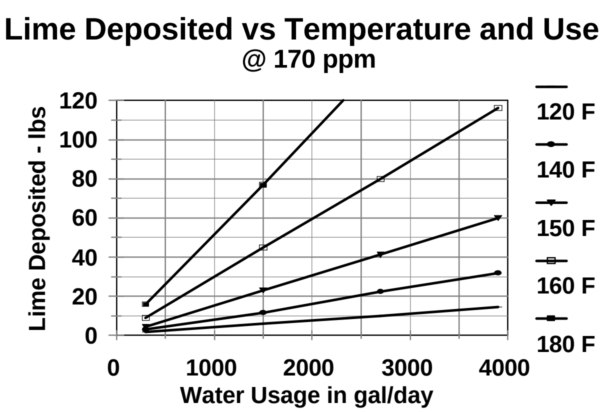

Figure 1. (ASHRAE,1995)

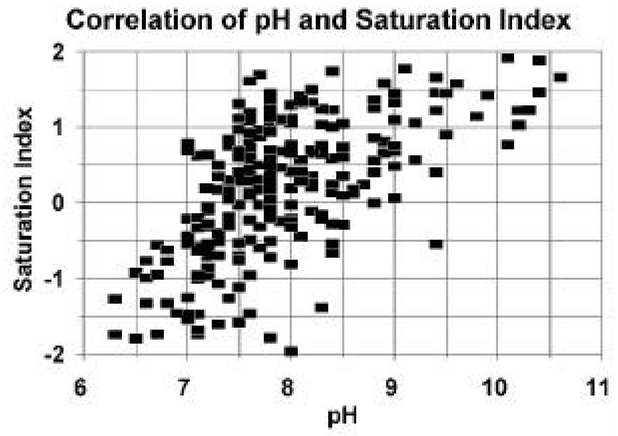

Figure 2.

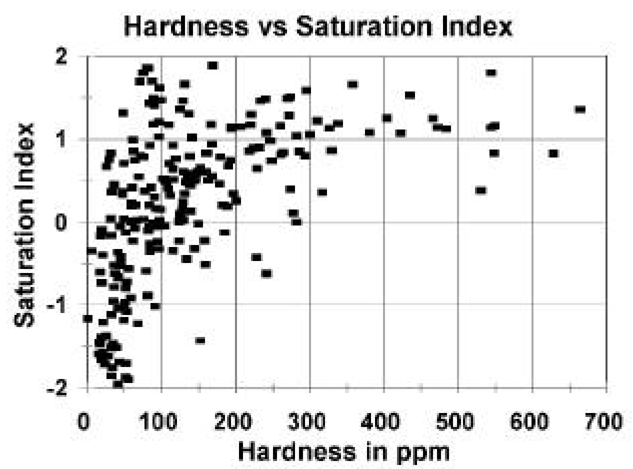

Figure 3.

Figure 2 presents a plot of LSI vs pH for a collection of 260 water samples (Carrier, 1965) from across the US. It is apparent that serious scale problems (LSI > 1) are unlikely at pH values less than 7.5.

Figure 3 presents a plot of LSI vs hardness for the same group of samples. It is equally clear from this data that serious scale problems are unlikely at water hardness values below 100 ppm. In addition, hardness values above 200 ppm suggest the potential for serious scaling. In developing the individual state maps of scaling potential, these data were used to establish the thresholds for scaling potential.

SCALING IN HEAT PUMP APPLICATIONS

Scaling is a phenomenon that can impact the performance of both open and closed loop heat pump systems. In closed loop systems, the ground loop and main refrigerant to water heat exchanger do not present a problem. Even if the system is filled with a water of high scaling potential, the small volume of water contained would limit the degree of scaling that could result.

The situation in the desuperheater (if used) is quite different. With the large throughput of water and exposure to the highest temperatures in the refrigeration cycle, the desuperheater provides optimum conditions for the formation of scale given a water with a scaling chemistry.

In some cases, desuperheaters in installations with very hard water have become completely plugged by scale buildup rendering them inoperable. Unfortunately, in most cases this has occurred without the owner's awareness of the problem. This results from the sequence of operation for desuperheaters. Basically, the desuperheater is intended to provide only a portion of the domestic hot water heating needs of the residence. Heat is available to be recovered when the heat pump is operating to produce space heating or cooling. When the heat pump is not operating, the domestic hot water heater meets the water heating requirements. As the formation of scale slowly reduces the capacity of the desuperheater, the domestic hot water heater simply picks up the difference. The gradual erosion of savings may proceed unnoticed by the homeowner.

For open loop systems, the same situation exists in the desuperheater as described above. In addition, the main refrigerant to water heat exchanger is also exposed to the well water. Depending upon the specific water chemistry, scaling could occur in both the heating and cooling modes but the cooling mode would be the more susceptible due to the higher temperatures involved.

Figure 4, modified from data in Carrier, 1965 illustrates the impact of scale formation on the performance of a heat pump operating in the cooling mode with 55 °F entering water at 2 gpm/ton. With just .03" of scale on the heat exchanger surface the heat pump power consumption is 19% higher than with a clean surface.

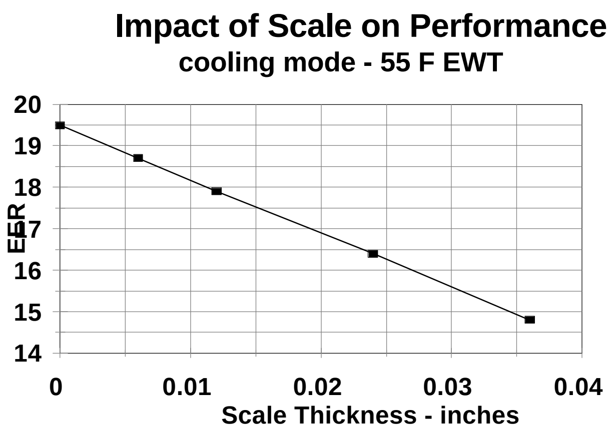

Figure 4.

In large commercial systems, the groundwater is isolated rom the building loop using a plate-and-frame heat exchanger. This eliminates the potential for scaling in the heat pump units. In addition, it reduces the maximum temperature to which the groundwater is exposed. In applications in which groundwater is supplied directly to the heat pump unit, the water encounters surface temperatures as high as 160°F in the hot gas inlet area. By contrast, in a system using an isolation heat exchanger, the maximum water temperature encountered would be in the range of 90°F. Since scaling is partially temperature driven phenomenon, the use of the isolation heat exchanger is more than simply a strategy of moving the scaling from the heat pumps to the plate heat exchanger. Due to the difference in exposure temperatures, it reduces the propensity for scale formation of a given water chemistry relative to that encountered in systems where the water is used directly.

