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Operational management of large scale UTES systems in Hospitals

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1. Introduction

Most hospitals have a very high demand of heating and cooling, both for medical and comfort reasons. Furthermore, the need for heating/cooling is continuous, 24 hours a day, 365 days a year. Due to the high demands and the need for both heating and cooling UTES (Underground Thermal Energy Storage) is a very interesting technology for hospitals.

For a stable and efficient working UTES system it is necessary that the thermal energy (heat and cold) in the underground is managed accurately. The amount of charged thermal energy should preferably be in balance with the amount of cold and heat supplied from the store. Besides the quantity of stored energy, the quality (temperature) is also of concern. These items require particular attention during all project stages; design, construction, commissioning and operational management. Especially in the latter stage when it should be ensured that the sustainable UTES system is indeed functioning sustainably and at its optimum.

This paper compares the application and performance of ATES (Aquifer Thermal Energy Storage) and BTES (Borehole Thermal Energy Storage) systems for hospitals and aims to search for similarities and differences between both technologies.

2. ATES and BTES; principles, similarities and differences

Both ATES and BTES exchange thermal energy with the underground. However the transfer of heat to/from the underground is different. ATES makes use of an underground water-bearing layer (aquifer), e.g. a sand, sandstone, or chalk layer. The transfer of thermal energy is realized by extracting groundwater from the aquifer and by re-injecting it into the aquifer at the modified temperature level at a separate location nearby (convective heat transfer). In the case of BTES heat and cold are stored in the underground using a BHE (Borehole Heat Exchanger), which usually consists of a number of plastic U-loops installed in boreholes. A BTES system is closed loop, which means that the transfer of thermal energy is realized by circulation of a heat transfer fluid (normally water or water with antifreeze) through the plastic piping in the boreholes to transfer heat/cold with the surrounding ground (conductive heat transfer).

Principle and characteristics of ATES

The principle of ATES is shown in Figure 1. In summer, groundwater is extracted from the cold well(s) and used for cooling purposes. The warmed up water is then injected into the warm well(s). In winter the process is reversed. Water is pumped from the warm well(s) and applied as a heat source, e.g. as a low temperature heat source for a heat pump. After the exchange of heat the chilled groundwater is injected into the cold well(s). ATES systems require that relatively high well yields can be obtained on site. Because of this the applicability depends strongly on site-specific hydrogeological conditions.

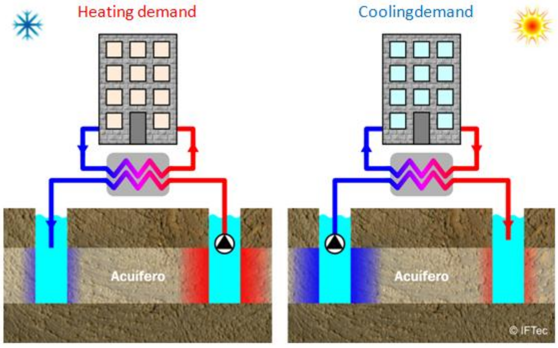

Fig. 1. Principle of ATES

The injection of warmed up and chilled groundwater changes the temperature of the aquifer around the wells, resulting in a warm groundwater bubble around the warm well and a bubble of cold groundwater around the cold well. Figure 2 displays an example of the temperature evolution in the cold and warm well in time. In the example the natural groundwater temperature is 11ºC and the injection temperatures are 14ºC in the warm well (during cooling operation) and 6ºC in the cold well (during heating operation). The temperature in both the cold and warm well tends to be a relatively constant value after approximately 5 years of running. The variation in the extraction temperature during the heating/cooling season from both the warm and cold well is less than 3 K. This results in relative stable supply temperatures from the ATES to the secondary circuit in the building.

