Current status of ground source heat pumps and underground thermal energy storage in Europe

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Abstract

Geothermal Heat Pumps, or Ground Coupled Heat Pumps (GCHP), are systems combining a heat pump with a ground heat exchanger (closed loop systems), or fed by ground water from a well (open loop systems). They use the earth as a heat source when operating in heating mode, with a fluid (usually water or a water-antifreeze-mixture) as the media transferring the heat from the earth to the evaporator of the heat pump, utilising that way geothermal energy. In cooling mode, they use the earth as a heat sink. With BHE geothermal heat pumps can offer both heating and cooling at virtually any location, with great flexibility to meet any demands. More than 20 years of R&D focusing on BHE in Europe resulted in a well-established concept of sustainability for this technology, as well as sound design and installation criteria. Recent developments are the Thermal Response Test, which allows in-situ-determination of ground thermal properties for design purposes, and thermally enhanced grouting materials to reduce borehole thermal resistance.

For cooling purposes, but also for the storage of solar or waste heat, the concept of underground thermal energy storage (UTES) could be proven successfully. Systems can be either open (aquifer storage) or can use BHE (borehole storage). While cold storage meanwhile is established on the market, heat storage, and in particular high temperature heat storage (>50 °C) still is in the demonstration phase.

Despite the use of geothermal heat pumps for over 50 years now (first in USA), market penetration of this technology, is still at its infancy, with fossil fuels dominating the market of heating of buildings and air-to-air heat pumps dominating the market of cooling of buildings. In some countries, namely Germany, Switzerland, Austria, Sweden, Denmark, Norway, France and USA, already larger numbers of geothermal heat pumps are operational. In these countries meanwhile installation guidelines, quality control and contractor certification becomes a major issue.

Keywords

Ground Source Heat Pumps, Underground Thermal Energy Storage

Introduction

First, some abbreviations have to be mentioned, which are used frequently throughout this text:

- GSHP Ground Source Heat Pump
- BHE Borehole Heat Exchanger (in USA, the term Vertical Loop is common)
- UTES Underground Thermal Energy Storage

Most European countries do not boast abundant hydro-geothermal resources that could be tapped for direct use (some exceptions are e.g. Iceland, Hungary, 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 GSHP 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 took place, are such that by far the most demand is for space heating; air conditioning is rarely required. Therefore, unlike the "geothermal heat pumps" in the USA, the heat pumps usually operate mainly in the heating mode. Only in very recent years the installation of GSHP in Southern Europe, in particular in Greece and Western Turkey, is on the way to exceed demonstration status, with the first pilot plant for GSHP with BHE in Greece, installed with Swiss technical support, dating from around 1993 [1]. This effort has led to the subsequent implementation of a project at the campus of the National Technical University of Athens, where the Mining Engineering Building is heated and cooled by the application of geothermal heat pumps combining a hybrid system of groundwater well and BHE [2], and is meanwhile followed by others [3]. With the inclusion of larger commercial applications, requiring cooling, and the ongoing proliferation of the technology into Southern Europe, the double use for heating and cooling will become of more importance in the future.

GSHP technology status

Ground Source Heat Pumps (GSHP), or Geothermal Heat Pumps, are systems combining a heat pump with a system to exchange heat with the ground (fig. 1). The systems can be divided basically into those with a ground heat exchanger (closed loop systems), or those fed by ground water from a well (open loop systems). The means to tap the ground as a shallow heat source comprise:

- groundwater wells ("open" systems)
- borehole heat exchangers (BHE)
- horizontal heat exchanger pipes (incl. compact systems with trenches, spirals etc.)
- "geostructures" (foundation piles equipped with heat exchangers)

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 (see [4], [5], [6]). While in the 80´s theoretical thermal analysis of BHE-systems prevailed in Sweden [7], [8] monitoring and simulation was done in Switzerland [9], [10], and measurements of ground heat transport were made on a test site in Germany [11].

A typical BHE-installation is shown in fig. 1. These systems use the earth as a heat source when operating in heating mode, with a fluid (usually water or a water-antifreeze-mixture) as the media transferring the heat from the earth to the evaporator of the heat pump, utilising in that way geothermal energy. In the cooling mode, they use the earth as a heat sink. For each kWh of heating or cooling output, they currently require 0,22 - 0,35 kWh electricity, which is 30%-50% less than the seasonal power consumption of air-to-air heat pumps, which use the atmosphere as a heat source/sink.

