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ΗΠΕΙΡΟΥ

The Geothermal Heat Pumps Technology Status

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Summary

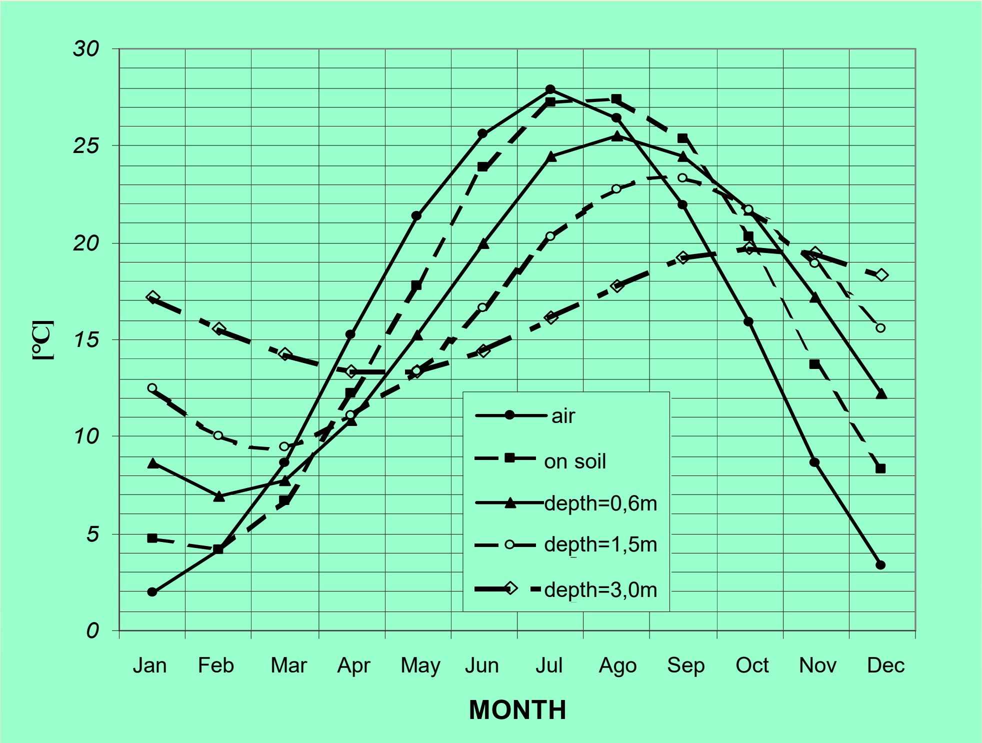
1. Description of Geothermal Heat Pumps and of their functional advantages;
2. Heat exchanger typologies and installation issues;
3. Strategical and cost issues.

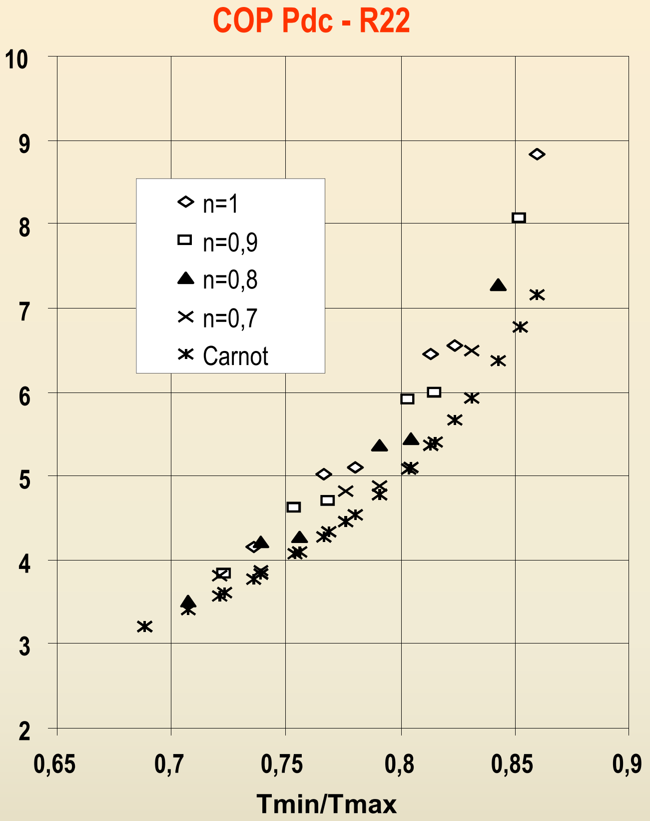
Classification of the GHPs

1. **Ground-Coupled Heat Pumps – GCHPs**
   Heat Pumps coupled directly with the soil through ground heat exchangers;
2. **Ground Water Heat Pumps – GWHPs**
   Heat Pumps coupled with underground water through buried wells;
3. **Surface Water Heat Pumps – SWHPs**
   Heat Pumps coupled with water surface bodies through immersed coils.

Geothermal Opportunities

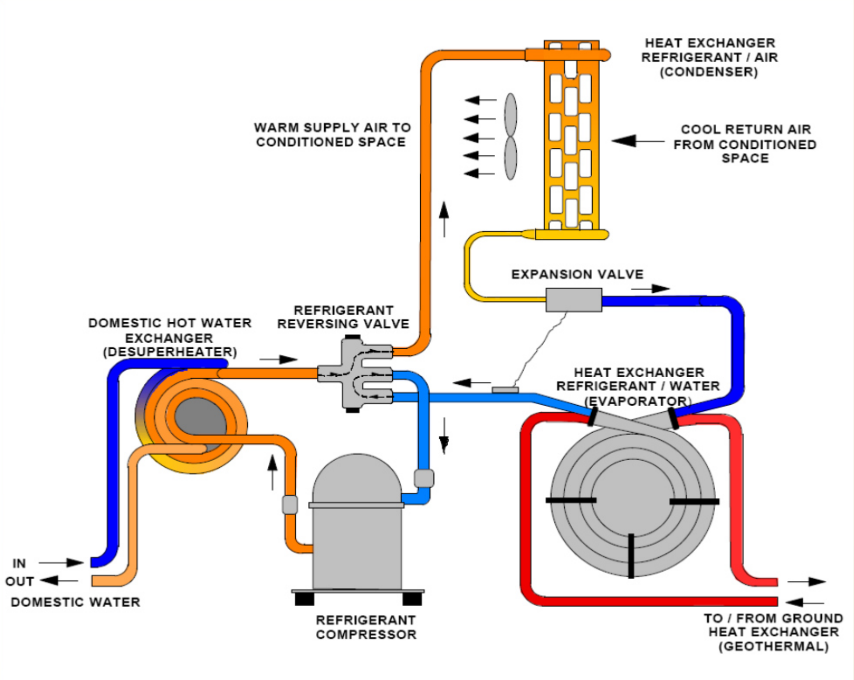
Temperature trends vs time for ambient air and for soil at different depths