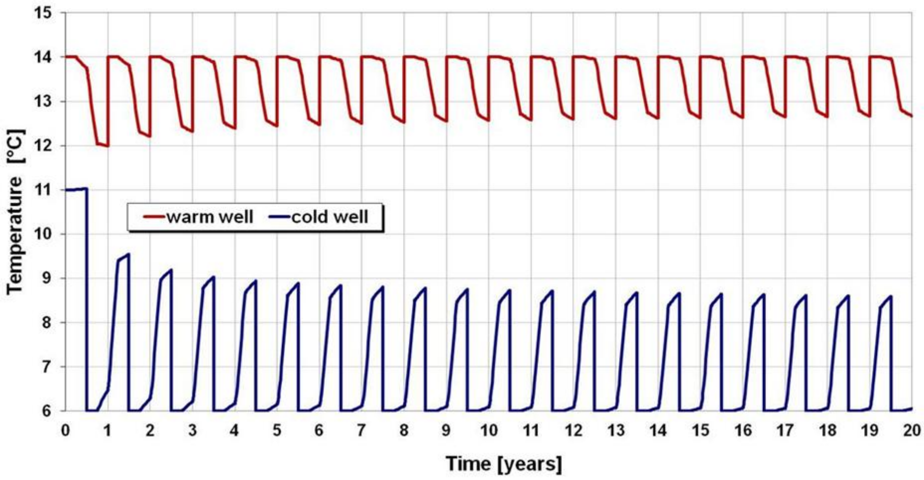

Fig. 2. Evolution of temperature at warm and cold well during 20 years (IF Technology, 2011).

The maximum load (kWt) of an ATES system is related to the maximum yield of the wells and the ΔT between extraction and injection. Because the heat/cold is transported through the aquifer with the extracted/injected groundwater (convective heat transfer), the thermal transport to/from the well is rather quick, therefore the time in which an ATES system is working consecutively at peak load is of less importance. The amount of heat and cold (kWht) that can be stored is depending on the distance between the warm and cold well(s), the thickness of the aquifer and the heat capacity of the aquifer.

Principle and characteristics of BTES

The principle of BTES is shown in Figure 3. During winter the BHE is used for extraction of heat from the ground, e.g. as a heat source for a heat pump. The chilled circuit water is returned to the BHE and the ‘cold-energy’ is stored in the ground. In summer the heat flow is reversed.

The stored cold is extracted and passed through a heat exchanger to provide cooling to the building. The store circuit water will pick up energy from the building and thus be raised in temperature. This water, the temperature of which is higher than the ground temperature, will be returned in the BHE where the 'warm energy' is stored in the ground around the boreholes for the next heating season. Closed loop BTES systems depend less on site-specific hydrogeologic conditions than ATES and are better suited for areas where relatively high well yields are not obtainable.

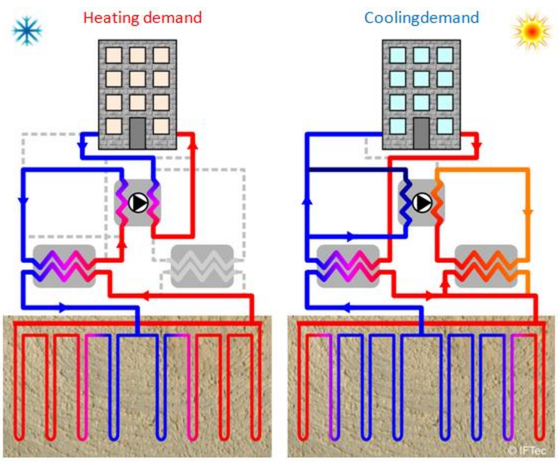

Fig. 3. Principle of BTES.

In contrast with an ATES system the supply temperatures from a BTES system to the secondary circuit in the building are not stable. The temperature of the fluid in the BHE will increase gradually during the cooling season and decrease during the heating season (see Figure 4). The maximum load (kWt) of a BTES system is mainly related to the total length of the BHE and the thermal conductivity of the surrounding ground. The transport of heat/cold in the underground is mainly by conduction and is driven by the temperature gradient between the fluid in the BHE and the surrounding ground. In comparison with ATES, the velocity of the heat transport through the underground is slow. Due to this BTES systems are sensitive for working during many hours consecutively at system peak load. The amount of thermal energy that can be stored depends on the depth of the boreholes, the distance between the boreholes and the heat capacity of the underground.

