Shallow geothermal energy –
history, development, current status, and future prospects

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ABSTRACT

The paper gives an account on the early steps towards use of heat pumps, and then focuses on the situation in Europe. Details are given on R&D-activities in Germany from the 1980s on, and on the related work in IEA-cooperation. Reports and findings from conferences of that time are highlighted, as well as steps towards guidelines and standards. Some examples of milestones in practical application are given. An assessment of the current status, both in technical development and market, and some cautious expectations for future development complete the picture.

Taking advantage of the steady temperature inside the earth goes back into prehistoric times, when caves or holes were used for storing food and for living, both in cold and hot climates. However, active use of this thermal energy reservoir required a tool for changing temperature, the heat pump to increase it, and the chiller (or a heat pump in reversed mode) for decreasing temperature. Practical application of the heat pump process was already done in the 19th century, with the example of the steam generation in Ebensee salt works in Austria.

The first claims on a heat pump extracting heat from the earth were made by Heinrich Zoelly in a Swiss patent of 1912. However, the first documented application in reality dates from 1945, in Indianapolis, USA, and in Europe the first groundwater heat pump is reported in 1950 in Thun, Switzerland. Information on a few more ground-source heat pumps in Europe is from the 1960s, and it took the two oil-price peaks in 1973 and 1980/81 to spark interest in heat pumps. R&D on geothermal heat pumps had a first boom in the 1950s in USA and Canada, and after the first oil price crisis in 1973, it started in Europe and Japan, and resumed in North America. Today, grounds source heat pumps and underground thermal energy storage are an accepted part of sustainable solutions for providing heat or cold, and the number of ground source heat pumps in Europe alone rose to over 1.7 Mio in 2015 (Antics et al., 2016). Furthermore, universities, research institutes, and private companies all over Europe are active in shallow geothermal R&D today.

1. INTRODUCTION

Being interested in history since school times, the author would not need a justification for his expeditions into the heritage of shallow geothermal. However, the reason why to put some thoughts and accounts on paper for a larger audience should be explained shortly. Recent history of science and technology (and of society in general) has a pivotal break at the end of the 20th century: Up to then, information was contained and distributed in paper form, in books, journals, studies, letters… - just like all the many decades ago, basically since antique times. The development of the internet changed everything.

In the 1980s, it already became possible to research for literature and data in electronic databases. ‘On line’ was a true word then, e.g. with telephone handsets inserted into acoustic couplers and electronic signals crawling through telephone lines. The access to literature databases was costly, and usually required some training with the necessary search algorithms in order to retrieve something meaningful. A predecessor of the internet we know today was already up and running, but limited to the scientific world. From 1990 on, the structures were opened to commercial use – and the online-world began, slowly first, and then, quickly, with increasing momentum. More and more information became available, and search machines like Yahoo and later Google allowed for retrieval of information from the gigantic amount of data stored electronically. Today, finding really valuable information nevertheless can be like looking for a needle in a haystack, and quite often just straw is found.

Literature research by browsing through catalogue cabinets in libraries, or trying to get hold of the original papers cited in books and papers, is definitely a thing of the past. Most scientific journals, conferences, etc. meanwhile offer search through the internet. Hence the information printed on paper before the advent of the internet is hardly found today. And most of the reports and publications from the early development of shallow geothermal energy use are just that – words and graphs printed on paper. The author hopes to make some of the development of shallow geothermal available to those who did not experience that time in person, and to bring into perspective the status achieved today and the expectations for the future.
2. HISTORY

Temperature changes on the surface decrease inside the ground, and beneath a depth of about 10-20 m the earth has steady temperature throughout the year. This fact is used by animals since there is life on land, and since prehistoric times also by human beings, hiding in holes or caves to keep cool in hot climate, or warm in cold winters. In areas with suitable geology whole cities were dug into the rock. Areas with similar, well-suited volcanoclastic rocks in New Mexico in the USA, and in Cappadocia in Turkey, have resulted in astonishingly similar ‘cave cities’, where people and their food supply stay comfortable despite harsh outdoor climate. Old, rural houses and storage sheds in Iceland and Northern Scandinavia used to be partly underground, as still can be seen in places (figure 1). And even into the modern era deep cellars are used for food, wine, etc., and even to store ice harvested in winter for cooling in summer. Mechanical refrigeration has ended the natural ice business, but new, modern approaches to use of underground space have emerged.

