LONG-TERM COLD AND HEAT STORAGE AND SHORT-TERM COLD STORAGE IN AN AQUIFER FOR AIR CONDITIONING IN AN HOSPITAL

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ABSTRACT

The Bleuland Hospital is a medium-sized hospital with 450 beds.
In the near future the cooling capacity has to be extended due to several extensions of the building complex and the addition of cooling sections to already existing ventilation systems. The total cooling capacity will increase by 500 kW until 1100 kW in total.

In this project the extension of the existing cooling capacity will be realised with long-term cold storage in an aquifer instead of a conventional chiller. Compared with a chiller the use of aquifer thermal energy storage (ATES) reduces the electricity consumption by 50 %.
Moreover the heat, that is extracted from the ventilation supply air in summer, is stored in the aquifer to be utilized in winter for (pre)heating the ventilation air.
The integration of ATES in the present installation with 2 chillers enables also short term cold storage in summer. Thus the risk of cold shortage due to climatic influences (warm summer and/or mild winter) will be compensated without costly investments in extra chiller capacity.
The combined use of the aquifer system for both seasonal cold and heat storage, as well as short term cold storage makes the system more profitable. Consequently ATES can also be attractive for smaller projects with existing cooling systems that have to be extended. This will enlarge the market potential for ATES.

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1. INTRODUCTION

The Bleuland Hospital is a medium-sized hospital with 450 beds in the west of The Netherlands. In the present situation 2 chillers with a total cooling capacity of 600 kW, can just meet the maximum cooling load in summer.
In the near future the cooling capacity has to be extended drastically due to several extensions of the building complex and the addition of cooling sections to already existing ventilation systems.
The total cooling capacity will increase by 500 kW until 1100 kW in total.

Seasonal cold storage in subsurface sandlayers (aquifers) is an attractive alternative to an extra new chiller because the consumption of electrical energy is reduced to the small amount required for mainly the well pumps.

Figure 1 shows the principle of ATES

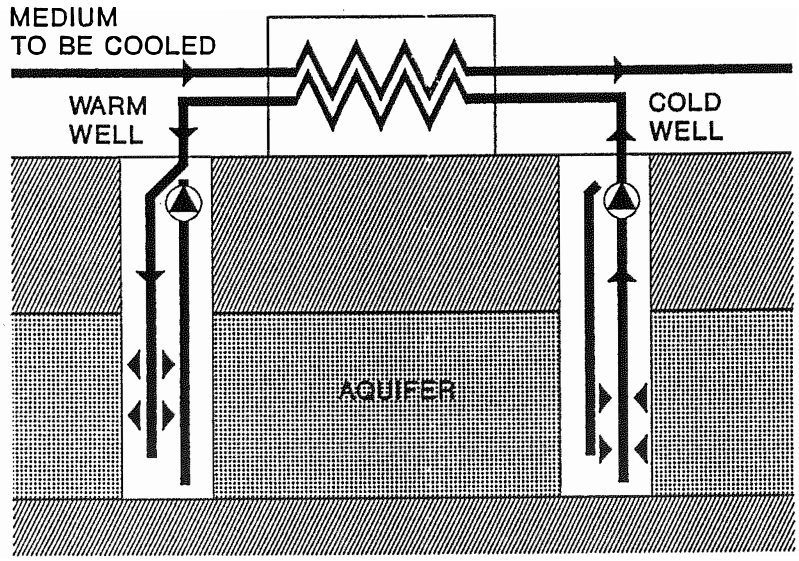

Figure 1 Working principle of an aquifer thermal energy storage system.

In summer the groundwater is pumped up from the cold well and supplies cold energy via the heat exchanger to the building. The warmed up groundwater is injected into the warm well. In winter mode the warm well water is cooled down to the required storage temperature and injected into the cold well.

A pre-feasibility study showed the profitability of aquifer cold storage and indicated that the utilization of the stored "summer-heat" for heating the ventilation air in winter could be favourable. As the present cooling system already contains 2 chillers, short term cold storage in the aquifer seemed to be a cost effective way to reduce the sensitivity to climatic influences (especially too mild winters!).

Afterwards a site characterization was carried out, which showed the presence of a suitable aquifer at a depth of 75 - 90 m below groundlevel and a groundwater temperature at this depth of nearly 12 °C.
Based on this information the system, including the above mentioned extra system options, was optimized and a cost-benefit analysis was performed.

It is expected that the realization of the system will start this summer and that the system will be operational before the end of 1991.

2. SYSTEM DESCRIPTION

2.1 General

Figure 2 shows schematically the cooling system with the integrated aquifer system.