PREDICTING SCALE FORMATION

The goal of this work was to produce a series of maps indicating the regions of the US in which the potential for scaling in heat pump heat exchangers. Little data is available that offers a comprehensive evaluation of individual aquifer water chemistry. To characterize aquifers in terms of a national scope, it is necessary to focus on a single parameter in order to acquire data of a uniform level of accuracy and resolution. For purposes of this work, hardness was chosen as the parameter upon which to base the indication of scale potential.

As discussed earlier, to make a qualitative determina-tion of scaling potential (using LSI or RSI), it is necessary to know the calcium hardness, M alkalinity, TDS, pH and tem-perature. Of these, temperature is known as far as what would be encountered in a heat pump, pH is easily measured in the field without the necessity of a lab test and TDS tends to mirror hardness in terms of concentration (high hardness accompanies high TDS). Alkalinity is helpful in character-izing the type of hardness(carbonate or non carbonate) and whether or not it is of the variety that will cause scaling but for a first order indication of potential it can be assumed that all the hardness is carbonate. As a result the key parameter is hardness.

Hardness has been quantified and mapped on a national basis by others (Pettyjohn and others, 1979; Moody and others, 1988 and USGS, 1995) in the past. This data forms the basis for the maps developed under this work. For each state a map was developed with hardness of the principal groundwater aquifer indicated as one of three levels: <100 ppm white, 100 ppm to 200 ppm gray, and >200 ppm dark gray. These three concentrations are indicative of areas in which there would be little concern as to scaling and no particular precautions are necessary, areas where scaling could occur given suitable conditions and areas in which some degree of scaling is likely to occur.

In areas of moderate concern (gray), a field test of the pH would be advisable. If the results of the test indicate a pH of 8.0 or above it would be useful to gather the necessary data to calculate the values for RSI and LSI.

For areas of likely scaling (dark gray), it would be advisable to monitor the performance of the heat pump particularly in regions with high cooling requirements and/or where a desuperheater is used in the absence of a water soft-ener. If periodic tests (of power consumption and refrigerant system pressures - standard tests made by service technicians) indicate that scale is occurring it will be necessary to remove this scale from the heat exchanger (and desuperheater if one is used). This can be done by circulating a weak acid solution through the heat pump heat exchanger for a short period to dissolve the scale.

Figures 5 and 6 are samples of the maps produced for each of the states indicating hardness contours for the three levels of concentration mentioned above. It is important to point out that the data used addresses only the principal groundwater aquifer. In many areas, there is more than one aquifer used for water wells. In addition the data is appro-priate only to those applications using a private water well. For homes connected to a municipal water system, it is likely that some form of treatment is provided to address very hard water. The complete report (Rafferty, 2000) can be obtained from the Geo-Heat Center.

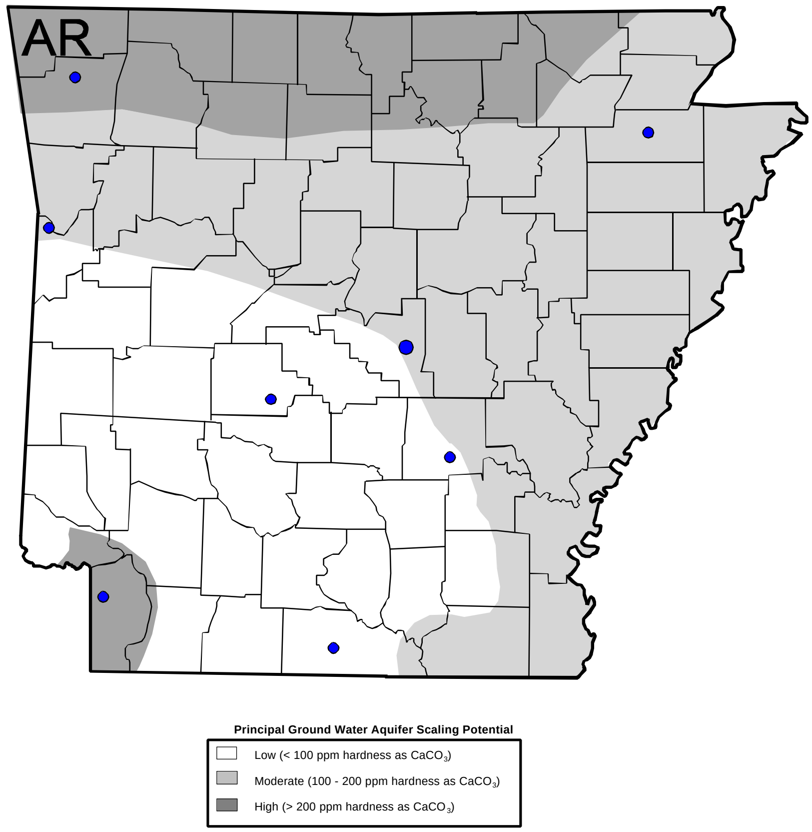

Figure 5.

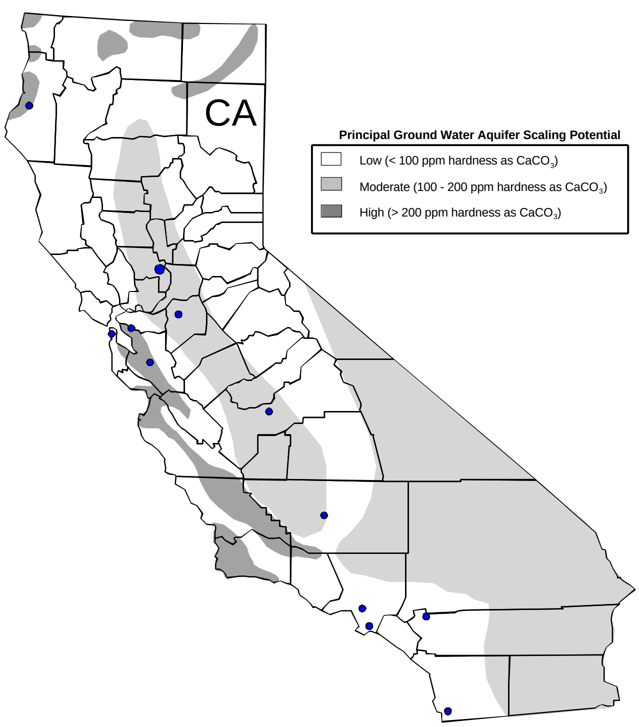

Figure 6.

