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# Monitoring of a borehole thermal energy storage in Sweden

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## Abstract

*This paper presents the description of the first stage of a project consisting on the monitoring of a newly installed borehole thermal energy storage (BTES) system that started to operate during the autumn of 2015. The BTES system is designed for approximately 4 GWh per year of heat injection and 3 GWh per year of heat extraction and will provide heating and cooling to a set of institutional facilities at Stockholm University, Sweden. The energy storage system consists of a set of 130 borehole heat exchangers, 230 meters deep. Strategic locations within the bore field have been selected to carry out the measurements. The monitoring system comprises temperature and energy flow meters. The temperature measurements are performed using a distributed temperature sensing set-up which allows to measure temperature along the depth of the boreholes, providing a large amount of data for the characterization of the thermal processes in the ground. During the upcoming years, the measured data will be utilized to evaluate and optimize the actual operational condition of the system, and to test the validity of assumptions made during the design phase. Moreover, the measured data will be utilized for validation of current bore field design methods and to have a better understanding of the thermal interaction between neighboring boreholes.*

**Keywords** - *ground-coupled heat pump; multiple bore field; borehole heat exchanger; monitoring system*

## 1. Introduction

During the past few years, there has been a steady growth for the market of medium and large Ground-Coupled Heat Pump (GCHP) installations (larger than 50 kW) for both residential and non-residential buildings [1]. In large GCHP systems the heat pump is coupled to a bore field consisting of a large number of densely packed borehole heat exchangers. In such systems,

due to the significant thermal interaction between neighboring boreholes, the yearly mean temperature of the ground in the bore field volume varies according to the net heat exchange with the ground over a year. As a result, large arrays of borehole heat exchangers are suitable for seasonal storage of sensible heat in the subsurface, e.g. to store solar heat into the ground and increase its temperature within the storage volume compared to undisturbed conditions. Such systems are often called Borehole Thermal Energy Storage (BTES). Currently, in Sweden, there are approximately 400 BTES systems and the yearly growth rate of this technology is around 10% [1].

Performance and reliability of GCHP and BTES systems are guaranteed if the temperature of the secondary fluid ( $T_f$ ) circulating within the borehole heat exchangers lies within a given temperature range during operation (e.g.  $0^\circ\text{C} < T_f < 35^\circ\text{C}$ ). Nowadays, the design process is supported by modeling tools that enable to simulate the behavior of a bore field and to estimate how the temperature of the secondary fluid varies in time throughout the whole life time of the system (roughly 25-30 years). The accuracy of the model utilized is crucial to ensure the expected quality of the design.

Small scale experimental set-ups ([2], [3], [4]) and in-situ monitoring of full scale installations ([5], [6], [7], [8]) have been used to better understand the thermal processes in the ground and the interactions between bore field and external systems ([9], [10], [11], [12]). Although in-situ monitoring of bore fields is a challenging task due to the large size of the system and the long time-span of investigation, it has become a more common practice during the past few years thanks to the great interest from the industry. There are, however, only few documented installations where measured data has been logged for time-span of no longer than 10 years [5], and are suitable for the validation of simulation models and bore field design methodologies.

Guidelines to collect suitable measurement data in GCHP systems were given by [13]. According to these authors the thermal properties of the ground should be determined from accurate measurements. The bore field geometry and fluid properties should be well-characterized, and flow rates and inlet and outlet temperatures measurements should be logged accurately and continuously for several years from the beginning of the operation. Other measured parameters such as climatic conditions and backfill material properties are suggested by [12] as valuable information to support the data analysis for long term bore field monitoring. Moreover, measurements of the distribution of thermal loads across the bore field and along the depth of the boreholes, as well as temperature measurements in observations wells could also provide valuable information for the characterization of the thermal processes in the bore field system.

This paper describes the first stage of a monitoring project on a newly installed BTES system at Stockholm University, Sweden. The BTES will supply the majority of the heating demand required by a group of office buildings and labs, and will be used during summer time to store released

condenser heat from two large chillers and from the heat pump which are utilized for ventilation and cooling purposes. The aim of the paper is to provide the reader with a global idea of the overall installation, with a detailed picture of the BTES system and the measurement equipment installed to perform the monitoring.

The BTES system description focuses on the geometrical configuration of the bore field and on the thermal loads utilized for the design of the system. The description of the monitoring system illustrates the sensors employed and the strategy utilized to place them within the system.

