Aquifer Thermal Energy Cold Storage System at Richard Stockton College

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ABSTRACT

Aquifer Thermal Energy Storage (ATES) systems have been designed, installed and operated for over 25 years. In the US there were four pilot projects operated over twenty years ago, however the recent completion of a 2 MW_t seasonal cold store system at Richard Stockton College is believed to be the first commercial ATES system in the US. The substantial design experience in the Netherlands was utilized since the geology is similar to that in the Netherlands. This presentation reviews its design and initial startup operation. Specifically problems with regulatory agencies, finding contractors, and other hurdles are discussed. The financial implications of each of these are analyzed.

1. BACKGROUND

The Richard Stockton College of New Jersey installed a BTES geothermal heating/cooling system (1600 tons / 5.6 MWt) serving the sizable majority (400,000 SF / 36,000 m^2) of its academic buildings in 1994. Originally the thought was to install an aquifer geothermal system, however permitting would have taken an extra two years and it was not clear that permits would be obtained in a very environmentally sensitive and highly regulated part of the State, both by the NJ Department of Environmental Protection and the Pinelands Commission. In 1997 the College commissioned an Aquifer Thermal Energy Storage (ATES) feasibility study coordinating with planning of two new buildings; a Multipurpose Recreation Center (MPRC) and a Health Sciences academic building (WQ) with a large cooling load. It was thought that with a four year positive experience of the borehole system that the regulatory agencies would have fewer concerns with an ATES system. Again the College decided to forgo implementing an ATES system when the regulatory agencies made it clear that the permitting procedure would result in significantly delaying the building projects. More recently College revisited ATES when it was decided to connect five buildings, which were not connected to the original BTES geothermal system, with a chilled water loop system. The chilled water loop would tie together four existing buildings and their standard chiller cooling towers to ensure backup if needed. It also connected a new "green" building under construction. Since there was no urgency to building this ATES system the thought was to resurrect the ATES project in conjunction with the chilled water loop project. The ATES system is now fully installed and is currently storing chilled water for use in the Summer 2009. It is believed that this is the first fully operational commercially viable ATES system in the US. In the early 1980s the US Department of Energy sponsored four ATES pilot projects (two cold and two warm projects) for cooling or heating buildings. While successful as pilot projects no others were constructed in the meanwhile.

Stockton College is located in the United States near the southeastern edge of the New Jersey Coastal Plain. At this location, the total thickness of unconsolidated sediments is estimated to be approximately 1.35 km (4500 ft) with multiple layers of sand and clay formations. The upper formation, Kirkwood, combined with the generally permeable sediments of the Miocene Cohansey Sand, makes up the Kirkwood–Cohansey aquifer system, a highly productive regional aquifer found throughout a large portion of the Coastal Plain of New Jersey. The formation properties can be found in Table 1.

The energy supply system with ATES uses the cooling tower at the borehole field (BTES) manifold house to charge the aquifer with chilled water during the winter months. In the summer, this stored cold energy is withdrawn from the aquifer to provide cooling to the buildings. Since a significant cooling capacity is delivered by the aquifer, chillers in a new building were avoided. Cold water wells and warm water wells are connected to building loads through two heat exchangers, one to direct cold and heat between the campus cooling loop and the aquifer storage and one to direct cold from the cooling tower to the aquifer storage.

Table 1. Major aquifer properties

Aquifer property	**Metric unit value**	**English unit value**
Depth below surface	35-60 m	115-200 ft
Transmissivity	750-775 m²/d	9200-9400 ft²/d
Hydraulic conductivity	31-32 m/d	102-104 ft/d
Vertical hydraulic conductivity	0.006-0.027 m/d	.02-.09 ft/d
Hydraulic gradient	0.0019 - 0.0024	0.0019 - 0.0024
Direction hydraulic gradient	ENE	ENE
pH	5.1	5.1
Iron	0.78 mg/l	
Alkalinity as CaC03	1.0 mg/l	
Chloride	1.4 mg/l	
Ammonia Nitrogen	9.5 mg/l	
Nitrate Nitrogen	<0.1 mg/l	
Sulfate	1.9 mg/l	

During the winter months the cooling tower runs whenever the outdoor wet bulb temperature is low enough to generate 5ºC (41º F) water. On the groundwater side of the heat exchanger a temperature of 6.1ºC (43º F) is generated. This water is injected into the aquifer cold storage. During summer water is withdrawn from cold wells to cool the buildings. The maximum flow rate in the groundwater circuit is 272m³/h (1,200 gpm). As long as the flow rate required for cooling does not exceed 1,200 gpm all cooling is provided from the aquifer storage. In case the flow rate would exceed 1,200 gpm, the cooling of the new building is provided from the aquifer storage and the base load cooling of the existing buildings (Performing Arts Center (M), Health Sciences Building (WQ) and small gymnasium (I) and Multipurpose Recreation Center (MPRC)) is taken over by the existing chillers located on those buildings. No chillers and cooling towers are installed in the new academic building (F), thus saving the cost of 250 Tons of chiller capacity. In addition this system replaces the need for including redundant cooling capacity, which would have been added and/or capacity for other new buildings currently under consideration including a new Student Center presently under construction.

