GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS A WORLD OVERVIEW

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INTRODUCTION

Geothermal (ground-source) heat pumps (GHP) are one of the fastest growing applications of renewable energy (see discussion at the end of this article) in the world, with annual increases of 10% in about 30 countries over the past 10 years. Its main advantage is that it uses normal ground or groundwater temperatures (between about 5 and 30ºC), 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 12,000 MWt (thermal) and the annual energy use is about 72,000 TJ (20,000 GWh). The actual number of installed units is around 1,100,000, but the data are incomplete. Table 1 lists the countries with the highest use of GHPs.

Table 1. Leading Countries Using GHP

Country	MWt	GWh/yr	Number Installed
Austria	275	370	23,000
Canada	435	600	36,000
Germany	640	930	46,400
Sweden	2,300	9,200	230,000
Switzerland	525	780	30,000
USA	6,300	6,300	600,000

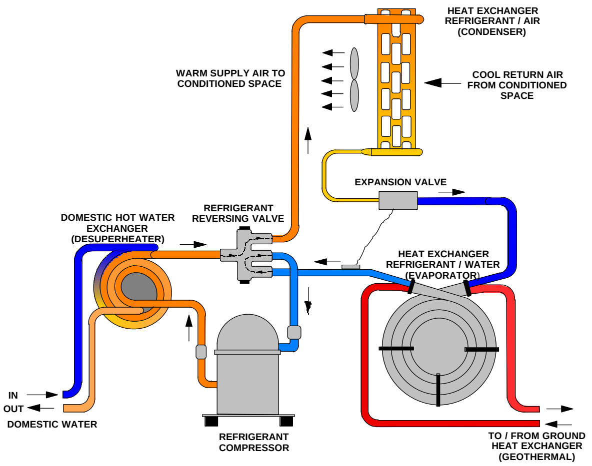

Figure 1a. ***GHP in the heating cycle (source: Oklahoma State University).***

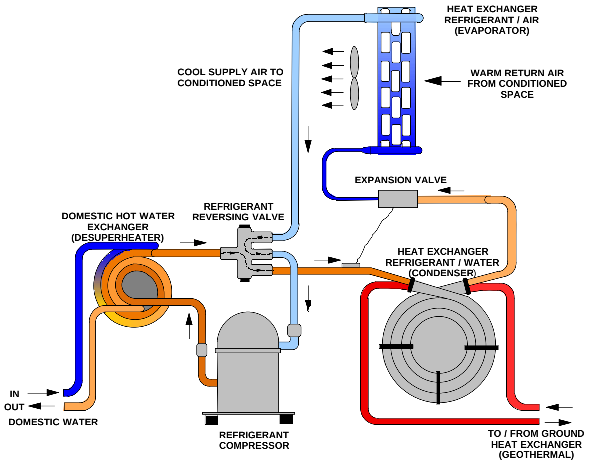

Figure 1b. ***GHP in the cooling cycle (source: Oklahoma State University).***

GHPs use the relatively constant temperature of the earth to provide heating, cooling and domestic hot water for homes, schools, government and commercial buildings. A small amount of electricity input is required to run a compressor; however, the energy output is of the order of four times this input. These "machines" cause heat to flow "uphill" from a lower to higher temperature location- really nothing more than a refrigeration unit that can be reversed. "Pump" is used to described the work done, and 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, which was then modified as a GHP by Robert Webber in the 1940s. They gained commercial popularity in the 1960s and 1970s. See Figure 1 for diagrams of typical GHP operation.

GHPs come in two basic configurations: ground-coupled (closed loop) and groundwater (open loop) systems, which are installed horizontally and vertically, or in wells and lakes. The type chosen depends upon the soil and rock type at the installation, the land available and/or if a water well can be drilled economically or is already on site. See Figure 2 for diagrams of these systems. As shown in Figure 1, a desuperheater can be provided to use reject heat in the summer and some input heat in the winter for the domestic hot water heating.

