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on Direct Application of Geothermal Energy

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Geothermal heat pumps and geothermal district heating systems - the German experience

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Introduction

Ground source heat pumps play a key role in geothermal development in Central and Northern Europe. With borehole heat exchangers as heat source, they offer geothermal heating at virtually any location. In the vast majority of plants no space cooling is included, leaving ground source heat pumps with some economic constraints. In areas with deep, hot aquifers, hydrogeothermal doublets can be found, serving district heating networks. The approach of a deep borehole heat exchanger (in excess of 2 km depth) is not very economic. However, some new projects of this type are in planning stadium for areas where no permeability is expected in the target depth.

Geothermal heat pumps

The climatic conditions in Central and Northern Europe, where most of the market development for geothermal heat pumps in Europe takes place, are such that by far the most demand is for space heating; air conditioning is rarely required. Therefore, unlike the systems in the USA, the heat pumps usually operate in the heating mode only.

Shallow geothermal resources (< 400 m depth by governmental definition in several countries) are omnipresent. Below 15 - 20 m depth everything is geothermal (Fig. 1): the temperature field is governed by terrestrial heat flow and the local ground thermal conductivity structure (± groundwater flow). In some countries, all energy stored in form of heat beneath the earth surface is per definition perceived as geothermal energy (VDI 2001; BFE 1998); the same approach is used in North America. The ubiquitous heat content of shallow resources can be made accessible either by extraction of groundwater or, more frequent, by artificial circulation like the Borehole Heat Exchanger (BHE) system. This means, the heat extraction occurs – in most cases – by pure conduction, there are no formation fluids required.

The most popular BHE heating system with one or more boreholes typically 50 - 200 m deep is a closed circuit, heat pump coupled system, ideally suited to supply heat to smaller, de-central objects like single family or multi-family dwellings (see Fig. 2). The heat exchangers (mostly double U-tube plastic pipes in grouted boreholes) work efficiently in nearly all kinds of geologic media (except in material with low thermal conductivity like dry sand or dry gravel).

The means to tap the ground as a shallow heat source comprise:

- groundwater wells ("open" systems)
- borehole heat exchangers (BHE)
- horizontal heat exchanger pipes (incl. compact systems with trenches, spirals etc.)
- "geostructures" (foundation piles equipped with heat exchangers)

A common feature of these ground-coupled systems is a heat pump, attached to a low-temperature heating system like floor panels / slab heating.

Experimental and theoretical investigations (field measurement campaigns and numerical model simulations) have been conducted over several years to elaborate a solid base for the design and for performance evaluation of BHE systems. While in the 80´s theoretical thermal analysis of BHE-systems prevailed in Sweden, monitoring and simulation was done in Switzerland, and measurements of ground heat transport were made on a test site in Germany (Sanner, 1986).

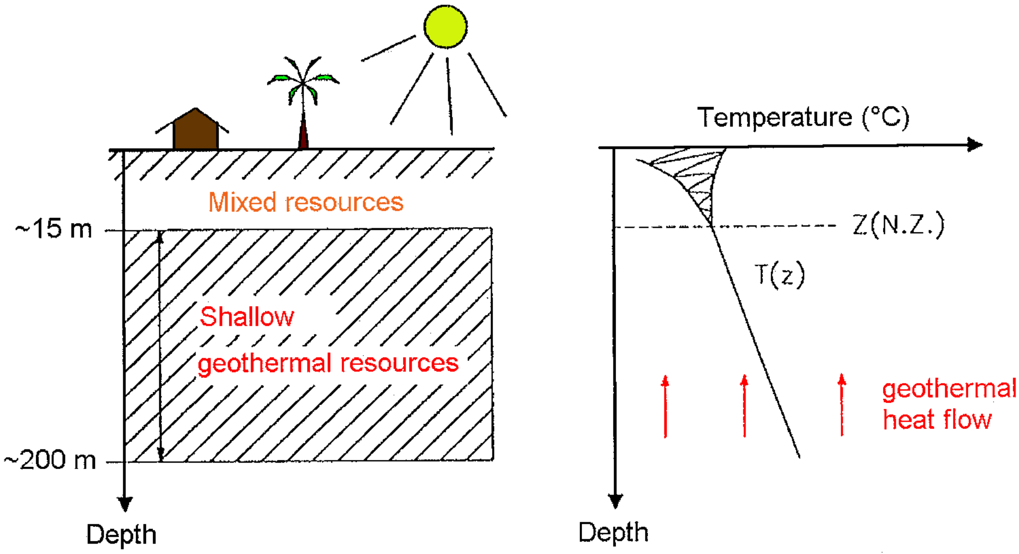

Fig. 1: Geothermal energy, comprising geothermal and mixed resources in the shallow subsurface.

