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District Aquifer Thermal Energy Storage (DATES)

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Abstract

Use of ATES/HP (Aquifer Thermal Energy Storage combined with Heat Pumps) is since the early '90s a popular way of heating and cooling larger (office) buildings in the Netherlands. The moderate climate and capable aquifers make a good combination for this technique. The downside of using this technique for just a single building is mostly a mismatch between the potential capacity of the aquifer and the power demand of the building. In stead of equipping groups of buildings with separate ATES/HP systems, it can be profitable to combine several systems in a District ATES (DATES) system. This article will show you the principle of DATES with real life examples. In these cases DATES has some advantages compared to ATES/HP or district heating solutions with central heat/cold production. Compared to ATES/HP it's possible to drill fewer wells depending on the aquifer capacity. DATES can be more flexible and have reduced network cost compared to central heating/cooling systems. The network allows energy exchange between buildings, which reduces the need for, or capacity of, regeneration installations and mobilises residual capacity from single buildings.

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Keywords: Aquifer thermal energy storage; District heating and cooling; District aquifer thermal energy storage.

1. Introduction

Since its introduction in the early 90's, the Aquifer Thermal Energy Storage (ATES) combined with a heat pump has become one of the standards for cooling and heating in buildings across the Netherlands. For the most large office buildings, schools, hospitals, green houses and even campuses. Most systems are made for individual buildings, but an increasing number of buildings are connected to a District ATES system (DATES). In this article we introduce you to DATES. We will compare DATES to ATES and district heating solutions. What are the design issues, as well as the advantages and lessons learned so far? Firstly we'll start with some basics around ATES.

1.1 ATES/HP building concept

In the Netherlands groundwater temperature is typically around 12°C, therefore in most cases directly usable for cooling and combined with a heat pump usable for heating. A standard ATES/HP configuration consists of two wells (a warm well and a cold well), a heat pump and a dry cooler. In summer the cold well is used to extract the cold groundwater to cool the building. The heat is stored in the warm well (approximately 12 – 18 °C). In winter the warm well is used to provide 'heat' for the heat pump. After passing the evaporator of the heat pump, the cooled groundwater (approx. 12 – 6°C) is stored in the cold well. To make this process work efficiently the building needs to be provided with a low temperature heating circuit (supply temperature of about 50 °C, return about 40 °C), and a high temperature cooling circuit (supply temperature of about 10 °C, return about 18 °C).

This is necessary to comply with the technical abilities of heat pumps and ATES cooling (See fig 1). Apart from the heat pump, a dry cooler and a (gas fired) boiler can be installed to provide extra power on very hot or cold days. The dry cooler is also able to provide cold under certain outdoor conditions.