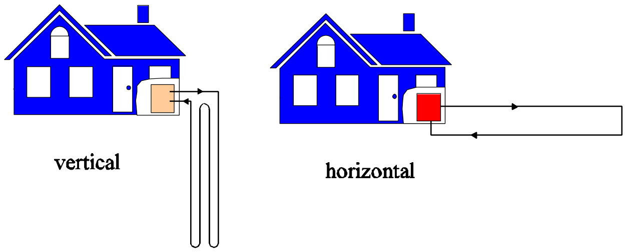

Figure 2a. *Closed loop heat pump systems (source: Geo-Heat Center).*

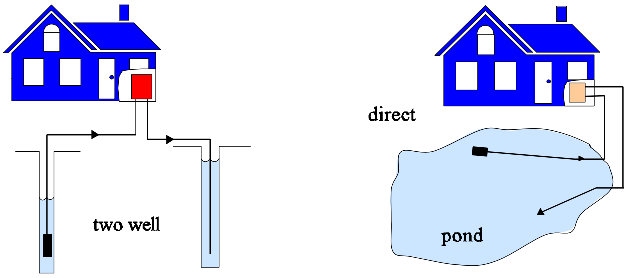

Figure 2b. *Open loop heat pumps systems (source: Geo-Heat Center).*

In the ground-coupled system, a closed loop of pipe, placed either horizontally (1 to 2 m deep) or vertically (50 to 100 m deep), is placed in the ground and a water-antifreeze solution is circulated through the plastic pipes to either collect heat from the ground in the winter or reject heat to the ground in the summer (Rafferty, 1997). The open loop system uses groundwater or lake water directly in the heat exchanger and then discharges it into another well, into a stream or lake, or on the ground (say for irrigation), depending upon local laws.

The efficiency of GHP units are 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) which is the ratio of the output energy divided by the input energy (electricity for the compressor) and varies from 3 to 6 with present equipment (the higher the number the better 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 and is dependent upon backup 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 and cooling season, respectively, and takes into account system properties.

UNITED STATES EXPERIENCE

In the Unites States, 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 1,000 full-load heating hours per year. In Europe, most units are sized for the heating load and are often designed to provide just the base load with peaking by fossil fuel. As a result, the European units may operated from 2,000 to 6,000 full-load hours per year, with an average of around 2,300 annual full load hours. Even though the cooling mode rejects heat to the earth, and thus is not geothermal, it still saves energy and contributes to a "clean environment." In the United States, GHP installations have steadily increased over the past 10 years with an annual growth rate of about 12%, mostly in the mid-western and eastern states from North Dakota to Florida. Today, approximately 80,000 units are installed annually, of which 46% are vertical closed loop systems, 38% horizontal closed loops systems and 15% open loop systems. Over 600 schools have installed these units for heating and cooling, especially in Texas. It should be noted at this point, that in the United States, heat pumps are rated on tonnage (i.e. one ton of cooling power--produced by a ton of ice) and is equal to 12,000 Btu/hr or 3.51 kW (Kavanaugh and Rafferty, 1997). A unit for a typical residential requirement would be around three tons or 10.5 kW installed capacity.

One of the largest GHP installations in the United States is at the Galt House East Hotel in Louisville, Kentucky. Heat and air conditioning is provided by GHPs for 600 hotel rooms, 100 apartments, and 89,000 square meters of office space for a total area of 161,650 square meters. The GHPs use 177 L/s from four wells at 14EC, providing 15.8 MW of cooling and 19.6 MW of heating capacity. The energy consumed is approximately 53% of an adjacent similar non-GHP building, saving $25,000 per month.

One of the recent converts to this form of energy savings is President George W. Bush, who installed a geothermal heat pump on his Texas ranch during the election campaign (Lund, 2001). 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%.

EUROPEAN SITUATION

Ground-source heat pumps (GSHP) can offer both heating and cooling at virtually any location, with great flexibility to meet any demands. In western and central European countries, the direct utilization of geothermal energy to supply heat through district heating to a larger number of customers so far is limited to regions with specific geological settings. In this situation, the utilization of the ubiquitous shallow geothermal resources by decentralized GSHP systems is an obvious option. Correspondingly, a rapidly growing field of applications is emerging and developing in various European countries. A rapid market penetration of such systems is resulting; 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 R&D focusing on GSHP in Europe resulted in a well-established concept of sustainability for this technology, as well as sound design and installation criteria. A typical GSHP with borehole heat exchanger (BHE; a "vertical loop" in U.S.-terms) is shown in Figure 3. These systems require currently for each kWh of heating or cooling output 0.22 - 0.35 kWh of electricity, which is 30 - 50% less than the seasonal power consumption of air-to-air heat pumps, which use the atmosphere as a heat source/sink.

