D 1a E-USE(aq)

Technical performance & monitoring report

Belgian pilot

Climate-KIC is supported by the EIT, a body of the European Union

Authors: Hendrik-Jan Steeman [Arcadis], Pieter Doornenbal, Nanne Hoekstra [Deltares], Martin Bloemendal [TU Delft]

ABBRIVIATIONS

ATES	Aquifer Thermal Energy Storage – Ground water wells and ducting up to the heat exchanger with the HVAC system
DTS	Distributed Temperature sensing with fibre optics
HVAC	Heating, Ventilation and Air Conditioning – Cooling and heating system of the building, including the heat pumps but excluding the ATES system
MEP	Mechanical, Electrical & Plumbing
PVT	Photovoltaic + Thermal solar panels

1 INTRODUCTION

1.1 Barriers to overcome and issues to address

Aquifer Thermal Energy Storage (ATES) has proven to be profitable both economically as well as energetically. However, large scale adoption of the technology is limited by several barriers which were identified in the Climate-KIC E-use(aq) project.

In this pilot the focus lies on the following barriers:
- Barrier 3 : unpredictability's because of unfamiliarity with the underground and its characteristics
- Barrier 6 : presumed relatively large initial investments with unclear savings during operation

This project report describes activities to address one of those barriers, which is the need to obtain energy balance over a long time period through the addition of renewable heat source and heat sharing between buildings.
To sustain an ATES system, on average the thermal energy stored in the aquifer must be as much as the retrieved amount, so that structural and unlimited growth of either warm or cold well is prevented. Since buildings hardly ever have a heating demand equal to cooling demand, measures need to be taken to optimize system performance by storing extra heat or cooling capacity from other (sustainable) sources. In case of a heat deficit, one way to gain additional heat is from solar radiation. Since ATES systems also need electricity to drive the heat pump, using both solar heat and power would improve the energetic and economic performance of such systems. Also because typically in moderate climates, solar heat is abundant in summer, while demand for heat is largest in winter, temporal storage of heat in an ATES system would utilize the potential heat production during summer.

The goal of this pilot is twofold:
- Establish a strategy to deal with unfamiliar underground characteristics, based on a state-of-the-art monitoring campaign with glass fibers and on the experience of the partners involved
- Clearly measure and document energy savings related to the Aquifer Thermal Energy Storage (ATES) systems

To achieve the goals of the pilot the following activities are carried out:
- Installation of fiber optic cables in the wells
- Drilling of extra monitoring wells
- Monitoring and transfer of available data from energy meters
- Setup of a detailed energy model and energy balance
- A thorough follow-up of the system operation to assure correct operation

1.2 Partners involved

Deltares is the Climate-KIC partner who takes the lead in this pilot. Besides this, Deltares is also responsible for the subsurface fiber optic cable temperature and groundwater quality monitoring. Deltares is assisted for this pilot by Arcadis, who is responsible for the follow-up of on-site activities, the energy monitoring, the energy model and the data analysis. Nike, as a site owner and user, and IFTECH, as the ATES contractor and operator, is involved by granting access to all data of the ATES and Heating, Cooling and Air Conditioning (HVAC) systems.

1.3 Organizational history

In the period 2014-2016 Nike constructed a new distribution center (DC) in Ham (Belgium) for the European market. Arcadis was involved in this construction project as the engineering company responsible for structural works, MEP design, Sustainability and LEED certification. As part of the zero energy concept of the new site, Arcadis designed the HVAC system in which ground source heat pumps and free chilling make use of an ATES system for seasonal storage and recovery of heat.

After contacts between Deltares, Arcadis and Nike this distribution center was chosen to be the Belgian pilot for the E-use(aq) project.

The ATES system was installed and paid for by Nike. Yet an additional monitoring well and subsurface monitoring system is funded by the E-use(aq) project to allow for a detailed monitoring of the sub-surface temperature distribution (barrier 3). To address barrier 6 Deltares asked Arcadis to set up an energy monitoring system of the ATES performance and to analyze and model the energy performance of the ATES system.

2 PILOT DESCRIPTION

2.1 Site description

Nike's new distribution center consists of the expansion of Nike's European Logistics Center at Ham with a new, versatile and flexible storage facility. With this new storage facility Nike wants to set the new standard in the logistics landscape and to be an example on the European market. The new storage facility is a leading example in the fields of sustainable building technology and innovative transport technology.

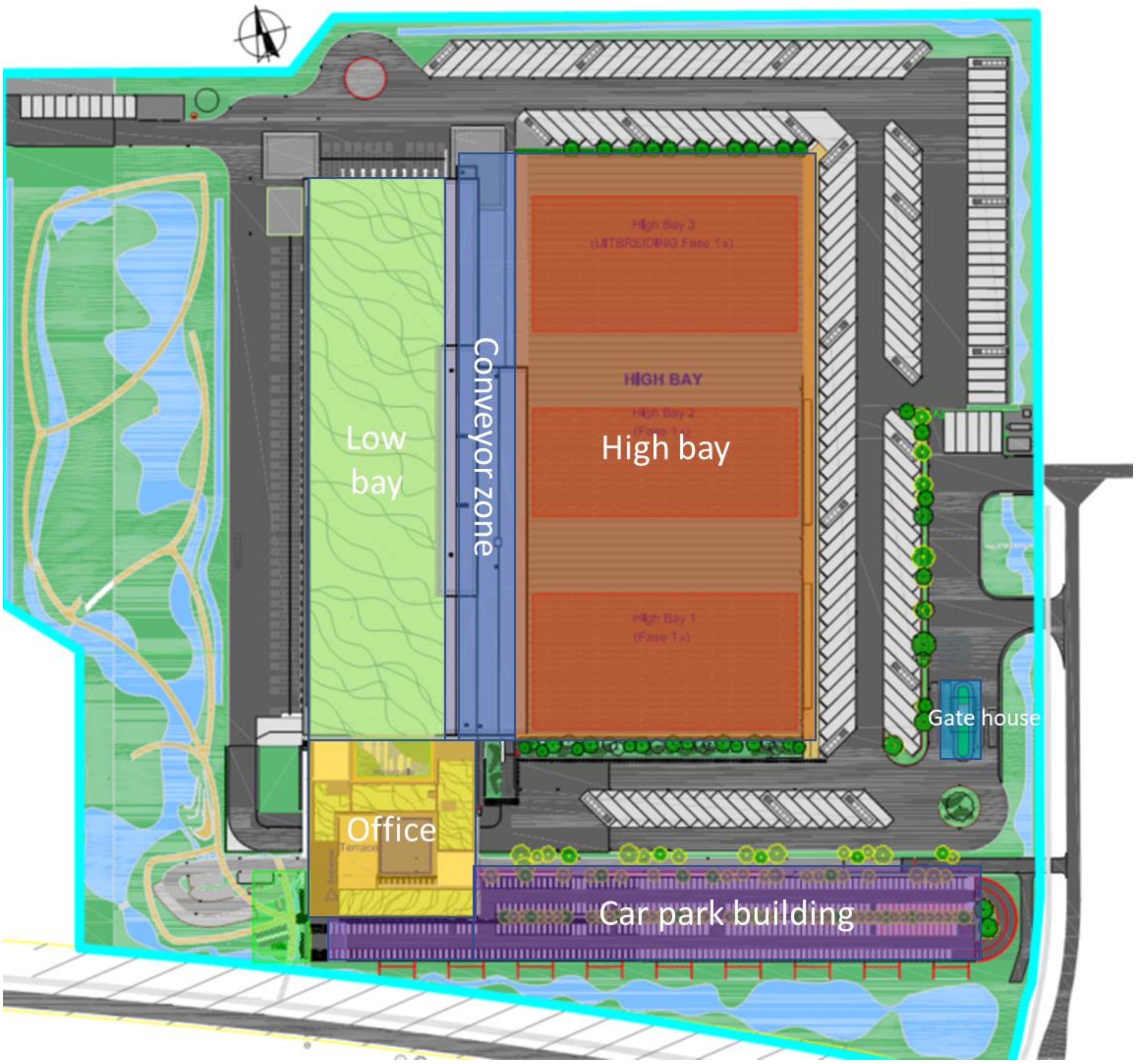


Figure 1 Site description

The new DC contains the following parts:

- A High Bay building which functions as a full automatic storage facility for Nike products, with a footprint of about 234 m length x width 123 m and a cornice height of approximately 45 meters above ground level. The building is split into three parts: High Bay 1, 2 and 3. The import and export of goods to this building is done by a fully automated system, described as MHE (Material Handling Equipment). There are therefore no persons involved in this process, except for maintenance personnel.

- Connected to the High Bay there is a conveyor zone, acting as a functional link between High and Low Bays in which conveyors transport the goods to and from the HIGH BAY. On the ground floor no conveyors are foreseen but technical areas, storage areas and a central circulation road for forklifts over the entire length of the High Bay.

- The Low Bay building (252 m x 72,5m) connects over the entire length of the Conveyor-zone: inside this building goods are sorted, labeled and packaged to be shipped using the 'shipping docks' or be temporarily stored in the High Bay. All goods enter the Low Bay via the ‘Receiving docks’ on the north side and leave through the ‘Shipping docks’ on the west side. The Low Bay contains five floors. The sixth floor is a technical floor

- An office building with two floors containing offices and functions related to the Low Bay (workshops, technical rooms, sanitary rooms, shower blocks). Inside the office building a restaurant and kitchen is present, serving hot food for all staff on site. This office building is adjacent to the south of the Low Bay building.

- The car park building at the south side of the project site consists of two floors, thus minimalizing the building footprint. The upper platform is an open parking lot, partly shaded by a canopy structure carrying thermal-photovoltaic panels (PVT). The parking building is shielded to the south by a green undulating landscape. A visitor parking is located at ground level, outside the parking building.

- A gate house was erected next to the main access to the site, located on the east side, adjacent to the ring road for trucks: the building has a footprint of 6x10 m

The new storage facility is a leading example in the fields of sustainable building technology and innovative transport technology. This was also acknowledged by the US Green Building Council by awarding the building the LEED Gold label.

Some key features of the building related to sustainability are listed below:

Sustainability topic		
1	Compact design and clad rack structure – Effective insulation	Compact building design combined with highly insulated and integrated shell, led to ultra-low, near *passive-house* heating & cooling demands.
2	100% LED-lighting (exterior and interior lighting)	By being ultra-efficient, resulting in less maintenance, offering superior visibility for picking and packing, LED offers a robust, sustainable lighting solution
3	Regenerative cranes and efficient conveyors	Tackling the largest energy demand on site by providing on energy efficiency at high speeds and regenerative braking in descend.
4	ATES + PVT	ATES relies on seasonal storage of cold and warm groundwater in an aquifer. The solar heat or winter cold gained through combined photovoltaic and thermal solar panels (18,2 kW PVT) helps to maintain the thermal balance of the ATES warm and cold well while also producing renewable electricity.
5	PV-panels	The high-bay roof will be covered with PV. In combination with wind-generated power (to be investigated in the future), this should cover the complete MHE power needs.
6	Integrated water management (closed water loop	An integrated closed loop water strategy focuses both on water-efficiency and storm, discharge water buffering, infiltration and recycling (on-site water treatment installation
7	Low impact materials	Focus on using less materials in the first place, and reduce the materials life cycle impacts by looking at recycled, renewable or CO2-based materials.
8	Bio diverse landscaping	Throughout the campus, green roofs, green walls, green walkways are connected in a continuous network of biodiversity that provides regulating, recreational and habitat ecosystem services.

