EARTH HEAT PUMPS AND UNDERGROUND THERMAL ENERGY STORAGE IN GERMANY

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Key words: Heat pumps, direct cooling, space heating, commercial applications, thermal energy storage, environmental considerations

In the last years, the technical development of Earth Heat Pumps (Ground Source Heat Pumps, GSHP) in Mid Europe has advanced substantially, together with an increase in experience and knowledge. The paper gives an overview of the existing technology. The technological and market evolution from the first European plants in the early 70's is described shortly, and the state-of-the-art is shown using examples of the two largest plants with earth heat pumps in Germany. An important feature for applications of earth heat pumps in the commercial field in Europe now is space cooling, which has not been in demand in the past. Direct cooling from ground heat exchangers ("cold storage") is a new approach, sometimes combined with heat pumps in the cooling mode. Ecological and environmental calculations show the advantages of such "cold storage" plants. The latest example of this technology, the project for an Aquifer Thermal Energy Store (ATES) for the Reichstag Building, Berlin, is presented.

1. INTRODUCTION

The first German GSHP described in the literature by Waterkotte (1972) is dated from 1967/68, some years before the first Oil Crisis. This was more than 20 years after the first plant in North America in 1945 (Crandall, 1946), when an engineer experimented with horizontal pipes set at **1.5** m depth as heat source for a heat pump. The vertical earth heat exchanger was introduced in Europe in the late 70's (Rosenblad, 1979; Drafz, 1982), and from that time on has been used in various types mainly in Sweden, Germany, Switzerland and Austria (Sanner, 1992).

Contrary to the evolution following the first Oil Crisis, heat pumps now are produced at a satisfactory level of quality. The technical development of the heat pump itself has not grown much since 1980, but increased experience resulted in better reliability. Concerning heat pump systems, much progress has been made in system integration, in control systems and strategies, in reducing costs of ground coupling, in correct system layout etc. Not like the boom in 1980, a broader market penetration today could take place on a sound technological basis.

In Austria and Switzerland, the evolution was much slower. The peak in sales numbers in Austria was in 1981, and in the following years the shipments have been almost stable. A clear decrease can be seen in accordance to the falling oil prices from 1986 on. In Switzerland, ca. 4000 heat pump plants with vertical earth heat exchangers have been built since 1980, the number per year more or less stagnant in the last years. In both countries broad experience exists with heat pump plants, and for ground coupled systems in particular in Switzerland. Heat pumps are considered an advanced and modern technology and have a high standing in public opinion (not so in Germany).

For the customer, economy is still the main objective when deciding on heating equipment. But other considerations, as saving fossil fuel and, most important, reducing CO_2-emissions, are growing in importance in public discussion. An increasing number of people were willing to spend more money for environmentally benign systems in the last years (the current economic recession is, hopefully, only a temporary setback). Hence a small, but steadily increasing market can be expected for heat pumps, and in particular for advanced ground coupled heat pump systems with superior reliability and satisfactory performance. Some examples are described in more detail on the following pages.

2. GSHP WITH VERTICAL EARTH HEAT EXCHANGERS IN GERMANY

In figure 1 the schematic of a typical GSHP as used for heating residential houses is shown. These plants are of the heating-only type, where the heat sink is commonly a hydronic floor heating system. Integration of additional heat sources, such as boilers or firesides, is possible. A buffer storage tank of 0.4-1 m^3 for water is used to de-couple the fluid flow in the heat pump evaporator and in the heat distribution system. The heat output is controlled by on/off operation, the buffer storage allows sufficiently long running respectively stopping time. A general overview of the state-of-the-art is given in Sanner (1992).

