Ground-source heat pumps represent one of the fastest-growing renewable energy technologies, with current worldwide installed capacity at 9500 MW for thermal applications. John Lund and his colleagues in the heat pump industry present a comprehensive look at the status of the technology around the world today.

Ground-source heat pumps

A world overview

Geothermal heat pumps – strictly speaking, ground-source heat pumps – are one of the fastest growing applications of renewable energy in the world, with an annual rate of increase of 10% in about 30 countries over the past ten years. The main advantage of the technology is that it uses normal ground or groundwater temperatures (between about 5°C and 30°C), which are available in all countries of the world.

Most of this growth has occurred in the United States and Europe, though interest is developing in other countries, such as Japan and Turkey. The present, worldwide installed capacity is estimated at almost 9500 MWth (thermal) and the annual energy use is about 52,000 TJ (14,400 GWh). The actual number of installed units is estimated at about 800,000. Table 1 lists the countries with the highest use of ground-source heat pumps.

TABLE 1. Leading countries using ground-source heat pumps

Country	Capacity (MWth)	Generation (GWh/year)	Number installed
Austria	275	370	23,000
Canada	435	300	36,000
Germany	560	840	40,000
Sweden	2000	8000	200,000
Switzerland	440	660	25,000
USA	3730	3720	500,000

Ground-source heat pumps (GSHPs) use the relatively constant temperature of the Earth to provide heating, cooling and domestic hot water (DHW) for homes, schools and government and commercial buildings. A small amount of electricity input is required to run a compressor; however, the energy output is in the order of four times this amount. These ‘machines’ cause heat to flow ‘uphill’, that is, from a lower to higher temperature location. In essence, they are nothing more than a refrigeration unit that can be reversed. The word ‘pump’ is used to described the work done, while the temperature difference is called the ‘lift’ – the greater the lift, the greater the energy input. The technology isn’t new, as Lord Kelvin developed the concept in 1852. This was then modified into the form of a GSHP by Robert Webber in the 1940s, with the pumps gaining commercial popularity in the 1960s and 1970s. Figures 1A and 1B illustrate typical GSHP operation.

GSHPs come in two basic configurations, ground-coupled (closed loop) and groundwater (open loop) systems, which are installed in the ground, a well or a lake. The type chosen depends upon such factors as the soil and rock type at the installation, the land available, and, where relevant, whether a water well can be drilled economically or is already on site. Figures 2A and 2B provide illustrations of these systems. As shown in Figure 1, a de-superheater can be provided, so that reject heat can be used in the summer and some heat input in the winter for DHW heating.

In the ground-coupled system, a closed loop of pipe is placed in the ground, either horizontally (1–2 metres deep) or vertically (50–250 metres deep), and a water–antifreeze solution circulated through the plastic pipes. This solution collects heat from the ground in the winter, or rejects heat to the ground during the summer.[1] The open loop system uses groundwater or lake water directly in the heat exchanger, and then discharges it into another well, a stream or lake, or on the

Drilling for a GSHP installation in progress in Cornwall, UK. GEOSCIENCE

ground (say for irrigation), depending upon local laws.

The efficiency of GSHP units is described by the coefficient of performance (COP) in the heating mode and the energy efficiency ratio (EER) in the cooling mode (COP_h and COP_c, respectively in Europe). This is the ratio of the output energy divided by the input energy (i.e. the electricity for the compressor) and varies from 3 to 6 with present equipment. The higher the number, the greater is the efficiency. Thus a COP of 4 would indicate that the unit produced four units of heating energy for every unit of electrical energy input. In comparison, an air-source heat pump has a COP of around 2.5, and is dependent upon back-up electrical energy to meet peak heating and cooling requirements. In Europe, this ratio is sometimes referred to as the 'Seasonal Performance Factor' ('Jahresarbeitszahl' in German) and is the average COP over the heating or cooling season, respectively, taking into account system properties.

> Although President Bush is not known as an environmentalist, he has referred to the ground-source heat pump system on his ranch as 'environmentally hip'

