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Underground Thermal Energy Storage for the German Parliament in Berlin, System Concept and Operational Experiences

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ABSTRACT

After the German re-unification in 1990, the Reichstag building in Berlin was completely refurbished to house again the German Parliament, the "Bundestag". The design of this work was in the hands of the British architect Sir Norman Foster, and since the first presentation of his plans in 1992 the energy concept included a geothermal component, i.e. the storage of thermal energy in the underground. Two aquifers at different depth are used to store cold (ca. 60 m) and heat (ca. 300 m).

The paper explains the system concept and the realised installation and presents first results of a monitoring campaign. The underground storage is operational since 1999, however, the full capacity of the total system and the final operational strategy could not be tested before completion of the energy network and all buildings involved in 2003. Both storage systems, after minor teething problems, performed to satisfaction. The monitoring was of great importance to detect and solve some operational inaccuracies and to optimise the system hardware as well as the operational strategies.

INTRODUCTION

Today the site on the Spree peninsula in Berlin is the central governmental and parliamentary district of Germany (fig. 1). The new buildings for the Chancellor's office (Bundeskanzleramt), the offices of the members of Parliament, the press office, etc. are a nice contrast to the old walls of the former Reichstag building (fig. 2), now housing the plenary hall of the German parliament, the "Deutscher Bundestag".

All these buildings are connected by an energy network for heat, cold and electricity. The components are distributed over the various buildings, including heat-and-power co-generation (CHP), boilers, chillers, an absorption heat pump, and two different underground stores for thermal energy in the form of aquifer storage systems.

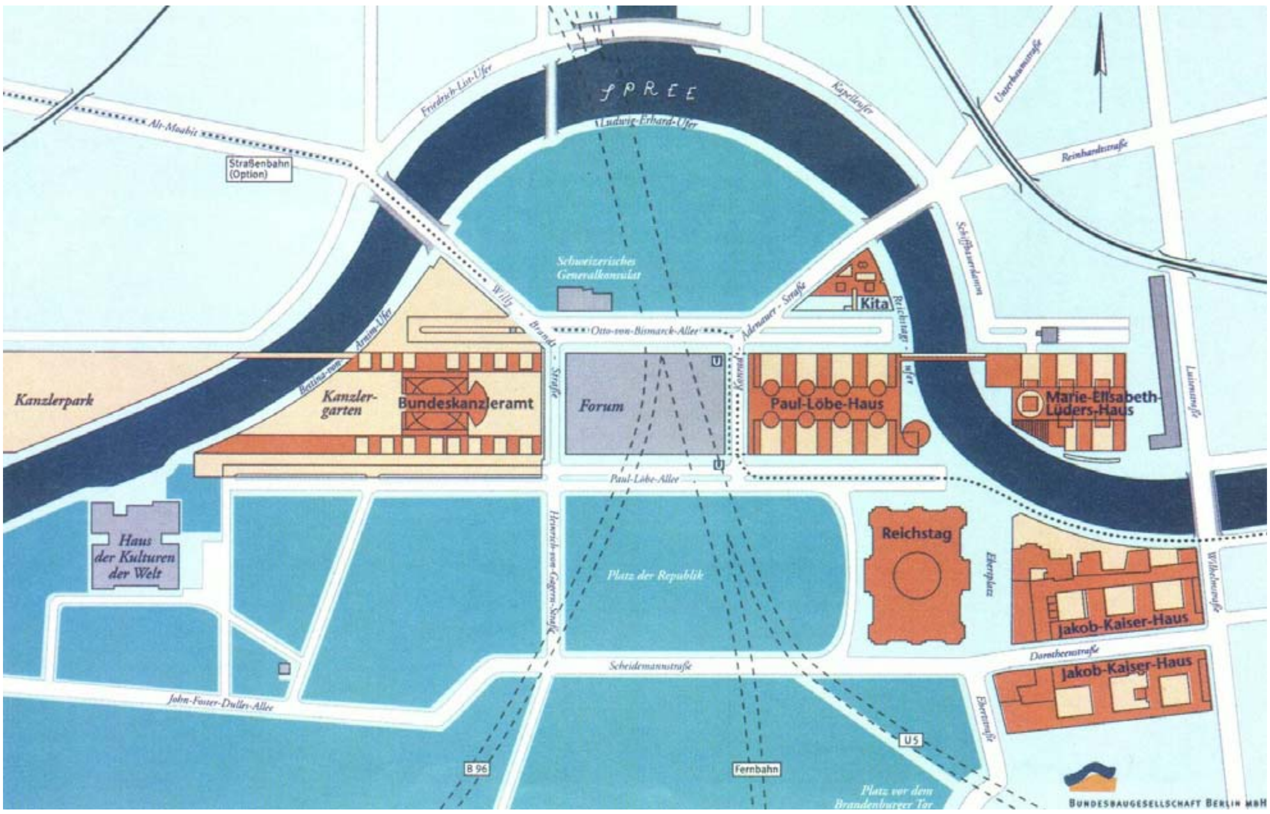

Figure 1: Location of the buildings of the German Parliament in Berlin (Graphics: Bundesbaugesellschaft Berlin)