While cold storage is charged in winter with a temperature of 6.1ºC (43ºF), in summer the first water extracted will be 43ºF, but the extraction temperature from the storage will gradually rise in the course of the summer, to at most 8.9ºC (48ºF). The amount of cooling that can be delivered from the aquifer storage to the buildings connected to the building loop has been evaluated using the Pomona, NJ, NOAA weather data for the year 1962, which is the Typical Reference Year (TRY). Assuming that the aquifer storage has reached the equilibrium stage, this results in the values given in Table 2.

Under design conditions, with a maximum extraction temperature of 48ºF, the maximum injection temperature in the warm wells will be 65ºF (18.3ºC). The average injection temperature in the warm wells is estimated at approximately 59.2ºF (15.1ºC). About 113 million gallons (427,000 m^3) of cold water can be charged into the aquifer.

Table 2. Cooling provided by ATES system

Building	**Ton Hours/y**	**MWh/y**
New F building	295,000	1,040
PAC, WQ & I	162,000	570
Gym	118,000	415
MPRC		
Total	575,000	2,025

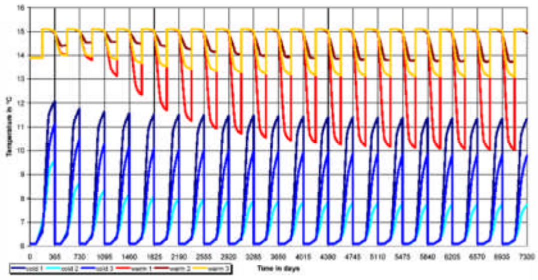

Figure 1. Well temperatures twenty year loading and unloading of three warm wells and three cold wells

2. Aquifer Storage System

The groundwater system extracts stored chilled or warm water from the sand aquifers and re-injects it into the sand aquifer after it has lost its energy. Extraction and injection is achieved by means of wells, the perforated part of which is placed in the Lower Cohansey aquifer. The wells are interconnected by piping. The heat transmission between groundwater system and building chilled water loop, as well as between groundwater system and cooling tower loop, is accomplished with heat exchangers (HEX). Since the groundwater system is in direct contact with the aquifer, there are a number of potential risks:

- Silt and sand in extracted groundwater can cause wear in the heat exchangers and clogging of the injection wells. These problems can be overcome by properly flushing the wells at the implementation stage (development), by over dimensioning the wells (low flow speed towards the bore hole wall) and by providing a gravel pack around the screen of the well, in which the grain size of the gravel is in the right proportion with regard to the grain size of the natural soil material.

- Groundwater may contain gases (O_2, CO_2, N_2, CH_4). Because of the high pressure in an aquifer the gases will remain dissolved. During extraction and transport of the water the pressure will fall and the groundwater may become degasified. Injecting gas bubbles may cause acute clogging of the injection wells. A slight over pressure in the system will suffice to prevent groundwater degasification. This implies that it may be necessary to add groundwater if the pressure in the system becomes less than the minimally required value, which may occur during standstills. By correctly dimensioning the submersible pumps and the injection valves and piping, the entire system will have over pressure with regard to atmospheric pressure during operation.

- The groundwater in the aquifer has a low pH and dissolved iron. A materials selection on the basis of groundwater quality and air-tightness of the system will prevent corrosion and iron precipitation from occurring.

The aquifer storage system consists of three cold wells and three warm wells. The dimensions of the wells are given in Table 3. For this dimensioning, it was assumed that it would not be possible to screen the Lower Cohansey aquifer over the full height and that the Membrane Filter Index value of the groundwater in the aquifer is 2s²/l; criteria that were met.

