# Ground Source Heat Pump Systems: R & D and Practical Experiences in FRG

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## ABSTRACT

To improve performance and economy of Ground Source Heat Pumps (GSHP), and to investigate environmental aspects, the research plant in Schwalbach near Wetzlar, FRG, has been operated since 1985 with financial support from the German Federal Ministry for Research and Technology. Vertical earth heat exchangers with brine circuit or direct expansion have been tested. FD-computer-models have been developped to simulate heat transport in the ground, and validation was done against data from the test plant.

GSHP with vertical earth probes and brine circuit are well suited to be used in larger numbers, the performance is good (SPF approx. 3) and monovalent plants are possible. Monitoring of 4 residential houses with brine circuit earth probes in different geological areas of Germany showed problems and advantages of the system. Currently not so popular in Germany, space cooling gains more interest from the viewpoint of comfort. 2 plants with a "passive" cooling (no cooling machine working) and different distribution systems are in operation.

## KEYWORDS

Ground source heat pump; vertical earth heat exchanger; field tests; computer simulation; combined heating and cooling.

## SCHWALBACH GSHP RESEARCH PLANT

### Field test

For testing ground source heat pumps and monitoring their impact to ground temperatures, a test plant has been installed near Wetzlar, FRG (Sanner, 1986, Sanner, 1987). The plant consists of a central drillhole 101 mm in diameter and 50 m deep, surrounded by 9 temperature probes also 50 m deep in 2.5, 5 and 10 m distance (fig. 1). Geology and climatic conditions of the site are described in Sanner *et al.* (1986). The temperature probes have 24 sensors in 2 m vertical distance; semiconductors are used