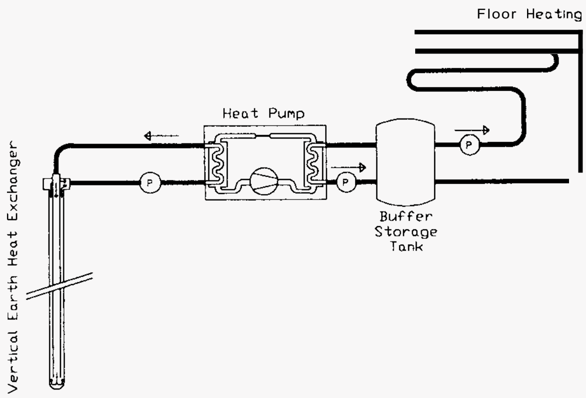

Figure 1: Schematic of "conventional" GSHP in Mid Europe

Various types of vertical earth heat erchangers have been used (fig. 2), with the double-U-tube made of polyethylene the most popular design. It offers good heat exchange through large surface area at low cost. Drilling methods suitable for most ground conditions are available (Sanner & Knoblich, 1991), with the down hole hammer being the fastest in hard rock. Drilling costs have decreased slightly over the last years. Installation is facilitated by use of pre-fabricated manifolds and modules with circulation pump. Nevertheless, the low number of units installed per year does not yet allow substantial cost reductions. The antifreeze in the ground coupling circuit usually is monoethylenglycol (25-33 % in water), whereas methanol might be a future alternative.

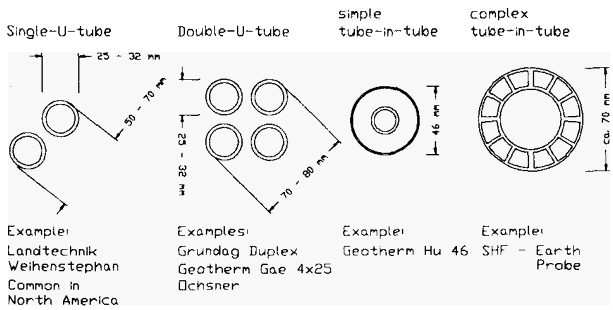

Figure 2: Cross-sections of typical vertical earth heat exchangers

For heating-only plants in residential use in Mid Europe, the key parameter for earth heat exchanger layout usually is the specific performance, in Watts per meter of borehole length. In existing plants this parameter ranges from 40-100 W/m with a typical average of 55-70 W/m (Sanner, 1992). For design purposes, the average borehole length required for one kW of heat pump heating capacity is of interest. A literature study (Sanner, 1992), monitoring of some plants (Sanner *et al.*, 1990) and evaluation of some recent projects gave the picture shown in figure 3, with 8.38 m borehole per kW heating capacity. However, the values are only suitable for simple plant layouts with heat pump runtimes of less than 2000 hours a year.

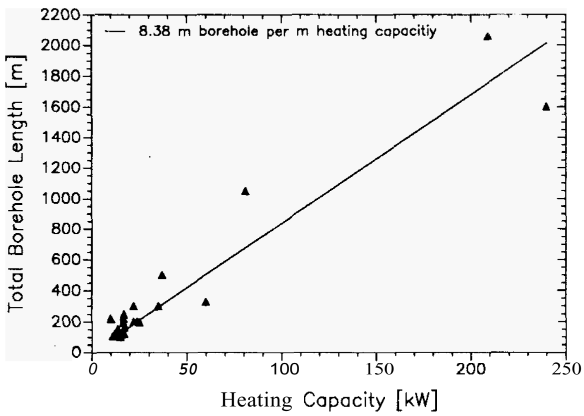

Figure 3: Borehole length versus Heat Pump Heating Capacity for 20 European GSHP-plants.

For applications in combination with other heat sources or in the "cold storage" mode discussed below the specific performance may differ considerably. It is therefore essential to observe a second parameter, the specific heat extraction per meter of borehole length for a year. This value ranges between 50-200 kWh/m/y for Mid European plants (Sanner, 1992). Saving first cost money by installing too short a vertical earth heat exchanger, resulting in too much heat extracted from the ground over a given borehole length, would lead to decreasing temperatures over the years and thus jeopardize long-term operation in a heating only plant.