## 2. General Description of System

The system described in this paper is a step in Akademiska Hus' efforts to minimize the amount of energy purchased for a group of buildings located at Stockholm University Campus, in the area known as Frescati. Akademiska Hus is a Swedish real state owner that builds, owns and manages properties with educational purposes such as Colleges and Universities

The proposed energy solution for this project is based on a BTES system that replaces a solution mainly based on district heating. The new system is expected to drastically reduce district heating expenses with a minor increase of electricity consumption. Figure 1 shows an illustration of the building group and the underlying BTES system.

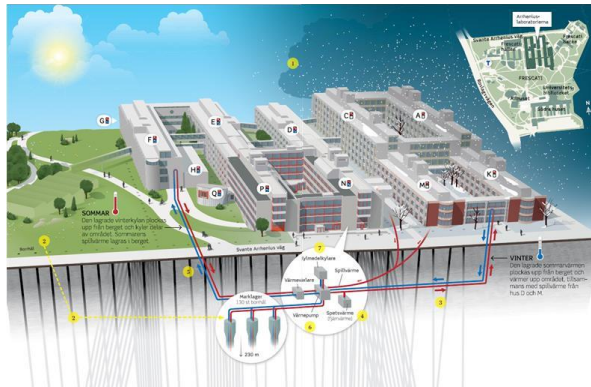


Figure 1 Illustration of the group of buildings and the BTES [14].

The BTES system is designed for approximately 4 GWh/year of heat injection and 3 GWh/year of heat extraction and will provide a large share of the heating and cooling needs for one newly constructed and a group of existing buildings. These facilities include offices and laboratories for a total area of approximately 60000 m<sup>2</sup>.

The thermal loading condition of the building group is characterized by a heating demand that is mostly required during the cold season with heating

peak loads up to 2500 kW and a cooling demand featuring constant base load of 500 kW throughout the whole year and cooling peak loads up to 2600 kW during summer time.

Most of the cooling demand is provided by means of two large chillers. The BTES is designed to work in synergy with the heating system, the ventilation system and the chillers, to provide heating and cooling needs for the building cluster as efficiently as possible. A scheme of the overall installation is shown in Figure 2.

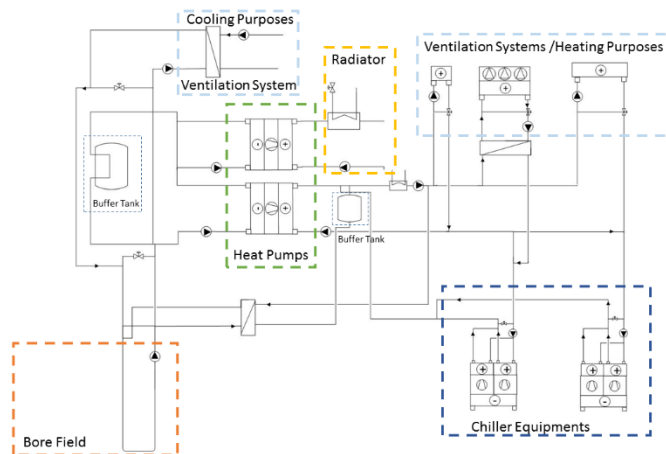


Figure 2 Scheme of the overall components of the heating and cooling system [15].

The BTES is connected with two heat pumps (800 kW each), with the condenser side of the chillers and with the ventilation circuit of the newly constructed building. During winter time, the majority of the heating demand will be covered by the BTES system and by the heat recovered at the condenser of the chillers. District heating will be utilized as a back-up to cover the heating peak loads. In summer time, the cooling loads will be covered by the chillers. The BTES system will be utilized to recover and store the heat rejected at the condenser side of the chillers. During shoulder season, the cooling demand is partially supplied directly by the bore field (free cooling).

### 3. Description of the Borehole Thermal Energy Storage

The bore field configuration has been selected to ensure that, under nominal condition, the temperature of the secondary fluid circulating within the ground loop is within the range 2.5°C and 31°C during the whole life time of the system.

The measured values of hourly energy demand covered by the district heating system and of the hourly electricity consumption of the chillers during

2011 and 2012 were utilized to evaluate the expected ground thermal loading condition. To prevent the system from operational problems, the ground load profile is estimated from utmost heating and cooling loads conditions from 2011 and 2012 and a COP of 6.5 when the system operates under heating conditions. The estimated ground load profile is shown in Figure 3. The bore field has been designed for a peak heat extraction of 1400 kW during winter time and a peak injection power of 2500 kW. The analysis of ground load profile indicates that net annual load is around 1400 MWh/year of heat injection.