Under design conditions the temperature range in the cold water circuit I is 6 - 11 °C. The required exit temperature of the air is 14 °C.
This circuit is cooled by the chillers 1 and 2. Via circuit I several already existing air conditioning units are feeded with cold water for cooling ventilation supply air. These air conditioning units will not be replaced within a short time. The adaptation to make them suitable for cooling with the aquifer system is too expensive. The maximum cooling load in this circuit is 300 kW.

Under design conditions the temperature range in the cold water circuit II is 10 - 20 °C. The required exit temperature of the air is 14 °C. This circuit is cooled by the cold storage. The cold energy passes through the plate heat exchanger TSA1, which separates the circuit water and the briny aquifer water. In case of high cooling loads after-cooling with the chillers is possible.
Circuit II feeds all the air conditioning units, that will be newly installed or replace old units, and also the existing ventilation/heating units that will be extended with a cooling section. None of the nine air conditioning unbits contains a recirculation section. Two of the existing ventilation systems contain a twin coil heat-recovery unit (efficiency ca. 50%).
The heat exchangers in these air conditioning units have much larger surfaces than usual because of the higher cold water temperature. To avoid high pressure losses the air velocity in the air conditioning units has to be chosen somewhat lower (2,2 m/s instead of 2,8 m/s) than usual. The maximum cooling load in this circuit is 800 kW.

In this case the ATES system consists of one cold and one warm well. The wells are located close to the hospital. The distance between both wells is approximately 150 m.

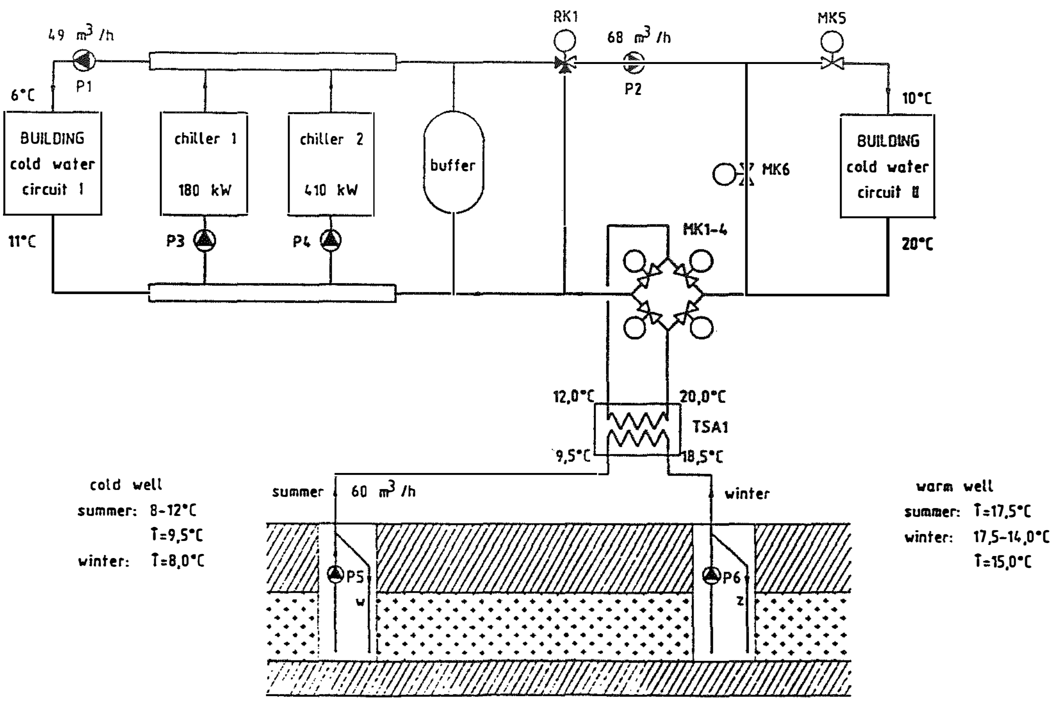

Figure 2 The ATES system integrated in the cooling system of the Bleuland Hospital.

2.2 Summer mode

The return water in circuit II is cooled with groundwater that is pumped up from the cold well. With the 4 two-way valves MK1-4 the flow direction through heat exchanger TSA1 is adapted to keep counterflow in both the summer and winter mode. The three way valve RK1 controls the supply temperature at 10 °C and admixes water of 6 °C from the chillers if the storage can't deliver the whole cooling capacity.
The average number of cooling hours is 2000 per summer season.

The cooling capacity in the air handling units is regulated by adjusting the water flow through the cooling coils. This control strategy gives the highest possible temperature range of the cooling water, which leads to an efficient use of the cold storage.

The maximum well flow for one couple of wells is 60 m^3/h for this specific aquifer. A bigger flow is not attractive because of the high costs of investment for 2 extra wells. The well flow can be controlled in 3 steps with intermediate throttle control.