The ATES system makes use of the groundwater to exchange energy with the building. In winter, groundwater is pumped from the warm well to the buildings heat exchanger. The building extracts heat from the groundwater to use as energy source for the heat pumps, while the groundwater will be injected in the cold well at lower temperature. In summer, the direction will be reversed and groundwater will be pumped out of the cold well to the heat exchanger, where the building will gather cold from the groundwater. The groundwater has been warmed up by the building and will be injected in the warm well.

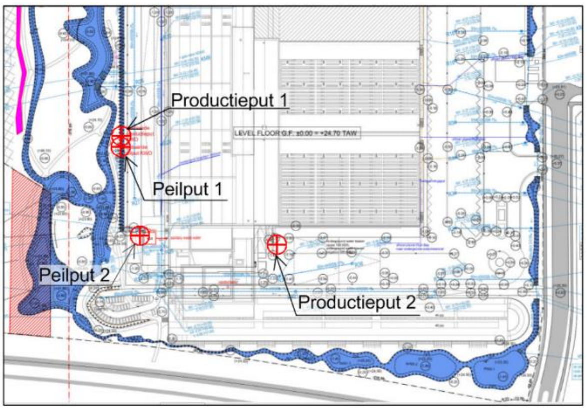
A structural / yearly imbalance between heating and cooling demand will lead to the depletion of the warm or cold well and a reduced heating/cooling capacity. Extra measures are necessary to create robustness against possible imbalance.

Solar cogeneration is a relatively innovative concept: solar heat is used to restore the imbalance between heating and cooling requirements while generating renewable electricity from the sun. To do so photovoltaic solar thermal collectors are added to the ATES system. During summer these panels produce warm water which is stored into the warm well of the ATES system, replenishing this well. When needed this heat can be used to produce domestic hot water or in winter aid in heating the buildings. PV-electricity is produced simultaneously.

Control of the ground balance is possible by loading the warm well with solar generated heat when necessary, or by using the PVT-technology in reverse mode to release heat to the air by cooling down the panels at night. The PVT-system was chosen for its ability to load heat in the ATES system as in the design stage a larger heating demand was expected.

2.2 System installation

2.2.1 ATES system



The ATES system in this pilot consists of 2 groundwater wells that have been drilled into the subsurface at a depth of 162,5 m in a specific geological formation (Zanden van Diest). This formation consists of fine sand containing glauconite. The screen for the extraction and infiltration of the groundwater is installed between 80 m and 160 m (ground level). Besides the 2 production wells, 2 measuring wells with level ducts have been drilled in the field, in order to confirm to the permit requirements. The monitoring well near the production well 1 (warm well) was drilled to final depth of the production well. Monitoring well 2 was foreseen to be shallower (in accordance with environmental legislation). Yet, in order to enable a detailed monitoring of subsurface temperatures, also monitoring well 2 was drilled to final depth. The monitoring wells installed in the same borehole as the warm and cold well and the stand-alone monitoring wells were then equipped with fiber optic cables to monitor the evolution of subsurface temperatures. An overview of the wells on site is shown in this picture.

Table 1 Key figures of the ATES design

Parameter	Value
Number of production/infiltration wells	1 warm well + 1 cold well

Number of monitoring wells	2
Max flow rate	80 m³/h
Max cooling power ATES	1300 kW
Max heating power ATES	650 kW
Estimated annual ATES cooling demand	900 MWh
Estimated annual ATES heating demand	863 MWh

Table 2 Characteristics of the different wells

Well	Characteristics (meters below ground level)
Production well 1 (warm well)	Depth : 162,5 m screen: 80-160m monitoring screen 1: 92,5-95m monitoring screen 2: 17,5-20m
Production well 2 (cold well)	Depth : 162,5 m screen: 80-160m monitoring screen 1: 120-122m monitoring screen 2: 20-22m
Monitoring well 1	Depth : 162,5 m monitoring screen 1: 160-162,5m monitoring screen 2: 60-62,5m monitoring screen 3: 20-22,5
Monitoring well 2	Depth : 162,5 m monitoring screen 1: 156-161m monitoring screen 2: 94-99m

Table 3 Hydrogeological characteristics

Parameter	Value
Aquifer name	Sand of Diest
Aquifer thickness	-3 to -164,5m below ground level
K-value	11 m/d

The PVT-system consists of 35 BLO-260 TripleSolar PVT-panels placed on the roof of the office building, accounting for 119m² of PVT surface and 18,2kW of peak power production. In the pilot these panels can be used in 3 different ways:

1. Generate domestic hot water
2. Charge the ATES with solar heat to restore ATES thermal balance
3. Charge the ATES with extra cooling capacity (in winter time) to restore ATES thermal balance

The annual energy that can be charged/discharged strongly depends on the entering fluid temperature. For ATES applications temperature of about 10°C to 13°C is expected when charging or discharging heat in this pilot. At 10°C entering fluid temperature about 3000MJ/m²/year heat can be charged or 1100MJ/m²/year of heat can be discharged according to the technical documentation of the panels. Although relatively small, the PVT-systems provides means to balance the ATES in two directions.

2.2.2 Monitoring system: Subsurface temperature monitoring using Distributed Temperature Sensing with fiber optics

Introduction

The ATES wells and observation wells were installed between 2014-2016. In July 2016 the ATES system was started and warm water was injected in the warm water well. In July 2016 a temperature measuring campaign using Distributed Temperature sensing (DTS) with fiber optics was started.

Data collection

Due to the harsh environment Deltares installed the fiber optic cable, data is collected in a double ended setup. Within a double ended data collection both channels are used to correct for attenuation within the cable and temperature offset. When a cable is damaged during the monitoring period the double ended configuration setup doesn't work and for the whole cable the data is worthless. Hence it is recommended to collect the data in a single ended way with a double ended cable configuration (see figure 2 b, Hausner et al, 2011). Both sides are measured but stored in a single ended configuration. In this set-up it possible to calibrate the single ended measurements afterwards, so that a higher accuracy of the measurements can be achieved.
The DTS data was measured in a single ended monitoring manner using a double ended setup.

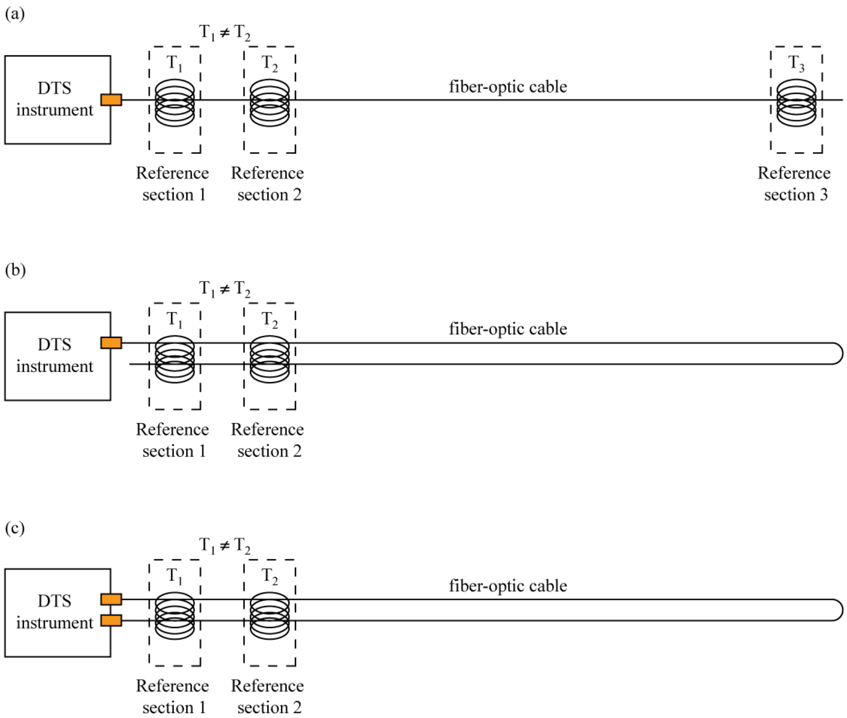


Figure 2 Experimental monitoring set-ups (Hausner et al., 2011) a)Simple single-ended configuration; b)Duplexed single-ended configuration; c)Double-ended configuration

For each position on the fibre optic cable it is possible to define a x, y, z position, which forms the basis for the 3-d visualisation. A commonly used setup is that the fibres are installed in the subsurface around ATES wells. At each position the fibres are connected to each other, so all positions can be monitored using only one channel connection.

Table 1 Name of observation well, lengths along the fibre and length of fibre below ground level

Name of observation well	Begin [m]	Bottom [m]	End [m]	Length of fibre BGL [m]
Production well 2	324	443	561	120
Production well 1	1608	1696	1785	90
Reference well 2	765	925	1084	160
Reference well 1	1247	1410	1574	165

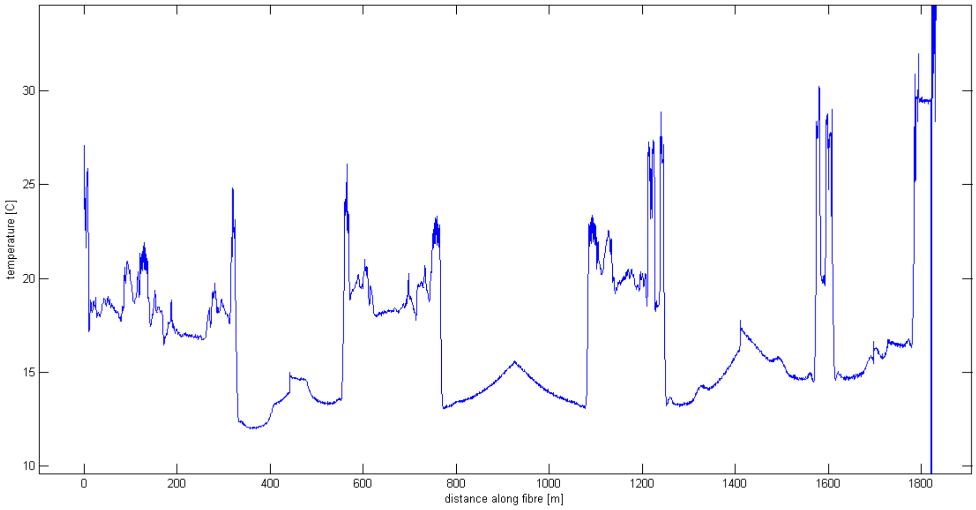


Figure 3 Distance, temperature graph along the fiber showing positions of the 2 production wells (324-561 and 1608-1785) and the 2 observation wells (765-1084 and 1247-1574)

2.3 System operation

The ATES system is operational since July 2016, yet in the first months the HVAC controls were not yet fully functional due to delays in the construction phase.

2.3.1 Performance testing phase

In this phase the necessary tests were performed on the ATES-system itself (ground water side) as on the HVAC-systems that are connected to the ATES to assure the well-functioning of the system. For the HVAC side, the focus lied on the controls and Building Management System (BMS). These tests of the HVAC controls showed that due to the inexperience of control engineers with ATES systems a lot of mistakes are made in the software of the building controls. A thorough performance testing and commissioning of the system is hence crucial to realize the full potential of this technology.

After 6 months the HVAC controls were fully operational, yet it can be stated that performance testing phase covered the entire first year of operation. (2016-2017)

2.3.2 Tailoring phase

After establishing that the system works as described in the performance testing phase, a next step is to tailor the operation of the system to the specific use of the building. This tailoring is a response to the observation that the anticipated use of the building during design stage, is not always in alignment with the actual use of the building. In this particular pilot it was for instance found that the building is cooled to a much lower setpoint than initially communicated by the client. This can result in a shift from a yearly net heating demand to a net cooling demand or vice versa.

