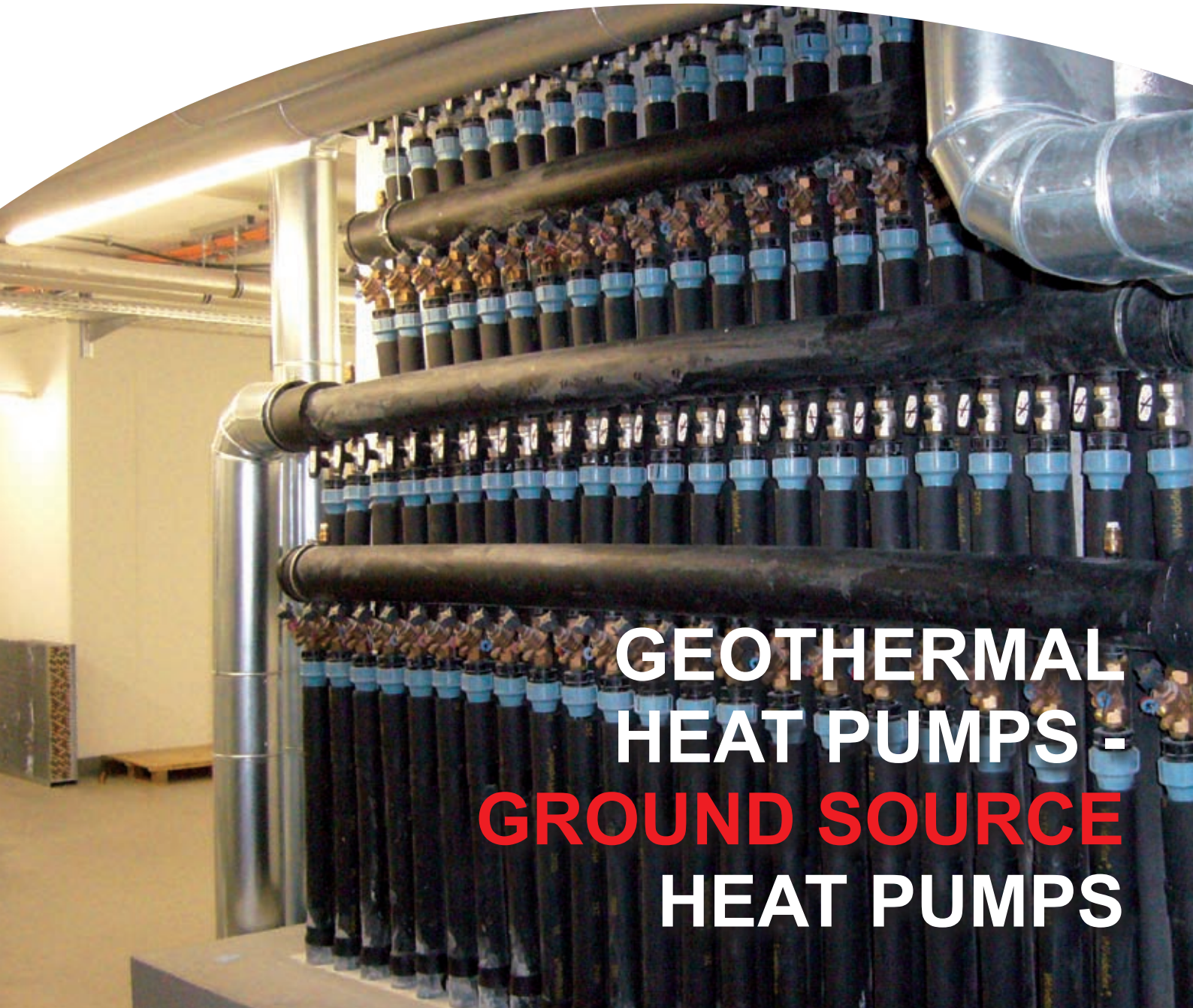




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# GEOHERMAL HEAT PUMPS - GROUND SOURCE HEAT PUMPS





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# Geothermal Heat pumps - Ground source Heat pumps

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# Geothermal Heat Pump (GSHP) - Market

**G**round Source Heat Pumps are a modern technology for heating and cooling of buildings. They make use of geothermal energy (the heat stored beneath the earth surface) almost anywhere throughout Europe. Ground Source Heat Pumps allow both to save primary energy as well as to save heating and cooling cost.