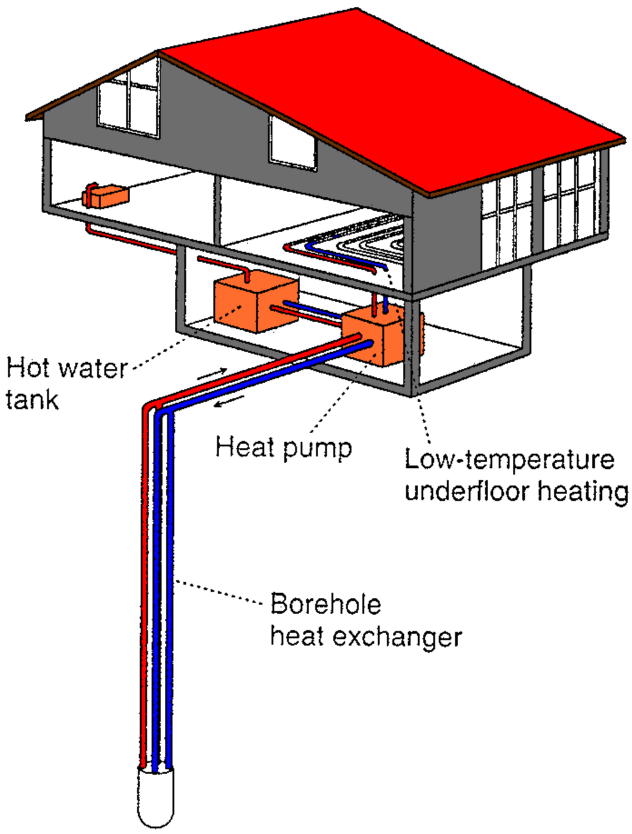

Fig. 2: Typical application of a borehole heat exchanger (BHE) / heat pump system in a Central European home. Typical BHE length: 100 m.

In the German test plant at Schöffengrund-Schwalbach near Frankfurt/Main, a 50-m-BHE was surrounded by a total of 9 monitoring boreholes at 2.5, 5 and 10 m distance, also 50 m deep. Temperatures in each hole and at the BHE itself were measured with 24 sensors at 2 m vertical distance, resulting in a total of 240 observation locations in the underground. This layout allowed to investigate the temperature distribution in the vicinity of the BHE, as shown in Fig. 3. The influence from the surface is visible in the uppermost ca. 10 m (see also Fig. 1), as well as the temperature decrease around the BHE at the end of the heating season. Measurements from this plant were used to validate a numerical model for convective and conductive heat transport in the ground.

The long-term reliability of BHE-equipped heat pump systems, along with economic and ecological incentives (see below), led to rapid market penetration. This was accompanied by the development of design standards (e.g. VDI 2001) and easy-to-use design tools (e.g. HELLSTRÖM et al. 1997).

