

## Shallow Geothermal Energy – the Past, the Current Status, and a Future Outlook

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### ABSTRACT

The history of “modern” shallow geothermal installations dates back somewhat more than a century, while the phenomenon of stable temperatures in the underground has been used by humans since ancient times. By the time of EGC 2025 it will be more than 110 years since the first theoretical concept of a ground-source heat pump (GSHP) and 80 years since the first known real-world GSHP installation in the USA. In Europe, more than 75 years ago groundwater heat pumps were installed in Switzerland; horizontal ground loops were used 55 years ago and borehole heat exchangers (BHE) followed five years later, with documented cases in Germany from 1969 and 1974, respectively.

In Europe, the development first gathered pace in Sweden, Switzerland, Germany and Austria in the wake of the oil price crises in 1973 and 1980/81, albeit with a severe dip in particular in Germany in the second part of the 1980s. Several measures and developments helped to revitalise the market and to accomplish the status we see today: Financial incentives from governments and utilities, methods for reliable site characterisation and system design, technical guidelines and standards, and proper processes for licensing and environmental regulation. The inclusion of cooling with GSHP offered economic advantages, and Underground Thermal Energy Storage (UTES) allows for further options of shallow geothermal applications.

In 2024, the market for ground-source heat pumps amounted to about 110'000 new units installed per year, and a total of more than 2.4 million systems existing throughout Europe. In some countries like Switzerland and the Netherlands, the high density of

installations already requires measures to secure sustainable exploitation of shallow geothermal heat. In other parts of Europe, however, the status of technology, installation skills and proper regulation still needs to be improved.

As shallow geothermal technologies offer great opportunities for energy efficiency and reduction of emissions, the future of technical development and market growth should be bright. However, the challenges to install and operate GHSP and UTES in an environmentally benign and sustainable way are growing with an increasing number of systems. Further efforts in research, development, training and regulation will be required to secure the desirable bright future for shallow geothermal energy use in Europe.

### 1. INTRODUCTION

The term “Shallow Geothermal Energy” covers a wide field with many applications, indeed the largest sector of geothermal energy use in Europe by far. However, the definition of the realm of shallow geothermal energy was disputed frequently. In fact, part of shallow geothermal often was not accepted as “geothermal”, but was said to be “solar energy stored in the ground”. A common understanding was reached in science that most of it actually is truly geothermal, as stated e.g. by Rybach et al (1999): “*Below 15 - 20 m depth everything is geothermal: the temperature field is governed by terrestrial heat flow and local ground thermal conductivity structure ( $\pm$  groundwater flow)*”. This made the so-called “neutral zone” the upper limit of true geothermal energy.

However, definitions today are even more inclusive. The idea was to create a clear limit that can be used also in administrative and legal circumstances. Hence the question was shifted from “where did the energy originally come from?” to “from where the energy is released for application?”. This is consistent with biomass, for instance, where the ultimate energy source

is solar energy powering photosynthesis, but the plants etc. are considered as energy source. A clear boundary for geothermal in this sense is the surface of the earth, and a first such definition was set in 1998 in the German guideline VDI 4640 (1998-2020): “*Geothermal energy (ground heat): Energy stored below the surface of the solid earth in the form of heat.*” As can be seen from that definition, even the earth surface required a clarification in the form of “solid earth”. This is a main difference to North America, where heat from surface water bodies (lakes, rivers) is also included, and the term “Geoexchange” is often used.

The German definition later formed the basis for the European definition in Directive 2009/28/EC<sup>1</sup> on renewable energies: “*‘geothermal energy’ means energy stored in the form of heat beneath the surface of solid earth*”. The version currently in force, Directive (EU) 2018/2001,<sup>2</sup> contains the same wording.

The lower limit of “shallow geothermal” also is not fixed definitely. In the beginnings, borehole heat exchangers seldom exceeded 100 m depth, and groundwater wells for heat pumps even less. A first line was drawn artificially in a support scheme for (deep) geothermal in Switzerland in the early 1980s, when the availability of support was limited to installations deeper than 400 m. This limit was used widely, e.g. in guideline VDI 4640 (1998-2020): “Guideline VDI 4640 deals with the thermal utilisation of the underground down to a depth of approximately 400 m”. Today, a lower limit of shallow geothermal is not fixed, however, values of 400 m or 500 m are given in different countries for administrative purposes.

When looking at the possible applications, most important in economic terms are geothermal heat pumps (also called ground-source heat pumps, GSHP, ground-coupled heat pumps etc.). Here a heat pump is used to raise the temperature of the heat in the ground to the level required for use in buildings. In Underground Thermal Energy Storage (UTES), the temperature in the underground (rock, soil, groundwater) is increased by injecting heat e.g. from industry or solar thermal installations, and this heat later is recovered by heat pumps or direct heat exchange, depending on temperature. Both GSHP and UTES can also be designed for cooling. There is an overlap between large GSHP installations with a central borehole- or well-field and UTES plants. In IEA ECES Annex 8, a suggestion for distinction was proposed: “To be considered a UTES system [...], a GSHP system should have a heat dissipation to (or extraction from) the surrounding ground of no more than 25% of the annual thermal energy turnover” (Sanner and Nordell 1998). A third application is direct use of shallow geothermal energy, e.g. for direct cooling or for pre-heating / pre-cooling of fresh ventilation air.

## 2. THE PAST

### 2.1 The Beginnings, in Europe and world-wide

Development of heat pump technology dates back to the 19<sup>th</sup> century, starting with theoretical work in France and the UK, and leading to a first application in Saline Ebensee, Austria, in 1857. A patent application for a ground-source heat pump was filed by H. Zoelly in Switzerland in 1912. More info on the early development is given in Sanner (2017).

The first well-known example of heat pumps for house heating in Europe used river water: From 1938 on, the town hall in Zurich, Switzerland, was heated by a heat pump using river water from the Limmat river as heat source (Egli, 1944). This heat pump had a very long service life of 63 years, with the compressor replaced in 1964, before being retired in 2001. The technology was soon replicated for other buildings of the Zurich city administration due to the shortage of coal in WW II. However, the use of river water does not constitute a geothermal installation following the European definition (cf. chapter 1). True geothermal heat pumps, using groundwater, followed after 1945 and were first reported in Switzerland (and Europe) from buildings for Therma AG, Schwanden GL in 1948 and Metallwerke Selve, Thun BE in 1949 (Zogg 2008).



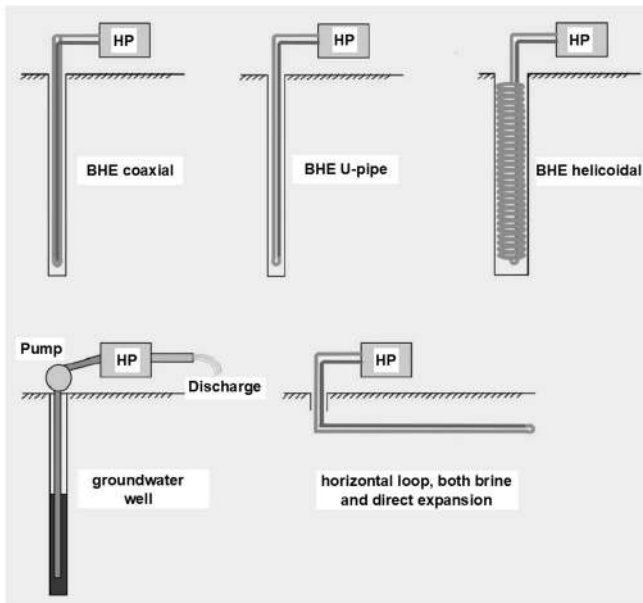
**Figure 1: Rathaus Zürich (town hall, centre, at and partly over the river Limmat), October 2025.**

The first documented application of a true ground source heat pump dates from 1945 in the United States. A direct-expansion system with horizontal pipes in the ground, in 3 circuits totalling 152 m, and a compressor with 2.2 kW was installed in a suburb of Indianapolis (Crandall 1946). The years between 1945 and the early 1950s were a heyday for heat pump development in North America. Kemler (1947) listed the ground-coupling methods already available at that time (Figure 2); almost all technologies used today are present, like vertical U-pipes, coaxial pipes and screw-type

<sup>1</sup> <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028>

<sup>2</sup> <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02018L2001-20240716>

(helicoidal) pipes, as well as horizontal pipes and groundwater wells. The editorial of the respective issue 9/1947 of “Heating and Ventilating” reads: “*At the present time there is considerable interest in securing all available information regarding the heat pump - how it functions, its economics, how it obtains its heat. In an article on page 69, Dr. E. N. Kemler describes various methods for obtaining heat from the earth for heat pump operation.*”



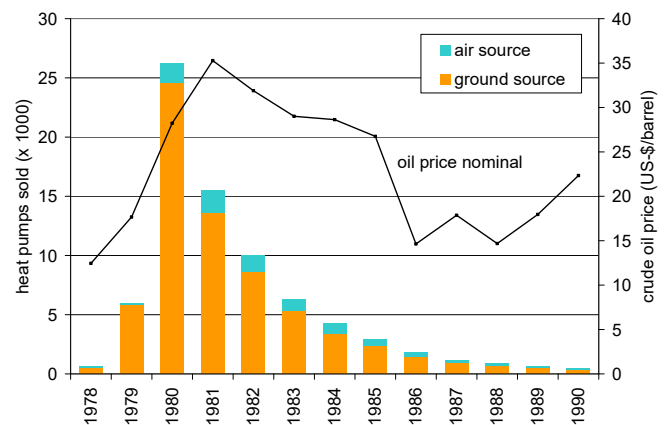
**Figure 2: Ground-coupling methods as shown by Kemler (1947); re-drawn and harmonised in Sanner (2017).**

The largest ground-source heat pump of that time was constructed 1948 as a groundwater heat pump for the Equitable Building (later named Commonwealth Building) in Portland OR, supplying 2.4 MW of heat (ASME 2008). Theoretical work for ground loop design methods started, and pipe sizing methods on a scientific basis were published. The calculation methods for evaluating temperature development in the ground system were mainly based on Kelvin’s line source theory (again, more info in Sanner 2017).

Years of low fuel prices in the 1950s and 1960s brought the development in America to a halt, prevented further interest in heat pumps in Europe, and resulted in the retirement of many existing ground source heat pumps. However, the oil price shock in 1973/74 changed that completely. Oil prices soared, and alternatives for replacing oil could be found much easier in stationary applications like heating than in transport. Heat pumps became interesting as an option for house heating.

It took some time after 1973 to develop the necessary components, but heat pumps were available quite in time for the second oil price crisis in 1980/81. Unfortunately, knowledge and experience of installers was almost non-existent, and the quality of heat pumps

rushed out of (small) factories in a sudden surge often was not satisfactory. That led to a collapse of the heat pump market in most countries even before the oil price decreased again; as an example, Figure 3 shows heat pump sales and oil price development in Germany in those years.



**Figure 3: Development of heat pump sales and crude oil price in Germany 1978-1990 (after data from destatis and BWP).**

Interestingly, most of the heat pumps in Germany of that time used ground as a heat source; air-source units are scarce (Figure 3), quite opposite to the situation today. The development of ground source systems in Europe had started already before the first oil price shock. Already in 1969, a ground-source heat pump using horizontal loops became operational in Germany (Waterkotte 1972). Groundwater wells as heat source for heat pumps were “re-discovered” soon after (Drafz 1972), while borehole heat exchangers (BHE) followed some years later. The earliest example of BHE reported from Germany was installed in 1974 south of Stuttgart, it comprised 5 BHE each 50-55 m deep and allegedly was operated for approx. 30 years (Moegle 2009).

In the later 1970s, several publications from Germany, Sweden, Austria and elsewhere presented practical applications of GSHP of different types, mainly based on groundwater wells or horizontal loops as heat source (Table 1). Systematic research and development for GSHP was supported early in Sweden, where the Bygghorsningsrådet (Swedish Council for Building Research) provided funds from 1975 on (Figure 4), with a total up to 1981 of almost 8.4 million SEK in grants and about 2 million SEK in loans (for real-life installations); at the exchange rates of 1980<sup>3</sup>, this would be 1.83 million € and 0.43 million €, respectively.

