NEW DEVELOPMENTS IN GEOTHERMAL HEAT PUMPS - WITH A VIEW TO THE SWISS SUCCESS STORY

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ABSTRACT
Global geothermal heat pump (GHP) system growth is exponential, with 20 % annually. Promoting factors are identified and discussed. GHP technology is still developing, now increasingly supplying large building complexes with heating, cooling and domestic hot water. A combination of supporting conditions brought Switzerland to a top international rank in GHP applications.

Keywords: growth trends, promoting factors, technology development, space heating and cooling, large building complexes.

1. GROWTH TRENDS, SUCCESS FACTORS

Geothermal heat pumps (GHP) are one of the fastest growing applications of renewable energy in the world and definitely the fastest growing segment in geothermal technology, in an increasing number of countries. At the occasion of World Geothermal Congresses 1995, 2000, 2005 and 2010 John Lund et al. assembled relevant statistical data. Global status data are plotted in Figure 1 (semi-logarithmic scale), which clearly show that the growth is exponential – with an annual growth rate of 20 %.

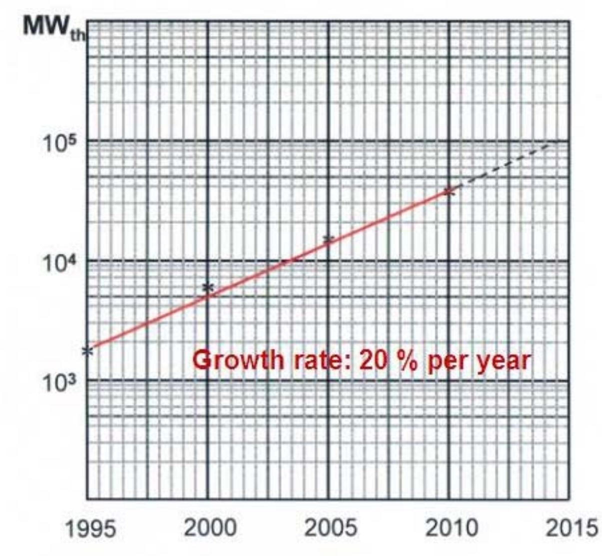

Fig. 1 Global growth of installed GHP capacity is exponential with 20 % per year. Data from Lund et al. (2010) plotted.

Although GHPs are increasingly installed, their advancing is highly different from country to country. The success factors leading to market penetration and expansion are identified and discussed below.
When compared to other segments of geothermal technology the GHPs have definitely less requirements (i.e. number of success factors), see Table 1.

Table 1: Comparison of success factors for various geothermal technologies ("conditions needed for success", Lund 2011)

Factor	Flash plants	Binary plants	Direct use	GHP
Resource	xxx	xx	x	o
Ownership	xxx	xxx	xx	x
Permits	xxx	xxx	x	o
Environment	xxx	xx	x	o
Finances	x	xx	xxx	x
Risks	xxx	xx	x	o
Expertise	xxx	xxx	xx	x
Market	xxx	xxx	xxx	xx
Hero/Leader	xx	xx	xxx	x
Transmission	xxx	xx	x	o
Public acceptance	xxx	xx	x	o
xxx : major, xx : minor, o : none				

Ownership does not really matter; the GHPs are installed in buildings with clear land ownership. Decisive is that the builder-owner is aware of the advantages and benefits (e.g. costs, environmental friendliness) of GHP technology. Unlike with other forms of geothermal direct use (like district heating) a local hero –who is fully convinced in the geothermal solution and is ready to fight for it through all phases and instances– is not really needed for GHPs, only knowledgeable architects, designers, installers etc. In the following, specific success factors are dealt with in more detail.

Production sustainability

Reliable long-term operation is a prerequisite of widespread acceptance of GHP systems. For GHPs the issue of sustainability concerns the various heat sources (horizontal and vertical heat exchanger pipes, groundwater (Rybach and Mongillo 2006). Theoretical and experimental studies have been performed to establish a solid base of long-term reliability of GHP production characteristics (Rybach et al. 1992, Rybach and Eugster 1998, Eugster and Rybach 2000, Signorelli et al. 2005). Experience shows that properly designed GHP systems operate fully satisfactorily over decades.