Since the late 80's the discussion is open, as to wether brine systems (conventional approach) or direct expansion GSHP will lead to better performance. In direct expansion plants, the refrigerant is circulated directly through the vertical earth heat exchangers which act as evaporators. According to tests in Austria and Germany (Halozan, 1991; Knoblich *et al.*, 1993), direct expansion may lead to higher Seasonal Performance Factors (SPF) when designed and constructed properly. The synopsis of 10 plants with brine circuits and 9 with direct expansion shows that no significant dependence of SPF upon layout, shown here in the form of borehole meter per kW heating capacity, can be seen (fig. 4). Only three plants of a design with rather long vertical earth heat exchangers, which do not seem *to* be very economic from the first cost point of view, can achieve higher SPF. *So* other factors have more impact on SPF, and the theoretical potential for better performance cannot show up in real installations. Direct expansion may be a good solution when using horizontal coils in the ground, where high SPF's have been measured with moderate first cost. In vertical earth heat exchangers it is doubtful if the more complex system integration and control can offset the possibly slightly better performance at the current degree of development.

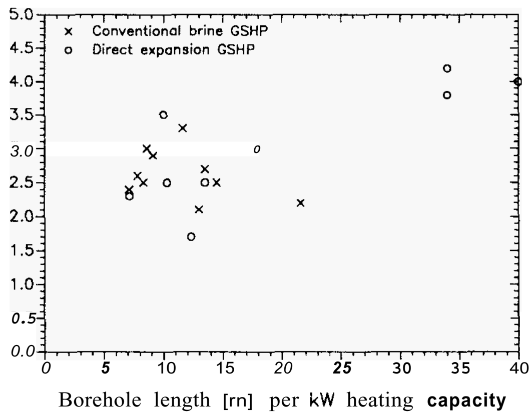

Figure 4: SPF versus layout parameter for exisiting GSHP-plants with brine circuit resp. direct expansion.

Since in the residential building sector in Germany space cooling **is** considered an exotic luxury, nearly all such GSHP-plants are of the heating-only type. With today's fuel and electricity prices, the pay-back time **for** the more expensive GSHP installation is rather long or even infinite. Hence the sales numbers are low. Recently an increase in demand for heat pumps is reported, in particular in the eastern states of Germany (former GDR), where incentive schemes are available from state authorities. However, a boom as in North America, with allmost all GSHP for heating and cooling, or even sales on a satisfactory level as in Switzerland and Sweden (with suitable energy pricing policies), cannot be expected for Germany in the residential building sector. To make use of the environmental benefits of GSHP (Faninger, 1991), a political impulse is required.

3. LARGE GSHP-PLANTS IN GERMANY

With the example of two larger GSHP-plants the state-of-the-art of this technology in Germany will be shown. In January 1993 the first borehole for the largest GSHP plant in Germany was drilled. The site is in Kochel am See, Bavaria, directly north of the Alpine front. The ground consists of hard calcareous marls (fig. *5)*. 21 holes of 98 m depth each are equipped with double-U-tube heat exchangers, the total borehole length summing **up** to 2085 m (Sanner *et al.*, 1992). Six heat pumps with total heating capacity of 209 kW are grouped in 3 sub-systems. The plant provides heat **for** a building complex containing 35 flats with 2400 m^2 total floor area. As shown in fig. 6, the heat pumps provide heat for the hydronic system with floor heating and radiators as well as domestic hot water. Each sub-system consists of two heat pumps, with hot tap water heated by the smaller one. This strategy allows good performance even in part-load conditions, and the larger heat pump is not required to operate at a higher temperature level for hot water. Cooling is not required, which is the standard in the residential sector in Germany.

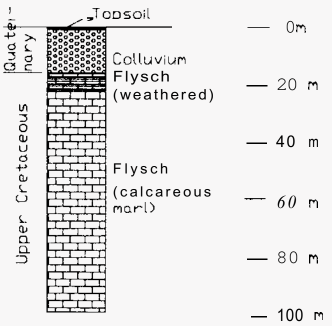

Figure 5: Geological profile at the GSHP-site Kochel am See

One advanced feature of the plant are the bottom parts of the vertical earth heat exchangers, where 4 polyethylene tubes are welded in a massive, cone-shaped block of polyethylene containing flow channels for connecting the tubes and thus forming the double-U. This technique is cheap and very reliable (no metal parts, massive bottom), resulting in slim heat exchangers (easy installation). Another feature are the manifold- and pumping modules, one for each of the borehole lines, installed outside the buildings in the ground at the highest point of each borehole field (fig. 6). The modules are pre-assembled in the factory and allow fast installation of the piping. The plant has been operational since fall 1993.