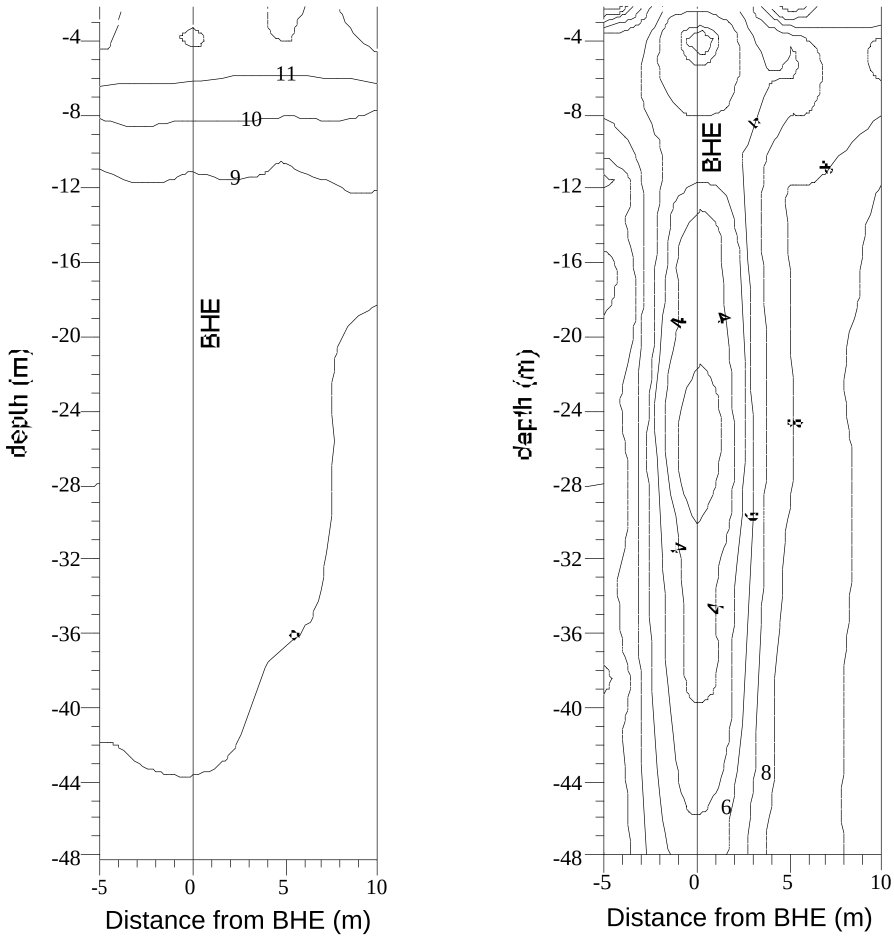

Fig. 3: Measured temperature distribution in the ground at the beginning of the monitoring period (left, on 1.10.1986, after a total of ca. 2 hours of test operation) and at the end of the first heating season (right, on 1.5.1987), Schwalbach GSHP test plant, Germany

Within the full swing of heat pump applications in Europe ground-coupled heat pumps play a significant role. The development started around 1980 when the first BHE-coupled heat pump systems were built in Germany and Switzerland. Following a larger number of new units installled during the oil price crises and a subsequent low (except for Switzerland) the number of new installations is again increasing since the mid-90's, and a sound and steady market growth can be observed.

The share of GSHPs in supplying the residential heat demand also varies from country to country (see Table 1). The fraction is still small but steadily growing; in Switzerland about every fourth new one- or two-family house is now being equipped with a GSHP system.

The development can also be seen in individual regions. In Fig. 4 the number of installations realized within an incentive program of the German utility RWE is depicted. Not only the total number of heat pumps installed in the RWE-area is rapidly increasing, but also the share of BHE-equipped heat pumps. For all heat pumps installed in this area until 1982, the ground (mainly with horizontal coils) was heat source for 6 %, and groundwater for another 30 %. In 1998, the BHE alone accounted for ca: 66 % of the heat sources.

Table 1: Share of ground coupled heat pumps in total residential heating demand (after data from VAN DE VEN, 1999)

Country	%
Austria	0.38
Denmark	0.27
Germany	0.01
Norway	0.25
Sweden	1.09
Switzerland	0.96

