VII

DEVELOPMENT OF GEOTHERMAL HEAT PUMPS

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ABSTRACT

Shallow geothermal systems are usually combined with heat pumps (ground source heat pumps; GSHP). GSHP are widely spread all over Europe, with a long history in the centre (Austria, Germany, Switzerland) and in Sweden, and a subsequent market development in Benelux, France, Finland, Ireland, UK, and the Eastern countries. The use of GSHP in Southern Europe still is in its infancy.

Well designed, installed and maintained GSHP systems work over many decades without any problems and do not pose any threat to the environment. A number of technical guidelines of engineer's associations and ground-water protection authorities have established a common state of the art.

The current situation with a dramatic increase of GSHP installations in many countries (e.g. Germany, fig. 9) has changed the established market, as new players with poor experience and poor training now participate in it. A strong quality assurance and accompanying training and certification programs are urgently needed to prevent negative environmental impacts and damage in the public image of the whole GSHP sector.

INTRODUCTION

Shallow geothermal systems typically are combined with heat pumps (ground source heat pumps, GSHP). Solid underground or ground-water serve as heat source or heat sink. Shallow geothermal systems use typically the heat of the first 400 m of depth of the solid earth. A list of the largest installations currently built with BHE in Europe is given at the end of this paper.

Ground-water is tapped with open circuit systems: there is a borehole needed to pump up the water to the heat pump and there is a structure needed to return the used water into the underground (re-injection well or infiltration structure).

The heat of the solid underground is normally used by a closed circuit pipe system, which is installed horizontally (horizontal loops, incl. compact systems with trenches, spirals etc.) or vertically (borehole heat exchangers; BHE). A third possibility are so-called "geostructures": the loops are installed in foundation piles or foundations walls which are embedded in a water-saturated underground.

The closed loop systems use normally three circuits: heat source circuit, heat pump circuit and heating circuit (see figure 1). The first is filled with a water-antifreeze mixture. Direct expansion with only two circuits may be used with horizontal loops (figure 2).

For the vertical BHE, application of heat pipes (using CO_2 or propane), which work without circulation pumps, have found a new interest during the past few years (figure 3). Heat pipes can only be used for heating (heat extraction from the ground), however, combined systems with heat pipes inside classical BHE circuits have been suggested recently. Vertical systems may also be used as short-term and/or seasonal underground storage systems

In middle Europe the GSHP systems are mainly used as heating systems. Cooling (free cooling and active cooling with the heat pump) is normally only used in larger commercial installations. Of course, in Northern Europe the heating demand is higher; however, even in Scandinavia we find commercial installations with high cooling loads. In Southern Europe the cooling ability of a GHSP is more important than heating.

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Regardless of the wide variety of special shapes and systems, this paper outlines only the most common systems. Special attention is given to the BHE systems: they cover the largest market share, but they still can hold a certain risk regarding environment and ground-water protection - if built and used without adequate diligence.

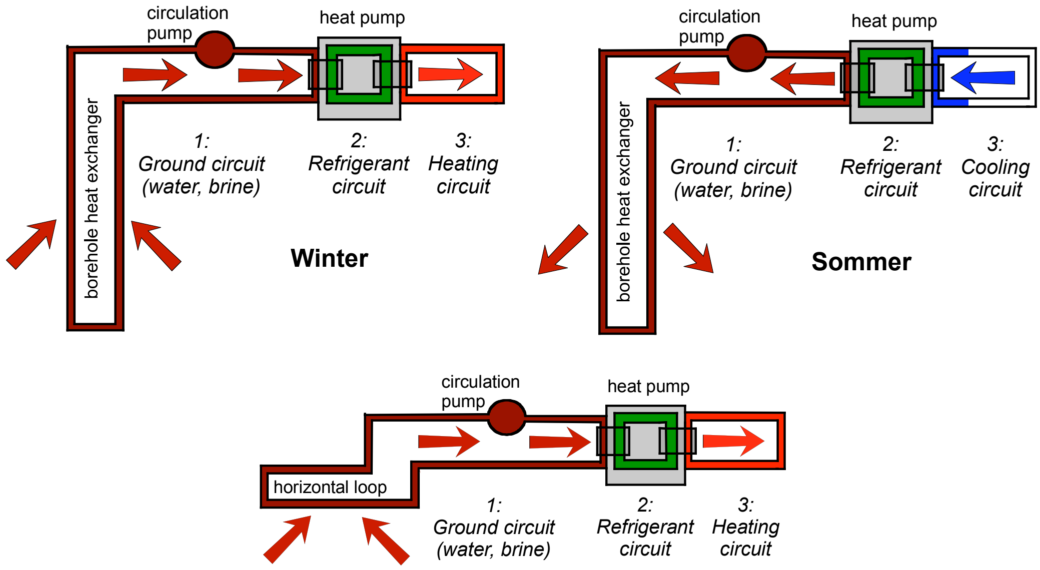

Figure 1: Basic scheme of a "classical" GSHP with water/brine circuit, with BHE or horizontal collector; this system can be reversed for cooling

