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Technological Status of Shallow Geothermal Energy in Europe

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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.

Underground Thermal Energy Storage (UTES) systems also use shallow geothermal technologies. They may or may not comprise heat pumps, and are used for storing heat or cold either in the solid ground (with borehole heat exchangers) or in aquifers. Large installations of the aquifer storage type (ATES) for cooling purposes can be found e.g. in Southern Sweden and in the Benelux countries.

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.

1. INTRODUCTION

Shallow geothermal systems typically are combined with heat pumps (ground source heat pumps, GSHP; for other options see chapter 4). 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).

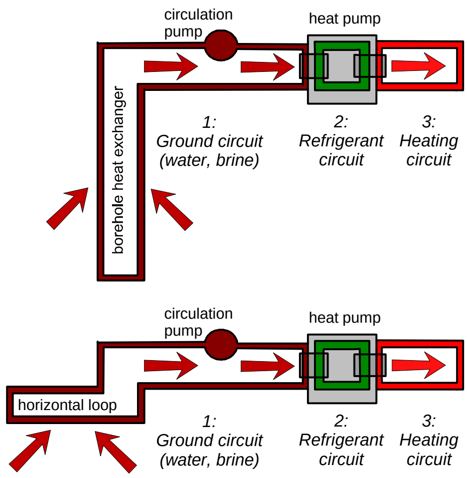

Figure 1: Basic scheme of a "classical" GSHP with water/brine circuit, with BHE or horizontal collector; this system can be reversed for cooling

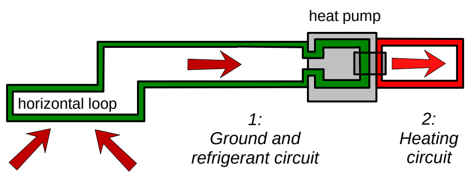

Figure 2: Basic scheme of a direct expansion GSHP with horizontal collector; this system can only be used for heating

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.

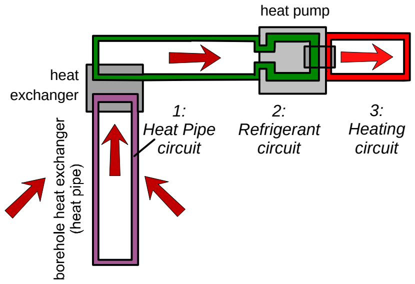

Figure 3: Basic scheme of a GSHP with heat pipe BHE; this system can only be used for heating

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.

2. 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).

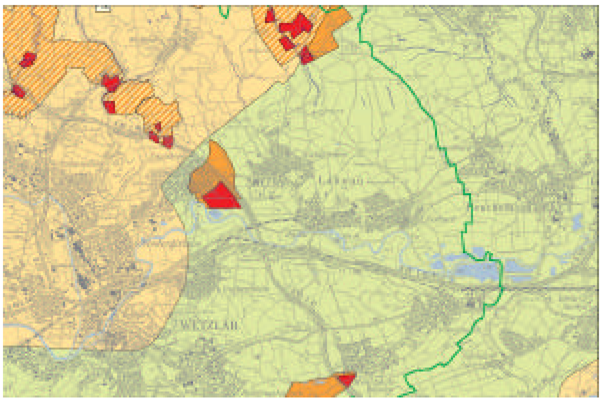

Figure 4: Example of map for BHE licensing from state of Hessen, Germany; green areas allow for simplified license for GSHP <30 kW heating output, red areas show inner water protection zones (no license possible), all other areas individual decisions (www.hlug.de).

3. 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.

3.1 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.