The thermal properties of the ground were estimated in-situ by performing two Thermal Response Tests (TRTs) in different boreholes apart from each other. These resulted in an average thermal conductivity of 3.92 W/mK.

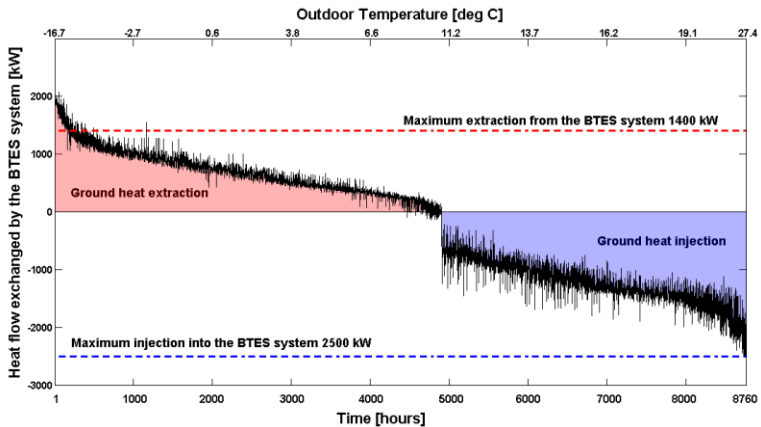


Figure 3 Annual total energy transferred to or from the ground and annual outdoor temperature [15].

The BTES consists of 130 boreholes, 230 meters deep, with a borehole diameter of 115 mm. Double PEM U-pipe heat exchangers are utilized and all boreholes are water-filled (not grouted). The boreholes are placed unevenly within the bore field area and there are both vertical and inclined boreholes (as illustrated in Figure 4 and Table 1).

The location of the boreholes around the perimeter of the building and the final choice of the bore field pattern allow exploiting a larger storage volume in comparison to the available drilling area.

The bore field has been divided according to the amount of manifolds into 14 zones. Each zone consists of a group of borehole heat exchangers connected to a common manifold. In Figure 4, each of these zones is identified

as “manifold” and highlighted with continuous and dashed lines. The continuous lines represent the borehole groups equipped with DTS and flow meters, referred from now on as “measurement boreholes”. The dashed lines demark other borehole groups that are not monitored in detail. Table 1 presents a detailed description of the bore field configuration including position, orientation, manifold number and groundwater level. Measurement boreholes are highlighted in the table by using bold font.

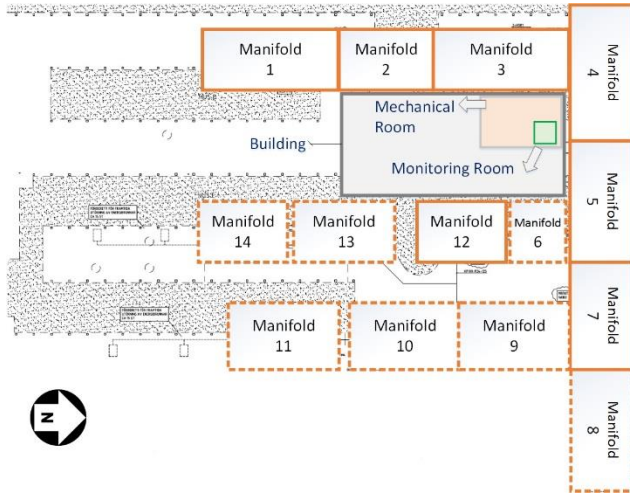


Figure 4 Bore field configuration and illustrative division of its manifolds.

#### 4. Monitoring System of the BTES installation

The measurement system utilized for monitoring the BTES consists of temperature and heat flow meters. Ten boreholes at strategic locations of the bore field area were selected. The position of these measurement boreholes has been chosen to monitor both the central and the peripheral part of the storage area. These boreholes are conveniently placed with respect to the control room where all the data are collected.

The temperature measurements are performed by means of a distributed temperature sensing instrument (type ORYX DTS) which uses optical fibers as linear sensors [16]. This instrument is able to measure temperature with a spatial resolution of 1 meter. Optical fiber cables of type 50/125 having two graded index multimode fibers protected with a thin stainless tube and a plastic coating have been inserted in the boreholes outside the pipes. Figure 5 illustrates fiber installation procedure. Measured data from similar fiber optical cable installations has been reported in [2].