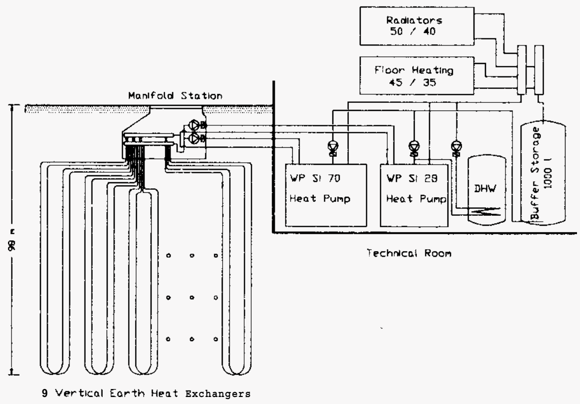

Figure 6: Schematic of a sub-system of GSHP plant Kochel a.S.

Another large plant was built in winter 1993/94 in Frankfurt-Hochst (Sanner & Euler, 1994). Originally 16 vertical earth heat exchangers in boreholes of 100 m depth were planned, but the initial drilling revealed a layer of mineralized artesian water below 73 m depth in fissures and fractures of a Tertiary limestone (fig. 7). Hence the design was changed to 32 boreholes each 50 m deep, to ensure a barrier thick enough to keep the artesian water in place. The vertical earth heat exchangers are of the same type as in Kochel am See, the manifold station is located centrally in the borehole field, and the complete manifold and connecting pipes are HD-polyethylene welded together.

In Frankfurt-Höchst, the GSHP is only part of the building energy system (fig. 8). The total heat load of 445 kW is met by a Combination of two gas-fuelled engines for cogeneration and the heat pump. In full-load operation most of the electricity produced in cogeneration is used for the heat pump compressor, at partial load up to 100 kW of electricity can be supplied to the building net.

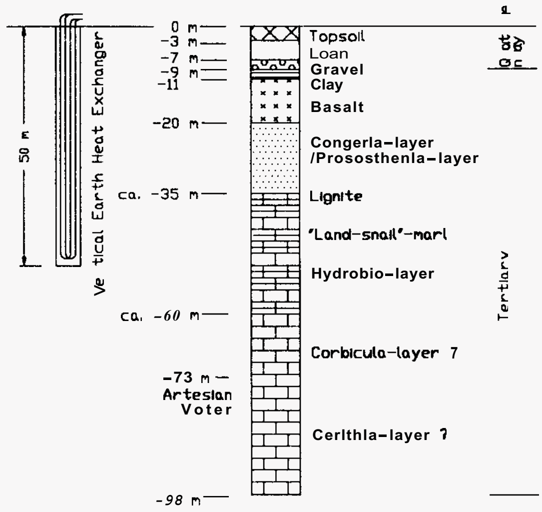

Figure 7: Geological profile at the GSHP-site Frankfurt-Hochst

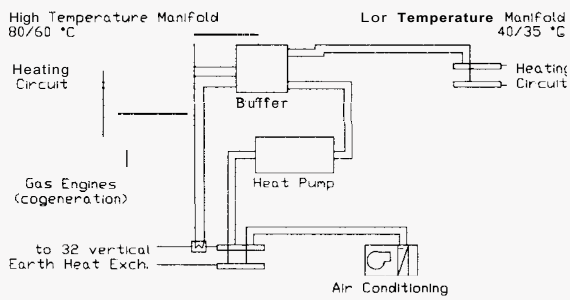

Figure 8: Schematic of GSHP-plant Frankfurt-Hiichst

4. GSHP-PLANTS WITH COLD STORAGE

During heating operation in wintertime, a cold region is generated around the vertical earth heat exchangers. This cold can be used as heat sink for the heat pump during cooling operation in summertime, as is standard in North American GSHP-plants. With advanced cooling devices, allowing higher cold supply temperatures (e.g. cooling ceilings), it is also possible to use the cold in the ground directly. If this is done for part or total of the cooling load, a cold storage plant has been constructed. The principle is given in fig. 9.