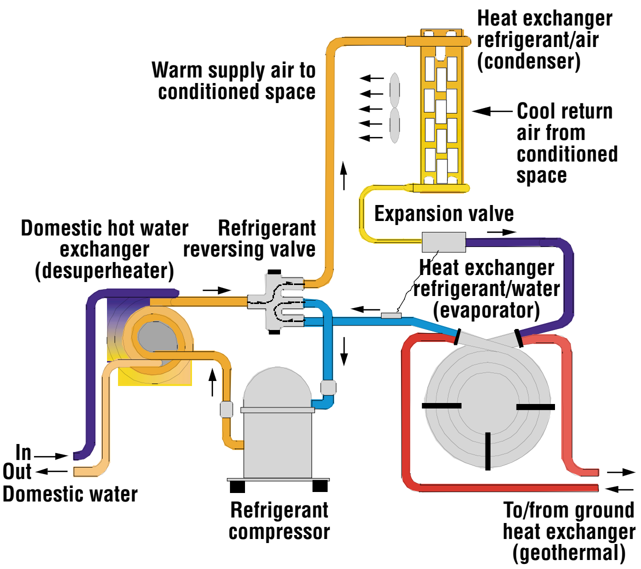
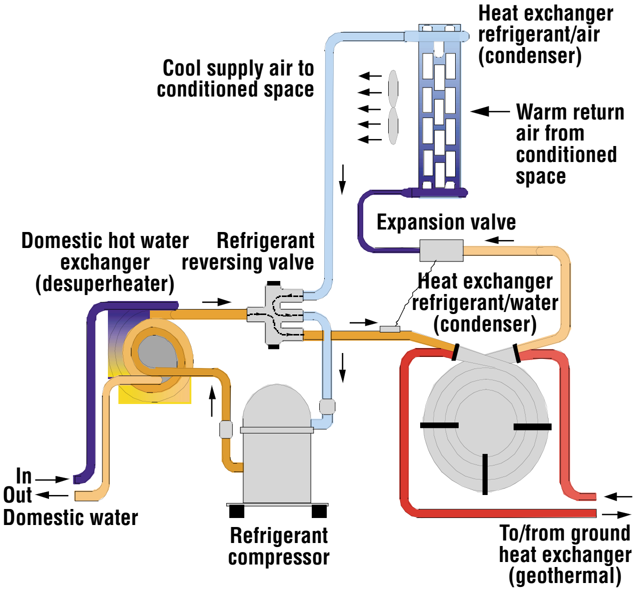


FIGURE 1A. **GSHPs in the heating cycle. Source: Oklahoma State University**



B. **GSHPs in the cooling cycle. Source: Oklahoma State University**

US EXPERIENCE

In the US, most units are sized for the peak cooling load and are oversized for heating (except in the northern states), and thus are estimated to average only 1000 full-load heating hours per year. In Europe, most units are sized for the heating load and are often designed to provide just the baseload, with peak requirements provided by fossil fuel or even supplementary electric heating. As a result, the European units may operate from 2000 to 6000 full-load hours per year, with an average of about 2300 annual full-load hours. Even though cooling mode rejects heat to the earth and is thus not geothermal, it still saves energy and so contributes to a 'clean environment'.

GSHP installations have steadily increased over the past 10 years or so in the US, with an annual growth rate of about 12%, mostly in the Midwestern and Eastern states from North Dakota to Florida. Today, approximately 50,000 units are installed annually, of which 46% are vertical closed loop systems, 38% horizontal closed loop systems, and 15% open loop systems. Over 600 schools have installed these units for heating and cooling, with a significant proportion of these in Texas. It should be noted at this point, that in the US, heat pumps are rated on tonnage (i.e. one ton of cooling power – produced by a ton of ice) which is equal to 12,000 btu/hour or 3.51 kW.[2] A unit for a typical residential requirement would be around three tonnes or 10.5 kW of installed capacity.

One of the largest GSHP installations in the US is at the Galt House East Hotel in Louisville, Kentucky. GSHPs provide heat and air conditioning for 600 hotel rooms, 100 apartments, and 89,000 m^2 of office space, for a total area of 161,650 m^2. The GSHPs use 177 litres of water per second from four wells at 14°C, providing 15.8 MW of cooling and 19.6 MW of heating capacity. The energy consumed is approximately 53% of that used by an adjacent, similar non-GSHP building, saving $25,000 per month.

One of the recent converts to this form of energy saving is President George W. Bush, who installed a geothermal heat pump on his Texas ranch during the election campaign.[3] Even though he is not known as an environmentalist, he referred to his system as 'environmentally hip'. This vertical closed loop installation cuts his heating and cooling cost by 40%.

THE EUROPEAN SITUATION

In Western and Central European countries, the direct

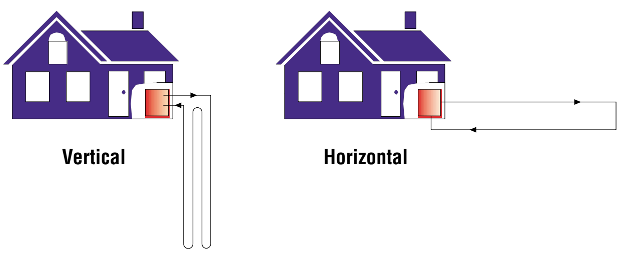
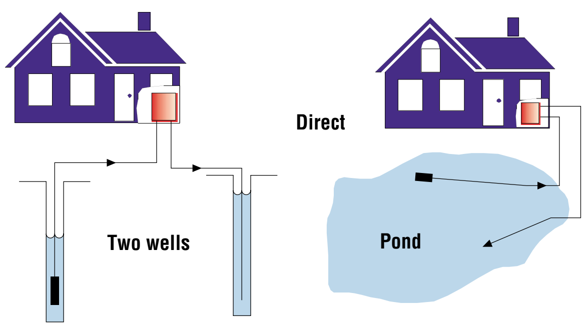