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DESIGN ISSUES IN THE COMMERCIAL APPLICATION OF GSHP SYSTEMS IN THE U.S.

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ABSTRACT

Commercial ground-source heat pump (GSHP) systems can best be described as an emerging HVAC technology in the U.S. Verified, scientifically-based design tools have only recently become available. This paper discusses some of the key design issues in both ground-coupled and groundwater heat pump systems. Guidelines in the form of acceptable values are provided for pumping, flow rates, equipment performance and costs.

INTRODUCTION

Ground-source heat pump (GSHP) systems have been in service in commercial buildings in the U.S. for approximately 50 years. The earliest systems employed groundwater and central chillers, and many of these are still in service. Groundwater systems have remained consistently popular, and in the last 10 years have been joined by various closed-loop designs. Although started in the residential sector, closed loop systems are now emerging in the commercial building market. Due to the high cost of some conventional HVAC systems, GSHPs can often compete more effectively in first cost in commercial applications compared to residential applications. Coupled with the substantial energy savings available, the prospect for much wider use of the systems in commercial buildings is very positive. Currently, the two building categories in which GSHPs have made the greatest penetration are schools and office buildings. According to the Geothermal Heat Pump Consortium (GHPC, 1999), there are now over 600 schools in the U.S. with GSHP systems.

TERMINOLOGY

One of the most confusing issues for those unfamiliar with GSHP systems is terminology. Many terms are used to describe these systems and some are more effective than others. For purposes of this paper, the terms developed by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE, 1999) will be used. As indicated in Figure 1, the general term for all systems is ground-source heat pumps (GSHP). Parallel terms to this, used for marketing purposes are GS systems, GeoExchange and Geothermal Heat Pumps (GHP). Subcategories under GSHP are ground-coupled (GCHP), groundwater (GWHP) and surface-water (SWHP) systems. In addition to those shown in the figure, other designs in occasional usage for commercial applications are standing-column and hybrid systems. Standing-column systems use a deep well, typically completed in a competent formation to supply well water to the heat pumps in the building. After passing through the heat pumps, approximately 90% of the water is returned to the bottom of the well. The remaining 10% of the water is disposed of on the surface. This assists in bringing "new" water into the well from the aquifer to stabilize temperature. A submersible well pump provides circulation for the system. Well depth requirements are typically in the range of 50 ft per ton. To date, this system has been most popular in the northeast portion of the U.S.

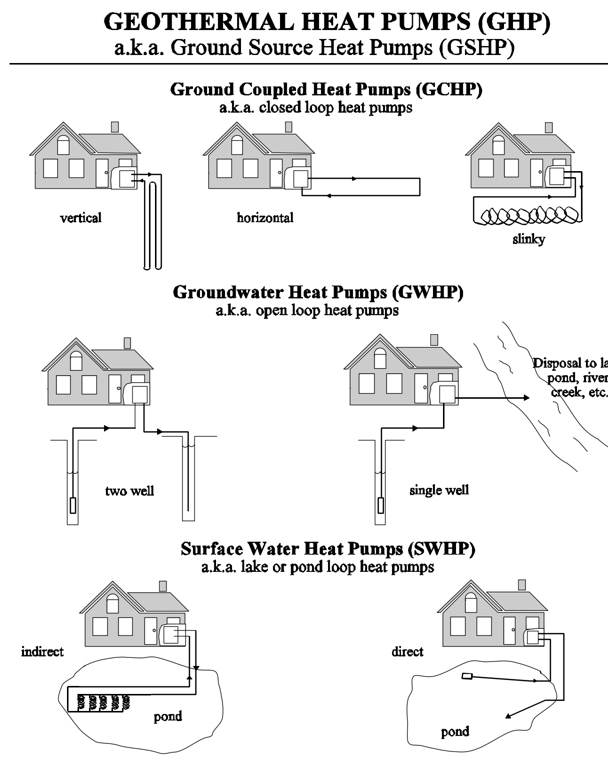

Figure 1.

The hybrid system is a variation on the closed-loop system. A smaller ground loop is installed to support only the heating requirement of the building. This downsized loop, in parallel with a cooling tower serves the heat rejection load of the system. The hybrid is a strategy to reduce system first costs in heavily cooling-dominated climates.

HEAT PUMP EQUIPMENT

Water-to-air unitary heat pumps in the 0.5 to 20 ton range are the type most often used in commercial GSHP systems. These units are of the "extended range" type, designed to operate with entering water temperatures in the 32 to 100°F range. Units are available in a wide variety of configurations including vertical, horizontal, counter-flow, split, rooftop and console; but, the vertical and horizontal designs are the most frequently employed. Although desuperheaters are available for commercial applications, they are not often used. Due to the size of the loads, dedicated water-to-water heat pumps are applied to commercial water heating applications.

In the past 10 years, unitary heat pumps have achieved substantial improvements in the areas of both performance and noise reduction. Approximately, a 40% increase in EER has been achieved in the units of 5 tons or less. Motivated by marketing issues in the residential sector, manufacturers have added more efficient fan motors, larger evaporator coils, more effective refrigerant-to-water heat exchangers and scroll compressors. In the >5 ton size range, somewhat smaller gains are evident for many manufacturers since improvements made in the residential-sized equipment have been less applied here. This is particularly true in units of >10 tons. Where cooling EERs in the mid-teens (ARI 330) are common for small units, larger equipment of >10 tons is often characterized by EERs of less than 10.

Paralleling the gains in energy efficiency are similar improvements in the operating noise characteristics of this equipment. In part, these issues are related. The use of scroll and rotary compressors in newer equipment has reduced the vibration associated with the compressor. The larger and slower turning fan wheels coupled with lower coil face velocities have reduced the air side noise as well. The result, from some manufacturers, is a substantially quieter unit compared to the older water-loop system equipment.

HEAT PUMP RATINGS

Water-to-air heat pumps are rated, at present, under one of three specifications. For units applied to the so-called water-loop heat pump systems (with a central boiler and cooling tower), the Air Conditioning & Refrigeration Institute (ARI) 320 rating applies. Cooling performance (EER) is reported at an entering water temperature of 85°F and heating at 70°F. This equipment is not intended for and should generally not be applied in GSHP systems.