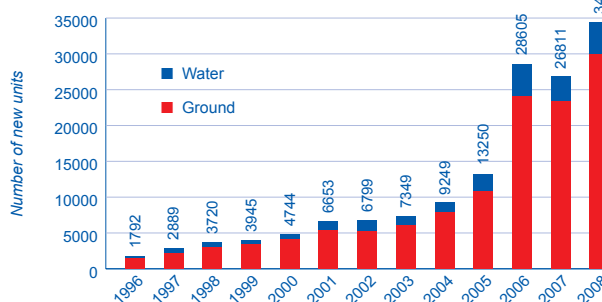
**Ground Source Heat Pumps** systems consist of three main components: the ground side, the heat pump itself, and the building side. A good design must take care of the whole system, matching the components in such a way that the most effective operation and the highest comfort can be achieved. This brochure is intended to show the advantages of Ground Source Heat Pumps and other uses of shallow geothermal energy.

**Ground Source Heat Pumps** have seen a tremendous market development in some European countries over the last years. Sweden and Switzerland are leading since the beginning in the 1980s, however, some other countries with a slow start in the same time, like Germany, now show good growth rates. In France, the development started later, but the opportunities for a widespread, successful use of GSHP are very good.

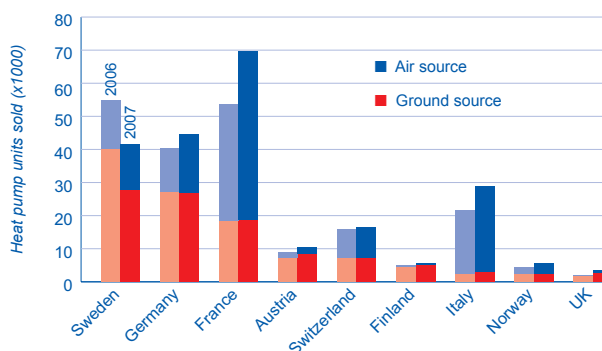
As shown in the first graph as an example, the sales in Germany achieved an almost steady increase over the last decade.

Sweden (>250'000) and Germany (ca 150'000) today show the highest absolute numbers of GSHP; the highest market share (GSHP per capita) has been achieved in Sweden, while the highest areal density of GSHP can be found in Switzerland.

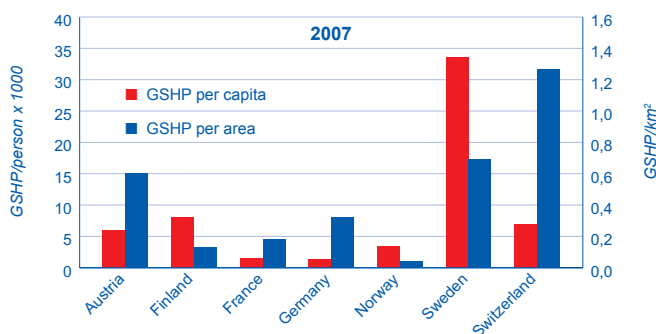
Development of annual sales of GSHP in Germany (after data from BWP / GtV-BV)



Annual sales for groundsource and airtsource heat pumps in some European countries (after data from EHPA)



Number of installed GSHP in some European countries, compared to area and population (calculated after data from EHPA)



# Geothermal Heat Pump (GSHP) Technology

**G**eothermal heat pumps (also called Ground Source Heat Pump, GSHP) are systems with 3 main components:

- the ground side to get heat out of or into the ground
- the heat pump to convert that heat to a suitable temperature level
- and the equipment inside the building transferring the heat or cold into the rooms

The heat pump is a device which allows transformation of heat from a lower temperature level to a higher one, by using external energy (e.g. to drive a compressor). The amount of this external energy input, be it electric power or heat, has to be kept as low as possible to make the heat pump ecologically and economically desirable.

The measure for the efficiency of a heat pump system is the Seasonal Performance Factor (SPF), which is the average Coefficient of Performance (COP) in a given plant over a year or a heating/cooling season:

$$\text{SPF} = \frac{\text{useful heat}}{\text{(electric) power input}}$$

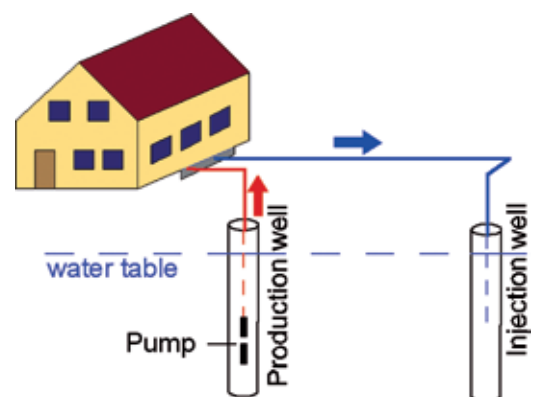
A geothermal heat pump offers the best conditions for achieving high SPF.

Shallow geothermal systems are very versatile and can be adapted to almost every subsurface condition. Typically the ground system is linked to a heat pump for achieving sufficiently high temperatures. Ground systems can be classified generally as open or closed systems, with a third category for those not truly belonging to one or the other.