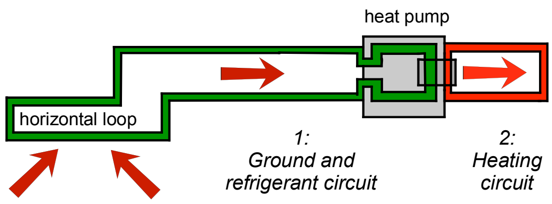

Figure 2: Basic scheme of a direct expansion GSHP with horizontal collector; this system can only be used for heating

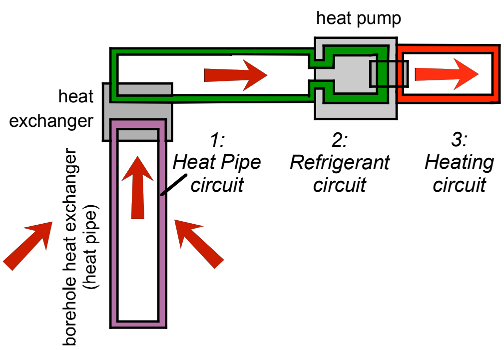

Figure 3: Basic scheme of a GSHP with heat pipe BHE; this system can only be used for heating

1. LEGISLATION

Every GSHP installation needs a license from the relevant authority for ground-water protection, water management or mining. Depending on the local laws a building permit is also sometimes needed. All licences must be applied for in advance. Closed circuit installations may allow implicit and simplified proceedings. Usually the licensing authorities impose special conditions for the construction and the operation of GSHP. These special conditions vary depending on the risk potential of the installation.

Within the countries with a developed GSHP market (e.g. Austria, Germany, Sweden, Switzerland) national or regional water management and/or ground-water protection authorities have published guidelines for the licence proceedings, as well as for the construction and operation of GSHP installations. Many authorities provide maps and web-based GIS-applications with indication of which type of GSHP is allowed or recommended at which location (figure 4).