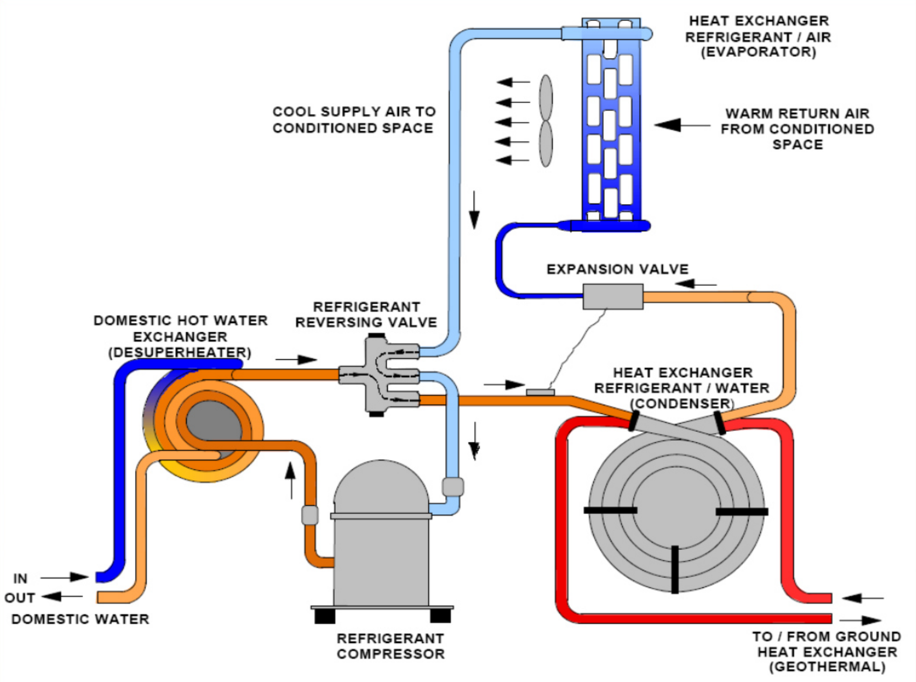


- The earth can provide a source of energy at almost unchanging temperature.
- The underground is like a heat reservoir: a heat source in winter seasons and a heat sink in summer.
- Burying holes or trenches in the soil is not a well-known practice.

Geothermal Heat Pumps at a glance



HEATING CYCLE



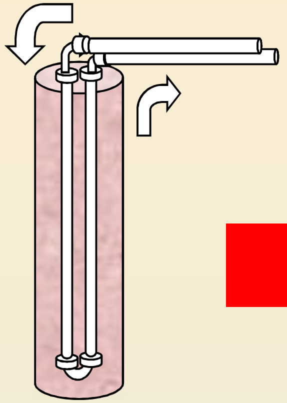
COOLING CYCLE

Advantages of GSHPs

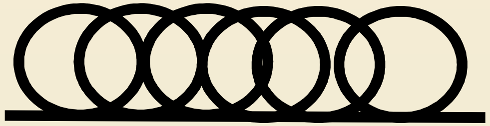
- lower energy and overall operating costs;
- significantly reduced greenhouse emissions;
- high reliability with low maintenance;
- lower life-cycle costs;
- easier modular design that facilitates a zone-controlled approach in heating and cooling, reaches a greater comfort and increases energy efficiency;
- compactness of the equipment that reduces room reserved to heating and cooling systems;
- improved exterior aesthetics and environmental friendliness, (no more need for external units or cooling towers)

Typologies of Heat Exchangers (HXs) for GHPs

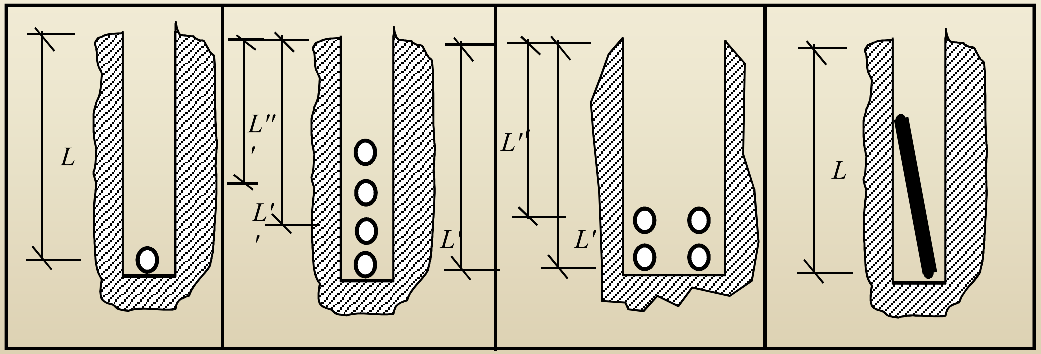
Vertical HXs (borehole)