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 (Figure 5). The first Swiss experiments with BHE also started around the same time, with the first modern BHE made of PE-

<sup>3</sup> Values prior to 1999 extrapolated using SEK/DEM exchange rate.

pipes installed in 1980 (Rohner 1991); Austria followed soon after.

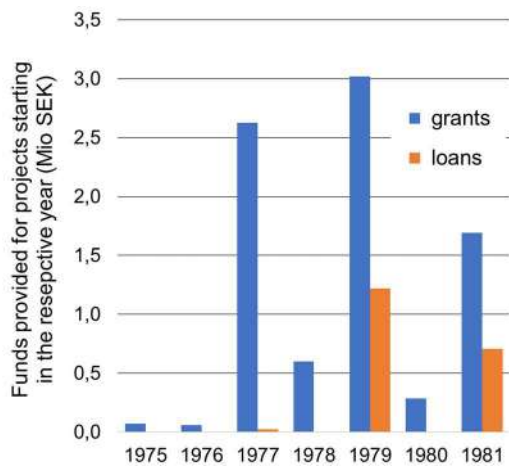


Figure 4: Funds provided by Bygghälsöversynsgruppen for R&D on GSHP, 1975-1981 (data from a list in Mogensen 1983b).

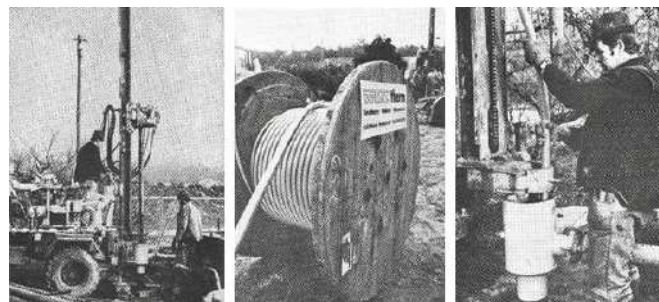


Figure 5: Drilling for BHE (left), BHE steel coil (centre) and BHE installation (right) around 1980, from photos in WTA (1981).

The first (West-)German document on regulation of ground source heat pumps (LAWA 1980), edited by the joint working group on water of the relevant state authorities, included a few pages on the “new technology” of BHE, showing a coaxial BHE as example. In the years after 1980, the number of BHE installations documented in publications increased in Austria, Germany, Sweden and Switzerland (Table 2).

Table 1: Ground Source Heat Pump installations in Europe as described in literature up to 1980 (from Sanner 1992, selected and with an addition).

Year	Source type	No. wells / BHE	Depth / length loop	Heating capacity	Country	City
1973	HL		1100 m	19 kW	DE	Gelsenkirchen
1974	GW	1+1	30+70 m	20 kW	DE	Münster
1974	BHE	5	50-55 m	n/a	DE	Schönaich
1975	HL		1000 m	18 kW	DE	Dhünn
1975	HL		400 m	11 kW	DK	Farum
1976	GW	1+sink	43 m	18 kW	DE	Olsberg
1976	GW	1+1	n/a	46 kW	DE	Südkirchen
1976	GW	1+1	28+27 m	23 kW	DE	Bösensell
1976	GW	1+1	18+18 m	42 kW	DE	Hannover
1976	HL		n/a	17 kW	DE	Südkirchen
1976	HL		400 m	12 kW	DE	Karlsruhe
1977	GW	2+2	20+20 m	326 kW	DE	Verl
1977	GW	1+1	n/a	31 kW	DE	Kall
1977	HL		9600 m	209 kW	DE	Kropp
1978	HL		n/a	9 kW	AT	Bludenz
1978	DX-h		600 m	8 kW	DE	(in NRW)
1979	DX-h		500 m	6 kW	DE	(in NRW)
1979	HL		n/a	10 kW	SE	Orsa
1980	GW	1+1	56+56 m	37 kW	DE	Stolberg
1980	HL		1600 m	15 kW	DE	Warthausen
1980	BHE	8	38 m	22 kW	DE	Schöffengrund
1980	BHE	30	10 m	35 kW	NL	Nijmegen
1980	HL		340 m	10 kW	SE	Surte

HL Horizontal Loops 10 installations  
 GW Groundwater Wells 8 installations  
 BHE Borehole Heat Exchangers 3 installations  
 DX-h Direct Expansion (horizontal) 2 installations

**Table 2: Ground Source Heat Pump installations with BHE described in literature 1981-1985 (from Sanner 1992, selected).**

Year	Source type	No. BHE	Depth	Heating capacity	Country	City
1981	BHE	4	50 m	24 kW	AT	Faak am See
1981	BHE	4	48 m	17 kW	DE	(in NRW)
1981	DX-v	16	10 m	9 kW	UK	Belfast
1982	BHE	8	27 m	10 kW	SE	Järfälla
1983	BHE	2	50 m	15 kW	CH	Rorschacherberg
1983	BHE	3	50 m	14 kW	CH	Frauenfeld
1983	DX-v	24	17 m	12 kW	DE	Elspe
1983	BHE	7	150 m	81 kW	SE	Täby
1985	BHE	3	40 m	17 kW	DE	Waldmohr

BHE Borehole Heat Exchangers

DX-v Direct Expansion (vertical)

Further experiments with BHE were reported from UK, Netherlands and Sweden, and first investigations into the temperature development in ground and groundwater under heat extraction were communicated (Balke 1979). Furthermore, work on methods for calculation and simulation of ground temperatures started (Neiss and Winter 1976, Blaude 1979, Runesson et al. 1979, Claesson and Johansson 1980).

The design of early ground source heat pump installations was done by estimation and guesses, through trial and error. With growing numbers and supported by the emerging scientific work on understanding the ground heat transport, rules of thumb could be established, e.g. in metres of horizontal loop length per kW of heat pump evaporator capacity. To help in correct design, an investigation into sizing methods for horizontal ground loops was finalised in Germany in 1980 (von Cube et al. 1980), and a year later a similar report was published in Sweden (Claesson and Dunand 1981). In Switzerland, Schwanner and Hopkirk (1982) collected info on BHE installations.

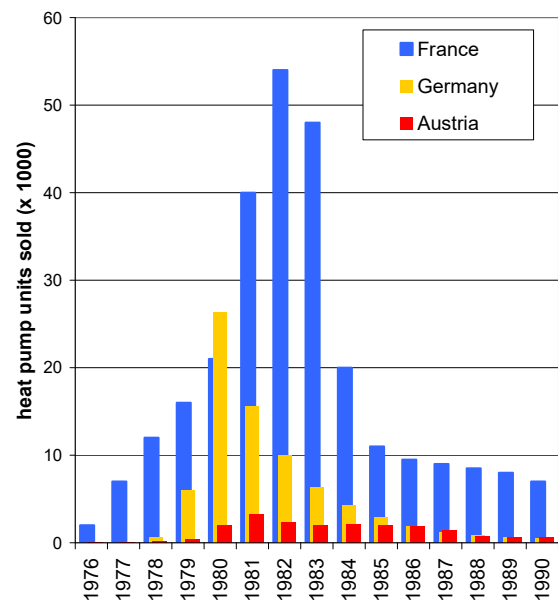
## 2.2 Major steps to create and sustain growth

The boom of geothermal heat pump sales around 1980 and the subsequent decline was not everywhere as strong as in Germany or France (Figure 6). In particular in Sweden, where electric heating was commonplace, and in Switzerland the heat pump sales and also the technical development continued. Major steps to regain a foothold in the 1980s and to instigate new growth in the 1990s were undertaken in several countries and consisted of systematic research and development, technical guidelines and standards, proper site investigation and adequate regulation.

### 2.2.1 Systematic research and development, simulation, design calculations

While other countries saw only minor and isolated research projects on ground-source systems prior to or during the boom in 1980, substantial research and development activities had accompanied the early development in Sweden. Few conferences on heat

pumps and underground energy use took place in that period in Europe, mainly in the north; after 1980, however, the number of conferences and workshops increased and allowed for exchange of experience and new discoveries (more info in the appendix).



**Figure 6: Development of heat pump sales in France, Germany and Austria 1976-1990; all heat pump types considered, heat pump water heaters excluded (after data from BWP and EHPA).**

Financial support was given for R&D on ground source heat pumps in the countries where a heat pump industry and market existed, and international cooperation was sought to maximise knowledge gains. Joint projects in the framework of the IEA proved very helpful, first in the IEA Heat Pump Implementing Agreement (established in 1978) and later also in the IEA Energy Storage Implementing Agreement (signed already in 1975). Under the name "IEA Technology Collaboration Programme" these schemes are still operating today.

One of the first activities in the IEA Heat Pump IA concerned ground source heat pumps: Annex 2

“Vertical Earth Heat Pump Systems”, led by Sweden with partners from Austria, Canada, Denmark, and the United States, was completed in 1983. In 1986 another collaboration followed; Annex 8 “Advanced In-Ground Heat Exchange Technologies” brought together institutions from Canada (NRC Ottawa), Germany (Giessen University / Helmut Hund GmbH), Switzerland (ETH / Polydynamics) and USA (Oak Ridge National Lab). Each had either a test site for BHE, or used measurements from commercial plants with additional sensing, like in Elgg ZH in Switzerland.

One of the test sites within Annex 8 was Schwalbach GSHP research station south of Wetzlar, Germany (Figure 7). A private company, Helmut Hund GmbH, had embarked on a project for a full-scale research station for BHE in 1985, 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).



Figure 7: GSHP research station in Schöffengrund-Schwalbach, Germany, January 1988.

Schwalbach GSHP research station was equipped with a BHE of 50 m depth, several surrounding boreholes with temperature sensors, and two wells for groundwater observation (Figure 8). A heat pump could extract heat from the BHE, and two blowers allowed to dissipate the resulting condenser heat into the ambient air. This setup was designed for operation over extended periods, independent of any heating requirements of a building (Sanner 1986). Figure 9 depicts an original plotter graph of the temperature recovery after 4 weeks of heat extraction, showing the delay in temperature increase around 0 °C while frozen groundwater was melting.

Another Annex 8 test site was a facility in Elgg ZH in Switzerland, where a coaxial multi-chamber BHE of 105 m depth was installed in the mid-1980s. Equipped with various sensors, it was monitored closely for five years, and periodically for a further ten years. In addition to the BHE, two further boreholes were drilled at distances of 0.5 m, 1.0 m und 2.0 m and equipped with temperature sensors (figure 10). The temperature curve in the vicinity of the BHE was measured, modelled and simulated for a further 24 years of operation. The system was then virtually shut down and

the recovery of the underground temperatures was simulated for a further 30 years (figure 11).

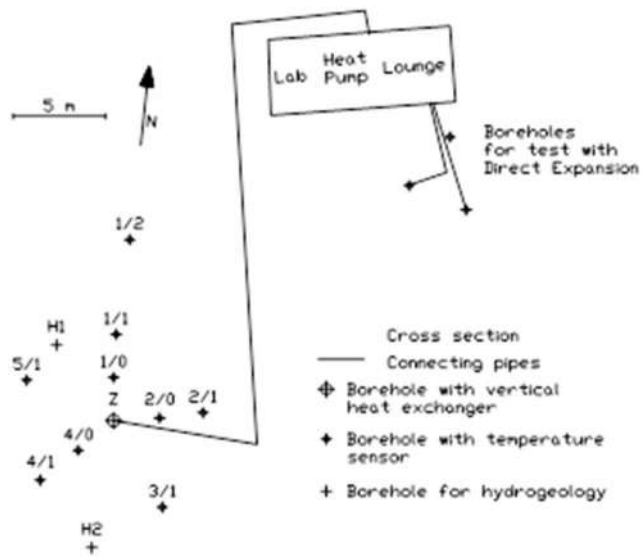


Figure 8: Final plan of the installation of Schwalbach GSHP research station as of 1988.