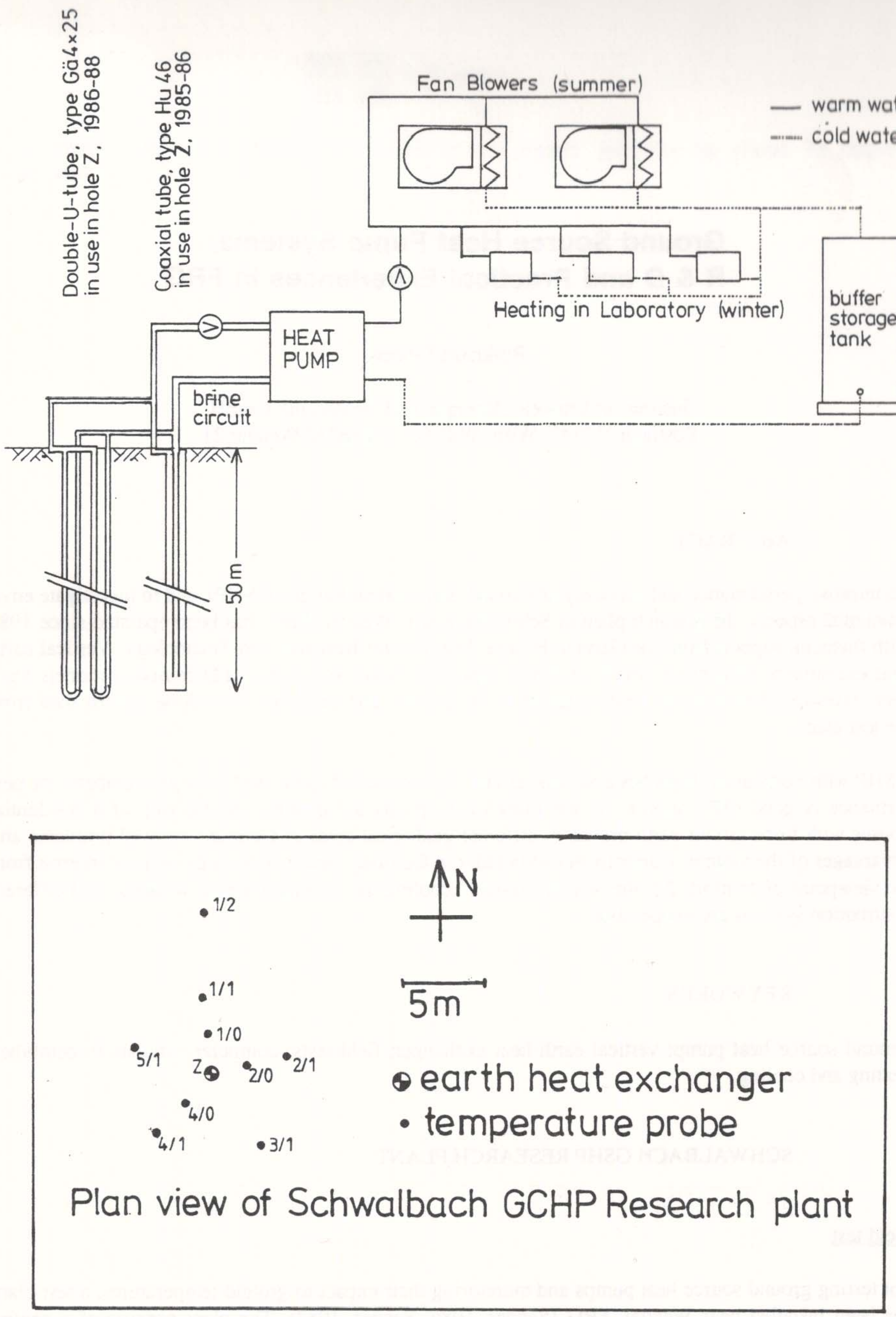

Fig. 1: Layout of Schwalbach GSHP Research Station

as sensors to ensure long-term stability (Sanner and Herr, 1986). A further temperature probe has been inserted in central drillhole Z together with the earth heat exchanger to monitor temperatures on the outer heat exchanger surface.

As shown in fig. 1, a complete installation for simulating the heat load of a small residential house even in summer has been constructed. A choose of three modes for controlling the plant is given: Manual control, heating simulation (meet the required heat load) and constant brine temperature. The latter is essential for easy validation of computer simulations, the temperature inside the earth heat exchanger can be kept nearly constant and reaction of the circumjacent ground can be monitored.

The research plant commenced operation in September 1985, and tests with brine circuit ground source heat pumps haven been made until fall 1988. A schematic outline of the temperature outside the earth heat exchanger and the ambient air temperature is shown in fig. 2. After the cold and severe winter 1985/86 (minimum air temperature -22 °C), when heating simulation was done, a recovery of earth temperatures in spring and summer 1986 could be recorded. In fall 1986 the earth heat exchanger and one month later the heat pump has been replaced by other types, and heating simulation could not begin before January 1987. In spring 1987 thermal recovery of the ground can be seen again, followed by tests with constant brine temperature in autumn and heating simulation in winter 1987/88. Thermal recovery in spring and further runs with constant brine temperature in summer 1988 are omitted in fig. 2.