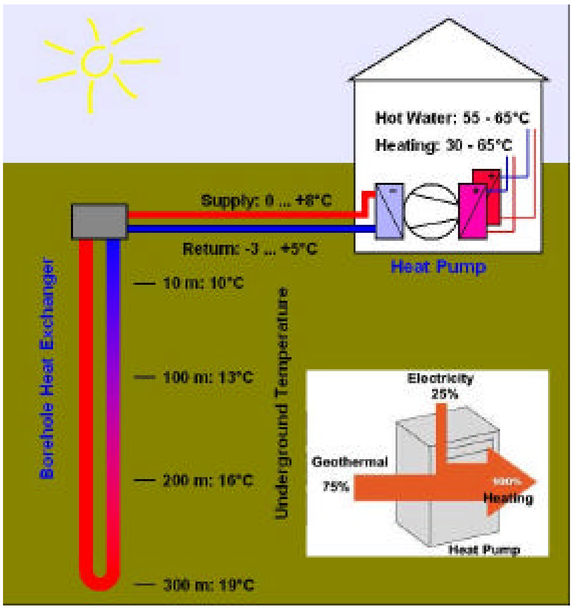

Figure 5: Basic scheme of a borehole heat exchanger installation. System and underground temperatures are given (www.fws.ch).

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 described at the last EGC (Sanner et al., 2003) took 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.

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.

3.2 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.

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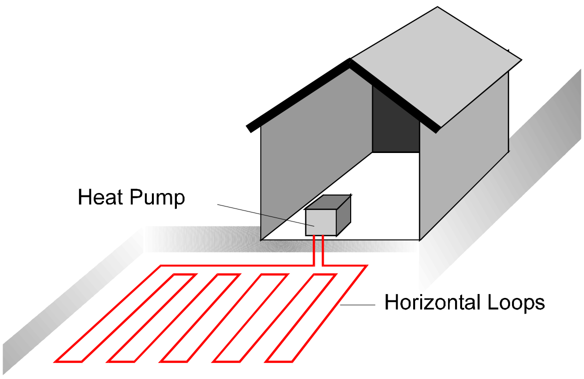

Figure 6: Basic scheme of a GSHP installation with horizontal loops.

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.

3.3 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 structure (return well or infiltration structure) forms also a direct link to the ground-water.

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.

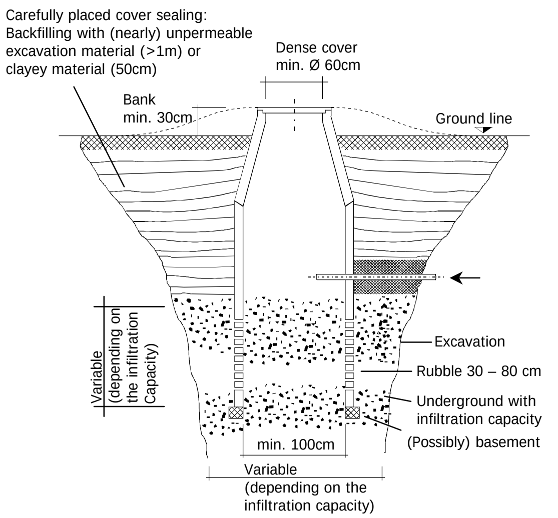

Figure 7: Basic scheme of a infiltration structure (BAFU 2007).

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.

4. UNDERGROUND THERMAL ENERGY STORAGE

In Underground Thermal Energy Storage (UTES) systems the temperature of a body of groundwater or solid soil/rock is changed, e.g. by injection cold groundwater in wintertime for cooling in summer. This technology only works with large installations, where the volume of the warm or cold part of the underground is large compared to the envelope. Since the first commercial seasonal cold storage application for a printing company in the Netherlands in 1987 (Kooiman & van Loon, 1991), the market has developed rapidly in particular in The Netherlands and the Northern part of Belgium (Flanders), and in Scandinavia.

Heat storage in the underground is done up to relatively high temperatures. Experiments in the 1980s in France and USA with temperatures >100 °C have not been successful, and the high temperature aquifer storage system at Utrecht University in the Netherlands (operational for up to 90 °C since 1991) was abandoned after several years, when the combined heat and power plant used for supplying the heat in summertime was changed. However, heat storage with temperatures up to 70 °C in the shallow geothermal realm could be demonstrated in several installations successfully, using both BHE or aquifer storage technologies (fig. 8.). A very interesting combination of a shallow (ca. 60 m) aquifer cold storage system with a deeper (ca. 300 m) aquifer heat storage system is in operation since 1999 for the German Parliament in Berlin (Sanner et al., 2005).