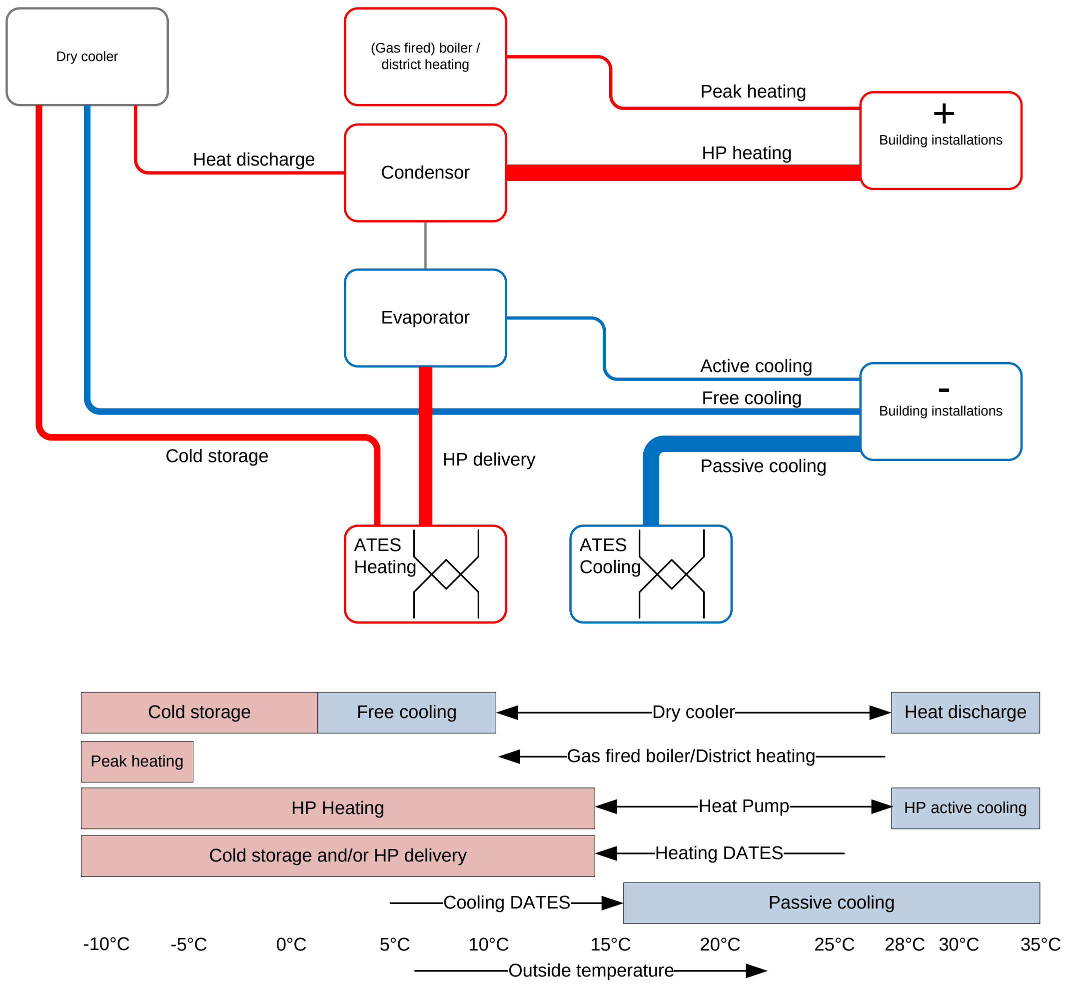

Fig. 1. Standard ATES/HP configuration and indication of operational mode depending on outside temperature

Under the main components in fig 1 the main functions are displayed as a function of the outdoor temperature. Explanation: The dry cooler is able to store cold in the ATES from about 3°C and lower, from 3°C to 10°C it can supply cold to the building directly and when the heat pump is used as a chiller, it can dissipate the heat from the condenser. The heat pump will provide heat from about 14°C and lower and provide cold (like a chiller) from 28°C or higher. The ATES system will provide 'heat' to the evaporator, when the heat pump is working, from about 14°C and lower. The ATES system will provide cold (so called 'passive cooling') from about 16°C and higher.

1.2 *Legislation and standardisation of ATES/HP in the Netherlands*

Since the introduction of ATES, legislation has always played a role to protect groundwater interests and to allocate the use of this natural (energy) resource in an orderly way. Along with the increasing popularity of ATES/HP systems in the Netherlands, the need for mandatory standardisation became the next issue to maintain quality standards.

Knowledge institute ISSO, together with their partners in the market, play a key role in the development of standards for ATES/HP systems. ISSO stands for 'Instituut voor Studie en Stimulering van Onderzoek voor gebouwinstallaties (shortly, Institute for Building Installations)'. ISSO organizes courses and publishes several standards in the form of "Publications". "Publication 39" (Power plants with ATES [1]) is the most important one. Since July 2013 legislation has become active [2] in the Netherlands tying designers, contractors and maintenance companies directly to the ISSO "Publication 39" standard to achieve optimal use of the aquifers and good overall system performance. This standard is mainly focused on single user systems (one building with ATES), but all ATES systems including DATES are concerned.