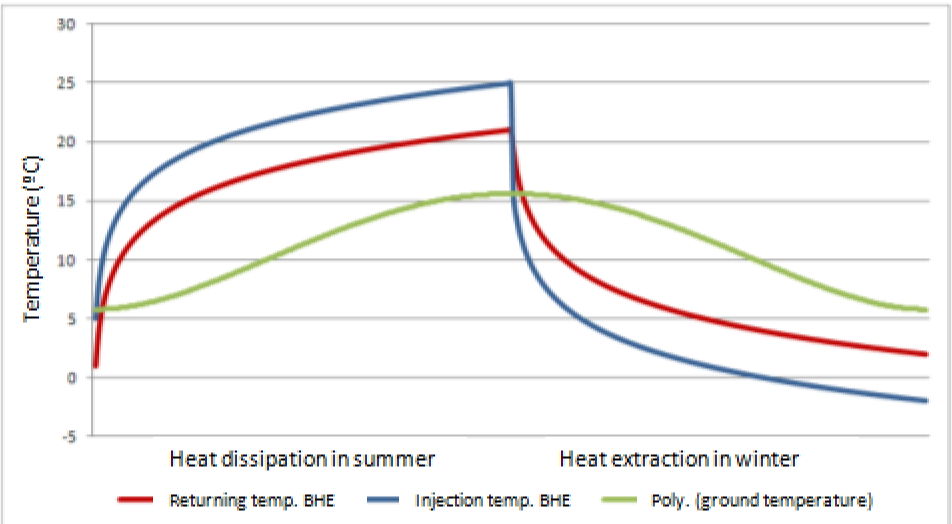

Fig. 4. Evolution of fluid temperature in the BHE and underground over a year (Wennekes, 2010).

Similarities

The annual amount of heat dissipated to the underground (stored heat) should preferably be in balance with the annual amount of extracted heat (stored cold). Thermal balance in the underground is favourable for the system performance, both for ATES and BTES. For ATES it may also be of importance for legal reasons as energy balance is often required in the groundwater extraction/injection permit.
Both ATES and BTES are in many cases applied in combination with heat pumps (HP) and provide in general only part of the peak heating and/or cooling load. The remaining load is provided with conventional equipment such as gas fired boilers and chillers.
The total efficiency of the energy system depends not only on the performance of the ATES/ BTES system but also on the required building supply and return temperatures. To increase the possibility of direct cooling and achieve higher energy saving, moderate cooling temperatures and a large ΔT are recommended (e.g. 10ºC/16ºC or even better 12ºC/20ºC). For heating the supply temperature should be at maximum 50 ºC.

Table 1. Favorable building supply and return temperatures for ATES and BTES

	Cooling	**Heating**
Supply temperature*	As high as possible to increase the possibility of direct cooling.	As low as possible in order to achieve a high COP of the HP.
Return temperature	As high as possible to maximize the part of direct cooling and minimize the share of active HP cooling	As low as possible to maximize the HP application.

* Variable supply setpoints (depending on the outdoor temperature) are recommended, both for heating and cooling

Differences

In the case of a good functioning ATES system the supply temperature from the wells is relatively stable, whilst the supply temperature from a BTES system will increase/decrease quickly and significantly during the heating/cooling season. This difference is of particular importance during cooling operation as it limits strongly the possibility for direct cooling.

Table 2. Operational differences between ATES and BTES

	Cooling	**Heating**
ATES	Good contingence for direct cooling due to relatively stable low extraction temperature from cold well(s). The possibility of direct cooling exists as long as the groundwater extracted from the cold well(s) is a few degrees below the return temperature of the HVAC system. When direct cooling is not (or no fully) possible, the possibility for active HP cooling remains. Since the extraction temperature from the cold well(s) can never be higher than the natural groundwater temperature, the HP cooling performance is high and stable.	To charge the cold wells for the next cooling season with chilled groundwater at sufficiently low temperature, the leaving evaporator temperature of the HP must be kept at a constant low set-point (e.g. 6 ºC). If the heating supply temperature is also a fixed set-point, the COP of the HP will be constant throughout the heating season.
BTES	Because of limited possibilities for direct cooling due to the quickly increasing temperature in the BHE, most of the cooling will be provided by active HP cooling. Increasing temperature in the BHE may lead to decreasing HP efficiency. To ensure an efficient	After the cooling period, the BHE temperature will be relatively high. Due to this and because there is no need for a low evaporator temperature, the COP of the HP at the start of the heating season will be rather high. However, because of a falling BHE temperature during the

	performance, the return temperature of the BHE should not exceed the maximum design temperature (e.g. 30ºC).	heating season, the COP will decrease gradually. To ensure a minimum HP performance, the return temperature from the BHE should never be lower than the minimum design temperature (e.g. 0ºC).

3. Monitoring of system performance

Key Performance Indicators (KPIs)

The KPIs for ATES and BTES are displayed in Table 3. The relevance is indicated with bullets. The numbering corresponds with the explanation below.