Figure 1: Storage shed partly underground in Emmaboda, Sweden, amid modern houses in 2007

Scientific description of the decrease of temperature changes with depth has started in the late 17th century, when temperature readings were taken in the cellar of the Observatoire de Paris, and Antoine Lavoisier later installed a thermometer there. Buffon (1778:495) describes the steady temperature reading throughout the seasons. Two decades later the German Alexander von Humboldt visits the place during his studies in Paris. Humboldt (1799:82) states: ‘The average temperature which the observations done since 1680 revealed is 9.6 R’. This value is equal to 12 °C, and the seasonal temperature variations are recorded as maximum 0.03 R (0.04 °C).

In Scotland, ground temperature measurements were done since 1838 over many years on the grounds of the Royal Observatory in Edinburgh (figure 2). These data were used by both Thomson (1860) and Everett (1860) to empirically validate their formulas for the decrease of surface temperature variations towards depth and the retardation of phase. Thomson (1860) calculates that temperature variation is only 1/20 of the variation on the surface in 8.1 m depth, and 1/400 in 16.2 m depth.

The temperature in the shallow geothermal realm is also influenced by the geothermal heat flux and the resulting geothermal gradient. With mines exploiting deeper and deeper resources, miners in the middle ages started to feel the geothermal heat. The first to attribute this to a hot interior of the earth and to give a cause (an internal fire) for it was Kircher (1665). He also mentioned a geothermal gradient, citing reports from miners in the region of Chemnitz, Germany.

Figure 2: Measurement of ground temperature at the Royal Edinburgh Observatory, average values 1838-1854, after data from Everett (1860)

It took more than hundred years before another scientist started to put numbers to the geothermal gradient. Buffon (1778:495) first also cites account from miners from Eller, Germany: “à mesure que les mineurs descendent, ils recontrent une température d’air toujours plus chaude” (the deeper the miners descended, the higher the air temperature they encountered). He then lists numbers for the temperature increase towards depth, like the readings from Giromagny near Belfort (taken by de Gensanne) shown here in table 1.

Table 1: Temperature increase with depth as given by Buffon (1778) for Giromagny; original values converted to modern units by the author

<table>
<thead>
<tr>
<th>Depth</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>101 m</td>
<td>12,5 °C</td>
</tr>
<tr>
<td>206 m</td>
<td>13,1 °C</td>
</tr>
<tr>
<td>307 m</td>
<td>19,0 °C</td>
</tr>
<tr>
<td>432 m</td>
<td>22,7 °C</td>
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</table>

Cordier (1827) endeavoured on a collection of data on underground temperatures from various places, and concludes: ‘If some observations that seem to have to big uncertainty are discarded, the others prove in more or less obvious way that there is a temperature increase from the surface towards the interior of the earth; hence it is justified to concede such increase. […] The differences between results that have been obtained in the same way are not only a result of lacking experience, but can also be attributed to a
certain irregularity of the distribution of the under-
ground heat from one country to the other.’ Cordier
(1827) thus not only described the geothermal gra-
dient, but also the basis for heat flow maps. For the
site of the Observatoire de Paris he calculated an in-
crease by 3.6 °C per 100 m.

Still the idea of a hot interior of the earth was not fully
accepted in the early 19th century. The recording of
underground temperatures was intended to prove or
contradict that concept. Work bei Kupffer (1829),
Reich (1834) and Bischof (1837) provides a wealth of
data, showing geothermal gradients of 2-4 K per
100 m. Bischof (1837) seems to be the first to un-
derstand that also the thermal conductivity of the rocks
influences the value for temperature increase towards
depth. Towards the end of the 19th century, Lebour
(1882) can present 57 series of underground tempera-
ture data, mostly from France and England, and
obtains geothermal gradients of 1.1-6.4 K per 100 m
from these data. The highest gradients, of more than
5 K per 100 m, were found in mines in Cornwall.
The effects of seasonal variations of surface tempera-
ture, decrease of such variations into the ground, and
the geothermal heat flow from below control the
shallow geothermal systems. A typical temperature
distribution resulting from the interplay of these
factors is shown in figure 3. At the end of the 19th
century, these factors were fairly well understood.