2. Introduction to DATES

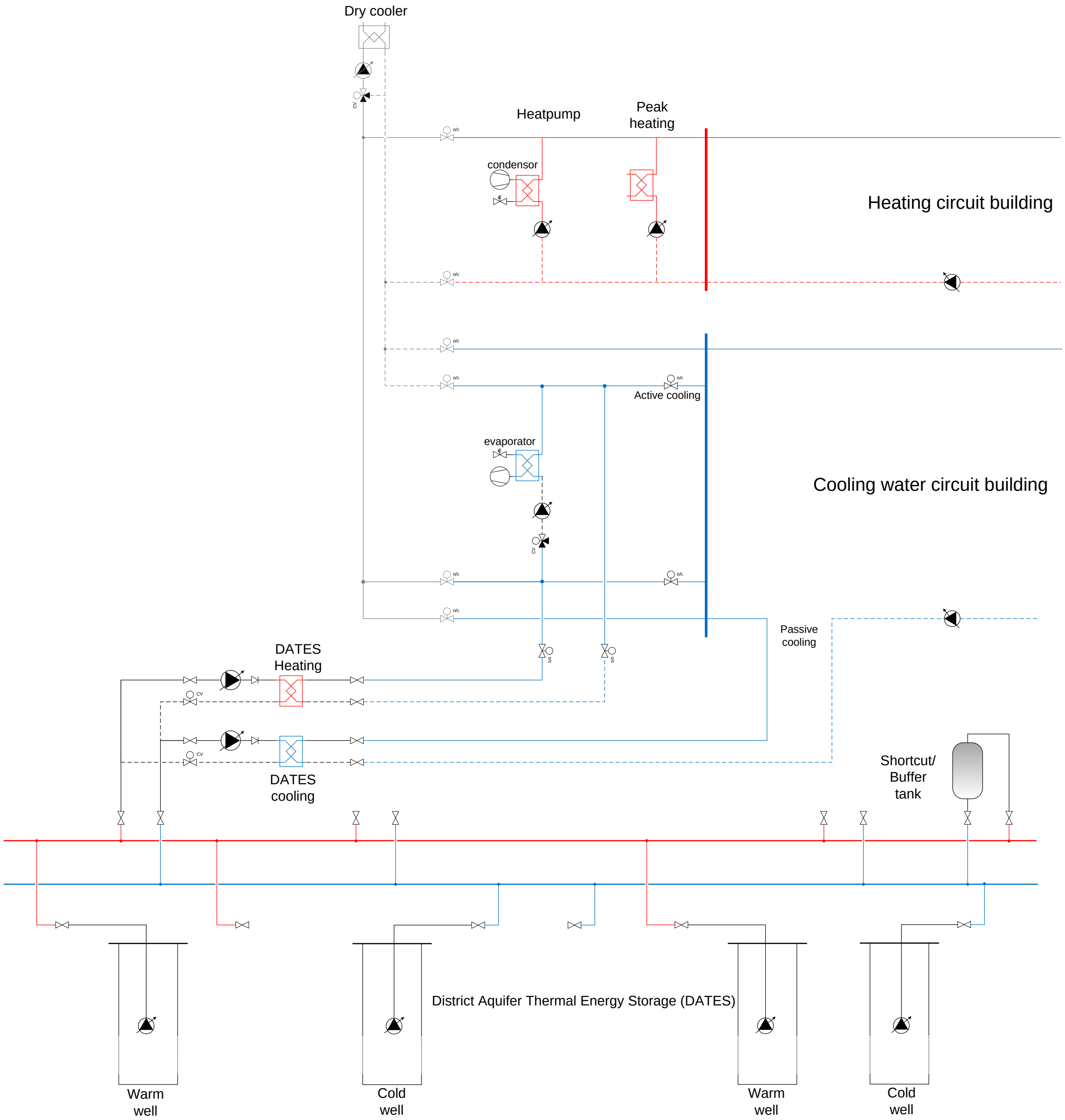

Fig. 2. Schematic of DATES

2.1 Energy concept and hydraulic concept of DATES

DATES connects the wells and the buildings in an area using a groundwater filled distribution network. The network consists of a warm circuit (14-18 °C) and a cold circuit (7-10 °C) in an open (2 pipe) network configuration. New 'prosumers' and wells can be added. Each building is able to pump groundwater from the warm circuit to the cold one and/or in the opposite direction, depending on the energy demand. The two circuits are connected to each other using a central shortcut including a thermal stratified buffer tank. The shortcut is necessary to avoid pumps to be placed in serial. The buffer tank will accumulate cold or heat on the short term enabling energy exchange between buildings and preventing the wells from switching too frequently in low load conditions. The resulting net energy demand will be provided by the wells in the DATES system. The principal diagram is displayed in fig 2 (including the functions of fig 1).

2.2 Opportunities of DATES compared to ATES

Optimal use of the aquifer capacity
ATES makes use of groundwater in aquifers. These aquifers have specific characteristics which enables a specific flow rate per well. This flow rate will never match exactly the building demand. So part of the aquifer capacity (or capacity per well) remains unused. With DATES the remaining capacity can feed the network and provide other buildings with energy. This will result in less wells than the 2:1 ratio (two wells, one building) for individual ATES systems.

Less wells will, although the total flow rate flow rate stays the same, result in lower total costs. To illustrate this an aquifer in Amsterdam is chosen, where one well is able to deliver a maximum flow rate of about 250 m³/h. The cost calculation is based on [8] for all the installation parts, the well drilling and development is based on real offers and shown in Table 1. When building five small systems, 250 m³/h will cost you as much as 250% in stead of 100% for one large system.