Table 3. Key Performance Indicators (KPI) for operational management

KPI	Description	ATES	BTES
1.	Building return temperature	●	●
2.	Building supply temperature	●	●
3.	Infiltration temperature	●	-
4.	Extraction temperature	-	●
5.	Energy balance	●	●
6.	Stored energy	●	-
7	Ratio sustainable and non sustainable production	●	●
8.	Heat pump performance	●	●
9.	Well performance	●	-
10.	Pumped water amounts	●	-

- not/less relevant KPI ● relevant KPI

1. The building return temperature determines the possible contribution of the ATES/BTES system. Too high return temperature during heating operation and too low return temperature during cooling operation will limit the contribution. E.g. if a heating circuit is designed for a 60 ºC supply temperature and a return of 30 ºC and the HP is designed for a supply of 50 ºC the HP can contribute 67% and the gas boiler the remaining 33%. If the return temperature is higher, like for example 40 ºC, the contribution of the HP is only 50%.

2. Regarding the building supply temperature two things are of importance:
    a. The supply temperature has to match with the design setpoints of the HVAC system in order to meet the comfort requirements.
    b. The supply temperature may not be higher during heating nor lower during cooling than the design values in order to meet the required energy performance.

3. In the case of ATES is it of importance that the stored cold/heat is of good quality (good temperature). Too high infiltration temperature in the cold well(s) or too low infiltration temperature in the warm well(s) will have a negative impact on the maximum system capacity and efficiency in following years. The injection temperature is often also of importance for permitting reasons, as permitting authorities on groundwater injection often dictate maximum injection temperatures.

4. For the operational management of a BTES system the extraction temperature is a very important KPI. A strong rise/fall in a short period could indicate that the system has been functioning for too many hours consecutively at system peak load. For ATES the extraction temperature is of importance for the current performance, but less important for the operational management, whereas it mainly depends on the injection temperature of previous years.

5. Thermal balance in the underground is of importance for a sustainable and optimal performance of the ATES/BTES system. For ATES systems it is often also a permit condition. In the Dutch General Administrative Order on Ground Energy is defined that: *The total amounts of heat and cold, expressed in MWht, which after the commissioning are added to the ground by an open loop ground energy system have to be equal at least once in the first period of five years and after this period at least once in the following periods of three years*. (MINISTERIE VAN INFRASTRUCTUUR EN MILIEU, 2010)

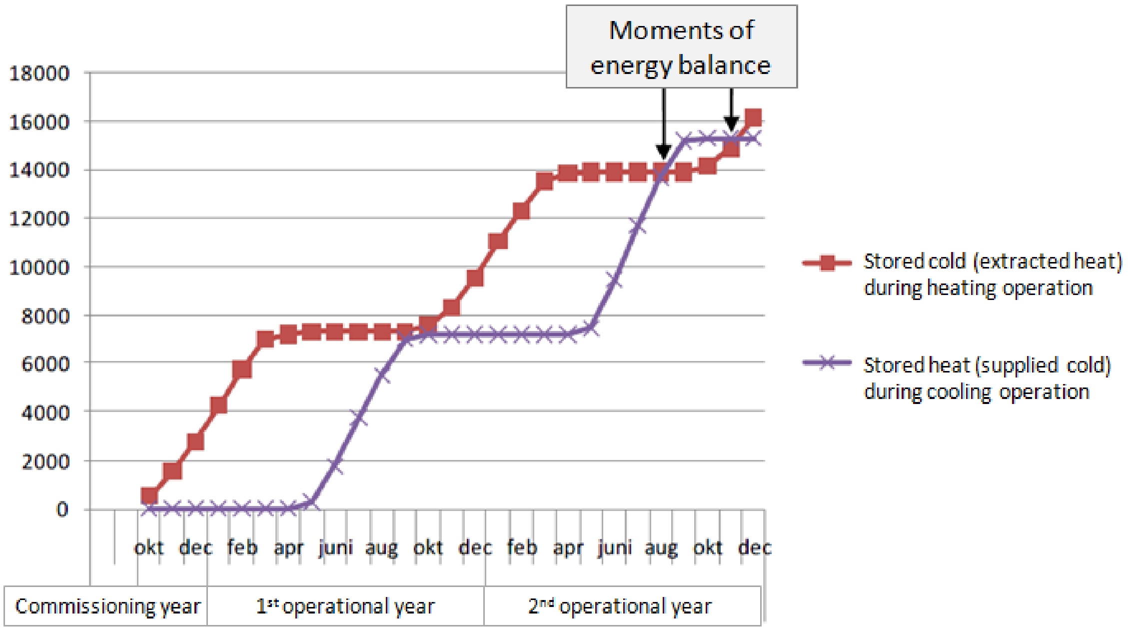

Fig. 5. Energy balance in underground (SIKB, 2012)