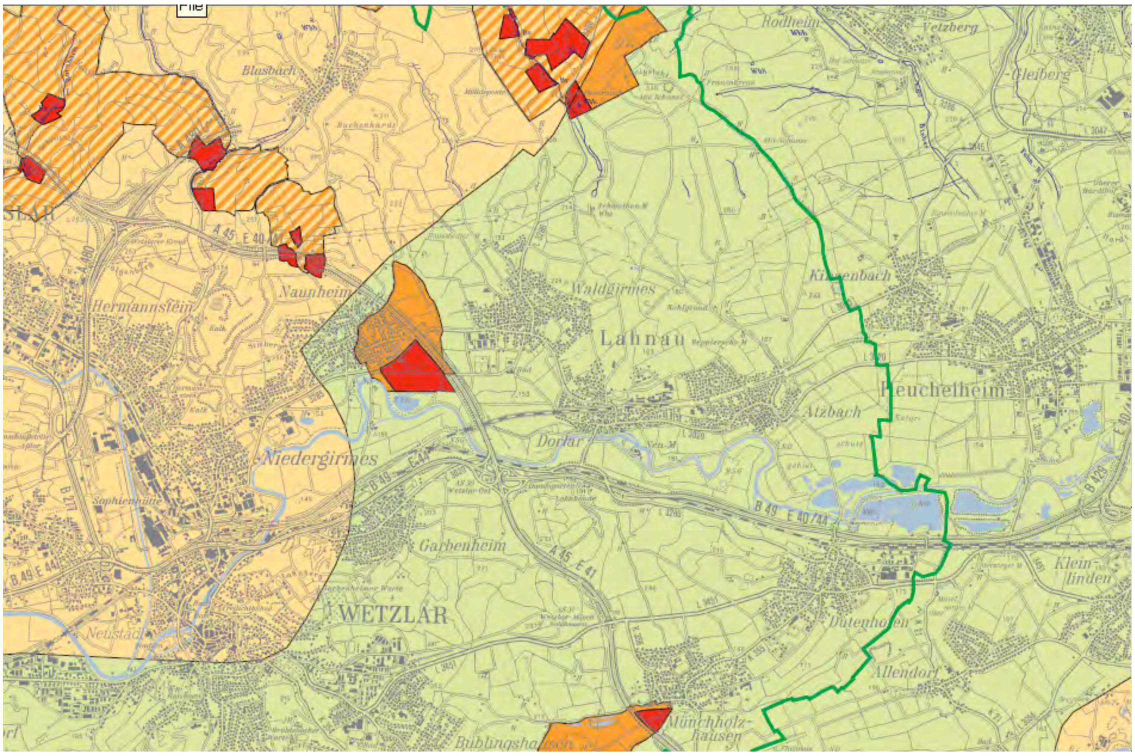

Figure 4: Example of map for BHE licensing from state of Hessen, Germany; green areas allow for simplified license for GSHP <30 kW heating output, red areas show inner water protection zones (no license possible), all other areas individual decisions (www.hlug.de).

2. GSHP SYSTEMS

The following three GSHP systems are mainly used in Europe: Ground-water heat pumps, BHE, and horizontal loops with three circuits. The market shares of these systems change from country to country – even from region to region.

2.1. Borehole Heat Exchangers (BHE)

BHE (see figure 5) are typically made of two U-shaped pipes of polyethylene (PE100, or PE-X in high temperature applications). The complete BHE is usually pre-fabricated and tested in the factory. The BHE is installed carefully into the borehole by the drilling contractor. Immediately after insertion of the BHE into the borehole, the annulus is grouted diligently and densely through an injection tube (“tremie pipe”) from to bottom to the top. The grouting has two purposes; (1) to establish a good and dense contact to the underground and (2) to prevent any vertical water movement along the borehole.
In Scandinavian countries the practice in hard, crystalline rock allows for keeping the borehole open and the annulus filled with water; however, a sealing to the surface is required. Single-U-tubes are the standard for Scandinavian BHE.

The BHE have a typical depth between 80 and 350 m (changing from country to country). The single tubes have diameters of 32 or 40mm (25mm with very short BHE’s).

On the technology front, the improvements take on.

- Thermally enhanced grouting now is available in different brands and is used routinely.
- Thermal Response Tests are a standard practice in the design of larger installations, and test rigs are available for use in most European countries by now.
- While direct expansion (e.g. with ammonia) in BHE did not catch on, as already hinted in 2003, the use of heat pipes as BHE (cf. fig. 3) meanwhile grew out of the stage of R&D and pilot plants (Kruse & Rüssmann, 2005; Mittermayr, 2005). These systems are commercially built and a good alternative in small

to medium plants with heating demand only, however, they cannot replace the BHE with water/antifreeze in all applications.

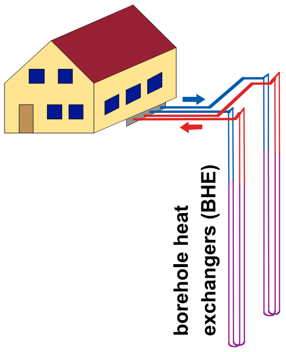

Figure 5: Basic scheme of a borehole heat exchanger installation

BHE need a ground-water protection license and sometimes – depending on the local laws – a mining license. The used geothermal heat is free of charge (at least for the time being). However, licenses carry a fee to be paid to the authorities, which in some regions can be quite substantial and can be a barrier to GSHP market development.

From the point of view of the ground-water protection authorities, the primary risk potential of a BHE are uncontrolled water flows into and along the borehole. In some countries the heat carrier fluid (antifreeze) is no longer considered as an important threat. Therefore no BHE are allowed in ground-water protection areas, in areas with several ground-water storeys, with confined or heavily mineralised ground-water (cf. figure 4).
Ground-water authorities impose usually special conditions to installers and/or house owners, e.g.:

- Correct dimensioning (e.g. after VDI 4640, SIA, …),
- adequate BHE, piping and joint material,
- adequate drilling equipment,
- correct drilling mud disposal,
- minimal quality of grouting,
- immediate communication of special incidents,
- final testing and commissioning of the BHE's,
- leakage prevention, and
- precepts for final shut-down of BHE's

If correctly dimensioned and built, the risk potential during operation is minimal.

2.2. Horizontal Loops

Horizontal loops (see figure 6) are installed at a depth between 1.0 and 1.5m. The tubes are usually made of Polyethylene (PE100) and have a size of up to 25 mm. From the point of view of ground-water protection these systems do not pose a threat to ground-water if installed above the maximum water level.
Authorities impose usually special conditions to installers and/or house owners, e.g.:

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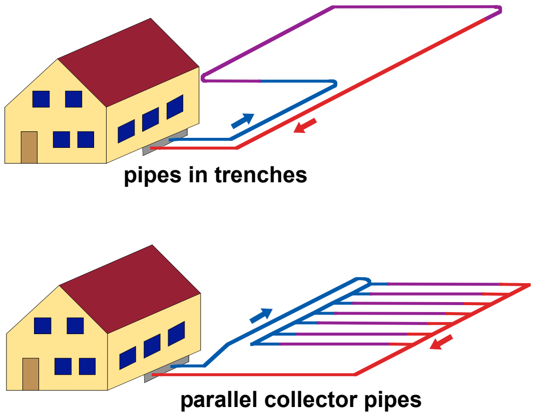

Figure 6: Basic scheme of a GSHP installation with horizontal loops.