Table 1. Investment cost well drilling and well equipment versus capacity

Percentage of investment costs	Percentage of maximum cooling/heating capacity
100%	100%
90%	80%
80%	60%
60%	40%
50%	20%

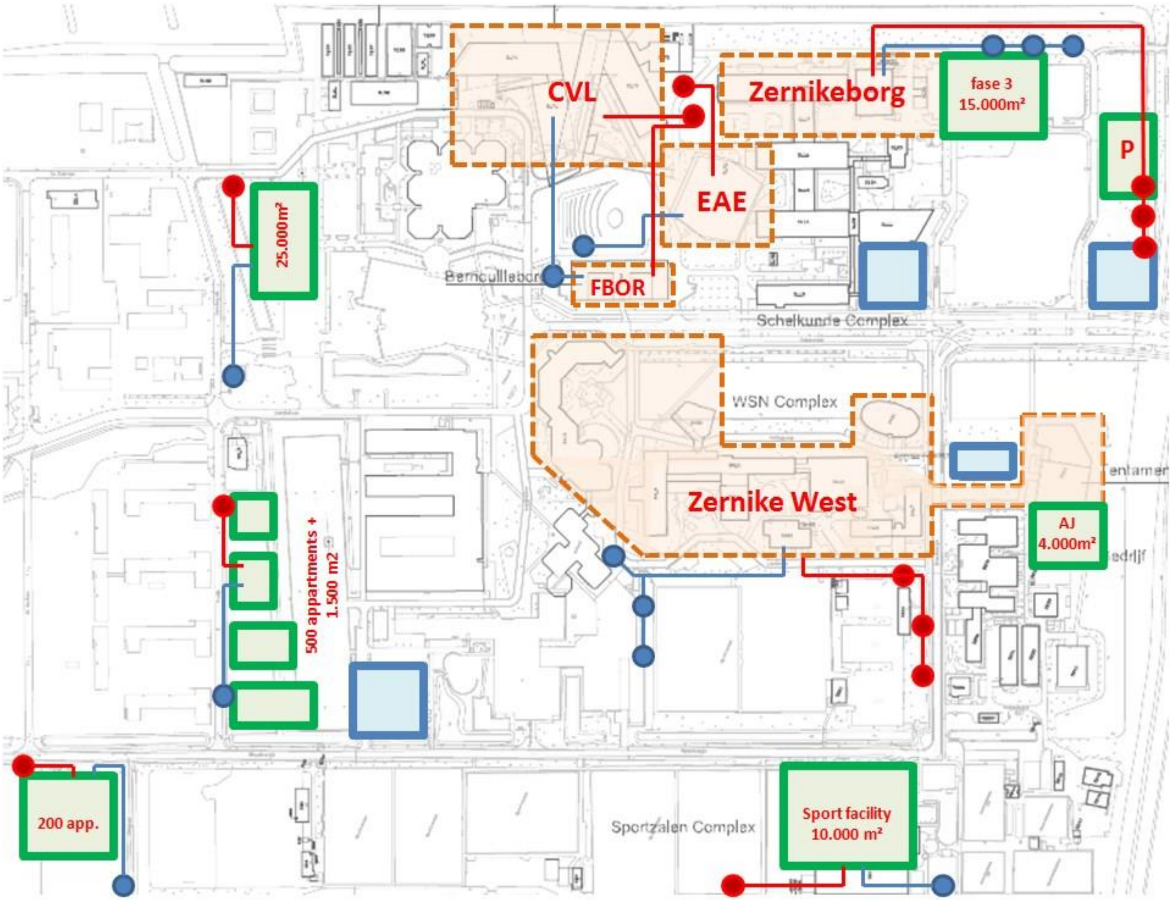

Fig. 3. Individual ATES system per building, Zernike Campus University of Groningen

Example of optimal use of the aquifer: University of Groningen
The Zernike Campus of this University already has a number of individual ATES systems. One for a large data centre and others for research and educational buildings. In the near future new buildings are planned: apartment blocks for students, educational buildings and sport facilities. The aquifer in Groningen enables high capacity wells (250 m³/h). At this moment a large energy imbalance exist in the ATES system caused by the data centre (subsurface heat surplus), which will be discussed in the *Energy exchange between buildings and flexible use of ATES power* section.

For the future plans a comparison is made between individual ATES systems (fig. 3) and a DATES system (fig. 4). For the ATES system a total number of 24 wells would be required while in the DATES version 10 wells would be sufficient. In the DATES version distribution pipework is needed (3,100 m) while in the ATES version more investments have to be done in regeneration installations. In this case the DATES solution turned out to have 19% lower investment costs [8]. (energy regeneration will be discussed in the *Energy exchange: Minimising regeneration units* section).