Figure 2: View from the balcony of the chancellor's office facing East, towards the Paul-Löbe-building (offices for MPs) and the Reichstag building with the new cupola in the right background (photo: Sanner)

The original Reichstag building was completed in 1894. In 1933 it was partly destroyed by fire, and not repaired in the following years, until even greater destruction at the end of world war II in 1945. However, the massive walls withstood and survived, while the interior was completely gone. Situated in the west of Berlin, but with its eastern facade only a few metres from the border (and later the Berlin wall), it was reconstructed only in 1973, in a simple and temporary way (without the original copula). Already this reconstruction comprised groundwater wells for direct cooling; however, the hydrochemistry was not addressed sufficiently, and the re-injection wells were clogged with iron after a short while, rendering the whole groundwater cooling system useless.

After the German re-unification in 1991, and the decision to have the capital of the unified Germany in Berlin, plans to completely refurbish the building were set into effect. Sir Norman Foster did win the competition of 1992, and in his winning concept already an aquifer storage for cooling was included. In 1995 the old building became a piece of art, wrapped by Christo, and after that the whole interior was torn down. While the first deep drilling for the heat storage went on, it was possible to see the sky through the entrance portal (fig. 3). The completely renovated building, with a new copula (acting also as a part of the ventilation system), was inaugurated in 1999.

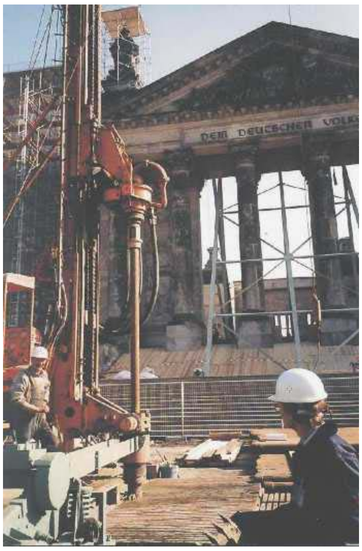

Figure 3: Drilling of the first deep well in front of the main entrance in 1996, while the complete interior of the building has been removed before rebuilding (photo: GTN)

The aquifer storage (ATES) for the first concept by Norman Foster in 1992 had been drafted by Justus-Liebig-University, Giessen, and Kaiser Bautechnik, Duisburg. After the successful competition, these partners investigated, designed and modelled a cold storage ATES using the Quarternary sands on site (Sanner, 1994; Sanner et al., 1994; Knoblich et al., 1994). In 1995, a suggestion was made by GTN for a heat storage ATES in greater depth in combination with the planned CHP-plants, in order to make use of waste heat during electric power production in summertime (Lützke, 1996). Also the system was enlarged to cover not only the Reichstag building, but also the office buildings of the parliament planned in the vicinity (Seibt and Kabus, 1997; Kabus, 1998).

Kühn, Bauer und Partner from Munich continued the design of the energy system, and GTN did the investigation and final layout and planning of the two ATES. In this context the first deep drilling of more than 300 m was done for exploration in 1996. After completing of the drilling and construction of the ATES systems, a test operation could start in autumn 1998 (Kabus and Seibt, 2000). The official inauguration was in 1999, but it took until end of 2002 before all the buildings and components linked to the energy network were completed, and the intended operation could be realised.

The accompanying RandD-project was starting in a first theoretical phase in 1997 (state-of-the-art-report, Sanner , 1999), and the monitoring began in 2000. The first monitoring phase ended in 2003 and thus could not yet investigate the final operation of the completed system (Sanner, 2004). The results shown in this paper concern this first monitoring phase.

LAYOUT OF THE ATES SYSTEM

The two aquifers are in different geological layers at different depth (fig. 4). In Quarternary sands in ca. 60 m depth an aquifer is used for storage of cold to cover summer cooling loads, and two sets of 5 wells each access that aquifer. Another aquifer in Lower Jurassic sediments (Hettangian and Lower Sinemurian) in about 320 m depth serves for storage of excess heat from CHP in summertime, to assist heating during winter. Here only 2 wells are required, and temperatures may reach up to 70 °C.

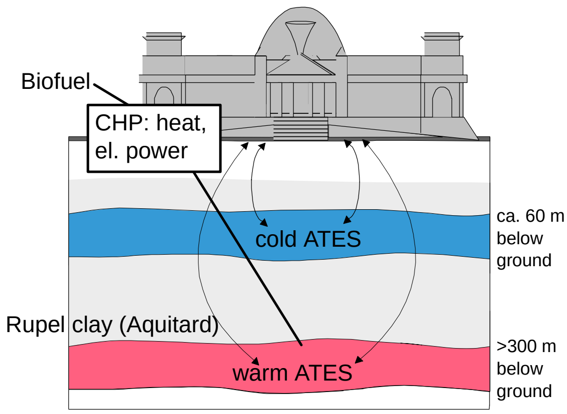

Figure 4: Schematic of the two ATES layers beneath the Reichstag building

The heat storage aquifer is overlain by a confining layer of about 140 m thickness, consisting of claystones/siltstones of the Upper Sinemurian (70 m thickness) and by the Oligocene Rupel clay (another 70 m). This confining layer prevents convective heat losses from the storage formation into the Tertiary sediments. The warmer group of wells of the cold storage ATES in the Quarternary (the northern group) is also protected from losses to the surface by a clay lens. The detailed geology and the basic load concepts justifying the storage operation are described in Kabus and Seibt (2000).