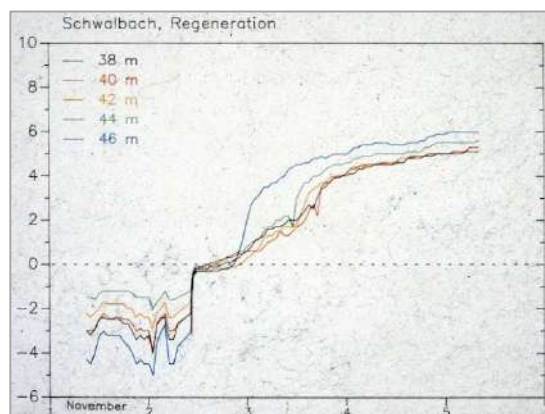


Figure 9: Plotter graph from 1986 of temperature recovery at the outer wall of the BHE in Schwalbach research station, after brine temperature inside the BHE had been kept at about -5 °C for 4 weeks.

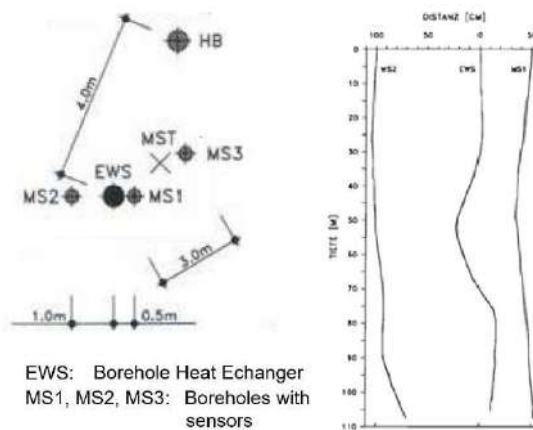
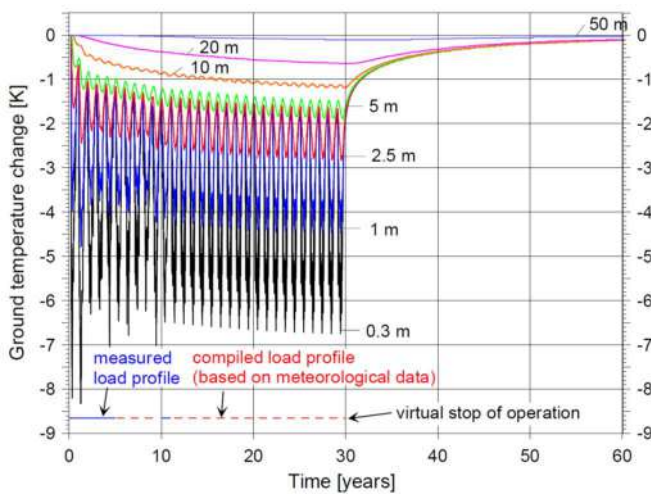


Figure 10: Situation in Elgg, Switzerland, with BHE and sensor boreholes (left); to the right the trajectory of boreholes MS2, EWS and MS1.

After the operating phase, the underground temperatures recover almost completely to their original values. This behaviour was demonstrated for an isolated system with a single BHE and purely seasonal heating operation (Figure 11).



**Figure 11: Simulated ground temperature changes of the BHE at Elgg relative to the undisturbed situation in December 1986 over 30 years of operation and 30 years of recovery (from Rybach and Eugster 2002).**

The measured sites within IEA Heat Pump IA Annex 8, allowed for understanding of heat transport in different ground situations, and to validate simulation models both developed within Annex 8 and from other groups (see below). Some more, similar research installations were built and operated in the following years in Europe, including:

- HTL Burgdorf, Switzerland (1990-1996)
  - EDF Lab les Renardières, France (around 1999, cf. Figure 12)
  - BRGM Orléans, France (after 2000)
- and others.

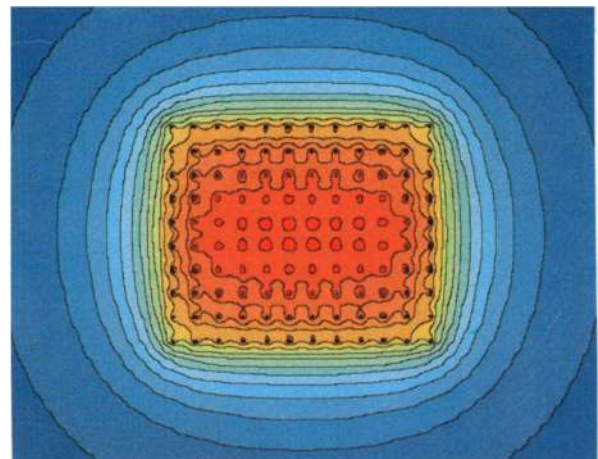


**Figure 12: BHE test site at EdF laboratory les Renardières near Moret-Loing-et-Orvanne, France, July 1999.**

Work on simulation of ground heat exchange was carried out at universities and research institutions in

several countries, like Germany (e.g. RWTH Aachen), Switzerland (ETH Zürich), Austria and France. The strongest legacy however has the “Ground Heat Group” at the department for Mathematical Physics of Lund University in Sweden. The main documents of the Lund group are: Claesson et al. (1985), Eskilson (1987) and Hellström (1991), together with a plethora of individual papers and studies.

The simulation models of the 1980s and 1990s could only be used at universities and research institutions with sufficient knowledge and computing capacity. They were used for research purposes and large projects, like the borehole thermal energy storage (BTES) installation in Luleå, Sweden, with 120 BHE each 65 m deep, built in 1982/83 (Nordell 1985). The temperature development inside and outside the BTES was simulated with the help of the Ground Heat Group in Lund, an example of a horizontal cross-section is shown in Figure 13. Outside of R&D-projects, however, in the 1980s just rules of thumb were in use for the practical design of GSHP plants (for BHE, usually 50 W/m in Germany and 55 W/m in Switzerland, without reference to ground thermal characteristics).



**Figure 13: Simulation result of large BTES for heat storage (from title page Claesson et al 1985).**

The results from test sites and practical experience indicated that ground thermal parameters could not be ignored, in particular for BHE design. Hence in the early 1990s “specific heat extraction rates” in W/m were suggested for different types of rock and soil, and found their way even into the early issues of guidelines like VDI 4640 (see below). Other factors like average annual operating hours, ambient temperatures, geothermal gradient, etc. usually were not considered, and for plants with more than very few BHE the mutual thermal interference of neighbouring BHE was ignored. The limited validity of the W/m-approach, in particular for non-residential or larger installations, was pointed out from the research side (e.g. Sanner 1999a).

To improve thermal design for systems using BHE, simpler calculation methods than the simulations mentioned above were required. PCs were widely available in the 1990s, and already used as design tool

for many applications. The Ground Heat Group in Lund had developed some simple PC programmes for calculation of the thermal response of one or more BHE to a given heat load (Claesson and Eskilson 1988), and these programmes were further refined and presented at an IEA workshop in Montreal, Canada (Claesson 1991). Through a cooperation of the universities in Lund, Sweden and Giessen, Germany, the development of a tool for practical design of BHE plants, based on the Lund PC programs and the practical knowledge from Giessen, was started in 1992.

A first presentation of this program under the name EED (Earth Energy Designer) followed at Calorstock 1994 in Helsinki, Finland (Hellström and Sanner 1994). A thorough test phase among a group of scientists, designers and installers experienced in BHE ended with a workshop in Rauischholzhausen near Giessen, Germany, in February 1996 (Figure 14), and the program was released as EED 1.0 later in the same year.



**Figure 14: Some of the experts at the workshop for  $\beta$ -Testers of EED 1.0 in Rauischholzhausen, Germany, 1.2.1996 (from left: Ladislaus Rybach, Joachim Poppei, Ernst Rohner).**

### 2.2.2 Guidelines and standards

As mentioned earlier, documents on GSHP were prepared already around 1980. A doctoral thesis at the Technical University of Graz, Austria, looked deeper in the functioning of BHEs (Katona 1986), and a compendium on ground source heat pumps and the design and installation practice around 1990 was published by the Informationszentrum Wärmepumpen (IZW, heat pump information centre) in Karlsruhe (Sanner 1992).

The first true guideline documents on heat pump use in connection with shallow geothermal energy in Europe considered the impact of this technology on ground and ground water. Because groundwater wells and horizontal loops were the technologies used in the late 1970s (cf. Table 1), concerns about thermal impact on groundwater and leakage of working fluids were addressed. In Germany, a joint working group of the state authorities (LAWA) agreed on some fundamentals for the harmonised handling of such regulation. In LAWA (1980) mainly groundwater heat pumps are covered, however, an early version of coaxial BHE is also shown. The first guideline in

Austria was issued in 1986 by the Austrian Association of Water Management, ÖWWV (today ÖWAV), considering ground water heat pumps (ÖWWV 1986).

In Switzerland, issuing guidelines started with a collection of design criteria in 1988 (SIA 1988) and a manual on BHE (Burkart et al. 1989). The first proper technical guideline, AWP Merkblatt T1, was published in 1992 by the Arbeitsgemeinschaft Wärmepumpen (AWP) in Zurich. It dealt with GSHP using BHE and was the first in Europe to:

- demand factory-produced BHE loops,
- specify a minimum distance of 5 m between BHE,
- and stipulate grouting of the borehole annulus by pumping grout down to the bottom of the borehole in a pipe and filling the annulus from bottom to top.

Subsequently AWP developed a full set of documents, covering all ground coupling methods (and in addition the use of surface water), with the latest and last version issued in 2007.

The technical guidelines from AWP were followed by environmental guidelines from the Swiss federal administration (BUWAL 1994). Further guidelines were published in Austria in 1983 (ÖWAV RB 207), in Switzerland in 1996 (SIA D 013) and in Sweden in 1997 (Normbrun 97, by SGU, the Swedish Geological Survey). In Germany, the guideline committee VDI 4640 was established in 1995, and the drafts of the first two parts (on generic and environmental issues and on GHSP design and installation, respectively) were published in 1998. The definite versions came into force in 2000 and 2001, followed by a 3<sup>rd</sup> part on UTES in 2001 and a 4<sup>th</sup> part on direct uses (pre-heating and pre-cooling of ventilation air, and direct cooling) in 2004. The number of countries with guidelines and standards for shallow geothermal installation grew steadily thereafter (Table 3), and in 2025 a total of 36 documents from 9 countries, and in addition on the European level (CEN), can be counted.

**Table 3: Number of guidelines and standards on shallow geothermal energy in Europe (only on national or supra-national level; numerous further documents exist).**

	1995 *	2008 *	2017 *	2025
Standards, guidelines	7	13	29	36
Countries	3	4	8+CEN	9+CEN
	AT, CH, DE	AT, CH, DE, SE	AT, CH, DE, FR, IT, SE, SP, UK and CEN	AT, CH, DE, FR, IT, NL, SE, SP, UK and CEN

\* data from Sanner (2018)

### 2.2.3 Site investigation methods, TRT

In the beginning, the ground thermal parameters were mostly ignored. For horizontal loops it soon became apparent that freezing temperatures in soils with silt and

clay lead to frost heaving and also subsidence, hence a sand bed was recommended if the soil was not sandy. Groundwater wells always required some sort of exploration for the water yield, usually in form of a pumping test. For BHE, the underground originally was an issue for drilling and installation, in order to choose the appropriate drilling method and installation technique. Outside of R&D the importance of thermal parameters became apparent only after the number of GSHP with BHE increased and design rules were considered around 1990.

Thermal parameters were estimated from the expected geology, which might be confirmed or not by the actual drilling. The draft of VDI 4640-1 from 1998 contained a respective list of data for selected, common rock types. The values were found in literature and databases; the most comprehensive collection of measured values was available at ETH Zürich. The VDI table was updated repeatedly and still is considered as reference today.

The idea to determine the thermal parameters under a given site *in situ* was published in Choudary (1976) and Mogensen (1983a). This “Thermal Response Test” (TRT) was used in existing installations, e.g. for the investigation of a borehole thermal energy storage plant (BTES) in Linköping (Hellström 1997).