FIGURE 2A. **Closed loop heat pump systems. Source: Geo-Heat Center**



B. **Open loop heat pumps systems. Source: Geo-Heat Center** utilization of geothermal energy to supply heat to a larger number of users through district heating is so far limited to regions with specific geological characteristics. In this situation, utilization of the ubiquitous shallow geothermal resources by decentralized GSHP systems is an obvious option. Correspondingly, a rapidly growing range of applications is emerging and developing in various European countries. This is resulting in rapid market penetration by such systems; the number of commercial companies actively working in this field is ever-increasing, and their products have reached the 'yellow pages' stage.

More than 20 years of ground-source heat pump R&D in Europe has resulted in a well established, sustainable concept for the technology, as well as sound design and installation criteria. A typical GSHP with borehole heat exchanger (a BHE, or 'vertical loop' in US terms) is shown in Figure 3. Currently, for each kWh of heating or cooling output, these systems require 0.22–0.35 kWh of electricity – 30–50% less than the seasonal power consumption of air-to-air heat pumps that use the atmosphere as a heat source/sink.

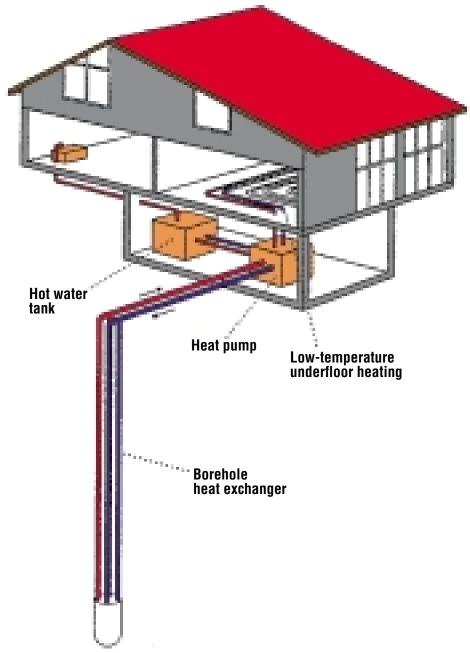


FIGURE 3. **Typical application of a BHE/heat pump system in a Central European home. Typical BHE length is ≥ 100 metres**

The climatic conditions in many European countries are such that by far the greatest demand in the domestic sector is for space heating, and air conditioning is rarely required. Heat pumps usually operate, therefore, in the heating mode. However, with the increasing number of larger commercial applications requiring cooling and the ongoing proliferation of the technology into Southern Europe, the dual use for heating and cooling will become of greater importance in the future.

It is difficult to find reliable figures for the number of heat pumps installed in Europe, and in particular for individual heat sources. Figure 4 gives recent data for the number of installed units in the main European countries using heat pumps. The extremely high number for Sweden in 2001 is the result of a large number of exhaust air and other air-to-air heat pumps; however, Sweden also has the highest number of GSHPs in Europe (see Table 1). In general, though, it can be concluded that market penetration of GSHPs is still modest throughout Europe, with the exception of Sweden and Switzerland.

Installation of borehole heat exchanger at a small house in Bielefeld, Germany, using a small, powerful Rotomax drilling rig

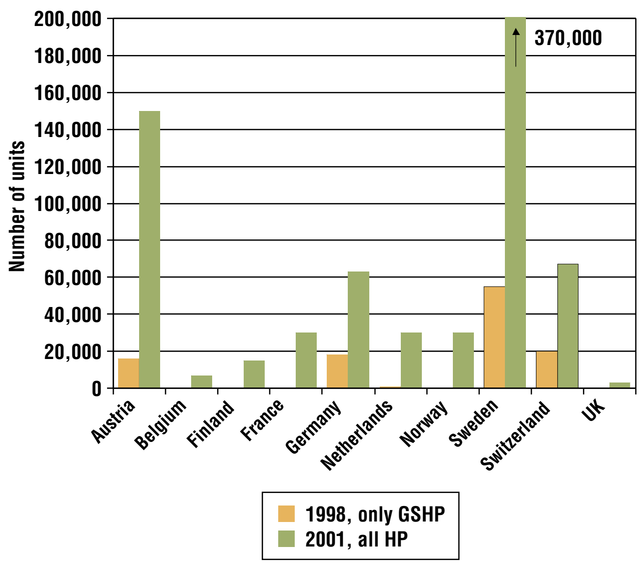


FIGURE 4. **Number of installed heat pump units in some European countries. Source: based on data from 'Prospects for ground-source heat pumps in Europe'[4] and 'Neuer Trend: Vom Boden an die Wand'[5]**