Slinky (spiral) HXs



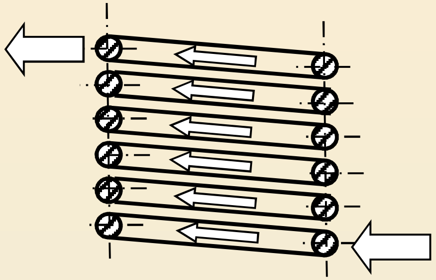
Horizontal HXs



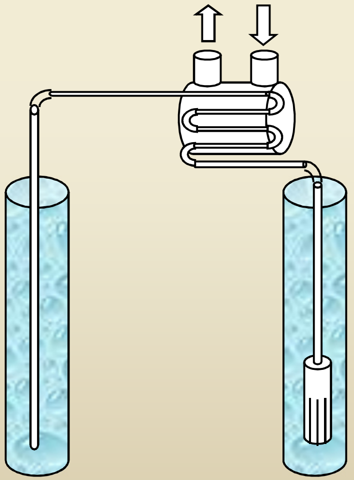
Closed Loop

Open Loop

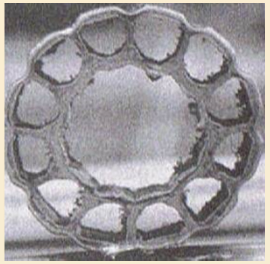
Coils



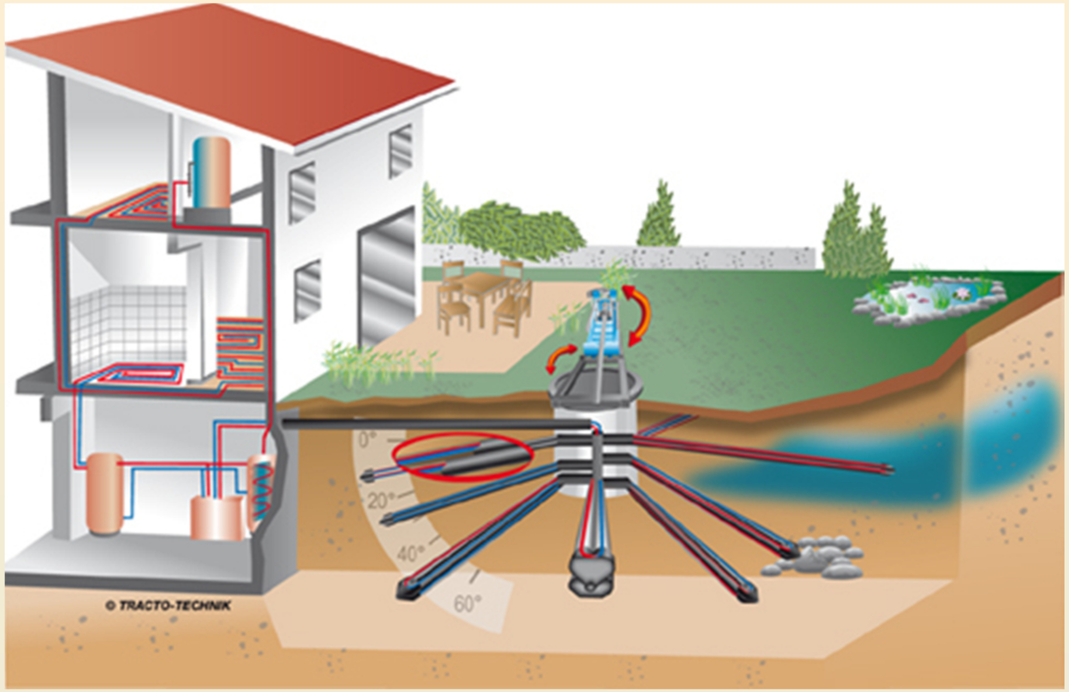
HXs for water wells



Heat Exchangers (HXs) for GHPs



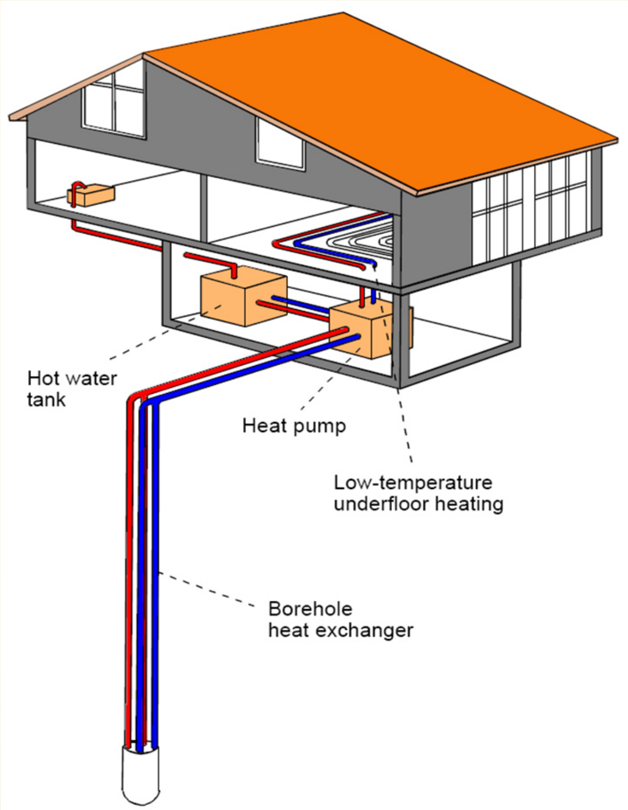
Heat Exchangers (HXs) for GHPs

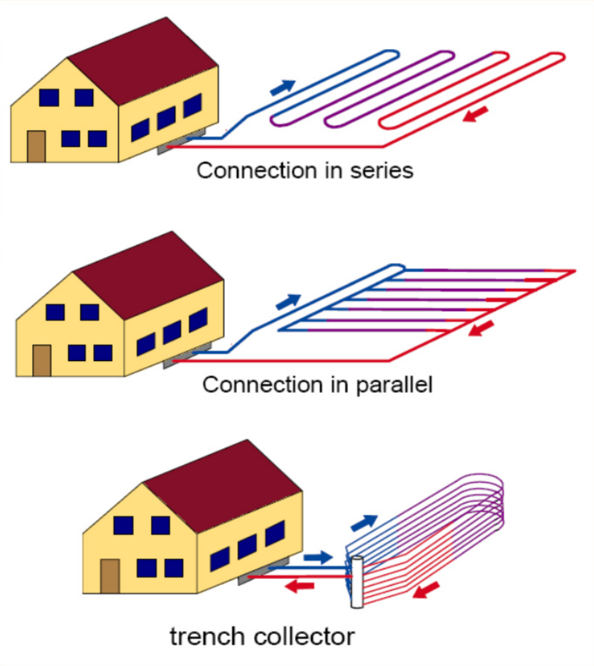


Radial Boreholes at different angles for maximum space exploitation

Tracto Technik - Germany

Actual layouts for GSHPs

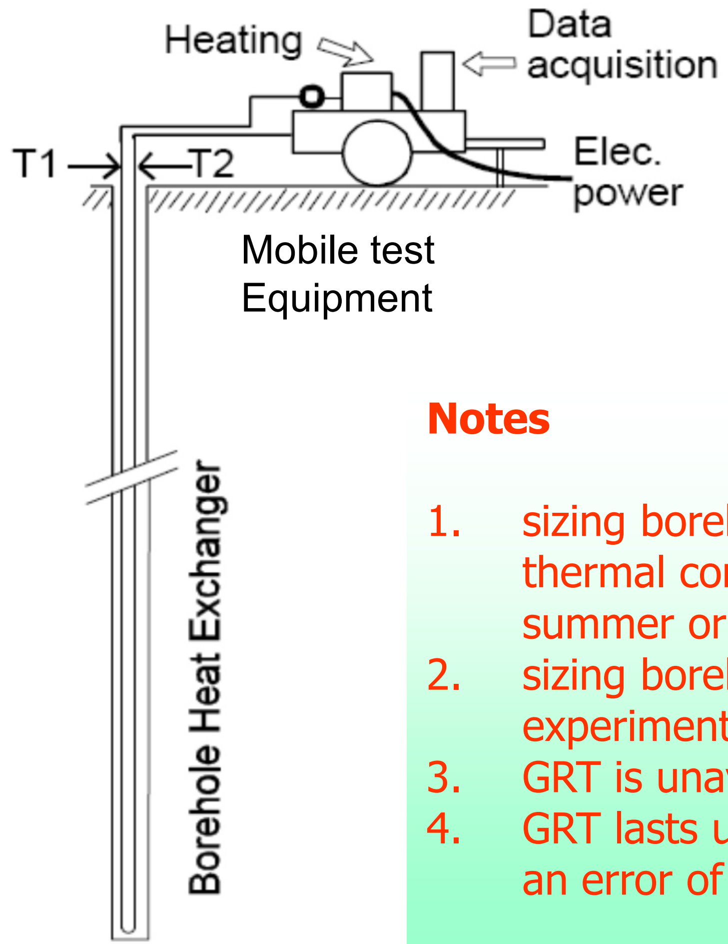


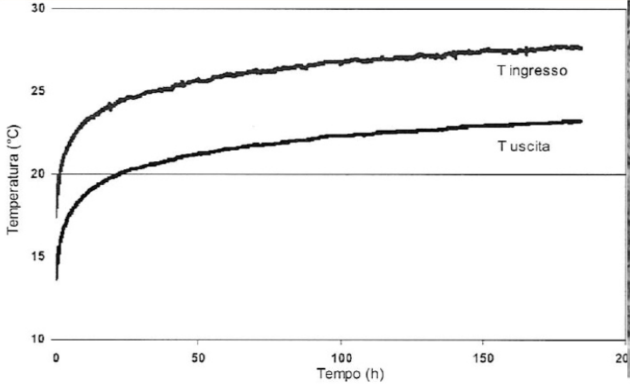


Design Issues

1. Balancing problems if a parallel a series scheme or for the HXs is chosen;
2. Tube diameter related with pressure drops, with pumping and initial costs as well as handling during installation;
3. Air purging depending on careful hydraulics arrangement;
4. Fluid quantity and antifreeze;
5. Heat transfer potential for available spaces around or under the building.
6. Right grouting to assure good thermal conduction

Ground Response Test (GRT)





Notes

1. sizing borehole HXs heavily depends on soil composition, thermal conductivity, use of the thermal system (winter, summer or both)
2. sizing borehole HXs after GRT is based on reliable experimental data;
3. GRT is unavoidable for large HXs fields;
4. GRT lasts up to 70 hours to reach the stationary regime with an error of about ±5%

