

## 3-YEAR MONITORING RESULTS AND EXPERIENCES WITH AN AQUIFER THERMAL ENERGY STORAGE SYSTEM IN A BELGIAN HOSPITAL

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**Abstract:** The first aquifer thermal energy storage (ATES) system of Belgium went in operation in 1998. Until today, besides various small installations, over ten large (> 500 kWt) ATES systems were installed for different applications. This paper provides an overview of 3-years monitoring of the ATES system combined with a heat pump in a Belgian hospital. 78% of the cooling energy was delivered by the ATES system given a primary energy saving of 11,789 GJ comparing to a conventional cooling application. This resulted in a 63% CO<sub>2</sub> emission reduction. The implementation of the ATES technology went together with some unavoidable growing pains. Some of these problems were caused by the unusual combination of technologies and working parties. Drilling companies get involved in the process of HVAC installation. Most critical are the connection points between the traditional and innovative installation part, defined as the boundary zone between the underground and aboveground installation. As typical example, the communication between the control systems of the HVAC and the ATES system can be mentioned.

**Key Words:** *ground coupled heat pump, ATES, monitoring results*

### 1 INTRODUCTION

Aquifer Thermal Energy Storage or ATES was introduced on the Belgian market since 1995. VITO performed research activities on the applicability of this technology, the integration in the HVAC installation, the geohydrological boundary conditions and dissemination of information. In Belgium, it still stays difficult to give ATES systems a broad implementation. Since 1998, many building owners showed interest in the technology, but this isn't translated into a steady increase of realized projects. This is mainly caused by the hydrogeological circumstances. In Belgium, the Northeastern part of the country has very good technical and economical potential for the application of ATES. However, the most interesting economical and industrial areas are located outside this region. A thick clay layer covers the Western part of Belgium, the southern part mainly exists of Silurian schist and Devonian rock. At this time, over ten large ATES-systems (> 300 kW) and dozens of small systems (< 50 kW) are operational. Due to the high-energy prices and new developments concerning medium sized ATES systems (between 50 and 300 kW), the technology becomes more and more interesting for other parts of the country with interesting payback periods.

A number of ATES projects are monitored within the framework of a subsidy program for the stimulation of innovative energy technologies, called "Energy Demonstration Program" (initiative of ANRE - Administration on Natural Resources and Energy - of the Flemish authorities). Enterprises can get financial support on the condition that the project is extensively monitored. These projects act as an example and the program gives a good

overview on the real possibilities and limitations of the demonstrated technology. This gives interested parties a boost on the further implementation of innovative technologies. Three clinics of Northern Antwerp (KLINA) decided to cooperate and to extend to 400 beds. For that purpose, a completely new hospital was built with full climatization. The KLINA hospital was one of the first in Belgium to incorporate comfort cooling in the patient rooms. In order to avoid expensive cooling with traditional refrigeration a system with long-term storage of cold and heat in the groundwater was installed.

## 2 DESCRIPTION OF THE GROUND COUPLED HEAT PUMP SYSTEM

An ATES system was installed in combination with two reversible heat pumps. This system contains one cold and one warm well with each a depth of approximately 65 m (diameter drilling = 80 cm). The maximum groundwater flow amounts to 100 m<sup>3</sup>/h for both charging and discharging of cold. The two reversible heat pumps have each a heating power of 195 kW and, depending on the season, are used for heating or cooling. The ATES system provides cooling by means of pumping up groundwater from the cold well (see also Figure 1). This groundwater incorporates the building warmth and is injected in the warm source. At inadequate cooling power or if an insufficiently low temperature is reached by the system, the heat pumps are integrated. The condenser warmth is also removed by means of the ATES system to the warm well. In the winter groundwater is pumped up from the warm source with the aim of preheating the ventilation air. This way the winter-cold is taken by the ATES system and injected in the cold well.

