

# 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 ( $\pm$  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,

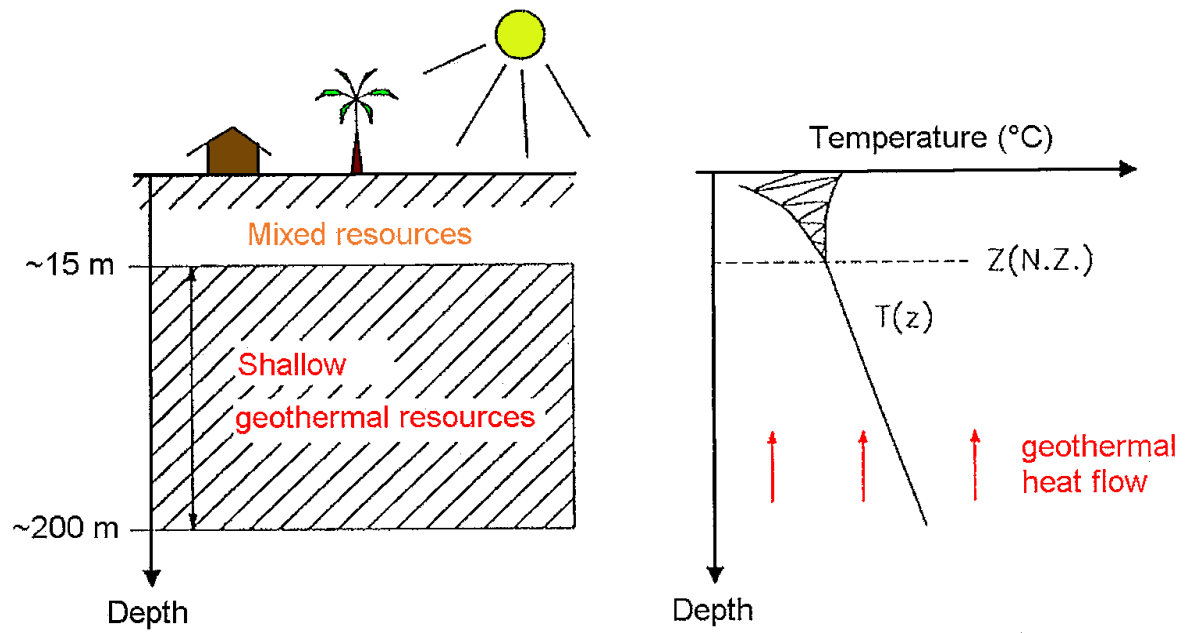


Figure 1. Geothermal energy, comprising geothermal and mixed resources in the shallow subsurface.