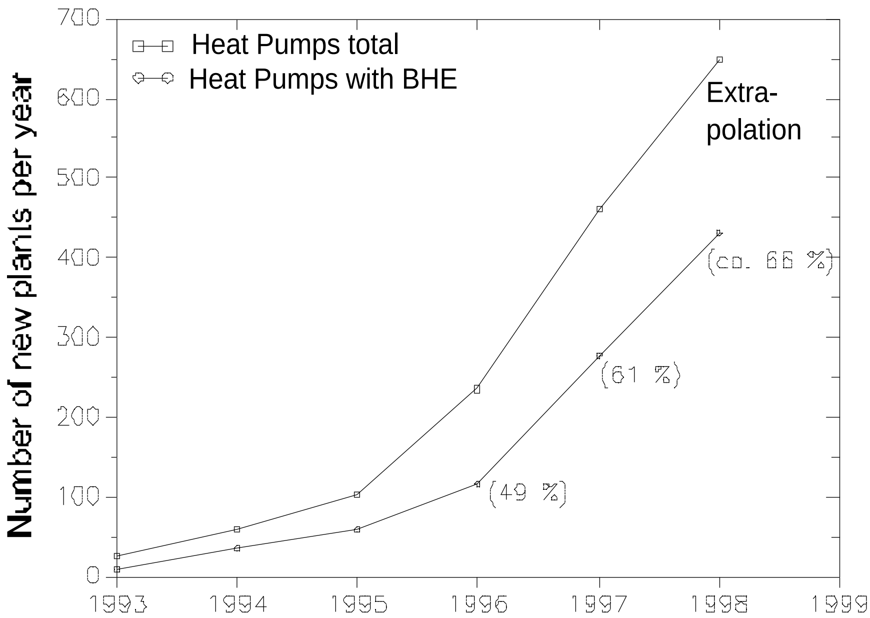

Fig. 4: Market development for heat pumps in the RWE-area (data courtesy of RWE)

A relatively new trend in Germany and even more in the Netherlands is using GSHP in residential development projects. 50, 100 ore more houses are built in a limited area, and all are quipped with GSHP. Several studies have been made mainly for sites in the Ruhr region and the Rhein-Main-area. Here the limits of natural thermal recharge may be reached for heating only operation. According to the heat load of the houses and the distance between houses, the length of BHE has to be increased, to tap more ground volume. An example is shown in Fig. 6, based upon a calculation for 60 houses. Each house has a supposed heat load of 7 kW and 2 BHE to supply heat to the heat pump. A distance of 15 m between BHE means a total area for the house, garden, street etc. of 450 m^2, which is not uncommon in condensed building areas. The necessary increment of BHE length with 15 m distance over a single, isolated plant is about 60 % for the 30-year-operation, and for 20 m distance (800 m^2) it is still ca. 25 %.

The calculation was done without considering the influence of moving groundwater. However, in a large field of houses, the impact of the groundwater is good for the houses upstream, and bad for those in the flow direction. In the end, for a large enough area there is virtually no advantage in groundwater flow. One method to avoid increased BHE length is to provide artificial thermal recovery in summertime. This may be from waste heat, warm surface water, excess heat from solar collectors, etc. For the group of 60 houses with 450 m^2 area each, recharging of a total of 300 MWh of heat in the period from May to September will allow for only 14 % increase over the single plant.

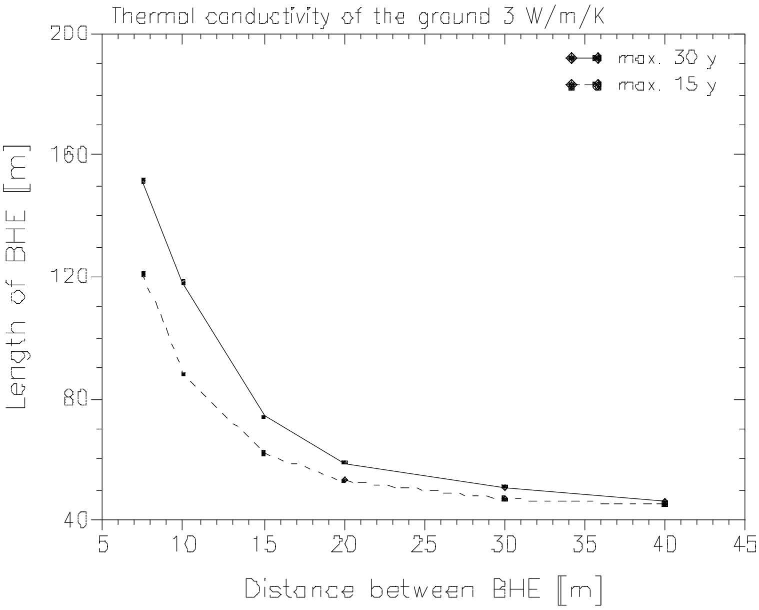

Fig. 6: Influence of distance between borehole heat exchangers (BHE) on the necessary BHE-length for operation in a 15-year or 30-year timeframe. Field of 60 houses (7 kW heat load each) with 2 borehole heat exchangers for each house. No groundwater flow, no artificial thermal recharge (after SANNER 1999)