Numerical Approach and Simulations

1. Boundary conditions have to be set based on experimental data or on theory simplifications
2. time approach has to be unsteady;
3. at least two years have to be simulated before focusing on results as the first year allows heat accumulation;
4. depending on geometries 3D is needed.

CREA made simulations for Horizontal Heat Exchangers in order to investigate about their suitability in environmental and cost terms Different analysis were performed using Gambit Preprocessor and Fluent CFD Code.

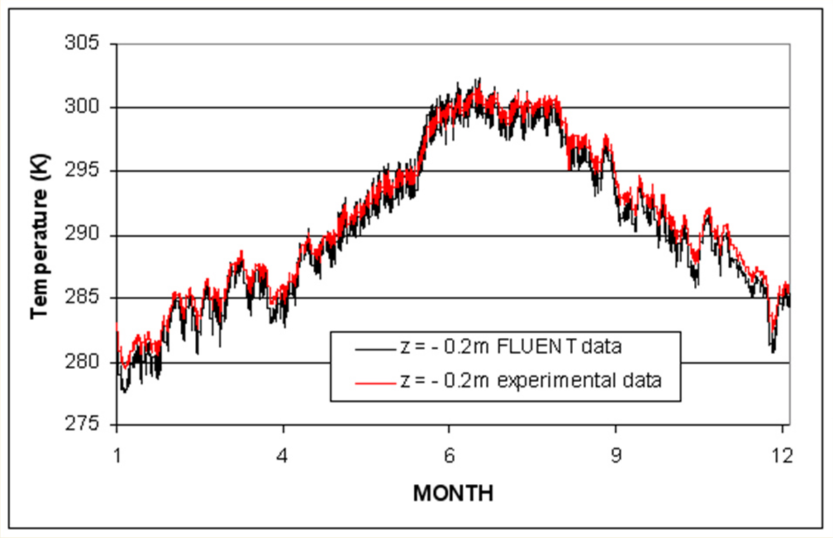
- Different geometries (Linear, Slinky and Helical HXs) behaviour depending on soil characteristics and operating conditions.
- The 2D analysis for validating boundary conditions was made with a simple rectangle of 1m x 6.9m [length x depth].
- The 3D analysis for temperature field solving was performed on a parallelepiped of 1m x 0.5m x 2m [length x width x depth] with a 0.05m diameter polyethylene (PE) pipe at the depth of 2m, length of 1m and thickness of 2mm.

Data for simulations

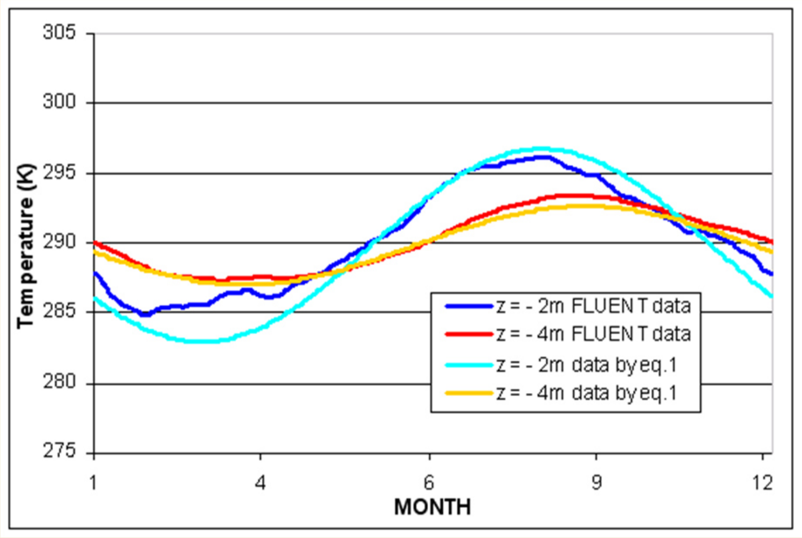
Available climatic data were:

- temperature and velocity of the air
- temperature of the underground soil at two depth (0.1 and 0.2 m)
- solar radiation of the year 2002.
- Data were averaged hour after hour and were recorded by an automatic station, located in Lecce (Italy), at the coordinates:
- Latitude 40°26'16" North
- Longitude 18°14'42" East.

