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Possibilities for Heating and Cooling through Underground Thermal Energy Storage in the Mediterranean area

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Introduction

Because of the climatic conditions around the Mediterranean sea and on the islands, cooling is the premier task of building thermal energy systems. The systems used currently almost all depend on refrigeration cycles driven by electricity (compression chillers) or high-temperature heat (absorption chillers). The result is a tremendous need for energy just for space cooling. In places where at times enough cold (winter air, rivers from mountains, etc.) exist, Underground Thermal Energy Storage is a very effective method to save energy.

Underground Thermal Energy Storage (UTES) systems can be divided into two groups:

- Systems where a technical fluid (water in most cases) is pumped through heat exchangers in the ground, also called "closed" systems (BTES)
- Systems where groundwater is pumped out of the ground and injected into the ground by the use of wells, also known as "open" systems (ATES).

An advantage of closed systems is the independence from aquifers and water chemistry, an advantage of open systems the generally higher heat transfer capacity of a well compared to a borehole. This makes ATES usually the cheapest alternative, if the subsurface is hydrogeologically and hydrochemically suited. The basic underground concepts are explained in Fig. 1.

Borehole Storage (BTES)
Systems with boreholes and pipes

- high specific heat
- medium thermal conductivity
- no groundwater flow

Examples:
- Sediments like shale, marl, clay etc.; limestone, sandstone and others may also be suitable
- Igneous rocks like granite, gabbro, etc.; some metamorphic rocks like gneiss

Aquifer Storage (ATES)
Groundwater as heat carrier

- medium to high hydraulic conductivity and transmissivity
- high porosity
- low or none groundwater flow

Examples:
- Porous aquifers in sand, gravel eskers
- Fractured aquifers in limestone, sandstone, igneous or metamorphic rock

Fig. 1: Basic characteristics of UTES systems

UTES technical alternatives

In more Northern climates, there are basically two operation principles for ATES systems:

- continuos operation, i.e. the flow direction is kept constant all the time
- cycling operation, where the flow direction is reversed between loading and unloading cycles.

Because the continuous regime only is feasible for plants where the load can be met with temperatures close to natural ground temperatures, and the storage part is more an enhanced recovery of natural ground temperatures, this regime is hardly feasible in Mediterranen regions, were natural ground and groundwater temperatures are to high for direct cooling all year round.

With the cycling regime (s. fig. 2), cold can be stored below/above the natural ground temperature. The ground volume around each well or group of wells can develop into a definitive cold and warm reservoir. It is possible to keep a ground volume above or below the natural temperature all the time. A disadvantage compared to the continuos regime is the more complicated well and system design with each well being able to produce or to accept groundwater.

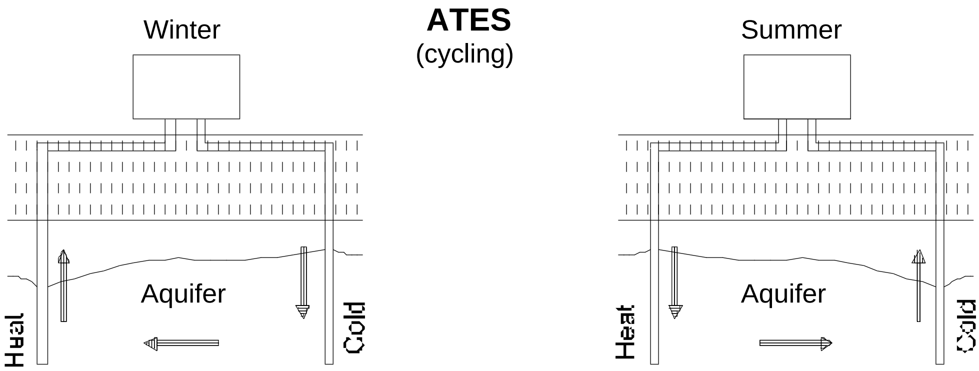

Fig. 2: Loading and unloading operation of a cyclic ATES

In borehole storage systems (BTES), the same borehole heat exchangers are used for loading and unloading always. BTES systems cannot react as fast as ATES, as heat transport is dominated by conduction only. The same reason dictates that the thermal output of one well is much higher than that of a borehole heat exchanger.