Finances

Finances of course are a key issue. Although GHPs need considerable initial investment (higher than for common fossil-fired systems), the overall performance is more favourable. The higher installation cost is due to the earth works (usually drilling and completion) and components (heat pump, connections, distributors). On the other hand, running costs are generally low (mainly only electricity for heat pumps and circulation pumps).

Prices/costs are certainly of paramount importance. Two factors are important in this respect for GHPs: 1) no need to burn fuel, 2) subsidies. This means that GHP operation costs are significantly lower and the environmental benefits entitle to subsidies in many countries. The economics of GHP systems can best be considered in comparison with other, conventional and fossil fired systems. For the comparison, a common single-family house with 150 m^2 living space, a heating system with 7.5 kW_t capacity (heating needs), and an annual energy requirement of 65 GJ for a season of 2'400 heating hours per year is considered, in comparison with gas and oil heaters (Auer, 2010). Table 2 shows the comparison.

Table 2: Cost comparison of heating technologies: 1) BHE based GHP heater, 2) gas condensing heater, 3) oil heater (numbers from Auer, 2010)

Cost item	GHP / BHE	Gas heater	GHP / BHE*	Oil heater
Investment cost	**18’000 €**	**8’800 €**	**18’000 €**	**12’500 €**
Higher GHP investment	**9’200 €**		**5’500 €**	
O & M cost/year	**680 €**	**1’720 €**	**680 €**	**2’000 €**
GHP savings/year	**1’040 €**		**1’320 €**	
Amortisation period **- without investment payment** **- at 6 % interest**	 **9 years** **13 years**			 **just < 5 years** **just > 5 years**

*) BHE: Borehole Heat Exchanger

Of course the future price development of oil, gas and electricity is unknown; usually it is assumed that electricity prices will increase significantly slower than oil and gas prices. In the above comparisons the issues of CO_2 emission (i.e. a CO_2 taxation) are not considered. A CO_2 tax for space heating is already introduced in several European countries. It can be expected that this trend continues and thus the GHP systems will have increasing advantages. In addition, the above comparison is made only for heating. The great advantage of GHP systems is that the same equipment can be used for cooling in summer, a real benefit in times of global warming.
Equally important is the subsidization of heat pump systems in some areas by the electric utilities (which are often owned by the municipalities); it is very common for direct grants in the investment phase and/or indirect funding breaks via reduced electricity rates for households and small and medium-sized businesses. Subsidization pays off for the electric utility on balance, since the pump systems use more electricity than oil heating, for instance.

Expertise

The proper design of GHP systems has already been discussed above. Equally important is the professional standard at installation. The consideration and optimization of the three main GHP circuits (heat source, heat pump, heating/cooling unit) belongs to the planning stage. While heat pumps and heating/cooling units (hydronic or fan-coil systems) can readily be purchased “off the shelf” the installation (=drilling and completion) of GHP boreholes is a demanding task, quality assurance is needed. In several countries (USA, Canada, EU countries) the professional standard of drillers and installers is documented by certificates, engineering norms like VDI 4640 in Germany or SIA 384/6 in Switzerland define the standards to be followed.

Licensing, environmental benefits

In general, GHP installation needs permits. In most countries the water protection agencies (local, regional, national) are providing permits. Regulation varies from country to country; is some cases even within the same country. Usually some standard forms need to be filled and submitted; usually the permitting procedure is easy and straightforward. However, It is common practice that in groundwater protection areas the installation of GHP systems is limited or forbidden.
GHPs operate with little or no greenhouse gas (GHG) emissions since no burning processes are involved. GHPs driven by fossil fuelled electricity reduce the CO_2 emission by at least 50% compared with fossil fuel fired boilers. If the electricity that drives the geothermal heat pump is produced from a renewable energy source like hydropower or geothermal energy the emission savings are up to 100%.

Reducing current CO_2 emissions is the central option in all the efforts to mitigate global warming. Here a clear distinction must be made between actual emission reduction and merely avoidance of additional emission: by new GHPs only additional CO_2 emission can be avoided ("saving"), not a reduction of actual emissions. When GHPs are installed in refurbishment (to replace fossil-fueled systems) actual emission reduction can be achieved. Emission reduction is also evident when electric heater/cooler installations, driven by fossil-based electricity, are replaced by GHP systems.