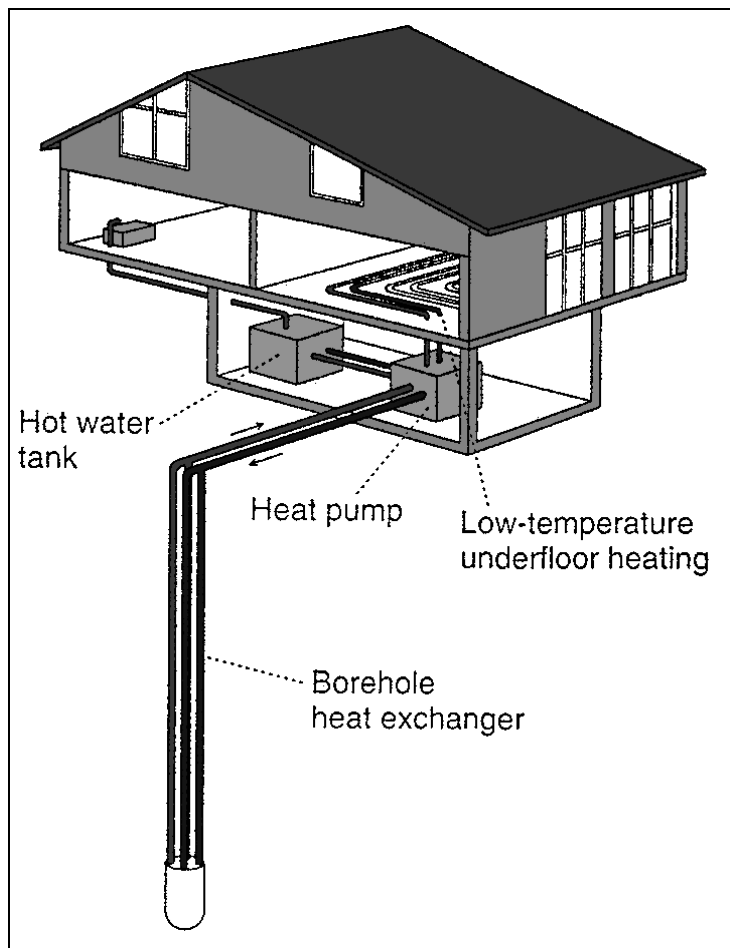


Figure 2. Typical application of a borehole heat exchanger (BHE) heat pump system in a central European home. Typical BHE length: 100 m.

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).

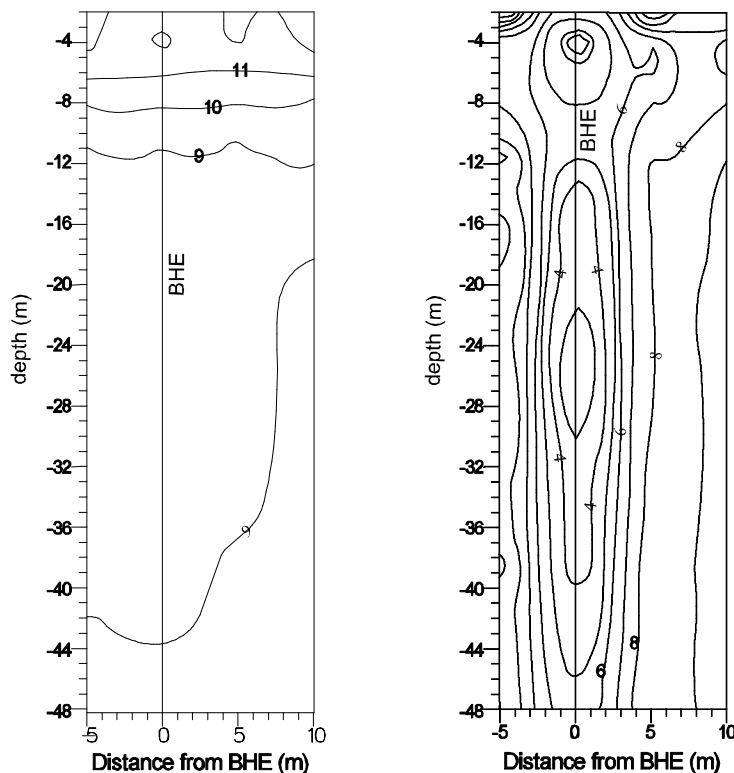
In the German test system at Schöffengrund-Schwalbach near Frankfurt/Main, a 50-m BHE was surrounded by a total of 9 monitoring boreholes at 2.5, 5 and 10 m distance, also 50 m deep. Temperatures in each hole and at the BHE itself were measured with 24 sensors at 2 m vertical distance, resulting in a 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.