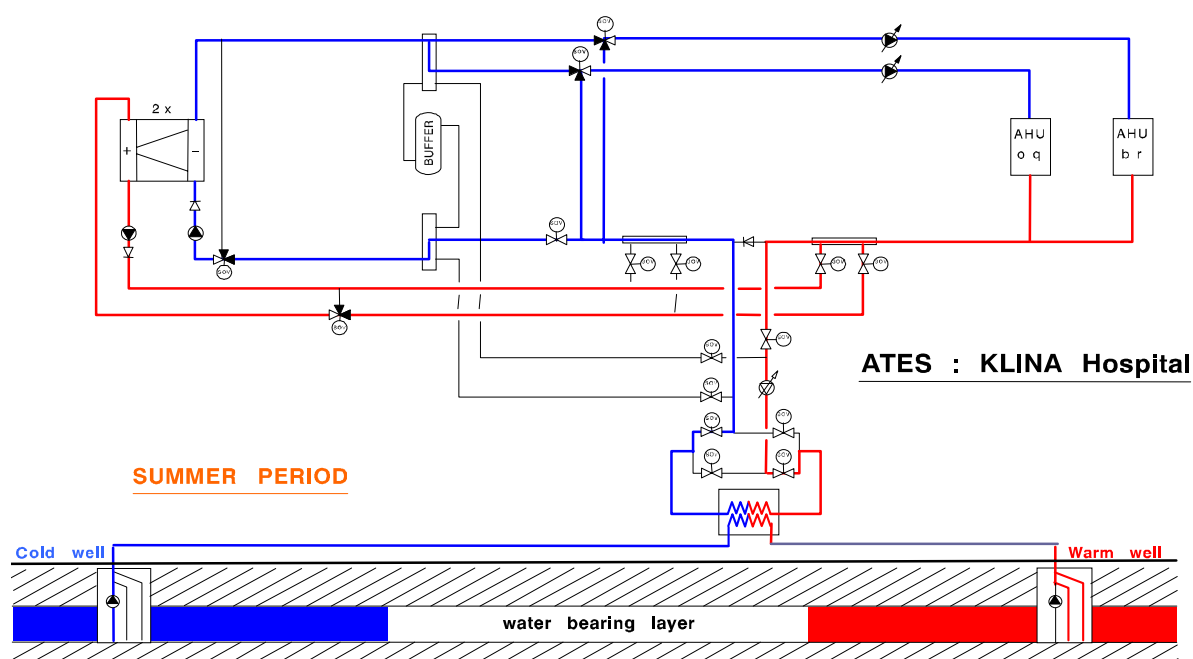


Figure 1: Hydraulic scheme HVAC system KLINA

Table 1 gives the specifications of the ATES system.