The rating intended for GWHP systems is ARI 325. Under this rating EER and COP are both reported at entering water temperatures of 70°F and 50°F. A heavy pumping penalty (~250 w/ton) is applied in the rating calculations to reflect the well pump power requirements in a typical residential application. This level of pumping may not be appropriate for many commercial applications.

ARI 330 is the rating intended for GCHP systems. Heating performance is reported at an entering water temperature of 32°F and cooling at 77°F. A much smaller pumping penalty is included to reflect the power requirement of a small loop circulating pump.

None of these ratings are reflective of the performance that would occur in a large commercial application. They are useful primarily for the comparison of one manufacturer's equipment to another. Beyond this, the ratings described above are all single-point values and are not "seasonal" in nature as with fossil fuel equipment (AFUE) and air-source heat pumps (HSPF and SEER).

DESIGN CONSIDERATIONS FOR COMMERCIAL GCHP SYSTEMS

The successful application of commercial GSHP systems relies upon the careful consideration of three issues: heat pump selection, loop design and pumping.

As mentioned earlier, only extended range heat pumps should be specified for closed-loop systems. Units should be required to achieve a minimum ARI 330 rating of 13.0 (Kavanaugh and Rafferty, 1997) in high speed (if 2-speed units are used). To preserve maximum latitude for the owner, all units should be capable of operation under the control of nothing more than a heat pump thermostat. Consideration should be given to the use of several smaller tonnage units in place of a smaller number of large units due to the potential for greater performance in the smaller equipment. Beyond this, the use of smaller units can reduce ductwork costs and mechanical floor space requirements since units of 5 tons or less can often be installed in the ceiling space.

Loop design is a complex issue, but a few key points warrant special attention. Among these are building load, borehole spacing, borehole fill material, and site characterization. In commercial buildings, the loop length requirement is, even in moderately cold climates, driven by the cooling load. In making the loop length calculation, the peak block load rather than the installed capacity should always be used. Basing the calculation on the installed capacity results in longer length and higher first cost. Due to the relatively linear cost relationship in loop installation, over-sizing carries a much higher penalty than is the case with conventional equipment. The generally higher cooling loads in commercial buildings, tend to reject, on an annual basis, much more heat to the ground than they remove from it. When boreholes are located close to each other, there is interference between them such that heat transfer from one borehole is negatively influenced by adjacent boreholes. For a large number of boreholes arranged in a grid pattern, this can be a significant influence on the required loop length. For commercial systems in moderate-to-warm climates, a minimum borehole spacing of 20 ft is recommended (Kavanaugh and Rafferty, 1997) to lessen the impact of borehole interference.

The material used to fill the void between the U-tube and the borehole wall (called fill or backfill) exerts a heavy influence on the performance of vertical systems. Due to its location in the critical heat transfer region, the thermal conductivity impedes heat transfer and results in the need for longer ground loops. Unfortunately for many years, the industry recommended grouting the boreholes with a "high solids" bentonite grout. The thermal conductivity of the standard grouts available in the drilling industry is approximately 0.43 Btu/hr ft°F; whereas, most native soils are in the range of 0.6 to 1.2 Btu/hr ft°F and rocks 1.0 to 3.0 Btu/hr ft°F. It is apparent that the use of standard grout should be avoided. To address this situation, thermally enhanced grouts (bentonite with sand added) have been developed with a thermal conductivity of 0.85 Btu/hr ft°F, and both cement and bentonite-based grouts with conductivities up to 1.4 Btu/hr ft°F are under development (Allen, 1998).

An accurate design cannot be accomplished without adequate information about the soil and rock thermal properties at the site. As a result, for larger commercial systems, it is often worth considering a test bore and possibly an in-situ thermal properties test. The test bore is an opportunity to determine the nature of the materials in the subsurface. It not only permits a better estimate of the thermal properties, but also alerts the driller to the drilling conditions and provides an indication of the depth at which a transition occurs from soft to hard formations. In the largest projects, an in-situ test may be a useful investment. This is a test in which a single borehole is completed with a U-tube and backfilled at the site. A load is connected to the U-tube, and temperature and load data recorded for an interval of time (usually 12 to 48 hrs). Analysis of the data can yield accurate values for the thermal conductivity and thermal diffusivity of the subsurface materials.

Excessive pumping energy is one of the most common reasons for less than expected savings in commercial GSHP systems. In order to control pumping costs, it is necessary to adequately address flow, head and control. Loop flow rate in these systems should not exceed 2.5 to 3.0 gpm block load ton. Pump head in smaller systems consists of approximately 1/3 due to the heat pump unit, 1/3 for the ground loop and 1/3 for the building piping. Head loss in the heat pump units should be no greater than 12 ft for units <5 tons and 20 for larger units (Kavanaugh and Rafferty, 1997). Ground loop head loss is determined by the layout and size of the structure; but, piping should be designed for unit head losses no greater than 4.0 ft/100 ft of pipe as recommended by ASHRAE. Careful loop design should result in a peak pump power of 7 ½ hp/100 tons (Kavanaugh and Rafferty, 1997). Variable-speed control is recommended for larger systems to minimize pump power consumption. In smaller systems, a variety of strategies are available including grouping of similar zones into smaller loops, using individual pumps for each heat pump and interlocking pump operation to heat pump operation.

DESIGN CONSIDERATIONS FOR COMMERCIAL GWHP SYSTEMS

Key issues in the design and application of GWHP systems are isolation of the groundwater from the building mechanical system, optimization of the groundwater flow rate, avoidance of open tanks in the system, accurate specification of the water wells and accurate control of the well pump.

Water wells are the foundation of an open-loop system. Unfortunately, the design of the wells is often left to the contractor since HVAC design engineers are unfamiliar with water wells. This is not an advisable strategy. Wells, like any other part of the mechanical system, must be carefully designed and specified if they are to be successful. Guide specifications for water wells are available from a variety of sources (NGWA, 1981; Roscoe Moss Company, 1985; Rafferty, 1998) and should be incorporated into the construction documents to assure quality construction and materials are used, and that the well produces water of an adequately low sand content. For systems using an injection well, it is critical that the injected fluid be "sand free" (<1 ppm). Surface tanks are not an appropriate method for sand removal. Sand should be controlled by careful well construction (screens and/or gravel packs and development) as a primary strategy and surface strainers or separators as a secondary strategy. Open tanks, intended to settle sand, allow oxygen to enter the water and CO_2, if present, to escape. Both of these occurrences impact water chemistry and can accelerate corrosion and scaling.