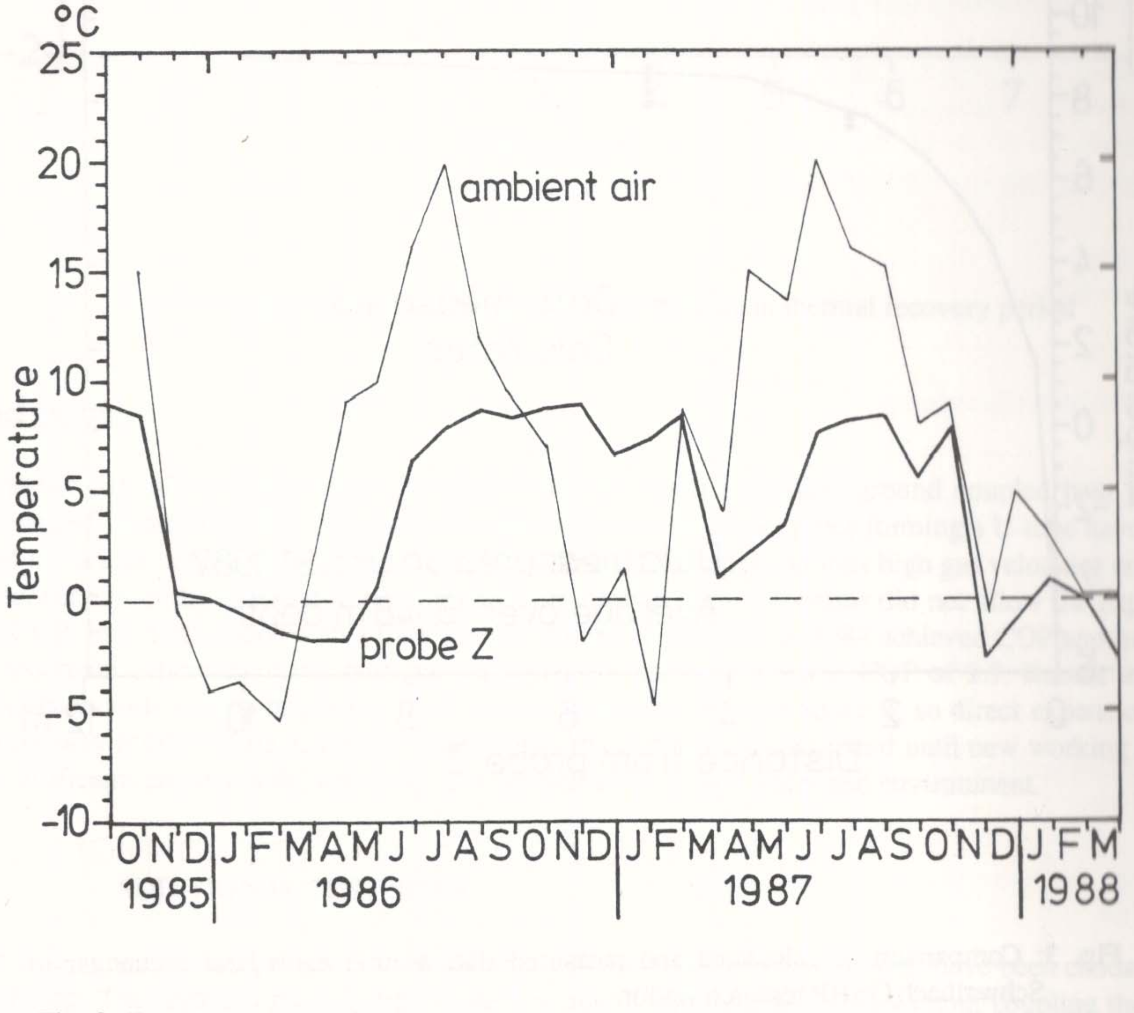

Fig. 2: Temperatures outside earth heat exchanger (average over 10-48 m) and in ambient air, Oct. 1985 - March 1988

## Computer simulations

A computer model based on the method of Finite Differences (FD) has been developped to calculate heat transport in the ground (Brehm and Knoblich, 1989). The code, named "Tradikon-3D", has been validated against data from Schwalbach research station. Figure 3 shows a temperature profile from the earth heat exchanger to the farfield probe 1/2, after 26 days of constant brine temperature -5 °C. The calculated values predict satisfactorily the data measured during a test run in October 1987. The thermal recovery of the ground after another 30 days of constant brine temperatures below 0 °C in August 1988 has been calculated and compared to the recorded temperatures in fig. 4.

With the aid of the computer model improvment in the layout of ground coupled heat pump plants is possible, ground temperatures can be predicted and thus long-term operation guaranteed. In additional test sites the model has been used in realistic circumstances.