Thermal behaviour of the soil for setting boundary conditions



The boundary condition matches experimental data



Eq.(1) can be used with a good accuracy at depths not less than 1m.

$$T(z,t) = T_M + a \cdot e^{-z\sqrt{\frac{\omega}{2D_T}}} sin\left(\omega t - z\sqrt{\frac{\omega}{2D_T}} + b\right)$$ **Eq.(1)**

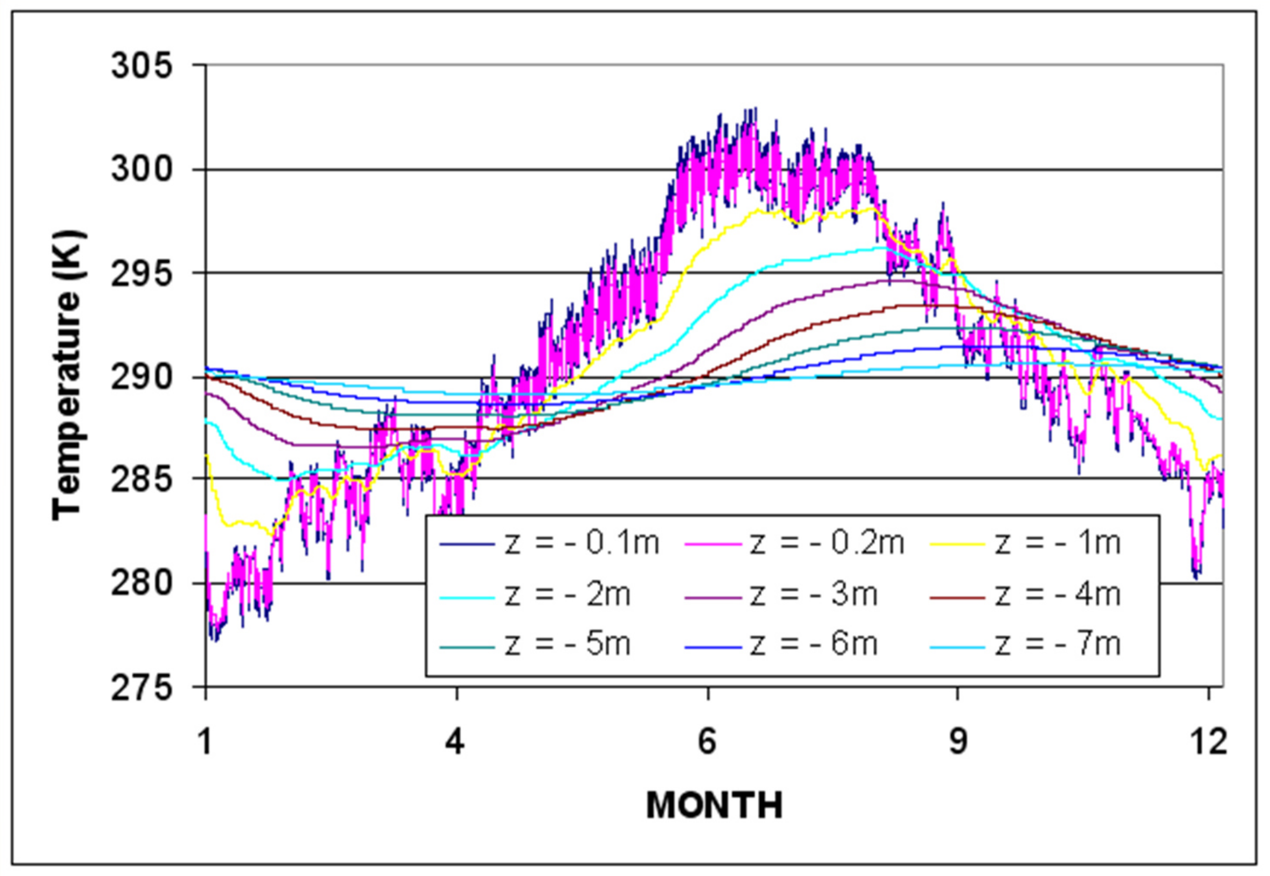
$$\omega = 2\pi / \tau$$

$$b = (\tau - 4t_M)\pi / 2\tau$$

a	Half min-max temperature difference on soil surface
b	Phase constant
D_T	Ground thermal diffusivity
T_M	Mean temperature in the period
t_M	Time needed to reach the maximum temperature on the surface

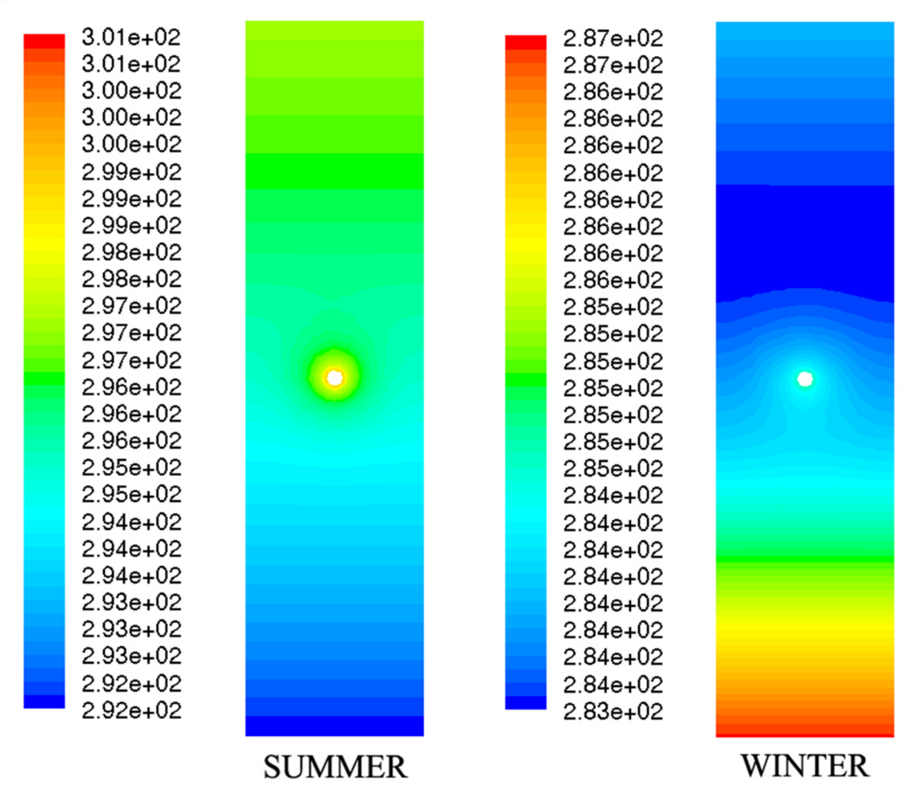
Coefficient	**Value**
T_M	16.84°C
a	16.95°C
τ	1 year
t_M	218th day