Table 3. Well dimensions

Design parameter	Dimensions
number of wells	2 x 3
diameter cold and warm wells	28" (0.70m)
depth	200 ft (60.9m)
screen depth	115 - 200 ft (35.1 - 61.0m)
effective length of screen	65 ft (19.8m)

The down-the-well piping includes a wire-wrap screen at the level of the storage aquifer. The space around this screen is filled with a fine gravel pack. A riser pipe and a pump chamber are located, successively, between the top of the screen and the ground surface. The pump chamber consists of a plastic pipe with a sufficiently large diameter to accommodate the submersible pump (Figure 2). The resulting layout of the well field and the piping is presented in Figure 3.

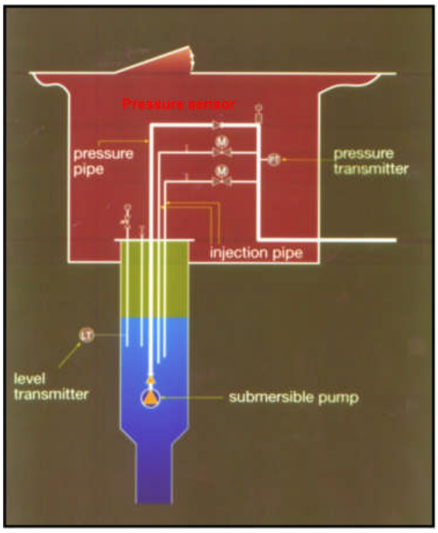

Figure 2. Well schematic

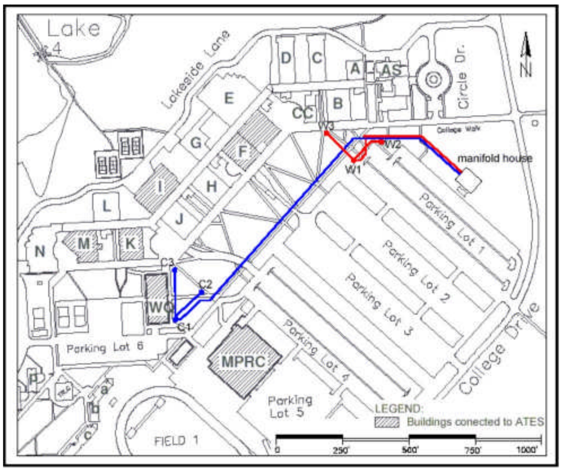

Figure 3. Well and Piping layout related to buildings

The configuration of the wells is chosen considering the maximum allowable injection pressure, the available land area for the positioning of wells, the thermal interaction between cold and warm wells, and the hydraulic impact on the groundwater level at the wetlands. Due to the relatively large groundwater flow, the thermal interaction is the main determining factor in this design.

To determine the hydraulic impact of the extraction and infiltration of groundwater from/into the lower Cohansey aquifer, calculations have been made with the software program MLPU. (See Figure 4). The maximum change of head in the storage aquifer is calculated to be about 5.2m (17ft). This change of head occurs in the direct surrounding of the wells.

To calculate the impact of the storage system on the phreatic groundwater level, it is assumed that the groundwater extraction and infiltration during wintertime takes place at maximum flow rate during one period without interruption. This approach results in the worst case situation with respect to the impact on the phreatic groundwater level. It is also assumed that the hydraulic resistance of the intermediate layer covering the Lower Cohansey aquifer is 1,000 d. The resulting modelling suggests that the hydraulic impact of the storage system on the phreatic groundwater level at the wetlands NW of the College site will be less than 5 cm (2”). This result is significant in determining that the impact of the system would not adversely affect the surrounding wetlands.

Calculations with the computer code HST2/3D have been made to determine the volume of cold groundwater to be stored during the winter in order to meet the cold demand during summertime. The calculations have been made assuming a gradient of the groundwater head (groundwater flow) of 0.0022 in the direction ENE.

Table 4. Assumptions for the HST2/3D calculations

Parameter	**Charging (winter)**	**Discharging (summer)**
injection temperature	43ºF (6,1ºC)	59.2ºF (15.1ºC)
maximum useable temperature		48ºF (8,9ºC)
required cooling capacity		2025 MWh (575,000Ton Hours)

Figure 5 gives the calculated temperature fields in the storage aquifer after 20 years of operation and calculated values in Figure 1. The results from the calculations are summarized in Table 5 for the fifth year of operation. From comparing the amount of cold groundwater that should be charged in winter to meet the cooling demand in summer with the amount that actually can be charged with the cooling tower in an average winter, it can be concluded that the cooling tower capacity is adequate for this project.