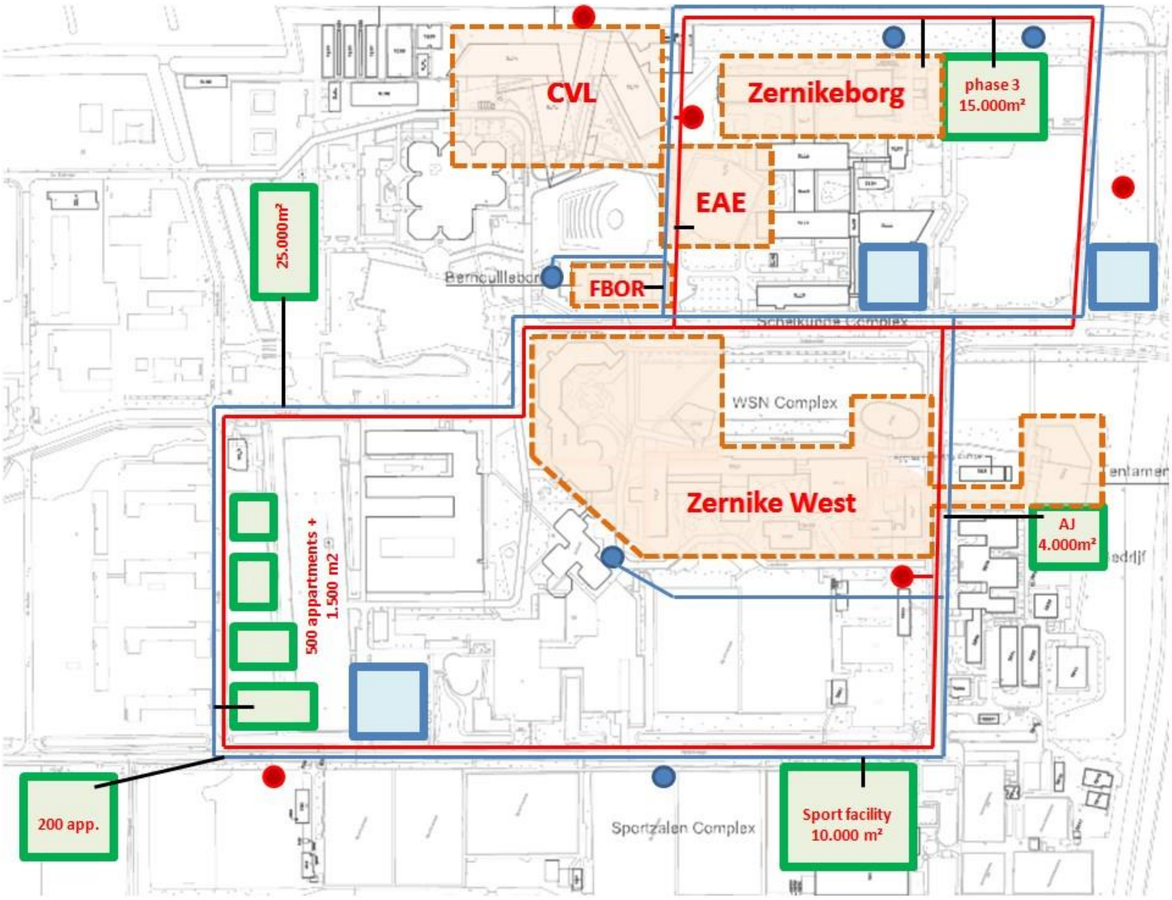

Fig. 4. DATES system, Zernike Campus University of Groningen

Lowering hydrological impact

Hydraulic influence between wells will have a negative impact on the well capacity especially when the aquifer is mediocre. With DATES, the wells can be 'freely' positioned, as long as they're near the network, in such a way that negative hydraulic influence is avoided. Also the thermal influence (warm/cold) and natural flow in the aquifer have to be taken into account (for optimal well positioning see also [4] Optimization of well field configurations). Placing the wells along the loop in stead of clustering is reducing the hydrological impact in the subsurface [4][5]. In figure 5 the calculated drawdown in the wells is calculated for three different situations [5]. Where option B, which is comparable with fig 4 (Zernike Campus), has the smallest hydraulic impact.

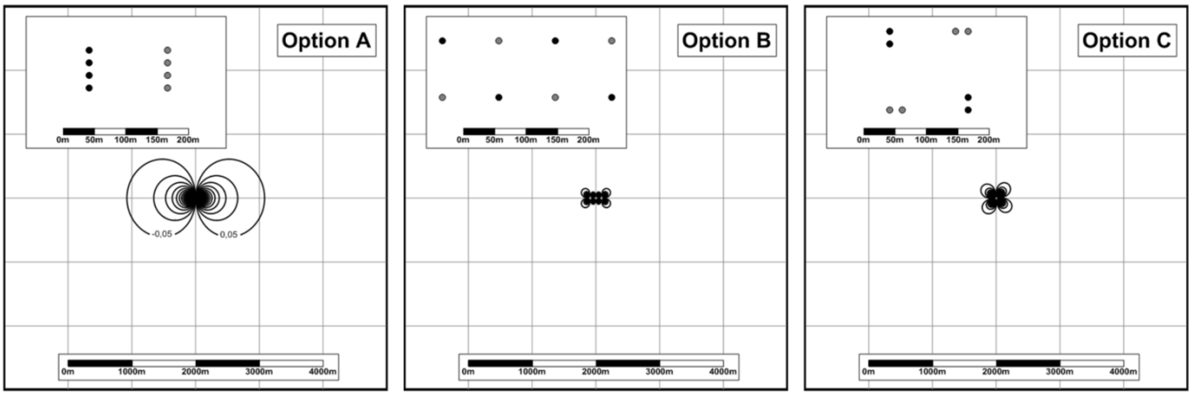

Fig. 5. Calculated drawdown in the aquifer in three situations with different well field layout and equal numbers of wells and total flow rate[5]