**Table 1: Specifications of the ATES system**

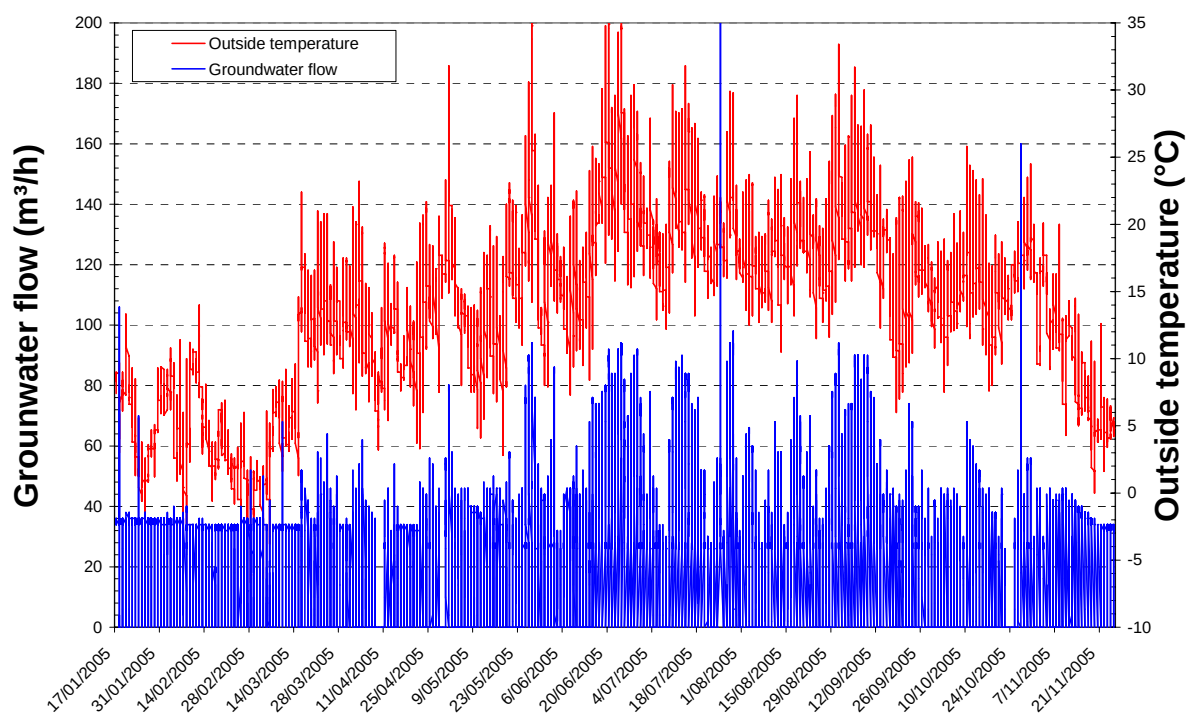
| <b>Parameter</b>                    | <b>Value</b>          |
|-------------------------------------|-----------------------|
| Maximum flow per well               | 100 m <sup>3</sup> /h |
| Maximum cooling power               | 1.2 MW                |
| Diameter drilling                   | 0.8 m                 |
| Depth wells                         | 65 m                  |
| Length filters                      | 36 m                  |
| Thickness aquifer                   | 40 m                  |
| Number of cold wells                | 1                     |
| Number of warm wells                | 1                     |
| Distance cold – warm well           | 100 m                 |
| Undisturbed groundwater temperature | 11.7°C                |
| Injection temperature warm well     | 18°C                  |
| Injection temperature cold well     | 8°C                   |

### **3 MONITORING RESULTS**

A central building management system (BMS) is installed, to fully control the operation of all devices of the system and also to provide system monitoring. A full analysis of the ATES system is made by retrieving data on all energy flows (and temperatures), electricity consumption for all auxiliary equipment (boilers, refrigerators, pumps), etc. All measurements are stored on a half hourly basis on a computer. For temperature measurements immediate values were stored. Due to some technical problems and data logging incompatibility the logging is started at 01/12/2002 (2 years after commissioning). The results presented in this paper cover the period 01/12/2003 - 30/11/2006. The installation and integration of such a groundwater system in combination with a traditional HVAC system isn't self-evident. This was proved with the installation of the first ATES systems where some problems occurred on the integration aspects. A good cooperation between drillers, building/HVAC designers and contractors is absolutely necessary with a clear demarcation of the responsibilities.