Table 5. Results hydrothermal calculations (year 5)

Water to be charged in cold wells in winter	325,000 m³ (86 MGallons)
Water to be produced from cold wells in summer	245,000 m³ (65 MGallons)
Average production temperature from cold wells	45.7 ºF (7.6 ºC)
Max. production temperature from cold wells	48.0 ºF (8.9 ºC)
Storage thermal efficiency	68%

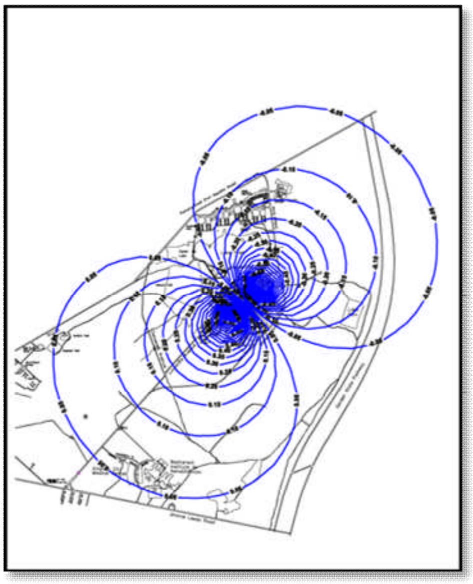

Figure 4. Hydraulic influence

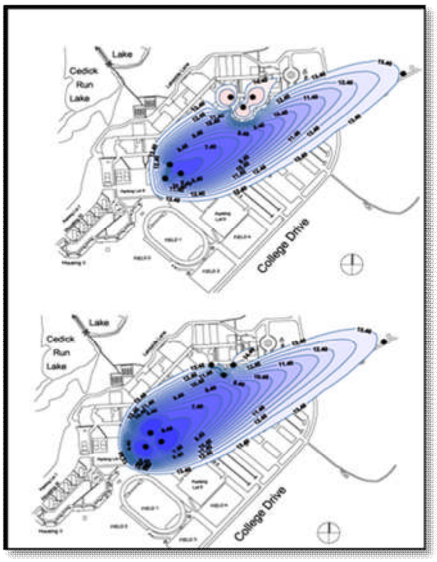

Figure 5. Thermal influence after twenty years Top: at end of summer. Bottom at end of winter. (scale much smaller than Fig.4)

Both Figure 4 and Figure 5 illustrate that the warm wells are thermally influenced by the upstream cold wells. It is also illustrated that the temperature from the most west cold well, C1, is increasing significantly during the summer period. This implies that the thermal efficiency of store might be improved by extracting more water from the other cold well(s) during the summer. The flow rate is controlled by means of frequency converters. Table 6 summarizes the dimensions of the major components.

Table 6. Major components

Component	**Parameter**	**Dimensions**
Submersible pumps	flow rate	200 - 400 GPM (45.4 - 90.8 m^3/h)
	lift	120ft (39.4m)
Well housing	internal dimensions	5x5x5ft (1.5x1.5x1.5m)
Transport piping	material	high density polyethylene
Heat exchangers	logarithmic temp. diff.	2 ºF (1,1ºC)

3. Cost Effectiveness

Fuel Costs:
A combination of the building simulation program, micro-AXCESS Energy analysis Program, Version 10.01, and actual measured demand of the existing buildings provides the basic information for determining electrical use demand. At today's electrical costs the estimated savings for the ATES system is approximately $90,000/annum.

Maintenance:
The only major maintenance item that is different between the traditional and the ATES systems is that there is an avoided 250 T (900 kWt) chiller and cooling tower for the ATES system and subsequent reduced maintenance. This is estimated at $4000/annum. There is also a possibility that there will be deferred maintenance required on the existing chillers and cooling towers since they will not be used as heavily.

In addition, normal maintenance of the wells occurs during seasonal back flushing during the change-over period between charging and discharging of "cold". There is a very small possibility that the wells will need additional maintenance (past experience is 1 in 200 systems). In this case an acid treatment for a larger than normal iron deposition would be required with an additional maintenance cost of approximately $5000/annum. We believe that this is a highly unlikely scenario.

Table 7. Electrical Demand

Standard Chiller		**ATES System**		**Electrical Savings**	
kWh	kW peak	kWh	kW peak	kWh	kW peak
770,862	594	344,288	202	426,574	445

Replacement:
The existing cooling towers and chillers will have a much lower use. However, they are currently fairly new (approximately 6 years old) and this savings will only be realized in fifteen years or more. This is also treated as a benefit not quantifiable. If this project were entirely for new buildings, then the avoided cost of chillers and cooling towers would be immediately realized.

Installation Analysis:

There is a large difference in actual cost with the original estimate due to several factors. In addition, potential energy savings have also escalated – but at a smaller rate compared with the project cost. While the payback period is much larger than originally estimated, the internal rate of return on the investment is still larger than the cost of the bond, which funded this project. And the expectation that energy costs will continue to rise in the future still makes this a good investment. The result is summarized in Table 8.