Plate-and-frame heat exchangers are used in GWHP systems to isolate the building loop from the groundwater. It is often mistakenly believed that the object is to design the heat exchanger in such a way as to have the heat pump entering water temperature as close to the groundwater temperature as possible. In most cases, this is not an effective strategy since it causes the loop flow and groundwater flow to be equal. In most applications, maximum system performance occurs when the groundwater flow rate is in the range of 1.0 to 2.25 gpm/ton (depending upon well pump head) and building loop flow in the range of 2.5 to 3.0 gpm/ton. This results in the approach temperature on the heat exchanger occurring at the building loop entering/groundwater leaving side. Generally, an approach of 3 to 7ºF is used (Kavanaugh and Rafferty, 1997). Maximum heat exchanger pressure drop should be less than 10 psi on the building loop side.

The groundwater flow as mentioned above should not be simply selected to match the building loop flow. It is determined from an analysis of the well pump power compared to the heat pump unit performance at various groundwater flows. As groundwater flow is increased, the heat pumps see more favorable entering water temperatures resulting in better performance, but the well pump power requirements increase at the same time. At some point, for every application, there is an optimum groundwater flow and this is the point for which the system is designed. Figure 2 demonstrates this strategy based on constant well pump head. In actual applications, pump head does not remain constant but varies with flow resulting in much steeper curves.

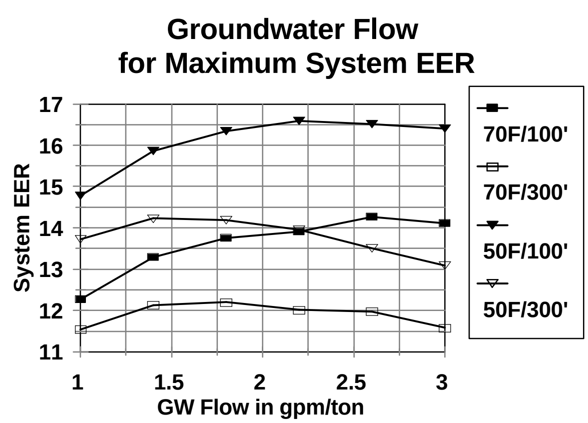

Figure 2.

Control of the well pump is a key aspect of the system design. There are a variety of control schemes, but two are fairly common: dual set point and variable speed. In the dual set point approach, the well pump is started above a loop temperature set point in the heating mode. The loop temperature is permitted to "float" in between the set points. System thermal mass is a key consideration in the dual set point approach. To avoid the short cycling on the well pump, the range around each set point (difference between cut in and cut out temps) must be sufficient to result in an acceptable pump cycle time. Table 1. Presents some guidelines on recommended controller ranges for the pump controller. Variable-speed control of the well pump is sometimes used for GWHP systems. In this case, the pump speed is varied in response to some temperature or load signal from the loop. It is critical that the pump and motor manufacturers are aware that their equipment will be installed in a variable-speed application.

Table 1. Recommended Controller Range for Dual Set Point Operation

Pump hp	System Water Volume in gal/block ton: 6	8	10	12	14	16	18
<5	6	5	4	3	2		
7.5+	18	13	11	9	8	7	6

COSTS

There has been a great deal of concern over the capital costs for GSHP systems in the U.S. Many feel that this is a significant barrier to expanded use of the systems. While this is true in the residential arena, the economics of larger commercial applications are more positive. In general, GCHP systems can be installed for an increment of 0 to 20% more than conventional systems (exclusive of rooftop package equipment).

The type of GSHP systems has a substantial impact upon the capital cost as well. Figure 3 presents a comparison of the costs for the ground loop portion of the three most common GSHP systems (GCHP, GWHP and Hybrid). Several points are apparent from the plot. GWHP systems due to the much more pronounced economy of scale are significantly less cost for large system sizes. In fact, if shallow (<300 ft depth) wells can be completed, GWHP systems are 40 to 70% less cost than GCHPs. Even at well depths of 600 to 800 ft. GWHP systems are less cost than GCHP systems in the >150 ton range (Rafferty, 1995). Hybrid systems can also greatly reduce first cost in warm climates.

The extent to which capital cost can be reduced depends upon the relative heating and cooling loop length requirements. In cases where the heating loop length requirement is 50% of the cooling loop length, capital costs for the ground loop portion of the system can be reduced by 30 to 35%.

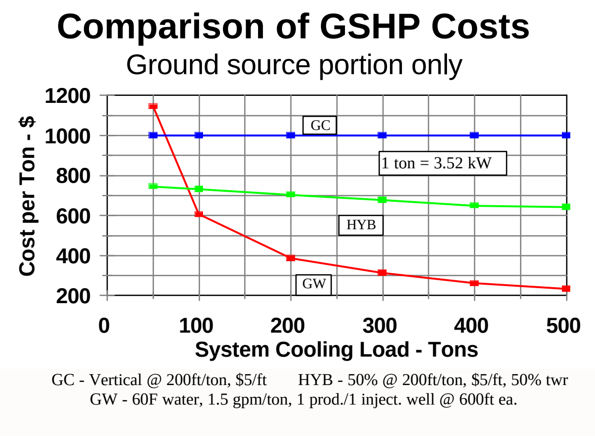

Figure 3.

GCHP systems are currently being installed in commercial buildings in the U.S. for $10 per square foot of floor space and less. In most cases, the ground loop constitutes approximately 25 to 35% o the total system costs. Figure 4 presents a summary of the relative costs for a small office building (Kavanaugh and Rafferty, 1997). It is apparent that there is much more potential for cost control on "inside the building" portions of the building than there is in the ground loop.

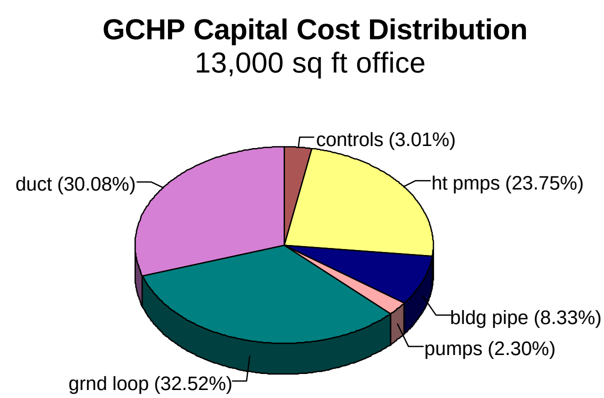

Figure 4.