#### **3.1 Groundwater Flow and Temperatures**

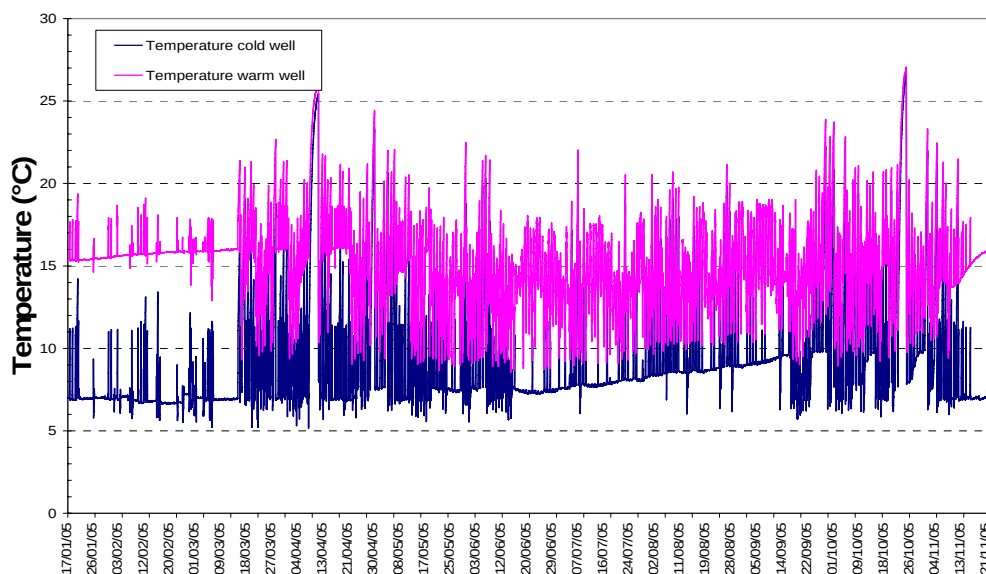
During the monitoring period more than 534,000 m<sup>3</sup> of groundwater was moved from the cold to the warm well and 515,000 m<sup>3</sup> groundwater in the opposite direction. Figure 2 shows the outside air temperature compared to the groundwater flow of the ATES system in the year 2005.



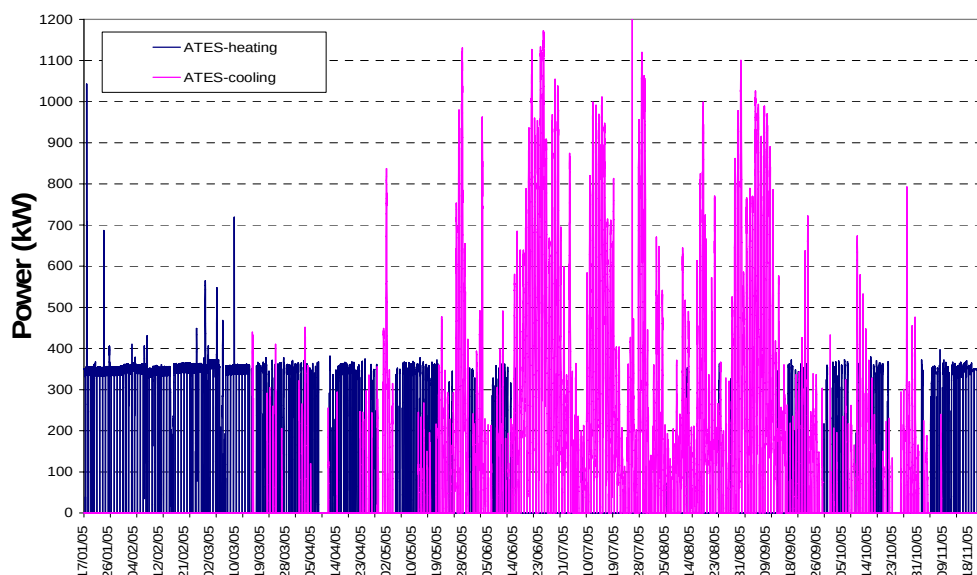
**Figure 2: Groundwater flow versus outside temperature (year 2005)**

It is observed that the groundwater flow from the ATEs system follows the outside air temperature quite well. Due to the large amount of working hours during winter mode the flow is relatively low (35 m³/h) and constant ensuring that enough cold can be stored in the cold well for use in summer period. In the summer period the flow is increased towards the projected value of 100 m³/h. Fluctuations in flow are more likely in the summer period.

Figure 3 shows the groundwater temperature of the warm and cold well. As it can be seen, there is an increase in cold well temperature during summer period (7°C in June 2005 up to 10°C in September 2005). The groundwater temperature at the end of the cooling season is still high enough, and lower than the natural groundwater temperature (~12°C). This means that there is still some potential for cooling the building and that the ATEs system is working properly. Somewhat same conclusions can be drawn for the winter period. Groundwater is extracted from the warm well at temperatures of 16°C and injected in the cold well at temperatures of 7°C. Figure 4 shows the heating and cooling power of the ATEs system.