Knowledge, outreach

The most important driving force of GHP development is simply knowledge and know-how. Besides, various applications and wide-scale realizations, high-level quality assurance and successful demonstration facilities are needed. Architects, engineers and building physicists are become nowadays increasingly knowledgeable about GHP system design and installation; drilling companies have the necessary special equipment to perform quick jobs. Heat pump promotion associations implement publicity campaigns to disseminate the good news about the benefits of the –in many countries still new– technology. All these factors led already to spectacular boosts of the GHP market in the last few years, especially in countries where only a couple of years before literally no installations existed.

2. TECHNOLOGY DEVELOPMENTS

Currently numerous new developments are evident, in various fields. Here the following shall be covered: 1) increasing applications of GHPs for space heating as well as for cooling (especially in moderate climate), 2) innovative solutions like energy pile systems, and 3) the tendency of supplying large-scale installations.

Heating and cooling with GHPs

The subsurface can be utilized as a heat sink as well as a heat store, utilizing the immense renewable storage capacity of the ground. In moderate climate the ground below about 15 m depth is in summer significantly colder than outside air. Thus a large geothermal store with favorable heat capacity is available where the heat can be exchanged (extracted from the building and deposited in summer, extracted from the ground store and supplied to the building in winter). The thermal capacity of the system depends –besides on the volume– on the thermal and hydrogeologic characetristics of the installation site; these must be carefully considered in system dimensioning. In summer, most of the time the heat pump can be bypassed and the heat carrier fluid circulated through the ground by the BHEs and through the heating/cooling distribution (e.g. floor panels). By these means the heat is collected from the building and deposited it in the ground for extraction in the next winter ("free cooling"). When free cooling alone cannot satisfy the cooling needs, heat pumps can be reversed for cooling since they can operate in normal (heating) and reverse (cooling) mode.

Innovative solutions like energy pile systems

It is increasingly common that borehole heat exchangers (BHE; usually the most frequently used ground-source heat pump component) are installed beneath (new) buildings. Energy piles are foundation piles equipped with heat exchanger piping. The piles are installed in ground with poor load-bearing properties. The energy piles use the ground beneath buildings as heat source or sink, according to the season. The systems needs careful design, taking into account especially the spacing between the piles, the ground thermal properties, and possible static influence of temperature changes in the piles.

Figure 2 shows installation and system sketch of energy piles.

Fig. 2 Sketch of energy piles below buildings (left), installation of heat exchanger loops in piles (right).
1: piles, 2: connections, 3: distributor, 4: base plate, 5: heat pump.

A prominent example of a well-engineered energy pile installation is Terminal E at Zurich airport. The technical data are as follows:
Building and energy: 85’200 m^2 surface area to supply, heating need 3020 MWh/a, cooling need 1’170 MWh/a; energy piles: 310 of total 440 piles, pile length 30 m each, 0.9-1.5 m diameter; heat pump/cooling machine: 630 kW heating power, seasonal performance factor 3.9; cooling power 470 kW, seasonal performance factor 2.7. Figure 3 shows the Terminal.

Fig. 3 Terminal E at Zurich airport, Switzerland – heated and cooled by an energy pile/heat pump system.

Large building complexes with GHPs

While in the early days of GHP development they have been nearly exclusively used for single family houses nowadays the GHP systems are becoming standard for large-scale buildings or complexes like schools, factories, shopping centers etc. The BHE fields for heating and for cooling are usually spatially separated. A typical example is the Richti development in Wallisellen near Zurich, Switzerland (Fig. 4) with 250 BHEs.