CONCLUSION

Commercial application of GSHP technology remains in it's infancy in the U.S., but the potential is great. Some of the early commercial systems were designed using "rules of thumb" carried over from residential practices. Predictably, these systems encountered operational problems. The recent development of design tools for the engineer will assist in the design and installation of more cost effective, reliable and efficient systems in the future. Though it is likely that the use of ground-source systems in the residential sector will remain limited to the niche market, it now occupies in the high-end 3,000+ square foot market, the prospect for much greater penetration in the commercial building market is very bright.

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GEOTHERMAL DIRECT-USE IN THE UNITED STATES IN 2000

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INTRODUCTION

Geothermal energy is estimated to currently supply 19,429 billion Btu/yr (20,478 TJ/yr - 5,689 GWh) of heat energy through direct heat applications in the United States. The corresponding installed capacity is estimated at 5,373 MWt. Of these values, direct-use is 8,044 billion Btu/yr (8,478 TJ/yr - 2,355 GWh) and 573 MWt and geothermal heat pumps the remainder. It should be noted that values for the capacity and the energy supplied by geothermal heat pumps are only approximate since it is difficult to determine the exact number of units installed and most are sized for the cooling load, thus they are oversized in terms of capacity for the heating load (except possibly in the northern U.S.).

Figure 1 shows a comparison of the direct heat use for the various applications for 1990, 1995 and 2000. Figure 2 shows the growth of the various direct-use applications since 1975 (excluding heat pumps). Most of the applications experienced some increase in use; however the largest annual energy growth has been in geothermal heat pumps. Aquaculture has the largest annual energy growth rate of the direct-use categories, increasing in annual use by 16.9% compound per year over the past five years. From 1990 the growth rate for direct-use was 8.3% annually and for geothermal heat pumps estimated at 7.7% annually for a total of 7.9% annually.

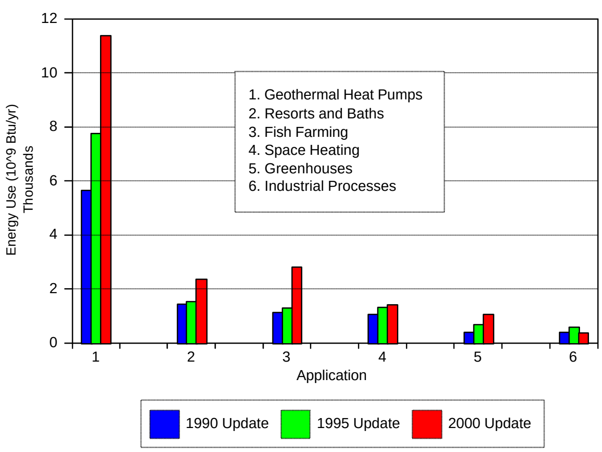

Figure 1. Direct Heat Utilization in the United States compared at 1990, 1995 and 2000.

Resorts and spa use and development has actually remained fairly constant with only slight growth - most of the increase is due to better reporting of the data. There has been a major decrease in the industrial section, as the gold and silver heap leaching projects in Nevada are no longer using geothermal energy. In addition, the lithium-bromide chiller used on the Oregon Institute of Technology campus has been replaced with an electric chiller (due to the low efficiency of the geothermal system), thus there is no direct-heat cooling in the U.S. (except for geothermal heat pumps). Today, 35.0% of the annual energy use for direct-use is in the aquaculture industry, 29.4% is in bathing and swimming (resort and spa pool heating), 17.5% in space heating (including district heating), 13.4% in greenhouse heating 4.7% in industrial processing, including agriculture drying and snow melting as shown in Figure 3a. If geothermal heat pumps are included, then they contribute 59% to the annual energy use, and direct-use contributes 41% as shown in Figure 3b.

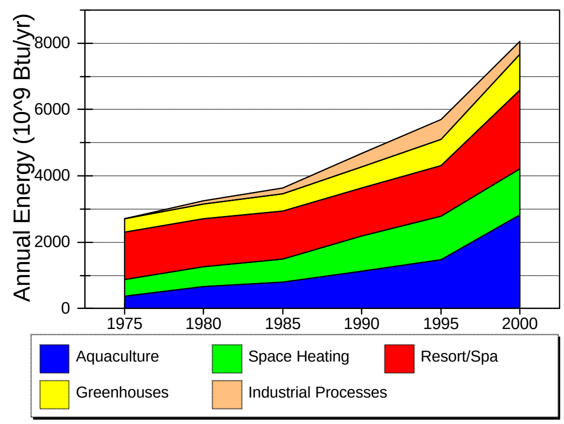

Figure 2. Growth of the U.S. direct energy utilization by category without heat pumps.

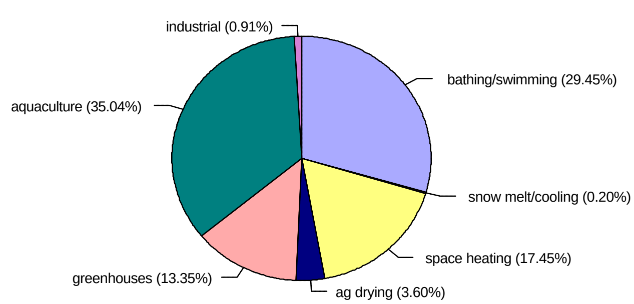

Figure 3a. 2000 direct-use percentages by category based on annual energy use.

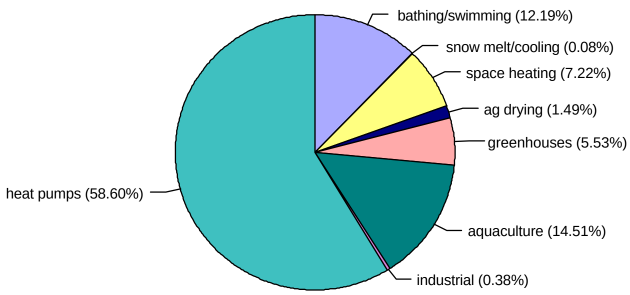

Figure 3b. 2000 direct-use and geothermal heat pump annual energy use percentages.