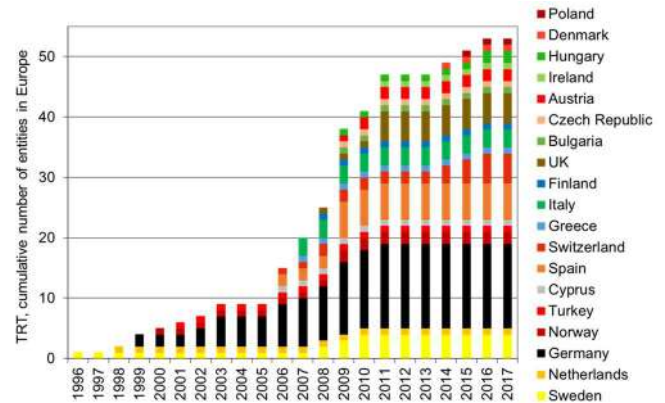
As for a mobile test, in 1981 a company brochure (WTA 1981) described an early version of an on-site test for the “thermal yield” of the BHE in the given geology – not a proper TRT, however, and not allowing the determination of thermal conductivity. Equipment for a true, mobile TRT was developed at Luleå Technical University in 1995, to measure the ground thermal properties for BHE between some 10 m to over 100 m depth (Eklöf and Gehlin 1996). Outside Europe, a similar development was going on independently since 1996 at Oklahoma State University in the USA (Austin 1998). The mobile TRT soon became standard practice in Sweden (Figure 15).



**Figure 15: Swedish test rig, coupled to a borehole heat exchanger in the late 1990s.**

A somewhat different test rig was developed and tested in the Netherlands (van Gelder et al. 1999), and the first two TRTs in Germany were performed in summer 1999 (Sanner et al. 1999). It took some years for mobile TRT to be understood as a very valuable tool to put BHE

sizing on a secure basis, and about ten years after the first mobile TRT in Sweden, the speed of proliferation throughout Europe increased. While Sanner et al. (2005) reported about a dozen TRT rigs in 7 countries, Sauer et al. (2018) counted for 2017 at least 19 European countries where TRT equipment existed, with a total of more than 50 entities (companies and institutions) performing such tests (Figure 16). Some example of TRT-devices from the 2010s is shown in Figure 17, and a world-wide review of TRT development can be found in Spitler and Gehlin (2015).



**Figure 16: Uptake of TRT in Europe - cumulative number of entities performing TRT (from Sauer et al. 2018).**



**Figure 17: A German TRT rig, an insulated box moved on a crawler, on a site in Wallis, Switzerland in 2011 (left) and a small, portable TRT-device by the same company (right, photos Kahl).**

#### 2.2.4 Regulation

Clear and efficient regulation is paramount for technologies that interact with the environment. Regulation has to make sure that installations cause no harm to nature and to other legitimate uses. No regulation at all will sooner or later result in problems and damages; on the other hand, too strict regulation and burdensome licensing procedures might kill an emerging technology.

While horizontal loops originally were not regulated at all, groundwater wells of the size required for GSHP almost everywhere required a permit. With groundwater being an important resource for drinking water, irrigation etc., concerns about contamination and competing uses had to be addressed. The respective

authorities in most countries regulated GSHP with groundwater wells from the beginning, and the necessary knowledge and tools existed already. Re-injection of the extracted groundwater after thermal use was and is mandatory in most but the smallest installations, and rules how to deal e.g. with injection of heated water from heat pumps in cooling mode had to be established.

The situation was different for BHE. As long as only few of them existed, there was little done by authorities outside protection zones e.g. for drinking water wells. The legal basis for regulation of boreholes that did not serve for extraction of commodities like groundwater was unclear; while for the drilling process environmental legislation might take effect, there was hardly anywhere a provision just for heat extraction or injection. With growing numbers of BHE installations, some regulation became necessary, but there was confusion and ambiguity in the early approach.

In Germany, the water household law (WHG) since 1957 had a clause defining such measures as water use that induce “permanent and non-negligible detrimental changes of the physical, chemical and biological nature” of the water. As temperature changes concern the physical properties of the water, operation of BHE was understood as groundwater use subject to a permit. Questions related to the terms permanent, non-negligible, detrimental were not raised by the authorities; this was deemed the case unless proven otherwise. Furthermore, the mining law (BBergG) from 1980 had a provision on geothermal heat that was applied to shallow geothermal once the wider definition of geothermal energy using the “surface of the solid earth” as limit was adopted. Now a BHE might need also a mining permit. While there were exceptions for smaller installations on a single lot, the requirements and licensing practice varied from state to state and sometimes from district to district. Some harmonisation at least on the state level was required, not only in Germany, but also in other federal countries like Austria and Switzerland. The situation of course was easier in more centralised countries like France or Sweden.

The individual cantons in Switzerland started issuing guidelines on environmental evaluation and permitting in the mid-1990s (first in canton Bern), and in 1996 a map of the canton Bern was published showing areas suitable or non-suitable for shallow geothermal installations. The first guideline for GSHP-permitting in Germany was issued by the state of Baden-Wuerttemberg in 1998, and in the early 2000s most other German states followed, as did most Austrian states (Figure 18). Many of the documents contained maps showing zones with favourable or unfavourable conditions as well as areas forbidden for shallow geothermal installation.

Once technical guidelines and standards existed from the late 1990s on, permitting authorities could refer to these for proper design and installation of shallow geothermal systems. This brought more clarity and

predictability for applicants, the industry – and the authorities themselves.



**Figure 18: Title pages of documents concerning licensing procedures for GSHP/BHE from 7 German states, 4 Swiss cantons and 3 Austrian states, around 2010 (upper row from left: Baden-Wuerttemberg, Berlin, North Rhine-Westphalia, Lower Saxony; upper centre row: Bavaria, Hesse, Rhineland-Palatinate; lower centre row: Neuchatel, Solothurn, Ticino, Zürich; lower row: Lower Austria, Styria, Tyrol).**

### 2.2.5 Technological developments

Most early GSHP were small in size and intended for heating single family houses. Only use of groundwater wells allowed for larger capacities. In UTES, a certain minimum size is required to limit thermal losses, but the first applications were primarily experiments in a smaller scale, in order to prove concepts for later upscaling.

In Sweden larger BHE plants were built already in the 1980, and in the 1990s the first larger installations with BHE followed in Germany and Switzerland. Capacities and size of BHE fields increased, and the limit of 10 km total BHE length for a single plant was surpassed in Sweden in 1985 and in Germany in 1999 (Table 4). In 2001 the new headquarters of the German air traffic control agency (Deutsche Flugsicherung, DFS) were inaugurated, equipped with a field of 154 BHE each 70 m deep (Figure 19), the first plant in Germany with sizing based on values from a TRT (done in 1999). Most larger plants were equipped for heating and cooling from the ground, some for direct cooling (see below). This improved both the economy (double use

of the BHE field) and the sustainability, supporting the thermal balance in the ground over the year.

**Table 4: Examples of large BHE plants in Europe up to the year 1999.**

Location	Country	BHE depth	BHE number	Year
Täby	SE	150 m	7	1983
Finspång	SE	110 m	24	1984
Finspång	SE	120 m	120	1985
Hagsätra	SE	80 m	25	1985
Kristinehamn	SE	110 m	17	1988
Upplands Väsby	SE	110 m	64	1989
Düsseldorf	DE	35 m	77	1990
Järfälla	SE	110 m	20	1990
Kristinehamn	SE	110 m	15	1992
Kochel am See	DE	98 m	21	1993
Frankfurt-Höchst	DE	50 m	32	1993
Wollerau	CH	135 m	32	1994
Älvsby Storforsen	SE	160 m	32	1995
Mettmann	DE	100 m	12	1996
Tranås	SE	170 m	8	1996
Golm (Potsdam)	DE	100 m	160	1999

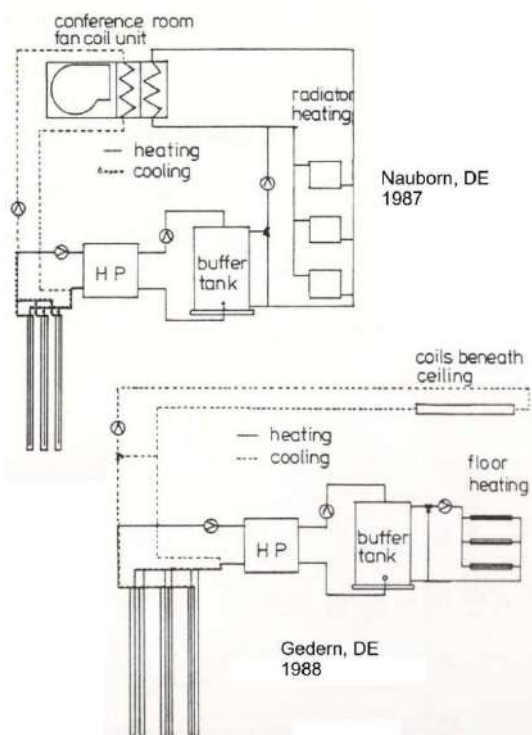


**Figure 19: Headquarters of DFS in Langen, Germany, seen from the site of the BHE field; the manhole in the foreground gives access to one of the large manifolds (photo from October 2007).**

Heat pumps can easily act as cooling devices, either by reversing the internal circuit via a 4-way-valve, or by changing the position of evaporator and condenser in a hydraulic circuit outside the heat pump. The reversible heat pump option was used intensely in GSHP in North America since about 1945. As air conditioning was deemed not necessary for residential houses in Northern and Western Europe, heat pumps here were not designed for cooling. Heat pump operation is not required in direct cooling, by simply using cold groundwater from wells through heat exchangers. This cooling option has a very low energy input, as no compressor needs to be driven by electricity.

While groundwater has a rather stable temperature when extracted, the fluid inside BHE pipes and the surrounding ground warms up when heat is injected. Nevertheless, direct cooling with BHE is possible, as long as the loads are low enough and sufficient heat is taken out off the ground for heating in wintertime. Karl Hess filed a patent in Switzerland for the concept of direct cooling in GSHP plants with BHE in November 1986; it was granted as CH 671 622 A5 in September 1989.

Independently, two actual GSHP plants using direct cooling were built in Germany in the same time. The first one in 1987 used fan-coil units supplied from the BHE circuit to cool a meeting room in an office building. With just  $0.12 \text{ kW}_{el}$  for a small pump and fans,  $2.5 \text{ kW}_{th}$  of cooling could be provided (Sanner 1990). In 1988, another plant was built in a single-family house, this time using pipes at the ceiling for cooling of a few rooms (Figure 20). The extremely low operation cost of direct cooling lead to more installations in residential and commercial buildings in the years after, sometimes in a combination of basic cooling directly from BHE and cooling using a heat pump in periods with higher loads. The double use of GSHP for heating and cooling, and in particular for direct cooling, greatly improved the economics of GSHP.



**Figure 20: Schematics of the first GSHP plants with direct cooling from BHE in Germany, from Sanner (1990).**

The final aspect of technological progress for shallow geothermal installations is the improvements of individual components. Heat pumps as such have been developed further over the years, resulting in much better efficiency in terms of COP ratings under fixed conditions. Furthermore, the biggest obstacle for the heat pump industry (and all the refrigeration sector)

could be overcome, the replacement of working media depleting the ozone layer. The chlorofluorocarbons (CFC, like R12) were first replaced by hydrochlorofluorocarbons (HCFC, e.g. R22) with a lower ozone depletion potential, all of which then were phased out from 1989 on by the “Montreal Protocol” of 1987. The replacements are either hydrofluorocarbons (HFC, e.g. R32), containing no chlorine, or natural working fluids like propane (R290), ammonia (R717) or CO<sub>2</sub> (R744).

More specific for GSHP are developments in ground-coupling technologies. First attempts considered the BHE cost, by replacing coaxial BHE with metal tubes (cf. Figure 5) or large-diameter plastic pipes with U-tube-BHE made from much cheaper standard PE pipes. Improvements in installation and grouting practices enhanced work quality and saved time, and advances in drilling technology allowed for shorter drilling time and/or cost reduction. The Nordic practice of hammer drilling and insertion of a single-U-pipe in an open, groundwater-filled borehole also has been refined and still is the quickest and cheapest way for construction of BHE, if geology permits.