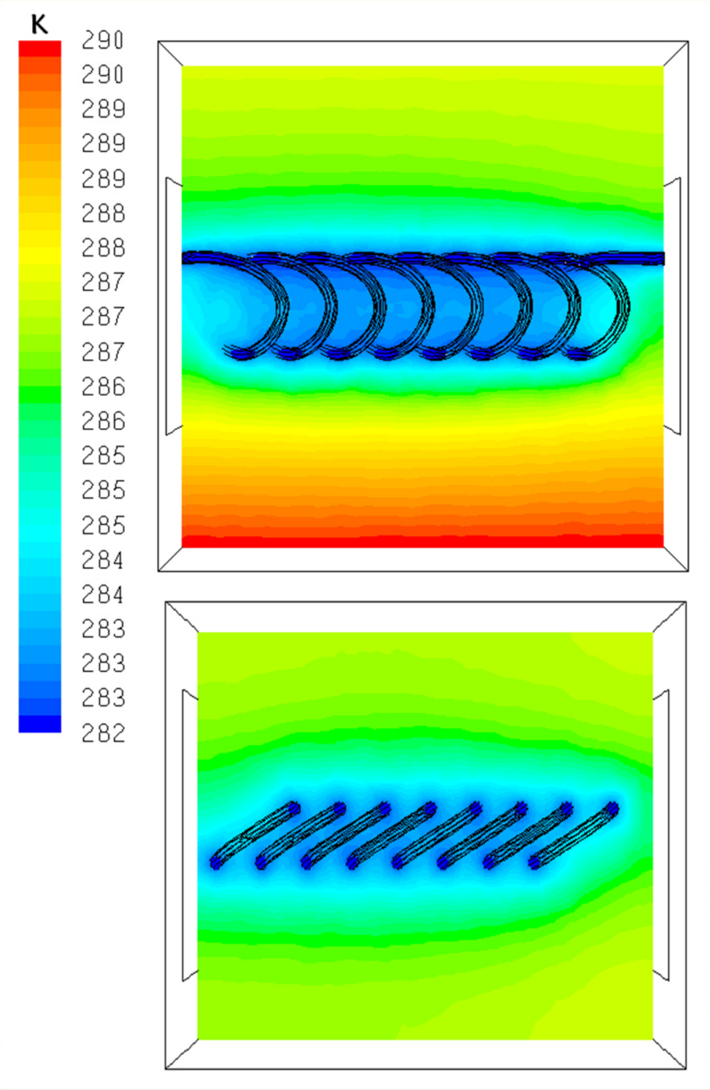
Thermal behaviour of the soil for setting boundary conditions



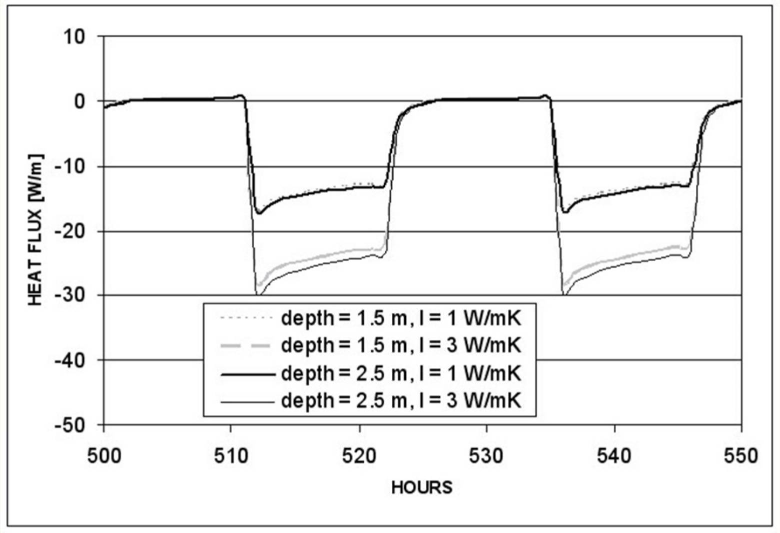
Moving down from the surface the temperature daily oscillations get completely dumped after 1m, the year ones disappear deeper and a phase shift due to the thermal inertia of the ground can be observed.