6. Stored energy is related to the energy balance, but with this KPI the focus is not on what has been supplied from the ATES but on what is in stock for the near future. This can be explained with the following example: after the commissioning 100,000 m^3 water is pumped from the warm well at the natural groundwater temperature of 12 ºC to the cold well in which it is infiltrated at 8 ºC. The supplied heat is 464 MWht, but the amount of cold in stock is 928 MWht, because the design injection temperature during cooling demand is 16 ºC.

7. When an energy installation contains equipment or systems for sustainable production (e.g. ATES/BTES and heat pumps) and not sustainable production (such as gas fired boilers and chillers) it is important to monitor whether the contribution of the sustainable system part meets the design starting point. For this the PER (primary energy ratio) can be calculated, which is the ratio between useful energy output (supplied heat and cold) divided by the total primary energy input. This ratio is a measure for the overall efficiency, taking into account the energy losses related to the generation of electricity. A higher PER corresponds to a more energy-efficient system.

8. The COP (Coefficient of performance) / EER (Energy Efficiency Ratio) is a measure for the heat pump performance and is the thermal production (output) divided by the electrical consumption (input).

9. The well performance can decrease over time due to well clogging. A measure to monitor this is the Specific Capacity, which is the pumping rate (yield) divided by the drawdown.

10. The granted amounts for groundwater extraction/injection must in general be measured and reported to the competent authority. Exceeding the granted amounts could lead to sanctions or penalties. E.g. in the Netherlands the permit holder pays € 0.19 for every m^3 of pumped groundwater that exceeds the limit.

Measurement, data collection and interpretation

The monitoring of system performance requires not only the installation of sufficient and appropriate measuring equipment but also data collection and adequate interpretation of measuring results, the latter needs specific knowledge, experience and time. To produce efficiently reliable information from measuring data it is recommendable to apply energy management software (EMS), such as LIFT which is a web-based EMS developed specifically for UTES and geothermal systems.

Fig. 6. Monitoring process, from measuring to optimization

4. UTES applications in hospitals

Röpcke-Zweers Hospital (Hardenberg, Netherlands); example of an ATES application

The Röpcke-Zweers hospital is a non academic hospital in the east of the Netherlands focused on basic care for people in the area. It is part of the care organization Saxenburg Group. The hospital counts 197 beds and the current floor surface is about 20,000 m^2. In 2013 the hospital will be extended with another 20,000 m^2.
The heating and cooling of the hospital is provided by a central energy plant. From the energy plant the produced heat and cold is distributed to the HVAC installation in the hospital building. The heat production is provided with a heat pump (which is connected to an ATES system) in series with two gas fired boilers (see Figure 7). The HP/ATES system provides approx. 18% of the currently installed peak heating load. The current cooling peak load is for the most part (> 70%) provided as direct cooling from the ATES system. The remaining part is covered by the heat pump (in chiller mode) and chillers (see Figure 7).
The ATES system is designed to cover the total demand in the extended future situation of the hospital. The current heat pump is not sized for the future situation. The groundwater system of the ATES consists of two cold wells and 2 warm wells which are connected to one heat exchanger in the central plant room. The maximum groundwater yield is 175 m^3/h.
The ATES system is in operation since 2006. Until 2011 the performed level of monitoring was rather limited focusing mainly on the functional performance of the groundwater system. From the commissioning until 2011 the system has been applied more for heating purposes than cooling, resulting in a great thermal imbalance with an excess of cold in the underground. Since 2011 the monitoring is intensified and is now focusing on the functional performance, energetic performance and permit compliance. The KPI results of 2011 are displayed and checked with the target values in Table 4. The monitoring results and reports are currently used as input for an operational plan in order to optimize the application and performance of the ATES system.