It is expected that the market will further expand, in the leading countries like Sweden and Switzerland as well as in other countries like Germany to follow. The growth can be exponential as the Swiss example shows (Fig. 7). The ecological incentives like avoiding greenhouse gas emissions will further support GSHP development; the CO_2 tax implemented in Germany and in sight in other countries is a further (financial) incentive.

Geothermal district heating

In Fig. 8 the larger geotehrmal plants in Germany are shown. Some of them are large GSHP-plants, but a number of them is using deep geothermal ressources and supplies heat to district heating nets. Table 2 lists the relevant data of these geothermal district heating networks.

Two examples are shown in more detail in fig. 9 and 10. The plant from fig. 9 is located in Switzerland, but very close to the German border. It is a very successful hydrogeothermal plant with high availability and a minimum of problems. Part of the net is the first cross-border geothermal system between Switzerland and Germany, because the district heating of the locality Lörrach-Stetten in Germany is supplied form the Swiss geothermal heating plant.

The other example (fig. 10) is located in NE-Germany. The schematic shows the second system concept as completed after a refurbishment in the early 90s. It is a complex system with a large absorption heat pump. Operation of the heat pump and fuel economy was not always satisfactory. One major problem is the relatively shallow depth for a doublet system (ca. 1400 m) and the resulting low temperature (s. Tab. 2). Meanwhile another rebuilding is planned, changing the geothermal doublet into an Underground Thermal Energy Storage, where waste heat from a combined heat- and power-plant during summertime will be stored in the underground. This will increase temperatures, reduce heat pump operation and enhance the economy substantially.

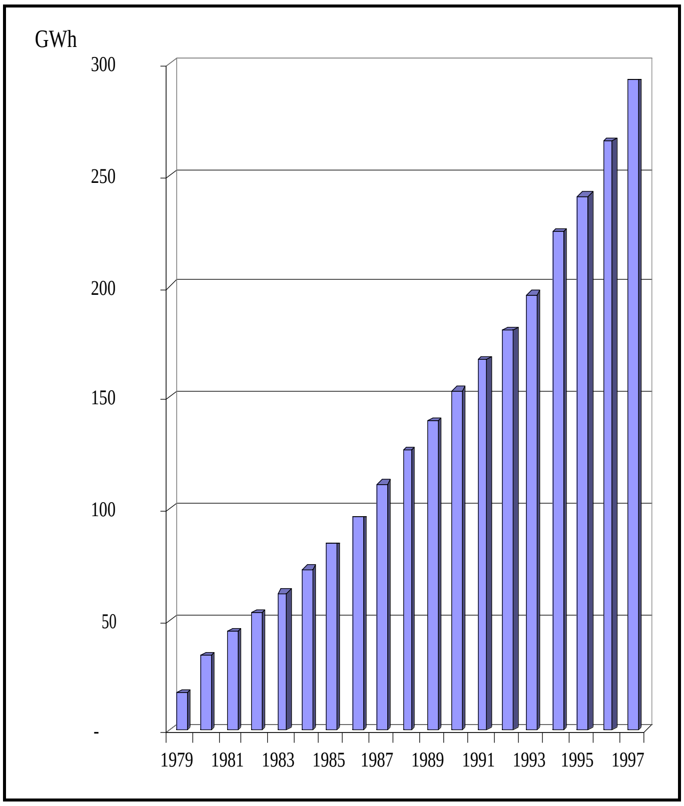

Fig. 7: Compilation of geothermal heat production (before the heat pump) by BHE systems in Switzerland. The values are based on AWP sales statistics (AWP = Arbeitsgemeinschaft Wärmepumpen Schweiz). The compilation has been commissioned by the Swiss Federal Office of Energy, Bern (after WILHELM & RYBACH, 1999).