This tailoring phase covered the second year of operation (2017-2018)

2.4 Monitoring

Available data – subsurface monitoring

Table 4 summarizes the monitored parameters and explains if the datapoint concerns a single parameter (single value) available in the ATES controls or a distribution (series of values) measured using DTS. The data discussed in this report covers the second year of operation: 1/09/2017 to 31/08/2018 for the single parameters. For the subsurface temperature distributions, monitoring data is available for the period 10/10/2017 – 01/10/2018. The monitoring campaign stopped at the end of September.

Table 4 Available (monitored) parameters

Type	period	Parameter	Unit
Single parameter	Hourly	Temperature injected in cold well	° Celcius
Single parameter	Hourly	Temperature injected in warm well	° Celcius
Single parameter	Hourly	Temperature extracted from cold well	° Celcius
Single parameter	Hourly	Temperature extracted from warm well	° Celcius
Single parameter	Hourly	Volume extracted from cold well	m^3/h
Single parameter	Hourly	Volume extracted from warm well	m^3/h
Temperature distribution (DTS)	Hourly	Temperature in warm well from 0 to 90m	° Celcius
Temperature distribution (DTS)	Hourly	Temperature in cold well from 0 to 120m	° Celcius
Temperature distribution (DTS)	Hourly	Temperature in monitoring well 1 from 0 to 165m	° Celcius
Temperature distribution (DTS)	Hourly	Temperature in monitoring well 2 from 0 to 160m	° Celcius

The data in Table 4 (volume and temperature difference) is used to calculated the energy for heating and cooling delivered by the ATES. The single parameters monitored in this pilot are data that are generally available in the ATES system and can be used to monitor the functioning of the wells, thermal balance and temperature performance of the ATES. This information can then be used to optimize the energy performance by acting as an indicator of the need for charging extra cold or heat in the system. Other possible optimizations based on this data can consist of modification of cooling curves to maximize free chilling or optimization of pump control to achieve higher temperature differences and lower pump energy use.

The DTS data is generally not available in ATES systems. This data can be used to validate the ATES design and the groundwater models used during design phase. It provides more insight on the actual temperatures in the ground water and could be used in the case of multiple well pairs to decide which well to use while assuring a reserve of cold/heat remains available in the soil for later demand.

Available data – energy monitoring

All energy flows depicted in Figure 4 are monitored. Together they allow to monitor the complete energy performance of the system. In the energy concept of the Belgian pilot, geothermal heat pumps provide the main source of heating. Cooling is realized directly with geothermal cold (free chilling) or active cooling with the heat pumps (ATES as heat sink) or simultaneously with the heating. The energy concept, as designed, is illustrated in Figure 4. The energy flows that are actively monitored are numbered in this figure. The monitoring of these flows will allow us to calculate the energy efficiency and energy savings of the ATES concept applied in this project in answer to **barrier 6** (presumed relatively large initial investments with unclear savings during operation). It is clear that the combination ATES-Heat pump provides a lot of possible working modes to optimize energy consumption. It should be noted that not all of the working modes appear at the same time.

The following operation modes are possible
Dominant heating demand

a. Heat pump in heating mode (7) + heat from ATES (10+20)
b. Heat pump in heating mode (7) + heat from ATES (10+20) + Gas boilers (12)
c. Heat pump in heating mode (7) + heat from ATES (10+20) + simultaneous heating/cooling (9)

Dominant cooling demand

a. ATES free chilling (13) + heat to ATES (21)
b. ATES free chilling (13) + heat to ATES (21) + Heat pump in heating mode (7) + simultaneous heating/cooling (9)
c. Heat pump in cooling mode (14+15) + ATES free chilling (13) + heat to ATES (21) + Reheat (11)
d. Heat pump in cooling mode (14+15) + heat to ATES (21) + Reheat (11)

Additional modes

e. Charging extra heat with PVT (5+21)
f. Charging extra cold with PVT (4+20)

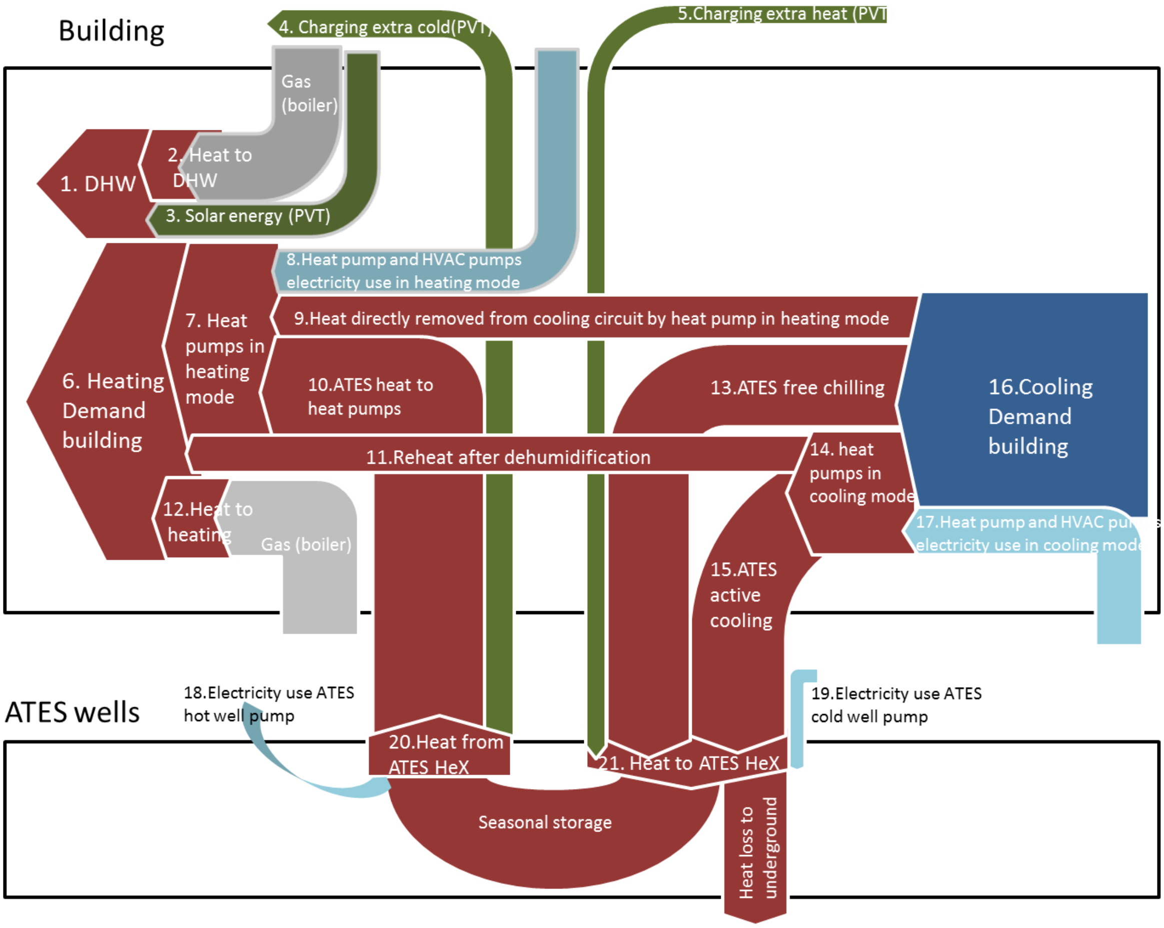


Figure 4 Sankey diagram of Belgian pilot (expected annual operation)

Geobiochemical groundwater monitoring

Before ATES operations start and 2 years later, elaborate geobiochemical groundwater monitoring was performed. Measurements and analyses executed are listed in the annex.

3 RESULTS

3.1 Subsurface monitoring

After the second year of operation we are able to analyze a complete year after startup, with a complete heating and cooling season. The first heating season lasted until mid May 2017, after which the first complete cooling season started.

Temperatures injected and extracted

Figure 5 shows stable injection temperatures in the cold well during heating season. The average injection temperature is estimated at 8-9°C, based on the graph.
The extraction temperature from the cold well in summer starts at the beginning of the cooling season at about 9°C. Compared to the first monitoring season, this is approximately 1°C higher, which is explained by the altered control strategy of the heat pump in heating mode and the slightly higher injection temperature during loading of cold.

At the end of the second monitoring year, the extraction temperature is increased to approx. 11-11,5°C, which is also higher than the first monitoring year. The green line in Figure 5, representing the total volume of cold water injected minus the volume of cold water extracted, returns to zero by the 15th of August, significantly sooner than the end of the cooling season. This also indicates a predominant cooling demand. The total amount of water that's been pumped from the cold to the warm wells is also higher, due to the higher energy demand in the second year of operation.

In the first operational year, the temperature difference over the ATES system was different in winter compared to the summer because of the 'unloaded' start of the installation. The second year, the installation starts with loaded wells because of the previous operational season and its energy demand. This justifies the balance in temperature difference in the second operation year between heating and cooling season (Figure 7). The higher energy demand for both heating and cooling is also represented in a higher water displacement, indicated by the top of the green line, which is higher than the first operational year.