Figure 3: Original plotter graph from 1987 showing the undisturbed temperature development along a bore-
hole 50 m deep over one year, from August 1986 to August 1987, in the Schwalbach GSHP research
station

In order to actively use the shallow underground for
energy production or storage, a tool is required for
changing temperature, the heat pump to increase it,
and the chiller (or a heat pump in reversed mode) for
decreasing temperature. An early vision of such a
machine with two cylinders in series is given by
Thomson (1853), the processes is intended both for
heating and cooling. In a note added to the article in
1881 Thomson writes that in the meantime, machines
based in his principle were used for cooling, e.g. for
transporting meat on ships, and continues: “The
method of heating air described in the article remains
unrealized to this day”.

Practical application of thermodynamic processes was
developed in the second half of the 19th century, pri-
marily for refrigeration (e.g. producing ice). Working
fluids were water vapour, methyl ether, carbon diox-
ide, and ammonia.

Today it is generally accepted that the first practical
application of the heat pump principle was made by
Peter von Rittinger in 1857, using vapour compression
in a closed batch circuit to evaporate water and thus
produce salt from concentrated brine in the Ebensee
salt factory in Austria. He explained his idea in the
words ‘Steam can generate mechanical work, but
hardly any physicist will doubt the sentence expressed
in the reversed sense, mechanical work can generate
steam’ (Rittinger, 1855). The compressor was driven
by water, a readily available resource in the area, and
thus valuable firewood could be saved with the
process. The heat pump reputedly had a thermal ca-
pacity of 14 kW (Zogg, 2008).

3. DEVELOPMENT IN THE 20TH CENTURY
3.1 Development until the first oil price crisis 1973
It is well known that on 13th February 1912 a patent in
which a ground-source heat pump is described was
applied for by Heinrich Zoelly, of some fame in water
and steam turbine design and with the development of
steam turbine locomotives. The main claim in this
Swiss patent No. 59350, granted in 1919, was as follows (cited after Wirth, 1955; translation by the author):

„Heizverfahren, dadurch gekennzeichnet, dass man durch einen Elektromotor einen Kompressor treibt, welcher einen Wärmeträger in einem Kreisprozess fördert, dessen Verlauf gleichartig ist mit demjenigen, den der Kälteträger durch die Tätigkeit einer Kompressionskältemaschine erfährt, wobei Mittel vorgesehen sind, um den Wärmeträger aus dem Erdboden Wärme aufnehmen zu lassen.“

(Heating process, in which an electric motor drives a compressor which forwards a heat carrier medium in a process cycle, the principle of which is equivalent to the process cycle a refrigerant experiences in the operation of a compression cooling machine, and where facilities are foreseen to allow the heat carrier medium to take in heat from the ground.)

For house heating, heat pumps were first applied in the 1930s, for instance 1938 in Zurich, Switzerland, where the town hall was heated by a heat pump using river water as heat source, with entering water temperatures as low as 1.2 °C in winter (Egli, 1944) – not a geothermal system by definition, but ‘hydrothermal’ as to the EU Directive 2009/28/EU on renewable energies. The heat pump supplied up to 100 kW heat and achieved an annual COP of almost 2.2 (including river water pump) in 1938/39 (Zogg, 2008). More heat pumps were installed for other buildings in Zurich, due to the restriction on coal supply from abroad during the Second World War: for an indoor swimming pool in 1941, for supply to the district heating net in 1942, and for two buildings of the city administration in 1943/44. The heat pump in the town hall had a very long service life of 63 years, with the compressor replaced in 1964, before being retired in 2001. It was still operational for heritage purposes in 2008 (Zogg, 2008).

Directly after the war, only few heat pumps where installed in Europe. Zogg (2008) reports a groundwater heat pump (thus truly geothermal by definition) around 1950 in Thun, Switzerland. A capacity of 440 kW was achieved, and the low supply temperature to the heating system of 40 °C, unusual for that time, allowed for an excellent annual COP of 4.5.