German experience

Since 1996, the statistics for heat pump sales in Germany have distinguished between different heat sources (as is shown in Figure 5). Within recent years, sales of GSHPs have shown a steady increase, after an all-time low in 1991 when fewer than 2000 units were shipped. The share of GSHP (ground and water), which was less than 30% in the late 1980s, had risen to 78% in 1996 and 82% by 2002. Even in the period 2001–2002, when the German building market was shrinking due to the poor economic situation, there was still a slight increase in the number of GSHPs sold. There is still ample opportunity for further market growth, and the technological prospects endorse this expectation.

GSHP applications in Germany are most numerous in the residential sector, with many small systems serving detached houses, but the larger installed capacity is in the commercial sector, where office buildings requiring heating and cooling dominate. In most regions of Germany, the low humidity in summertime allows for cooling without de-humidification, for instance, by using chilled ceilings. These systems are well suited to using the cold of the ground directly, without chillers, and they show extremely high efficiency with a cooling COP of 20 or more. The first system using BHEs and direct cooling was built in 1987,[6] and since then the technology has become a standard design option.

In Germany, GSHP technology has left the RD&D stage way behind, the emphasis nowadays being on optimization and quality of installation. Measures such as technical guidelines (VDI 4640), certification of contractors and quality awards are beginning to be enforced to protect industry and consumers against poor quality and insufficient longevity of GSHP systems.

The geothermal heat pump boom in Switzerland

GSHP systems have spread rapidly in Switzerland, with annual increases up to 15%. At present, there are over 25,000 GSHP

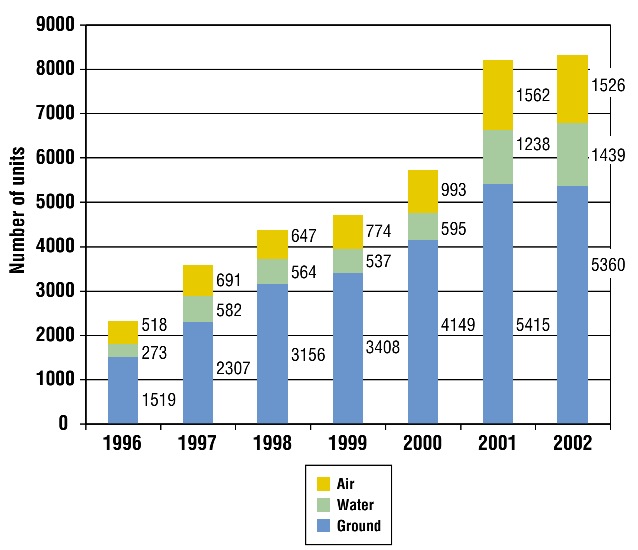


FIGURE 5. **Number of annual heat pump sales in Germany, by heat source. Source: data from IZW e.V., Hannover and BWP e.V., Munich; heat pumps used for DHW production only are not included**

systems in operation. The three types of heat supply systems used from the ground are:

- shallow horizontal coils (making up less than 5% of all GSHPs)
- BHEs at 100–400 metres deep (65%)
- groundwater heat pumps (30%).

In 2002 alone, a total of 600 km of boreholes were drilled and equipped with BHEs.

GSHP systems are ideally suited to tap the ubiquitous shallow geothermal resource. The reliability of their long-term performance is now proved by theoretical and experimental studies, as well as by measurements conducted over several heating seasons.[7] Seasonal performance factors of over 3.5 are routinely achieved.

The measurements and model simulations prove that sustainable heat extraction can be achieved with such systems.[8] The reliable long-term performance provides a solid base for problem-free application; correct dimensioning of BHE-coupled GSHPs allows widespread use and optimization. In fact, the installation of GSHPs, starting at practically none in 1980, progressed rapidly, with such systems now providing the largest contribution to geothermal direct use in Switzerland.

The installation of GSHP systems in Switzerland has progressed rapidly since their introduction in the late 1970s. This impressive growth is shown in Figures 6 and 7.

The annual increase is remarkable: the number of newly installed systems increases at an annual rate of over 10%. Small systems (under 20 kW) show the highest growth rate (more than 15% annually; see also Figure 1). In 2001, the total installed capacity of GSHP systems was 440 MWth, and the energy produced about 660 GWh. Several thousand wells were drilled in 2002 to install double U-tube BHEs in the ground; average BHE drilling depth is now around 150–200 metres, and depths of more than 300 metres are becoming more and more common. Average BHE cost, including drilling, U-tube installation and backfill, is now around US$45/metre. In 2002, a total of 600 km of BHE wells were drilled.