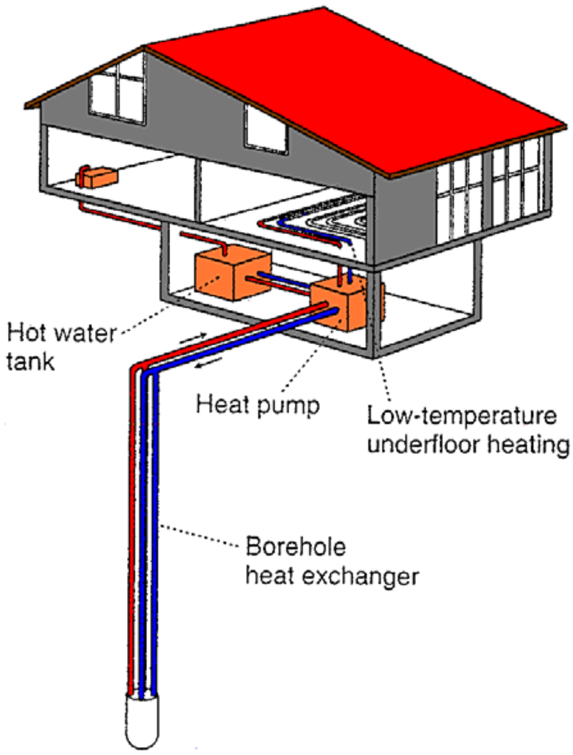


Fig. 1: Typical application of a BHE / heat pump system in a Central European home, typical BHE length ≥100 m

The ratio of useful energy over electricity consumption of a heat pump at given operating conditions is defined as the "Coefficient of Performance" or the COP. The COP depends on the temperature of the input water from the ground circuit, which depends on geological conditions (thermal and hydraulic parameters of the underground, climatic setting) and technical parameters (length and type of ground heat exchanger, material, type and quality of grouting, etc.). Other factors that affect the COP of a heat pump are the heating/cooling load, the type of the building heating/cooling system and the relevant supply temperatures. Since at depths below ca. 10 meters the ground temperature is constant throughout the year (depending upon prevailing weather conditions or ambient temperature) and increases slightly with depth beneath the ground surface, BHE show better performance and energy efficiency than horizontal ground heat exchangers.

In the USA, the Water-Source Heat Pump Engineering Committee conducted laboratory tests comparing efficiency ratings under the different standards for a variety of models. These results, which correspond to units with rated power less than 40 kW, indicate the existing ARI standards specify minimum COP for ground loop heat pumps 2,5 for heating and 2,9 for cooling. The Committee's recommended adjustment to the minimum efficiency requirements proposed for water-source heat pumps under ASHRAE 90.1 as of 2001 are 3,1 for heating and 3,9 for cooling for ground loop systems. Values from similar measurements in Europe, mainly in the Swiss heat pump test centre in Töss, already show substantial higher ratings. For a source temperature of 0 °C, values close to COP = 5 can be achieved for 35 °C heating supply temperature, and still values around COP = 3.5 for 55 °C supply temperature (see Fig. 1).

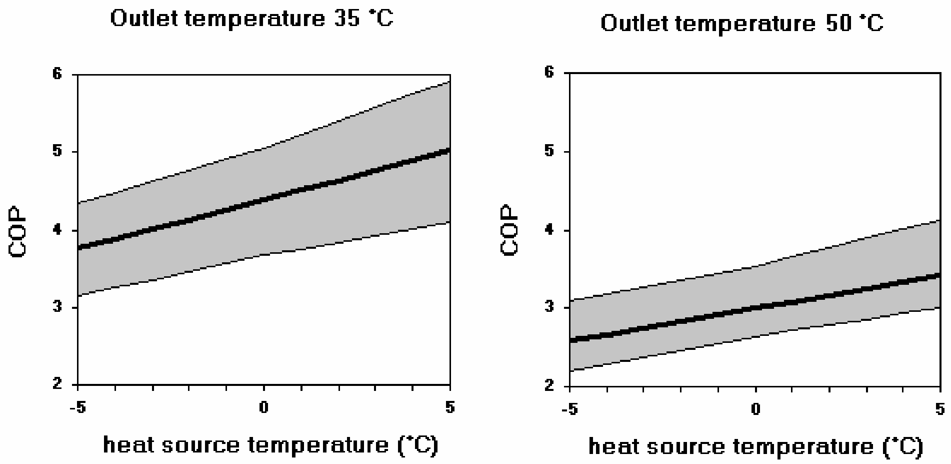


Fig. 2: Values of COP for brine/water heat pumps (as used typically in geothermal heat pump systems), measured in the Heat Pump Test Centre Toess (extract from http://www.wpz.ch/)