Examples of UTES for cold storage

Many plants with ground water wells (ATES) are specially dedicated to cold storage, to secure cooling in summertime (SANNER et al., 1996). Loading of the store frequently is done by pre-heating the ventilation air in wintertime, or by using cooling towers etc. to collect cold in winter for storage. This principle is extremely popular in the Netherlands, but is also used in Sweden and Canada. Large projects like the Prins-van-Oranje-hall of the Utrecht trade fair are equipped with this technology.

Other projects use the heat pump for heating in wintertime, thus cooling down the ground, and use thar cold for cooling during summer. The boundary between true UTES and mere GSHP here is not very rigid.

One of the most prominent ATES plants for heating and cooling is part of the SAS head office in Solna/Frösundavik north of Stockholm, operational since 1987 (JOHANSSON, 1992). The geological situation is very favourable; an esker, mainly coarse sand and gravel deposited by a sub-glacial river, offers very good hydraulic conductivity ($k = 3 \cdot 10^{-1}$ m/s in the central part and $k = 5 \cdot 10^{-3}$ towards the margins), and easy construction of wells. Cold in wintertime is produced by pre-heating the ventilation air and by the heat pump evaporator (fig. 3). In summertime, the chiled groundwater can be used for direct cooling with ca. 2000 kW cooling capacity. Heating and cooling load are in a good equilibrium, e.g. for the year 1989 3.1 GWh cooling and 3.8 GWh heating. The ATES system allows to bridge the time gap between the heating and cooling season, and to minimise energy input from outside. In 1989, external energy input amounted to 1.4 GWh, which results in a seasonal performance factor for the whole heating and cooling supply of 4.9.

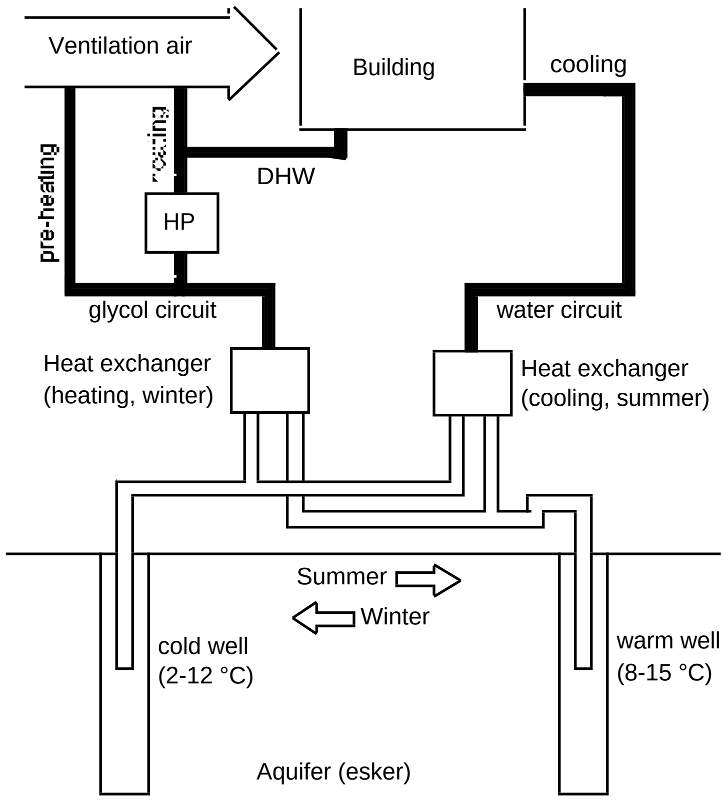

Fig. 3: Schematic of ATES plant for SAS headquarters, Solna, Sweden

An example for a BTES system, mainly for space cooling, is the new headquarters of the German Air Traffic Control in Langen, just a few kilometers southeast of Frankfurt airport (MANDS et al., 2000). The office building will offer room for ca. 1200 employees; the basic data of the building are:

• total building volume	230’000 m^3	(8’122’450 cu ft)
• total floor area	57’800 m^2	(622’160 sq. ft)
• heated/cooled area	44’500 m^2	(479’000 sq. ft)

A borehole thermal energy storage with two borehole fields comprising a total of 154 borehole heat exchangers (BHE) each 70 deep is integrated into the heating and cooling system. Both fields supply a total cooling capacity of 340 kW and 330 kW heating capacity. This equals 80 % of the annual cooling energy and allows 70 % of the annual heating with the heat pump. Heat and cold distribution inside the building is primarily done through the ceilings/floors and through ventilation air (fig. 4)

During summer the cold water from the borehole heat exchangers is used directly to cool the cooling ceilings, and the underground is slowly heated. In winter this heat is used as heat source for heat pumps. The peak cooling loads are met by conventional chillers, and the peak heating loads are covered by districted heating.