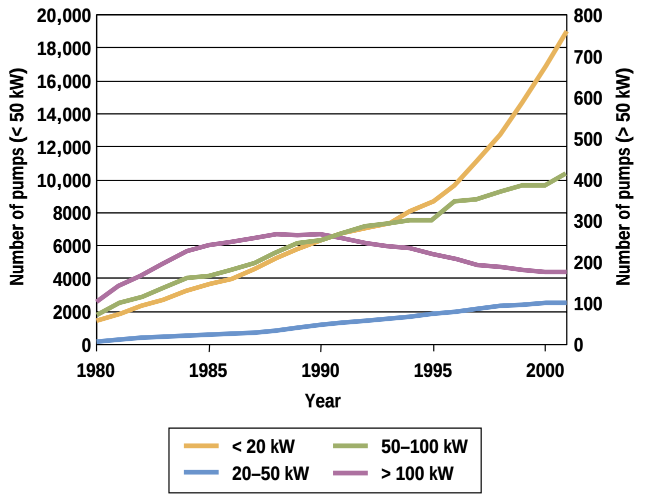


FIGURE 6. **Ground-coupled heat pump installations in Switzerland, 1980–2001. Source: Report to Swiss Federal Office of Energy[9]**

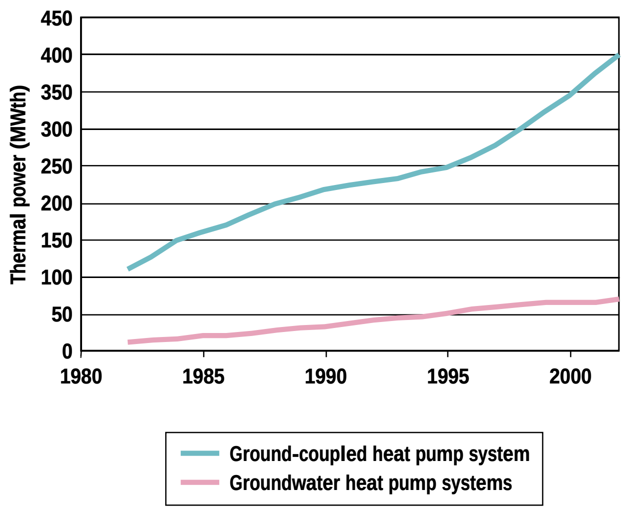


FIGURE 7. **Development of installed capacities (MWth) of (top) BHE-coupled and (bottom) groundwater-based geothermal heat pumps in Switzerland during the years 1980–2001. Source: Report to Swiss Federal Office of Energy[9]**

The main reason for the rapid market penetration of GSHP systems in Switzerland is that there is practically no resource for geothermal energy utilization other than the ubiquitous heat content within the uppermost part of the Earth's crust. There are also various technical, environmental and economic reasons for the GSHP boom in Switzerland.

Technical incentives

- Appropriate climatic conditions on the Swiss Plateau (where most of the population lives) include long heating periods, air temperatures around 0°C, little sunshine in winter and ground temperatures around 10°C–12°C at a shallow depth.
- The constant ground temperature provides a correctly dimensioned GSHP with a favourable seasonal performance factor and a long lifetime.
- The GSHP systems are installed in a decentralized manner, to fit individual needs. Costly heat distribution (for instance, through use of district heating systems) is avoided.
- There is a relatively free choice of location next to (or even underneath) buildings, and little space demand inside.
- There is no need, at least for smaller units, for the thermal recharge of the ground. Thermal regeneration of the ground is continuous and automatic during periods of non-use (such as the summer).

Environmental incentives

- There is no risk associated with transportation, storage, and operation (as there is, for instance, with oil).
- There is no risk of groundwater contamination (as there is with oil tanks).
- The systems operate without emissions, and help to reduce greenhouse gas emissions, principally CO_2.

Economic incentives

- The installation cost of a GSHP system is comparable to that of a conventional, oil-based system.[10]

- GSHP systems have low operating costs – there are no oil or gas purchases, burner controls etc. as there are with fossil-fuelled heating systems.
- Local electric utility rebates exist for environmentally favourable options such as heat pumps.
- Introduction of CO_2 tax is due soon (foreseen for 2004).

A further incentive that accounts for the rapid spread of GSHP systems is 'energy contracting', where the utility company plans, installs, operates and maintains the GSHP system at its own cost and sells the heat (or cooling) to the property owner at a contracted price (cents/kWh).

The outlook for GSHP in Switzerland is positive. While the majority of GSHP installations serve for the space heating of single-family dwellings (which can also include sanitary water warming), a number of innovative solutions are rapidly emerging. These include use of multiple BHEs, combined heat extraction/storage with, for instance, solar energy, geothermal heating/cooling and 'energy piles' (building foundation piles, equipped with plastic heat exchanger tubes). GSHP areal density in Switzerland is the highest worldwide, with an average of more than one unit every 2 km^2. This secures Switzerland a prominent ranking in geothermal direct use; for installed capacity per capita, it is among the top five countries worldwide. It is expected that the GSHP boom in Switzerland will prevail for quite some time.