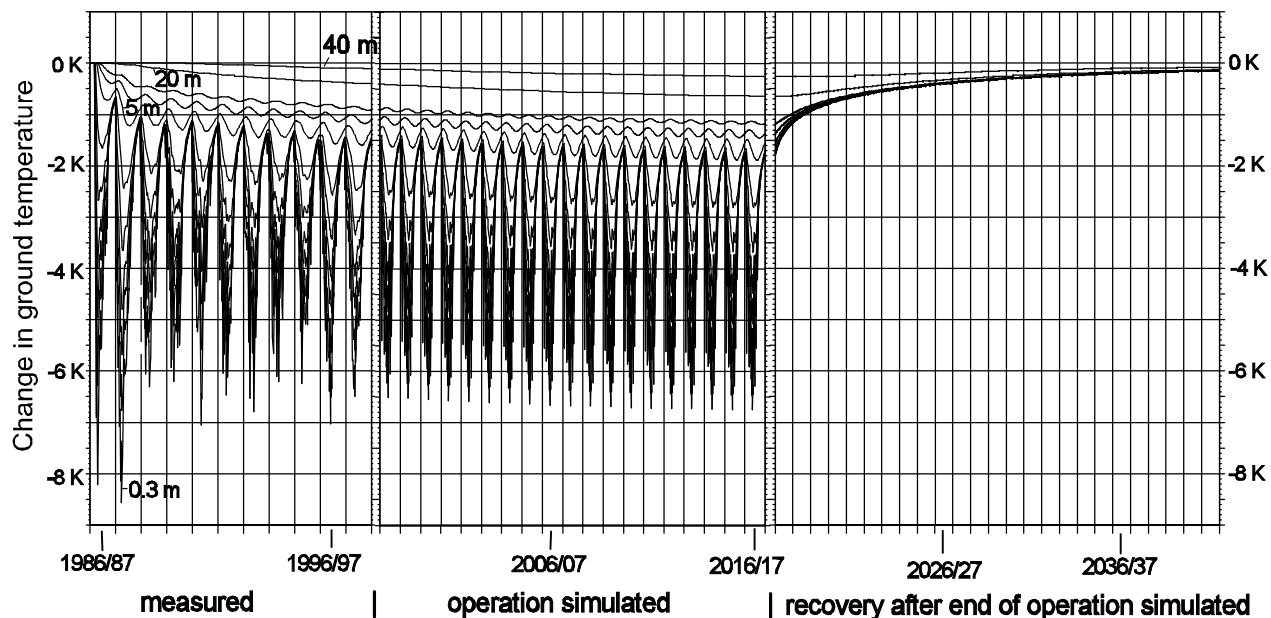
The ground temperature results are highly informative with respect to the long-term performance (for details see Rybach and

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 cools 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

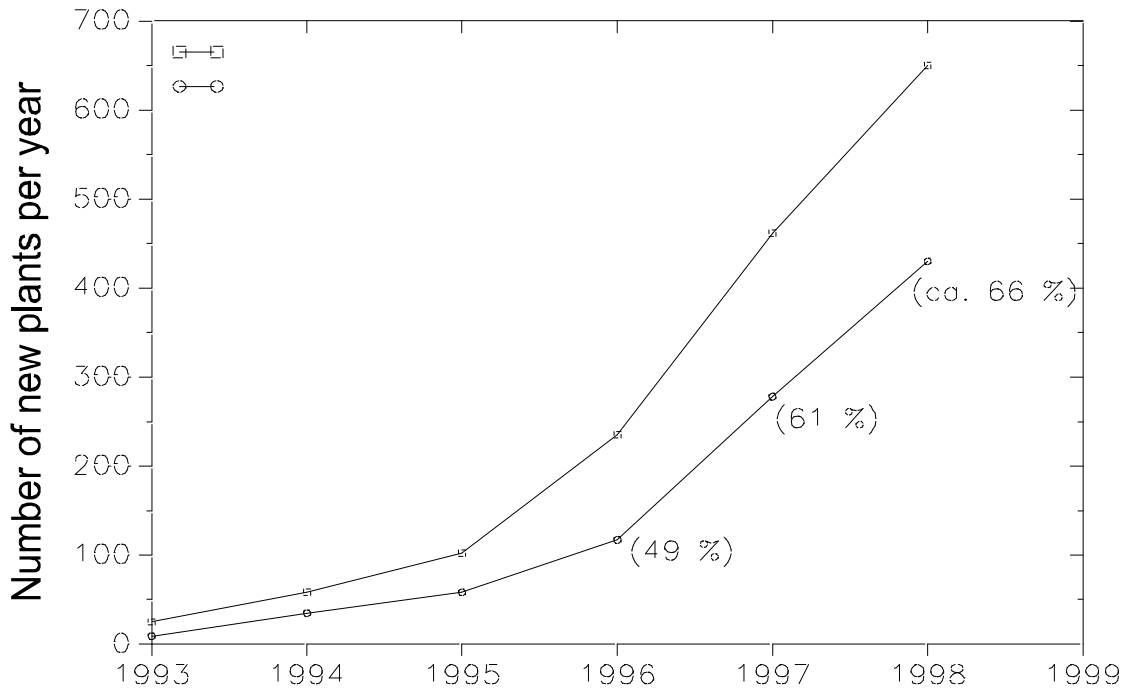
Within the full swing of heat pump applications in Europe, ground-coupled heat pumps play a significant role. The development started around 1980 when the first BHE-