To choose the right system for a specific installation, several factors have to be considered: Geology and hydrogeology of the underground (sufficient permeability is a must for open systems), area and utilisation on the surface (horizontal closed systems require a certain area), existence of potential heat sources like mines, and the heating and cooling characteristics of the building(s). In the design phase, more accurate data for the key parameters for the chosen technology are necessary, to size the ground system in such a way that optimum performance is achieved with minimum cost. The individual types of ground systems are described in more detail on this and the following pages.

## Open systems

This type is characterised by the fact that the main heat carrier, ground water, flows freely in the underground, and acts as both a heat source/sink and as a medium to exchange heat with the solid earth. Main technical part of open systems are groundwater wells, to extract or inject water from/to water bearing layers in the underground (“aquifers”). In most cases, two wells are required (“doublette”), one to extract the groundwater, and one to reinject it into the same aquifer it was produced from.



Groundwater heat pump (open system, doublette)

With open systems, a powerful heat source can be exploited at comparably low cost. On the other hand, groundwater wells require some maintenance, and open systems in general are confined to sites with suitable aquifers. The main requirements are:

- Sufficient permeability, to allow production of the desired amount of groundwater with little drawdown.
- Good groundwater chemistry, e.g. low iron content, to avoid problems with scaling, clogging and corrosion.

Open systems tend to be used for relatively larger installations.

## Closed systems

### a) horizontal

The closed system easiest to install is the horizontal ground heat exchanger (synonyms: ground heat collector, horizontal loop). Due to restrictions in the area available, in Western and Central Europe the individual pipes are laid in a relatively dense pattern, connected either in series or in parallel.

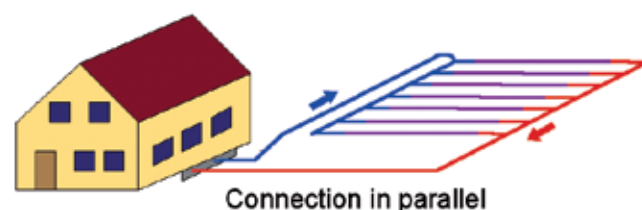
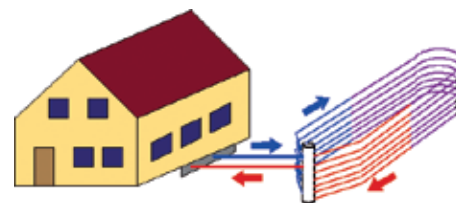
For the ground heat collectors with dense pipe pattern, usually the top earth layer is removed completely, the pipes are laid, and the soil is distributed back over the pipes. In Northern Europe (and in North America), where land area is cheaper, a wide pattern (“loop”) with pipes laid in trenches is preferred. Trenching machines facilitate installation of pipes and backfilling.



A manifold

To save surface area with ground heat collectors, some special ground heat exchangers have been developed. Exploiting a smaller area at the same volume, these collectors are best suited for heat pump systems for heating and cooling, where natural temperature recharge of the ground is not vital. Hence these collectors are widely used in Northern America, and one type only, the trench collector, achieved a certain distribution in Europe, mainly in Austria and Southern Germany. For the trench collector, a number of pipes with small diameter are attached to the steeply inclined walls of a trench some meters deep. Other types include screwtype “energy baskets”, “Slinky” collectors, etc.

The main thermal recharge for all horizontal systems is provided by the solar radiation to the earth’s surface. It is important not to cover the surface above the ground heat collector, or to operate it as a heat store, if it has to be located e.g. under a building.

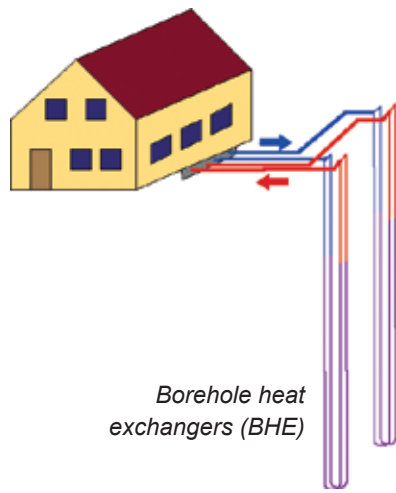


Horizontal ground heat exchanger  
(West/Central European style)

Compact ground heat exchangers  
(top: trench collector, bottom: slinky collector)

## b) vertical

As can be seen from measurements dating as far back as to the 17<sup>th</sup> century, the temperature below a certain depth (“neutral zone”, at ca. 15-20 m depth) remains constant over the year. This fact, and the need to install sufficient heat exchange capacity under a confined surface area, favours vertical ground heat exchangers (borehole heat exchangers).