An important tool for design of BTES is the thermal response test. Three such tests were done at borehole heat exchangers with 70 m drilling depth. This allowed for measuring the soil thermal conductivity and the influence of the thermally enhanced grout on the borehole thermal resistance:

- Soil thermal conductivity up to λ = 2.8 W/m/K
- Borehole thermal resistance, with thermally enhanced grout lowered to r_b = 0.08 K(/W/m)

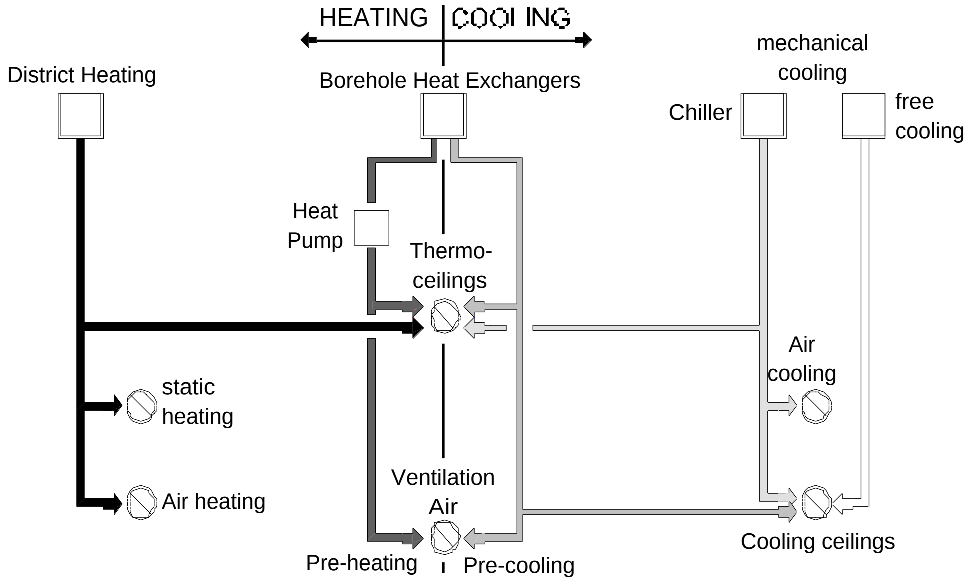

Fig. 4: Schematic of the heating- and cooling concept for the German Air Traffic Control (DFS) headquarters

Cold sources and opportunities in the Mediterranean

Studies have shown that UTES systems for cooling can be applied in the Mediterranean area. The main cold source can be the ambient air in cold winter nights, as e.g. shown for a project in Egypt (ABBAS et al., 1996; ABBAS, 1998), both in a ATES and a BTES alternative. In certain locations streams from the mountains bring cold water in winter and spring and can be used as cold sources. A ATES project based on water from Seyhan river was studied for the new extension of the academic hospital of Çukurova University in Adana, Turkey. Within a collaborative project of the IEA, Annex 8 of the Energy Conservation through Energy Storage Implementing Agreement, a study on the UTES potential in Turkey was prepared.

From the experience in other areas, and from the Turkish potential study it can be concluded that the relevant geological conditions for UTES systems can be found frequently around the Mediterranean Sea, and also that for most underground situations a suitable UTES option (ATES, BTES, hybrid) can be adapted.

The first operating UTES on the coast of the Eastern Mediterranean sea was constructed in 2001 in the port city of Mersin, Turkey. It is an ATES system with 2 wells, serving for heating and cooling in a supermarket. Heat pumps are used both for heating and cooling, and the relevant heat- and cold-source is provided by the groundwater system. First operational experiences are very promising, and a dissemination of this technology can be expected.

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