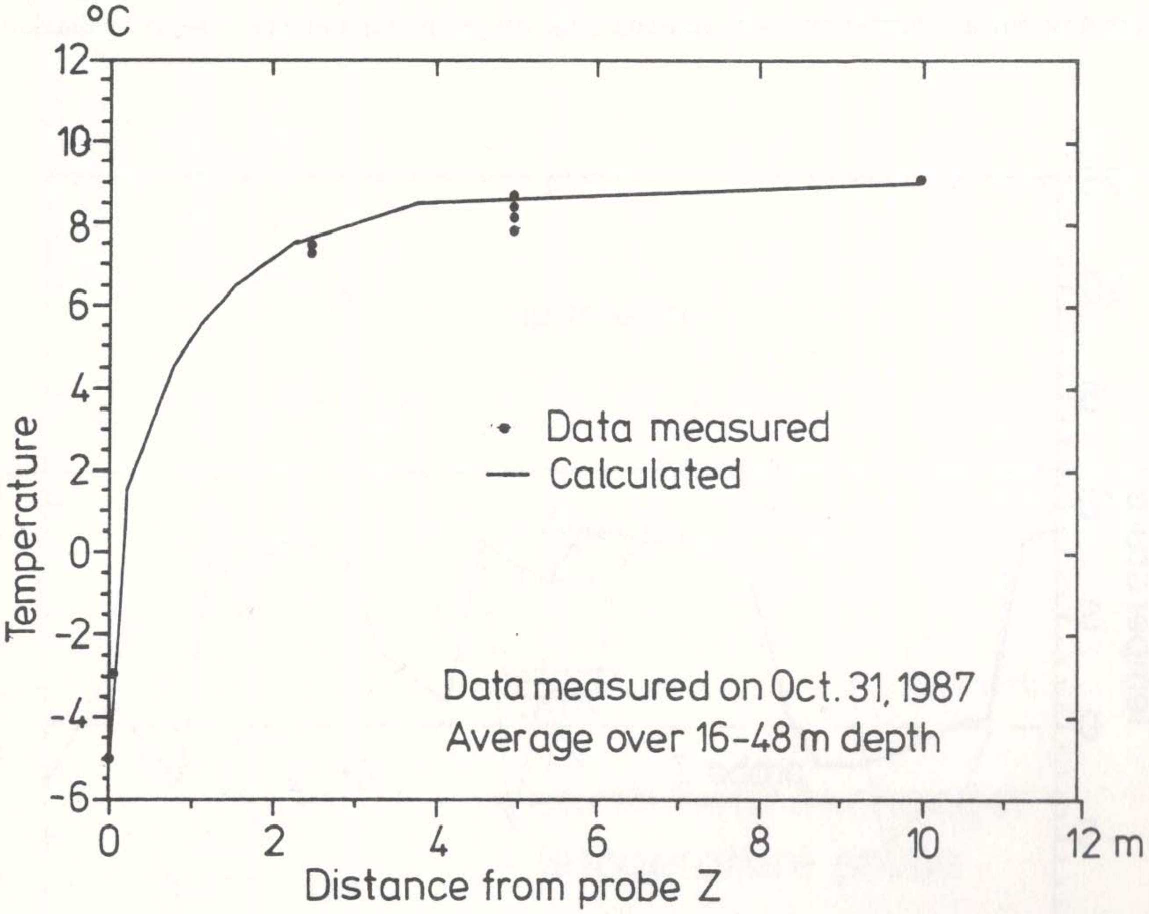

Fig. 3: Comparison of calculated and measured data around earth heat exchanger in Schwalbach GSHP research station