DIRECT USE DEVELOPMENT OVER THE PAST FIVE YEARS

There were 27 new projects identified in 7 states and 10 existing projects were expanded a significant amount over the past five years The new projects are mainly aquaculture pond and raceway heating in the Imperial Valley of California and along the Snake River Plain in Idaho, and greenhouses in Montana and Utah. The expanded projects include the Klamath Falls and Oregon Institute of Technology district heating projects, six greenhouse projects in California, Idaho and New Mexico, and two aquaculture projects in the Imperial Valley of California. Two major industrial projects, both silver and gold heap leaching in Nevada no longer use geothermal energy in their process, due to the expense of royalty payments for geothermal energy from federal lands. The remainder of the increase was due to better reporting of space heating and resort/spa pool heating.

During this period, the thermal capacity of the direct heat projects increased by 143 MWt , representing an annual energy utilization of 2,634 billion Btu/yr (2,776 TJ/yr) (Lienau, et al, 1995). Geothermal heat pumps increased in capacity by 2,956 MWt, representing an annual energy utilization of 3,617 billion Btu/yr (3,812 TJ/yr) (Lienau, et al., 1995). A mini-heating district in Midland, South Dakota has been added as a new project, even though it was started in 1969. This project was unknown to the geothermal community until 1997 (Lund, 1997).

The majority of the increase in direct utilization since 1995 is in aquaculture (Imperial Valley of California and Snake River Plain of Idaho), greenhouse heating, and snow melting (Klamath Falls, Oregon). The increase in space heating and resorts/spa is mainly do to refinement of the data, since most of these projects already existed and have minor increases in size.

A summary of the direct utilization in the United States is presented in Table 1.

TABLE 1. DIRECT-USE BY INDIVIDUAL STATES

State	Numbers of sites	Installed Capacity MWt	Annual Use 10^9Btu	Annual Use TJ	Load Factor
Alabama	2	1.74	41.6	43.9	0.80
Alaska	14	4.50	86.0	90.7	0.64
Arkansas	2	1.22	27.7	29.2	0.76
Arizona	12	21.54	277.2	292.2	0.43
California	100	114.51	1908.2	2011.2	0.56
Colorado	39	29.77	526.5	554.9	0.59
Georgia	3	1.49	31.2	32.9	0.70
Hawaii	1	0.29	2.0	2.1	0.23
Idaho	73	101.60	1225.8	1292.0	0.40
Louisiana	2	1.74	41.6	43.9	0.80
Mississippi	2	1.74	41.6	43.9	0.80
Montana	34	15.47	275.8	290.7	0.60
New Mexico	13	54.47	643.6	678.4	0.40
Nevada	332	68.83	1035.3	1091.2	0.50
New York	2	0.88	11.5	12.1	0.44
Oregon	628	59.48	585.6	617.2	0.33
S. Dakota	6	8.61	118.4	124.8	0.46
Texas	3	4.04	26.0	27.4	0.22
Utah	17	51.10	425.3	448.3	0.28
Virginia	1	0.32	2.9	3.1	0.27
Washington	6	1.61	36.2	38.2	0.75
West Virginia	1	0.12	3.5	3.7	0.80
Wyoming	21	28.33	670.1	706.3	0.79
TOTAL	1314	573.40	8043.6	8478.2	0.47

Aquaculture Pond and Raceway Heating

The largest increase in geothermal direct-use in the United States in the past five years was in aquaculture pond and raceway heating. Ten new pond heating projects were recently identified in the Imperial Valley of California along with the expansion of two existing projects (Rafferty, 1999). Approximately 8.06 million pounds (3.66 million kg) of Tilapia, catfish and hybrid striped bass are raised here annually. Most are shipped live to markets in Los Angeles and San Francisco. A second area identified as having a significant increase in aquaculture projects is along the Snake River Plain of southern Idaho. Seven new projects were identified in this area, adding an additional 2.20 million pound (one million kg) of Tilapia and catfish in annual production. These installations use cascaded water in raceways for raising their fish, whereas in the Imperial Valley, ponds and tanks are the most common. Fish from these sites are also shipped live to cities in Canada and the northwestern US states. In addition, aquaculture projects using 70 to 90^{o}F (21 to 32^{o}C) water are found in the southern states of Texas, Arkansas, Louisiana, Mississippi, Alabama and Georgia. It is difficult to calculate the exact energy used by the various installations, thus based on data from a limited number of operations, the remaining are proportioned according to the amount of fish raised annually.

Geothermal Heat Pumps

Geothermal heat pumps has steadily increased over the past five years with an estimated 45,000 units installed in 1997 of 3.4 ton (12 kW) size capacity (Ragnarsson, 1998). Of these, 46% are vertical closed loops, 38% horizontal closed loop and 15% open loop systems. Projections for the future are that the growth rate will increase about 10% annually, so that by 2010 an estimated 120,000 new units would be installed in that year. It is estimated that 400,000 units are presently installed in the U.S., thus, this rate would add an addition 1.1 million units for a total of about 1.5 million units by 2010. Using a COP of 3.0, and a 1,000 full load hours per year in the heating mode, the 400,000 units remove approximately 11,400 billion Btu/yr (12,000 TJ/yr) from the ground. The cooling mode energy is not considered, since this rejects heat to the ground; however, the cooling mode does replace other forms of energy.

The majority of the geothermal heat pump installations in the U.S. are in the mid-west and southern states (from North Dakota to Florida). There have been few installation in the west, due to some environmental concerns and lack of general knowledge on the subject by HVAC companies and installers. Hopefully recent geothermal heat pump seminars, offered by the Geo-Heat Center, will improve the understanding and use of this technology in the west.

Space and Pool Heating

Data from space heating (other than district heating) and for pool heating at resorts and spa were updated. We lacked information for approximately 20% of these sites, and thus estimates were made for the missing data based on the knowledge and experience of the authors. This increase, in most cases, is not due to new installations, but reflects the gathering of better data. The other space heating category that increased by a significant percentage was snow melting. These systems were recently added in Klamath Falls and include new sidewalk and handicap ramp heating on the Oregon Institute of Technology campus (2,700 ft^2 - 250 m^2) and sidewalk heating in downtown Klamath Falls (94,000 ft^2 - 8,700 m^2) (Boyd, 1999 and Brown, 1999). In addition, a major highway geothermal snow melting systems in Klamath Falls, that had been used for 50 years, was replaced in the Fall of 1998 and is used to heat approximately 22,000 ft^2 (2,000 m^2) of concrete pavement (Lund, 1999).