If correctly dimensioned and built, the risk potential of such a installation during operation is minimal. Horizontal loops need a ground-water protection licence. The used geothermal heat is free of charge.

2.3. Ground-Water Heat Pumps

The heat source circuit of a ground-water heat pump installation is open: The production well reaches down to the ground-water layer; the water return facility (return well or infiltration structure) forms also a direct link to the ground-water (fig. 7).

From the point of view of ground-water protection, this system has the highest risk of all GSHP types. Harmful substances can pollute the ground-water layer. Authorities usually impose strong conditions to the construction and the operation of ground-water heat pumps.

- A hydrogeological preliminary study is always necessary, including:
  - natural thermal condition of the ground-water,
  - thermal as-is state of the ground-water,
  - estimation of thermal potential,
  - hydrograph of yearly ground-water table and temperature sequence,
  - ground-water chemistry,
  - estimated impact of ground-water cooling,
  - impact on other (present and future) utilisations
  - evaluation of conformity with actual laws.
- Only professionally built and maintained installations are allowed.
- Strong requirements for the wells or infiltration structures (see figure 7).
- The used water has normally to be completely returned to the ground-water layer.
- No direct discharging of any waste or rain water into the ground-water.
- No well on roads, gateways or parking areas.
- Accessibility for well control
- Any chemical regeneration of old wells needs an ground-water protection allowance.

If correctly dimensioned and built, the risk potential during operation is minimal. Ground-water heat pumps need a ground-water protection licence as well as a water management licence. The used ground-water heat is chargeable.

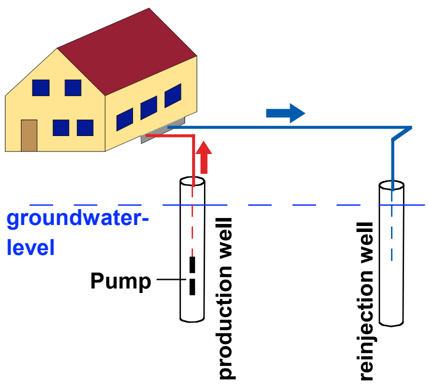

Figure 7: Groundwater heat pump system (open loop)

3. EXPERIENCE, DESIGN

Since the early 1980s GSHP installations have been monitored and studied (e.g. Sanner, 1987; Eugster, 1991). The first design tools that actually could be used for simple calculations have been developed in Sweden (Claesson & Eskilson, 1988); other computer methods (like numerical model with FD-method, e.g. Brehm, 1989) could at that time only be used for research purposes. Originally only empiric values were known, the omnipresent rules of thumb for BHE in the 1980s were:

- 55 W/m in Switzerland, cf. the first issue of guideline T1 (AWP, 1996)
- 50-80 W/m in Germany (Sanner, 1992); even the values given in the tables of the current version of VDI 4640 are based on the empirical values, and will be replaced by values determined by calculation in the revision which will be published soon.

Meanwhile the easy design tools have been optimised and adapted: A program used frequently us the Earth Energy Designer V2.0, published in 2000 (Hellström et al., 1997; EED, 2000).

Some newer design tools, based on the same g-function idea (Eskilson, 1986) as in EED, were developed in Europe. Other design tools have their origin in the USA and Canada. Especially the US tools were used often in GB. Another trend is to combine building load calculation / heat pump / underground design into integrated packages (Koenigsdoerff & Sedlak, 2006), however, with the underground design part somewhat limited.
The publication of VDI guideline 4640, part 1 and 2 in German and English represented until today a broad description of the central European state of the art in planning, dimensioning and constructing the geothermal part of a GSHP. At the moment, the VDI guideline 4640, sheet 1 and 2, are revised. More guidelines are listed in the references.

In Switzerland there is a Swiss standard about BHE and BHE-fields in preparation (SIA 384/6). The Swiss norm should be published in early 2009. New standards for drilling (incl. geothermal are prepared e.g. in UK (HVCA TR330) and France (NF X 10/999 ”Réalisation, suivi et abandon d´ouvrage de captage ou de surveillance des eaux souterraines”).