Table 1 Bore field description

MF <sup>(a)</sup>	BH <sup>(b)</sup>	Inclination		GW <sup>(c)</sup> Level [m]	MF <sup>(a)</sup>	BH	Inclination		GW <sup>(c)</sup> level[m]	MF <sup>(a)</sup>	BH <sup>(b)</sup>	Inclination		GW level[m]	MF <sup>(a)</sup>	BH <sup>(b)</sup>	Inclination		GW <sup>(c)</sup> level[m]
		$\alpha$	$\beta$				$\alpha$	$\beta$				$\alpha$	$\beta$				$\alpha$	$\beta$	
1	1	0	0	4.4	4	<b>34</b>	<b>14</b>	<b>0</b>	<b>4.2</b>	8	68	14	0	9.05	11	101	0	0	5.6
	2	7	0	4.4		36	7	0	4.2		69	0	0	9.05		102	7	0	5.6
	3	0	0	4.4		37	14	0	4.2		70	7	0	9.05		103	2	0	5.6
	4	7	0	4.4		38	0	0	4.2		71	14	0	9.05		104	14	0	5.6
	5	0	0	4.4		39	7	0	4.2		72	0	0	9.05		105	0	0	4.5
	<b>6</b>	<b>7</b>	<b>0</b>	<b>4.4</b>		40	14	0	4.2		73	7	0	9.05		<b>106</b>	<b>-7</b>	<b>0</b>	<b>4.5</b>
	7	0	0	4.4		41	0	0	4.2		74	14	0	6.8		107	7	0	4.5
	8	7	7	4.4		42	7	0	4.2		75	7	0	6.8		108	0	0	4.5
2	9	0	0	4.4	5	43	14	0	4.2	9	76	14	0	6.8	12	109	-7	0	4.5
	10	7	0	4.4		44	0	0	4.2		77	0	0	6.8		110	7	0	4.5
	11	-7	0	4.4		45	7	0	4.2		78	7	0	6.8		111	-7	0	4.5
	<b>12</b>	<b>0</b>	<b>0</b>	<b>4.4</b>		46	14	0	4.5		79	14	0	6.8		112	7	0	4.5
	13	7	0	4.4		<b>47</b>	<b>0</b>	<b>0</b>	<b>4.5</b>		80	0	0	6.8		113	0	0	4.5
	14	-7	0	4.4		48	7	0	4.5		81	7	0	5.5		114	-7	0	4.5
	15	0	0	4.4		49	0	0	4.5		82	14	0	5.5		115	7	0	4.5
	<b>16</b>	<b>7</b>	<b>0</b>	<b>4.4</b>		50	7	0	4.5		83	0	0	5.5		116	0	0	4.5
3	17	-7	0	4.4	6	51	-7	0	4.5	10	84	7	0	5.5	13	117	-7	0	4.5
	<b>18</b>	<b>0</b>	<b>0</b>	<b>4.4</b>		52	7	0	4.5		85	14	0	5.6		118	7	0	4.5
	19	7	0	4.4		53	0	0	4.5		86	0	0	5.6		119	0	0	4.5
	20	-7	0	4.4		54	-7	0	4.5		87	7	0	5.6		120	-7	0	4.5
	<b>21</b>	<b>0</b>	<b>0</b>	<b>4.2</b>		55	7	0	4.5		88	14	0	5.6		121	7	0	4.5
	22	7	0	4.2		56	14	0	6		89	0	0	5.6		122	0	0	4.5
	23	-7	0	4.2		57	0	0	6		90	7	0	5.6		123	-7	0	4.5
	<b>24</b>	<b>0</b>	<b>0</b>	<b>4.2</b>		58	7	0	6		91	14	0	5.6		124	7	0	4.5
4	25	7	0	4.2	7	59	14	0	6	11	92	0	0	5.6	14	125	0	0	4.5
	26	-7	0	4.2		60	0	0	6		93	7	0	5.6		126	-7	0	4.5
	27	0	0	4.2		61	0	0	6		94	14	0	5.6		127	7	0	4.5
	28	14	0	4.2		<b>62</b>	<b>14</b>	<b>0</b>	<b>6</b>		95	0	0	5.6		128	0	0	4.5
	29	0	0	4.2		63	0	0	6		96	7	0	5.6		129	-7	0	4.5
	30	7	0	4.2		64	7	0	6		97	14	0	5.6		130	7	0	4.5
	31	14	0	4.2		65	14	0	9.05		98	0	0	5.6		<b>Bold Font:</b> Measurement borehole			
	32	0	0	4.2		66	0	0	9.05		99	7	0	5.6		(a) MF = Manifold (b) BH = Borehole			
33	7	0	4.2	67	7	0	9.05	100	14	0	5.6	(c) GW = Groundwater							