Increased system reliability
ATES systems are designed with an acceptable fouling rate in mind. To maintain the well capacity flushing equipment is used. Although serious fouling should always be considered a serious problem, in a DATES network the need for maintenance is less urgent. A few well related issues won't cut the energy supply as a whole.

2.3 Opportunities of the DATES network

Minimizing piping costs through smart placement of wells
As we've seen in the Zernike case, by using district heating and cooling extra piping is needed compared to ATES. But it's not the same as normal district heating, where a big central heating plant has to supply every user. Wells can be positioned 'strategically' by putting wells near a big user or a cluster of big users. Smaller diameter piping is sufficient, because the energy needed is 'around the corner'.

To illustrate what the consequences are for the pipework in the field, a hydraulic simulation is done for a fictional campus area (fig. 6 and 7). On the campus twelve buildings are situated 50 meters apart from each other, each requiring a flow rate of 40 m³/h. Two situations are simulated: situation 1 with wells positioned alongside the campus loop and situation 2 with the wells 'strategically' within the loop. The maximum allowed flow velocity in the pipes is 2 m/s in both the situations. The flow rates in both the situations are calculated [3] and displayed in fig 6 and fig 7 respectively. The thickness of the piping represents the required internal diameter (chosen material: HDPE PN10).

The flow rates in fig. 7 are much lower than in fig. 6, and as a result, the needed pipe work diameters are smaller. Large diameter pipes are quite expensive compared to 'normal' diameters. To get an idea of the consequences for the network costs, in table 2 the standard price of straight pipe work is given. Although the same length is needed in both situations, the smaller diameter pipe in situation 2 results in about 35% of the total cost compared to situation 1.