> One little-known fact about these systems is the dramatic reduction in carbon dioxide emissions that they can realize

Geothermal heat pumps in the UK

While the UK can lay claim to the efforts of Lord Kelvin in developing the theory of the heat pump, the adoption of the technology for heating buildings has been inexorably slow. The first documented installation of a GSHP comes from the 1970s,[11] while a later pioneer championed the installation of small closed loop systems in houses in Scotland during the early 1990s. Even so, the adoption of this technology in the UK was considerably far behind the burgeoning activity in Northern Europe and North America, due to a relatively mild climate, poor insulation levels of the housing stock, a lack of suitable heat pumps and competition from an extensive natural gas grid.[12]

In the mid-1990s, the slow development of GSHPs took place in the UK with lessons being learned from practices adopted in Canada, the US and Northern Europe. It has taken time to identify the technology appropriate for use with the housing stock, and to overcome issues that are unique to the UK. An additional obstacle is the complexity of its geology within a relatively small geographical area. In the last two years GSHPs have been officially recognized as having a role to play in several UK initiatives, such as the affordable warmth programme, and in meeting renewable energy and energy efficiency targets.

One little-known fact about these systems in the UK is the dramatic reduction in carbon dioxide emissions that they can realize, when compared to conventional systems. A GSHP connected to the UK electricity grid will lead to overall reductions in CO_2 emissions of between 40% and 60% – immediately. As the country's generating grid (presumably) gets cleaner in years to come, so the emission levels associated with long-lifetime GSHPs will continue to fall. Architects and developers are also facing new assessment criteria for buildings, and are beginning to take account of the carbon performance of new properties.

From very modest beginnings, GSHPs are now beginning to appear at locations all over the UK, from Scotland to Cornwall. Self-builders, housing developers and housing associations are amongst the users of these systems. Domestic installations, ranging in size from 2.5 kW to 25 kW and using a variety of water-to-water or water-to-air heat pumps, are now operational, employing several different ground configurations.

A recently announced funding scheme, the Clear Skies programme, will assist in giving the technology official recognition, establishing credible installers, standards and heat pumps that are suitable for the UK domestic sector. Together with a 1000-house programme launched last year by Powergen, a major UK utility, it is expected that there will be significant growth in interest and many successful installations of GSHPs in the domestic sector throughout the UK over the next few years.

Another important area of activity is the application of geothermal heat pumps in commercial and institutional buildings where heating and cooling is required. In 2002, the IEA Heat Pump Centre commissioned the first of a series of country studies into the contribution that heat pumps could make to CO_2 reductions.[13] The first of these looked at the UK, concluding that the largest contribution geothermal systems could make would be in the office and retail sector. The first non-domestic installation, at only 25 kW, was for a health centre on the Isles of Scilly. In the period 2000–2003 this was rapidly followed by installations growing in size and sophistication up to 300 kW. The sites range from schools, through single- and multi-storey office blocks to several visitor/exhibition centres. Notable examples are the National Forest Visitor Centre, in Derbyshire, office blocks in Chesterfield, Nottingham,

ABOVE The UK's first non-domestic GSHP installation is sited here, at a health centre on the Isles of Scilly GEOSCIENCE. **TOP RIGHT** Work on heat pump installation at a new IKEA distribution centre, Peterborough, UK. GEOSCIENCE **FAR RIGHT** End of double U-tube BHE GEOWATT

Croydon, and Tolvaddon Energy Park in Cornwall. A large installation has just been commissioned at a new distribution centre for furniture retailer IKEA in Peterborough. These installations use a variety of heat pump configurations, including simple underfloor heating, reverse-cycle heat pumps delivering heating or cooling, and sophisticated, integrated units delivering simultaneous heating and cooling. Stand-alone and hybrid configurations have been used, with some applications using large horizontal ground loop arrays, and others employing grids of interconnected boreholes.

Geothermal heat pumps in Sweden

Ground-coupled heat pumps gained popularity in Sweden in the early 1980s, and by 1985 about 50,000 units had been installed. Then, because of lower energy prices and problems in quality, the heat pump market deflated, and during the next 10 years, the average number of units installed per annum was about 2000. In 1995, however, public awareness and acceptance of ground-coupled heat pumps began to grow, due to strong support and subsidies from the Swedish state. In 2001 and 2002, around 27,000 ground-coupled heat pumps were installed (see Figure 8) according to sales figures from the Swedish Heat Pump Organization (SVEP), covering about 90% of the residential market. The total number of installations is therefore estimated to be about 200,000.