Today the dimensioning of BHE and horizontal loops is more conservative than it was 15 years ago. Also the new Swiss standard will show the same trend. The old rules of thumb should definitely no longer be used. A large number of planners and engineers have to change their way of dimensioning. It’s an information challenge as well as a formation challenge.

The new lower design values are based on a longer and broader experience. They reflect also the actual trend towards a higher density of GSHP installations in the central European countries.

4. CURRENT MARKET AND QUALITY SITUATION

The market penetration in different European countries is quite different (fig. 8.). Sweden leads by far in numbers of GSHP per capita, while Switzerland has the most dense GSHP pattern (numbers per capita). During the pas few years the GSHP market has shown a dramatic increase (e.g. Switzerland: around 20% per year over 5 years, Germany: more than 100% in 2006; cf.fig. 9).

Beside the heat pump and the pipe manufacturer the established experienced players of the GSHP branch can no longer control this situation by its own means. Existing companies grow very fast. New players (planner, engineers, installer, driller) push on the market. Many of these new players (new companies, grown existing companies) only have a very poor experience in the GSHP techniques; and some do not have any appropriate experience. This fact makes the GSHP situation very critical and even dangerous.

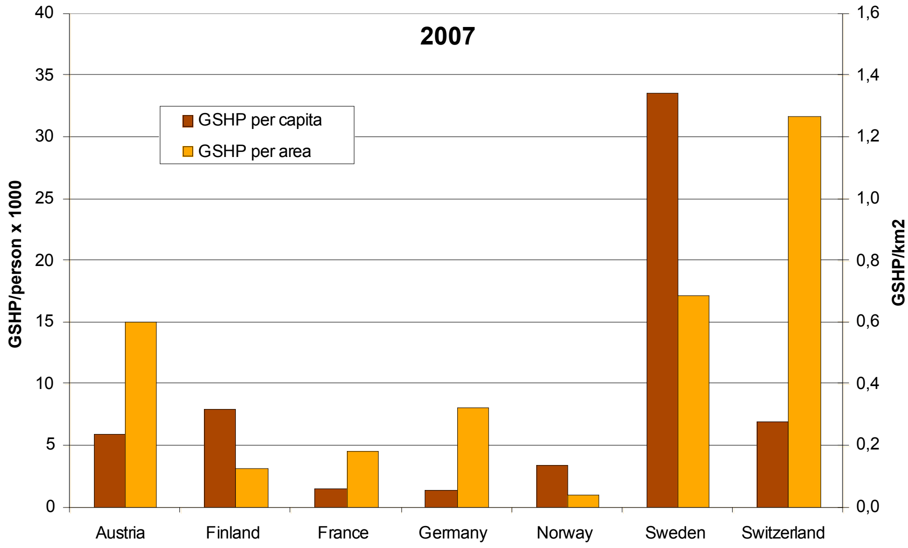

Figure 8: Number of heat pumps per capita and per area in some European countries (calculated after data from EHPA).

The share of qualitatively poor work increases:

- planners without appropriate training or experience,
- installers without experience,
- new drilling teams without appropriate training or experience.

Good quality work starts with a correct planning/dimensioning of the installation. The selection of material and equipment is very important; and last but not least the construction itself and the commissioning of the complete installation.

Small and large installations need in principle the same proceeding. With large plants the planning work is more intensely. The final layout of BHE is often made after a first test drilling and additional studies and tests (thermal response test, temperature logs, testing of cuttings).

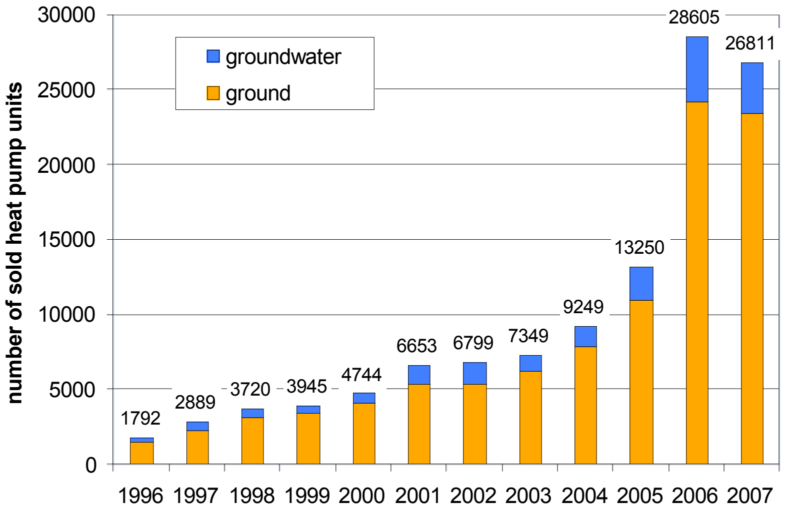

Figure 9: Annual number of new ground source heat pump units in Germany since 1996 (after data from BWP 2007).