It is clear that the three biggest items causing the substantial change in cost is due to the cost of drilling the wells, the cost of the well houses and the cost of the well heads adding to approximately $1 million variance from the estimated cost.

The drilling costs were originally estimated based on the Dutch experience. We believed that their experience would be applicable since their labor costs are similar to our's in New Jersey. Two factors in this difference are that we were subject to prevailing labor rates (by State mandate) and the drillers were not experienced in the process. And the cost of stainless steel increased substantially from 2004 to 2007. In addition, the cost of fabrication was found to be exceptionally high in the US, again due to lack of experience with these designs. We were concerned that the lack of experience in fabrication might also result in a less than satisfactory outcome. Stockton decided to order the well heads and associated equipment from a Netherlands firm experienced in these well head and associated hardware fabrications. This resulted in added cost of shipping via container. The additional cost of well houses was due to a decision to build two substantial structures – one for the cold well cluster and one for the warm well cluster. The decision was based entirely on aesthetics since we wanted to showcase the ATES project. Normally these well heads would be in a subterranean vault.

Table 8: Comparison of initial estimate with actual costs of ATES project

Components	Investment		
	Original	**Actual**	**Deviation**
Six 28" wells	$360,000	$1,013,800	$653,800
Six well houses	$40,000	$268,983	$228,983
Well heads, and components	$105,000	$315,184	$210,184
ATES well piping	$24,000	$92,700	$68,700
Electric service well control cables	$55,000	$194,000	$139,000
Controls and frequency controllers	$80,000	$120,000	$40,000
Bond/insurance		$36,000	$36,000
Mobilization/Demobilization		$14,500	$14,500
Prints etc		$8,400	$8,400
Signage		$13,000	$13,000
well inspections/commissioning		$41,000	$41,000
Subtotal	**$664,000**	**$2,117,567**	**$1,453,567**
Contingency 10%	$66,000	$179,620	$113,620
Misc. Fees , Code Review etc	$15,000	$23,000	$8,000
Engineering and supervision 15%	$112,000	$252,000	$140,000
Subtotal additional	**$193,000**	**$454,620**	**$261,620**
Total	**$857,000**	**$2,572,187**	**$1,715,187**
Credit avoided cost	-$300,000	-$1,020,000	-$720,000
NJ Clean Energy Rebate	-$200,000	-$92,865	$107,135
Additional investment	**$357,000**	**$1,459,322**	**$1,102,322**

Other cost increases were in electrical cabling due to working with an already existing site. Increases of 50% in controls were due to inflation and overhead. Several items in Table 8 are self explanatory and were not included in the original cost estimate. Change orders can be separated into several groups. There was a decision to relocate one of the warm wells to accommodate the footprint of a new building. The well drillers found they could not complete the development of wells in budgeted time. Additional metering was added for research purposes. There was a problem with injection valves and the piping of several wells had to be pulled with a crane. A parking lot needed to be reconfigured during construction. An effluent filter was required by the regulatory body (Pinelands Commission) to ensure drilling spoils did not contaminate surrounding wetlands.

On the positive side of the ledger, the College will be able to utilize the 850 ton capacity of the system and will, over the short term, realize a savings in reduced need for 850 tons of chillers. This credit offsets a substantial cost of the project.

As an example of an expected rate of return on a $1.5 million investment, if fuel inflates at 5%/annum and our first year savings is $90,000, the internal rate of return over 20 years is 7%. Since the bonds utilized to pay for this project are at about 4%, The College will receive a net positive cash flow. Alternatively, the value of cash flow discounted at 4% after 20 years has a present value of approximately $2 million.

The additional value of ownership is intangible – but clearly of value as the College continues to develop its commitment to reduction of greenhouse gas emissions and its environmental image.

4. Conclusion

The Stockton ATES system is currently operating storing cold which will be utilized this Summer. Early data suggests that it is operating within the design criteria. The cost of installation was considerably higher than originally expected based on the Dutch experience. The almost threefold cost was largely due to the cost of well drilling and installation. It is expected that future installations in the US will be more cost effective utilizing the experience on this project. Some for the cost increase was due to including well houses that were designed to be above ground and aesthetically pleasing. The College will financially benefit sufficiently, resulting in a positive cash flow after paying interest on the bonds used to finance this project and including the avoided cost of additional traditional chillers. It will further reduce the College's carbon footprint, assisting in meeting the goal of becoming carbon neutral.