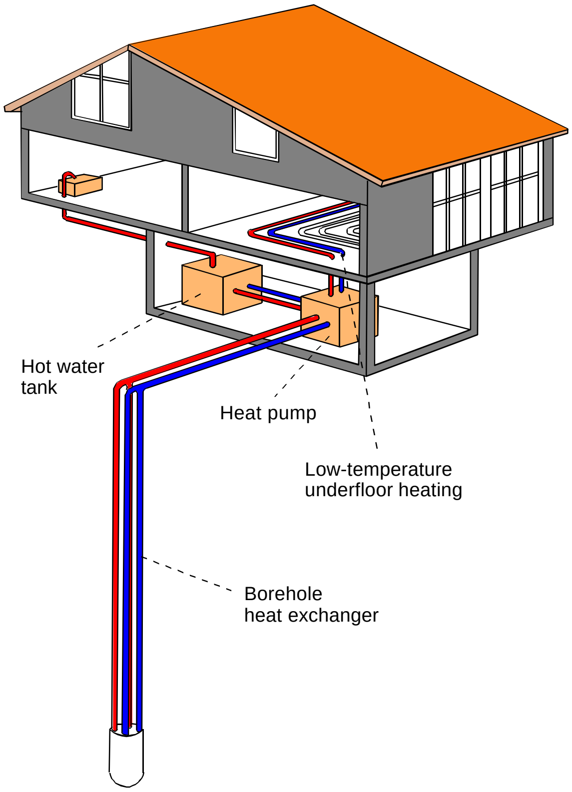

Figure 3. ***Typical application of a BHE / heat pump system in a Central European home, typical BHE length $100 m.***

The climatic conditions in many European countries are such that by far the most demand is for space heating; air conditioning is rarely required. Therefore, the heat pumps usually operate mainly 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 double use for heating and cooling will become of more importance in the future.

It is rather difficult to find reliable numbers of installed heat pumps in Europe, and in particular for the individual heat sources. Figure 4 gives some recent data for the number of installed units in the main European heat pump countries. 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 GSHP in Europe (see Table 1). In general it can be concluded, that market penetration of GSHP still is modest throughout Europe, with the exception of Sweden and Switzerland.

On the field of technical optimization, some developments of recent years should be mentioned:

- Thermal Response Test to determine the thermal parameters of the underground in situ;
- Grouting material with enhanced thermal conductivity; and
- Heat Pumps with increased supply temperatures for retrofit purposes.

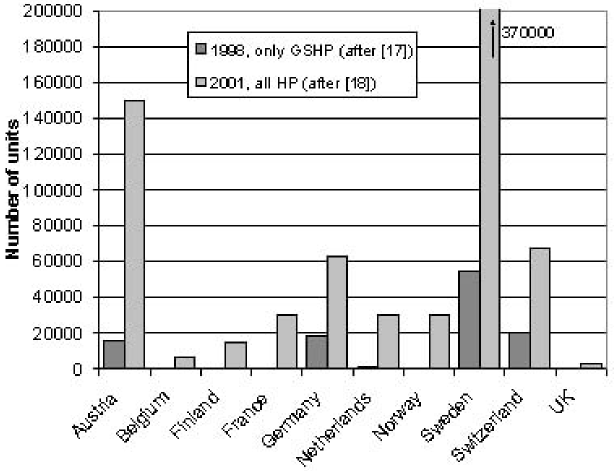

Figure 4. ***Number of installed heat pump units in some European countries (after data from Sanner, 1999; and Donnerbauer, 2003).***

For a thermal response test, basically a defined heat load is put into the BHE and the resulting temperature changes of the circulating fluid are measured (Figure 5) (Eugster and Laloui, 2002). Since mid-1999, this technology is in use in Central Europe for the design of larger plants with BHE, allowing sizing of the boreholes based upon reliable underground data. Thermal response testing was first developed in Sweden and USA in 1995, and now is used in many countries worldwide. Together with reliable design software (Hellström and Sanner, 2001), BHE can be made a sound and safe technology also for larger applications.

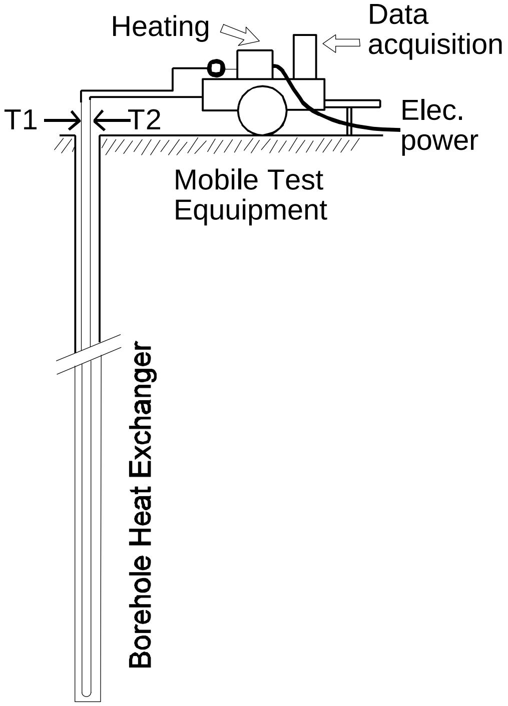

Figure 5. ***Schematic of a Thermal Response Test.***

Thermally enhanced grouting material has been available in USA for more than 10 years. Meanwhile, in Europe such material is also on the market, optimized for the relevant drilling habits and ground situation. The advantage of its use is a significant reduction in the borehole thermal resistance, which governs the temperature losses between the undisturbed ground and the fluid inside the BHE pipes. The table in Figure 6 gives some values for typical BHE; the effect could meanwhile also be demonstrated in situ, using the Thermal Response Test on BHE with different grouting materials.