The heat storage wells are located in front of the western side of the Reichstag building and north of the Paul-Löbe-building, respectively, and are connected to the CHP-plants operated by biofuel in these two buildings. The cold storage wells are located similarly, with 5 wells in a cluster at each end, and the warmer wells being those north of the Paul-Löbe-Building. Fig. 5 shows the groundwater-bearing pipes for each of the aquifers, and fig. 6 shows the related piping at the entrance to the Reichstag building (located beneath the main flight of stairs to the western entrance).

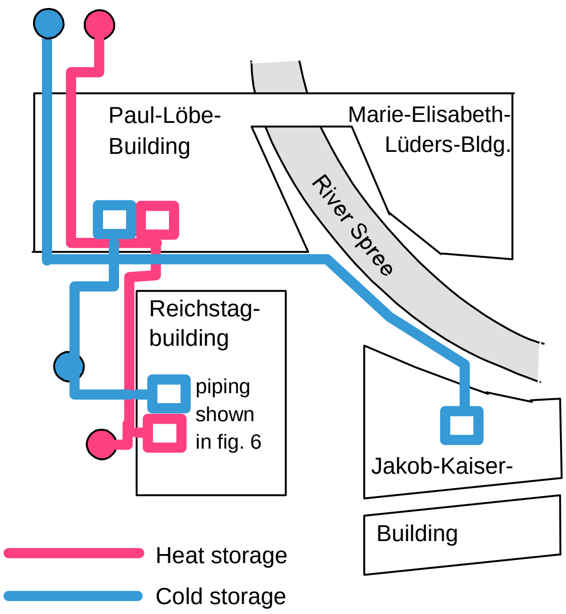

Figure 5: Groundwater-bearing pipe connections for the two ATES systems

Figure 6: Groundwater-bearing pipe connections at the entrance into the Reichstag building, cold storage system (above) with heat exchangers to the left, and heat storage system (below) (photos: GTN)

Because of the salinity of the water in the heat storage ATES, and because of the higher temperatures in that circuit, the piping is made of glass-fibre-reinforced resins showing a yellowish colour in fig. 6. The piping in the cold storage ATES can be made of standard plastics. In both cases it is of crucial importance to keep the piping under pressure at any time, and to prevent oxygen from entering the groundwater. This is the only way to avoid clogging like in the original 1973 groundwater cooling (see above). Even inside the wells a cushion of nitrogen is maintained on top of the water level to keep oxygen out.

On the heating and cooling side, the buildings are connected also. Fig. 7 shows the schematic of the heating network and the main heating components. The absorption heat pumps can also operate as chillers in summertime.

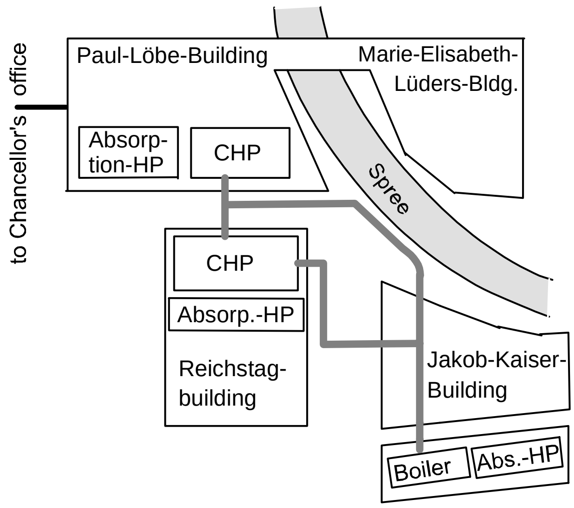

Figure 7: Heating network and main heating components in the individual buildings

The operation of the cold storage for the Reichstag building was paramount from the beginning in 1999 to keep the parliamentary work going on hot summer days. However, the dry coolers for storing ambient cold in wintertime are installed on top of the Paul-Löbe-Building, and this building was not completed until late 2002. Hence the cold storage could not be re-cooled in the first winters, and did heat up steadily over the summers. The water authorities did set a maximum temperature limit and required a temperature monitoring around the ATES. In this way the cooling could be maintained the first years, and now the aquifer can be cooled down again over the next winters. Table 1 gives the cold storage energy balance according to simulation.