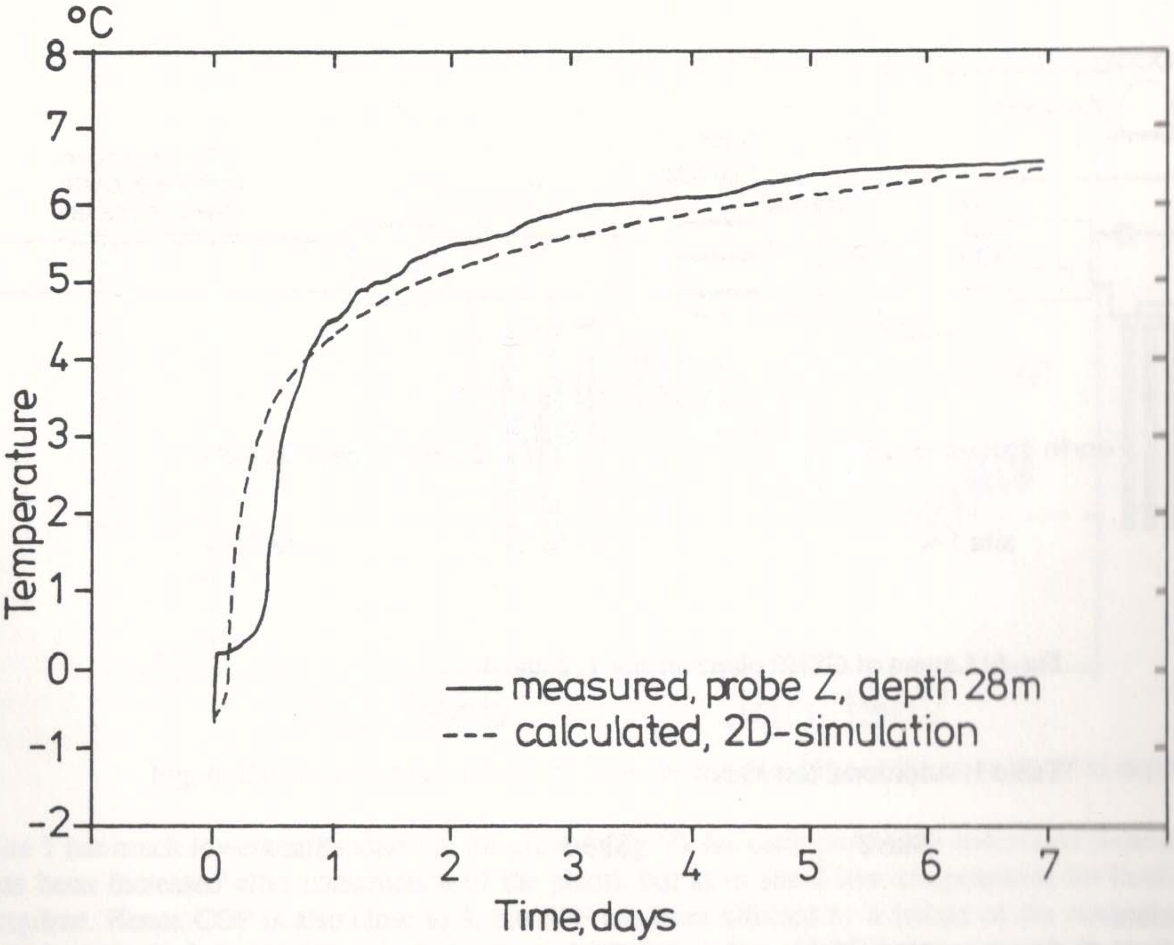

Fig. 4: Comparison of calculated and measured data in thermal recovery period

Direct expansion

In another part of the Schwalbach test field, R&D on direct expansion ground coupled heat pumps commenced December 1987. Evaporators made of PE-coated cupper pipes forming a U-tube have been tested in various configurations from 25 to 50 m depth. Thin pipes and thus high gas velocities ensured oil recovery from the evaporator, but high pressure drop in such evaporator did not allow the expected high COP. First tests ended with a COP round 2, later improvments in 1988 achieved COP approx. 2.5; the maximum efficiency using high gas velocities seems to be close to COP of 2.7. Recent tests in Schwalbach with a different design from Austria showed COP well above 3, so direct expansion is a possible way for the future. Currently further tests in Germany are suspended until new working fluids and lubrificants are available, which are less pernicious to ground water and environment.

## ADDITIONAL TEST SITES

Four ground source heat pumps (3 in residential, 1 in light commercial building) have been choosen for monitoring. The layout is given in fig. 5; site 3 is mainly the same as 1, but without coupling the fireside. Main parameters are listed in Tab. 1.