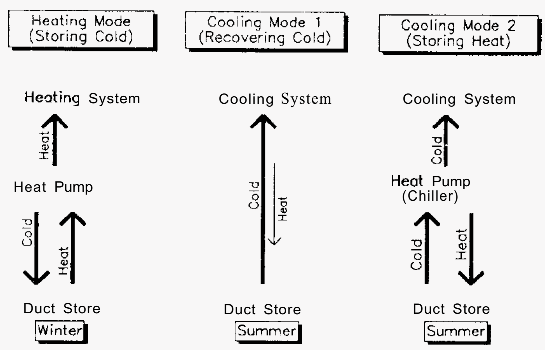

Fig. 9: Operation principles of GSHP-plants with cold storage

The first experiments with direct cooling by circulating cold brine from earth heat exchangers through fan coil units were done in Germany in 1987 with 2.5 kW cooling capacity (Sanner, 1990). An international overview of cold storage activities is given in Sanner and Chant (1992). The largest plant in Germany with direct cooling and reversible heat pumps for peak cooling load currently is the "Technorama" building in Dusseldorf (Sanner *et al.*, 1991; Sanner, 1993a).

The technical data of the "Technorama" **GSHP** are listed in table 1. The building uses passive solar techniques, as transparent insulation in the walls and a large sun space to the east. Hence the specific heat load is relatively small. Cooling is provided for the inner office rooms and the sun space, the outer office rooms are shaded and ventilated only. The plant has been operational since spring 1991.

Table 1: Data of "Technorama" Dusseldorf **GSHP** plant

Building:	
(Passive solar architecture)	
Floor area	6100 m^2
Heat load	180 kW
Cooling load	40-80 kW
Vertical Earth Heat Exchangers:	
Number	71
Type	single tuhe-in-tube, steel
Individual length	35 m
Total length	2700 m
Spec. performance	45 W/m
Spec. heat per year	67 kWh/m/y
Cold stored	ca. 80 MWh
Heat Pumps:	
Number	6
Heating capacity	32 kW individual
Heating capacity	190 kW total
Cooling capacity	ca. 80 kW total
"Direct Cooling" cap.	ca. 40 kW

The ground in Diisseldorf is of Quaternary age (fig. 10). The steel earth heat exchangers have been driven into the soft ground at an angle of ca. 30". They form 4 clusters, each with the heat exchangers in a fan-shaped configuration (fig. 11).

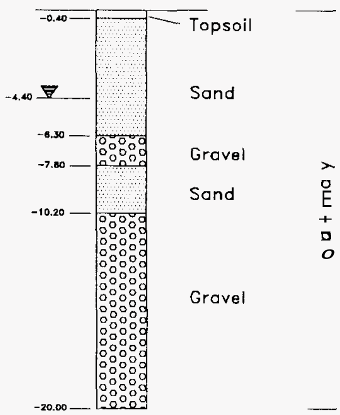

Figure 10: Geological profile at the GSHP-site Dusseldorf

In the "Technorama" building offices are housed high-tech companies with a large number of computers and other devices, all contributing to a high internal heat load. This fact and the need of the cooling system for low supply temperatures (around 10 "C) limits the possibility of direct cooling, which here can only be used in the springtime. Most of the summer the plant is running in the heat pump cooling mode (fig. 12). The "Technorama" plant has been monitored since 1992. Due to the poor performance of the monitoring system, reliable data are only available for part of the time. Nevertheless, the building occupants are very satisfied with the system, and specific energy costs are low.

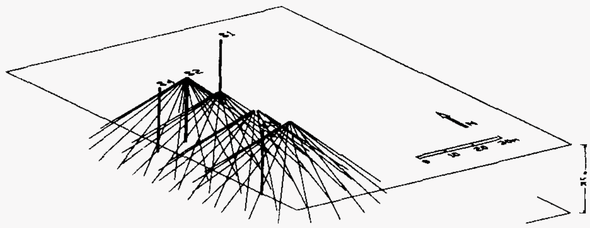

Figure 11: layout of "Technorama" Diisseldorf earth heat exchangers.