In a standard borehole heat exchanger, plastic pipes (polyethylene or polypropylene) are installed in boreholes, and the remaining room in the hole is filled (grouted) with a pumpable material. In Sweden, boreholes in hard, crystalline rock usually are kept open, and the ground-

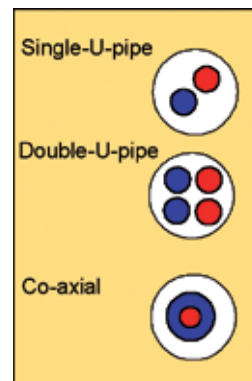
water serves for heat exchange between the pipes and the rock. If more than one borehole heat exchanger is required, the pipes should be connected in such a way that equal distribution of flow in the different channels is secured. Manifolds can be in or at the building, or the pipes can be connected in trenches in the field.



A drilling site

Several types of borehole heat exchangers have been used or tested; the two possible basic concepts are:

- U-pipes, consisting of a pair of straight pipes, connected by a 180°-turn at the bottom. One, two or even three of such U-pipes are installed in one hole. The advantage of the U-pipe is low cost of the pipe material, resulting in double-U-pipes being the most frequently used borehole heat exchangers in Europe.
- Coaxial (concentric) pipes, either in a very simple way with two straight pipes of different diameter, or in complex configurations.



Types of BHE

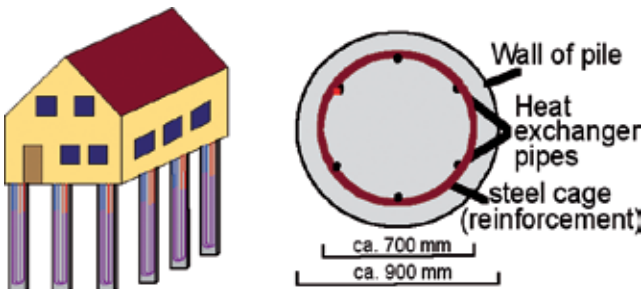
Ground source heat pump plants of every size have been realised with borehole heat exchangers, ranging from small houses with just one borehole to large buildings, requiring whole fields of borehole heat exchangers.

The heat source for thermal recovery of borehole heat exchangers is solar heat (in the upper part) and the geothermal heat flux (in the lower part), with some influence from flowing ground water or percolating water. However, the influence of groundwater in most cases is not very big, and the thermal conductivity of the ground is the main parameter.

The borehole filling and the heat exchanger walls account for a further drop in temperature, which can be summarised as borehole thermal resistance. Values for this parameter usually are on the order of 0.1 K/(W/m); for a heat extraction of 40 W/m, this means a temperature loss of 4 K inside the borehole. Thermally enhanced grouting (filling) materials have been developed to reduce these losses.

A special case of vertical closed systems are “energy piles”, i.e. foundation piles equipped with heat exchanger pipes. All kind of piles can be used (prefabricated or cast on site), and diameters may vary from 40 cm to over 1 m.