Mistakes may happen in every part of the work. Mistakes in planning may yield to a failure of the whole GSHP installation. Bad drilling work may also cause a failure of the BHE Unprofessional drilling work may pose a dangerous threat to the environment and may cause large damages in the neighbourhood of the borehole (artesian ground-water, gas blows, ground liquefaction).

Quality assurance is urgently necessary in the GSHP branch. Some actions are already implemented: There is a quality label for heat pumps, realised first in Germany, Austria and Switzerland. This label will be adopted by the European Heat Pump Association (EHPA). There are training courses for planners and installers in different countries (e.g. Austria, Switzerland).

A quality label for BHE-drilling companies exists in Switzerland since 2001 (see figure 10). In Germany, BHE drilling companies are invited to acquire a technical certification (e.g. DVGW W120 G1, G2). A quality label like the Swiss one exists since 2006. Also the large association of the construction sector in Germany, ZDB, started an own quality label in the frame of the RAL-labels; it will be controlled by the "Gütegemeinschaft Geothermische Anlagen", founded in Dec. 2006. In Austria a quality label for BHE drilling companies will be launched soon.

Figure 10: The Swiss quality Label for BHE drilling companies.

5. EUROPEAN NETWORKS

There has been an technical network in middle Europe called D-A-CH for the 3 countries Germany (D) – Austria (A) – Switzerland (CH). The heat pump part of the network was integrated in the European Heat Pump Association (EHPA). The drilling part (quality label) is still remaining in D-A-CH for the moment. An open question is, if there will be once an European quality label for BHE drilling companies.

EHPA forms a technical and marketing network for heat pump manufacturer in Europe. Many national heat pump associations exist already.

From the geothermal point of view there exist many national geothermal organisations (e.g. GtV, SVG). These organisations provide information and technical support. On the European level there is the European Geothermal Energy Council (EGEC), which mainly acts an information provider.

6. THE GROUNDHIT-PROJECT

2004-2008 the European Commission supported a project for R&D on advanced ground source heat pumps (GSHP). This project was coordinated by CRES (Greece), and connects partners from Austria, France, Germany, Poland, Portugal, and Romania. Beside the development of improved components an important goal is the transfer of experiences from the "classical" GSHP-countries into other regions, in particular East and South Europe and the Mediterranean.

The first project phase aimed at the development of the following components:

- Borehole Heat Exchanger (BHE) with good heat transfer efficiency and simple installation, in particular for regions lacking experience in drilling and installation of BHE.
- Heat pumps with high COP within the usual temperature limits for heat pump systems and BHE.
- Heat pumps with good COP also at elevated heating supply temperatures (retrofit in older heating systems).
- Heat pumps with high COP at elevated evaporation temperatures, e.g. from warm groundwater, thermal springs, etc.

Within the second project phase that started end of 2006 the components were tested and demonstrated in some pilot sites in Greece, Austria, and Portugal.

The results of the project are for download at http://www.groundhit.eu .

6.1. Borehole Heat Exchanger

The key element on the ground side of the GSHP is the borehole heat exchanger (BHE). The design targets of good heat transfer and simple installation lead to the adoption of a coaxial design. The coaxial BHE was already used in the early times of GSHP (fig. 11), and in the beginning of BHE application in Germany around

1980, the coaxial design was prevalent. The review of patent applications that was done within the project revealed several examples from Germany alone. In Germany, originally the coaxial BHE was the typical design (Sanner, 1987), while the double-U-tube came from Switzerland, about the same time (Rohner, 1991), and the single-U-tube from Sweden (however, also coaxial tubes have been used early in Sweden; see Mogensen, 1985).

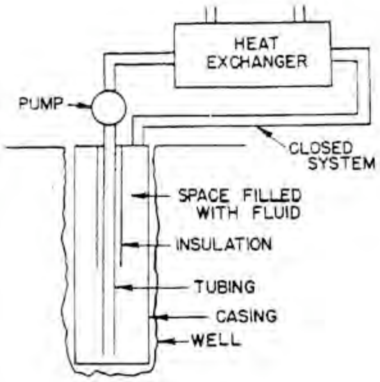

Figure 11: First drawing of a coaxial BHE, from Kemler (1947).