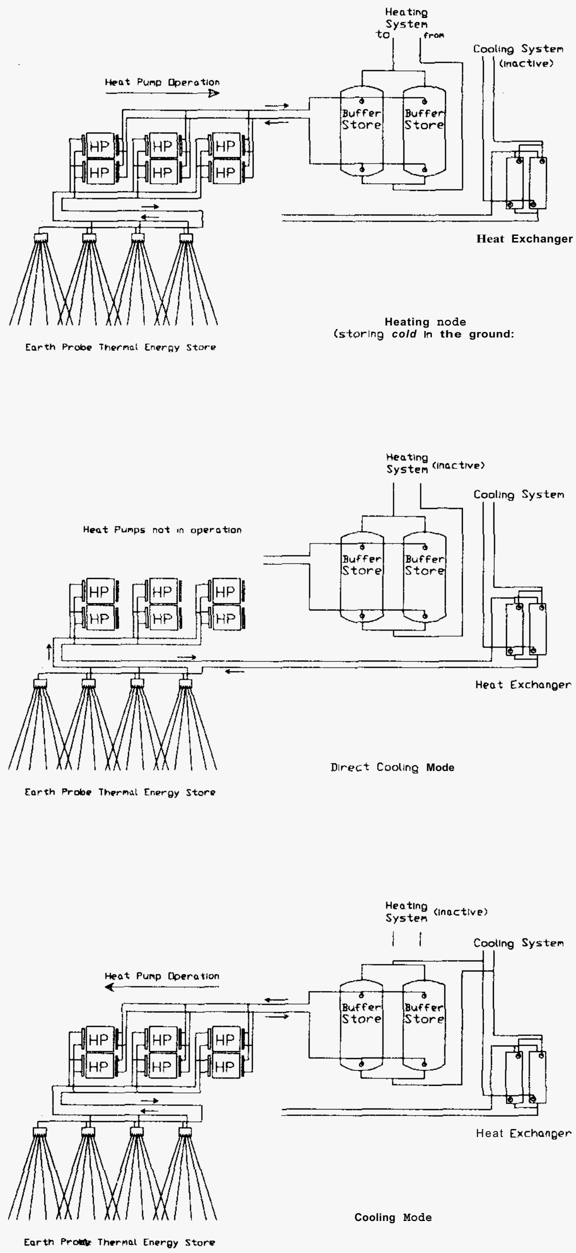

Figure 12: Schematic of "Technorama" Diisseldorf GSHP cold storage plant in 3 operation modes.

Three more plants of this type are operational in Germany today (Sanner, 1993b); the technical data are summarized in table 2. While the "Technorama" plant uses an all-air cooling system, in other plants cooling ceilings (coils in or beneath the ceiling are supplied with cold brine) or fan coil units are installed. For small cooling loads, as in the three other plants, the layout can be made for direct cooling mode only.

Table 2: Data of cold storage GSHP plants in Germany

	"Geotherm" Linden	"Ophthalm." Rathenow	"UEG" Wetzlar
Heat pump heating output	15 kW	64 kW	47 kW
System cooling capacity	ca. 11 kW	ca. 40 kW	40 kW
Number of vertical earth heat exchangers	3	10	8
Ind. length of vert. earth heat exchangers	40 m	60 m	80 m
Total length of vert. earth heat exchangers	120 m	600 m	640 m
Specific performance	83 W/m	71 W/m	49 W/m

A very large plant for office and laboratory buildings is planned in Golm near Berlin. After completion it will supply 4 MW of heating capacity and 1.8 MW of cooling capacity for 3 building complexes. Tests with one borehole was begun in 1993 to determine the thermal properties of the ground. Other plants exist in Switzerland ("Photocolor", Kreuzlingen, 130 kW heating capacity, and "In den Felsen" Wollerau, 275 kW heating capacity).

5. ECONOMY AND ECOLOGY OF COLD STORAGE GSHP

Cold storage can be a measure to reduce energy use for space cooling in Northern countries, with earth heat exchangers or aquifer thermal energy storage (ATES). The number of plants is increasing. In contrast to heating only GSHP, cold storage GSHP can be economic even today (Sanner, 1993b), because the expensive ground source part is used both in winter and summer (fig. 13). However, other considerations such as environmental aspects will certainly affect the energy prices in the future.