**Figure 3: Temperatures groundwater in warm and cold well (year 2005)**



**Figure 4: Heating and cooling supply by the ATES system (year 2005)**

The ATES system provides a capacity between 100 kW and 1.2 MW. In the winter period there is a more constant but lower capacity supply with an average of 350 kW (provide heat to building or cold charge of cold well). The presence of a heat pump significantly helps in the cold charging process. The number of charging hours increases and is independent of the outside air temperature. Furthermore, the injection temperature is more constant and at an interestingly low value. In the summer period the provided capacity varies much more and fluctuates in function of the intensity of overheating of the building.

### 3.2 Energy Balance

Figures 5 and 6 give a picture of the energy supply of the ATES system and the heat pump covering the entire monitoring period (three years). The largest part (74%) of the ATES cooling is applied directly for comfort cooling of the building (incl. surgery, pharmacy, etc). The remaining 26% is used for refrigeration of the condenser of the heat pump during

summer situation (operating as a cooling machine). This operation is necessary for supplying cold on low temperature (for dehumidification purposes).

Analogously the groundwater system provides heat, the proportion of direct heat supply to the building is rather limited (17%). Generally, the warm well will provide heat to the evaporator of the heat pump at heat demand. In this way, efficient heat supply is provided to the building and the cold well is charged.

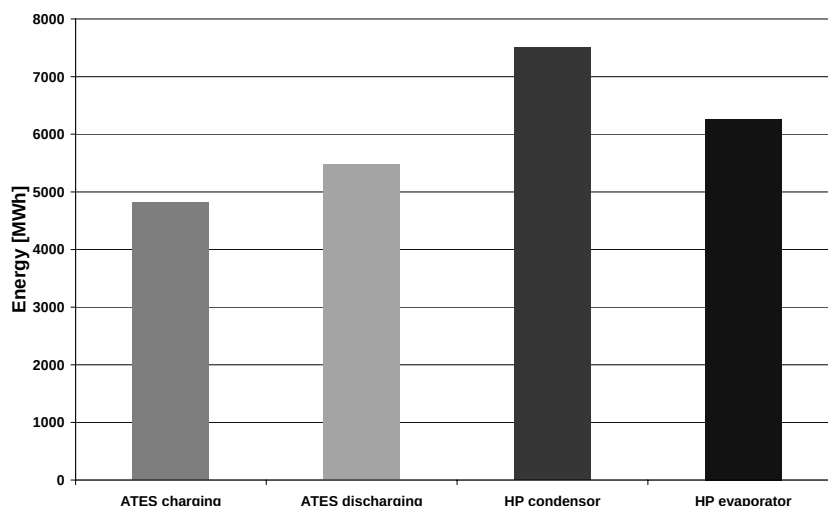


Figure 5: ATES energy amounts (over monitoring period)

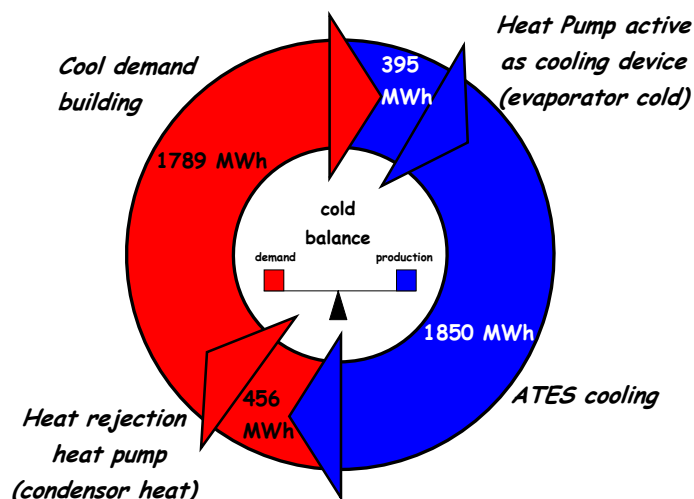


Figure 6: Cooling energy balance (over monitoring period)

During winter period the heat pump is delivering heat at a  $COP_{heating}$  of 6.1 for the first and 5.5 for the second heat pump. During summer period the heat pumps are operating as cooling machine at  $COP_{cooling}$  of 5.4 and 4.9. These high figures indicate that the working conditions (temperature levels of condenser and evaporator) are most favourable mainly because the ATES system is designed at relatively high temperatures and the secondary system (the AHUs) at low temperature. The electricity consumption of the ATES system over the monitored period was 229 MWh<sub>e</sub> given a  $COP_{cooling}$  of 45.