Energy Piles

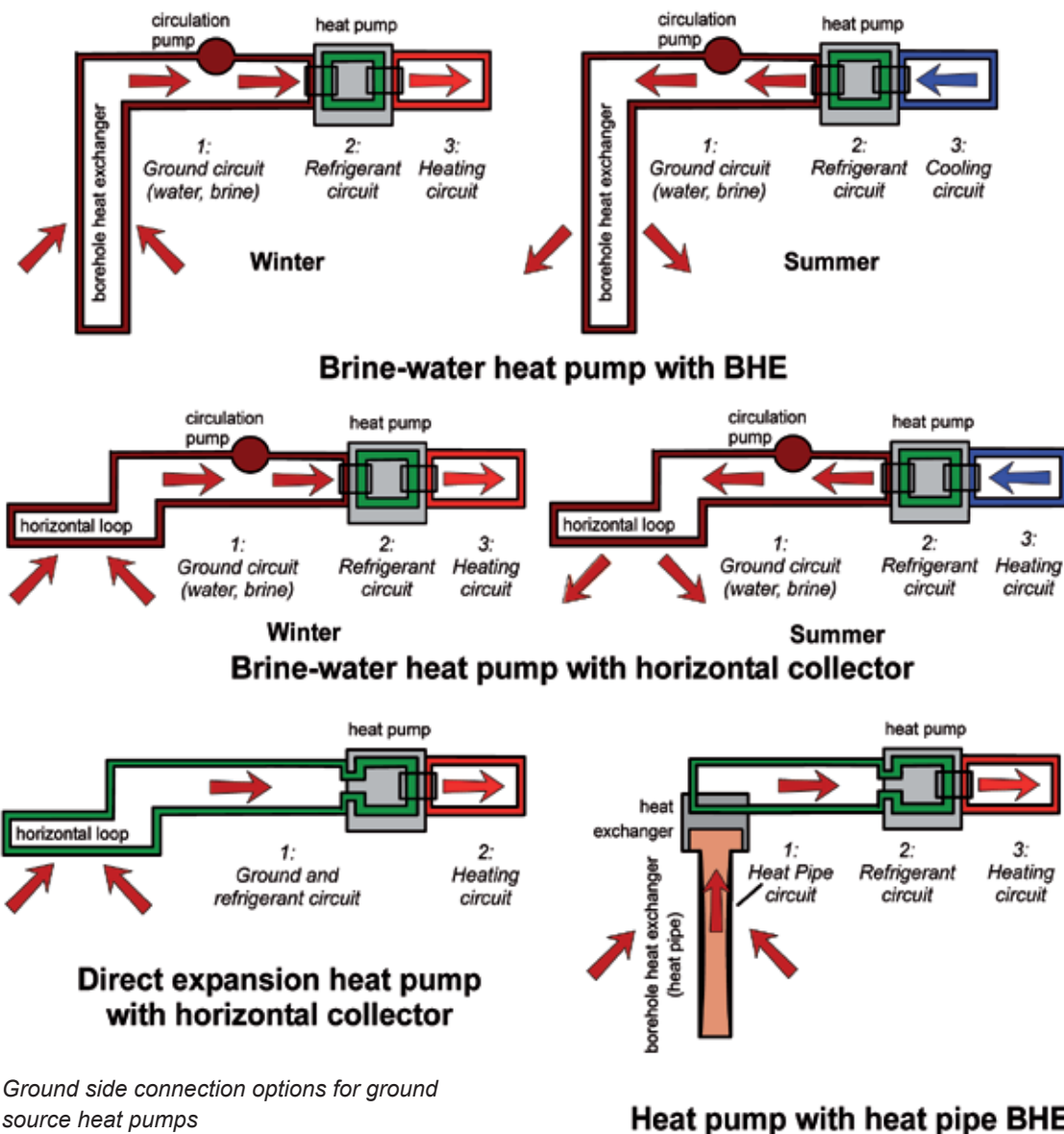


### c) ground coupling circuits for closed systems

A variation of the horizontal ground source heat pump is direct expansion. In this case, the working medium of the heat pump (refrigerant) is circulating directly through the ground heat collector pipes (in other words, the heat pump evaporator is extended into the ground). The advantage of this technology is the omission of one heat exchange process, and thus a possibility for better system efficiency. Direct expansion

requires good knowledge of the refrigeration cycle, and is restricted to smaller units. Also heat pipes as heat source have been tested; they work well for heat extraction, but not at all for heat injection.

With the classical brine (liquid) system, the ground can easily be used for cooling, also. Heat is rejected into the ground, either by running the heat pump in reverse, or by directly coupling the building circuit to the ground circuit.



Ground side connection options for ground source heat pumps

# Geothermal heat pump (GSHP)

## Applications

**G**SHP systems can be used from small, residential houses to large individual buildings or complexes (offices, hotels, schools, shopping, etc.). In the residential sector, typically heat pumps produced in larger series and in standard heating capacities from ca. 5 to 20 kW are used.

### Residential houses

For small houses, 1-2 borehole heat exchangers or a horizontal collector (brine or direct expansion) are the best suited options. The installation is not visible from outside, the heat pumps (incl. buffer tanks and/or DHW tank, where appropriate) do not need much space, and a fuel oil tank or connection to the gas grid is not required.



*Small, packaged heat pump for single family house, with DHW storage tank*

For the commercial sector, all the installation (heat pumps, manifolds) tends to be much larger than for residential houses. Heat pumps with capacities from ca. 50 kW upwards usually are constructed individually or in smaller numbers, adapted to the specific site conditions.



*Large ground source heat pump (ca. 400 kW) and manifold for larger project*

The range of applications for GSHP is widely spanned. Besides, geothermal applications can be present everywhere and anytime for heating and cooling. The maximum delivery temperatures typically are in the order of 50-55°C (with new developments offering increased values of 60-75°C for refurbishment of older buildings), and in cooling mode ca. 6-7°C.



*Small residential house in Germany, using direct expansion horizontal collector and small heat pump*





Larger residential house in Austria, heated by powerful heat pump and borehole heat exchangers

## Offices and commercial buildings

For applications in the commercial sector, large borehole heat exchanger (BHE) fields or groundwater wells are the preferred groundside alternative. While BHE are feasible virtually everywhere, and promise maintenance-free operation, their individual capacity is limited, resulting in huge BHE fields for systems with high heating/cooling demand (see table below). Groundwater wells, on the other hand, require specific geological site conditions and diligent managing of the wells, but can deliver much higher thermal output per well. So for large installations, ground water use is a favourable option.