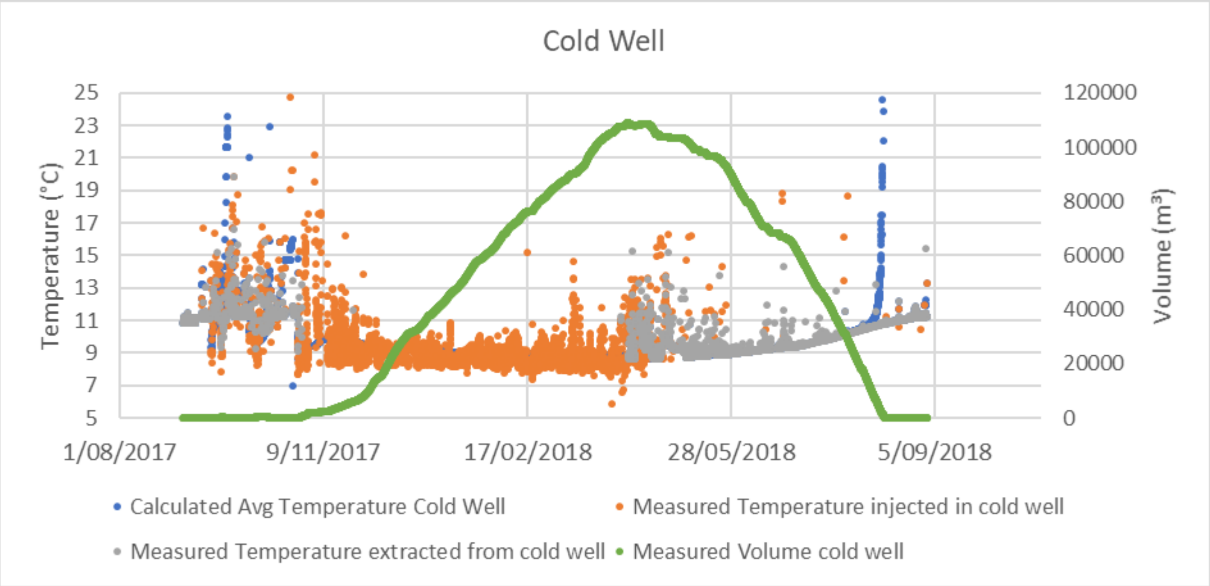


Figure 5 Temperature and volume of cold well during second year of operation

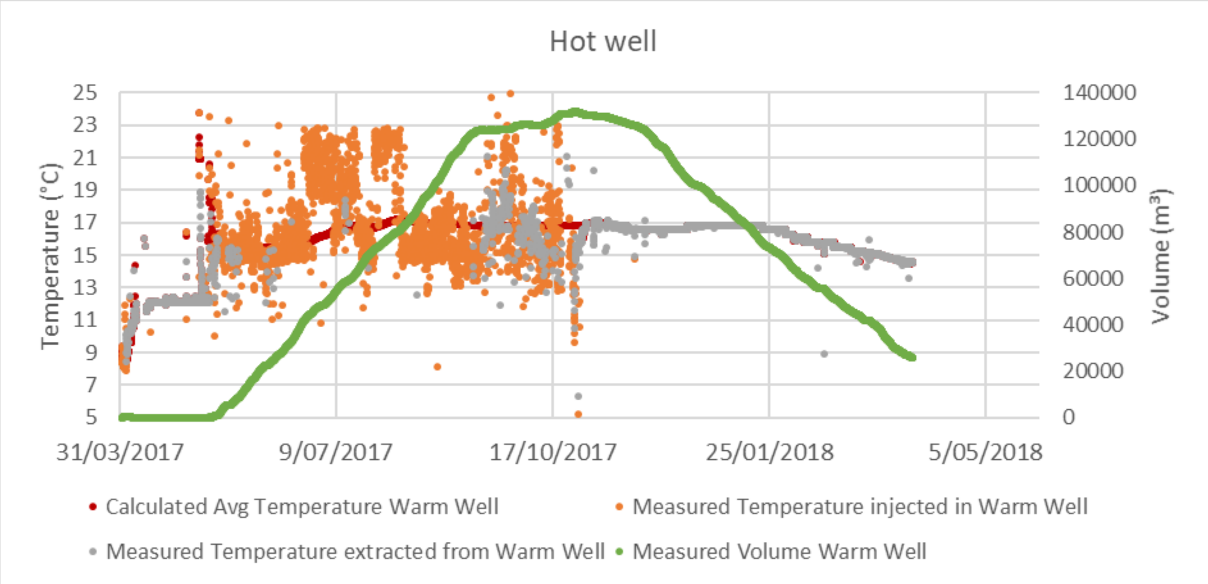


Figure 6 Temperature and volume of warm well during second year of operation

This loaded status is also represented in Figure 6. At the start of the heating season, the warm well reaches a peak temperature of about 17°C and during heating season, this temperature drops until it reaches its minimum at the end of the winter period. Notice that the minimum temperature (14 °C) is still higher than the natural ground temperature (12,7 °C).

If we consider the temperature difference between the extracted water and the natural background temperature and between the injected temperature and the natural background temperature, the amount of heating and cooling provided by the ATES can be virtually split up in a contribution of the warm well and of the cold well, as shown in Figure 8. In other words, if for instance cooling is required in the building, the cold water from the cold well is heated to the natural background temperature (contribution of the cold well) and is than further heated from background temperature to injection temperature in warm well (contribution of warm well). This figure shows that heat from the ATES is evenly divided between harvesting the warmth from the warm well as in storing cold water in the cold well. This cold storage however is not enough to deliver the large amount of cold in summer. About 1/3rd of the cooling delivered by the ATES comes from cold stored in the cold well, while the other 2/3rd is extra warmth, stored in the warm well. This means that the warm well has been prepared to deliver about 2 times the amount of heating compared to the previous year. This imbalance between heating and cooling will accumulate and must be controlled the next years.

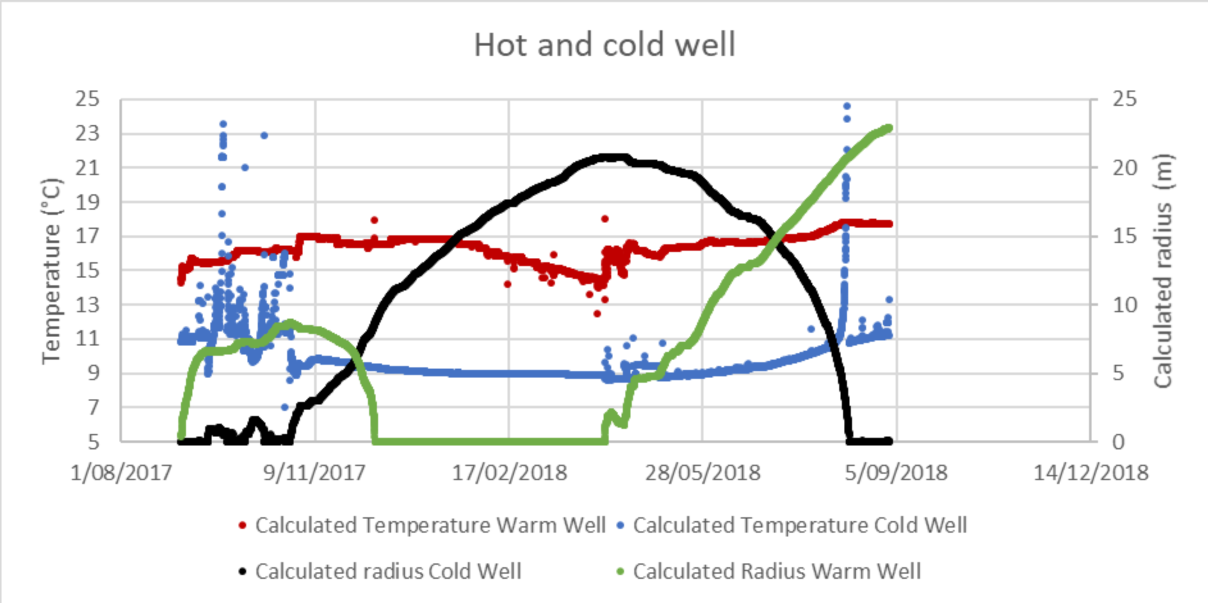


Figure 7 Evolution of Temperature Difference between wells and Calculated Radius of warm and cold well

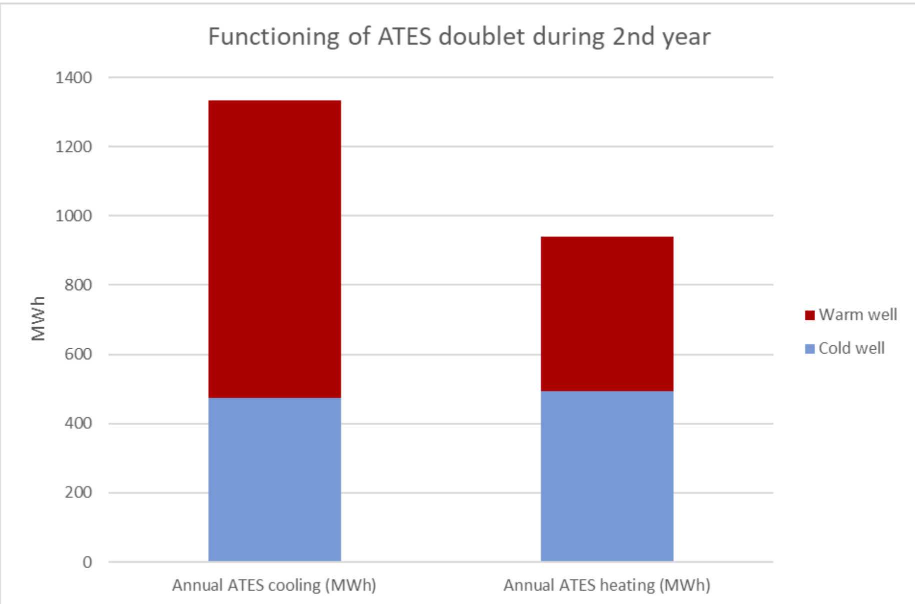


Figure 8 Annual heat and cooling capacity provided by the ATES

Storage Efficiency

The seasonal storage of heat and cooling capacity in the ATES and the fraction (and by consequence temperature) of the stored energy that can be recovered has an important impact on the energy efficiency of the ATES system. In Figure 9 the ratio extracted/injected volume and extracted/injected energy are given for the cold well. This figure shows that about 70% of the total volume can be recovered at a temperature of 10°C. Figure 10 shows that for the warm well 60% of the stored heat can be extracted at 17°C.

A difference in the behavior of the cold and warm well can be clearly noticed when examining Figure 9 and Figure 10 : the stored volume of the cold well is completely depleted, while only 90% of the energy is recovered. The inverse can be seen for the warm well: less than 80% of the stored volume of warm water is used, yet this accounts for more than 90% of the stored heat.

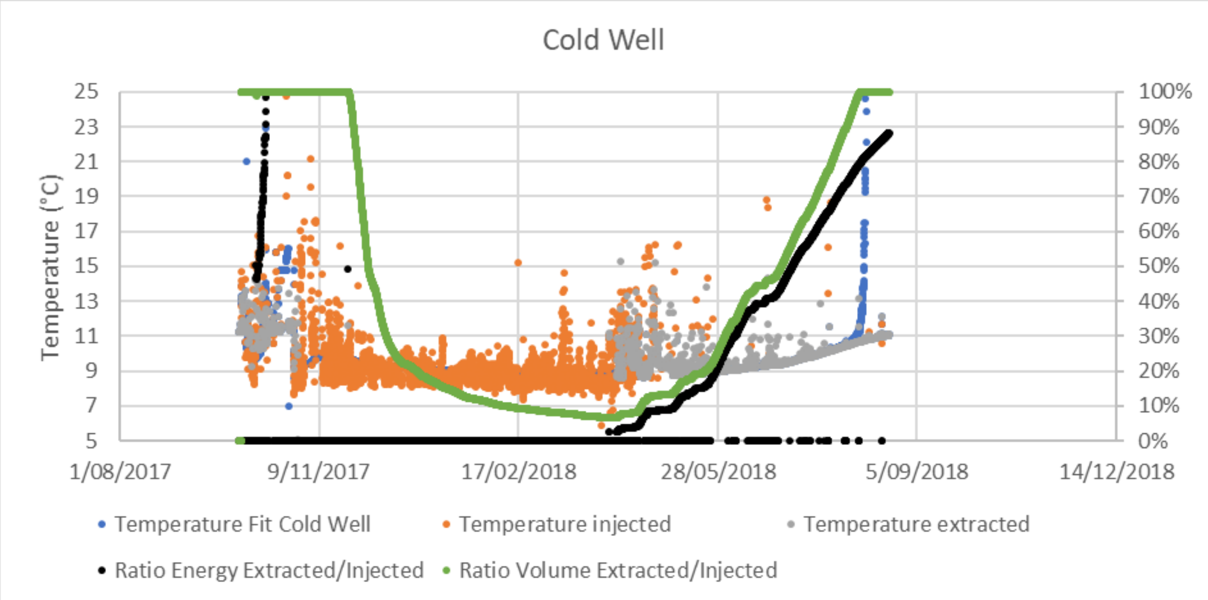


Figure 9 Cold well temperatures, volume unloaded/loaded and energy unloaded/loaded (1 year starting 30/09/2017)

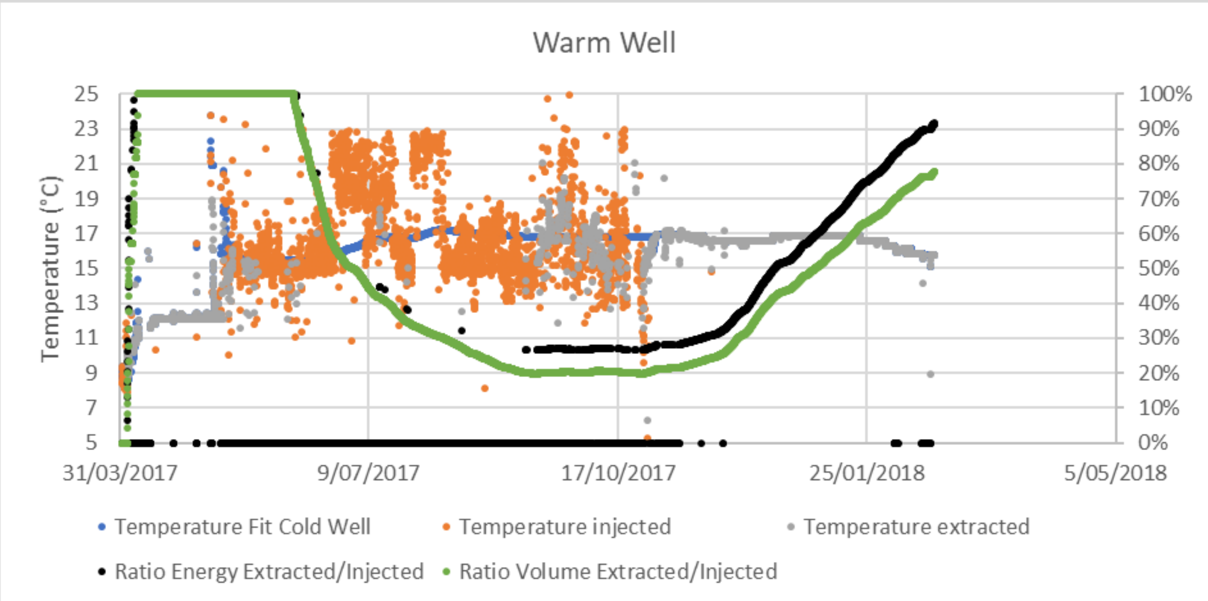


Figure 10 Warm well temperatures, volume unloaded/loaded and energy unloaded/loaded (1 year starting 01/04/2017)

Subsurface temperature distribution

Using the DTS monitoring system subsurface temperature profiles in the production and monitoring wells can provide additional information on the observed behavior of the ATES system.