Type of BHE	? grout	r_b
single-U, PE	0.8 W/m/K	0.196 K/(W/m)
	1.6 W/m/K	0.112 K/(W/m)
double-U, PE	0.8 W/m/K	0.134 K/(W/m)
	1.6 W/m/K	0.075 K/(W/m)

Figure 6. ***Table with data for r_b for different grouting materials.***

Up to now, the upper temperature limits encountered in commercially available heat pumps limit their application to low temperature heating systems. However, traditional heating systems already installed in older buildings in Germany require higher supply temperatures. To allow for retrofit of such systems with a heat pump, development of heat pumps allowing for 65EC and more are under way.

GERMAN EXPERIENCE

Since 1996, the statistics for heat pump sales in Germany allow the distinction of different heat sources (Figure 7). Within the last years, sales of GSHP have shown a steady increase, after the all-time low in 1991 with less than 2,000 units shipped. The share of GSHP (ground and water), which was less than 30% in the late-1980s, has risen to 78% in 1996 and 82% in 2002. Also from 2001 to 2002, when the building market in Germany was shrinking due to the poor economic situation, GSHP sales numbers still had a slight increase. There is still ample opportunity for further market growth, and the technological prospects endorse this expectation.

The application of GSHP in Germany is larger in numbers in the residential sector, with many small systems serving detached houses (Photo 1), but larger in installed capacity in the commercial sector, where office buildings requiring heating and cooling dominate. In most regions of Germany, the humidity in summertime allows for cooling without de-humidification (e.g. with cooling ceilings). These systems are well suited to use the cold of the ground directly, without chillers, and they show extremely high efficiency with cooling COP of 20 or more. The first system with BHEs and direct cooling was built already in 1987 (Sanner, 1990); meanwhile, the technology has become a standard design option. Some recent examples of GSHP systems in Germany can be found in Sanner and Kohlsch (2001).

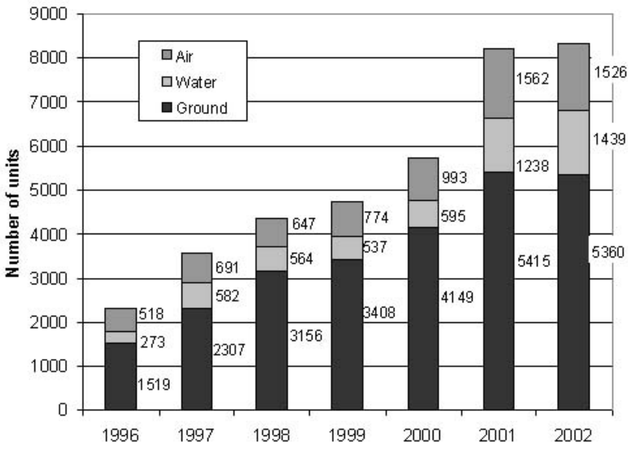

Figure 7. ***Number of annual heat pump sales in Germany, according to heat sources (after data from IZW e.V., Hannover and BWP e.V., Munich; heat pumps used for hot tap water production only are not included).***

Photo 1. ***Installation of borehole heat exchanger at a small house in Bielefeld, Germany, using a small, powerful Rotomax drilling rig.***

In Germany, the GSHP has left the R&D & D-status way behind, and the emphasis nowadays is on optimisation and securing of quality. Measures like technical guidelines (VDI 4640), certification of contractors, quality awards, etc., are beginning to be set into force to protect the industry and the consumers against poor quality and insufficient longevity of geothermal heat pump systems.

THE GEOTHERMAL HEAT PUMP BOOM IN SWITZERLAND

Geothermal heat pump (GHP) systems have spread rapidly in Switzerland, with annual increases up to 15%. At present there are over 25,000 GHP systems in operation. The three types of heat supply systems used from the ground are: shallow horizontal coils (<5 % of all GHPs), borehole heat exchangers (100 - 400m deep BHEs; 65%), and groundwater heat pumps (30%). Just in 2002 alone, a total of 600 kilometers of boreholes were drilled and equipped with BHEs.

GHP systems are ideally suited to tap the ubiquitous shallow geothermal resources. The reliability of long-term performance of GHP systems is now proved by theoretical and experimental studies as well as by measurements conducted over several heating seasons (Eugster and Rybach, 2000). Seasonal performance factors >3.5 are achieved.