In order to achieve optimum efficiency for a given heat pump, the temperature difference between evaporator (heat source) and condenser (heat delivery) must be as low as possible. For BHE, the target was a low borehole thermal resistance, i.e. a small temperature loss from the ground to the fluid inside the pipes. Main developments included thermally enhanced materials for grouting, pipes supporting turbulent flow inside, plastic pipes more resistant to scratching or cracking and to higher temperatures, etc. Also optimised hydraulics in piping and manifolds and more efficient circulation pumps allowed to reduce the energy demand of GSHP. On the building side, low temperature heating systems like floor heating or low-temperature radiators supported higher efficiency.

### 2.3 Setbacks

Many setbacks were experienced throughout the development of shallow geothermal applications. Economics were poor in many countries, and political developments exerted negative influence on GSHP markets – but politics could also have positive impacts when done properly.

#### 2.3.1 Problematic economics and poor reliability

From the beginning, shallow geothermal installations were more expensive to build than conventional heating and cooling options. Hence the economy of GSHP etc. relied heavily on possible savings during operation. The price increase of fuel oil and natural gas during the 1<sup>st</sup> and 2<sup>nd</sup> oil price crises and price extrapolations supported the development of GSHP in Europe in the 1970s, however, the extrapolated values did not materialise in the 1980s with fossil fuel prices decreasing (cf. Figure 3). The situation was better in Sweden, where lower electricity prices and established electric heating provided a more favourable environment.

The shallow geothermal market hence was, and is today, heavily dependent on good economic and political circumstances. International developments can have impacts as well as domestic measures like financial incentives or regulatory clarity. A good example for the different forces influencing the GSHP market is the development in Germany (Figure 21). Price increases as during the oil price crisis 1980 and the natural gas price crisis 2006-2009, when Russia disputed prices with Belarus and Ukraine and the pipelines to Western Europe were impacted, resulted in growing sales number. In both cases the boom was short-lived, in 2008/09 as a result of the world financial crisis. On the domestic side, financial incentives induced a more stable growth, while technical guidelines prevented a market breakdown as happened after 1980.

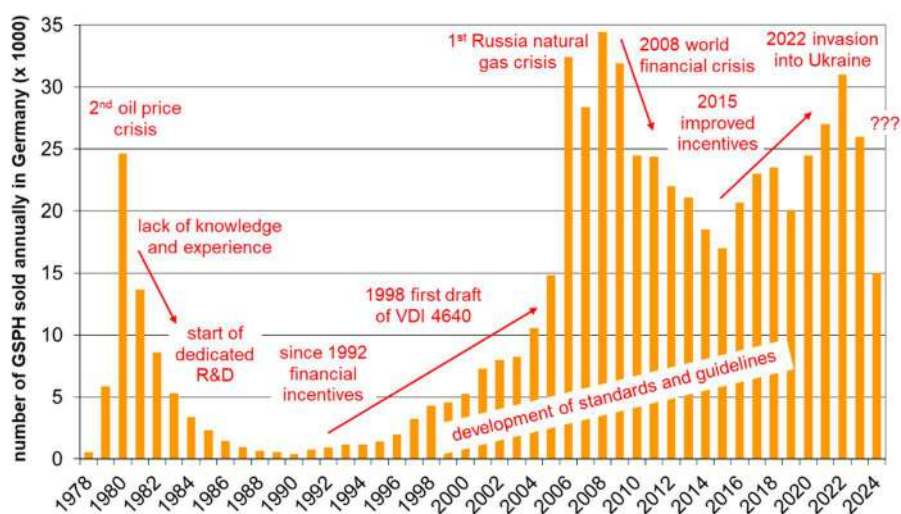


Figure 21: GSHP market in Germany and factors influencing sales (after data from BWP).

In Germany in the early 1990s, some installers aimed at an easy target to reduce cost, BHE length, as no design rules existed at that time. Shorter BHE for the same heat

pump size result in higher specific heat extraction, pushing the respective GSHP system beyond sustainable operation. BHE design resulting in heat

extraction rates of 80-100 W/m, or even more, was not unusual. As most problems with cooling down of the underground arise only after a few years of operation, costumers were not aware of this practice of under-sizing BHE length to cut cost. In order to provide some guidance and to prevent GSHP-technology from losing its reputation due to numerous heat pumps running poorly or even stopped for good, in 1994 the first steps towards a guideline were made, resulting in VDI 4640 (see above).

Another issue that jeopardised the reputation of shallow geothermal installations was poor workmanship. In times when the market was growing, inexperienced drillers and installers reached for a share of the business. The outcome of the work of these “cowboy drillers”, who appeared e.g. in Austria, Germany and Switzerland, often were shallow geothermal plants with leakages, blocked pipes, hydraulically inadequate manifolds etc., or even environmental damage. The response here were schemes to ensure quality, providing education, training and certification. Such certification often became mandatory for receiving drilling permits.

### 2.3.2 Mishaps and damages

While horizontal loops pose little risk in most cases, specific hazards exist when drilling for groundwater wells or BHE. Cases of excavators cutting through buried cables or pipes are known, however, this problem is not uncommon in the construction industry. Even pipes connecting BHE to the building have been damaged that way. For drilling, the most frequent problems stem from insufficient stability of the borehole or from groundwater, e.g. when artesian aquifers are encountered (Figure 22).

The most famous disaster caused by shallow geothermal drilling happened in the ancient city of Staufen in the Southwest of Germany. In 2007, drilling for BHE intersected a layer of anhydrite in Triassic sediments. Groundwater could enter into that layer and started transforming the anhydrite into gypsum, which has a higher volume and thus caused swelling of the sediment. The ground in the city centre started to rise (Figure 23) and cracks formed in the walls of historic buildings. Later the holes for the BHE were cemented and groundwater wells constructed, to pump water from the affected zone as a remediation. The heaving could be slowed and almost stopped that way, but pumping is still required today. In 2015, the accrued cost for remediation already totalled 9.5 million €. The total cost for saving and restoring buildings etc. can hardly be calculated.

The Staufen disaster had a severe impact on the public opinion towards geothermal energy use, not restricted to shallow geothermal. The slump in GSHP sales in Germany from 2008 on (cf. Figure 21) can mainly be

attributed to the world financial crisis, but a share of the Staufen damages can be assumed. Similar cases of swelling anhydrite caused by BHE drilling are known e.g. from Böblingen, Germany, and Lochwiller in Alsace, France. The events triggered restrictions in permitting and stricter rules for drilling and grouting.

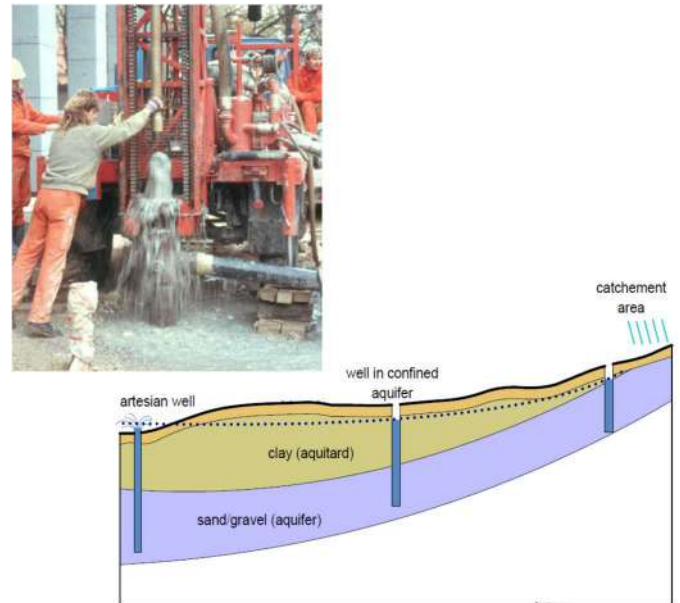


Figure 22: Schematic of confined and artesian aquifers and photo of BHE drilling hitting artesian water in Frankfurt, Germany, 1993.

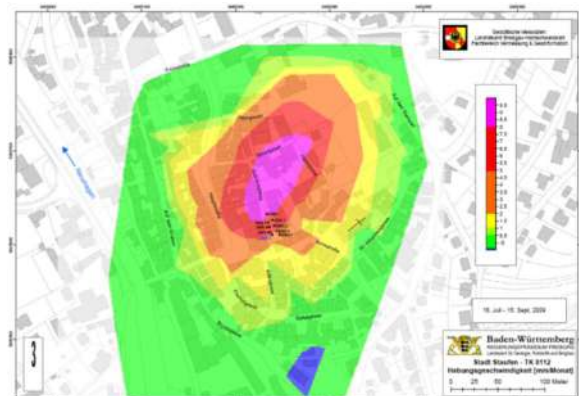


Figure 23: Map showing the ground heaving velocity in Staufen, Germany, in 2009; the purple area did rise by about 9 mm/month (map from Geological Survey of Baden-Württemberg).

### 3. THE CURRENT STATUS

Shallow geothermal energy uses are firmly positioned in the market today, with more than 2.4 million installed units all over Europe. GSHP are a routine option for heating and cooling, and the number of dedicated<sup>4</sup> UTES installations is growing. Design, technology, regulation and education are well advanced in many countries.

<sup>4</sup> Large GSHP plants often have a storage component (or artificial recharge), but are not intended as UTES.

### 3.1 Market penetration

From a few hundred GSHP prior to 1980, mostly with groundwater wells or horizontal loops as heat source, the number increased to about 110'000 existing units in 1998 (Sanner 1999b). The threshold of 1 million units was surpassed about 2010, and 2 million in 2019 (Figure 24). In 2024, about 2.43 million GSHP provide an installed heating capacity of 36.5 GW<sub>th</sub>. There is virtually no country in Europe without GSHP installations. In terms of absolute installed heating capacity, Sweden, Germany and Switzerland, countries with an early market development, are leading (Figure 25). Finland, the Netherlands and Austria had high growth rates in the last years and might catch up, while in France, a country with a strong GSHP market in the 2000s, air-source heat pumps have reduced the GSHP sales to a trickle. The highest market penetration (GSHP units in relation to the country population) has been achieved in Sweden (Figure 26).

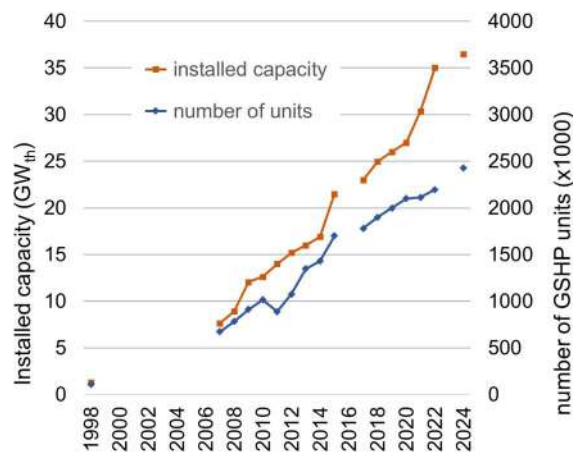


Figure 24: Growth of GSHP in Europe, data consolidated from Sanner (1999b), WGCs/EGCs, EREC Market Reports and EurObserv'ER.