A study within an IEA-project (Sanner, 1999) had shown that technical problems related with higher temperatures in UTES systems may be overcome. One main issue still are the changes in water chemistry with drastically changing temperatures in aquifer storage systems, resulting in clogging, scaling, corrosion and leaching. It is possible to design and build reliable High Temperature UTES plants today, but caution is necessary when working with groundwater. The investigation of promising system concepts revealed a number of opportunities to make use of UTES for saving energy and reducing emissions. For more information on UTES, see http://iea-eces.org .

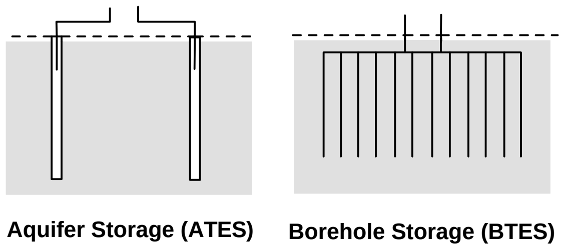

Figure 8: Basic methods for Underground Thermal Energy Storage (UTES)

5. 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.

Currently a DIN-standard is under development, for BHE drilling and installation. Also 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 2008. 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.

5. CURRENT MARKET AND QUALITY SITUATION

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. The queue time for a new borehole for example is since 2005 around half a year. 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.

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.

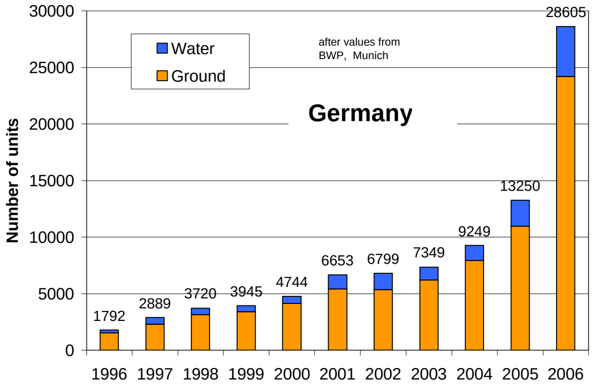

Figure 9: Annual number of new ground source heat pump units in Germany since 1996 (after data from BWP 2007).

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).

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.

6. EXAMPLE: QUALITY ASSURANCE OF BHE

Recommended features of a quality assurance shall be shown at the example of a small BHE installation. These actions base on the yet unpublished new SIA and VDI prescriptions:

- Exploratory enquiry for a BHE licence at the groundwater protection authority (map, GIS, e-mail, telephone call),
- Selection of an appropriate heat pump on the basis of a calculated heat demand, dimensioning of the BHE according to VDI, SIA or similar technical prescription,.
- Apply for a BHE and drilling licence,
- Apply for a building licence (according to local laws).
- Order a specialised drilling company. Quality features:
  - Drilling rig for rotary drilling or down hole hammer/airlift drilling,
  - Compressor (if applicable),
  - Preventer with different dense joints (figure 6),
  - Dense water/mud management,
  - Appropriate cutting transport hose,
  - Safe pneumatic hose,
  - Injection equipment (pump, mixer, material),
  - Material to handle incidents (gas, artesian water),
  - Barrier and signalisation material,
  - Trained drilling staff who knows all immediate measures in case of incidents,
  - Drilling staff knows the limits of the used drilling method

Figure 11: Drilling equipment with preventer and dense water/mud management

Figure 12: drain off the cuttings into a hutch using a safe transportation hose

- On site work (drilling company):
  - Report start of drilling work to authority/geologist,