It's important to point out that the total heating demand of the building also involves a static heating system with classic radiators and a boiler as heat supplier. It's typical that the ratio static/ventilation heating is about one.

#### 4 GREENHOUSE GAS EMISSION REDUCTION

In order to determine the primary energy savings, the ATES system is compared with a reference installation based on a water-cooled cooling machine and a gas-fired boiler for heating. Furthermore, the impact of the innovative installation on the CO<sub>2</sub> emissions over the monitoring period of 3 years is calculated and presented in Table 2.

For the primary energy savings and CO<sub>2</sub> emission reduction the following numerical assumptions were made:

- compression chiller efficiency  $COP_{cooling}$  = 3.5;
- gas-fired seasonal thermal efficiency  $\eta_B$  = 85%;
- average electrical efficiency Belgian power plant = 44%;
- CO<sub>2</sub>-emission factor electricity = 624 g/kWh<sub>e</sub>;
- CO<sub>2</sub>-emission factor natural gas = 181 g/kWh<sub>t</sub>.

**Table 2: Primary energy savings and CO<sub>2</sub> emission reduction (over monitoring period)**

|                                 | <b>ATES system + heat pumps</b> | <b>Gas-fired boilers + cooling machines</b> |
|---------------------------------|---------------------------------|---------------------------------------------|
| Electricity consumption         | 1,474 MWh <sub>e</sub>          | 1,603 MWh <sub>e</sub>                      |
| Gas consumption                 | 0 MWh <sub>t</sub>              | 9,235 MWh <sub>t</sub>                      |
| Primary energy consumption      | 12,060 GJ                       | 39,017 GJ                                   |
| <b>Reduction primary energy</b> | <b>- 26,957 GJ</b>              | <b>-</b>                                    |
| CO <sub>2</sub> -emissions      | <b>920 ton</b>                  | <b>2,829 ton</b>                            |
| <b>CO<sub>2</sub>-reduction</b> | <b>- 1,909 ton</b>              | <b>-</b>                                    |
| <b>CO<sub>2</sub>-reduction</b> | <b>- 67 %</b>                   | <b>-</b>                                    |

The application of ATES reduced the CO<sub>2</sub>-production with more than 1,909 ton over the past 3 years. The gas consumption for conditioning of the ventilation air is omitted entirely and is replaced by electricity consumption of the source and heat pumps. Because the heat pumps operate at a very high efficiency, the total electricity consumption remains under that of the reference installation. There is a total primary energy saving of 69% on the climatization of the ventilation air with a CO<sub>2</sub>-reduction of 67 % compared to the reference installation.

#### 5 COST BENEFIT ANALYSIS

Finally, the feasibility of each option has been assessed and presented in Table 3. Both the investment, maintenance and energy costs (electricity and natural gas) were calculated according to information obtained from the manufacturers and the owner of the hospital. The annual costs are the sum of total energy and maintenance costs. The maintenance costs are assumed to be a percentage of the investments costs.

**Table 3: Economic analysis of the ATES system compared to the reference installation**

|                                                             | <b>ATES system + heat pumps</b> | <b>Gas-fired boilers<br/>+ cooling machines</b> |
|-------------------------------------------------------------|---------------------------------|-------------------------------------------------|
| Annual costs per year                                       | 65 kEuro                        | 100 kEuro                                       |
| Investments costs                                           | 750 kEuro                       | 300 kEuro                                       |
| Static Payback Time<br>ATES system<br>(excluding subsidies) | 8.5 year                        | -                                               |
| Static Payback Time<br>ATES system<br>(including subsidies) | 2 year                          | -                                               |

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