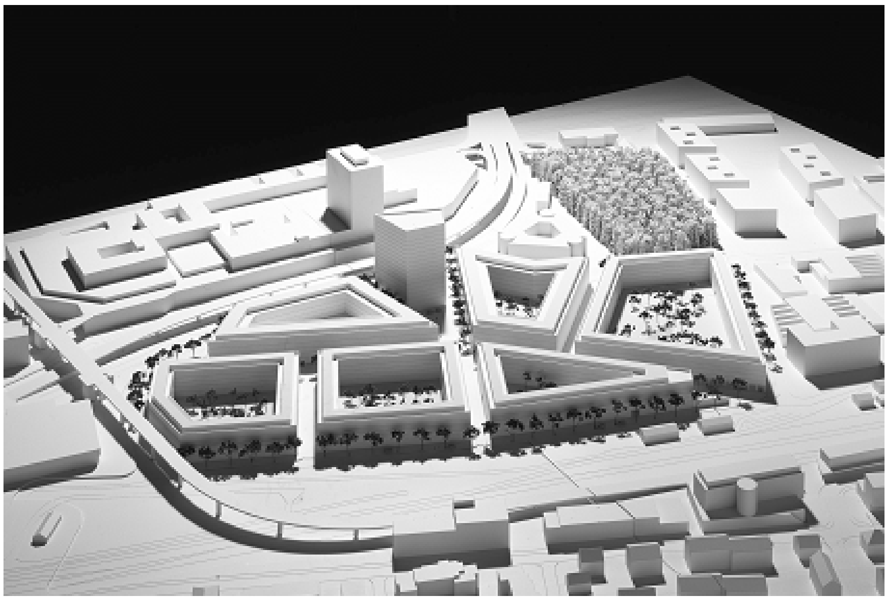

Fig. 4 Model of Richti development (now in construction).

Richti technical data and use data: 72’000 m^2 construction size, 1’200 inhabitants, 2’500 jobs, 35 % habitation, 10 % business, 55 % services; 5 GWh/a heating, 5 GWh/cooling; 250 BHEs 200 m deep (50 km total length). Total cost: 500 million CHF (~ 450 million US$).

4. THE SWISS GHP SUCCESS STORY

According to the compilation of global direct use data by Lund et al. (2010) Switzerland is a leading country: the areal GHP density (units per surface area) is the highest world-wide. Although not uniformly distributed over the country, in 2010 more than 2.5 units (standard size: 12 kW_{th}) operated per km^2. Average growth rate over the time period 2000 – 2010 is about 20 % per year. Nowadays numerous building complexes with several 100 BHE are established.

How come? A number of promoting factors led to this development. First, already in the late 1970ties the Swiss Federal Office generously supported basic studies, both theoretical and experimental. By these means the key operational parameters have been identified, the prerequisites of long-term system reliability determined, standardization as well as quality assurance could be established. In addition, favorable legal environment (licensing) as well as some subsidizing from various sources (at least until about 1997) was helpful. A first report about the Swiss GHP success can be found in Rybach and Kohl (2003).

A key result was a typical learning curve: decrease of up-front cost (the main obstacle to install GHP systems). Figure 5 shows the impressive decline (100 % over 24 years).

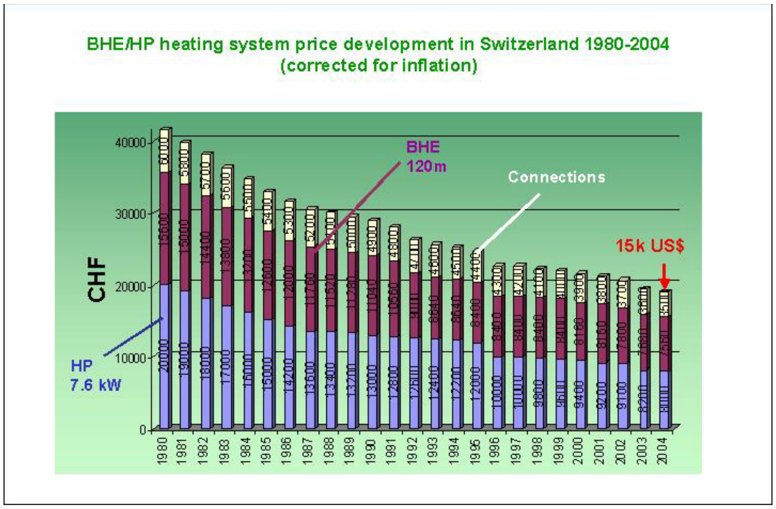

Fig. 5 Installation costs of geothermal heat pumps decrease significantly over time (for a typical, singe family dwelling). HP: heat pump. Diagram from http://www.fws.ch

One of the most important properties governing the yield of BHE-coupled GHP systems is ground thermal conductivity. Extensive measurement campaigns have been performed to secure the necessary data base; as the result a web-based catalogue is available to get numerical data for any location in the mostly populated area of Switzerland (north of the Alps; Leu et al., 1999). Customer confidence is of paramount importance for market penetration. The reliable functioning of GHP systems in the long term had to be demonstrated. Basic investigations like Rybach et al. (1992) and later studies (Rybach and Eugster, 2010) revealed that properly designed GHP systems operate in a fully sustainable manner.