Office building in Germany, baseload heat and cold provided by heat pump connected to 154 BHE



Supermarket for eco-food in Austria, heated and cooled by heat pumps on groundwater wells

For large projects, two basic configurations are possible:

- One or a few large heat pump(s) with high thermal output, delivering heat or cold through hydronic circuits to radiators, fancoil units, etc.
- A large number of smaller heat pumps, connected via a common fluid loop to the ground system, and providing heat or cold individually to shops, rooms, zones, while extracting or rejecting heat from or to the fluid loop.

### Some of the largest BHE systems in Europe

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



# Geothermal Energy Storage (GES)

The low temperature in the ground can also be changed artificially by storage of heat or cold, creating a geothermal energy storage (or Underground Thermal Energy Storage, UTES). The highest storage temperature achieved in GES is about 90°C, the lowest (for cooling) ca. 5°C. The heat sources for heat storage can be various, however, waste heat or solar heat are typical. For cold storage, the cold ambient air in wintertime or during night is the cold source. We distinguish 2 systems: open and closed circuits.

## Borehole Thermal Energy Storage: BTES

The system uses borehole heat exchangers (BHE) to store heat and/or cold in solid rock or soil, and in the groundwater that might be found therein. BTES do not need a ground water flow. Best suited is rock and soil with medium thermal conductivity, but high specific heat capacity. For effective storage, relatively large BHE-fields are required. The BTES used for storing solar heat in the underground in Neckarsulm Germany, e.g. consists of more than 500 BHE.

## Aquifer Thermal Energy Storage: ATES

In ATES the ground water is used directly as a heat carrier. High porosity and low or none natural groundwater movement are the best conditions. Groundwater chemistry has to be checked closely, in order to secure reliable long-term operation. ATES can provide high thermal output with few wells. Prominent examples for ATES have been built for H&C of the Reichstag building in Berlin, for the Jaarbeurs (tradefair) in Utrecht, NL, and with airports in Gardermoen (Oslo) and Arlanda (Stockholm).

### Applications:

The range of applications is large, as for Geothermal Heat Pumps:

- Buildings, through a small district heating network
- Shopping malls, airport buildings, fair and convention halls, offices
- Industry like plastics (e.g. Wavin in Hardenberg, NL) and foundry (system in construction for ITT Flygt in Emmaboda, Sweden)

*Houses with solar collectors in Neckarsulm, Germany*



*The BTES in Neckarsulm under construction (>500 BHE)*



*One well and the heat exchangers of the ATES for Arlanda airport, Sweden*



*Prins-van-Oranje-Hall at Jaarbeurs, Utrecht, NL, using ATES*



# Calculation of the share of energy from RES in geothermal heat pump systems

The amount of external energy input, be it electric power or heat, has to be kept as low as possible to make the geothermal heat pump ecologically and economically desirable. The measure for the efficiency of a shallow geothermal system is the Seasonal Performance Factor (SPF) (cf. page 4).

A geothermal heat pump offers the best conditions for achieving a high SPF, as the steady temperature in the underground permits to run more efficiently. The earth offers a steady, reliable and incredibly large heat source, heat sink and heat storage medium for thermal energetic uses.

The energy flow in a GSHP system is shown in the graph to the right.  $E_{RES}$  is the amount of geothermal energy captured by the ground source heat pump.

Within the new directive 2009/28/EC on Renewable Energies, the amount of geothermal energy captured by heat pumps to be considered energy from renewable sources  $E_{RES}$ , shall be calculated in accordance with the following formula:

$$E_{RES} = Q_{usable} * (1 - 1/SPF)$$

where

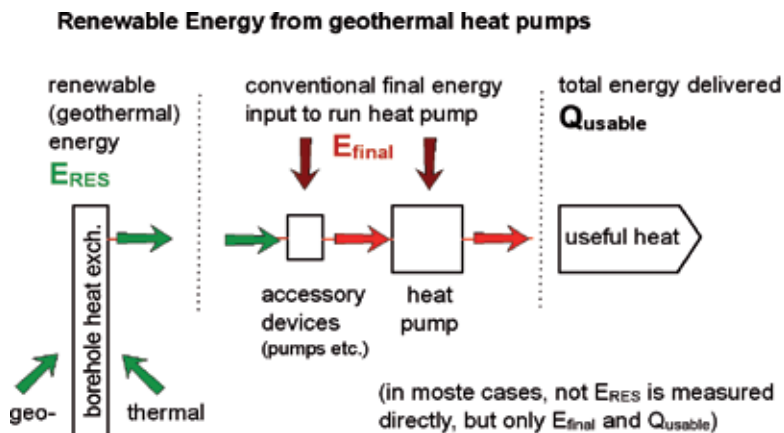
- $Q_{usable}$  = the estimated total usable heat delivered by heat pumps
- SPF = the estimated average seasonal performance factor for those heat pumps

Only heat pumps for which

$$SPF > 1,15 * 1/\eta$$

shall be taken into account, i.e. the heat pump SPF must be 15 % better than the overall efficiency for power production and distribution ( $\eta$ ) in order to ensure a positive renewable energy output over primary energy input.