Summary

The distribution of capacity and annual energy use for the various direct utilization categories is shown in Table 2. These figures are based on the best estimates made by the authors. We also feel that anywhere from 10 to 20% addition geothermal direct energy use is unreported throughout the country, due to their small size and often isolated location.

The total direct-use and geothermal heat pumps energy use in the United States is equivalent to savings of 5.6 million barrels (0.84 million tonnes) of fuel oil per year. This produces a savings of between 330,000 (natural gas) and 1,650,000 (coal) tons of carbon pollution annually if the replacement energy was provided by electricity and about half this amount if used directly in heating systems (35% vs 70% efficiency). If the savings in the cooling mode of geothermal heat pumps is considered, then this is equivalent to and additional savings of 3.3 million barrels (0.49 million tonnes) of fuel oil per year or from 190,000 (natural gas) to 960,000 (coal) tons of carbon pollution annually.

TABLE 2. SUMMARY OF GEOTHERMAL DIRECT-USE

Use	Number of Installations	Installed Capacity (MWt)	Annual Energy 10^9Btu	Annual Energy TJ	Use Factor
Space Heating	975	83	811	855	0.33
District Heating	18	99	592	624	0.20
Aquaculture	53	136	2,819	2,971	0.69
Greenhouses	37	119	1,074	1,132	0.30
Agriculture Drying	3	20	290	305	0.49
Industrial Processing	4	7	73	77	0.35
Resorts/Spas/ Pools	219	107	2,369	2,497	0.74
Snow Melting	5	2	16	17	0.27
Subtotal	1,314	573	8,044	8,478	0.47
Geo. Heat Pumps	400,000	4,800	11,385	12,000	0.19
Total		5,373	19,429	20,478	0.25

GEO-HEAT CENTER TECHNICAL ASSISTANCE

A study by Rafferty (1998) illustrates a relationship between the "explosive" growth in the geothermal heat pumps (GHPs), aquaculture and greenhouse industries' use of geothermal energy and the Geo-Heat Center's technical assistance in these area. A significant part of our activity, approximately 30%, are requests for GHP technical assistance from individuals planning a large home in a rural setting in a moderate-to-cold climate (typically in the Midwestern and Eastern states). This suggests that our activity in this area is an accurate reflection of the niche market currently served by GHP systems in the residential section and the large annual growth in new installations (between 40,000 and 50,000 units/year).

If we focus on technical assistance requests that are project related (not considering GHPs) they are almost equally distributed between aquaculture, district heating, greenhouses, space heating, small scale electric power and resorts/spas/pools. However, in the aquaculture pond and greenhouse heating area almost 60% of the requests are related to new projects (Figures 4 and 5). Outside of GHP, these areas, along with space heating, represent the bulk of our technical assistance work on new projects as shown in Figure 6. In aquaculture, most new geothermal applications are involved with Tilapia which is the fastest growing single species in aquaculture in general. Greenhouse projects are mainly used for growing flowers, as the vegetable market has difficulty competing with Latin American suppliers.

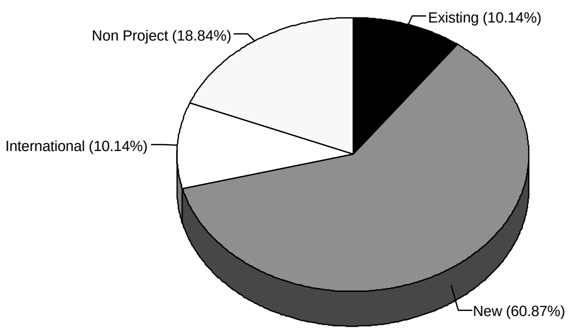

Figure 4. Distribution of Geo-Heat Center Technical Assistance Requests in Aquaculture.

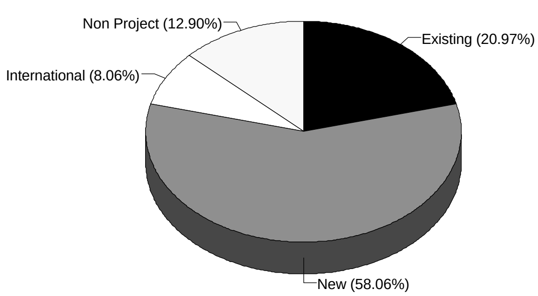

Figure 5. Distribution of Geo-Heat Center Technical Assistance Requests in Greenhouses.

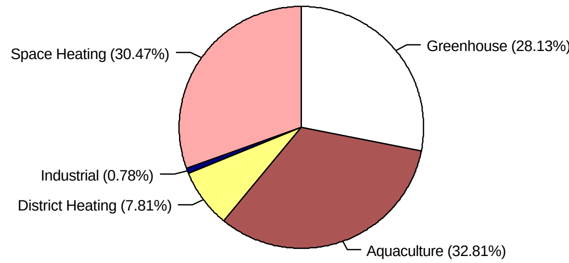

Figure 6. New Project Development Requests for Technical Assistance.

Thus, promoting greater use of geothermal resources for direct-use could best be done by targeting those areas in which there is already a clearly defined interest on the part of developers. Fortunately, both the greenhouse and aquaculture industries have well established professional and industry groups (and publications) to serve as information conduits for these efforts (Rafferty, 1998). The Geo-Heat Center staff is actively participating in professional trade shows and technical programs in these areas.

CONCLUSIONS

The growth in direct heat use has been approximately eight percent compounded annually over the past five years. This compares to the growth rate between 1985 and 1990. The period from 1990 to 1995 was lower at approximately six percent annually. Growth during 1995 to 2000 could have been higher, but competition from natural gas was a major factor. There are some positive signs on the horizon, in additional to the aquaculture growth, with proposed new district heating projects in Mammoth, CA, Reno, NV and Sun Valley, ID, and a zinc extraction plant in the Imperial Valley. The Reno project could expand district heating by 250 MWt with large commercial and industrial building heating (Lienau, 1997). The zinc project by CalEnergy Company, Inc., to be on line in mid-2000, will extract 33,000 tons (30,000 tonnes) of zinc annually from geothermal water using power from a new geothermal electric plant. The waste water from eight power plants (totaling 300 MWe), having 600 ppm of zinc will be utilized. In addition, the extraction of silica and manganese will also be considered.

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