Across the Atlantic, the years between 1945 and the early 1950s were a heyday of heat pump development. The first true ground-source heat pump was installed in Indianapolis in 1945 (Crandall, 1946), a direct-expansion system with horizontal pipes in the ground (figure 4). Development mushroomed, and also theoretical work for ground loop design methods started. The largest ground-source heat pump of that time was constructed 1948 as a groundwater heat pump for the Equitable Building, in Portland OR (ASME, 1980). More details on the period are given in Sanner (1992) and Sanner (2005). In Europe this development was mainly ignored in the difficult post-war time. The years of low fuel prices in the 1950s and 60s brought the development in America to a halt, prevented interest in heat pumps in Europe, and resulted in the retirement of many existing ground source heat pumps.

3.2 Development during the first and second oil price crisis, 1973-1985

In October 1973 the OPEC decided on a reduction of oil supply to the Western countries as retribution to the West supporting Israel in the Yom-Kippur-war. Oil prices soared, and alternatives were sought. It is much easier to replace oil in stationary applications like heating than in transport, and thus heat pumps became popular as heating option. It took some time after 1973 to develop the necessary equipment, and so the heat pumps were available quite in time for the second oil price crisis in 1980/81, caused by the revolution in Iran and the subsequent Iran-Iraq-war. Heat Pump sales and oil price development in Germany can be seen in figure 5.

The development had started already before the oil price shock. A first ground-source heat pump in Germany, using horizontal loops, became operational...
already in 1969 (Waterkotte, 1972). Groundwater wells as heat source for heat pumps followed soon after (Drafz, 1972). The number of publications on the different types shows clearly that BHE followed several years later (figure 6). This evaluation is based on my personal database, from which only European papers were considered here; some key publications are listed in table 2. The shape of the graph clearly reflects the heat pump boom around 1980, as seen in figure 5. It is also interesting to see from table 2 that environmental aspects were part of the spectrum of publications almost from the beginning (e.g. Müller, 1978; Halldin et al., 1979), as well as permitting issues (Dybowski, 1978)

Thus for the second oil price crises, heat pumps were available from factories large and small, mainly in Austria, France, Germany, Sweden, Switzerland, but also elsewhere. In Germany, most were coupled to horizontal loops or groundwater wells, some used air as heat source. Many heat pumps were installed in bivalent systems as addition to existing boilers, causing a plethora of problems in control, hydraulics, and temperature levels. The lack of experience, quality, knowledge of the installers, etc. ruined the reputation of heat pumps in Germany around 1980, and the sales numbers dropped before the oil price did (cf. figure 5). A similar development happened in France, the peak being slightly later, and in Austria, where the absolute numbers were lower and the decrease less drastic (figure 7). Smaller companies simply disappeared, and the large boiler manufacturers, having started also on heat pumps, closed their respective departments. Only a few companies with good knowledge and experience, and sufficient persistence, continued and became the core of the positive evolution after 1990.

<table>
<thead>
<tr>
<th>Table 2: Examples of early shallow geothermal publications in Europe, sorted into application fields (full bibliographical data in the references)</th>
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<tbody>
<tr>
<td>Early publications on GSHP</td>
</tr>
<tr>
<td>Ground-water</td>
</tr>
<tr>
<td>Horizontal</td>
</tr>
<tr>
<td>BHE</td>
</tr>
<tr>
<td>Undefined / other</td>
</tr>
<tr>
<td>Early publications on UTES</td>
</tr>
<tr>
<td>ATES</td>
</tr>
<tr>
<td>BTES</td>
</tr>
<tr>
<td>Undefined / other</td>
</tr>
<tr>
<td>Brun (1964), Delisle (1977), Andersson (1985)</td>
</tr>
<tr>
<td>Early publications on mathematic and calculation</td>
</tr>
<tr>
<td>Other early publications (e.g. environment, drilling)</td>
</tr>
</tbody>
</table>
Borehole heat exchangers had their start just during the boom. First experiments are reported from UK, Netherlands and Sweden. In Germany, first BHE were installed in the late 1970s, but not documented in publications. The first (West-)German document on regulation of GSHP (LAWA, 1980), edited by the joint working group on water of the relevant state authorities, dealt mainly with groundwater heat pumps, but included also a few pages on the “new technology” of BHE, showing a coaxial BHE as example (figure 8).