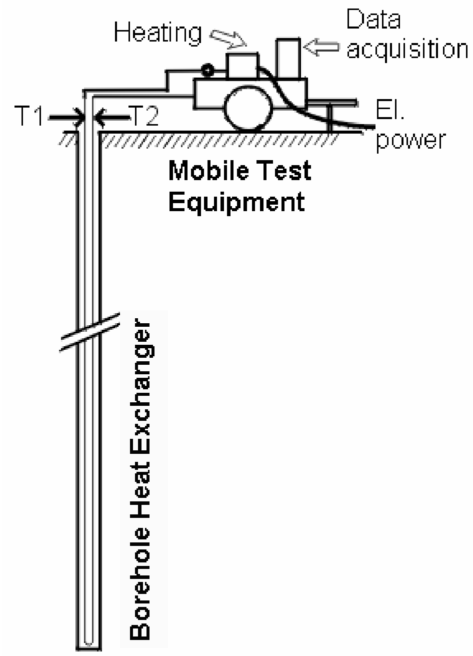
Although the maximum COP of existing ground source heat pumps is around 4,5 their mean COP during operation is lower. This mean COP, usually called "Seasonal Performance Factor" (SPF), is defined as the mean COP during operation and varies at around SPF=3,0-3,8. In cases where high quality standards for all components of a geothermal heat pump system are applied and also an optimum building heating system exists, values of SPF=4,0 can be achieved; in these cases usually no domestic hot water can be provided by the heat pump.

When using (BHE), the required length for a given power output is highly dependent upon soil characteristics including temperature, moisture content, particle size and shape, and heat transfer coefficients. Correct sizing of the BHE continues to be a cause for continued design concern, and special attention should be placed on minimising interference between neighbouring BHE. Key points are building load, borehole spacing, borehole fill material and site characterisation. Due to the high capital costs involved, over-sizing carries a much higher penalty than in conventional applications.

Two important technical developments of recent years should be mentioned in this respect:

- Thermal Response Test to determine the thermal parameters of the underground in situ
- Grouting material with enhanced thermal conductivity

For a thermal response test [12], basically a defined heat load is put into the BHE and the resulting temperature changes of the circulating fluid are measured (fig. 3). Since mid 1999, this technology now also is in use in Central Europe for the design of larger plants with BHE, allowing sizing of the boreholes based upon reliable underground data. Thermal response test first was developed in Sweden and USA in 1995 [13], [14] and now is used in many countries world-wide, including Turkey. Together with reliable design software [15], [16], BHE can be made a sound and safe technology even for larger applications.



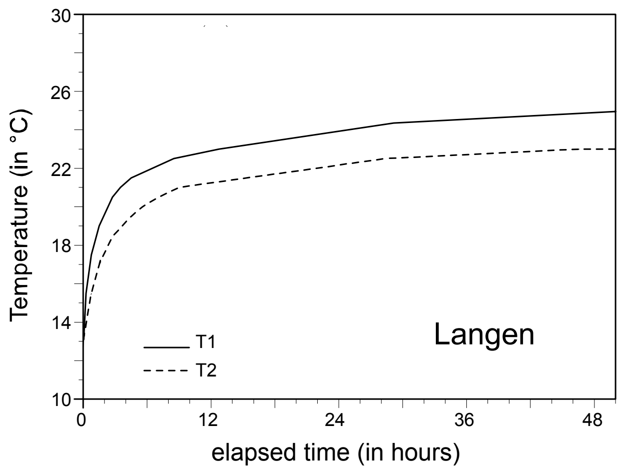


Fig. 3: left: Schematic of a Thermal Response Test
right: Example of measured data from a Thermal Response Test, from [12]

Thermally enhanced grouting material is available in USA since ca. 10 years. Meanwhile, also in Europe such material can be purchased. The advantage of its use is a significant reduction in the borehole thermal resistance (fig. 4), which governs the temperature losses between the undisturbed ground and the fluid inside the BHE pipes. The table in fig. 4 gives some values for typical BHE; the effect could meanwhile also be demonstrated in situ, using the Thermal Response Test on BHE with different grouting materials.