The GROUNDHIT BHE (fig. 12) is of a coaxial design (concentric, tube-in-tube) using standard plastic tubes and fittings, so no taylor-made components are required.
Because the borehole thermal resistance of a coaxial system can be quite favourable, efficiency of the BHE compared to double-U is improved. This results in a slight reduction in the necessary borehole length for a given heat pump.

6.2. Advanced Heat Pumps

The relevant heat pump development was carried out at CIAT in Culoz, France. The following prototypes have been built:

- High performance for standard GSHP applications (GROUNDHIT work package 2)
- High supply temperatures of 80 °C, mainly for retrofit applications (GROUNDHIT work package 3)
- High evaporating temperature up to 40 °C for use with thermal water (GROUNDHIT work package 4)

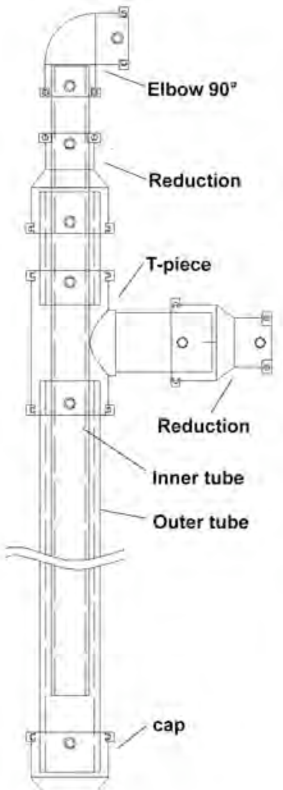

Figure 12: Drawing and photo of simple coaxial BHE as used in the GROUNDHIT project

The key for high COP, beside good compressor efficiency, is low temperature loss in evaporator and condenser. For the GROUNDHIT heat pump, a pinch of less than 2 K in the evaporator and less than 1 K in the condenser could be achieved (fig. 13). Special brazed plate heat exchangers from the CIAT EXEL range have been used towards this goal, and a specific distribution device for the evaporator. A very efficient scroll-type compressor is used, without capacity control; the ground-coupling and hydronic heating allow for the simple on-off-control, which enables the compressor to run more under optimum efficiency conditions.

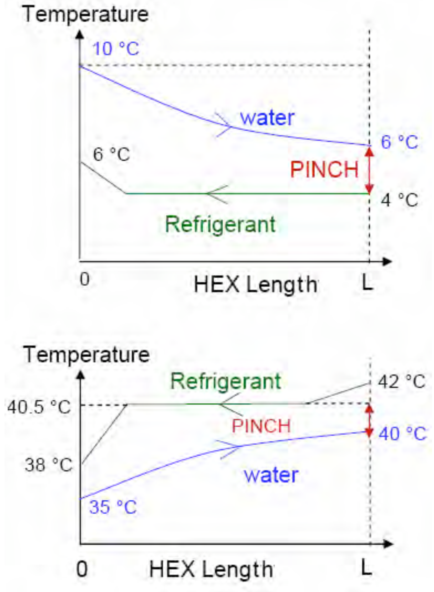

Figure 13: Temperature development in the heat pump for work package 2, over the length of the heat exchanger for evaporator (above) and condensor (below)

An increase of 12-15 % in the annual COP over the market average, as can be expected from the lab tests, means savings in the annual electric power bill of about 150 €, and can save up to 1.0 tons of CO_2-emissions a year, calculated for a heat pump unit with 15 kW heating capacity (exact conditions for calculation see in the appendix).

6.3. Field Test / Demonstration Sites

The demonstration sites (fig. 14) have been selected in order to best serve different purposes:

- In Setubal (Portugal), the high efficiency heat pump for standard conditions (from work package 2) will be tested and demonstrated. The climatic conditions call for a substantial cooling load; the heat and cold distribution follows standard practice. The critical part in the Setubal test site is on the ground side; ground source heat pumps yet are a novel application in Portugal, and experience with drilling and installation for BHE is non-existent. So this site offers optimum conditions for testing the setting-up of a GSHP system for heating and cooling in Southern Europe.
- The Gleisdorf site in Austria is located in a country with large experience in GSHP. The ground side should not cause any problems to the skilled Austrian drillers. The critical point here is in the heating supply side, where high temperatures for retrofit applications in existing buildings are required. With GSHP firmly established on the market for new buildings in Austria, the step into the much larger market of existing structures now can be demonstrated, and the huge potential for energy saving and emission reduction on that market in all of Central Europe might be opened.
- The site near Thessaloniki in Greece offers a low-temperature thermal water in a temperature range encountered often in the Mediterranean region. Thus the test of the heat pump with elevated evaporation temperature from work package 4 can be carried out here.