A German company brochure (WTA, 1981) shows photos of drilling and installation for a coaxial BHE, made from corrugated stainless steel for the outer pipe, and a rubber hose for the inner pipe. The first Swiss experiments with BHE also started around the same time, with the first modern BHE made of PE-pipes installed in 1980 (Rohner, 1991); Austria followed soon after.

3.3 Development after the “boom and crash”

As a result of the market disaster, more cautious approaches were used in Germany. In Sweden, where no sales crash of the type in France and Germany happened, proper R&D had accompanied the development, and now also other countries followed that example. Numerous conferences and workshops allowed for exchange of experience and new discoveries; table 3 gives an account of this activity. For the German speaking countries in particular the Symposia in Rauischholzhausen, the meeting centre of Giessen University, had a pivotal role in bringing research and practice together (figure 9).
Table 3: Conferences and workshops on shallow geothermal topics in Europe, or with high influence for Europe, in the last decades of the 20th century

<table>
<thead>
<tr>
<th>Year</th>
<th>Title</th>
<th>Venue</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>National events in Europe (Germany and Switzerland only)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td>La pompe à chaleur et son utilisation en Suisse</td>
<td>Lausanne, Switzerland</td>
<td>5.-6. May 1980</td>
</tr>
<tr>
<td>1995</td>
<td>5. Informationstagung der SVG, Wärmepumpen und Fernwärme</td>
<td>Riehen, Switzerland</td>
<td>15. April 1994</td>
</tr>
</tbody>
</table>
Table 3 continued

<table>
<thead>
<tr>
<th>Year</th>
<th>Title</th>
<th>Venue</th>
<th>Date</th>
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</table>

¹ Proceedings: Public Works Canada, Ottawa (1985)

On the R&D-side, more financial support was given for GSHP development in the countries where a heat pump market had started. In 1985 a private company, Helmut Hund GmbH, started on a project for a full-scale research station for BHE in cooperation with the University of Giessen and an installation company, Geotherm GmbH. The work was supported by the Federal ministry of research and technology (BMFT), and resulted in the Schwalbach GSHP research station shown in figure 10 (Sanner, 1986). In 1986 this project became part of Annex 8 of the IEA Heat Pump Programme.

Schwalbach GSHP research station was operated from 1985-89, the main results are summarised in Knoblich et al. (1993). The station consisted of a shack with heat pump and two fan-coil units towards the ambient air (figure 12), coupled to a borehole heat exchanger (BHE) of 50 m depth (Z in figure 11, 13 and 14). That BHE was surrounded by a number of boreholes with temperature sensor cables to the same depth, and two wells for hydrogeological investigation (figure 11).

Figure 10: Schwalbach GSHP-research station on a very cold day in January 1988

In Annex 8 ‘Advanced In-Ground Heat Exchange Technologies’ institutions from Canada (NRC Ottawa), Germany (Giessen Univ. / Hund), Switzerland (ETH / Polydynamics) and USA (Oak Ridge NL) worked together. Each had either a test site for BHE, or used measurements from commercial plants with additional sensing, like in Elgg ZH in Switzerland (Eugster, 1991).

Figure 11: Schwalbach GSHP-research station, final plan of the installation as of 1988

The pattern of the BHE and boreholes with sensors allowed for visualising the temperature distribution during heat extraction and recovery; an example is given in figure 13.
The system setup allowed for extracting heat from the ground, independent of any building heating requirement – a kind of ‘immobile TRT rig. This feature was used e.g. to investigate the heat transport in the ground by running tests with relative stable temperature in the BHE over various time periods, up to one month (figure 14). A Finite-Difference-model TRADIKON-3D for numerical simulation of the heat transport was developed at Giessen university and validated using the data from Schwalbach (Brehm, 1980); in particular the sophisticated freezing algorithms included in TRADIKON-3D could be checked against real data like those shown in figure 15. The IEA-cooperation strongly supported the work, with the possibility to compare the freezing effects with experiments at NRC Ottawa and the numerical simulation with the experiences from Oak Ridge NL in USA.