Figure 11 and Figure 12 show the temperature distribution in the warm and in the cold well. The filter screen in these wells is located between 80 and 160m below surface, yet as the glass fibres are placed in the monitoring tubes, the measured temperature distribution does not cover the entire filter.

Figure 13 provides the temperature profile over the entire depth of the well, at a location 10m from the warm well. This figure confirms earlier finding that on an annual base a net amount of heat is discharged to the subsurface (at the end of the heating season, April 4th, the temperature around the warm well is still higher than ambient temperature). The variation in temperature distribution along the screen gives insight in the geohydrology of the soil: the upper 40m of the well filter (-80m to -120m) is located in a more permeable layer than the lower 40m of the filter and around -90m there is also a less permeable layer. The most permeable layers will contribute the most volume to the

Figure 13 also shows that at the beginning of the heating season (15/11/2017) the temperature in the warm well around the filter of the warm well (80m-160m below surface) has reached a quite uniform temperature of 17°C, which corresponds with the calculated temperature of the warm well at that time (Figure 6).

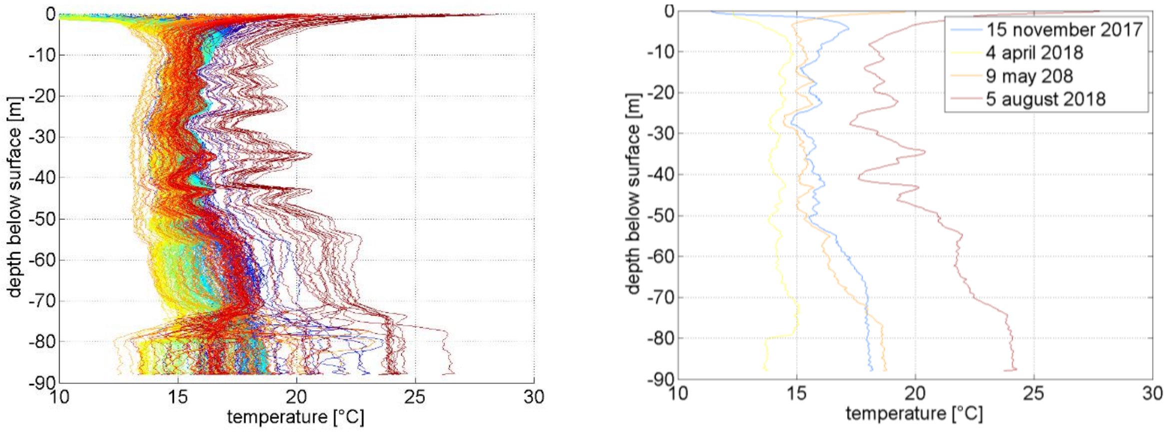


Figure 11 Temperature distribution in the warm well (01/10/2017 – 30/09/2018) Blue colors are in September 2017 and red colors in august 2018. Well screen is located between 80 – 160 m bsl.

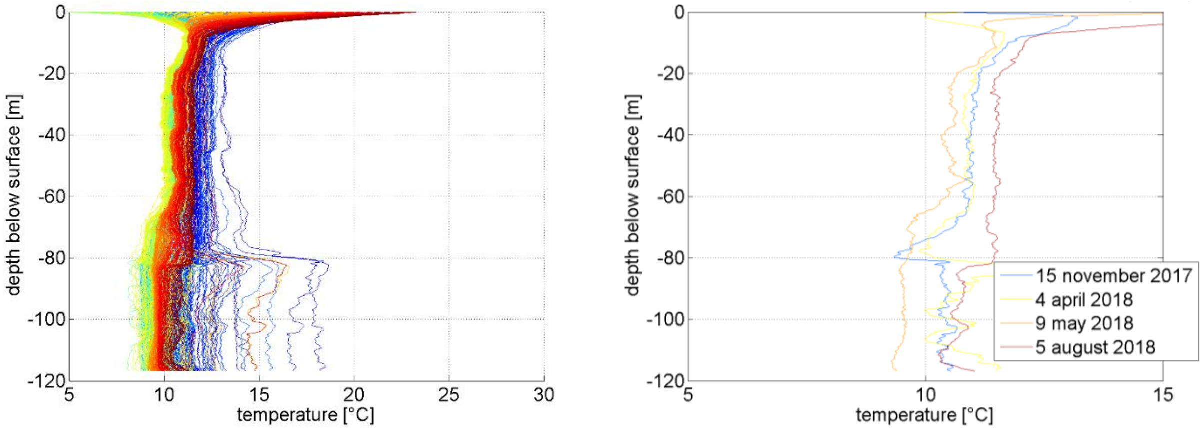


Figure 12 Temperature distribution in the cold well (01/10/2017 – 30/09/2018) Blue colors are in September 2017 and red colors in august 2018. Well screen is located between 80 – 160 m bsl

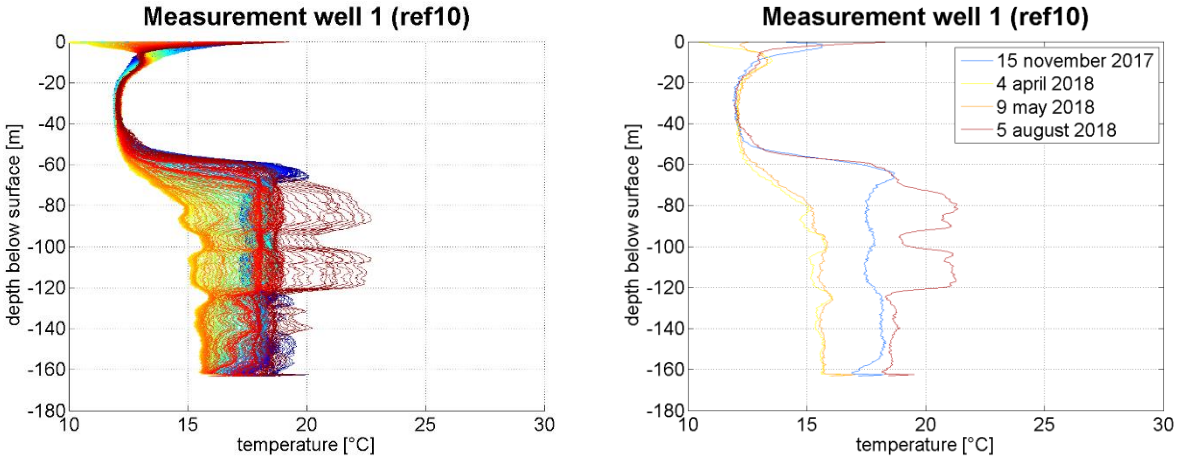


Figure 13 Temperature distribution in the monitoring well, 10m away from the warm well (01/10/2017 – 30/09/2018) Blue colors are in September 2017 and red colors in august 2018. Well screen is located between 80 – 160 m bsl

When examining the temperature at 80m below surface for both ATES wells and both monitoring wells (Figure 14), it can be seen that no effect of the ATES is observed in monitoring well 2 which is located half way between both ATES wells. There is currently no risk of ‘short circuiting’ the warm and cold well.

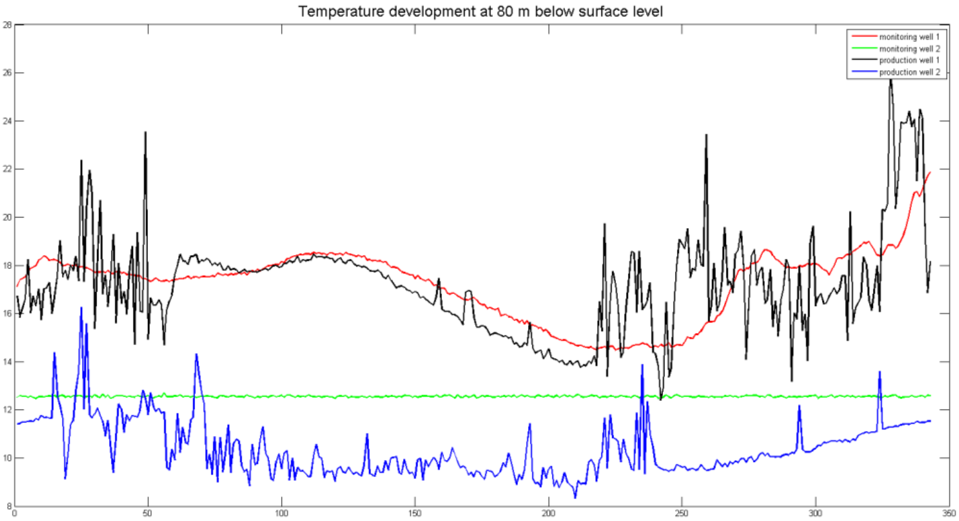


Figure 14 Temperature evolution at 80m depth for the 4 different wells

Geobiochemical groundwater monitoring

The results of the geobiochemical groundwater monitoring are presented in the table in the annex. Due to necessary changes in analytical methods, some compounds are, for the sake of sound reporting, listed in different columns.

The results show that there are no major changes in geochemical – including redox – conditions of the groundwater. A small increase in methane concentrations can be observed, indicating somewhat more anaerobic degradation. Some contaminants were found. Toluene is present in most wells, in low and decreasing concentrations. In some wells benzene (only in the 1st round) and mineral oil was found in low concentrations. In the 1st round a rather high concentration of vinyl chloride (VC) was detected in only one well, but this compound was not retraced in the 2nd round. A small but significant increase of VC degrading organisms may indicate biodegradation of this contaminant in the meantime.

3.2 Energy monitoring

When analyzing the data set of the energy monitoring it became clear that for the Low Bay a high quality dataset with little missing values was available. As the situation for the office is less positive, due to frequent loss of data, the energy monitoring will focus on the low bay.

Low bay

During the monitoring period (10/10/2017 – 01/10/2018) of about 1 year, a total heating demand of 1.762 MWh is measured. Figure 15 and Table 5 show that 69% is delivered by the heat pump and the gas-fired boilers guarantee the additional 31%.
Also a significant cooling demand of about 1.000 MWh is monitored. Just under half of this cooling demand is directly provided by free chilling from the ATES (45%). The heat pumps deliver the additional cold, where the condenser heat is directly used in the building or stored in the ATES.