Heat pumps are now the most popular type of heating device for small residential buildings with hydronic systems (water-based heating systems) in Sweden, whether replacing oil burners, as a result of current oil prices, electric burners, due to expected electricity rates, or wood stoves, for convenience. Conversion from direct electric heating is a much slower process. In addition to the residential sector, there are also some large-scale installations (both closed and open loop) for district heating networks. The average heat output of all heat pump units is estimated to be about 10 kW .

Swedish ground-coupled heat pump installations are usually recommended to cover about 60% of the dimensioning load – about 3500–4000 full-load hours per year – with electric heaters integrated in the heat pump cabinet covering the remaining load. Current trends suggest that the heat pump load fraction will increase to 80–90%.

It is estimated that about 70% of all installations are vertical, that is, boreholes. In the residential sector, the average depth of vertical installations is about 125 metres, and the average loop length of horizontal installations is about 350 metres. Single U-pipes – polyethylene tubes of 40 mm in diameter, and pressure norm at 6.3 bars – in open, groundwater-filled boreholes are used in almost all installations. Double U-pipes are sometimes used when heat is injected into the ground. Thermal response tests have demonstrated that natural convection enhances the heat transfer in groundwater-filled boreholes, when compared with sand-filled (and grouted) boreholes. The popularity of ground-coupled heat pumps has, however, raised concerns about the long-term thermal effects of boreholes on neighbouring boreholes.

Larger systems for multi-family dwellings are becoming more popular. Free cooling from vertical installations is marketed, but has found little interest in the residential sector. The increasing interest in cooling in the commercial and industrial sector opens up a new market for ground-coupled heat pumps.

The current trend in the technical development of heat pumps is for the slow replacement of piston compressors replaced by scroll compressors, which are valued for their relatively quiet operation and compact design. There is also an interest in variable capacity control; for instance, by using one large and one small compressor in the same machine, domestic hot water can be produced with the smaller compressor in the summer. Furthermore, Swedish manufacturers still use refrigerant fluid R407C, but there is a trend towards using R410A, as is found in most imported heat pumps, and there is also interest in propane. Research is ongoing in the construction of heat

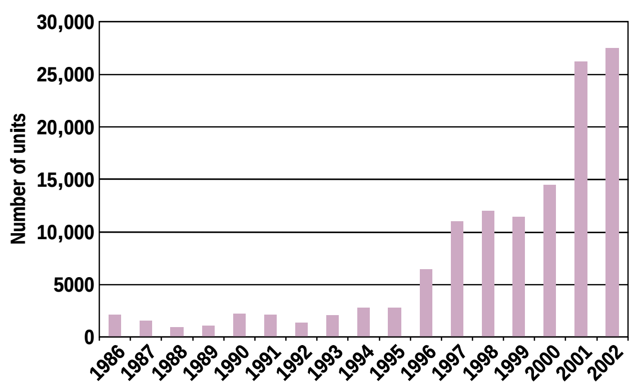


FIGURE 8. **Number of annual heat pump sales in Sweden. Source: based on data from SVEP**

The wellfield for the Nydalen GSHP in Oslo, Norway; the station will supply several buildings

pumps with very low volume of refrigerant. Some manufacturers are also marketing heat pumps that utilize exhaust air and the ground as heat sources. This exhaust air can be used for preheating the heat carrier fluid from the borehole, or for recharging the ground when the heat pump is idle.

In larger borehole systems, the heat balance of the ground has to be considered to ensure favourable long-term operational conditions. If the heat load dominates, the ground may have to be recharged with heat during the summer. Natural renewable sources such as outside air, surface water and solar heat should be considered. At Näsby Park near Stockholm, there is an installation under construction, with 48 boreholes to depths of 200 metres, where a 400 kW heat pump is used for base heat load operation for 6000 hours per year. The boreholes are recharged with warm (15°C–20°C) surface water from a nearby lake during the summer.

An example from Norway

In Nydalen, in the Norwegian capital of Oslo, 180 hard rock wells will be essential in the provision of heating and cooling to a building of nearly 200,000 m^2 in area. The project is the largest of its kind in Europe. An energy station will supply the emerging building stock in Nydalen with heating and cooling.[14] By using heat pumps and geothermal wells, heat can be both collected from and stored in the ground. In the summer, when there is a need for cooling, heat is pumped into the ground. Bedrock temperature may then be increased from the usual temperature of 8°C up to 25°C. During the winter, this is used for heating purposes. The output of the system is 9 MW heating and 7.5 MW cooling, and annual energy purchase will be reduced by an anticipated 60–70%, compared to heating with electricity, oil or gas. The combined heating and cooling ensures high utilization of the energy station.

The geothermal energy storage represents the most significant aspect of the project. Each of the 180 wells has a depth of 200 metres, providing 4–10 kW of heat transfer capacity. The total thermal storage volume of the bedrock is 1.8 million m^3, located below the building. Plastic tubes in closed circuits are used for heat transfer.