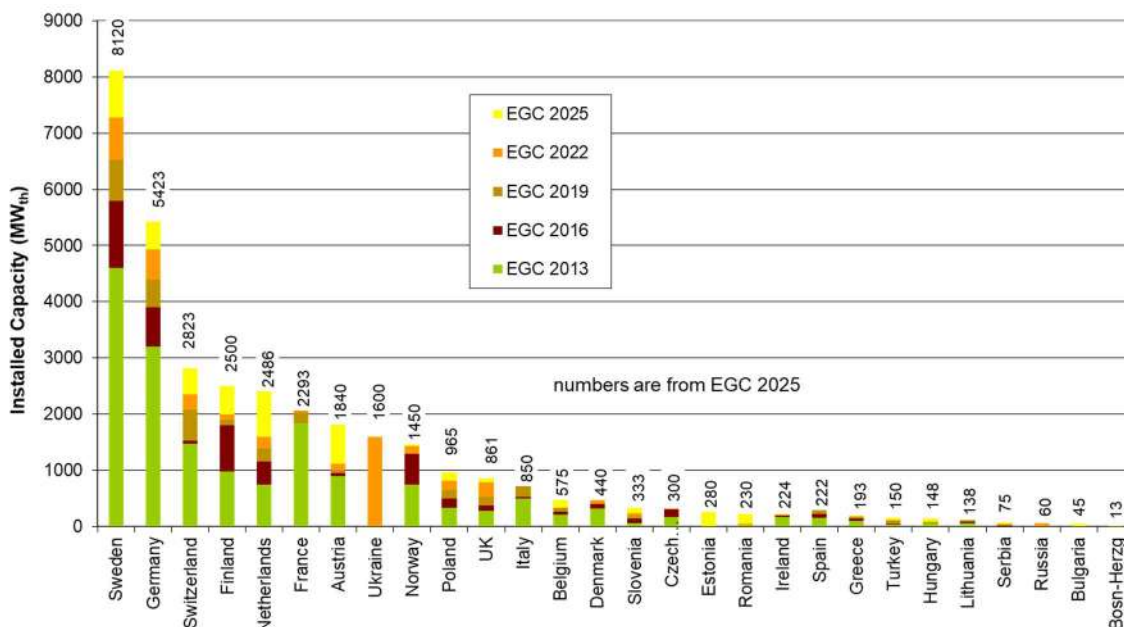


Figure 25: Installed capacity in geothermal heat pumps in Europe after EGC country update reports; only countries reporting at least 10 MW<sub>th</sub> are shown.

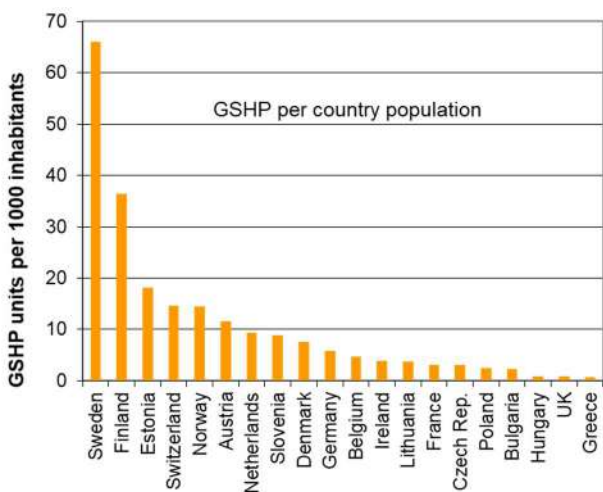


Figure 26: GSHP units per inhabitants in 2023/24, top 20 countries only.

GSHP, however, are a fraction only of the total heat pump market in Europe, and their share is decreasing. According to EurObserv'ER (2024), in 2023 about 5.6 million aérothermal heat pumps (air-water and air-air) had been sold, but just about 0.14 million geothermal heat pumps – a share of only 2.5 % of the total sales. For Germany, the decreasing trend is shown in Figure 27; the share of GSHP in annual heat pump sales was over 70 % in 2005 and dropped to about 8 % in 2024. As for the existing heat pump stock in the EU, EurObserv'ER (2024) lists for 2023 a total of more than 52 million aérothermal units, compared to about 2 million geothermal heat pumps (i.e. GSHP make up just 3.7 % of all heat pumps installed).

Looking at the geothermal sector, the picture is much brighter. Shallow geothermal systems constitute 64 % of the total installed capacity in geothermal energy in Europe, the biggest share by far (Figure 26).

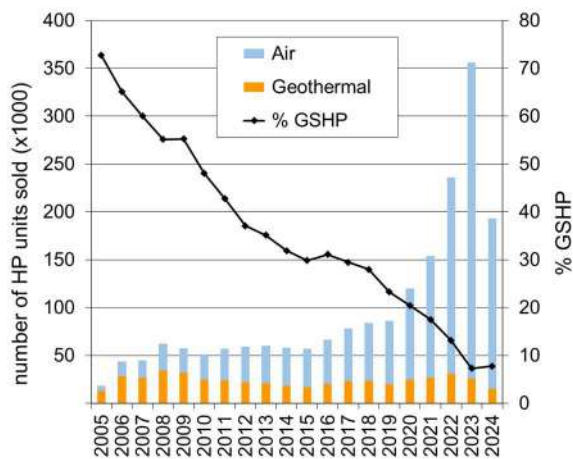


Figure 27: Share of GSHP in total heat pump sales in Germany (after data from BWP)<sup>5</sup>.

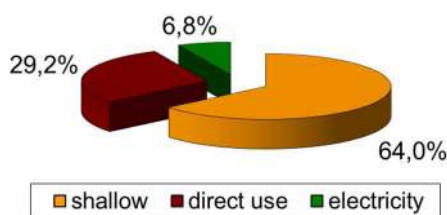


Figure 28: Shares of the geothermal sectors in installed capacity in Europe in 2024 (after data from EGC 2025).

The sector of refurbishment of existing GSHP plants is growing, with an increasing number of plants several decades old. The ground coupling system usually has a longer service life, with regeneration of groundwater wells and replacements of well pump- or circulation pumps the only measures required. The shortest lifetime has the heat pump, and in particular the compressor inside. In some countries like Sweden, a strong replacement market for heat pumps 20 and more years old in ground-source systems has developed already. As the new heat pumps generally have a higher efficiency (and thus higher extraction), the system designs need to be checked and adapted where necessary, either by limiting heat pump size or by enlarging the ground system (e.g. by adding new BHE to increase total BHE length).

After more than 50 years of development, shallow geothermal energy is firmly established on the heating and cooling market throughout Europe. In some countries GSHP are even widely known and popular today (e.g. Sweden and Switzerland); in Sweden single-family houses with GSHP are valued at higher prices in the real estate market!

<sup>5</sup> For “Air”, only air-to-water heat pumps are considered here.

### 3.2. Regulation and skills

Regulations for shallow geothermal installations are well developed in countries with mature markets, but in some other countries they still do not exist at all. Regulation is important to ensure that construction and operation of shallow geothermal plants do not harm the environment above and below ground, buildings, other geothermal users, etc.

Geological surveys have done a lot to provide the necessary information, much of their work supported by the EU e.g. within R&D projects. As a result, geological data, groundwater protection zones, hazards and more in many countries can be accessed online using GIS viewers. Simplified application and licensing procedures (preferably online) exist already in some places; an example from Sweden is given in Figure 29. EU legislation has put pressure on member states to simplify and speed up permits for renewable energy installations.



Figure 29: Example from the online application in Stockholm, a lot in a suburb without BHE and locations of existing BHE, from:

<https://boende.stockholm/energi-oppvarmning/varmepump/ansok-om-tillstand-for-varmepump/>

In some countries with high market penetration regulations and measures to avoid cooling down or heating up the ground are in force. Examples are Switzerland and the Netherlands, and densely populated city areas in Sweden. Hence as an additional tool in support of the electronic application in Stockholm, the program “Temperatursänkning 3000” allows to calculate the thermal effect of up to 16 neighbouring BHE<sup>6</sup>. The necessity of such thermal regulation of the underground is obvious when looking at the density of shallow geothermal installations in some areas; Figures 30 and 31 show examples from Switzerland and Sweden, respectively.

<sup>6</sup> The program is available for download at:

<https://boende.stockholm/siteassets/mitt-boende/energi-och-oppvarmning/varmepumpar/temperatursankning-3000.exe>

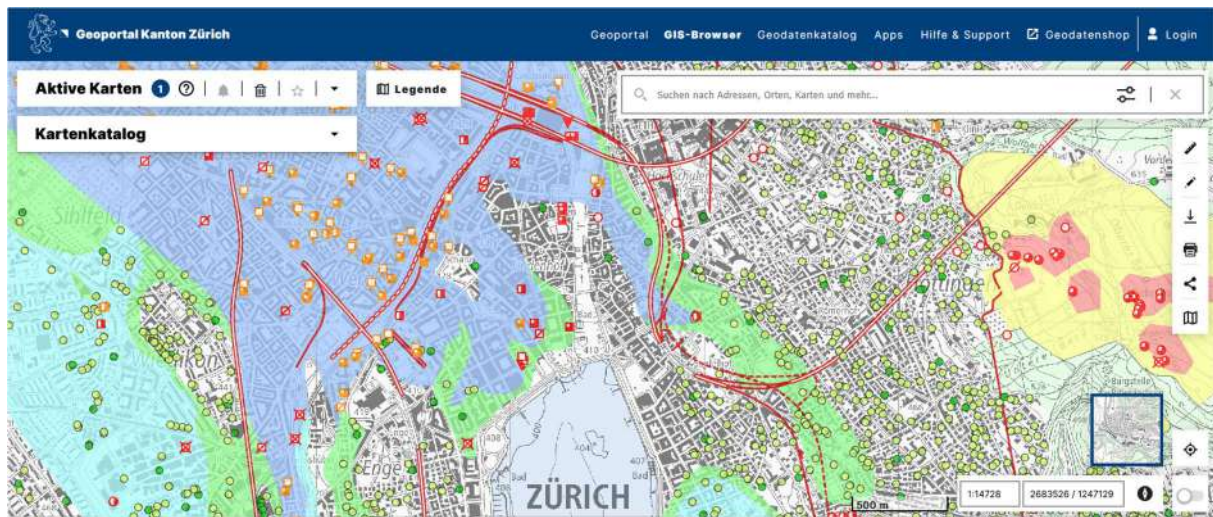


Figure 30: Screenshot from GIS portal for underground use in Kanton Zürich; green circles show BHE, orange markers show thermal use of groundwater (<https://www.zh.ch/de/planen-bauen/geoinformation.html>).

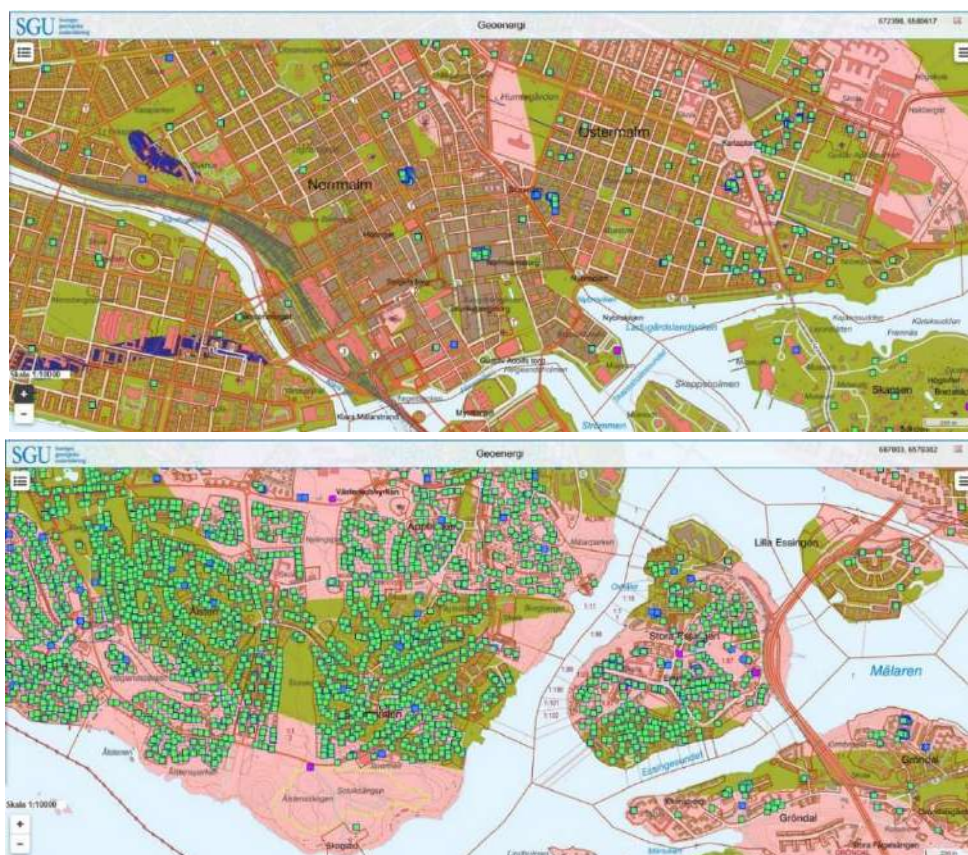


Figure 31: Screenshots from GIS of the Swedish Geological Survey (SGU) showing BHE (squares) in the centre of Stockholm (upper) and a Stockholm suburb (lower); in the centre, at least 3 clusters of BHE for large buildings can be seen (<https://apps.sgu.se/kartvisare/kartvisare-geoenergi.html>).