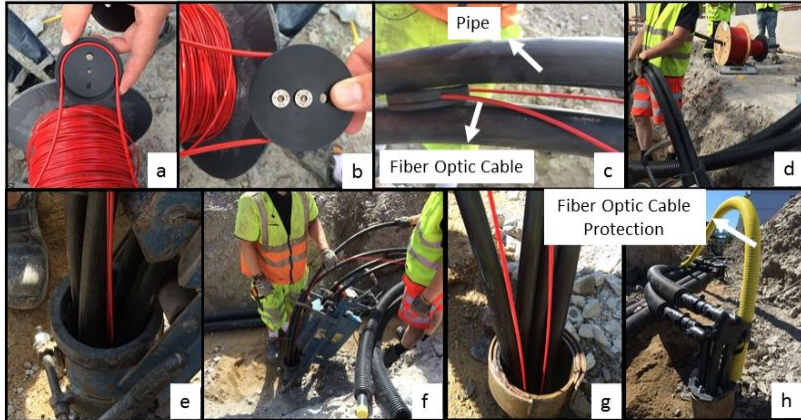


Figure 5 Chronological, (a) to (h), Illustration of the fiber optical cable installation into the boreholes

The yellow pipe shown in Figure 5h protects and guides the optical fiber cable into the measurement well. The fiber optic cables (in all measurements wells) are arranged in four loops which are plugged to the four available inlets of the DTS instrument. Extension fiber cables are used to cover the distance between the measurement boreholes and the control room. The connection between the glass fibers inside the cable is done by a welding process. For calibration purposes, reference sections have been prepared before and after each fiber welding point as well as inside the control room.

The heat flow exchanged in the ground loops is measured within the pipe via ultrasonic flow meters and temperature sensors in the supply and return pipes. This technique is applied to measure the heat flow in all measurement boreholes as well as the total flow passing through each manifold.

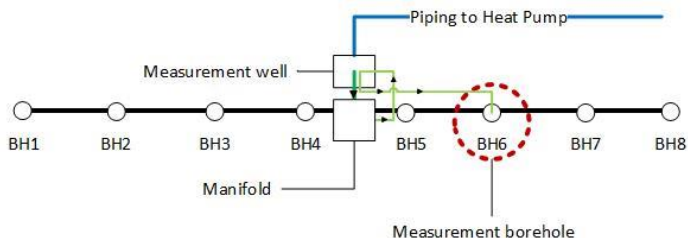


Figure 6 Sketch of the components in manifold 1 and illustration of how measurement wells and manifolds are connected with the measurement boreholes

Figure 6 shows a sketch of the piping connection for the flow meters. The piping coming from the mechanical room (where the heat pumps are located),

passes firstly through a measurement well (see Figure 7-a), and then to a manifold where the mass flow is split and distributed to the borehole heat exchangers (Figure 7-b). The return mass flow is then mixed in the return manifold and sent back to the measurement well before returning to the mechanical room. Figure 8 shows a photo of one of the measurement boreholes.



Figure 7-a Manifold and measurement well

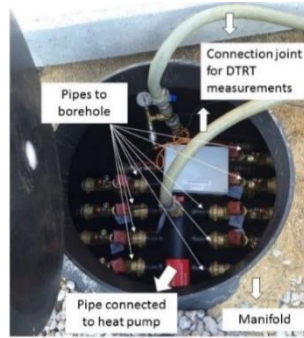


Figure 7-b Manifold and piping to boreholes

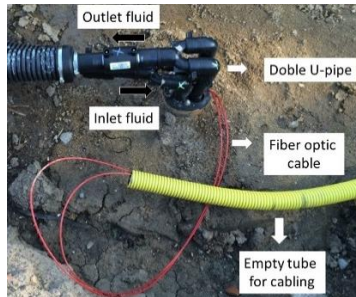


Figure 8 Measurement borehole

## 5. Conclusion

This paper presents the description of the first stage of a monitoring project on a newly installed BTES system. The paper provides the readers with a global idea of the overall installation and a detailed picture of the BTES and its monitoring system.

The monitoring system is conceived to supply exhaustive measurements of temperature and heat flows on a set of boreholes located at strategic locations. These data will be used in the upcoming years for validation of current design methods and to provide a better understanding of the thermal interaction between the boreholes. Moreover, the measured data may provide valuable information to evaluate the choice of input parameters utilized for the

design and to optimize the BTES operation with regards to the operation of the other energy systems connected to it.

## 5. Acknowledgment

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