The measurements and model simulations prove that sustainable heat extraction can be achieved with such systems (Rybach and Eugster, 2002). The reliable long-term performance provides a solid base for problem-free application; correct dimensioning of BHE-coupled GHPs allows widespread use and optimisation. In fact, the installation of GHPs, starting at practically zero level in 1980, progressed rapidly and now provides the largest contribution to geothermal direct use in Switzerland.

The installation of GHP systems has progressed rapidly since their introduction in the late-70s. This impressive growth is shown in Figures 8 and 9.

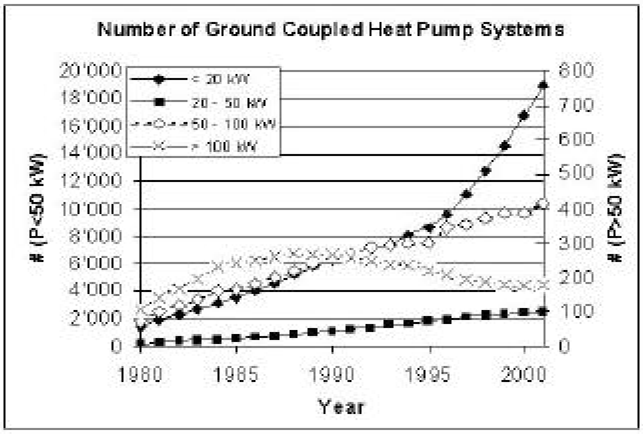

Figure 8. ***Development of geothermal heat pump installations in Switzerland in the years 1980 - 2001. From Kohl et al., (2002***).

The annual increase is remarkable: the number of newly installed systems increase with an annual rate >10%. Small systems (< 20 kW) show the highest growth rate (>15% p.a., see also Figure 1). In 2001, the total installed capacity of GHP systems was 525 MWt, the energy produced about 780 GWh. A large number of wells (several thousand) have been drilled in 2002 to install double U-tube borehole heat exchangers (BHE) in the ground (Photo 2). Average BHE drilling depth is now around 150-200 m; depths >300 m are becoming more and more common. Average BHE cost (drilling, U-tube installation incl. backfill) is now around 45 US$ per meter. In 2002, a total of 600 km of BHE wells were drilled.

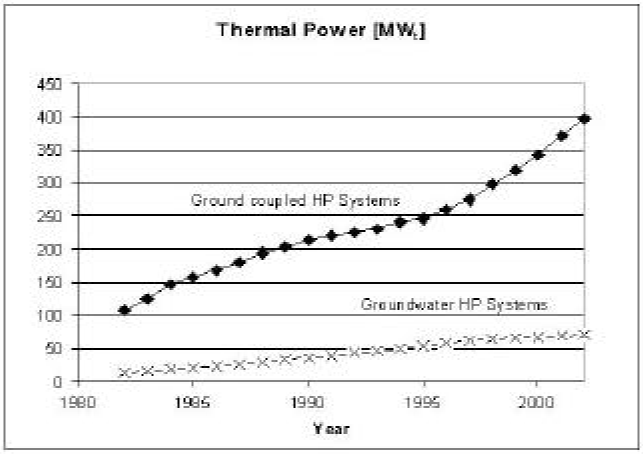

Figure 9. ***Development of installed capacities (MWt) of BHE-coupled (top) and groundwater-based (bottom) geothermal heat pumps in Switzerland during the years 1980 – 2001 (from Kohl et al., 2002).***

The Reasons of Rapid Market Penetration in Switzerland

The main reason for the rapid market penetration of GHP systems in Switzerland is that there is practically no other resource for geothermal energy utilization other than the ubiquitous heat content within the uppermost part of the earth crust, directly below our feet. Besides, there are numerous and various further reasons: technical, environmental, and economic.

Photo 2. ***End of double U-tube BHE (Geowatt).***

Technical Incentives

- Appropriate climatic conditions of the Swiss Plateau (where most of the population lives): Long heating periods with air temperatures around 0^0C, little sunshine in the winter, ground temperatures around 10 - 12^0C already at shallow depth;
- The constant ground temperature provides, by correct dimensioning, a favourable seasonal performance factor and long lifetime for the heat pump;
- The GHP systems are installed in a decentralized manner, to fit individual needs. Costly heat distribution (like with district heating systems) is avoided;

- Relatively free choice of location next to (or even underneath) buildings and little space demand inside; and
- No need, at least for smaller units, for thermal recharge of the ground; as the thermal regeneration of the ground is continuous and automatic during period of non-use (e.g. summer).