Thermal behaviour of the soil: the influence of the HXs

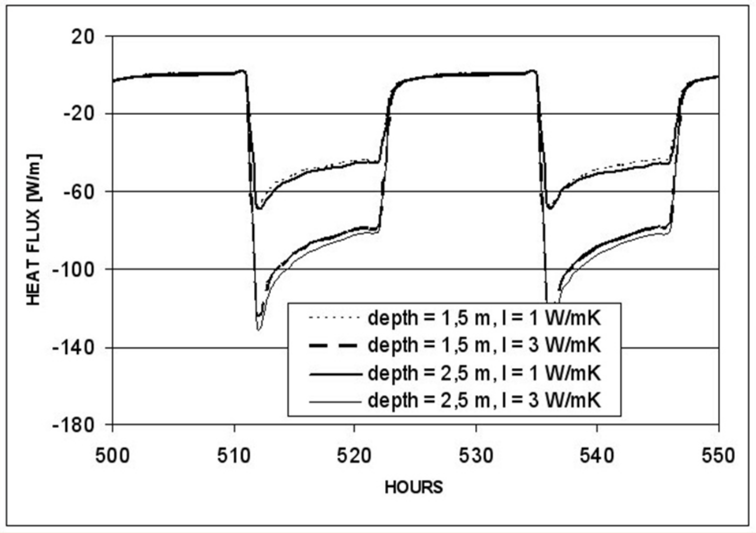




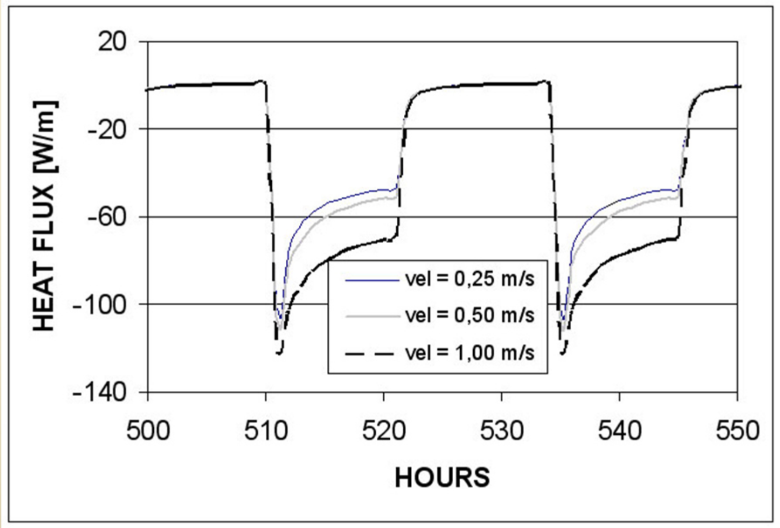
Heat Flux to and from the soil at unit lenght of trench



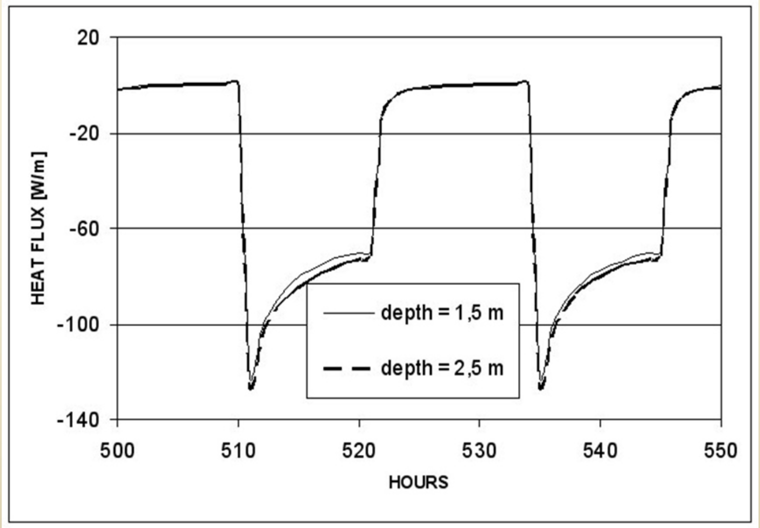
Linear HX; velocity= 1 m/s



Slinky HX, step = 0.3m ; velocity= 1 m/s



Step= 0.2 m; velocity= 1m/s; λ= 2W/m K



Step= 0.2 m; depth= 1.5 m; λ = 2W/m K

Results

- HXs geometries were compared in terms of heat transfer with the soil: the more compact setups (Helical and Slinky) showed a better performance compared to traditional single or multitube horizontal HXs
- Only a slight and acceptable increase of installation costs was found for more complex geometries if compared to linear horizontal HXs.
- Compact geometries was more influenced by the ground heat conductivities than installation depth. High conductive filling material improves more all HXs system performance rather than to dig a deeper trench.
- Small differences between Entering and Outlet Water Temperatures assure a good exploitation of the ground heat reservoir.
- The area of the soil thermally influenced by the pipe presence is small enough to let the designers count on high specific heat power per square meter (with systems operating the whole year).

Cost analysis

3 CASES and 3 SCENARIOS

Case 1, **small flat or villa in Lecce**;
10 kW of thermal power.

Case 2, **offices building in Lecce**
200 kW of thermal power.

Case 3, **commercial building in Lecce**
2500 kW of thermal power.

Scenario 1: constant cost of energy.

Scenario 2: present Italian average inflation rate: 2.5%

Scenario 3: assessment of a 6% trend

SYSTEMS COMPARED

- **Traditional HP**
- **GCHP with Vertical HXs**
- **GCHP with Horizontal HXs**

Hypoteses for the comparison

air temperature vs time;

underground temperature at 2m and 7m deep;

peak heating and cooling power respectively for winter and summer;

imposed mean temperature difference for water to water, soil to water, air to water, refrigerant to water heat exchangers;

estimated losses due to defrosting for air-water traditional heat pump;

on-off periods of the system.

Cost analysis

Annual electric energy consumption [kWh] for heating

	Traditional HP	Vertical GCHP	Horizontal GCHP
Case 1	2263	1553	1651
Case 2	63069	43699	46505
Case 3	785926	546232	581311

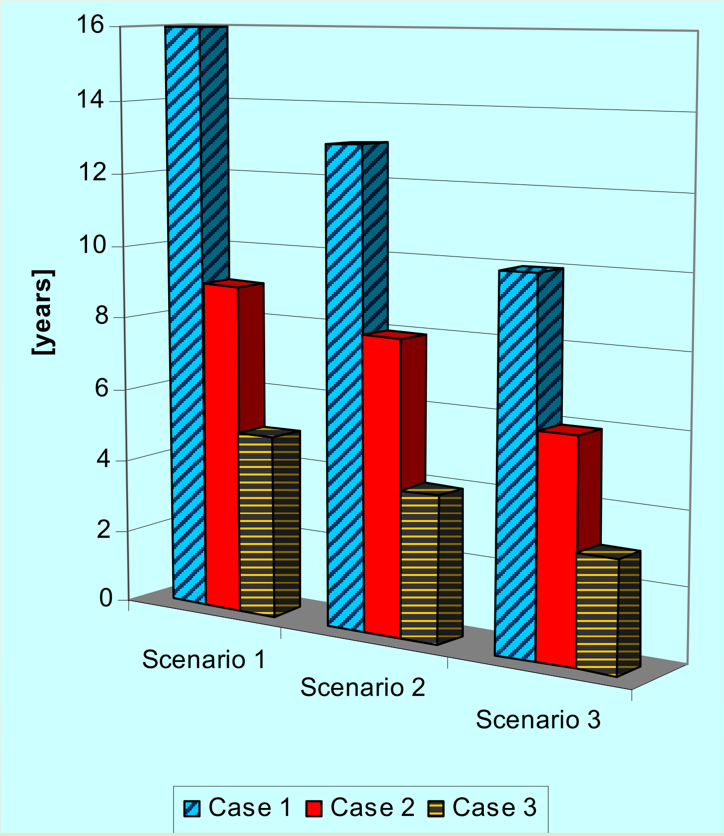
Annual electric energy consumption [kWh] for cooling