The storage temperature of the cold well is 8 °C. The so called cut-off temperature is 12 °C. During the summer season the extraction temperature from the cold well will range from 8 - 12 °C. The average temperature is 9,5 °C. The cut-off temperature coincides with the natural aquifer water temperature. This means that water with this temperature level remains always available.
At a cold well temperature of 9,5 °C and a well flow of 60 m^3/h the cooling capacity of the storage is 640 kW, corresponding to 80 % of the maximum cooling load in circuit II.
When the cut-off temperature of 12 °C has been reached at the end of the summer, the maximum cooling capacity of the cold storage is 480 kW corresponding to 60 % of the maximum capacity. This cooling load occurs at outdoor temperatures of ca. 24 °C (dry bulb). At the end of the summer season this temperature will generally be reached for only a few hours.

The injection temperature of the warm well ranges from 15,0 - 19,5 °C. The average injection temperature is 17,5 °C.

2.3 Short term cold storage in the aquifer

During extremely warm periods or at the end of the summer season, when the cold well temperature is relatively high, a cold buffer can be formed in the aquifer at night to be used next day. The cold is generated by the chillers that run at low cost during the night. The cold water circuit II is short-cutted by closing moter valve MK5 and opening motor valve MK6. Pump P2 pumps the maximum water flow through the chillers through the valve MK6 and the heat exchanger TSA1. The three way valve RK1 controls the mixing temperature at 6 °C.
The warm well water is pumped through heat exchanger TSA1, cooled down to 8 °C and injected into the cold well. The stored cold will be used next day.
The storage efficiency for the day/night cycle is expected to be approximately 85%. The low electricity tariff applies to 8 hours per night. This is long enough to store the cold required for one warm day.

2.4 Contribution of the storage to the supply of cold

The required cold energy for cooling is 480.000 kWh_{th}/year.
The contributions of the chillers and the aquifer storage are:

Chillers	170.000 kWh_{th}	(35%)
Aquifer storage	310.000 kWh_{th}	(65%)
Total	480.000 kWh_{th}	

2.5 Data review for the summer mode of the ATES system

Table 1 gives a review of the ATES system data for the summer mode.

TABLE 1	**SUMMER MODE / UNLOADING THE COLD STORAGE**	
Minimum production temperature	[°C]	8.0
Cut-off temperature	[°C]	12.0
Minimum injection temperature	[°C]	15.0
Maximum injection temperature	[°C]	19.5
Average injection temperature	[°C]	17.5
Cold supply by storage	[MWh]	310
Volume of aquifer water from cold well	[m3]	33000
Minimum well flow rate	[m3/h]	20
Maximum well flow rate	[m3/h]	60
Number of working hours for cooling	[h]	2000
Flow control in steps of	[m3/h]	20
Nr. of equivalent full-load hours cold storage	[h]	550

2.6 Winter mode

In winter mode the groundwater is pumped up in the warm well and passes the plate heat exchanger TSA1 to be cooled down to 8 °C. The cooled water is then injected into the cold well. The maximum well flow is 60 m^3/h. Flow control is identical to the summermode.

The cold for cooling the warm well water is extracted from the ventilation system supply air. In winter mode the "cooling coils" in the air handling units thus operate as conventional heating coils. The ventilation supply air is heated up to 10 to 14 °C, depending on the outdoor temperature, the air flow and the actual warm well temperature.

The water flow through the coils will be regulated in order to get an exit temperature of 6 °C. At extremely low outdoor temperatures (< -10 °C), when the exit water temperature from the coil tends to become lower than 3 °C, the fan of the air handling unit will be switched to half speed to avoid freezing of the coils.

The utilization of the stored heat for the heating of ventilation air saves energy for heating. From this point of view it is attractive to load as much cold energy as possible. Moreover this will create extra cold reserves, which reduces the risk of cold shortage in summer.
In practice the loading of cold is restricted by thermal short-cutting between the cold and the warm well.

During the first winter the warm well temperature is still 12 °C (natural soil temperature). Based on the average year there are ca. 3000 hours available to store cold, assuming a maximum injection temperature of 8.0 °C. It is calculated that 675 MWh cold energy can be loaded, corresponding to 134.000 m^3 water with an average temperature of 7.7 °C. Although this amount of cold water is four times as much as needed for cooling in summer, the extra loading capacity is attractive for the following reasons.
Firstly the thermal losses are relatively high during the first years and have to be compensated by extra storage of cold. Secondly a quick building-up of a cold buffer in the aquifer reduces the risk of cold shortage in summer.