Environmental Incentives

- No risk with transportation, storage, and operation (e.g. with oil);
- No risk of groundwater contaminations (as with oil tanks); and
- The systems operate emission-free and helps to reduce greenhouse gas emissions like CO_2.

Economic Incentives

- The installation cost of the environmentally favorable GHP solution is comparable to that of a conventional (oil based) system (Rybach, 2001);
- Low operating costs (no oil or gas purchases, burner controls etc. as with fossil-fueled heating systems);
- Local utility electricity rebates for environmentally favorable options like heat pumps; and
- A CO_2 tax is in sight (introduction foreseen for 2004).

A further incentive and reason for rapid spreading of GHP systems is "Energy Contracting" by public utilities. The latter implies that the utility company plans, installs, operates, and maintains the GHP system at own cost and sells the heat (or cold) to the property owner at a contracted price (cents/kWh).

Outlook in Switzerland

Whereas the majority of GHP installations serve for space heating of single-family dwellings (± sanitary water warming), novel solutions (multiple BHEs, combined heat extraction/storage {e.g., solar energy}, geothermal heating/ cooling, "energy piles") are rapidly emerging. With over one GHP units every two km^2, their areal density is the highest worldwide. This secures Switzerland a prominent rank in geothermal direct use (for installed capacity per capita among the first five countries worldwide). It is expected that the GHP boom in Switzerland will prevail for quite some time.

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 heat pumps for heating buildings has been inexorably slow. The first documented installation of a ground-source heat pump comes from the 1970s (Sumner, 1976). Another pioneer championed the installation of small closed loop systems in houses in Scotland during the early-90s. It then took time to discover why the adoption of this technology in the UK was so far behind the burgeoning activity in northern Europe and North America. The primary reasons are a relatively mild climate, poor insulation levels of the housing stock, lack of suitable heat pumps, and competition from an extensive natural gas grid. (Curtis, 2001)

In the mid-1990s, geothermal heat pumps slowly began to evolve–with lessons being learned from practices adopted in Canada, America and northern Europe. It has taken time to identify the appropriate technology to be used in UK housing stock and to overcome issues that are unique to the UK. An additional complication is the complexity of the geology of the UK within a relatively small geographical area.

In the last two years, geothermal heat pumps have been officially recognised as having a role to play in several UK initiatives–for example the affordable warmth program, renewable energy and energy efficiency targets.

The little known fact about these systems in the UK, is the dramatic reduction in carbon dioxide emissions that can be achieved compared to conventional systems. A geothermal heat pump connected to the UK electricity grid will lead to overall reductions in CO_2 emissions of between 40 and 60%--immediately. As the UK generating grid (presumably) gets cleaner over the years to come, so the emission levels associated with long-lived geothermal heat pumps will continue to fall even further. Architects and developers are also finding that new assessment criteria for buildings are beginning to take account of the carbon performance of new properties.

From very small beginnings, geothermal heat pumps are now beginning to appear at locations all over the UK, from Scotland to Cornwall. Self-builders, housing developers and housing associations are now customers of these systems. Domestic installations ranging in size from 25 kW to 2.5 kW, 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, and will establish credible installers, standards and heat pumps that are suitable for the UK domestic sector. Together with a 1,000-house program launched last year by a major UK utility (Powergen), it is expected that there will be significant growth in interest and many successful installations of geothermal heat pumps in the domestic sector throughout the UK over the next few years.

Another important area of activity is the application of geothermal heat pumps to 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 (IEA, 2002). The first of these was carried out on the UK, and the conclusions were that the largest contribution that geothermal systems could make is in the office and retail sector. The first non-domestic installation, at only 25kW, was for a health centre on the Isles of Scilly. This was rapidly followed between 2000, and today with installations growing in size and sophistication up to 300kW. The applications range through schools, single and multi-storey office blocks, and several visitor/exhibition centers. Notable examples are the National Forest Visitor Centre, in Derbyshire, office blocks in Chesterfield, Nottingham, Croydon, and Tolvaddon Energy Park in Cornwall (Photo 3). A large installation has just been commissioned at a new IKEA distribution center in Peterborough. These installations use a variety of heat pump configurations, ranging from simple heating only of underfloors, 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

Photo 3. Drilling for a GSHP installation in progress in Cornwall, UK (Geoscience).