Table 5 Heating and cooling demand Low Bay

heating demand	MWh	cooling demand	MWh
heat pump	1217	ATES free chilling	445
gas-fired boilers	545	heat pump	554
total	1762	total	999

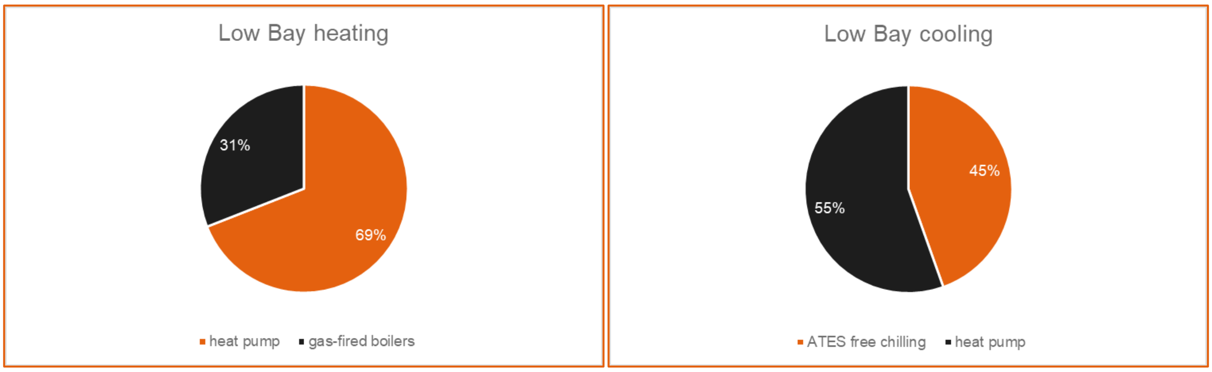


Figure 15 Spread heating and cooling production Low Bay

Figure 16 shows the flow rate profile of the ATES system compared to the nominal flow rate of 80 m³/h. A large amount of turning hours (7388 h or 84% of the time) and 3350 full load hours can be noticed.

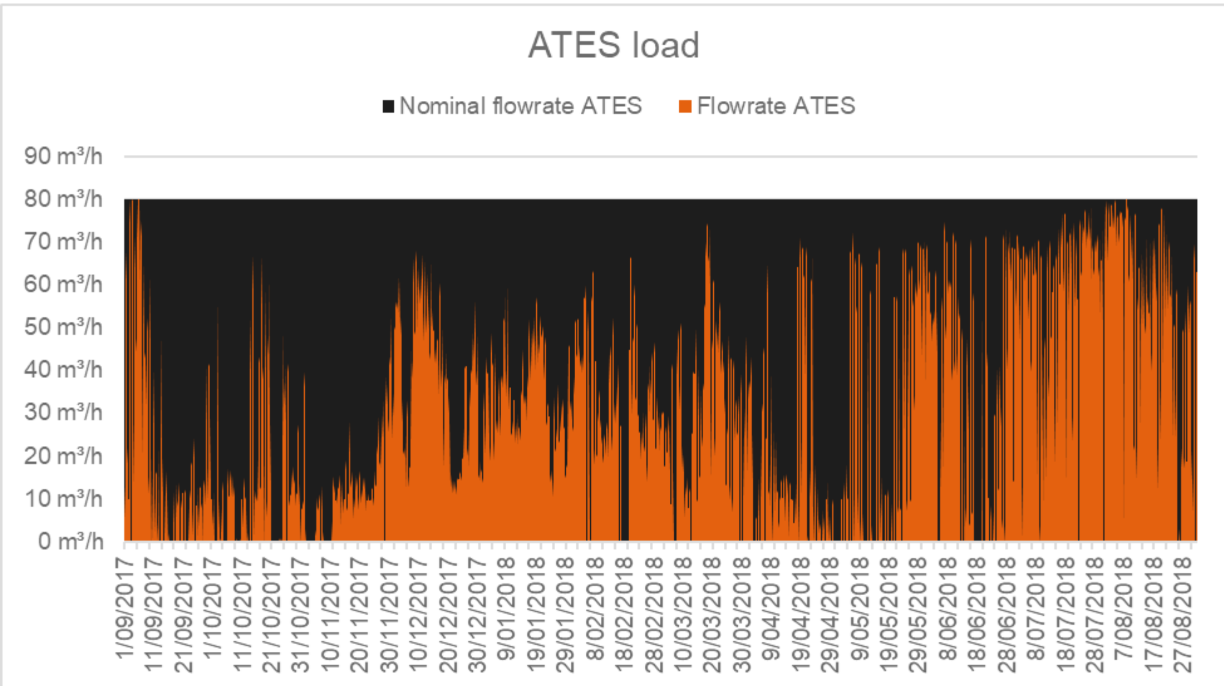


Figure 16 Annual load of the ATES

The high cooling demand of the low bay was not anticipated during design and is caused by a change in the cooling setpoint: instead of using a cooling setpoint of 27°C, a set point of 22°C is used in practice for cooling in the low bay, explaining the high amount of full load hours. When comparing the cooling demand of the entire building with the free cooling capacity of the ATES (Figure 17), it becomes clear that the change in setpoint results in a considerable amount of hours in which the free cooling capacity of the ATES is not large enough to cover the demand. Over an entire year the ATES system has a theoretical capacity of covering 83% of the cooling demand in free chilling mode.

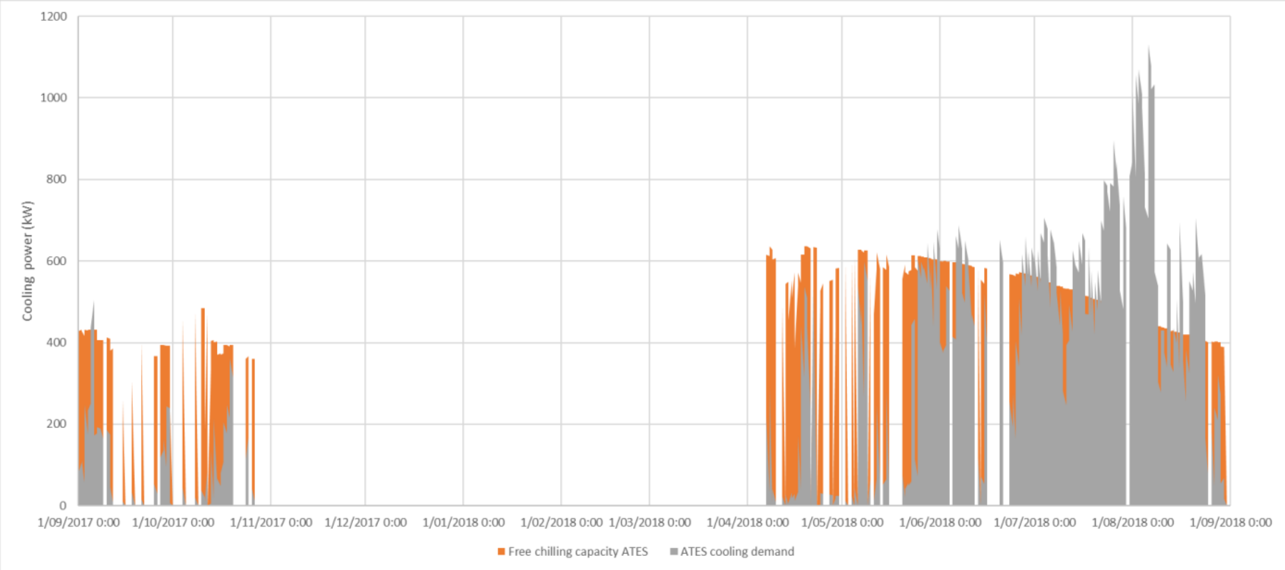


Figure 17 Free chilling capacity of ATES vs ATES cooling demand

4 EVALUATION OF SYSTEM PERFORMANCE

4.1 Use of the ATES system

A first analysis consists of the comparison between the Key Performance Indicators (KPIs) put forward in design and realized during the first and second year of operation. The first year of operation shows a higher cooling demand than estimated, while the heating demand covered by the ATES was 10% lower. The second year of operation, the cooling demand was even 48% higher than assumed during design, while the heating demand was slightly higher (9%) than estimated. These findings are coherent with the load of the ATES system as given in Figure 16.

Table 6 Comparison between design KPI's and measured KPI's

Parameter	Design Value	Values realized during first year of operation	Values realized during second year of operation
Number of production/infiltration wells	1 warm well + 1 cold well		
Number of monitoring wells	2		
Max flow rate (m³/h)	80	80	81
Max cooling power ATES (kW)	1300	918	1172
Max heating power ATES (kW)	650	681	631
Annual ATES cooling (MWh)	900	1126	1332
Annual ATES heating (MWh)	863	772	940

The reason for the significantly higher cooling demand of the building is situated in the low bay. While the low bay was designed for a setpoint temperature of 27°C (in summer), in practice a setpoint of 22°C is used. Due to the limited power of the local cooling emission system in summer the temperature only drops to 25 - 26°C, yet in midseason the low bay is effectively cooled to 22°C. This results in a very high cooling demand in the low bay which accounts for 75% of the annual cooling demand of the building.

Despite this unanticipated extra cooling demand and the fact that the ATES accounts for the only cooling of the building, sufficient cooling is provided thanks to the active temperature control of the cold water stored in the ATES and thanks to the possibility of using the heat pump in active cooling mode with the ATES as heat sink. On the other hand Figure 4Figure 8 shows that this extra cooling is realized by a net annual heating of the warm well. The Belgian legislation does not impose that the ATES should be balanced, yet charging extra cold or increasing the contribution of the ATES in the heat production will be beneficial for the future amount of free chilling.

Biogeochemical analyses of the groundwater give no indications of deteriorating groundwater quality. On the contrary, there are indications that contaminants, present in low concentrations and/or very localized, could be degraded by micro-organisms. The results do not show changes in redox conditions, so filter clogging by formation of precipitates is not expected.

4.2 Temperature performance

When designing an ATES system the maximum heating and cooling power required by the building needs to be translated into a necessary flow rate. The height of this flow rate is directly related to the investment costs (deeper ATES wells or more ATES wells needed with increasing flow rates). It is thus important to achieve a temperature difference between extraction and injection which is as high as possible so the maximum heating or cooling power and maximum energy efficiency can be realized with a certain flow rate.

The environmental legislation in the Northern part of Belgium imposes that the temperature of the injected ground water is limited to 25°C. This is thus an upper limit for injection in the warm well. Due to technical limitations of heat pumps (avoid freezing in the evaporator) the injection temperature in the cold well is limited to about 7°C.

As the extraction temperature vary through the year it is important that the designer makes a well-considered choice of the extraction temperatures used in the design. A conservative choice would be the use of the natural background temperature (which is equivalent to a complete depleted well). Yet as the maximum capacity is generally not required at the end of the heating or cooling season, a more economical choice can be made.

Table 7 Effect of extraction temperature on capacity

Approach	ATES capacity	Injection temperature	Extraction temperature	Resulting flow rate
Design Belgian pilot	Heating : 650kW	7°C	14°C	80 m³/h
	Cooling : 1300kW	25°C	11°C	80 m³/h
Conservative design	Heating : 650kW	7°C	12,7°C	99 m³/h
	Cooling : 1300kW	25°C	12,7°C	91 m³/h

The figure below shows that the extraction temperatures used in the design of the Belgian pilot are only reached at the very end of a heating or cooling season, which means that full capacity is available throughout the year and which confirms the design assumption of the extraction temperatures.