Monitoring campaigns have shown that geothermal heat pumps are superior in SPF to airsource heat pumps not only in theory, but also in practice. A study made by Fraunhofer ISE in Germany with



**Renewable portion ( $E_{RES}$ ) of total energy delivered by a heat pump typically is calculated as:**

$$E_{RES} = Q_{usable} - E_{final}$$

**SPF of a heat pump is calculated as:**

$$SPF = Q_{usable} / E_{final}$$

**Alternative calculation for  $E_{RES}$ :**

$$E_{RES} = Q_{usable} * 1 / (1 - SPF)$$

monitored data of ca. 80 heat pumps revealed an average SPF = 3.8 for GSHP compared to SPF = 2.9 for airsource heat pumps. Several GSHP excelled with a measured SPF well in excess of 4!

The ecological advantage of GSHP is steadily growing. Any improvement in heat pump efficiency, but also in the efficiency of electric power production as well as in the amount of clean, renewable sources contributing to electric power, automatically reduces the primary energy input and the emissions related to geothermal heat pump operation.



Heat pumps manufactured in France and in Germany

# Installed capacity and market development

Number of existing GSHP and installed capacity in 2008 (for countries with more than 10 MW<sub>th</sub> heat capacity)

Country	Number	Installed capacity (MW <sub>th</sub> )
Sweden	320687	2909,0
Germany	150263	1652,9
France	121886	1340,7
Finland	46412	857,9
Austria	48641	544,8
Netherlands	19310	508,0
Poland	11000	180,0
Ireland	9673	157,0
Italy	7500	150,0
Czech Rep.	9168	147,0
UK	10350	134,6
Denmark	11250	123,8
Belgium	9500	114,0
Estonia	4874	63,0
Hungary	350	15,0
Slovenia	1125	12,2

Source: Eurobserv'er

Geothermal heating and cooling is no longer exotic. The number of GSHP has increased steadily over the years, and the technology is well understood. For residential houses, GSHP already are a routine option in some countries. However, in total only a small portion of the potential of shallow geothermal energy is as yet in use in Europe.

Market penetration of geothermal heat pumps is still modest in most of Europe. Notable exceptions are Sweden and Switzerland, with Austria and Germany following closely; these are the countries with the original GSHP application in Europe

since the 1960s. However, the technology is popular meanwhile also in France and Benelux, and is strongly migrating into new regions:

- South-Western Europe and the Mediterranean, with an emphasis on cooling and heating
- Eastern and South-Eastern Europe, where slowly a demand for more comfort in houses is growing, and a group of people who can afford it.
- In United Kingdom and Ireland, meanwhile interest grows, some prestigious plants have been built, and the number of systems is rising

There is still ample opportunity for further market growth, and the technological prospects endorse this expectation. In several countries a market-driven economy exists already, and will be boosted further by the expected oil price development.

The use of GHP for commercial applications can yield economic and environment advantages. In particular in cases where heating and cooling is required, the ground as heat source and sink can act as a kind of seasonal buffer storage.

The size of individual GSHP units ranges from about 5 kW<sub>th</sub> for residential use to large units of over 500 kW<sub>th</sub> for commercial, institutional and industrial installations. In Europe, most units are sized for the heating load and are often designed to provide the base load with peaking by fossil fuel in larger installations.

The EU is one of the main regions in the world to use GSHP technology. At the end of 2008, their number is estimated at nearly 800'000 units, representing an installed capacity to the order of 8'920 MW<sub>th</sub> (cf. table).

Sweden alone has more than 320'000 units running, for a capacity of 3'000 MW<sub>th</sub>. Germany is ranking second in EU, with about 150'000 units installed at the end of 2008. In France, the GSHP market in 2008 is estimated at ca. 20'000 units, bringing the total number of geothermal heat pumps installed to about 122'000.

During the year 2008, the geothermal heat pump market exceeded the benchmark of 100'000 units being sold annually for the third consecutive time.

Projections with regard to heat production are really positive. If the sector for geothermal heat pumps keeps growing at the rate of about 15% per year until 2010, it could achieve a cumulative capacity of ca. 12'000 MW<sub>th</sub>.