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 lower energy prices and quality problems deflated the heat pump market, and during the next 10 years, an average of about 2,000 units were installed per year. In 1995, the public awareness and acceptance of ground-coupled began to grow due to strong support and subsidies from the Swedish state. In 2001 and 2002, about 27,000 ground-coupled heat pumps were installed (see Figure 10) according to the sales figures from the Swedish Heat Pump Organization (SVEP), which is believed to cover about 90% of the residential market. The total number of installation 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 in Sweden; where, the heat pump replaces oil burners because of current oil prices, electric burners because of expected electricity rates, and wood stoves because of convenience. Conversion from direct electric heating goes much slower. In addition to the residential sector, there are also some large-scale installations (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, which results in about 3500-4000 full-load hours per year. Electric heaters integrated in the heat pump cabinet cover the remaining load. There is a trend to increase the heat pump load fraction to 80 - 90%. It is estimated that about 80% of all installations are vertical (boreholes). In the residential sector, the average depth of vertical installations is about 125 m and the average loop length of horizontal installations is about 350 m. Single U-pipes (polyethylene tubes, diameter 40 mm, pressure norm 6.3 bars) in open, groundwater-filled 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 compared with sand-filled (and grouted) boreholes. The popularity of ground-coupled heat pumps has raised concerns of long-term thermal influence between neighbouring boreholes.

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

Technical development of heat pumps involves a trend where piston compressors are slowly replaced by scroll compressors, which are valued for the relatively quiet operation and compact design. There is also an interest in variable capacity control such as using one small and one large compressor in the same machine, so that domestic hot water can be produced with the smaller compressor in the summer. Most of the imported heat pumps use refrigerant fluid R410A. Swedish manufacturers still use R407C, but there is a trend to use more R410A and there is also an interest in propane. Research is ongoing to construct heat pumps with very low volume of refrigerant. Some manufacturers are marketing heat pumps that utilize exhaust air and ground as a heat source. The exhaust air can be used for preheating the heat carrier fluid from the borehole or for recharging of the ground when the heat pump is idle.

In larger borehole systems, the heat balance of the ground has to be considered in order to ensure favorable 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 (close to Stockholm), there is an installation under construction with 48 boreholes to 200 m depth; where, a 400-kW heat pump is used for base heat load operation during 6,000 hours per year. The boreholes are recharged with warm (15-20°C) surface water from a nearby lake during the summer.