Type of BHE	λ grout	r_b
single-U, PE	0.8 W/m/K 1.6 W/m/K	0.196 K/(W/m) 0.112 K/(W/m)
double-U, PE	0.8 W/m/K 1.6 W/m/K	0.134 K/(W/m) 0.75 K/(W/m)

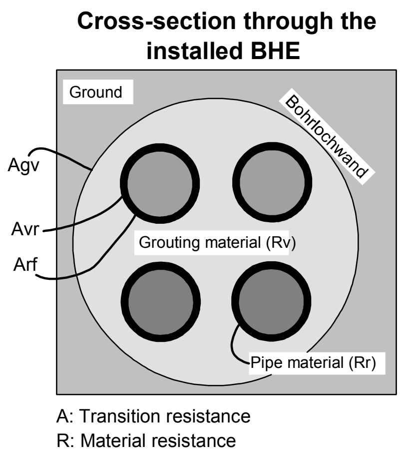


Fig. 4: left: Table with data for r_b for different grouting materials
right: schematic of the concept of borehole thermal resistance r_b

Market opportunities and barriers

Problems often encountered with BHE design include inadequate address of flow, pressure drop and control parameters, leaks associated with corrosion of fittings, poor workmanship, as well as with the selection of pipe material and of the circulated heat transfer fluid. All of the above require the need for both a specialised engineer and a specialised contractor for the installation of ground source heat pumps, which is a significant barrier to their market penetration. In countries with higher sales numbers of geothermal heat pumps (e.g. Sweden, Switzerland or Germany), measures like technical guidelines, certification of contractors, quality awards etc. are beginning to be set into force to protect the industry and the consumers against poor quality and insufficient longevity of geothermal heat pump systems.

Existing geothermal heat pump features make them only suitable for their operation with low temperature heating systems, which limits their application mainly to new buildings, and they are not designed to meet the high supply temperature demands of older heating systems already installed in many existing buildings all over Europe. The heat pumps which provide hot water feeding fan-coils, floor heating or low-temperature radiators, usually heat a water flow from 40°C to 45°C which circulates within the heating system of the buildings, with max temperature of 50°C. The higher the temperature of the supply water, the lower the COP of the heat pumps. Standard and maximum testing temperature values for liquid entering the indoor side in water-to-water systems are 40°C and 50°C respectively as per ISO 13256-2, and a maximum of 55 °C in some European guidelines.

The upper temperature limits encountered in commercially available heat pumps limit their application to low temperature heating systems, such as fan-coils, low temperature radiators or floor heating. However, traditional heating systems already installed in many buildings all over Europe, comprise a fossil fuel boiler and standard radiators, a high temperature heating system. These systems with radiators have been designed in order to use hot water of 80-90°C with a temperature drop of 10-20°C. As commercially available heat pumps are designed to provide water up to 50°C or 60°C with a temperature drop of 5-6°C, their installation in existing buildings implies the complete replacement of the high temperature heating system, namely the replacement of both radiators by fan coils or other advanced systems and piping of the buildings by pipes of larger diameter. In recent times, the development of a heat pump capable of delivering 65 °C water has been announced in Switzerland (SATAG/Viessmann; see http://www.satagthermotechnik.ch/english/aktuell.htm); this can be regarded as an initial step towards addressing the retrofit market for older buildings.

It is rather difficult to find reliable numbers of installed heat pumps in Europe, and in particular for the individual heat sources. Fig. 5 gives some recent data for the number of installed units in the main European heat pump countries. The extremely high number for Sweden in 2001 is the result of a large number of exhaust-air and other air-to-air heat pumps; however, Sweden also has the highest number of GSHP in Europe (see 1998 values in fig. 5). In general it can be concluded, that market penetration of GSHP still is modest throughout Europe, with the exception of Sweden and Switzerland (table 1). There is still ample opportunity for further market growth, and the technological prospects endorse this expectation. The Swiss example with a real boom of installed capacity (fig. 6) may encourage others. Also in Germany the trend is positive (fig. 7), with a share of GSHP (ground and water) of about 82 % in 2002.

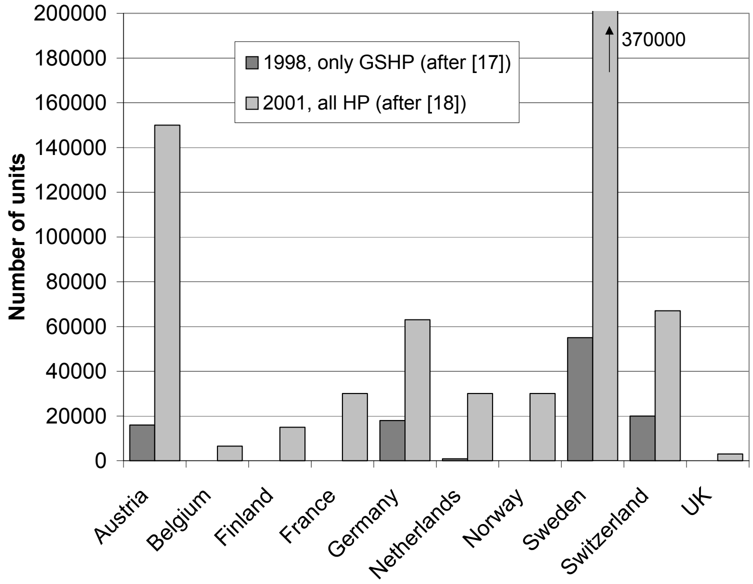


Fig. 5: Number of installed heat pump units in some European countries (after data from [17] and [18])