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

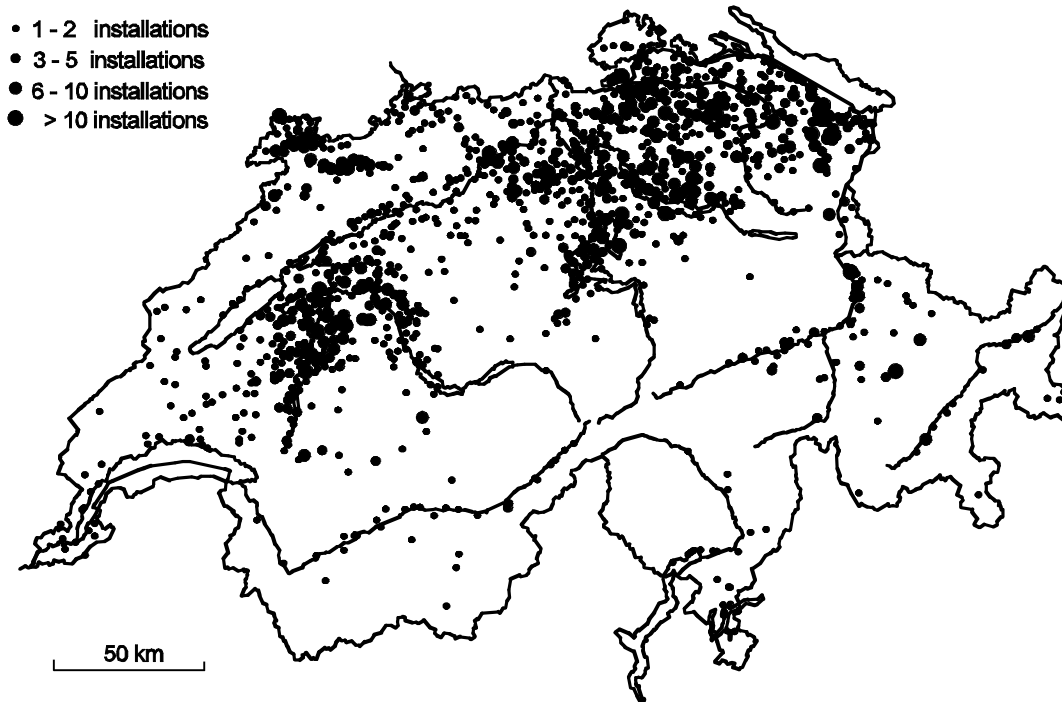
The development can also be seen in individual regions. In Figure 5, the number of installations realized within an incentive program of the German utility RWE is depicted. Not only the total number of heat pumps installed in the RWE-area is rapidly increasing, but also the share of BHE-equipped heat 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<sup>2</sup>). 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<sub>2</sub>.

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<sup>2</sup> only (in a country where ground property prices are high);

- Less space demand (several m<sup>3</sup>) than for conventional systems;
- Low operating costs (no oil or gas purchases, burner controls, etc., like with fossil-fueled heating systems);
- Local utility subsidies/rebates for environmentally-favorable options like electric heat pumps;
- BHEs provide CO<sub>2</sub>-free heating, and
- Current parliamentary discussions show that a CO<sub>2</sub> tax is in sight.