Similar Research installations were built and operated in the following years in Europe, including:
- HTL Burgdorf, Switzerland (around 1995)
- EDF Lab les Renardières, France (around 2000)
- BRGM Orléans, France (around 2000, still operational)

and others.

### 3.4 Design methods for BHE installations

In the beginning, the design of GSHP installations was done mainly by rules of thumb (usually 50 W/m in Germany and 55 W/m in Switzerland). Mathematical descriptions had already been developed during the first GSHP era in the USA around 1950, and furthermore in France, Germany and Sweden at the end of the 1970s (cf. table 2); however, these methods could not be used by most practitioners. A group of Physicists and Mathematicians at Lund University started in the 1980s to create accurate descriptions of the heat transport (Claesson et al, 1985), and later to simplify the calculations in the form of small computer programs. Together with the development of the PC, these methods could be easily applied and changed the design practice, at least for larger projects. For the single family house, the rules of thumb somehow survive until today, albeit guidelines in most countries meanwhile offer much better design options. In 1992 the mathematical excellence at Lund University and the practical experience at Giessen University were combined to create the first version of the program EED (Hellström and Sanner, 1994), which helped numerous BHE projects to a correct sizing.

The development of a method to determine the thermal conductivity of the underground, the TRT, also took place during the 1990s. The first mobile TRT in Europe was done in Sweden in 1995, followed by tests in the Netherlands, and in Germany in 1999. An excellent and very comprehensive account on the history of TRT, dealing in particular with the theoretical concepts and evaluation methods, is given in Spitler and Gehlin (2015).

### 3.5 Market and guidelines for GSHP

The 1990s were also the time when work on guidelines for shallow geothermal energy started, first with AWP T1 in Switzerland and then with VDI 4640 in Germany, the first draft of which was published in 1998. In the absence of signals from the oil price front, market development (figure 16) was mainly due...
to financial support programs (e.g. by electric utilities like RWE, or from the Federal ministry of economy since 1995). The experiences from R&D, design knowledge and eventually guidelines helped to secure that growth and to re-build costumer confidence lost in 1980. The downward trend could be stopped and reversed, starting a steady increase of GSHP sales in Germany well into the first years of the 21st century. Information campaigns helped also, and in Switzerland a working GSHP was even installed in a popular museum of natural history in St. Gallen (Sanner, 1994) (figure 17).

Figure 14: Original plotter graph from 1986 showing the temperature development in the BHE (“Sonde Z”) and the surrounding observation boreholes (cf. figure 11) during a long-term extraction test with target temperature -3 °C in October 1986 in Schwalbach GSHP research station

Figure 15: Original plotter graph from 1986 showing the temperature development at different depth in the BHE in Schwalbach GSHP research station in the beginning of November 1986, after a long-term extraction test with target temperature -3 °C in October 1986 (cf. figure 14)

3.6 A glimpse on UTES

Early industrial use of underground thermal energy storage was done since about 1960 in aquifers near Shanghai, China (Sun et al., 1991). First ideas to use ATES for storing solar energy were described by Brun (1964), and a Russian team proposed sandy gravel to store solar heat (Rabbinov et al., 1971). ATES for storage of waste heat from power plants was considered in the USA by Kazmann (1971) and Meyer and Todd (1973). In Europe, experiments and test plants for ATES started in the 1970s, and on BTES a few years later. The installations were intended for seasonal storage, and the heat sources investigated comprised both solar heat and waste heat. Storage of cold from ambient air in winter for cooling purposes was considered only towards the end of the 1980s.
With solar heat as source for UTES, R&D on the underground was also done within the solar energy sector, considering mainly two fields:

- Central Solar Heating Plants with Seasonal Storage (CSHPSS), referring to large central plants and local district heating

All types of storage were addressed, like water tanks, pits, phase change materials (PCM), and UTES. Solar heat storage was included in relevant cooperation programs of the IEA, in Implementing Agreements on solar energy as well as in that on energy storage. SAHPGS was in particular supported on the European level, with JRC Ispra involved in organising the workshops mentioned, and in carrying out own R&D.