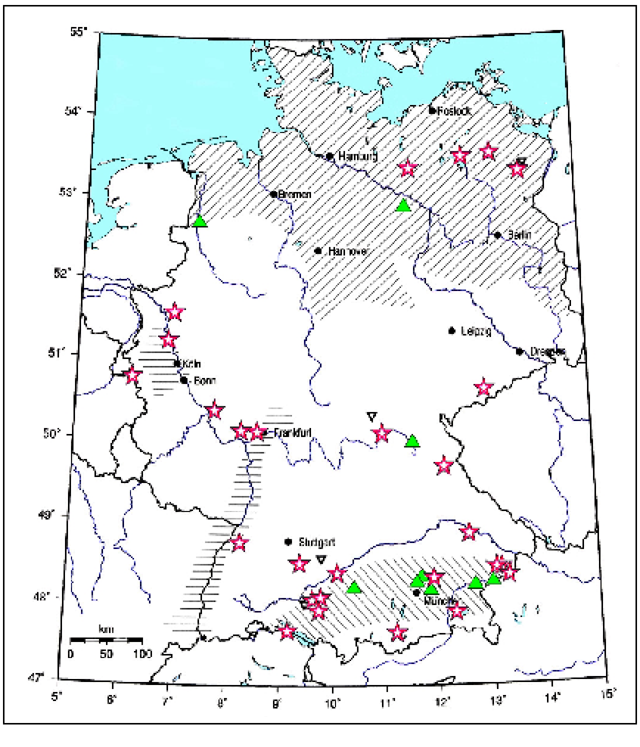

Fig. 8: Installations for direct use of geothermal energy in Germany (stars: operating, see Table 1; filled triangles: planned, see Table 2; open triangles: shut-down. Large sedimentary basins are indicated by hachures. Rhein Graben: =; Molasse Basin: \\\; North German Basin: /// (after SCHELLSCHMIDT et al., 2000)

Tab. 2: Large geothermal heating plants in Germany

Location	**Power**	**Tempera-ture**	**flow rate**	**Remarks**
Erding 11.91 E, 48.31 N	4.5 MW_{th}	66 °C	24 l/s	„singlet“, heat pump, use as drinking water
Neubrandenburg 13.27 E, 53.56 N	5.8 MW_{th}	54 °C	42 l/s	2 doublets, heat pump
Neustadt-Glewe	6.5 MW_{th}	95 °C	35 l/s	doublet, no heat pump
Prenzlau 13.87 E, 53.32 N	ca. 0,5 MW_{th}	30-40 °C	-	Deep borehole heat exchanger (2800 m)
Simbach-Braunau 13.02 E, 48.27 N	ca. 20 MW_{th} (expected)	90-100 °C	max. to be determined	doublet, net across German and Austrian border, new
Straubing 12.58 E, 48.87 N	4.1 MW_{th}	36 °C	40 l/s	doublet, heat pump
Waren/Müritz 12.68 E, 53.52 N	1.5 MW_{th}	60 °C	17 l/s	doublet
Wiesbaden 8.24 E, 53.32 N	1.8 MW_{th}	69 °C	13 l/s	„singlet“, heating for town hall

Beside the one deep BHE in Prenzlau (Tab. 2), similar projects have been propagated in Hamm, Iserlohn and now in Aachen. While the former two had to give way to natural gas supply, the project in Aachen has good chances of realization and will for the first time in Germany give reliable data from monitoring, as it is a project a the technical university in Aachen. Deep BHE can be installed almost everywhere, but economy seems to be poor, and now good data are available. This hopefully will change with the new project in Aachen, and a new evaluation of the concept of deep BHE might be possible.

