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Feasibility investigations for underground cold storage in Giza, Egypt

by Abbas M. Abbas [1] & Burkhard Sanner [2]

[1] National Research Institute of Astronomy and Geophysics, 11421 Helwan, Cairo, Egypt

[2] Institute of Applied Geosciences, Univ. Giessen, Diezstr. 15, D-35390 Giessen, Germany

ABSTRACT

Underground Thermal Energy Storage (UTES) can be used for building heating and cooling. In this study the possibilities for UTES in a hot climate are considered. Technical feasibility of cold storage both with borehole heat exchangers and with aquifer storage could be demonstrated for the climatic environment of the Cairo region, Egypt. Nevertheless, direct cooling is hardly possible all summer, and chillers will be required for peak cooling. The balancing of building cooling and heating loads (incl. hot tap water) and the storage of extra cold in winter nights can help to make UTES economic also in hot Mediterranean climate.

KEYWORDS

UTES, underground cold storage, aquifer storage, groundwater modelling

1. Introduction

To investigate into the feasibility for Underground Thermal Energy Storage (UTES) in Egypt, a theoretical building was considered in one of the areas with strongly growing urban development to the West of Cairo. Geophysical investigation and hydrogeological modelling for a building of 1 MW thermal energy load were camed out to the South of the Pyramids area of Giza (figure 1). The geophysical interpretation of geoelectric and seismic refraction data revealed the subsurface image:

- the underground in the eastern part of the area consists of a porous surface layer, followed by a clay layer and then by a second porous layer consisting of sand to marly sand. These deposits are belonging to the Quaternary Nil river sediments;
- the western part of the area is dominated by the Upper-Middle Eocene Pyramids cliff (mainly fractured limestone to sandy limestone).

The building under consideration (high class hotel, museum, cultural centre, etc.) is assumed to apply UTES-techniques for heating and cooling, as a part **of** the general modernisation plans for the Pyramids area. The expected benefits **are** energy savings and emission reductions, **as** well as introducing new technologies into the Egyptian market.

As Egypt is a hot country, it was more suitable to think about cold storage. In the present work, two assumptions were evaluated

- a borehole thermal energy storage (BTES) in the limestone rocks **of** the cliff;
- an aquifer thermal energy storage (ATES) in the Quaternary aquifer.

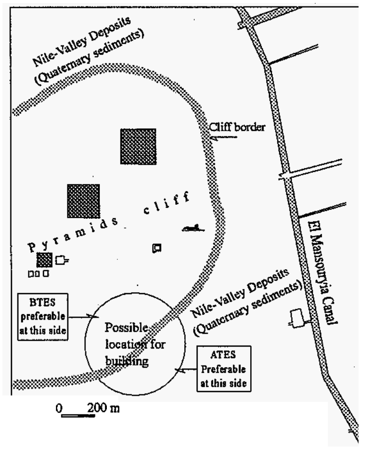


Figure 1: Possible location of the building under consideration

2. Site conditions

2.1 Hydrogeology

The hydrogeological conditions of the area under investigation have been delineated through some previous pumping tests, geophysical investigations and a hydrogeological modelling (ABBAS 1998). The geophysical and the hydrogeological models of the area (figure 1) indicate the possibility to evaluate the considered storage systems. Geology and geophysics have elucidated the contact between the middle Eocene fractured limestone rocks and the Quaternary alluvial deposits.

The Quaternary section is composed of a succession of (from top to bottom):

- a shallow layer consisting of a mixture of sand, bricks, plant roots, some clay, etc., representing a surface aquifer. Its average thickness **is** about ***5*** m;
- a clay layer (aquitard) of a thickness of about **7-9** m, vanishing at some locations and showing lenses at others;
- the third layer is sand and is considered as the main aquifer in the area; thickness ranges among **12-17** m. This aquifer is in contact with the **fractured** limestone of the Pyramids cliff **(figure 2).**

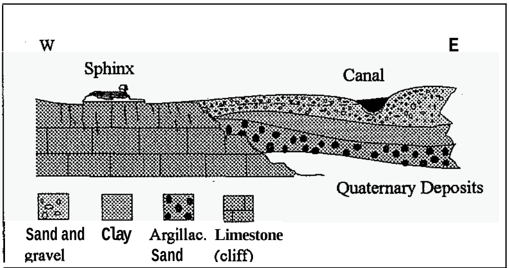


Figure 2: Geological cross section, showing contact of Quarternary aquifer with fractured limestone of the Pyramids plateau

2.2 Building assumptions

In the following discussion, a building (hotel) with an energy load of 1 MW for heating in winter (hot water for showers, swimming pools, etc.) and for space cooling in summertime has been assumed. This load is equivalent to about 300 rooms and about 400 persons occupying the place. The energy load of a luxury hotel may even be higher than 1 MW, but this figure **(1 MW)** was chosen to simplify the estimations. With weather data for Cairo for the year **1997,** the heating and cooling load distribution for the individual months was estimated (table **1).** Heat pump and chiller efficiencies were not taken into account at this step, since the accuracy of the load estimations alone may not be very high. A more exact study should in future be done with data from existing or planned buildings in the zone, to allow also a detailed economic analysis of such project.