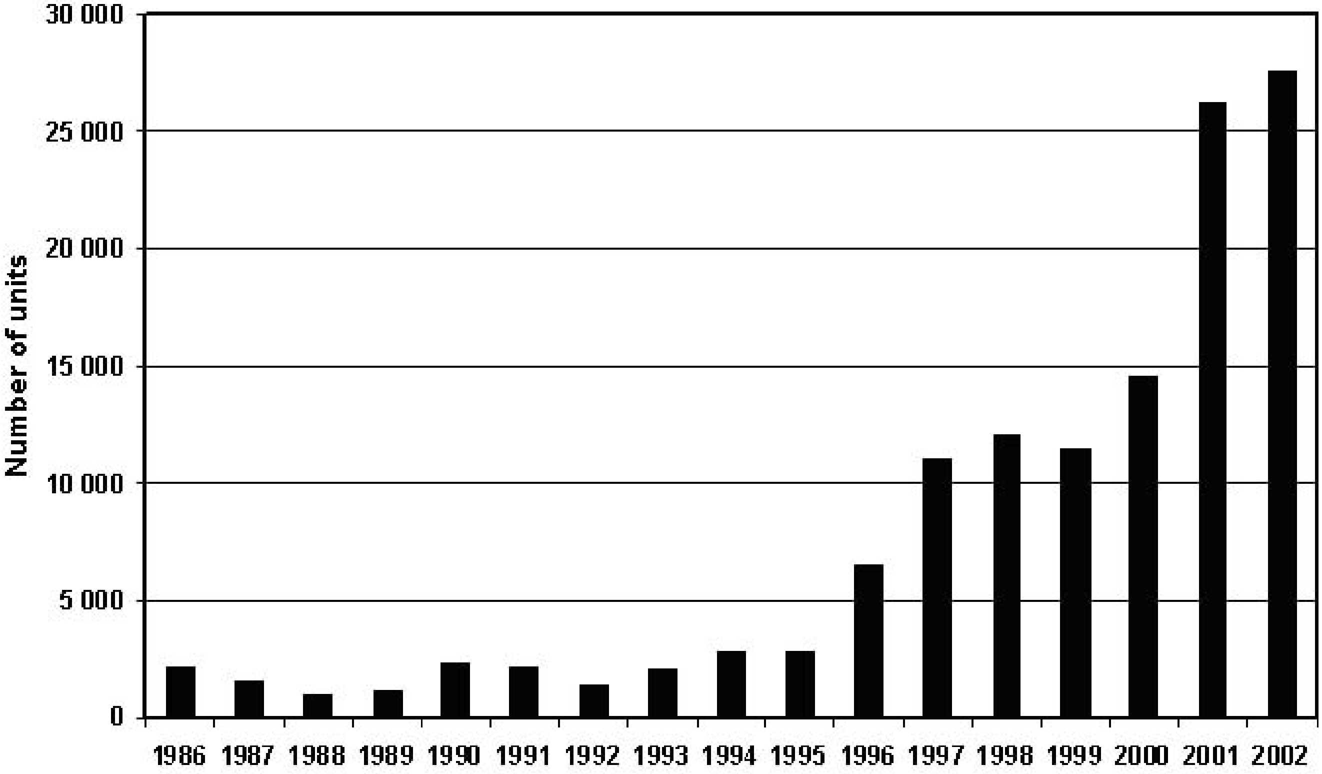

Figure 10. ***Number of annual heat pump sales in Sweden (after data from the Swedish Heat Pump Organization (SVEP)).***

EXAMPLE FROM NORWAY

In Nydalen, Oslo, 180 hard rock wells will be a key factor in providing heating and cooling to a building area of close to 200,000 m^2. The project is the largest of its kind in Europe (Photo 4)

Photo 4. ***The well field for the Nydalen GSHP in Oslo, Norway; the station will supply several buildings.***

An energy station will supply the emerging building stock in Nydalen with heating and cooling. By using heat pumps and geothermal wells, heat can both be collected from and stored in the ground. In the summer, when there's a need for cooling, heat is pumped into the ground. Bedrock temperature may then be increased from a normal of 8EC up to 25EC. During the winter season, the heat is used for heating purposes. The output is 9 MW heating and 7.5 MW cooling. Annual energy purchase is to be reduced by an anticipated 60-70 percent, compared to heating by electricity, oil or gas. The combined heating and cooling secures a high utilization of the energy station.

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

Total cost of the project is NOK 60 million (7.5 million Euro). This is about NOK 17 million more than the cost of a conventional solution (i.e. without the energy wells and the collector system). However, with an anticipated reduction in annual energy purchases of close to NOK 4 million, the project will be profitable. The project has received a total financial support of NOK 11 million from the government owned entity Enova SF and the Energy fund of the Municipality of Oslo.

Start-up of the energy Station was planned for April 2003, including about half of the wells. The remaining wells will most probably be connected to the station in 2004.

You can read more about the project at www.avantor.no (project owner) and www.geoenergi.no (thermal energy storage).

CONCLUSIONS: THE RENEWABLE ARGUMENT FOR GEOTHERMAL HEAT PUMPS

While installations of these systems have been quietly growing, there has 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 therefore, do not figure in renewable electricity considerations. However, there are two other factors--a question mark over the sustainability of the energy from the ground, and a widespread notion, based on air source heat pumps, that there is no net gain in energy output--and that they are, therefore, only an energy efficiency technology.

During the 1950s and 60s when air-source heat pumps came in to vogue, electricity was being generated in central station fossil fuel plants with efficiencies approaching 30%. Air-source heat pumps of the time delivered SPFs (COPs) (seasonal performance factors) ranging between 1.5 and 2.5 typically. While Table 2 shows that at the point of delivery in the building, 60% of the energy is extracted from the air, only 75% 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 second column of Table 2 demonstrates today's figures. New co-generation or combined cycle generating plant can deliver electricity with efficiencies exceeding 40%. 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.

Table 2. Energy and Efficiency Comparisons

	Old (Air-Source +Old Fossil Fuel)	**New (Water-Source + New Fossil Fuel)**
Electric generation efficiency	0.3	0.4
COP or SPF	2.5	3.5
Delivered energy/consumed energy	0.75	1.4
Delivered renewable energy	60%	71%
"Excess" renewable energy	-25%	40%

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.

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 it in order to maximize the delivery of renewable energy, it makes economic sense to couple expensive 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. The coupling of ground-source heat pumps to the current UK electricity grid, for example, can lead to reductions in overall CO_2 emissions of over 50% compared to conventional space heating technologies based on fossil fuels. This arises from the current generation mix on the UK grid. As the amount of CO_2 emitted by electricity generation falls, so the reduction in CO_2 emissions through the use of ground-source heat pumps will increase. With the use of renewable-derived electricity there need be no CO_2 emissions associated with the provision of heating (and cooling) of a building.

If one looks at the worldwide savings of TOE (tons of oil equivalent) and CO_2 for the current estimated installed capacity of geothermal (ground-source) heat pumps, several assumptions must be made. If the annual geothermal energy use is 65,000 TJ (18,000 GWh) and comparing this to electricity energy generation using fuel oil at 30% efficiency, then the savings are 35.8 million barrels of oil or 5.4 million TOE. This is a savings of about 16 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.

FURTHER INFORMATION

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

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