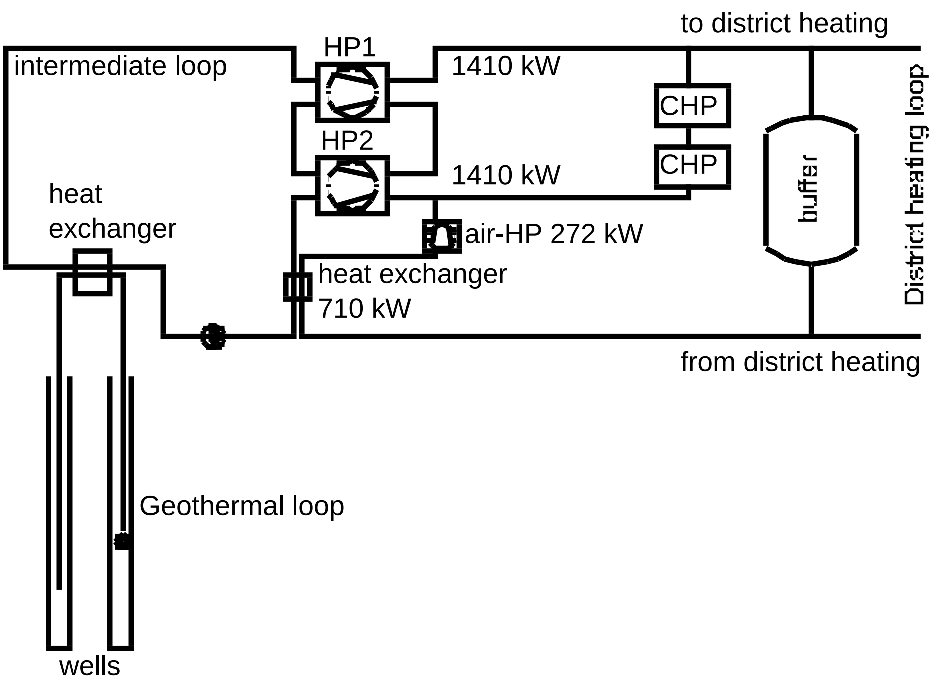

Fig. 9: Schematic of the geothermal district heating plant in Riehen, Switzerland

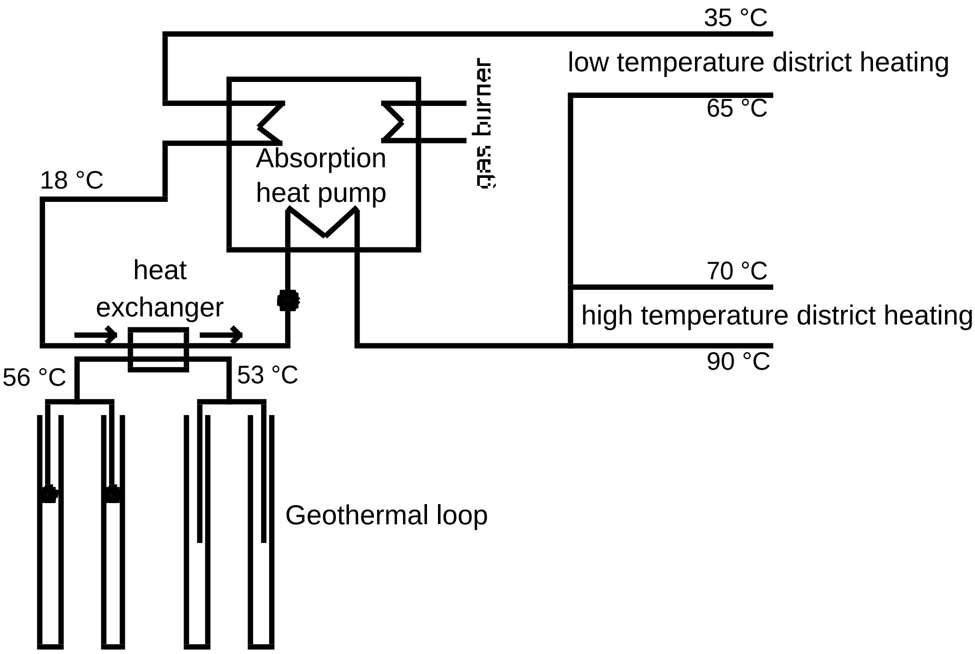

Fig. 10: Schematic of the geothermal district heating plant in Neubrandenburg, Germany, before rebuilding in 2002

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