A number of documents, essential for planning, installation and operation of GHP systems, have been produced: the engineering norm SIA 384/6 (2010), the Energy Pile Handbook SIA D0190 (2005) and the Licensing Application Guidebook BAFU (2008). These and many other informative and helpful documents, the latter downloadable from www.geothermie.ch, are all in German.

The Swiss Heat Pump Promotion Association FWS (www.fws.ch) is instrumental in quality assurance. It certifies, besides issuing quality labels for heat pumps, BHE driller companies. The BHE drilling meters are increasing impressively over the years (with a bout 20 % per year), see Figure 6. The increase for renovations is especially beneficial since it leads to actual CO_2 emission reduction (new GHP installations do not reduce CO_2 emission, they merely avoid (“save”) additional emission).

Finally the commercial role of electric utility companies like EKZ (of Canton Zurich) or EWZ (of Zurich City) is remarkable: they offer “Energy Contracting” (the company installs and operates the GHP system -for heating, cooling and warm water- and the consumer gets monthly bills). The equipment remains company property; usually the building owner can buy it after a certain period of time.

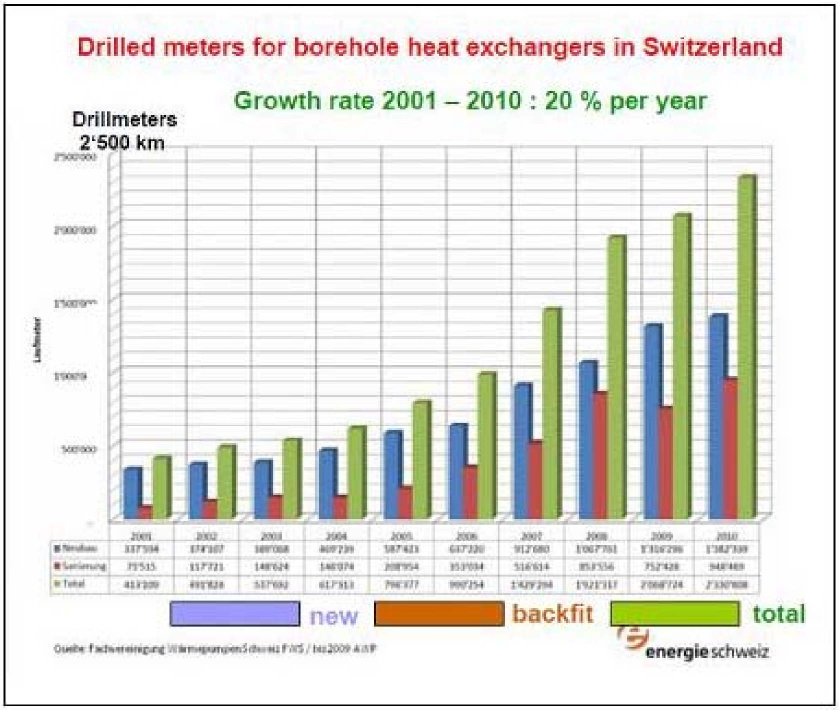

Fig. 6 Increase of drilling activities in Switzerland since 2001 (source: www.fws.ch) to 2'500 km in 2010. Increasing drilling for renovation ("backfit") is especially welcome since taking out of service fossil systems will actually reduce CO_2 emissions.

5. SUMMARY

Geothermal heat pumps are advancing, with different speed in various countries. Several factors can increase the speed; most of these have been considered and discussed above.

GHP technology is still developing, now increasingly supplying large building complexes with heating, cooling and domestic hot water.

A combination of supporting conditions brought Switzerland to a top international rank in GHP applications; hopefully similar developments can now happen in many countries too, including Japan.

Acknowledgment

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