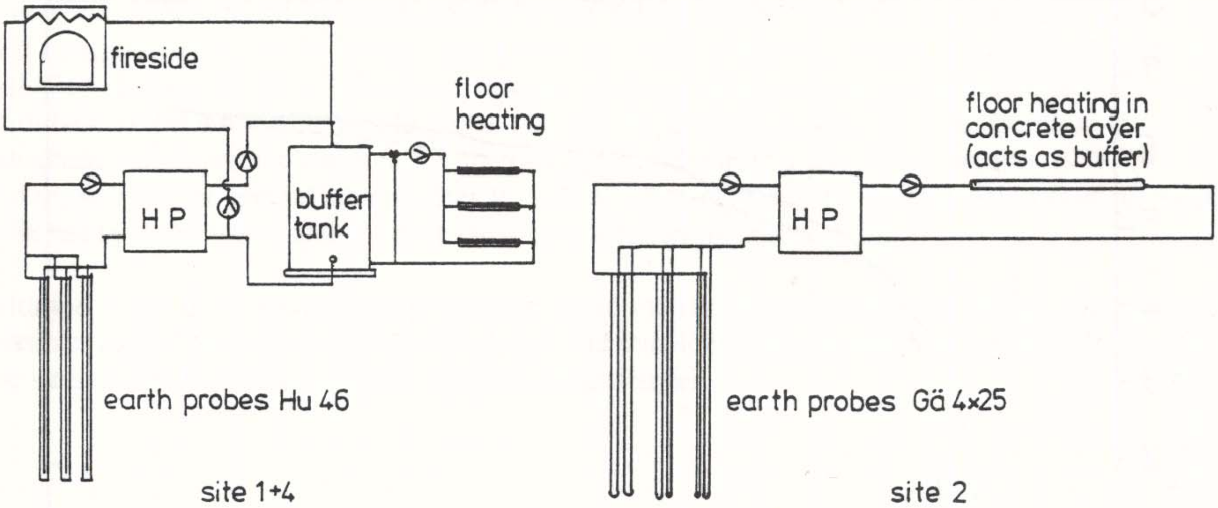

Fig. 5: Layout of GSHP plants in site 1, 2 and 4

Table 1. Additional test sites

| Site 1 | Site 2 | Site 3 | Site 4 |
|---|---|---|---|
| Location: | | | |
| Mühlheim/Ruhr | Hüttenberg | Göttingen | Waldmohr |
| Geology: | | | |
| Carboniferous | Tertiary | Mid-triassic | Lower-triassic |
| shales | marls | limestone | sandstone |
| Ground source heat pump: | | | |
| 25 KW | 22 KW | 17 KW | 17 KW |
| no DHW | no DHW | incl. DHW | incl. DHW |
| 5 probes | 5 probes | 6 probes | 3 probes |
| Gä 4x25 | Gä 4x25 | Gä 4x25 | Hu 46 |
| total 195 m | total 200 m | total 246 m | total 120 m |
| SPF for 1987/88 heating season | | | |
| 2.55 | 2.85 | 2.53 | 2.37 |
| maximum preformace (from earth) | | | |
| 78 W/m | 72 W/m | 42 W/m | 82 W/m |
| average over the whole year (from earth) | | | |
| 19 W/m | 14 W/m | 8 W/m | 6.4 W/m |

Best values have been achieved in site 2, where a rather simple design is used. The massive concrete floor allows long heat pump runtime during utility off-peak hours, a large heat exchange area to the room facilitates heating with low temperature (35 °C max.), and ground source layout results in earth temperatures mostly above 0 °C (fig. 6).

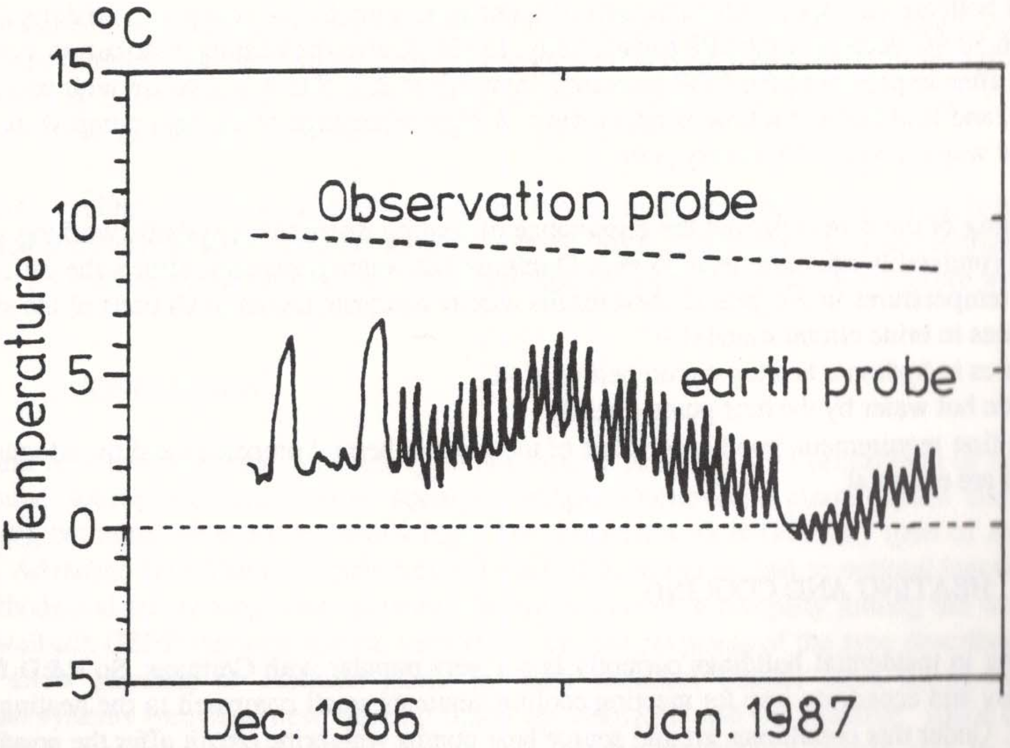

Fig. 6: Earth temperatures in site 2, Dec. 86 and Jan. 87, average over 10-48 m depth

Site 1 has much lower temperatures in the ground (fig. 7), the earth probes are undersized (heating load has been increased after construction of the plant), but as in site 2 low temperatures for heating are required. Hence COP is also close to 3, but SPF has been affected by a failure of the control system which made the heat pump to supply heating water of more than 45 °C for three month. In normal circumstances, a SPF of approx. 2.9 would have been resulted.