Table 1: Energy balance for cold ATES (simulated)

Summer	production temperature	6 ... 10°C
(retrieving)	injection temperature	15 ... 28°C
	cold retrieved	3.950 MWh/a
Winter	mean production temp.	22°C
(loading)	injection temperature	5°C
	cold stored	4.250 MWh/a
Balance	energy for pumping	220 MWh
	ratio of cold retrieved to cold stored	93 %

For the heat storage, similar problems did exist during the construction time of the surrounding buildings. The CHP engines within the Reichstag building supply only part of the total load and before the CHP in the Paul-Löbe-Building was operational, the storage loading temperature was limited, because even with the minimum circulation rate of the wells, the CHP in the Reichstag building could not supply enough heat to rise the temperature of the groundwater to be re-injected to the full 70 °C. Table 2 shows the energy balance for the heat storage according to simulation, with the store not yet being in a full equilibrium. The final performance after several years will still be better.

Table 2: Energy balance for heat ATES (simulated)

Summer	mean production temp.	20°C
(loading)	injection temperature	70°C
	stored heat	2.650 MWh/a
Winter	production temperature	65 ... 30 °C
(retrieving)	heat retrieved	2.050 MWh/a
Balance	energy for pumping	280 MWh
	ratio of heat retrieved to heat stored	77 %

Several different operational modes of the whole system are possible in order to produce electric power, heat and cold (and to make use of some heat that comes with electric power production). Fig. 8 shows a typical summer operation, with the CHP producing power, the heat coming with power production being used for what heating still might be required, for driving the absorption heat pump as a chiller, and the rest of the heat to be stored in the heat ATES. Cooling needs are satisfied from the cold storage on a higher temperature level and from the absorption chiller.

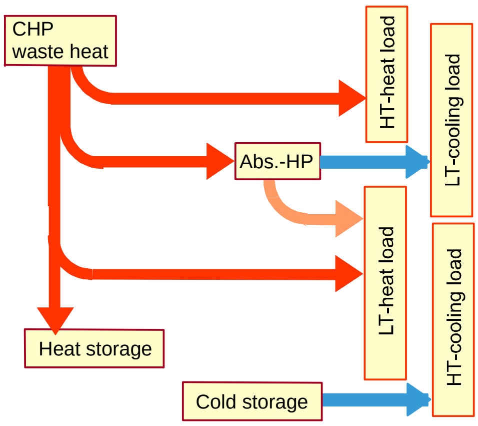

Figure 8: Summer operation with cooling and loading of heat store

In fig. 9 the two different heating modes are illustrated, one with (direct) heating from the heat ATES (as long as temperatures allow), the other with the absorption heat pump and the cold storage as heat source.

ENERGY MONITORING

From start of operation in 1999 until autumn 2002 both ATES could only be operated in one single operation mode (see above).

- The heat storage was operated in loading mode, with loading temperatures in the range of 40-50 °C because of the not yet completed second CHP plant in the Paul-Löbe-Building. A retrieval of heat at that temperatures was not deemed useful.
- The cold storage was only operated in retrieval mode (cooling), because the re-cooling equipment on the Paul-Löbe-Building was still missing. In consequence the underground around the northern group of cold storage wells warmed up steadily.

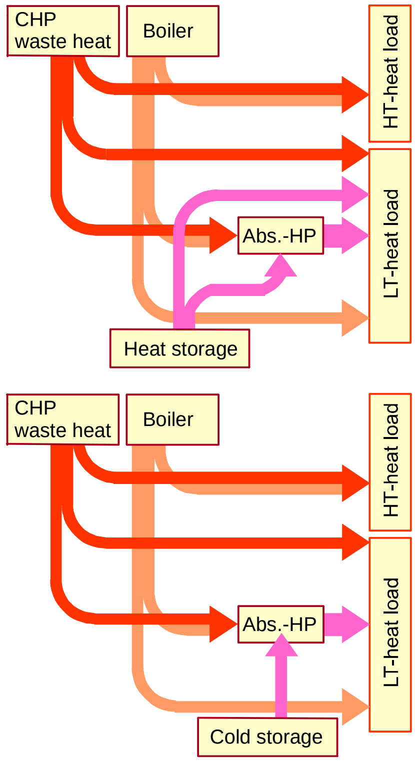

Figure 9: Winter operation with heat retrieval from heat store (above) and from cold store (below)

Since autumn 2002 the components in the Paul-Löbe-Building are operational and the two ATES system can be used as planned. The loading of the heat store now is done as close as possible to the maximum permissible temperature of 70 °C. With high heat surplus in summertime continuos loading can be done. The first regular loading-unloading cycle ended with the end of heat retrieval in winter 2002/2003. Fig. 10 shows the temperature development over the full cycle. Loading started in April 2002 with temperatures around 55 °C and continued the whole summer. After a phase of intermittent loading the retrieval began in November 2002 (blue curve). Retrieval was continuos and the average flow rates were higher than in loading mode, so the amount of hot water stored was retrieved faster.