The success of GSHP with a substantial number of new installations each year requires an adequate workforce with appropriate skills. On the side of the heat pump and the building energy systems, training and education is done by the HVAC industry traditionally in well-established structures. For the ground-coupling side, however, the situation still needs to be improved. In 2008-2011, project Geotrained was funded by the IEE programme of the EU to develop curricula and course

material for shallow geothermal designers and installers, and to organise test courses.

In February 2014 an association under the name Geotrained was founded in Brussels to put the activities on a permanent basis (more info in the Appendix). Today several countries have good structures for (further) education and training for designers, drillers, installers, regulators etc. Schemes are either operated

by professional associations as individual courses or by educational institutions as part of their portfolio. For the ground side, Geotrained can act as an umbrella and clearing house for harmonised standards, and to help in countries where no established structures yet exist.

### 3.3. Technological state-of-the-art

The ground coupling methods applied today comprise:

- Horizontal loops, which are an option for residential houses with gardens, but have also been applied as heat source/sink for low-temperature district heating. Other forms of very shallow ground heat exchangers in form of “energy baskets” (large-diameter spirals) or pipe loops/meanders installed vertically in trenches are also used.
- Groundwater wells, from very shallow wells in alluvial gravel layers to deep wells extending into the deep geothermal realm. To ensure reasonable pumping power, the static groundwater level in the wells should not be too deep and the permeability of the aquifer sufficient for a modest drawdown.
- Borehole heat exchangers (BHE), mostly as double-U or single-U, but also in coaxial or helicoidal form. BHE for direct expansion, heat pipes and standing column wells did not succeed on the market. The depth ranges from a few metres to >400 m, exceeding the realm of shallow geothermal. There is still the different practice of dealing with the borehole annulus - grouting in most of Europe and open, groundwater-filled holes in Northern Europe in hard rock.
- “Geostuctures”, i.e. foundation piles, retaining walls, tunnel walls etc. that contain heat exchanger pipes. This type of ground heat exchangers always requires proper sizing and operation to make sure the static purpose of the structures is not jeopardised by the thermal use.

On the application side, the variety in type and size is ever increasing. Numerous installations still just provide the heat source for a single heat pump, mainly in the residential sector. Often some cooling is part of these plants, either by direct (passive) cooling or by using the heat pump. For larger systems, many applications and system concepts have been realised, that can be grouped into few basic schemes:

- Large central installations provide heating and cooling for a building or a group of buildings. BHE or groundwater wells are coupled to an energy central with heat pump(s) etc. Often only a part of the thermal load is covered, with additional heating and cooling devices for peak demand. Most of the large plants in the early 2000s were of that type (an example is the DFS building, cf. Figure 17), and the concept is frequently used today.
- Since the early 2010s, more de-centralised installations were built, under the names anergy networks, cold district heating, thermonets

(“thermonets” in Denmark), 5<sup>th</sup> generation district heating. These systems basically consist of a pipeline or pipe circuit to which ground heat exchangers, heat pumps, other heat sources and sinks are connected. The simplest form is a BHE field, large horizontal ground heat exchanger or a set of groundwater wells that provide low-temperature heat to a number of heat pump evaporators through a pipeline. More elaborate schemes combine e.g. heat from cooling of data centres, residual heat from industry, cooling towers, heat pumps in residential buildings, heating of swimming pools, etc., and one or more large BHE fields to act as thermal buffers. A typical example is the anergy network of the ETH Campus Hönggerberg in Zürich (cf. Table 5). Installations of this type currently are known from Austria, Belgium, Denmark, Germany, Italy, Switzerland and the UK.

- Heat and/or cold storage (UTES) has a long tradition, originally for cooling purposes or for seasonal storage of solar heat. The latter could not attain economic viability yet, but UTES for heating and cooling and for storage of excess and residual heat from power plants, waste incineration, industrial processes etc. can be successful. Ground-coupling is either by groundwater wells for storage in aquifers (ATES) or by BHE for storage in soil or rock (BTES). Famous ATES examples include the Reichstag building of the German Parliament in Berlin and at least three airports: Oslo Gardermoen, Norway, Stockholm Arlanda, Sweden, and Schiphol, Netherlands (under construction). For BTES, the industrial heat storage at Xylem in Emmaboda, Sweden, and the storage of excess heat from district heating in summer in Backadalen, Gothenburg, Sweden can be mentioned.

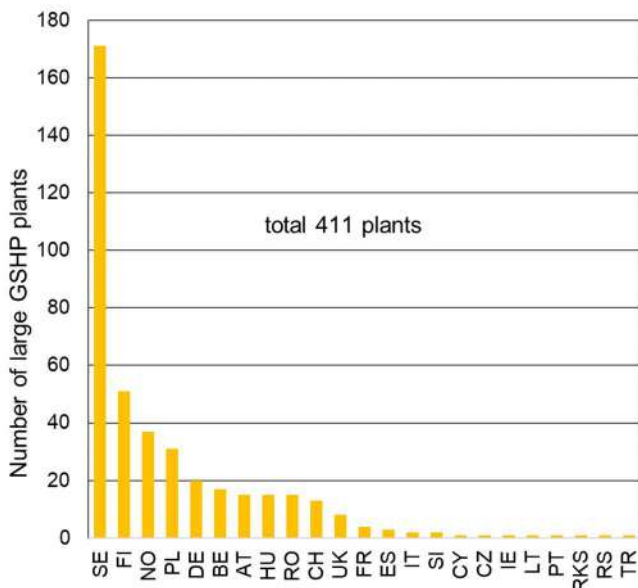
The size of large installations can be quite impressive, with up to almost 96 km of total BHE length in the biggest plant in Europe for a logistics centre in Finland. Table 5 lists the top ones with >40 km of total BHE length.

Currently more than 400 installations with a total BHE length of 10 km or more could be identified, with the two earliest examples from about 2000 in Germany, followed by one in Sweden in 2002 and another in Norway in 2003. Figure 32 shows the distribution of such plants per country (the database might not be exhaustive). It is apparent that the majority of installations are in the Nordic countries, with almost 42 % in Sweden alone. Over the years, the drilling depth for BHE in these plants increased and reached a maximum of 400 m in 2020, while the average remained at 200-250 m in recent years (Figure 33).

**Table 5: The largest BHE plants in Europe (>40 km total BHE length).**

Location	Country	Name	Total BHE length	BHE number	BHE length	Year
Sipoo	FI	SOK Logistics Centre	95.7 km	319	300 m	2012-16
Zürich	CH	FGZ Friesenberg *	91.8 km	367	250 m	2015-19
Zürich	CH	ETH Hönggerberg	87.0 km	435	200 m	2014-16
Köping	SE	Volvo Powertrain	58.2 km	210	277 m	2014-17
Rotkreuz	CH	Suurstoffi 2	54.0 km	193	280 m	2015
Espoo	FI	Lippulaiva shopping centre	51.0 km	170	300 m	2020
Wallisellen	CH	Richti-Areal	49.5 km	220	225 m	2012
Karlstad	SE	Campus Universitetet	48.4 km	205	236 m	2013
Jordbro	SE	Kalvsvik	48.1 km	136	354 m	2018
Vienna	AT	Eurogate II	48.0 km	320	150 m	2021
Szczecin	PL	Zdunowo hospital	46.0 km	241	191 m	2013
Lørenskog	NO	Nye Ahus hospital	45.6 km	228	200 m	2008
Zürich	CH	Neues Wohnquartier Freilager	45.1 km	205	220 m	2013-14
Barcelona	ES	Hospital Sant Pau	42.7 km	356	120 m	2013
Stockholm	SE	Kattrumpstullen	42.7 km	122	350 m	2019
Göteborg	SE	Backadalen	41.9 km	146	287 m	2018

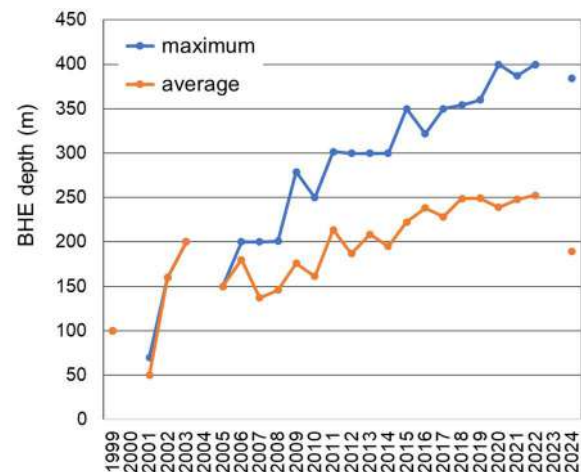
\* currently under extension to a total of 121.8 km by the end of 2026 (total 487 BHE each 250 deep)



**Figure 32: Number of large GSHP plants with BHE of ≥10 km total length (from own collection and data in EGEC Market Report 2024).**

Further development is required for the installation of shallow geothermal systems in existing buildings. Here a number of barriers are encountered:

- Incompatibility on the building side,
- constraints to placement and installation of the components for ground coupling,
- regulatory barriers, etc.



**Figure 33: Average and maximum drilling depth for large GSHP plants with BHE of ≥10 km total length (from own collection and data in EGEC Market Report 2024).**

A comprehensive report on these barriers was prepared as Deliverable 1.1<sup>7</sup> in project GEO4CIVHIC, funded under EU Horizon 2020. This and other projects looked into technologies to overcome such problems, provide drilling for minimalistic spaces and installation concepts for existing building infrastructure. The problems are even larger when older, historic buildings are concerned, as provisions for preservation have to be heeded. Some examples in project GEO4CIVHIC demonstrated the feasibility of GSHP in historic structures (Figure 34).

<sup>7</sup> For download at: <https://geo4civhic.eu/wp-content/uploads/2019/01/GEO4CIVHIC-D1.1.pdf>



**Figure 34: Two examples of historic buildings equipped with GSHP using BHE; above Porta degli Angeli, Ferrara, Italy, below Msida Bastion Historic Garden, Valletta, Malta (from GEO4CIVHIC project).**

Better technical solutions for GSHP in existing building stock could enlarge the shallow geothermal market substantially. At this moment, air-source heat pumps have less restrictions in that environment, beside possible noise problems. Blocks of multi-storey residential houses have already been successfully refurbished using energy networks and cold district heating might be an option for existing suburban neighbourhoods. To add shallow geothermal supply to individual houses, solutions depend on the available space, and require clean, unobtrusive drilling and installation work.

#### 4. A FUTURE OUTLOOK

All we can do when assessing future evolution is extrapolating current developments, factoring in possible constraints and new opportunities.

##### 4.1. Are there limits to implementation?

A major constraint might be the maximum heat extraction from the ground in a certain area and the density of installations. Shallow geothermal does not rely on the geothermal heat flux alone, as the heat balance on the surface, infiltration from precipitation, groundwater flow and lateral heat transfer all contribute. A simple estimate can clarify the amount of heat that might be extracted constantly within a country and which will be replaced by the geothermal heat flux from below. The geothermal heat flux varies throughout Europe, and thus an approximate mean value is set for calculation of the values in Table 6 (for

all of Europe, some 800-900 GW<sub>th</sub> can be estimated). When comparing these values to the installed capacities in Figure 25, it is clear only in Switzerland the installed capacity yet reaches a sizable percentage of the heat from geothermal heat flux.