The storage system is considered to be in thermal balance after 3 years. The average injection temperature in the warm well is then 17.5 °C. It is assumed that the warm well temperature decreases during the winter until 14 °C. The average production temperature in winter will approximately be 15 °C. In this case the achievable amount of stored cold energy is 870.000 kWh in an average winter. However to keep the storage thermally in balance 425 MWh (47.000 m^3 water with an average temperature of 7.2 °C) is sufficient.

The average cold storage during the first 4 years is assumed to be 550 MWh/year.

The data of the cooling system with ATES are summarized for the winter mode in table 2.

TABLE 2 WINTER MODE / LOADING THE COLD STORAGE			
		1st winter	balance
Average production temperature	[°C]	12.0	15.0
Average injection temperature	[°C]	7.7	7.2
Minimum well flow rate	[m3/h]	20	20
Maximum well flow rate	[m3/h]	60	60
Maximum cooling water flow rate	[m3/h]	68	68
Required cold energy in summer	[MWh]	310	310
Stored energy in winter	[MWh]	674	425
Storage reserve	[%]	118	37
Volume of aquifer water from warm well	[m3]	1.34e5	4.7e4
Number of working hours	[h]	3000	1200
Nr. of equival. full-load hours storage	[h]	2200	780

3. COST-BENEFIT ANALYSIS

3.1 Energy consumption

The consumption of electrical energy for cooling is:

Chillers	67.500	kWh_{el}/year
Transport pumps	17.700	kWh_{el}/year
Well pumps	16.900	kWh_{el}/year
Total	102.100	kWh_{el}/year

The cold to be stored in winter is 425 MWh_{th} when the storage system is in thermal balance. During the first 4 years 550 MWh_{th}/year cold will be stored to build up reserves. The consumption of electrical energy for loading is then:

Transport pumps	7.700	kWh_{el}/year
Well pumps	16.000	kWh_{el}/year
Total	23.700	kWh_{el}/year

The total electricity consumption in summer and winter is 125.800 kWh_{el}/year.

3.2 Saving of energy

The electricity consumption of a cooling installation with only chillers (reference installation) is 223.400 kWh_{el}/year.

The saving of electrical energy is: 223.400 - 125.800 = 97.600 kWh_{el}/year.
Assuming a conversion efficiency of 35% the saving of natural gas is 29.000 m^3/year.

The cold to be stored in winter is extracted from the ventilation air cq. heat is supplied to the air. Assuming a heating system efficiency of 70%, the saving of energy for heating is:

550.000 / 0,7 = 785.000 kWh_{th}/year
= 81.000 m^3 natural gas per year.

The lower contribution of two heat recovery units is not taken into account in this calculation.

The total saving of energy amounts to 110.000 m^3 natural gas per year.

3.3 Economic feasibility

The economic feasibility of the aquifer storage system is evaluated by comparing the system with a conventional cooling system with chillers only (the reference system). The data are showed in table 3.

TABLE 3 COSTS AND BENEFITS OF THE ATES SYSTEM

Total investments cold storage system	[Dfl]	912.000
Total investments reference system	[Dfl]	678.000
Extra investment cold storage system	[Dfl]	234.000
Total running costs cold storage system	[Dfl/a]	45.000
Total running costs reference system	[Dfl/a]	71.000
Saving of running costs cooling installation	[Dfl/a]	26.000
Saving of costs for ventilation air heating	[Dfl/a]	28.000
Saving of costs with cold storage system	[Dfl/a]	54.000
Pay-back-period cold storage system	[year]	4,3

The system with aquifer energy storage requires 35% higher investment costs than the reference system. These costs will be paid back within ca. 4,5 years, because of the savings of running costs. In The Netherlands a pay-back-period of 4 à 5 years is acceptible in the building sector.

4. CONCLUSIONS

An existing cooling system with chillers, that has to be extended, offers favourable possibilities for the integration of an aquifer thermal energy storage system.

The risc of cold shortage in summer due to climatic influences can be avoided by coupling the storage system with the existing chillers.
If the chillers have enough cooling capacity they can be used for additional cooling of the cold water circuit under extreme conditions.
Moreover the chillers can be used for short term cold storage in the aquifer during the night. The cold is to be used during the next day. The addition of this extra, relatively cheap feature guarantees the availability of cold, indepent of the climatic circumstances.

If an all-air system is installed in the building the air-water heat exchangers in the air conditioning units can be used for both cooling in summer and pre-heating in winter. The ventilation supply air is pre-heated in winter with the warm well water, thus loading the cold storage in the aquifer. In this way a considerable amount of natural gas can be saved.

The utilization of both the stored cold and heat makes the aquifer system more profitable and makes an aquifer system economic feasible for smaller projects. This will improve the market penetration of aquifer energy storage systems.