Numerical Simulation had been done already in the design phase, in order to predict the behaviour of the ATES. During the monitoring phase, the existing models for the two storages could be calibrated with geological data obtained during construction, and the monitored operation behaviour could be simulated. With the first longer retrieval period in winter 2002/2003, the numerical model for the heat store could be validated with measured data. Figure 11 shows the comparison of measured and simulated temperatures. After some initial differences at the beginning of the retrieval period, the curves show a quite good agreement.

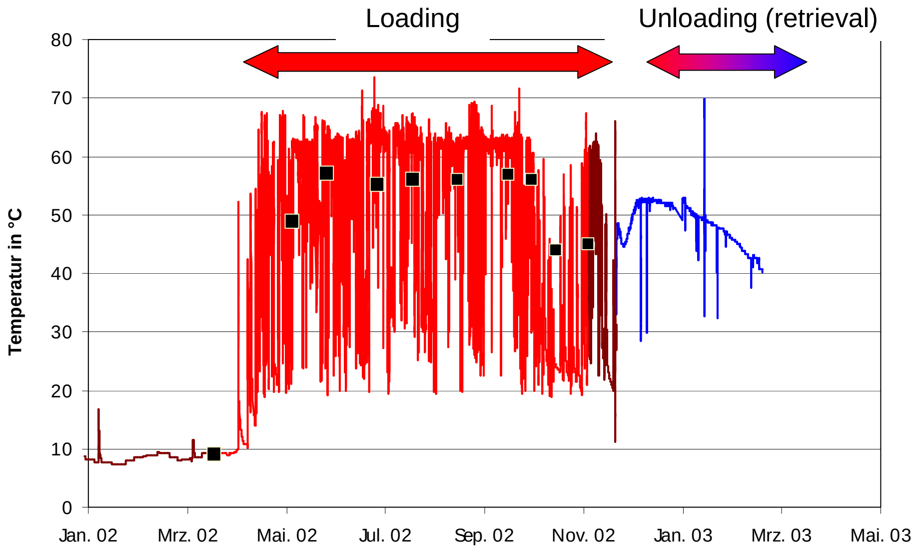

Figure 10: Well-head temperature on the warm side of the heat store over the loading/unloading cycle 2002/2003

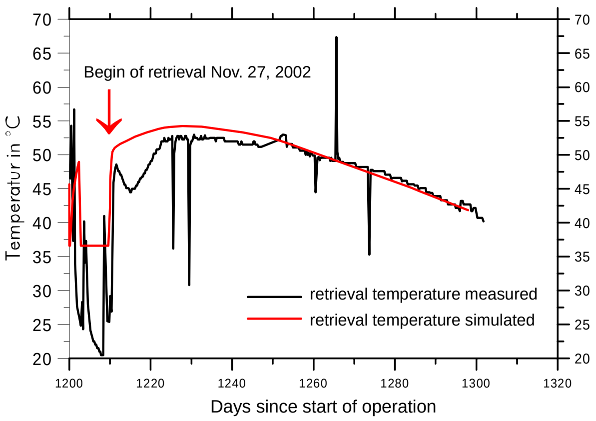

Figure 11: Comparison of measured and simulated well-head temperatures on the warm side of the heat store in winter 2002/2003

A validation of the model was also possible for the cold storage. The bubble of warmed-up water around the northern wells after 3 winters without re-cooling reached to the first monitoring well ("Pegel" in German). This can be seen in the model simulation (fig. 12) as well as in temperature logs from the monitoring well (fig. 13). It is now possible to compare the temperature development in the monitoring well with the simulated values at the same point in the model area (fig. 14), and the agreement is satisfactory.

The calibration of the model with the ground conditions found during construction and the validation with measured values from monitoring allows to predict the future behaviour of both ATES. This allows optimisation of the operation strategy of the stores, but can also be used to monitor a correct storage operation.