**Table 6: Estimates of heat from geothermal heat flux in some countries.**

Country	Area	Spec. geoth. heat flux	Total geoth. heat flux
Germany	357'588 km <sup>2</sup>	80 mW/m <sup>2</sup>	28.6 GW <sub>th</sub>
Sweden	447'435 km <sup>2</sup>	60 mW/m <sup>2</sup>	26.9 GW <sub>th</sub>
Switzerland	41'291 km <sup>2</sup>	90 mW/m <sup>2</sup>	3.7 GW <sub>th</sub>

In small countries with substantial shallow geothermal use like Switzerland and the Netherlands, regulation is in place to limit the heat extraction from the ground. Similar measures are necessary in densely populated metropolitan areas with many GSHP, like Stockholm in Sweden (cf. Figure 31). A long-term thermal balance can be achieved by recharging the ground from cooling in summer, excess heat from industry or data centres, solar heat etc. In Southern Europe, and elsewhere also in certain buildings like shopping malls, more heat from cooling is injected into the ground than is extracted for heating. A warming up of the underground would be the consequence, and heat need to be extracted (e.g. through air heat exchangers in wintertime or in colder nights). By regulating shallow geothermal systems to implement measures towards a balanced heat extraction / injection, sustainable growth has virtually no limits, and in heating-dominated climates the geothermal heat flux has to cover only the remaining heat gap.

Looking at the current use of shallow geothermal energy can give an idea of what is possible. The first to calculate the spatial density of GSHP in a country was Ladsy Rybach, e.g. in Rybach and Hopkirk (1995), when the number of GSHP with BHE in Switzerland was about 6000 (i.e. 0.145 units/km<sup>2</sup>). Today there are 3.09 GSHP installations per km<sup>2</sup> in Switzerland. Figure 35 shows that the Netherlands and Switzerland are leading in GSHP density in Europe, and large countries like France, Poland and Italy are far behind; Spain did not even make it into the top 20. If the leading countries can manage a density of 3 units/km<sup>2</sup> and more, the potential for the rest of Europe can be deemed vast.

##### 4.2. Which applications promise the highest potential?

Shallow geothermal energy offers significant advantages, starting with superior overall energy efficiency. Heat pump efficiency is higher than with air as heat source/sink. Shallow geothermal allows for very efficient cooling and thermal energy storage. Installations can range from very small units (near-zero-energy houses) to very large networks supplying heating and cooling to whole neighbourhoods or commercial / industrial areas. Promising applications include:

- Standardised installations for single-family houses.
- Heating of medium to large residential or non-residential buildings whenever a cooling demand exists in those buildings.
- Flexible and scalable heat and cold supply from shallow geothermal sources via cold district heating / 5<sup>th</sup> generation district heating / thermonets.
- Connection of heat sources, building heating and cooling, process cooling demands, etc. through energy networks, buffered by shallow geothermal ground installations.
- The full potential of shallow geothermal can only be exploited if the market in the existing building stock can be better addressed than today.
- Furthermore, an upcoming opportunity for UTES can be seen in the storage (in form of heat) of excess energy from renewable power production.

The role of AI in design and operation of shallow geothermal installations will increase substantially in future and might bring better efficiency and lower cost.

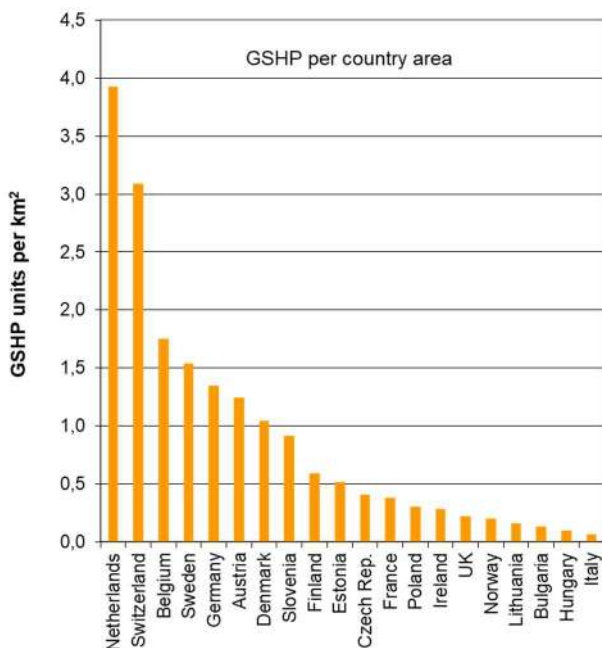


Figure 33: GSHP units per country area in 2023/24, top 20 countries only.

## 5. CONCLUSIONS

Ground Source Heat Pumps (GSHP) can be traced back for >75 years in Europe, and they are firmly established on the market today. Underground Thermal Energy Storage (UTES) in Europe dates back to the 1970s. The market development has seen booms and slumps as well as periods of steady increase. The overall growth

was supported on the technical side by systematic research and development leading to site investigation methods, (mainly TRT), design calculations, guidelines and standards, and technological development. On the non-technical side, financial incentives, adequate regulation, information and education did help. There were setbacks due to problematic economics and poor reliability, and mishaps and damages occurred.

A particular advantage, and disadvantage of GSHP is the fact that most of the system is under the earth surface and thus invisible. For public awareness campaigns, photos of houses, heat pumps and the (dirty) drilling work had to be used. A remarkable step for promotion of shallow geothermal energy was done in the 1990s in Switzerland, where, with support from Ernst Rohner sen. of Grundtag AG, a working GSHP has been installed as an exhibit in the basement of the popular museum of natural history in St. Gallen. A BHE 150 m deep was drilled outside, and the connections, heat pump and buffer storage lined clearly along a wall (Figure 36). A fan-coil unit did blow warm air into the room to prove the system works, and a geological profile explained invisible BHE. Alas, this exhibit was lost when the museum was rebuilt in 2014 – maybe somewhere else a new one might be shown?



Figure 34: GSHP in the museum of natural history in St. Gallen, Switzerland (photo from 1993); connection to BHE to the left, and the fan-coil unit in the far right.

Today shallow geothermal energy is firmly established on the market for heating and cooling. The sector grew to a total of about 36.5 GW<sub>th</sub> installed heating capacity in more than 2.4 million installations in virtually every country in Europe (data for 2024). A vast potential and promising technical solutions forecast a bright future for shallow geothermal energy in Europe.

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## Appendix

### Conferences and Workshops in the 1970s-90s

Exchange among scientists, engineers, installers and economists played a big part in making shallow geothermal energy a reliable energy source and in getting it into the marketplace. Conferences and workshops were the places enabling that exchange, from the late 1970s on. Among the largest events were the IEA Heat Pump Conferences, starting in Graz, Austria, in 1984 and then happening every three years in venues around the world, with the 15<sup>th</sup> issue scheduled for 2026 in Vienna.

Also important were the Energy Storage Conferences, also organised within the frame of IEA and including underground thermal energy storage and ground-coupling issues. The first of this so-called “Stock-Conferences” took place in 1981 in Seattle, USA, followed by Stockholm, Sweden, in 1983 and Toronto, Canada, in 1985, changing to a 3-year-schedule from then on. The 16<sup>th</sup> and most recent edition, ENERSTOCK 2024, was held in Lyon, France.

Geothermal conferences in that period just considered deep geothermal energy and in particular electric power generation, and the first conference combining geothermal, storage and ground-coupling technologies was the 4<sup>th</sup> Stock-Conference, JIGASTOCK in Versailles, France, in 1988. However, at the first large, world-wide geothermal conference held in Europe, WGC 1995 in Florence, Italy, shallow geothermal topics already had a firm presence.

Beside the huge, international events many smaller, regional meetings were organised; some examples include the Nordic Symposium of Earth Heat Pump Systems in Gothenburg, Sweden, already in 1979, a workshop “*La pompe à chaleur et son utilisation en Suisse*” held 1980 in Lausanne, Switzerland, a seminar on “*Ytjordvärme - markkolektorer*” (ground heat - horizontal loops) organised 1982 in Stockholm, Sweden, and the workshops on Solar Assisted Heat Pumps with Ground Coupled Storage in 1982 in Ispra, Italy, in 1985 in Vienna, Austria, and 1989 in Gothenburg, Sweden. For the German speaking countries, the Symposia held in 1991, 1994 (Figure A1) and 1997 in Rauschholzhäuser, the meeting centre of Giessen University, had a pivotal role in bringing research and practice together.

### Regulation, education and training

The Intelligent Energy Europe (IEE) programme of the EU supported some activities that helped with non-technical issues. In 2006-2009 Project GTR-H worked on Geothermal Regulations for Heat, analysed existing regulation and identified deficiencies, and came up with a framework for geothermal regulations (Figure A2). This was intended as guidance to scrutinise and improve existing regulation and to draft new regulation

where nothing existed yet. Another project funded by IEE from 2012-2015, ReGeocities, looked more specifically into the shallow geothermal sector and dealt with Regulations of Geothermal HP systems at local and regional level in Europe, with specific interest on GSHP in cities. Beside regulations, it also covered some technology and reviewed suitable shallow geothermal



technologies, integration of shallow geothermal systems in cities and buildings, and ways towards smart thermal grids. Public acceptance and the environmental impact of geothermal energy was also investigated. The final report is still available from the website of one of the project partners:



<http://ubeg.de/Regeocities/ReGeoCities%20Final%20Publizable%20Report.pdf>.

For training and education, project Geotrainet was funded by IEE in 2008-2011 to develop curricula and course material for shallow geothermal designers and installers (Figure A3), and to organise test courses: June 2009 in Uppsala, Sweden (Figure A4); September 2009 in Dublin, Ireland; March 2010 in Peine, Germany; March 2010 in Orléans, France; April 2010 in Newcastle, UK; July 2010 in Valencia, Spain; October 2010, Snagov, Romania; and January 2011 in Brussels, Belgium. The curricula and manuals are still available for download under:



<https://geotrainet.eu/resources/>.

In February 2014 an association under the name Geotrainet was founded in Brussels to put the activities on a permanent basis. Already in November 2013 an international course had been held in Lund, Sweden, followed by update courses in conjunction with EGC 2016 in Strasbourg, France, and EGC 2019 in Den Haag, the Netherlands. National courses were offered in countries without existing geothermal training activities, so in Portugal in October 2014 (Lisbon) and in Spain in November 2014 (Madrid) and in November 2016 (Barcelona). Part of the didactic material has been translated by member organisations into national languages for use in their own courses. With a growing sector of shallow geothermal education and training, the need to provide courses directly by Geotrainet is decreasing. The organisation has more to act as an umbrella and clearing house for harmonised standards, and to help in countries where no established structures yet exist.



Website Geotrainet: <https://geotrainet.eu/>



Figure A1: Participants of the 2<sup>nd</sup> Symposium on Ground Source Heat Pumps in Rauscholzhausen, Germany, 18.10.1994.

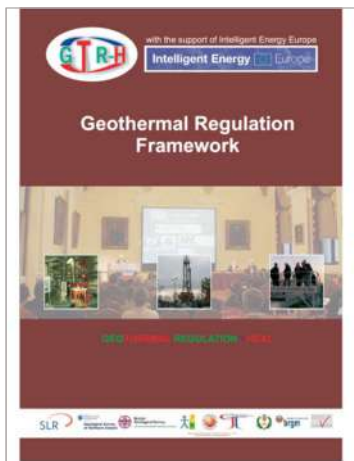


Figure A2: Geothermal Regulation Framework from the GTR-H project, 2009.

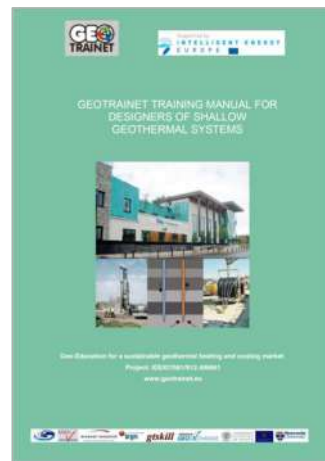


Figure A3: Manuals for designers (left) and drillers (right) from the Geotrainet project, 2011.

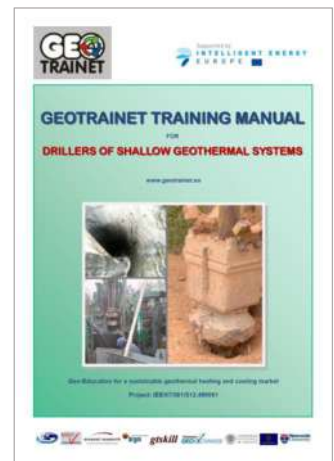


Figure A4: Participants of the Geotrainet-workshop in Uppsala, Sweden, in June 2009 at the SGU premises.