The current project shows that a good efficiency of a ground source heat pump can be achieved with advanced components (heat pump), but simplified installation techniques for the ground side (coaxial borehole heat exchanger). The advanced heat pumps developed for the standard application are close to the market and will form a part of CIAT´s Aurea line. Also the extension of the ground source heat pump technology towards heat supply temperatures hitherto not possible, and towards application of heat sources with elevated temperature, seems very promising.

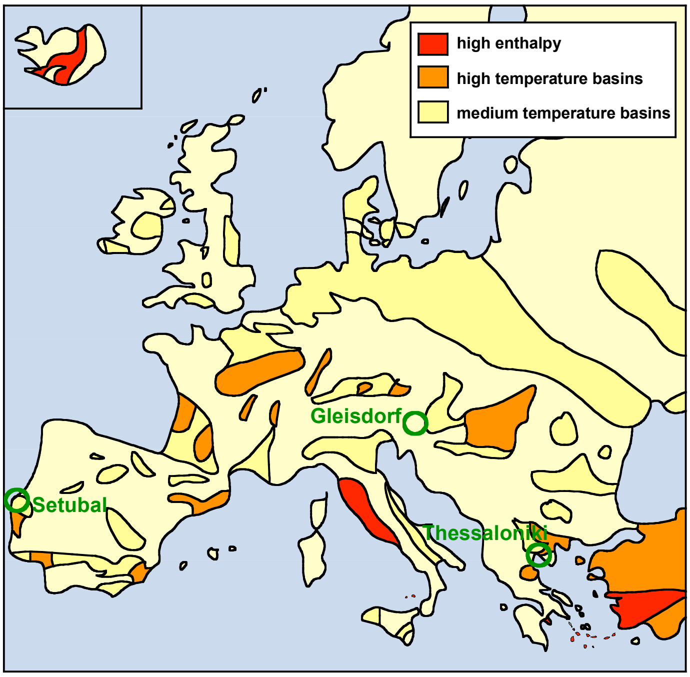

Figure 14: The three GROUNDHIT demonstration sites in the framework of the European geothermal structure

Table 1: List of largest GSHP-plants with BHE in Europe

Country	City, Project	Number BHE	Depth BHE	BHE total
NO	Lørenskog, Nye Ahus Hospital	350	200 m	70’000 m
NO	Oslo, Offices/Flats Nydalen	180	200 m	36’000 m
SE	Lund, IKDC / Chemical Institute	153	230 m	35'190 m
SP	Mollet de Valles, Hospital	138	145 m	20'000 m
TR	Istanbul, Ümraniye Mall	208	41-150 m	18’327 m
HU	Törökbálint, Office Pannon GSM	180	100 m	18'000 m
DE	Golm near Potsdam, Max-Planck-Inst.	160	100 m	16’000 m
SE	Stockholm, Blackeberg Quaters	90	150 m	13’500 m
NO	Oslo, Office park Alnafossen	64	200 m	12’800 m
SE	Örebro, Music Highschool	60	200 m	12’000 m
HU	Páty, Verdung Logistics Centre	120	100 m	12’000 m
BE	Melle, Office EANDIS	90	125 m	11’250 m
DE	Langen, Head Office DFS	154	70 m	10’780 m
CH	Zürich, Grand Hotel Dolder	70	150 m	10’500 m
PL	Rudy, former Cistercian Monastry	100	100 m	10’000 m

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<u>Guidelines:</u>

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Dr **Burkhard Sanner**, after graduation as a geologist in 1980, first worked in engineering geology, including a stay at Universidad de Costa Rica in 1981 for a soil mechanics project. Since 1985 concerned with geothermal energy, starting as project manager for an industrial R&D-project on ground source heat pumps, which became part of IEA Heat Pump Annex 8 in 1986. From 1990 on work in the field of geothermal energy and ground source heat pumps at Justus-Liebig-University, Giessen, Germany, finally as temporary professor for Applied Geosciences until 2004. In that time several R&D-projects within the framework of IEA, and frequently expert and evaluator for EC. Currently consultant and design geologist for geothermal energy systems with UBeG GbR, Wetzlar, Germany, and also representing the geothermal energy sector towards the EU-administration in Bruxelles, Belgium, as president of EGEC (European Geothermal Energy Council). Dr Sanner has held many positions of geothermal associations: 1992-2000 vice president and 2000-2006 president of the German Geothermal Association GtV, 2001-2007 member of the board of the International Geothermal Association IGA, since 1998 member of the Forum (governing committee) of the European Branch of IGA, since 2004 president of EGEC, until 2005 chairman and since then vice chairman of the guideline committee VDI 4640 (thermal use of the underground).