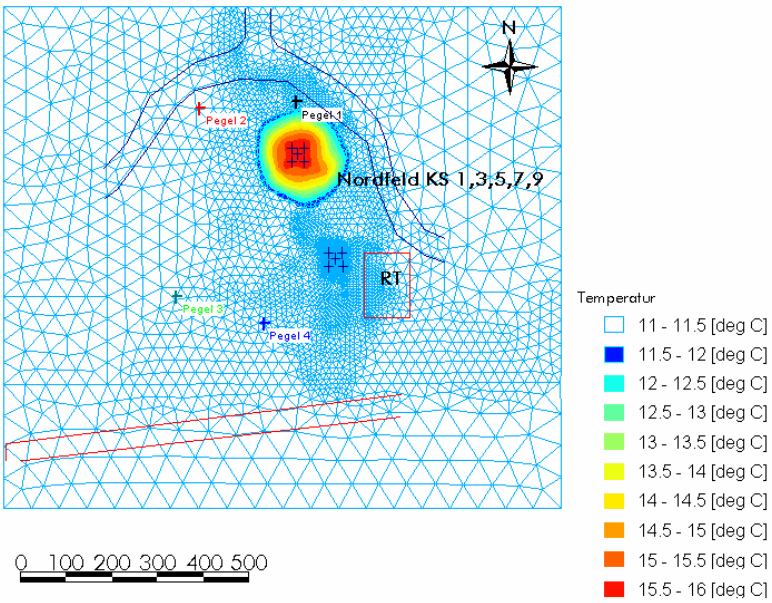

Figure 12: Cold ATES, simulated temperature distribution in March 2002

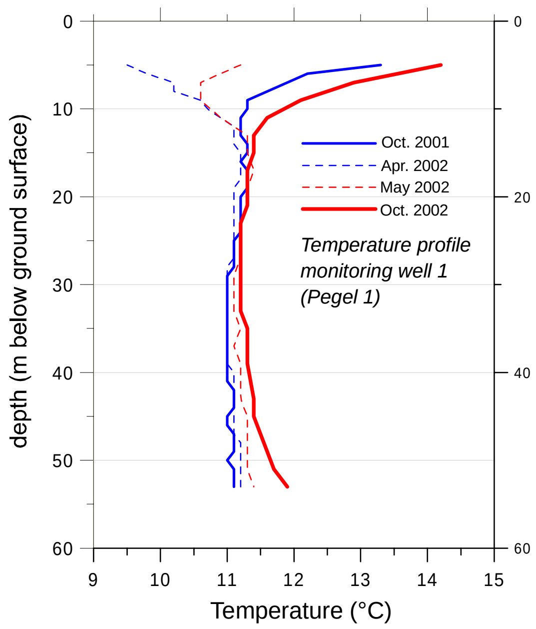

Figure 13:Cold ATES, temperature in monitoring well 1

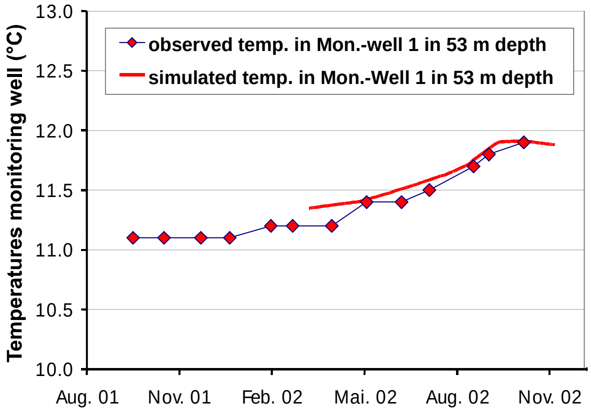

Figure 14: Comparison of the measured temperature development in monitoring well 1 with simulated values

CHEMICAL MONITORING

To evaluate the chemical development of the groundwater in both ATES, samples were taken and analysed by the university of Lüneburg. Beside the sampling of undisturbed water (done May 4, 2000), the retrieved water in each new cycle should be investigated. However, due to the late completion of the full system, this could not yet be done.

The sampling was done inside the building from the production flow of each aquifer. Prior to taking samples online-measurement was made for the parameters temperature, electric conductivity, pH-value, redox-potential and oxygen content. Only after all parameters became stable the samples were taken (fig. 15).

In fig. 16 the development of some selected parameters in the heat ATES is shown. A distinction is made between sampling from the undisturbed aquifer (cold well until autumn 2002, dashed lines) and from groundwater having been injected into the heat store (full line). The temperature from the cold well is ca. 19 °C, while in the warm well originally up to 39 °C had been injected, and 25-30 °C have been retrieved. Electric conductivity, pH-value and iron (Fe) do not change significantly, with no difference between cold and warm well, either. Redox potential is higher in the warm than in the cold well, as should be expected, and varies greatly. A slight increase can be seen in the parameters relevant for scaling (hardness, calcium, magnesium) until early 2001, when the values fall back again.

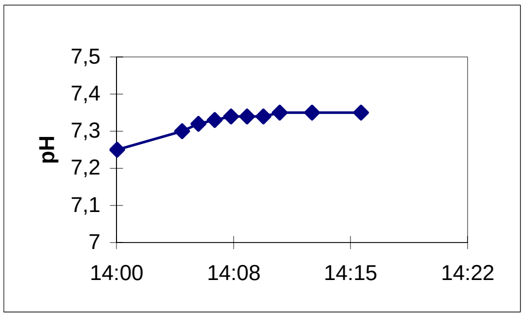

Figure 15: Chemical sampling May 4, 2000, online-measurement of pH until stability is reached

Because both ATES were not in the final mode of seasonal cycling operation until end of 2002, sampling of retrieved groundwater from the aquifers could only be done during short periods of test retrieval. Water from the heat store could first be sampled on July 13, 2000. Because the cold store was only operated in cooling mode in the first years, after the initial sampling on May 4, 2000, the next samples were not taken before autumn 2002, when this was done prior to the first loading (re-cooling) of the cold ATES. Tab. 3 lists the individual sampling campaigns.

