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INTRODUCTION

Borehole Thermal Energy Storage (BTES) systems are characterized by a large number of densely-packed borehole heat exchangers. BTES systems are designed to store energy as sensible heat in the underground. This energy can be collected from available heat sources, such as solar, waste heat, etc. In Sweden, there are approximately 400 large BTES systems, with a steady-state growth of 10 percent per year[1].

The BTES installation presented in this article is part of a project that aims at reducing the amount of energy purchased in a group of buildings at Stockholm University, located in the northern part of Stockholm, Sweden. This group of buildings is owned and managed by Akademiska Hus, a real estate developer dealing with academic buildings.

The BTES system is designed to deliver 4 GWh of heating and 3 GWh of cooling per year. The total building area is approximately 60,000 m². The buildings include office rooms and lab environments. Figure 1 shows an illustration of the BTES system together with the buildings to which the BTES system is connected.

Fig. 1: Scheme of the BTES system and the group of buildings to which BTES system is connected[2]. Graphic provided by: Akademiska hus (http://www.akademiskahus.se/)
In this article, we would like to provide readers with a general description of the overall heating and cooling installation and with a detailed picture of the BTES system and its monitoring system. The monitoring system consists of energy flow meters and temperature sensors located at several strategic positions in the borefield. The spatial distribution of the sensors will enable an exhaustive description of the real thermal process of the BTES. The characterization of the thermal response of the BTES is part of one of our on-going research projects at the Energy Technology Department at KTH, Stockholm (Sweden).


**AIM OF THE MONITORING PROJECT**

The BTES system will be monitored from the beginning of its operation, in spring 2016, and during the following years. The measured data will shed light on the thermal response of the borefield, which will help us to solve technical and research inquiries.

On the technical part, measured fluid temperature data will prove if the system performs according to design conditions. Optimization schemes of the BTES operation may be suggested as a result of accurate measured and predicted thermal responses of the ground. From the research point of view, measured data will be utilized for validation and calibration of current methods for borefield design. Moreover, the comparison of measured data against simulation values will provide a better understanding of the thermal interaction between neighboring boreholes.

**THE HEATING AND COOLING SYSTEM**

The overall heating and cooling system comprises chiller equipment, ventilation systems, radiators, heat pumps and the borefield storage. The overall system is designed to exploit synergies between the BTES and the remaining energy systems. This strategy increases the overall efficiency of the system while reducing the energy consumption in comparison with the replaced system (district heating). District heating will be used as a backup and to cover the peak demands in heating mode.

There are two major function schemes corresponding to the operation modes in the winter and the summer. In the winter, the BTES and the heat recovered at the condenser side of the chillers will provide the space heating. In the summer, cooling demand will be mostly covered by the chillers with a small portion supplied by the BTES system. The heat rejected at the condensers of the chillers will be stored in the boreholes. Two other function schemes are designed for the shoulder seasons.

![Function scheme of the overall heating and cooling system in a group of buildings in Stockholm](https://example.com/functionScheme.png)

*Fig. 2: Function scheme of the overall heating and cooling system in a group of buildings in Stockholm*.  
*Graphic provided by: Patricia Monzó*
**BTES DESCRIPTION**

In the design phase, the total length and the borefield pattern of the BTES is selected in order to ensure that the fluid temperature at the heat pumps’ inlet does not exceed a maximum temperature of 31 degrees Celsius in cooling mode and a minimum value of 2.5 degrees Celsius in heating mode for a given ground load profile and thermal properties of the ground.

The ground load profile is estimated from hourly values of both the energy consumption of the previous energy system (district heating) and the electricity consumption of the chillers measured during 2011 and 2012. The heating and cooling loads transferred from or to the ground are estimated for the utmost energy requirements among these two representative years. Consequently, the ground load profile is a composition of the heating demand during 2012 and of the cooling requirements from 2011. A COP of 6.5 is considered for the final estimation of the amount of heat extracted from the ground. Moreover, the borefield has been designed for a maximum 1400 kW of heat extraction in the winter and 2500 kW of heat injection in the summer. The ground load profile as a function of the outdoor temperature is illustrated in Figure 3. The analysis of the estimated ground load profile indicates that, on a net annual average analysis, there is a total imbalance of about 1400 MWh of injected heat into the ground.