The distribution of publications on UTES in the 1980s into the different storage options is shown in figure 18. ATEs and BTES are fairly well balanced. The main events in 1985 (Enerstock in Toronto, Canada) and 1988 (Jigastock in Versailles, France) brought about the majority of publications.


4. THE MARKET TODAY

The German GSHP market since the 1970s (figure 19) elucidates nicely some factors influencing the sales numbers, like events on the world markets, dedicated R&D, standards and incentives. The market in Germany developed quickly in the first years of the new Millennium and had another peak around 2006-2008. One reason was the insecurity in supply of natural gas from Russia, which had replaced fuel oil in the majority of houses in Germany. Alas, since that time the GSHP sales numbers are decreasing, while the share of air-source heat pumps is growing (figure 20). In 2015, for the first time less than 30% of new heat pumps in Germany used a geothermal source! A similar, but slower trend can be seen for Switzerland, still showing approximately 36% of ground source in the heat pump market (figure 20). Even more negative developments are reported from France. The situation throughout Europe is quite diverse, with some countries showing huge numbers of installations, and others with about the same population, but almost no GSHP (figure 21).
Figure 19: GSHP sales in Germany 1978-2015 and influencing events (sales numbers after data from BWP)

Figure 20: Heat pump sales 2010-2015 in Germany and Switzerland, and share of geothermal in total, after data from BWP and FWS

Figure 21: Total installed capacity in geothermal heat pumps in 2015 in Europe, after Antics et al. (2016)
In countries with substantial market development since many years (e.g. Sweden) already a replacement market has developed, as heat pumps achieve the end of their service life while the ground-coupling installations are far from worn out. If this ‘re-powering’ is done using new, more efficient heat pumps, it also requires thorough checks to make sure the old ground installation is capable to deliver the required heat (or inject the heat from cooling); this is often the case in combination with building refurbishment (e.g. better insulation), leading to reduced heat demand.

A specific challenge for the GSHP market of today is the low percentage of new construction. This requires addressing the existing building stock, a sector where geothermal installations are not easy to deploy. In Switzerland, a country with notoriously low new construction (“Switzerland is built up already”), an impressive share of >30 % of all drilling is done for existing buildings (figure 22), while the overall amount of BHE installation is rather stable since 2011 at approximately 2500 km of new BHE each year.

In the 21st century the development of GSHP continued steadily, and is well documented in material available online. Environmental aspects, work quality and permitting processes became more important, and in Switzerland, the country with the highest density of BHE world-wide, discussion even started about possible over-using the underground thermally.

5. WHAT MIGHT BE ACHIEVED IN FUTURE?
A basic fact not to be forgotten is that we are under the control of geology and climate – we cannot change the rock or soil outside the borehole, nor the overall temperature field. For BHE this means that optimisation by engineering is confined to the size of the borehole, and what we put inside. This is valid analogously for horizontal loops, energy piles etc. For BHE the parameter of ‘Borehole Thermal Resistance’ was introduced, combining all the effects from the rock outside the borehole into the fluid in the pipes (cf Eskilson, 1987). No borehole thermal resistance, i.e. \( r_b = 0 \text{ K/(W·m)} \), would mean instantaneous transfer of heat from the rock into the fluid and vice versa. Hence \( r_b \) can be used as a parameter to describe the quality of a BHE design, as influenced by geometry, pipe material, grouting, flow volumes, surfaces etc.

Because the ‘specific heat extraction rate’ of a BHE has no meaning without clearly defined boundary conditions, the ‘Hellström-Efficiency’ was introduced to allow comparison of BHE installations. It is defined as the ratio of heat extraction (under sustainable conditions) possible in a given, real installation to a heat extraction calculated under the assumption of \( r_b = 0 \text{ K/(W·m)} \) (Mands et al., 2008). An example of Hellström-Efficiency for a GSHP with 10 kW and rock with thermal conductivity \( \lambda = 2.5 \text{ W/(m·K)} \) is shown in figure 23, indicating the values achievable by some standard and some theoretical BHE designs.
While specific heat extraction rate and \( r_b \) may vary according to the rock type, BHE design, size of the project (number of BHE), load profiles, etc., the Hellström-Efficiency \( \eta_H \) always shows how close a given installation is to the theoretical optimum. Any claims for heat extraction rates that would result in \( \eta_H \) of 100\% or more can be dismissed as physically impossible. New designs and materials might help to move closer to the optimum in routine installations, but not beyond.