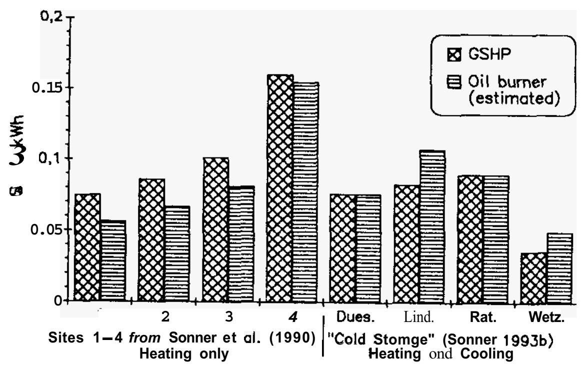

Figure 13: Cost of heating/cooling energy per kWh, incl. capital cost, in comparison to conventional design

From the environmental point of view GSHP have certain advantages. Even the simple heating only GSHP can achieve reductions in air pollution and CO_2-emission. Further evolution to higher SPF and more effective electricity generation as well as availability of suitable engine driven heat pumps decreases the environmental impact. Cold storage plants allow substantial reductions in most air pollutants (beside particles, due to coal fired power plants in Germany) and CO_2, the higher the reductions the more cooling can be supplied by direct cooling (table 3).

Table 3: Yearly CO_2-emissions in cold storage GSHP systems as compared to conventional heating/cooling plants

Plant	Conventional kg CO_2	Cold Storage GSHP kg CO_2	Reduction %
Dusseldorf	55,430	41,340	25.4
Linden	6,958	5,616	19.3
Rathenow	20,210	13,260	34.4
Wetzlar	52,498	27,032	48.5

6. UNDERGROUND THERMAL ENERGY STORAGE PROJECT "REICHSTAG", BERLIN

After the German unification in 1990 the parliament decided to have Berlin as the capital of the new Federal Republic. Just over 100 years ago the "Reichstag" building was inaugurated in Berlin, the site of the (not very powerful) German Parliament of the Wilhelminian era and later of the first republic. Since the fire of 1933 the "Reichstag" building has not been used for parliament, and after World War II it had been repaired intermittantly. Now the German Parliament, the "Bundestag", will have the building completely refurbished and equipped with up-to-date facilities for the sessions. The British architect Sir Norman Foster is in charge of the reconstruction, and work will begin in 1995.

The energy system for the "Reichstag" building is based on cogeneration plants fuelled with plant oil (e.g. from sunflowers). The heat produced in cogeneration will be used as energy input for absorption heat pumps, for heating in winter and cooling in summertime; maximum heating and cooling load is in the order of magnitude of 1 MW. The heat source/sink for the absorption heat pumps is projected as underground thermal energy storage, either with vertical earth heat exchangers or using an aquifer (ATES). For cooling operation, as much cold as possible should be supplied directly through cooling surfaces, which allow space cooling at temperatures as high as 20 °C. Hence the project is a generic cold storage plant.

The two alternatives have been investigated carefully (Sanner *et al.*, 1994). In one version 160 vertical earth heat exchangers with 100 m individual length are planned. The monthly average brine temperatures for this layout have been calculated as shown in fig. 14.

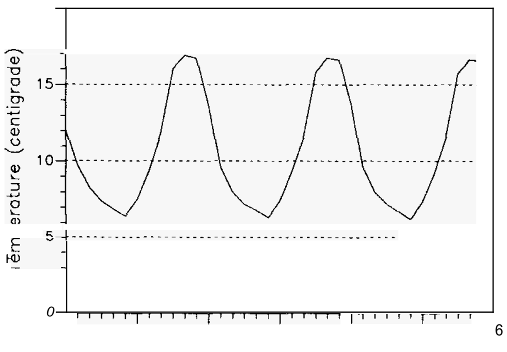

Figure 14: Monthly average brine temperatures for the first three years of operation, project "Reichstag" building, Berlin; storage with 160 vertical earth heat exchangers.