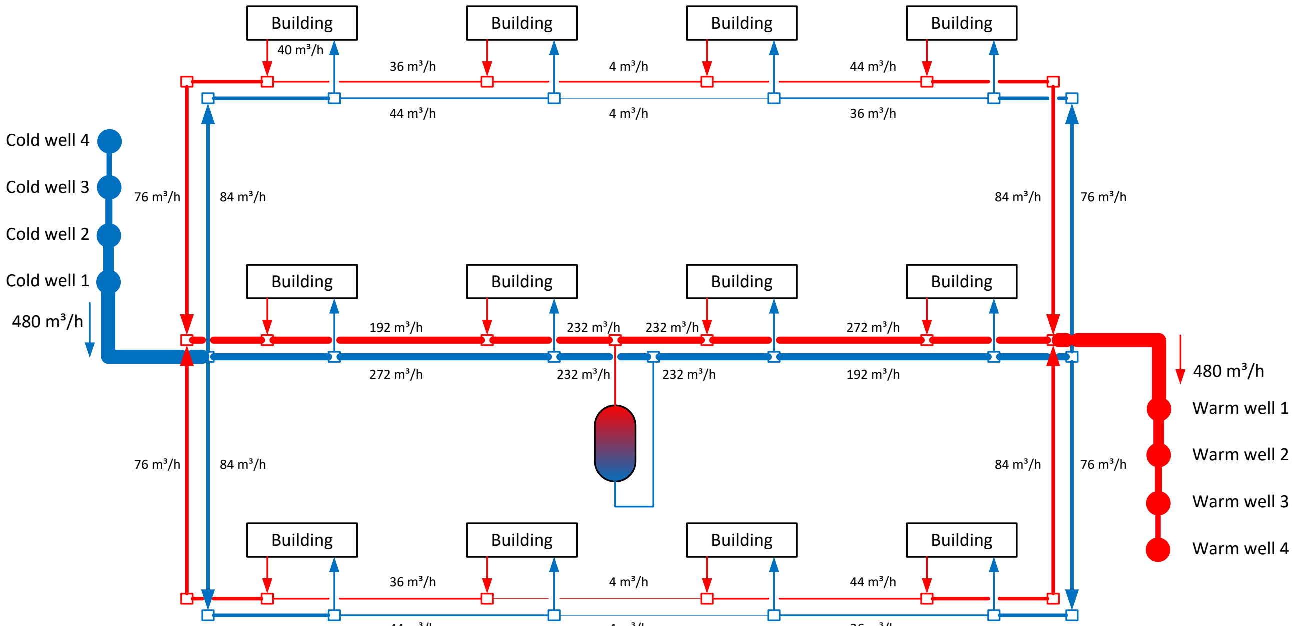

Fig. 6. Situation 1: DATES well locations alongside the loop

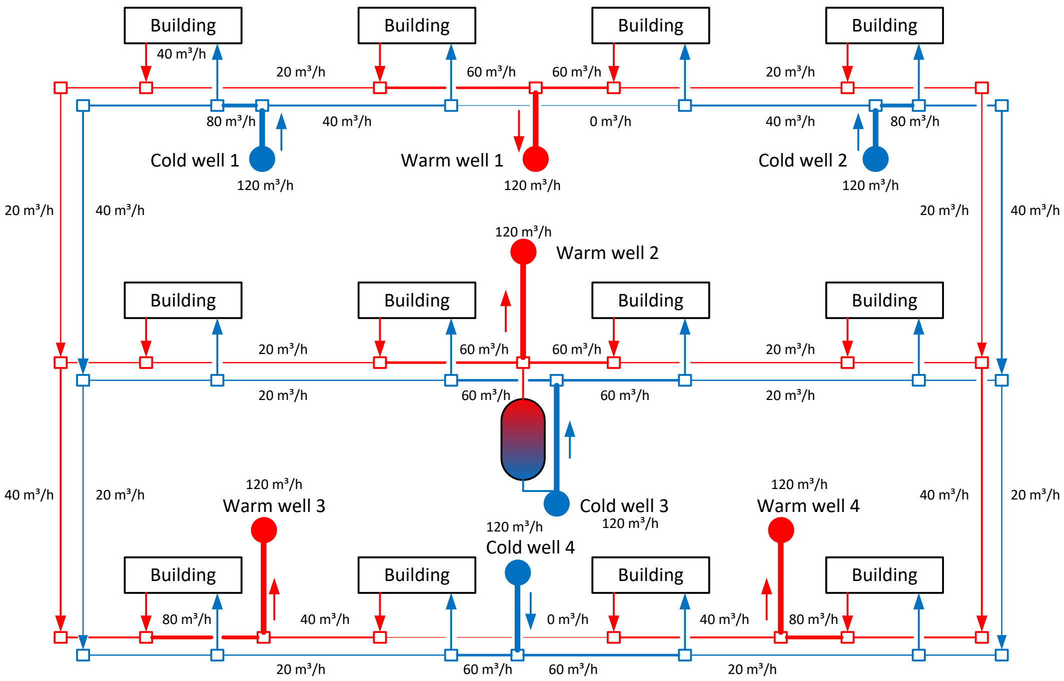

Fig. 7. Situation 2: DATES well locations within the loop

Table 2. Investment cost[7] pipe work (digging, bows, elbows and labor excluded)

Diameter pipe work [mm]	Cost [€/m] [7]	Length situation 1 [m]	Length situation 2 [m]	Cost situation 1 [€]	Cost situation 2 [€]
50	9.16	200	100	1,832	916
75	19.18	0	600	0	11,508
110	26.00	400	400	10,440	10,440
125	33.14	0	300	0	9,942
160	54.26	400	10	21,704	543
200	84.62	40	20	3,385	1,692
250	149.22	340	0	50,735	0
315	226.42	40	0	9,057	0
355	288.99	10	0	2,890	0
Total		1,430	1,430	€ 100,043	€ 35,041

The use of smaller piping doesn’t compromise flexibility, every new building will be able to give and take from the district system, including the one or two extra wells needed for the extra energy demand in the future. So there are no upfront costs for large piping and when plans change this doesn’t result in wasting these upfront investments (stranded investments).

An example of a DATES system in operation is the system of the Technical University of Eindhoven. On this campus a 3,000 m³/h well system is connected to a 450 mm HDPE network which is suited for 890 m³/h maximum flow rate. There is no need for larger piping due to the distributed wells and buildings.

Energy exchange between buildings and flexible use of ATES power

When connecting buildings with a piping network, transport and exchange of heat and cold is possible. This can be, even without the use of ATES, very useful to meet different energy demands. For example data centres and houses. In most cases the differences in energy demand are less obvious, such as the amount of people and equipment in a building, the orientation towards sunlight (insolation) and business hours. Also, different techniques of heating and cooling between buildings, like the use of core concrete activation (CCA) compared to air-handling units will cause different energy demands.

The DATES network is able to deal with both situations. First of all, when a building, like a data centre needs cooling only, the heat can be transported to offices or housing. Secondly, the whole network can contribute heat or cold to buildings with short term high energy demands.