Table 1: Share of ground coupled heat pumps in total residential heating market (after data from [19])

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

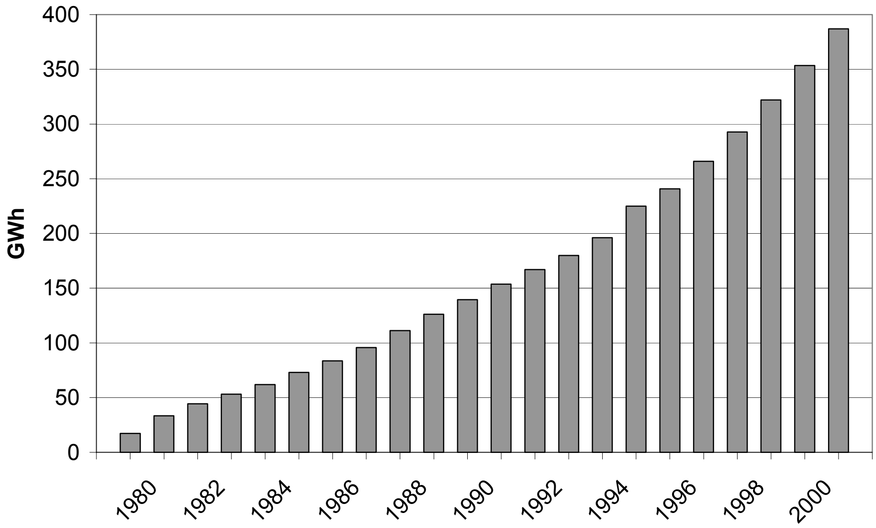


Fig. 6: Compilation of geothermal heat production (before the heat pump) by BHE systems in Switzerland. The values are based on AWP sales statistics (AWP = Arbeitsgemeinschaft Wärmepumpen Schweiz). The compilation has been commissioned by the Swiss Federal Office of Energy, Bern (see [20])

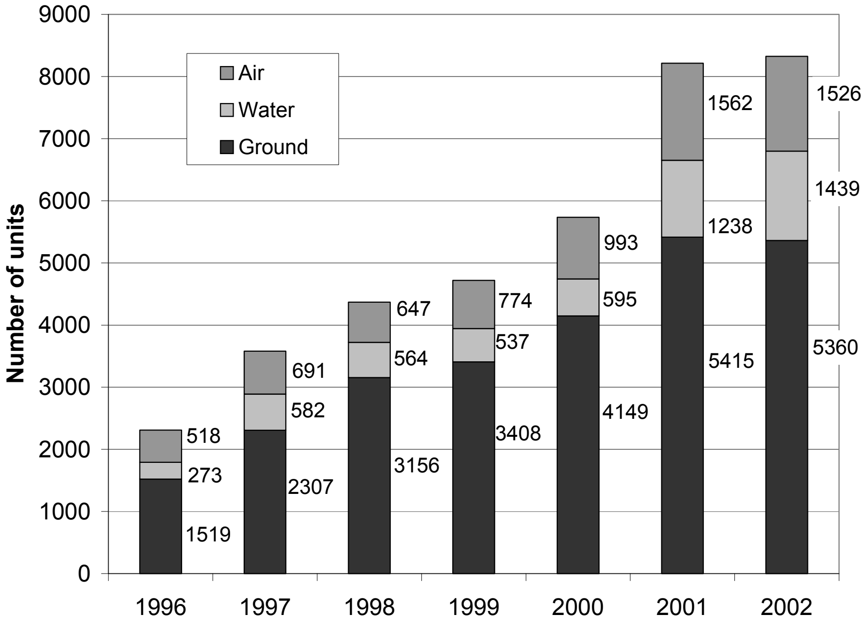


Fig. 7: Number of annual heat pump sales in Germany, according to heat sources (after data from IWZ e.V., Hannover and BWP e.V., Munich; heat pumps used for hot tap water production only are not included)

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