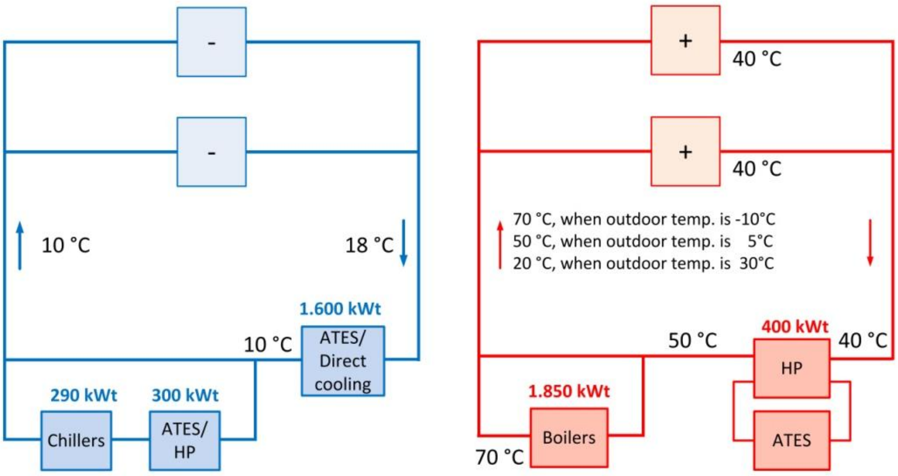

Fig. 7. Integration of the ATES/HP system in the HVAC installation of the Röpcke Zweers Hospital

Table 4. KPI results 2011, ATES/HP system Röpcke-Zweers hospital

KPI		Cooling			Heating		
		2011	Target	State	2011	Target	State
Building return temp.	ºC	14	18		46	45	
Building supply temp.	ºC	10	10		50	50	
Infiltration temp.	ºC	11.4	16.0		6.1	6.0	
Energy unbalance	MWht			In 2011 From commissioning	470 3,006	0	
Stored energy	MWht	586	1,125		128	1,125	
Percentage sustainable production	%	100	?		20	?	
Heat pump performance	EER/COP	?	?		?	?	
Spec. capacity wells	m³/h.m	70	>45		60	>45	
Pumped water amounts	m³	47,290	<245,000		133,480	<270,000	

Mollet Hospital (Mollet del Vallès Spain); example of a BTES application

The Hospital de Mollet is a 2010 inaugurated new hospital in Mollet del Vallès near Barcelona. The hospital has 160 beds and its service area covers eight municipalities with a total of 150,000 inhabitants. The floor surface is approx. 27,000 m2.
The heating and cooling demand of the hospital is covered by a BTES/HP system in combination with gas fired boilers and chillers (see Figure 8). The BHE is composed of 144 boreholes with a depth of 145 m. The total borehole length of over 20,000 m ranks the system in the European top five of biggest closed loop systems. The BHE is connected with the heat pump and HVAC system by means of a HPS (Heat Pump Skid). This standardized unit is developed for medium to large scale ATES and BTES/GSHP applications and is capable of providing heating, cooling, and simultaneous heating and cooling in combination with a non-reversible HP (modified water-water chiller).

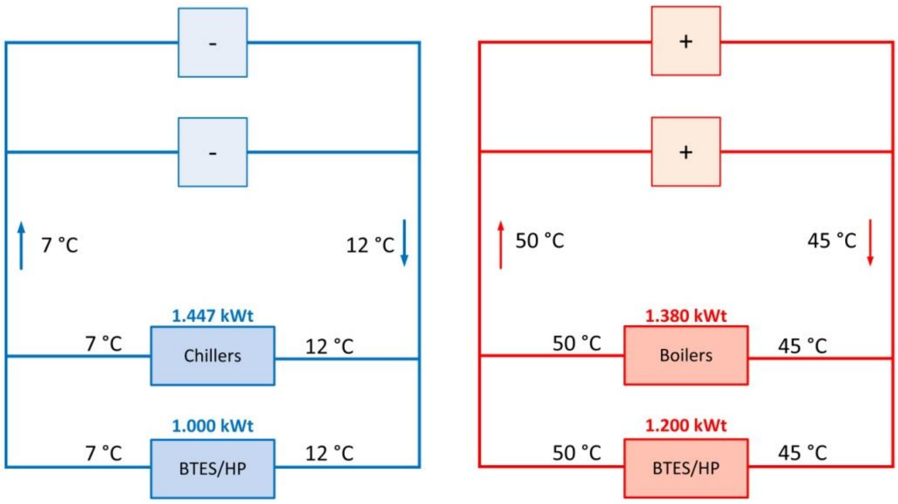

Fig. 8. Integration of the BTES/HP system in the HVAC installation of the Mollet Hospital

The BTES/HP system is currently only monitored on its functional performance and is missing metering for monitoring of its energy performance and the energy balance in the underground. The participation of the hospital in the EU-funded Green@Hospital project is expected to improve this situation as this project aims to integrate the latest ICT solutions in order to obtain a significant energy saving through a better management of energy resources and through loss reduction.