First calculations showed, that the storage of cold in winter from the heat pump heating operation is all but sufficient. ***So*** additional cold storage is required, and the source could be cold ambient air in winter nights. An additional amount of 200 MWh in January and

February and of 120 MWh in December and March may be collected that way (table 1). The following storage snnulations were done with the data including additional cold.

Table 1: Monthly energy loads of the assumed building (estimation based on climatic data for 1997)

Month	Heat load (MWh)	Heat load + additional storage (MWh)	Cooling load (MWh)
JAN	248.4	448.4	0.0
FEB	320.4	520.4	0.0
MAR	209.6	329.8	0.0
APR	131.6	131.6	50.8
MAY	24.4	24.4	256.4
JUN	0.0	0.0	302.0
JUL	0.0	0.0	369.6
AUG	0.0	0.0	313.6
SEP	0.0	0.0	215.6
OCT	14.0	14.0	172.4
NOV	97.6	97.6	48.8
DEC	218.2	338.2	0.0

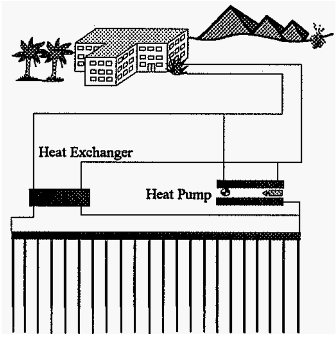
3. Storage systems

Several approaches were used to select **the** storage model in regard to the climatic conditions of Cairo. Eventually two systems have been evaluated at the chosen location and their feasibility has been investigated.

3.1 Borehole Thermal Energy Storage (BTES)

The main principle of borehole thermal energy storage is to use pipes or borehole heat exchangers (mainly vertical) to transfer thermal energy between the energy carrier fluids and the ground (figure **3).** The ground surrounding the pipe system is gradually heated while the store is loaded (or cooled in case of cold storage) by warm water flowing through the pipes (**BAKEMA** et al. 1994). The number of heat exchanger tubes depends mainly on the design of the storage (the energy load, the soil type, distance between pipes and the shape of the loops).

For the present application a PC-program has been used, through which it was possible to simulate different BTES-systems and also to calculate the changes in the thermal carrier fluid temperature for longer time periods ***(5,*** 10 or ***25*** years), within very short execution time. This program is called Earth Energy Designer (EED) (HELLSTROM et al. **1997).**



Borehole Storage System

Figure 3: Schematic of a borehole thermal energy storage (BTES)

For the present estimation typical thermal properties of marly limestone rock were selected to represent the underground

- Ground thermal conductivity $\lambda = 2.2$ W/m/K
- Ground heat capacity (vol.) $\rho c_p = 2.3$ MJ/m^3/K

Annual average ground **surface** temperature is relatively high with ca. 21 "C, according to the climatic conditions. Water was chosen as heat carrier fluid. To allow easier calculation, the total 1 MW system was divided into 4 subsystems of 250 kW each, and **one** subsystem simulated. The simulation period was chosen for 5 and 10 years, and the system should start operation in September. The total number of boreholes that should be drilled to cover the energy load demand was calculated by the program to be 480 borehole. Each borehole has a depth of 100 m. Figure 4 represents the variation of the heat carrier fluid temperature in the fifth year and the fluid temperature development over 10 years.

3.2 Aquifer Thermal Energy Storage (ATES)

The simple idea of ATES systems (**figure** 5) is to choose a (preferably) confined aquifer with suitable structural conditions, flow gradient and hydraulic conductivity. It is very important to determine these parameters precisely for minimising of thermal losses. **A** basic system may consist of two wells, one well for warm side and another well for cold side. If the system is charged in the Summer, then during the Winter warm groundwater will be extracted from the warm well, cooled down through the heat pump or heat exchangers and re-injected into the cold well. The reverse process will occur in summertime. The result of this process will be the building up of a heat volume surrounding the warm well and a cold volume surrounding the cold well (PROBERT 1995).