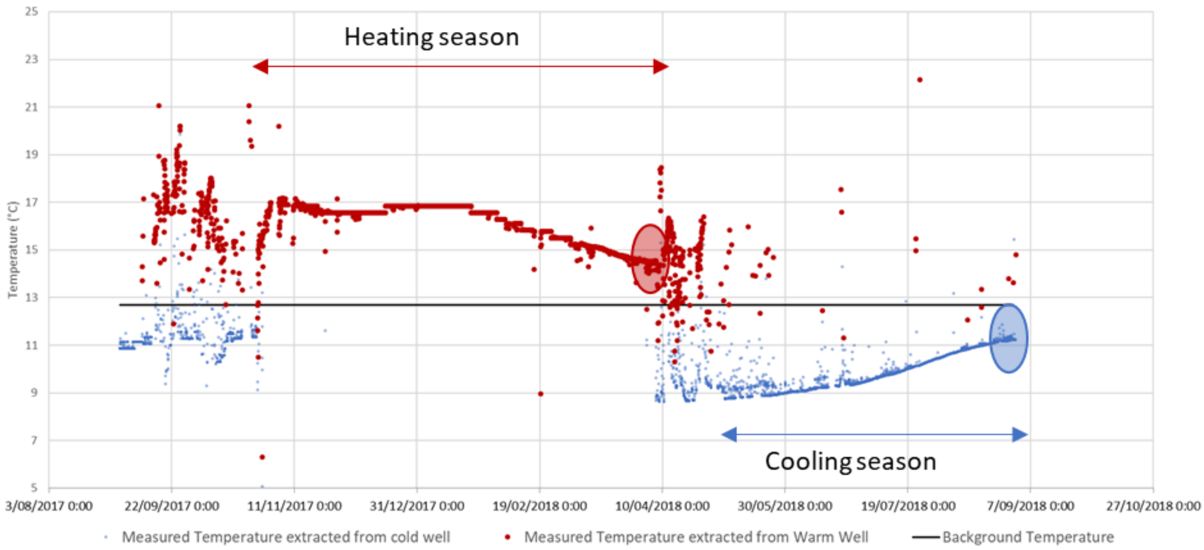


Figure 18 Extraction temperatures in the second year of operation

4.3 Energy performance

4.3.1 ATES system

As the dataset for the Low bay has the highest quality (very little missing data), the analysis of the energy performance is made for this part of the building. As the Low bay is responsible for circa 75% of the cooling demand and 67% of the heating demand, a representative analysis can be made.

Based on the monitoring data, a seasonal performance factor for heating with the heat pump of just under 4 can be calculated (electricity use of ATES pumps included). The cooling delivered to the building consists of direct cold of the ATES in free chilling combined with mechanical cooling from the heat pump. Hence a combined seasonal performance factor for the complete cooling production was calculated (electricity use of ATES pumps included). An SPF of 6,03 was found.

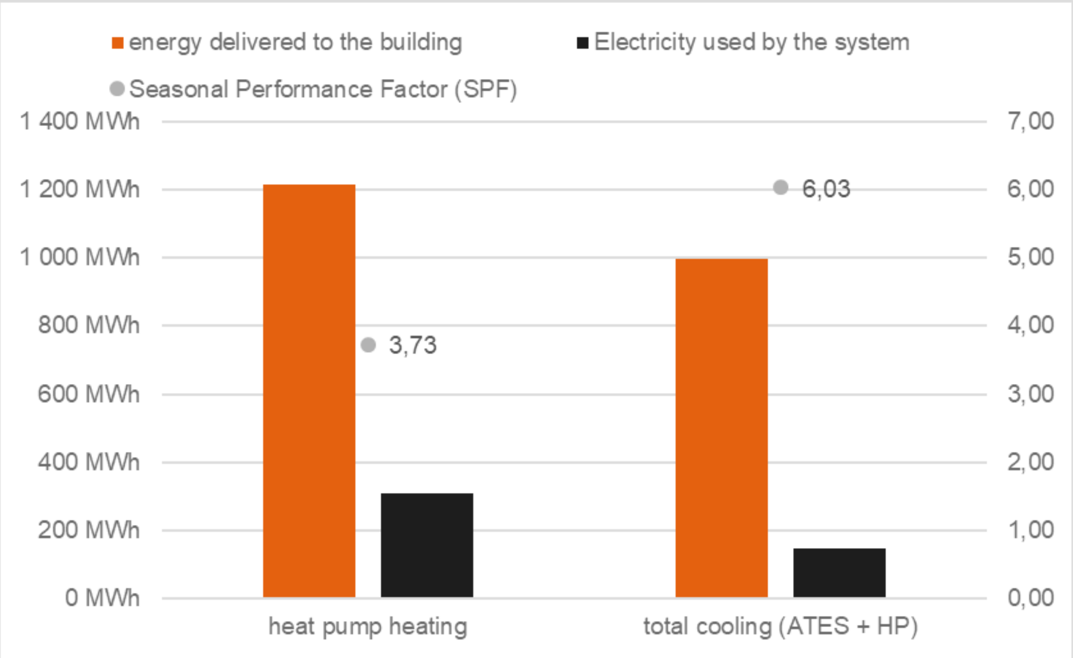


Figure 19 Actual system efficiency heat pump heating and total cooling production

This total cooling efficiency is quite high and rather impossible to obtain with other technologies that use active cooling. Yet it is lower than the anticipated SPF. This deviation can be explained by Figure 15 : during the second year of operation up to 55% of the cooling demand was covered by active cooling with the heat pump! This high amount of active cooling can be partly explained by the extremely warm weather in 2018, but can be significantly reduced by optimizing the setpoints of used in the HVAC controls (control of warm water and chilled water temperatures). If the hourly cooling demand is compared with the actual ATES cooling capacity at every moment in the cooling season, a free chilling potential of 83% of the demand is found. If this potential would be fully used a Season Performance Factor of 14,91 would be possible for the total cooling efficiency (Figure 20).

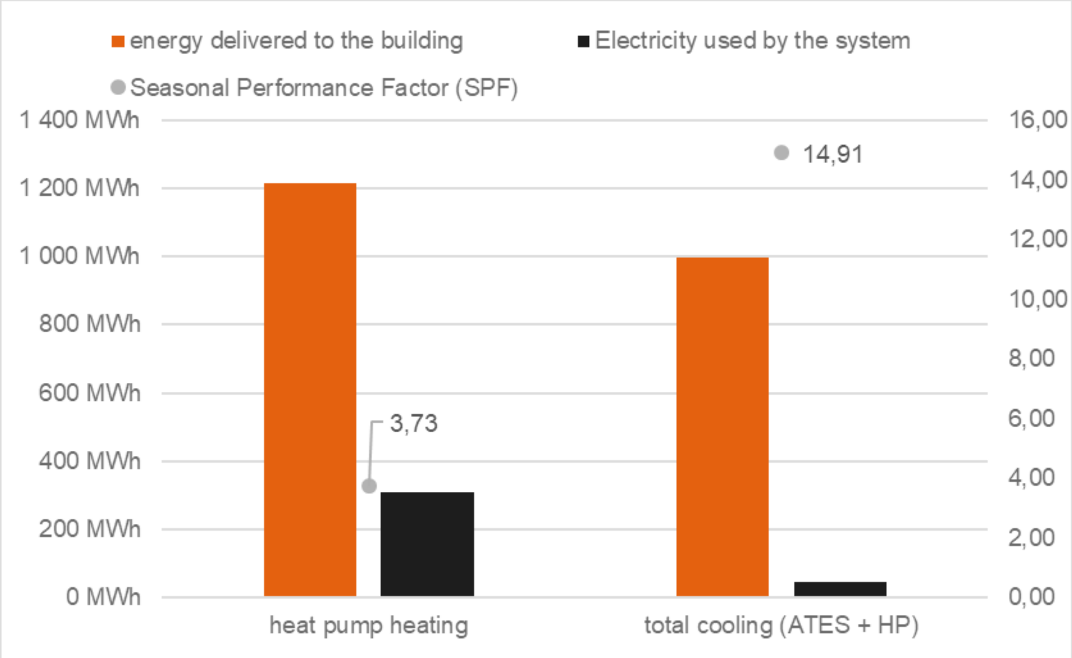


Figure 20 Potential system efficiency heat pump heating and total cooling production

69% of the heating demand in the Low bay was covered by the heat pump while the remaining 31% was covered by the boilers. Based on the measurement of the gas consumption, a global efficiency of 94% (higher heating value) is calculated for these gas-fired boilers.

Based on these monitoring results, a comparison with a conventional heating and cooling system (reference system) is made. This comparison puts into evidence the savings on the primary energy use and CO_2 emissions. As a reference installation, a gas-fired boiler with an efficiency of 94% and an water-cooled chiller with the same efficiency as the heat pumps is used in combination with a cooling tower.

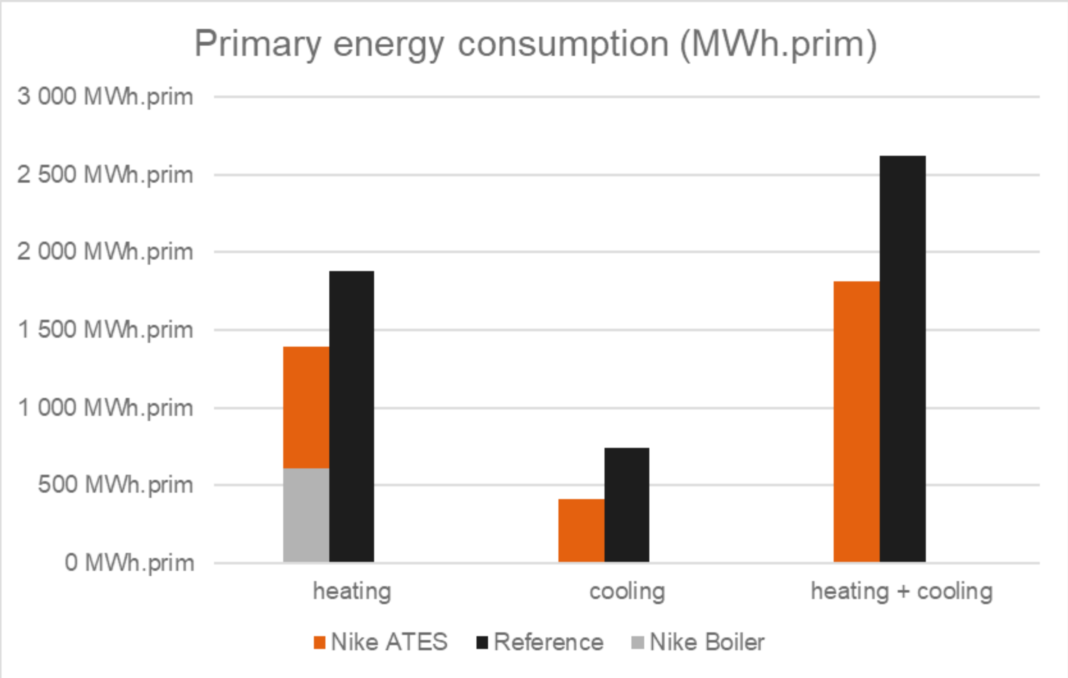


Figure 21 Primary energy use comparison

A global primary energy reduction of 31% is measured for the heating and cooling of the building. The primary energy savings in absolute figures are the highest in winter season, but the relative savings (%) are bigger in summer season.
Based on the energy use, a global CO2-emission for heating and cooling production can be calculated. A CO2-saving of 38% or 188 ton/year represent the high energy savings in this project.