Table 3: Chemical sampling, * marks samples of water retrieved from the store

Cold ATES	
May 4, 2000	group of cold wells (south)
Oct. 1, 2002	group of cold wells (south)
May 27, 2003	group of cold wells (south)
Sept. 16, 2003	group of cold wells (south)
Heat ATES	
May 4, 2000	cold well (north)
July 13, 2000	warm well (south) *
Jan. 5, 2001	cold well (north)
Jan. 8-10, 2001	warm well (south) *
May 8, 2001	warm well (south) *
Oct. 1, 2002	cold well (north)
May 27, 2003	warm well (south) *
Sept. 16, 2003	warm well (south) *

In total, the impact on the heat storage aquifer is negligible until now, what, of course, also is a result of the relatively low temperatures and the lack of a full cycle. The observations made now are not necessarily representative for the upcoming full operation.

When looking at the cold ATES (fig. 17), it is apparent that the parameters relevant for scaling (Calcium, total hardness and iron) decrease slightly. Most changes, however, are very small, and reliable conclusions cannot be drawn yet. In general, several complete storage cycles would have to be observed to finally evaluate the geological, environmental and energetical behaviour of the store.

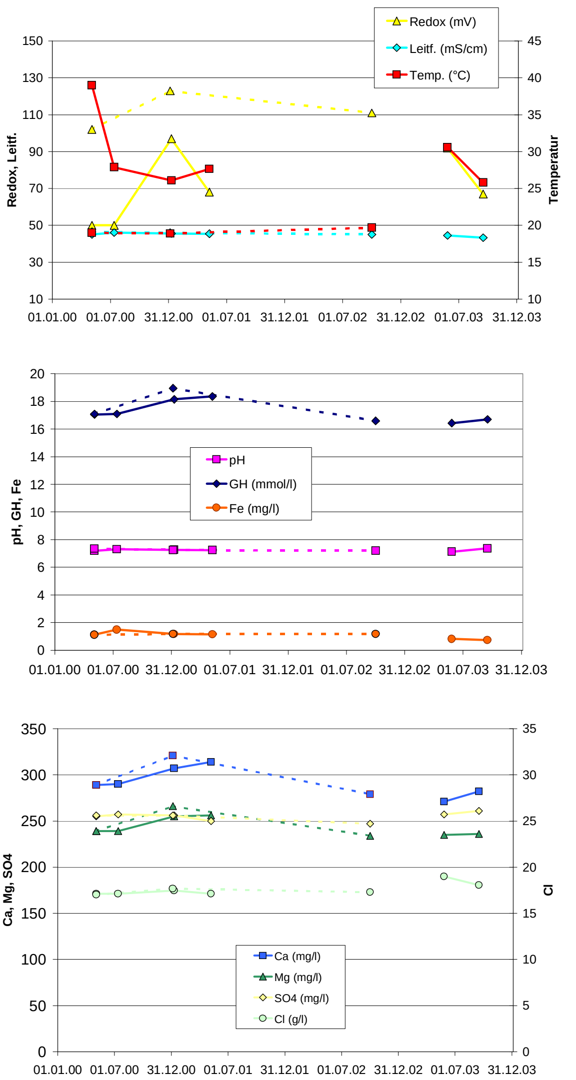

Figure 16: Hydrochemical development in the heat store; full lines warm well, dashed lines cold well