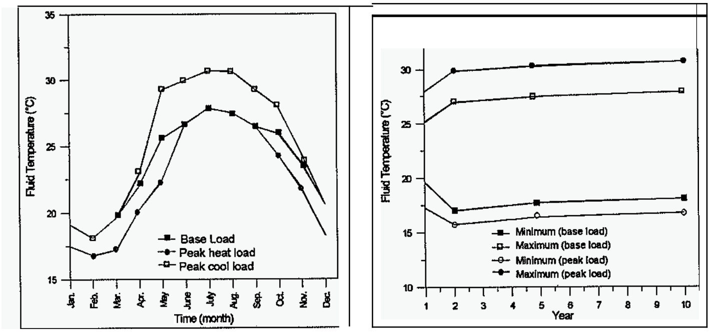


Figure 4: Fluid temperature development in the 10th year (left) and development of min. and max. fluid temperatures over 10 years (right), for BTES, calculated with EED

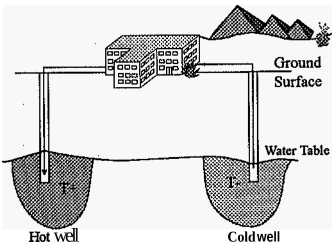


Figure 5: Schematic of an aquifer thermal energy storage (ATES)

The heat volume (warm well) and cold volume (cold well) can be side to side (in the same aquifer) separated by a specific distance, **or** the heat volume can be above the cold volume, if one thick aquifer or two separate aquifers will be used.

To evaluate the heat and cold volumes and their fluctuation through the storage operation, program CONFLOW (PROBERT 1995) was used. The input parameters for the aquifer, as determined by the geophysical and hydrogeological survey (ABBAS 1998) and optimised using a groundwater model, are:

- Aquifer thickness = 20 m
- Aquifer heat capacity (vol.) $\rho c_p(a)$ = 2.0×10^6 J/m^{3}K
- Regional flow = 3.2×10^{-8} m/s
- Hydraulic conductivity k = 1.9×10^{-4} m/s
- Fluid heat capacity (vol.) $\rho c_p(f)$ = 4.2×10^6 J/m^{3}K

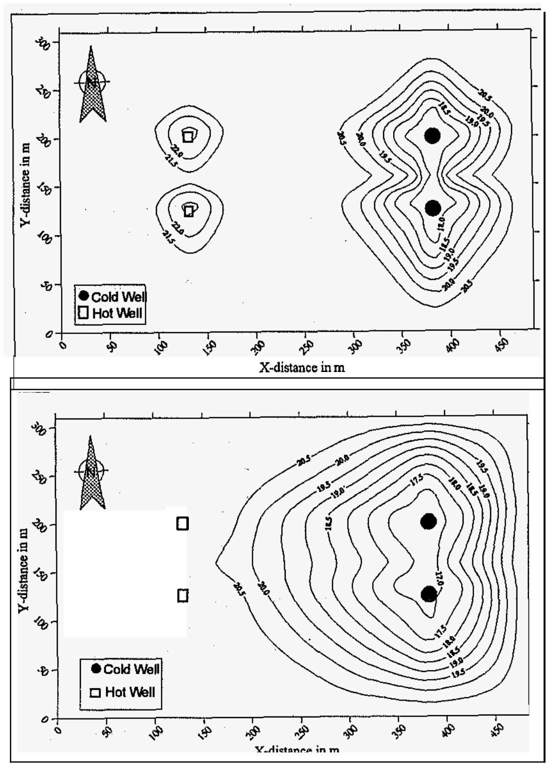


Figure 6: TRADIKON-3D simulation of one 250 kW ATES module with 2 + 2 wells (total of 4 modules for the building, i.e. 8 + 8 wells): Temperature distribution after 20 months (above) and after 9 years and 8 months (below); a volume of cold groundwater has accumulated around the cold wells.

Program CONFLOW was used to simulate 3 years of operation, and the necessary number of wells could be assessed to 8 cold and 8 warm wells for the whole 1 MW system.

The next step was to use the finite difference model TRADIKON 3-D to simulate the operation of the ATES and to check if the number of wells is sufficient for cold storage. The results of the calculations with the programs CONFLOW and TRADIKON-3D are:

1. A cold volume will build up in the winter in the subsurface (aquifer), showing successful cold storage operation **(figure 6).** This cold volume will be consumed through the successive hot months of the summer.
2. The temperature of the cold volume (storage) is not very low (approx. **16** °C), **due** to the natural groundwater temperature above **20** °C and the climatic conditions limiting cooling of the water in winter. To cover the cooling demands in summer, direct cooling is not always possible, and a cooling machine is required in particular in **peak** cooling periods.
3. Heat storage in combination with the summer cooling application cannot be done at temperatures allowing direct heating. A heat pump is required during the heating period, and even a back-up boiler may be necessary.

4. Conclusions

The present study has shown that the application of UTES technology is technically feasible even in a climate like that of Cairo. For other regions of Egypt, like the southern part (Assuan) or the Mediterranean coast (Alexandria), the local climatic conditions may limit UTES application, and further investigation is required. An economic evaluation of the proposed system could not be made in this study. However, the BTES alternative can be considered as hardly economic, with close to 500 boreholes and a total of nearly **50** km borehole length! An ATES, with a limited number of wells, can be made economically interesting easier, if the subsurface conditions are suitable. A crucial point is also the balancing of heating and cooling load, and with high ground temperatures above *20* °C like in Egypt, higher heating load or additional cold storage is necessary.

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