The design of the borefield also requires the characterization of the ground thermal properties, which were determined by in-situ thermal response tests (TRT) carried out at two different locations of the drilling area. The average ground thermal conductivity is 3.92 W/m K.

The BTES design results in a borefield with a total of 130 boreholes, comprising 45 vertical and 85 inclined heat exchangers. The boreholes are 230 m long and their diameter is 115 mm. The boreholes contain a double PEM U-pipe heat exchanger. The borefield is divided into 14 smaller zones. The boreholes in each zone are connected in parallel and to a common manifold. These zones are identified in Figure 4 as “manifolds”. The borefield does not follow a regular geometrical pattern, hence its borehole-to-borehole spacing is uneven. In Figure 4, the continuous lines represent the manifolds where monitored boreholes (the so-called “measurement boreholes”) are located. The thermal response of boreholes linked to manifolds marked by a dashed line is not monitored in detail.

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**Fig. 3: Total annual energy transferred to or from the ground correlated to the outdoor temperature[^1]**

*Graphic Provided by: Patricia Monzó*
THE MONITORING SYSTEM

The characterization of the thermal response of the borefield will be carried out by energy flows and temperature measurements. Energy flows result from measurements of the mass flows and temperature differences of the heat carrier fluid. Ultrasonic technology is used to determine the mass flow and resistance thermometers measure the temperature in the supply and return pipes. Energy flows are registered at each monitored manifold and each measurement borehole. A distributed temperature sensing (DTS) technique that utilizes fiber cables as a linear sensor is employed to characterize the temperature response along the borehole depth in the monitored boreholes.

A sketch of manifold 1 is shown in Figure 5 to illustrate the main components in a manifold. The outlet pipe coming from the heat pump and going into the group of boreholes first passes through a measurement well where the total heat flow is measured. Then, the circulating heat carrier fluid is distributed to each borehole as it passes through the manifold, as shown in Figure 6-b. Then, the heat carrier fluid circulates along the borehole heat exchanger and it returns to the manifold. The heat carrier fluid may return with different temperatures depending on the borehole in which it was circulated. All the returning fluid flows are collected in the manifold where the temperatures mix as well. This mixed temperature corresponds to the inlet temperature in the heat pump.

The measurement boreholes are also connected to the measurement wells. That is, once the volume flow is distributed by the manifold, the piping of the measurement borehole is connected to the measurement well, in which another energy flow meter registers its heat flow rate. The measurement boreholes are also instrumented with the optical fiber cables, as mentioned above.
Fig. 5: Sketch of the components in manifold 1
Graphic Provided by: Patricia Monzó

Fig. 6-a: Manifold and measurement well
Graphic Provided by: Patricia Monzó

Fig. 6-b: Manifold and piping to boreholes
Graphic Provided by: Patricia Monzó
A yellow empty pipe protects and guides the fiber optic cable from each borehole to its corresponding measurement well, as shown in Figure 7. In the measurement well, the fiber is spliced to an extension fiber cable that travels inside the building up to the data acquisition DTS equipment.

The procedure for installing the optic fiber cable along the borehole length is illustrated in Figure 8 on the next page.

**CONCLUSION**

This article has provided a detailed description of the first stages of an on-going monitoring project. The monitored installation is a newly built BTES which is part of a large energy cluster of heating and cooling systems. The monitoring system is made up of energy flow meters and temperature sensors situated at strategic locations within the borefield. It will allow an exhaustive characterization of the BTES system’s thermal behavior.

The thermal response of the BTES system is monitored from the beginning of its operation, in spring 2016, and during the following years. Measured fluid temperatures will demonstrate if the system performs according to design conditions. It may also be a cornerstone in the optimization of the BTES operation and provide useful information about its interaction with the other energy systems in the cluster. From the research perspective, measured data will be used for validation and calibration of borefield design methods and for better understanding of the thermal interaction between neighboring boreholes.
Fig. 8: Graphical description of the fiber optic cable installation in the borehole
Graphic Provided by: Patricia Monzo

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