- Indication of the exact drilling points through the client,
- Drilling work according to the state of the art:
  - e.g. pneumatic down hole hammer / airlift,
  - casing through unconsolidated layers down into the solid rock (1-2m),
  - drain off the cuttings into a hutch (figure 7),
  - write the drilling report,
  - report critical incidents (gas, artesian water, pollution, damages),
  - In case of incidents: perform correct immediate measures to prevent damages; call for experts to save the bore hole/BHE,
  - Correct disposal of the drilling mud,
  - Remove drill poles at final depth.
- Check BHE for damages,
- Affix an injection tube at the bottom of the BHE or prepare the injection rods,
- Prepare the prefabricated and factory-tested BHE on a decoiler with a hydraulic brake (figure 8),
- Install the BHE slowly and carefully into the bore hole Pay attention to a pressure balance inside/outside the BHE,
- Immediate backfilling of the borehole from the bottom to the top of the hole using the injection tube or the injection rods. Use only approved material in an approved mixture. Take care, that the BHE's are filled with water and sealed densely.
- Remove the borehole casing,
- Perform a flow test,
- Perform pressure testing according to DIN EN 805. Commissioning of the BHE to the client with the test logs,
- Mark, seal and protect the BHE against any damages (see figures 9 and 10),
- Hand out the drilling report to the authorities and the client.

- Final work (installer)
  - Connect the BHE's to the heat source circuit and the heat pump,
  - Installation and commissioning of the heat pump
  - Final testing of the GSHP installation,
  - Hand out a complete documentation of the GSHP installation to the client.
- Warranty according to the technical and/or legal prescriptions.

7. 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.

Figure 13: Preparing the BHE on a decoiler with hydraulic brake

Figure 14: Sealing the BHE's

Figure 15: Mark and protect the BHE against damages.

ACKNOWLEDGEMENT

The Swiss quality label for BHE drilling companies was launched by the Fördergemeinschaft Wärmepumpen Schweiz (FWS) (www.fws.ch) and is partly financed by SwissEnergy, a programme of the Swiss Federal Office of Energy.

The German quality label for BHE drilling companies is launched by an number of technical organisations of the GSHP branch (BWP, GtV, FIGAWA, DVGW).

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Guidelines:

AWP: Merkblatt T1: Wärmepumpen-Heizungsanlagen mit Erdwärmesonden. Arbeitsgemeinschaft Wärmepumpen (AWP), 1991/1996. Download: www.fws.ch

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SIA D0136: Grundlagen zur Nutzung der untiefen Erdwärme für Heizsysteme. SIA/BfE, 1-142, 1996

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Part 1: Fundamentals, Approvals, Environmental Aspects, Beuth Verlag Berlin, 2000, revision in progress
Part 2: Ground Source Heat Pump Systems, Beuth Verlag, Berlin, 2001, revision in progress.

Information on GSHP and quality improvement, e.g.:

www.egec.org

www.geothermie.ch

www.geothermie.de

www.ehpa.org

www.fws.ch

www.waermepumpe-bwp.de

Country	City / project name	No. BHE	depth BHE	total BHE length
NO	*Loerenskog, SiA hospital **	*ca. 300*	*150 m*	*ca. 45’000 m*
NO	Oslo, Nydalen district	180	200 m	36’000 m
SE	Lund, IKDC	153	230 m	35'190 m
SE	*Stockholm, Vällingby Centr.**	*133*	*200 m*	*26’600m*
SE	*Kista, Kista Galleria **	*125*	*200 m*	*25’000 m*
TR	Istanbul, Metro market	168	107 m	18’000 m
DE	Golm near Potsdam, MPI	160	100 m	16’000 m
SE	Stockholm, Blackeberg area	90	150 m	13’500 m
SE	Örebro, Musikhögskolan	60	200 m	12’000 m
DE	Langen, DFS	154	70 m	10’780 m
CH	Zürich, Grand Hotel Dolder	70	150 m	10’500 m

BHE: Borehole Heat Exchanger * under construction

Appendix: Very large European BHE plants with more than 10 km drilling, status end of 2006 (own data and additional information provided by Göran Hellström and Tunc Korun). The authors ask to notify if large –or even larger - installations of these type exist or are built elsewhere in Europe.
There are also very large installations using groundwater wells (e.g. for the new Oslo airport at Gardemoen in Norway); with these plants normally the boundaries between pure GHSP and UTES are vanishing.