The vertical earth heat exchangers are grouped in clusters of 20, with a central manifold and pumping station for each cluster. Numerical simulation of the plant operation has been made using the FD-model TRADIKON-3D, developed at Giessen University and validated against data from a full-scale field test (Sanner and Brehm, 1988). TRADIKON-3D is able to model combined fluid (groundwater) flow and heat transport by convection and conduction. Hence it is best suited for the modelling of vertical earth heat exchangers in areas with groundwater flow as well as for ATES. In figure 15 a horizontal cut at ca. 60 m depth through one of the clusters is given, showing the temperature distribution in winter and summer.

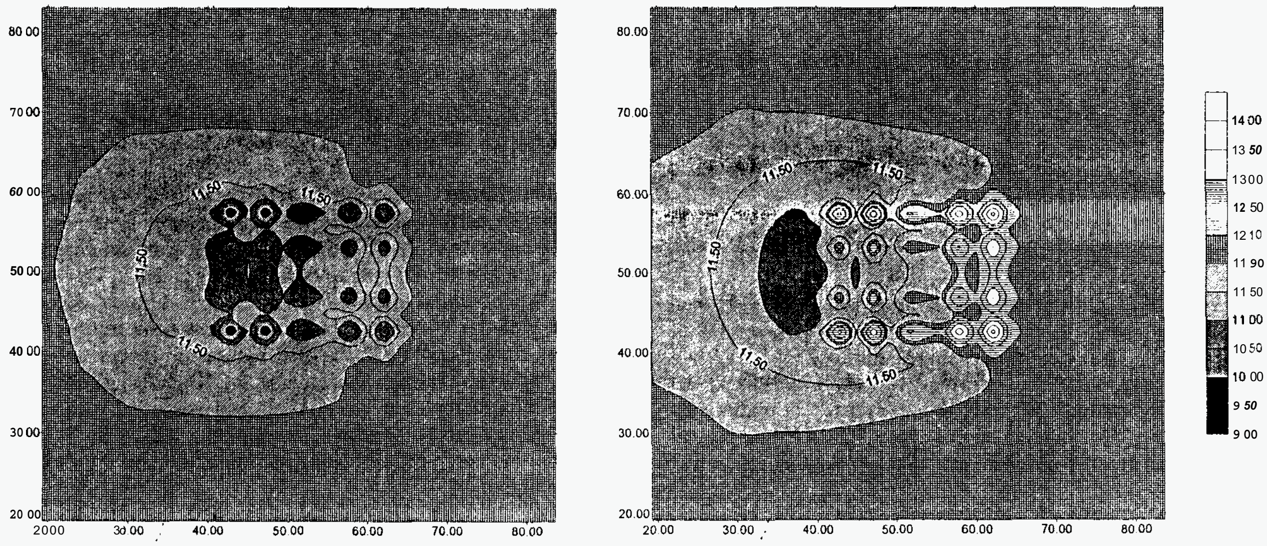

Figure 15: Temperature distribution around one cluster with 20 vertical earth heat exchangers, project "Keichstag" building, Berlin; left January 1st, right September 1st in the second year of operation. The axes are given in meter, the isotherms in centigrade.

In the other version, two groups of 4 wells are used for production respectively injection of groundwater. The water is heated (in summer) or cooled (in winter) by ca. 3 K before injection. The direction of operation is reversed each season, and the group used as injection wells during summer will soon become the "warm wells", the group used for injection in winter the "cold wells". The cold wells will be located directly at the eastern side of the building, and with short connecting pipes, with a supply temperature in the range of 9-14 °C, a much higher fraction of direct cooling can be achieved than in the version with vertical earth heat exchangers. Hence from the technical point of view the ATES is the preferred alternative.

The decision on the version for the final installation will he made mainly after environmental considerations. Since the aquifers in Berlin are widely used for drinking water supply, the water authorities are very cautious in licensing thermal uses of aquifers. The use of a deeper aquifer (>150 m, mineralized) or the version with vertical earth heat exchangers may be required. If the project is undertaken, a cold storage GSHP-plant for the German "Reichstag" building in Berlin would be a giant step forward for public awareness and broader acceptance of the use of the ground for energy purposes.

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