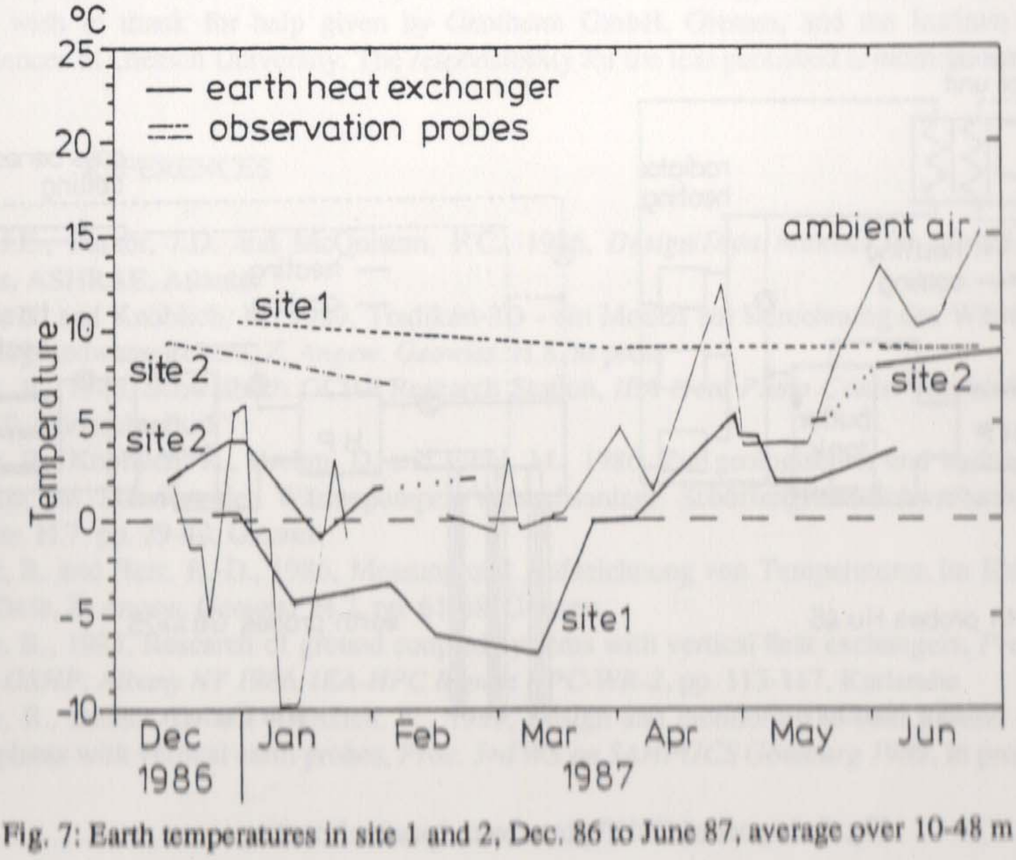

Fig. 7: Earth temperatures in site 1 and 2, Dec. 86 to June 87, average over 10-48 m depth

Site 3 and 4 both are equipped with domestic hot water generation by the heat pump. Making hot water of more than 50 °C decreases the SPF substantially. In site 3, also the heating distribution system was inadequate; after improvment the COP increased from 2.5 to 2.7. Site 4 is a house with passive solar architecture, and heat pump run time is rather short. A high percentage of the heat pump work was for domestic hot water, and so SPF is very poor.

The monitoring of the 4 sites proved the importance of heating distribution systems working with low temperature (preferably not more than 35 °C). Domestic hot water generation affects the efficiency as well as low temperatures in the ground. Best results require adequate layout of all parts of the system:
- Temperatures in brine circuit round 0 °C
- Temperatures in hydronic heating circuit below 35 °C
- No domestic hot water by the heat pump directly

To meet the first requirement, good knowledge of the ground thermal properties and the adequate earth probe layout are essential.

## HEATING AND COOLING

Space cooling in residential buildings currently is not very popular with Germans. So R&D focussed on a very easy and economic way for meeting cooling demands small compared to the heating load of the building. Under this conditions, ground source heat pumps with brine circuit offer the possibility of cooling without using any compression cycle.

The administration building of a company in Wetzlar is partly heated by a ground source heat pump plant since several years. With a refurbishment of the conference room in this building, a space cooling facility has been installed in 1987 as shown in fig. 8. An additional small pump circulates brine through a second heat exchanger in two fan coil units in summer. Heat pump and main circulation pump are not in use. Brine temperature of 10-14 °C allows cooling directly. A cooling capacity of 2.5 KW has been measured, driven by only 120 W for pump and fans.