	Traditional HP	Vertical GCHP	Horizontal GCHP
Case 1	270	132	197
Case 2	5779	2832	4209
Case 3	72237	35402	52612

Annual electric energy savings relevant to the conventional HP

	Vertical GCHP [%]	Horizontal GCHP [%]
Case 1	33.46	27.05
Case 2	32.41	26.33
Case 3	32.22	26.13

Cost analysis results

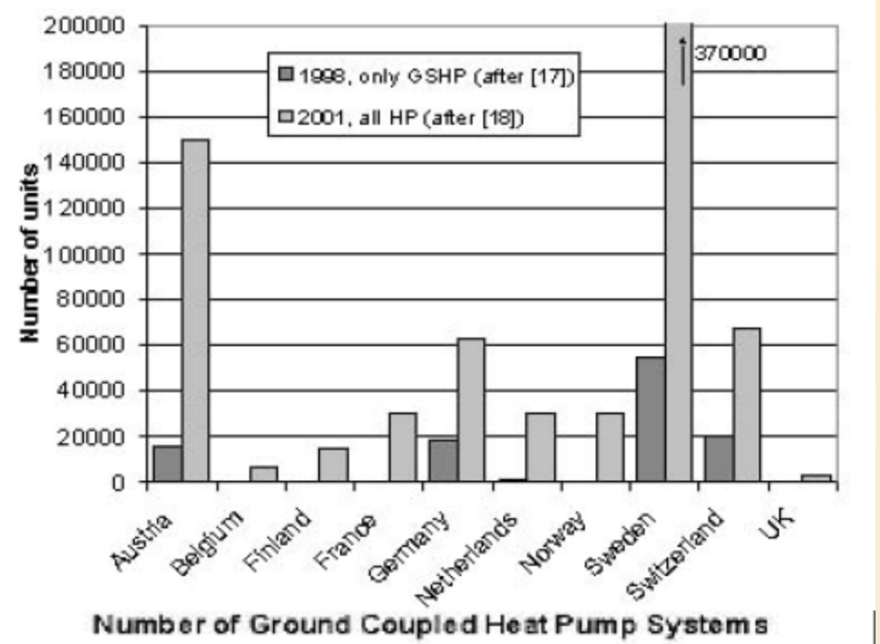


Convenience time of Horizontal GCHPs and. traditional HP

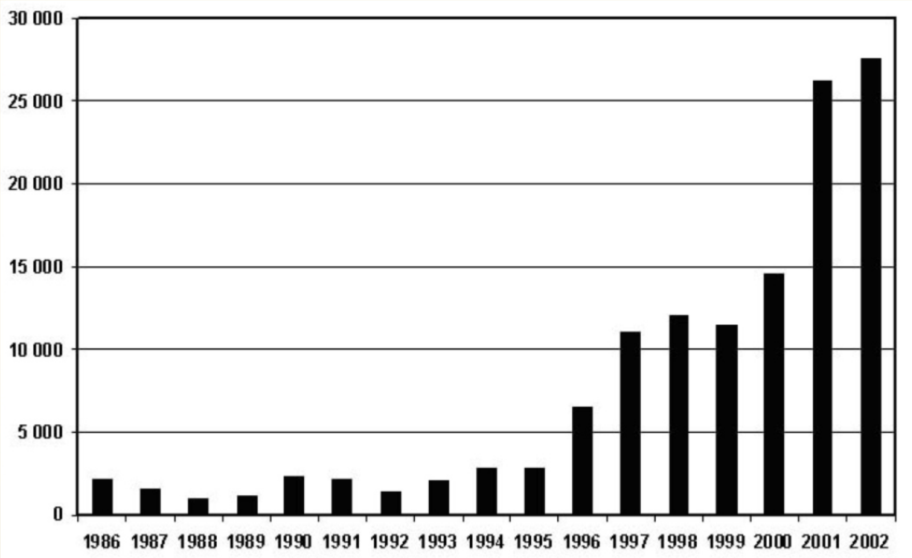
- The depth of 2m seems to be a good compromise between costs and increased efficiency compared to traditional solutions.

- This GCHPs solution showed its convenience especially for systems of medium and big size (minimum 3.5 years) and advantages could be much more, considering that the horizontal GSHPs installation can exploit other building works, involving digging.

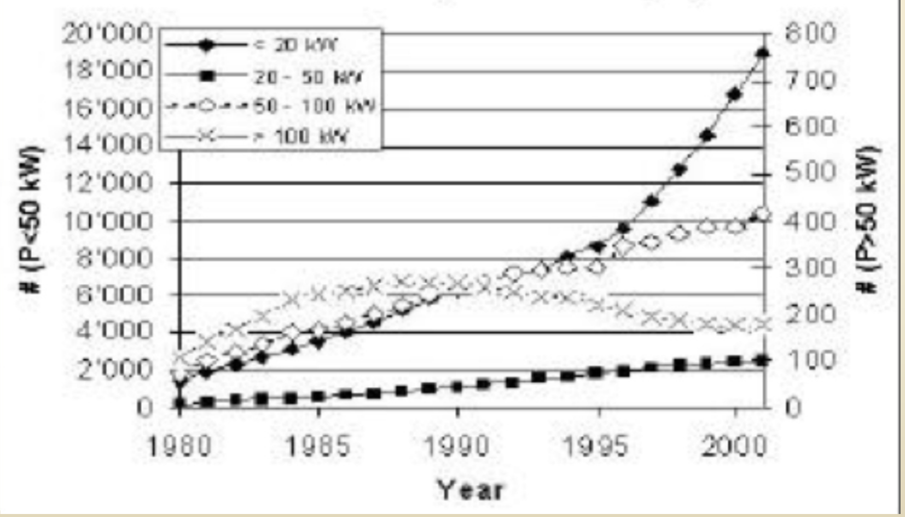
Where are GSHPs?



GSHPs in Europe
(Sanner, 1999; Donnerbau, 2003)



Number of Swedish GSHPs through the years
(SVEAP study 2002)



GSHPs in Switzerland through the years
(Kohl et al. 2002)