The key document identifying future R&D-goals for renewable heating and cooling, the ‘Common Roadmap’ of the RHC-Platform, lists the Key Performance Indicators towards 2020 as given in figure 24. The main areas are addressed: the efficiency of the heat pump and system, the efficiency of the ground-coupling components, and the cost for installation and operation. In the light of the constraints concerning higher efficiency, the issue of cost reduction seems to be the most important target.

### Figure 24: Key Performance Indicators as in the Common Roadmap of the RHC-ETIP from June 2014 (for download from the website indicated)

#### 6. SOME FINAL THOUGHTS

Looking back at about 40 years of well-documented development in Europe, and more than a century of ideas and proposals, the status achieved today is characterised by sound knowledge and good design (albeit some shortcomings in practical execution cannot be overlooked). Often a certain feeling of déjà-vu goes with seeing new developments praised, as two examples might show. One is the use of BHE for direct cooling, the other the screw-type BHE.

Using the ground directly for cooling was already studied in the 1930s, and a patent was granted on 20th November 1934 under No. 1,981,730 to E.F. Hawkins of Evansville IN by the US Patents Office. It concerned a kind of BHE some 10-30 feet long (3-10 m), using the cold temperatures in the underground to cool the drinking water supplied to houses (figure 25). No heat pump was used; just the natural temperatures should do the job. Already the first GSHP in USA in 1945 was equipped for heating and cooling, however, with the heat pump running as chiller in cooling mode. Direct space cooling using BHE was the topic of a Swiss patent filed by Karl Hess in 1986 and granted on 15.9.1989 as CH 671 622 A5. Without knowledge of this application, the German group working on the Schwalbach GSHP research station (cf. chapter 3.3) in 1987 successfully tried a similar approach in practice for the conference room of Helmut Hund GmbH in Wetzlar (figure 26). The brine in summertime was circulated by a small pump through the BHE and thus could provide cooling via fan-coil units, without heat pump operation. A year later, another installation using cooling ceiling instead of fan coils was tested. Meanwhile direct (‘passive’) cooling is widely used in moderate and not too humid climate, and was re-invented several times.

The other example pertains screw-type or ‘helicoidal’ heat exchangers, also (in most cases inaccurately) called ‘spiral’ or ‘coiled’ BHE (figure 27). Such design was already shown in the patent of Zoelly in 1913, and again in literature from the 1940, e.g. in Kemler (1947). A German patent applied for by U. Hansen in 1977, granted in 1979 under DE 27 00822 C3, showed a screw-type BHE, as did French patent application FR 79 11814 A1 of 1979.
Further attempts were applications DE 31 34177 A1 (by Siemens AG) and DE 31 49636 A1 by O. Schöppler, both in 1981. In 1998 Klemm et al. tried again with application DE 198 56 633 A1 (also as EP 1006331 A1 for Europe a year later). In 2006 a patent was granted to F. Graf under DE 10 2005 020887 B3 for a double-screw-type BHE. In Canada, O. Svec experimented with screw-type BHE in Ottawa clay (Svec and Palmer, 1989). A detailed Swiss report was prepared by Bassetti and Rohner (2005). Eventually design rules for this type of BHE were established in the new draft of VDI 4640-2 from 2015, and new tests with screws/spirals/coils are undertaken e.g. in Italy (Ferrari et al., 2016) and France (Philippe et al., 2016). Two EU-projects launched in 2015 also include work on ‘spiral co-axial vertical BHE’ (project GEOTeCH, http://www.geotech-project.eu/) and ‘helicoidal BHE’ (project Cheap-GSHP, http://cheap-gshp.eu/).

Figure 27: Examples of screw-type (‘spiral’, ‘coiled’) BHE, also called ‘energy baskets’, spanning a century
The story of GSHP is far from ending, and both the account of the past will have to be completed, and the new developments reported!

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