## Costs and prices

For geothermal heat pump systems, the cost is site dependent, but not in the same range as for deep geothermal systems. It is possible virtually everywhere to drill for a GSHP, and the cost is not so much different from one location to another one.

Nevertheless, the cost of a GSHP is influenced by the geological underground. To drill in granite is easier and quicker because it is possible to drill with air and a downhole hammer, as in the contrary it is slow to drill in clays and sands, where conventional rotary rig with mud and temporary casing might be required. The availability of groundwater limits the choice of open or closed systems. Thermal properties of the underground control the necessary BHE length.

The operational cost is mainly influenced by electricity and fuel prices, and by the efficiency of the GSHP system (SPF). Systems used for heating and cooling can usually be more efficient than heating only systems, as the underground installation is used all year round. The price of heat and cold from a GSHP meanwhile falls into the same range than conventional alternatives, including the amortisation of investment cost.

For large commercial installations with both heating and cooling needs, geothermal heat pumps or geothermal energy storage can result in substantial reductions in operational cost, with favourably short payback periods. In many cases the geothermal system can reduce the room required in the building for the heating and cooling system (e.g. by replacing cooling towers), and thus free valuable area for more profitable use.

*Participants of the first Geotrainer course, held at the Swedish Geological Survey (SGU) in Uppsala, Sweden*

## Environmental aspects

Geothermal heat pumps contribute strongly to emission reduction and to primary energy savings, both big advantages for the environment.

However, any perforation into the underground carries a possible environmental risk, in particular concerning the groundwater. Because groundwater is a premier resource of good drinking water, its protection has the highest priority when drilling for a BHE or a groundwater well for thermal use.

Proper regulations to guarantee groundwater protection are in place in the countries with a developed GSHP market, and such regulations will be required in all other countries also.

Reliable groundwater protection and sustainable, clean installation and operation of a GSHP plant requires knowledge on the side of planners and installers (drillers), but also on the side of the authorities. Education, training and certification are the key to guarantee skilled workforce and responsible work.

Project Geotrainer, supported by the EU in the Intelligent Energy Europe program, aims at providing the curricula, teaching materials, and sample courses for shallow geothermal training:

[www.geotrainer.eu](http://www.geotrainer.eu)



# Geothermal heat pumps - everywhere in Europe



Far North: Hotel Storforsen, Älvsby, Sweden, with 33 BHE



Heat pump for industrial use in DePuy factory, Lyon, France



Thermal response test in Spain



Large BHE field in Nydalen, Oslo, Norway, under construction



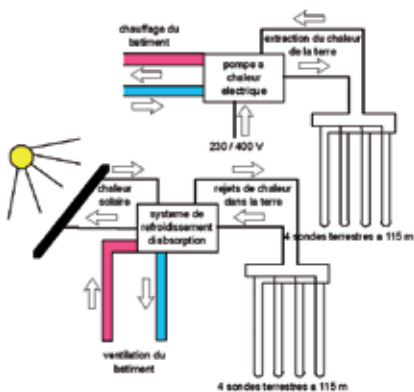
BHE drilling and manifold installation for office building in Törökbalint, Hungary



Geothermal groundwater heat pump for Glucksman gallery, Cork University, Ireland



Drilling for car sales office in Bucharest, Romania



Renewable Energy House in Brussels, Belgium, drilling for 4 BHE and schematic



House in Istanbul, Turkey, with 4 BHE



# Example: Geothermal system for “Bonner Bogen”, Bonn, Germany



Geothermal system with groundwater use, 2 x 3 wells, for campus with offices and a 5-star-hotel

Thermal capacity about 1 MW (baseload for the campus); the buildings are connected into a common circuit for heat and cold.

*Left: Location of wells*

*Below: Groundwater heat exchanger (left) and heat pump (right)*

## Advantages

The main benefits of geothermal heat pumps are:

- A Renewable Energy Source: the heat from the earth is inexhaustible, delivering heating and cooling 24 hours a day throughout the year, and available all over Europe with minor land use
  - Any geothermal heat pump contributes substantially to the reduction of Green House Gas emissions
  - A safe and controlled technology: Independent of the season, climatic conditions and time of the day; GSHP are technically proven, with longterm durability of installations; used since >50 years for heating & cooling
  - An energy adaptable with high performance: an answer to all energy needs: heating, cooling, hot water, energy storage; can be adapted and modulated according to type of resource, to size and nature of equipments, and in order to meet demands
- An economically sustainable energy: Indigenous, independent of external supply/demand effects and fluctuations in exchange rates, not sensitive to conventional energy prices; allows 'local' fossil resources such as oil, coal and natural gas to be saved
  - Furthermore shallow geothermal energy can help to improve the competitiveness of industries, and can have a positive impact on regional development and employment.

*(Source: BonnVisio – Bonner Bogen, UBeG)*





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