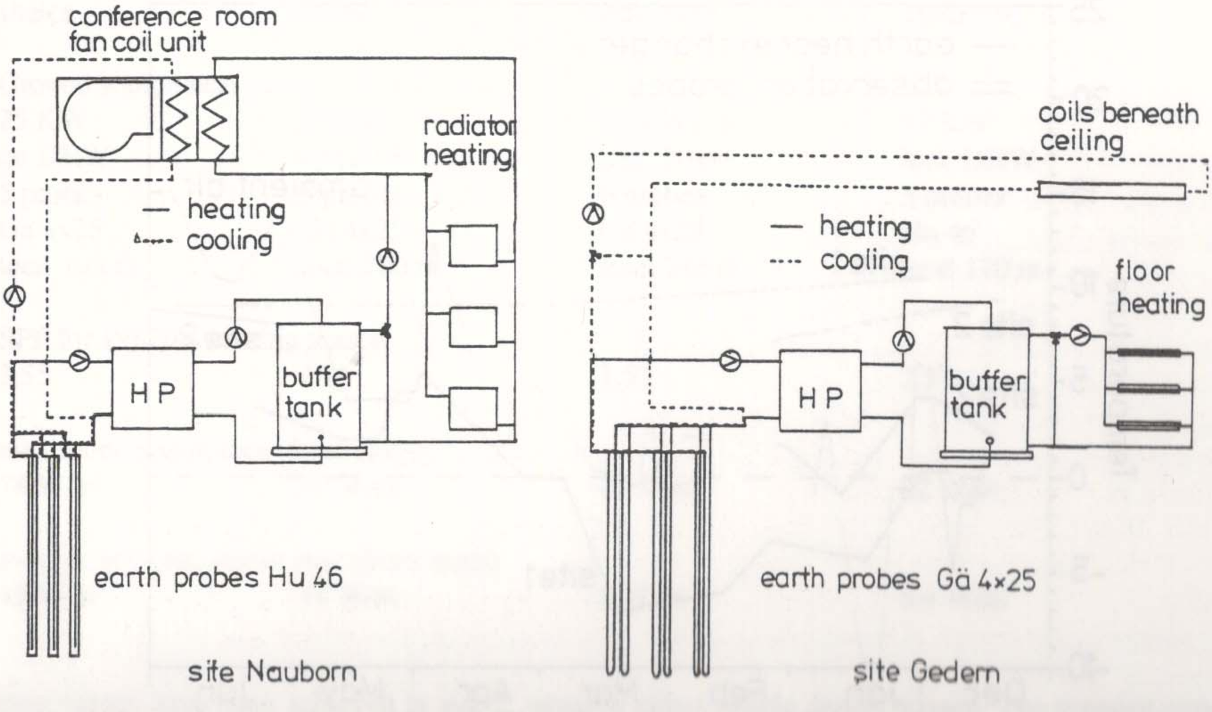

Fig. 8: Layout of GSHP plants with "passive" cooling

A residential house in Gedern has been equipped with similar space cooling in summer 1988. The brine is circulated through coils beneath the ceiling (a suspended ceiling covers them from sight). The brine temperature is controlled by a mixing valve to avoid condensing humidity. The system works completly silent, and without sensible air flow.

Such space cooling is feasible, if cooling load is only a small percentage of heating load. The exact design and the limits of the system are topic of ongoing R&D. Space cooling with reversed heat pump as known in North America (Bose *et al.*, 1985) will also be taken into account for future work.

## CONCLUSION

The actual very low oil prices in Germany do not foster a further market penetration of heat pumps at all. Ground source heat pumps have some advantages (monovalent plants, space cooling option, reliability), but initial costs are relativeliy high. The research work in Germany (part of Annex VIII in the IEA Advanced Heat Pump Programme) and other IEA countries lead to optimal layouts, construction methods and secure long-term operation. Geotherm GmbH, a company joining the working group for Schwalbach GSHP research station, installed more than 50 plants of the type described. Computer models allow planning of adequate plants for each situation. Further work is needed for direct expansion systems (provided new working fluids are available) and for "passive" space cooling. The use of small thermally activated heat pumps with ground heat source should also be investigated further. In respect to the environment and to rational use of fossil fuels, more ground source heat pumps are desirable also in Germany.

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