Of all countries, China has, with 2.1 GW<sub>th</sub>, the largest figure in installed geothermal capacity for direct use, followed by the USA with 1.8 GW<sub>th</sub> (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**

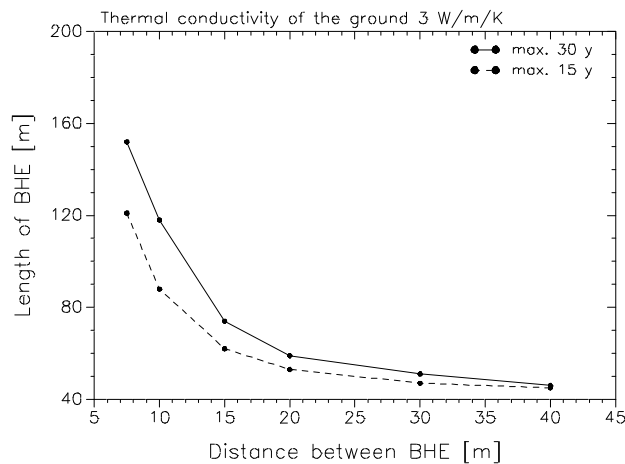
The total number of GSHP in Europe can only be estimated; in Table 3 such an effort is made. In the following, some developments in individual countries are characterized.

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<sup>2</sup>, 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<sup>2</sup>) 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).**

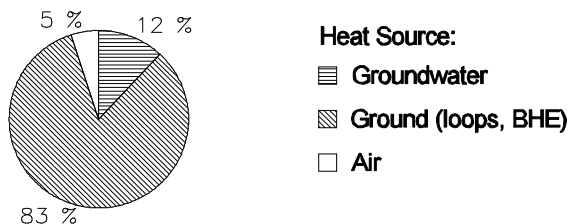
The calculation was done without considering the influence of moving groundwater. However, in a large field of houses, the impact of the groundwater is good for the houses upstream, and bad for those in the flow direction. In the end, for a large enough area, there is virtually no advantage in groundwater 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<sup>2</sup> 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<sub>th</sub> heating output, and with ground as heat source, direct expansion systems are predominant. In 1996, emission of 335,000 tonnes CO<sub>2</sub> 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 Kunsthhaus (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<sup>2</sup> 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, where 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 and 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<sub>th</sub>. 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 ( $\rho = 3.5 - 3.9 \text{ W/m/K}$ ). 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

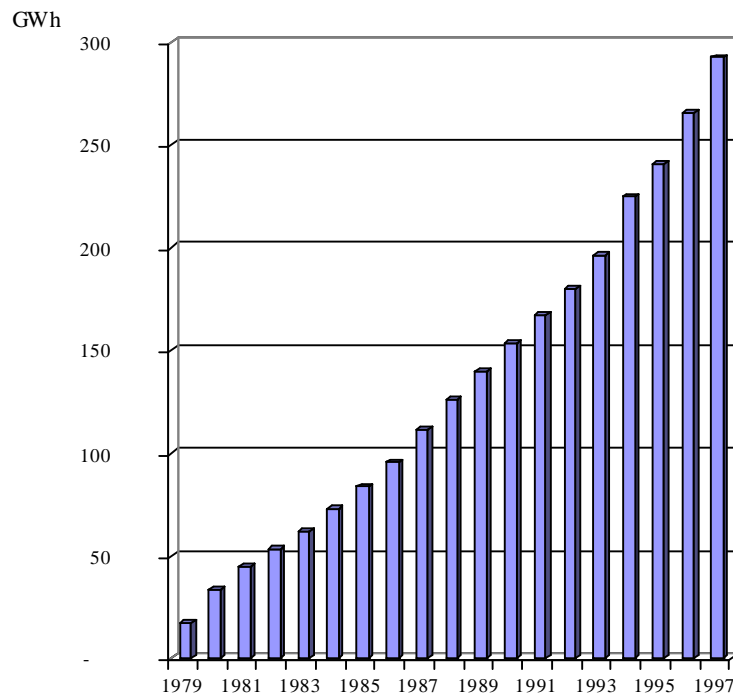
The European experience with GSHP systems so far is excellent. It is expected that the market will further expand, in the leading countries like Sweden and Switzerland as well as in other countries to follow. The growth can be exponential as the Swiss example shows (Figure 9).

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

## Geothermal heat production from BHE systems in Switzerland



**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<sub>2</sub> 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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