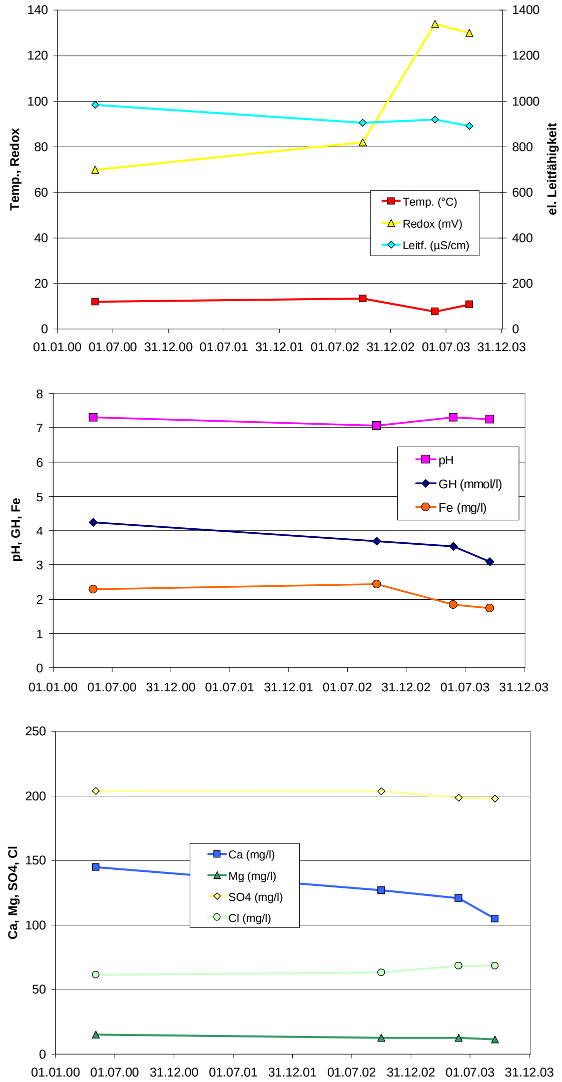

Figure 17: Hydrochemical development in the cold store

To test aquifer water for planned ATES in situ, a mobile test laboratory has been built in the framework of the accompanying RandD-program to the Reichstag ATES., in co-operation of the universities in Stuttgart and Lüneburg. A standard test procedure with step-wise heating of the water has been developed and applied for practical testing at several sites with various groundwater types (Knoche et al., 2003; Knoche et al., 2004). Alas, due to security reasons the mobile lab could not be used to test the aquifer water at the Reichstag site.

CONCLUSIONS

The two ATES systems for the German parliament in Berlin meanwhile are in full operation. The whole energy network that serves the buildings within the loop of river Spree has been completed.. The measured temperatures fit well the predictions from numerical simulation, both for the heat- and for the cold ATES.

Concerning the chemical stability of the water, over the first three years of operation no significant changes have been occurred. Keeping pressure, filtering and the nitrogen system show good results. The importance of these measures was drastically demonstrated when through a leak in a well oxygen could enter the system, and scaling was detected almost immediately.

Members of Parliament working in the new and refurbished buildings usually do not hear and see the energy system. The administration of the parliament has issued some information also for the MPs and the general public on the aquifer storage, and personnel responsible for guiding visitors has apparently been instructed in that way. For ATES, the Reichstag building is a phantastic showcase, however, also a showcase were visits are difficult due to the necessary security measures on that site.

The future development of both ATES should be monitored as well, in order to investigate the system performance in routine operation with the full system, and to act as an early warning system in case problems may built up. Also after the end of the initial monitoring period (which was financed by BMWA, see acknowledgement), the monitoring was continued in order to get a full set of data if and when a continuation of support for the accompanying RandD-proejct might be granted. Fig. 18 shows now the first full cycle 2002-2003 (as already shown in fig. 10) and in addition the second cycle 2003-2004 of the heat storage system. Both loading and retrieval temperatures are higher now, the ATES comes closer to the planned routine operation.

Replication potential for the Reichstag ATES can be seen in particular with the cold storage, which is already quite popular e.g. in the Netherlands. To implement such aquifer storage, the heat- and load characteristics should be clearly defined, the groundwater hydraulics well known, and in particular the chemistry of the groundwater must be known and dealt with correctly. Shallow geothermal systems like aquifer storage are not visible from the street, and such a showcase as is the Reichstag building can help much to promote this concept.

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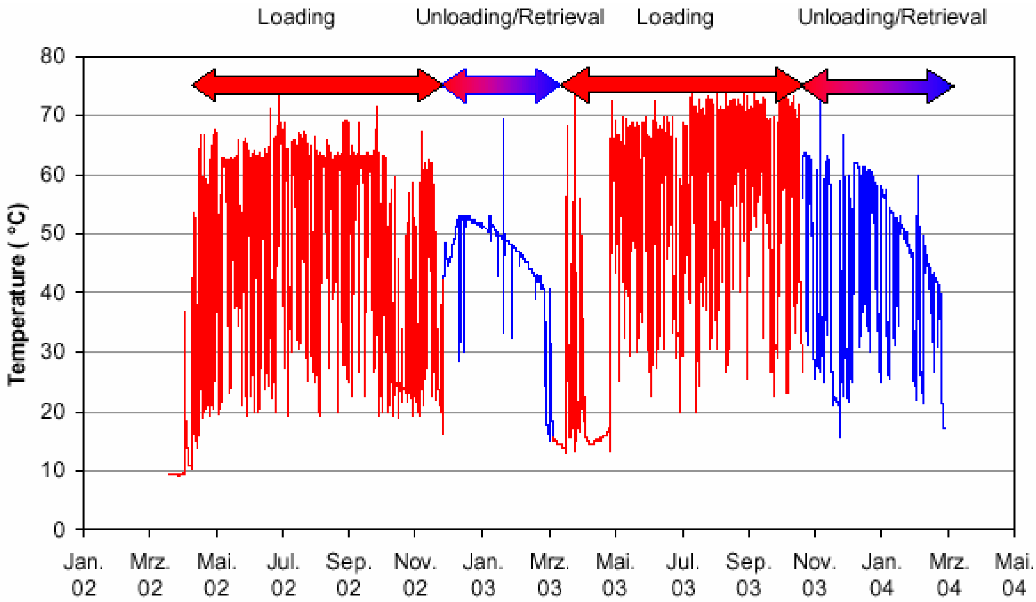

Figure 18: Well-head temperature on the warm side of the heat store over the loading/unloading cycles 2002/03 and 2003/04

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