Based on information from the period July 2010 – June 2011 on the total supplied heat and cold and the consumed energy data of the gas fired boilers and chillers, it is estimated that the BTES/HP systems covered in that period 56% of the cooling demand and 67% of the heating demand (Toimil et al., 2012). The estimated KPIs for the period July 2010 – June 2011 are displayed and checked with the target values in Table 5. The values given in the table are indicative and are based on data from the functional monitoring.

Table 5. Estimated KPI results period July 2010 – June 2011, ATES/HP system Mollet Hospital

KPI		Cooling			Heating		
		07/10-06/11	Target	State	07/10-06/11	Target	State
Building return temp.	ºC	13	12		46	45	
Building supply temp.	ºC	8	7		50	50	
Extraction temp.	ºC	<35	<35		>10	>10	
Energy balance	%				?	0	
Percentage sustainable production	%	56	-		67	-	
Heat pump performance	EER/COP	?	6		?	4,2	

5. Conclusions

- Hospitals have in general a very high demand of heating and cooling. The high demands and need for both heating and cooling make ATES and BTES in combination with heat pumps very interesting technologies for hospitals.

- The technical feasibility of an ATES/HP system depends strongly on site-specific hydro-geological conditions. Closed loop BTES/HP systems depend less on the local hydro-geology, which make the application almost always technically possible.
- Both ATES and BTES use the underground for seasonal thermal storage, but the transfer of heat to/from the underground is different. For ATES the thermal energy exchange is mainly by convective heat transfer in the aquifer, whereas for BTES it is mainly by conductive heat transfer in the underground. The difference in heat transfer is reflected in the performance:
  - In the case of a good functioning ATES system the supply temperature from the wells is relatively stable, whilst the supply temperature from a BTES system will increase/ decrease quickly and significantly during the heating/cooling season. Increasing supply temperature during cooling operation limits the possibility of BTES systems for direct cooling. Because of this the energy performance of ATES systems is in general higher.
  - The thermal transport in the aquifer to/from the wells of an ATES system is much quicker than the thermal transport in the underground to/from the BHE of a BTES system. Due to this BTES systems are more sensitive for working during many hours consecutively at system peak load.
- The total efficiency of the energy system depends not only on the performance of the ATES/ BTES system but also on the required building supply and return temperatures. To maximize the overall energy production efficiency it is recommended to apply high temperature cooling circuits and low temperature heating circuits in the building.
- ATES systems in general require permits for groundwater extraction and injection. In order to assess and guarantee permit compliance monitoring of ATES systems is often obliged.
- For a sustainable and optimal performance thermal balance in the underground is of importance for both ATES and BTES systems. Moreover thermal balance for ATES systems is often also a permit condition.
- ATES systems have more KPIs than BTES systems, resulting in a bigger monitoring effort.
- For optimization of system performance the operational management and monitoring should not only focus on functional performance and permit compliance but also on energetic performance.
- To achieve and guarantee optimal system performance during the whole operational stage, sufficient and appropriate measuring equipment is indispensible.
- To produce efficiently reliable information from measuring data it is recommended to apply energy management software (EMS).

References

IF TECHNOLOGY, (2011): *Energieopslag HAN te Nijmegen, Effectenstudie grondwatersysteem*. Arnhem. Netherlands

MINISTERIE VAN INFRASTRUCTUUR EN MILIEU, (2010): *AMvB Bodemenergie*. Staatscourant nummer 4830, 5 april 2010, artikel 6.11c. Netherlands

SIKB, (2012): *Besluitvormingsuitvoeringsmethode bodemenergiesystemen voor provinciale taken (BUM BE deel 1, versie 0.7)*. Gouda. Netherlands

TOIMIL, D., MAYORAL, G.R., TRULLAS, M., (2012): “Gestión de un sistema geotérmico cerrado de gran escala. Hospital de Mollet”. *Proceedings GeoEner 2012*. Madrid. Spain

WENNEKES, R.G.A., (2010): *Cursus Bodemenergie, Deel Bodemwarmtewisselaars*. EuroForum. Eindhoven. Netherlands