Energy exchange: Minimising regeneration units
In the Netherlands, regulations demand an energy balance in the aquifer (or, under certain conditions, a cold surplus). Apart from regulations, particularly in buildings with a great imbalance, thermal breakthrough between warm and cold wells may cause problems [6] when using ATES. To prevent this, dry coolers, cooling towers or other components are needed to balance the aquifer. As mentioned above, the network is able to exchange different energy demands, but nevertheless it is probable that there's some kind of imbalance in the long term. In that case the net difference needs to be compensated in another sustainable way

2.4 Important design issues for DATES
Although DATES isn't a complex concept, it's more than just a network and a few ATES systems. The most important points of attention during DATES design are:

- The energy concept and hydraulic concept of the building installations and the DATES system have to match. The key issue for ATES and even more in case of DATES systems is a good return temperature from the building to the network under all conditions.
- For an ATES system consisting of a single warm and a single cold well water is injected in the wells using pressure sustaining valves. In a DATES system sustaining only the pressure is not sufficient. The injection flow distribution over the wells also has to be controlled to guarantee equal groundwater distribution between the infiltration wells.
- During minimum load conditions the pressure drop in the DATES system becomes very low. For this reason it is difficult for the pump sets in the buildings to reach their desired minimum flow rates. This can be solved by creating some extra pressure drop in the buildings when pumps work at their minimum capacity.
- Stable system control and energy monitoring is a challenge due to the fact that installations are distributed over the area.
- The field pipe work of DATES can be laid in a straight line or in (more than one) circles as long as there is only one shortcut.

2.5 Example of changing ATES to DATES

Utrecht University
Since 2002 an ATES system is in operation on the Uithof Campus of the Utrecht University. This system was designed as a traditional ATES system consisting of 8 wells connected to a central heat exchanger. Above the heat exchanger domestic water was distributed to the buildings. The distribution network was a sort of "tree structure" starting with large pipes and ending with small ones. It functioned quite well but it was difficult to connect new buildings that were planned at the very end of the smallest branch of the distribution tree. One of these buildings was a new data centre. The number of wells had to be increased to 12, which was no problem, but the distribution network wasn't able to distribute the flows to the new buildings.

For that reason the decision was made to turn the system from ATES to DATES, which was realised in 2014. The old wells were adjusted to match with the DATES principal. That meant; the pressure sustaining valves were replaced by another type which not only sustains the pressure but controls the flow as well (see fig 8 right for components in the well housing). New connection points were made to connect the wells to the new DATES grid (see fig 8 left for a close look at a connection point). At these connection points flow, energy and temperature monitoring was accommodated. These measurements were necessary for permit reporting to the government and for system control reasons as well. Also the well flushing equipment is located in the connection point. In the buildings DATES delivery sets were placed with pumps, heat exchangers and control cabinets (fig 8 in the middle).

Although the data centre was the reason to change the system to DATES, plans kept changing. Since then two buildings have been merged with the system: building GML and building OWC and three other buildings will merge in the near future. The data centre will not connect, it's located somewhere else.

Fig. 8. left to right: DATES Connection point, building delivery set, "old" well with new reinjection valve

3. Conclusions

In this introduction to DATES we have shown you some of the characteristics and possible advantages of DATES compared to ATES or central energy supply systems for larger groups of buildings such as universities, hospitals, offices, greenhouses, data centres, etc.

DATES has a number of opportunities compared to ATES:

- a reduced number of wells to be drilled
- wells can be positioned 'freely' in the network minimising hydraulic impact
- increased system reliability considering well fouling and other ATES related issues

The DATES network has a number of opportunities too:

- the network mobiles ATES capacity to serve other meet peak demand for certain buildings
- due to differences in simultaneity the total needed capacity for DATES can be reduced
- due to the network, regeneration installations can be joint
- due to the energy exchange among buildings, only the net difference needs to be delivered/regenerated
- the network and the number of wells can be realised in several phases along with the needed capacity at that moment (minimising upfront investments)

For correct DATES operation there are some points of attention:

- correct network temperature is decisive for good performance, so the energy and hydraulic concept of every building installation has to meet the DATES requirements
- well positions and network lay out have to be chosen carefully because of hydraulic impact in the aquifer and minimizing network costs
- equal distribution of flow over the injection wells requires extra efforts (special control valves)
- minimum flow rates in the delivery sets have to be calculated accurately due to low hydraulic network resistance
- stable system control and energy monitoring is challenging due to the fact that installations are distributed over the area.

Nomenclature

ATES	Aquifer Thermal Energy Storage
DATES	District Aquifer Thermal Energy Storage
HP	Heat pump

ISSO	Instituut voor Studie en Stimulering van Onderzoek voor gebouwinstallaties (Dutch Knowledge Institute for Building Installations)

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