Total cost of the project is NKr 60 million (€7.5 million). This is about NKr 17 million (€2 million) more than the cost of a conventional solution, that is, one without the energy wells and the collector system. However, with an anticipated reduction in annual energy purchases of close to NKr 4 million (€500,000), the project will be profitable. The project has received a total financial support of NKr 11 million (€1.5 million) from the government owned entity Enova SF and the Energy Fund of the Municipality of Oslo. Start-up of the energy station began in April 2003, with about half of the wells operational. The remaining wells will most probably be connected to the station in 2004.

THE RENEWABLE ARGUMENT FOR GSHPS

While installations of GSHPs have been quietly increasing, there has only been limited recognition that they make a contribution to the adoption of renewable energy. This is partly because they are purely associated with the provision of heating and cooling, and do not therefore figure in renewable electricity considerations. However, there are two other factors that limit recognition. The first is that there is a question mark over the sustainability of the energy from the ground, while the second is the widespread notion, based on air-source heat pumps, that there is no net gain in energy output. They are therefore seen only as energy efficiency technology, rather than renewable.

> With the use of renewably derived electricity, there need be no CO_2 emissions associated with the provision of heating (and cooling) to a building

During the 1950s and 1960s when air-source heat pumps came into vogue, electricity was being generated in central, fossil-fuelled plant with efficiencies approaching 30%. Air-source heat pumps themselves could usefully extract 60% of the useful renewable energy from the air, and could typically deliver seasonal performance factors (SPFs) – that is, coefficients of performance – ranging between 1.5 and 2.5. This means that a pump powered by centrally generated electricity would extract up to 2.5 times the energy it used itself from the air, so at most 75% (30% x 2.5) of the original energy used to generate the electricity has been recovered as useful heat. Thus, while renewable energy from the air has been used to deliver thermal energy efficiently, no net gain has resulted. The first column of Table 2 shows this.

The second column of Table 2 demonstrates today's figures. New cogeneration or combined-cycle generating plant can deliver electricity with efficiencies exceeding 40%, while ground-coupled heat pumps are demonstrating SPFs in excess of 3.5. This results in an apparent 'efficiency' of 140%, with 71% of the final energy now coming from the ground. More importantly there is an excess of 40% over and above the original energy consumed in generating the electricity. It is this combination of the efficiency of ground-coupled water-source heat pumps with new electrical generation efficiency that results in the liberation of an excess of renewable energy.

TABLE 2. Energy and efficiency comparisons for heat pumps

	Old (air-source + old fossil fuel)	New (water-source + new fossil fuel)
Electrical generation efficiency	30%	40%
SPF (or COP)	2.5	3.5
Delivered energy/consumed energy	75%	140% (see text)
Delivered renewable energy	60%	71%
'Excess' renewable energy	–25%	40%

Of course, if the electricity can be generated from renewable sources in the first place, then all of the delivered energy is renewable. There are suggestions that, in order to maximize the delivery of renewable energy, it makes economic sense to couple renewable electricity to ground-coupled heat pumps as quickly as possible.

While the energy argument may be contentious, the reduction in CO_2 emissions is easier to demonstrate. For instance, the coupling of ground-source heat pumps to the UK electricity grid could lead to reductions in overall CO_2 emissions of more than 50%, compared to conventional space heating technologies based on fossil fuels (based on the current generation mix on the UK grid). With the use of renewably derived electricity, there need be no CO_2 emissions associated with the provision of heating (and cooling) to a building.

Several assumptions must be made when looking at the worldwide savings of tonnes of oil equivalent (toe) and CO_2 associated with the currently estimated installed capacity of GSHPs. If the annual geothermal energy use is 52,000 TJ (14,400 GWh), then comparing this to electrical energy generation using fuel oil, at 30% efficiency, gives savings of 28.6 million barrels of oil or 4.3 million toe – a saving of about 13 million tonnes of CO_2. If we assume savings in the cooling mode at about the same number of operating hours per year, these figures would double.

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13. International Energy Agency. *Reducing carbon emissions with heat pumps, the UK potential*. HPC-AR-15. IEA Heat Pump Centre, the Netherlands. November 2002.
14. More details about the project can be found at www.avantor.no (the project owner) or www.geoenergi.no (thermal energy storage).

FURTHER INFORMATION

International Ground Source Heat Pump Association, Oklahoma State University, Stillwater, Oklahoma (see www.igshpa.okstate.edu).
Geothermal Heat Pump Consortium, Washington, DC (see www.geoexchange.org).
IEA Heat Pump Centre, Sittar, the Netherlands (see www.heatpumpcentre.org).
European Geothermal Energy Council (see www.geothermie.de/egec_geothernet/menu/frameset.htm).