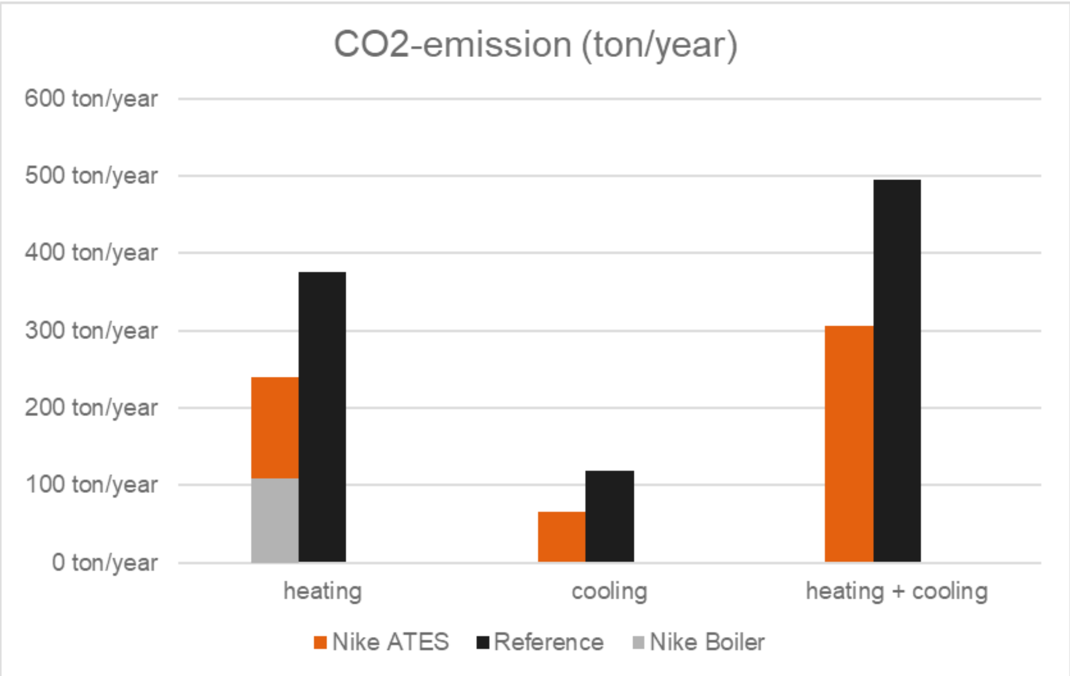


Figure 22 CO2-emission comparison

4.3.2 PVT system

Due to an error in the electricity sensor of the PVT panels, data is only available until June 2018. For this reason, the performance of the PVT system is evaluated for the period January 2018- June 2018. Table 8 shows that produced electricity and sanitary warm water is in line with the expected performance, based on the technical data sheets.

Table 8 Evaluation of PVT performance

Parameter	Design Value (per year)	Values realized during first half 2018
Electricity production	18,636 MWh	9,117 MWh
Sanitary warm water production	10383 MWh	5,831MWh

4.4 Financial return of the ATES system

4.4.1 Basis of comparison

To calculate the financial return of the investment in the ATES system, it is necessary to fix the basis of comparison. The financial analysis will be made by comparing the ATES system with the conventional boiler + chiller & cooling tower system used in chapter 4.3. The table below summarizes the most important characteristics of both systems. As the PVT installation was not used to charge heat or cold to the ATES system in the 2 years of monitoring, it is not taken into consideration in the financial analysis.

Nike Energy system	Reference
Heat pump used for heating/cooling Boilers used as peak heating ATES and heat pump investment: asbuilt	Same heat pump used as chiller Same boilers used as main heating Cooling tower investment: based on supplier data
Maintenance cost: ATES maintenance contract	Maintenance cost : supplier data
Energy use : as measured	Energy use : based on supplier correlations

Table 9: Basis of comparison for the financial analysis

To calculate the financial return of the ATES investment the standard EN 15459 was used, taking into account the following parameters:

- Actualisation rate: 5%
- Inflation : 2%
- Development of energy price: 2% above inflation
- Tax rate : 34%

As the life span of the ATES wells is far longer than the life span of the mechanical equipment (heat pumps, boilers, etc.) the final value according to EN 15459 is taken into account in our analysis. For this financial analysis a calculation period of 15 years is used. The investment costs and life spans mentioned in were used.

Component	Investment cost	Life span

ATES wells and piping	128.146,0 EUR	30 years
ATES mechanical equipment	79.665,5 EUR	15 years
HVAC mechanical equipment	61.964,6 EUR	15 years
Avoided closed cooling tower	150.734,8 EUR	25 years

Table 10 Investment costs used in the financial analysis

The net extra investment cost of the complete energy system is 119.042,3 EUR, the energy savings during the first year are as high as 50.375,0EUR.

4.4.2 Results

Based on the parameters described in the previous chapter and on the actual gas and electricity price paid by Nike, it is found that after only 3 years break even will be reached, leading to an internal rate of return (IRR) of 35,0%. The net present value of the investment is as high as 347.780,0 EUR.

These figures show that for this pilot the choice for an ATES energy system proved to be very lucrative. This is very positive result is caused by the beneficial geological situation (larger aquifer than anticipated) that led to a reduced investment cost, but most importantly by the ratio of the electricity price to the gas price that Nike pays: this ratio is as low as 1,77.

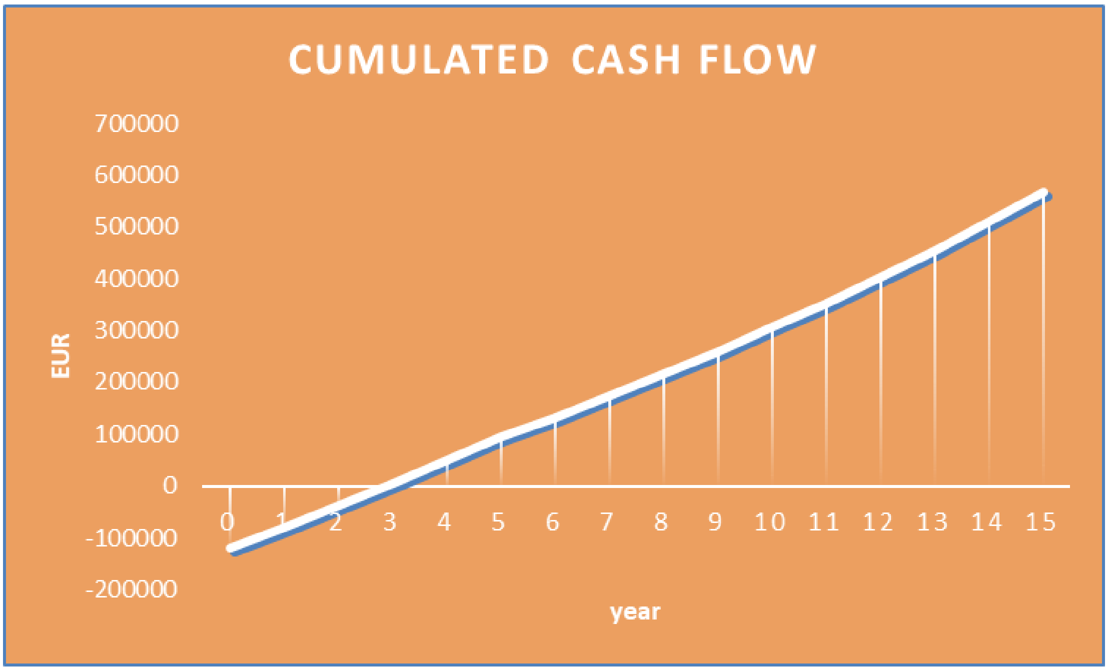


Figure 23 Cumulated cash flow of the Nike energy system

5 CONCLUSIONS

The aim of this pilot was to focus on the following barriers:

- Barrier 3 : unpredictability's because of unfamiliarity with the underground and its characteristics
- Barrier 6 : presumed relatively large initial investments with unclear savings during operation

To reduce the unpredictability related to the underground, the following approach was used in this pilot:

1. The drilling of a test well and performing detailed geohydrological analyses for this well
2. Reusing this test well as a production or monitoring well

This approach resulted in an excellent match of the ATES design and the measured values of temperatures and flow rates delivered by the ATES. It is our opinion that this approach could be successfully used in other European countries to address this barrier.

Despite the ATES system was subjected to much higher loads than anticipated during the design (eg. extreme warm summer of 2018), the system still managed to reduce CO_2 emissions with almost 40% compared to a reference system. The Belgian pilot however showed that a careful design and commissioning of the energy system controls are key to assure the energy performance and well-functioning of the system. It is our opinion that this commissioning should be a standard practice when installing ATES systems.

Based on the actual investment costs and the measured energy savings it was shown for this pilot that the payback period was as low as 3 years while the internal rate of return of the investment was as high as 35,0%. This pilot is hence a good reference to persuade possible users that barrier 6 can be overcome when working with experienced partners.

References

Hausner, M.B.; Suarez, F.; Glander, K.E.; van de Giesen, N.; Selker, J.S.; Tyler, S.W. Calibrating single-ended fiber-optic raman spectra distributed temperature sensing data. Sensors 2011, 11, 10859–10879

6 ANNEX: TABLE BIOGEOCHEMICAL MONITORING

Europe-wide Use of
Sustainable Energy from Aquifers
E-USE (aq)

eit Climate-KIC

Sample	sampling date	depht m bgl	Groundwate level m -top of tube	pH	EC µS/cm	TEMP °C	Redox mV	Oxygen mg/l	HCO3 mmol/l	Sulfide mg/l	Alkalinity mg/l	(NPOC) DOC mg/l	(IC) Li mg/l	(IC) Na mg/l	(IC) NH4 mg/l	(IC) K mg/l	(IC) Mg mg/l	(IC) Ca mg/l	(IC) F mg/l	(IC) CL mg/l	(IC) Nitrite mg/l
1.Productieput 1 (warme bron) PP-D	22/23 june 2016	92,5 - 95		6,8	260	14,2	-100	0,12	1,76	0,00	118	1,1							-	1	-
	16 oct 2018																				
2.Productieput 1 (warme bron) PP-OD	22/23 june 2016	17,5 - 20		6,2	482	14,3	-85	0,07	1,86	0,18	87	3,5							0,02	52	-
	16 oct 2018		2,46	6,3	392	16,4	-66	0,04		0,00	132	3,1	-	11	0,411	5,38	9,97	14,93	0,02	50	-
3. Peilput 1 (nabij productieput 1) PB-A	22/23 june 2016	20,0 - 22,5	1,63	6,2	471	14,3	-90	0,08	1,94	0,31	122	3,4							0,02	49	-
	16 oct 2018		2,3	6,3	382	12,8	-42	0,04		0,00	136	3,1	-	12	0,412	4,95	8,39	19,09	0,02	45	-
4. Peilput 1 (nabij productieput 1) PB-B	22/23 june 2016	60,0 - 62,5	1,58	6,3	279	14	-60	0,14	1,18	0,00	77	1,3							0,02	27	-
	16 oct 2018		2,05	6,4	179	13,9	-37	0,09		0,00	66	1,1	-	5	0,258	2,76	1,45	13,34	0,02	11	-
5. Peilput 1 (nabij productieput 1) PB-C	22/23 june 2016	160,0 - 162,5	1,53	6,8	289	16,2	-80	0,19	2,04	0,00	137	1,4							0,02	16	-
	16 oct 2018		1,65	6,9	236	16	-76	0,03		0,00	103	2,0	0,0111	5	0,302	8,46	6,94	23,39	0,02	12	-
6. Productieput 2 (koude bron)diepe peilbuis	22/23 june 2016	120 - 122	1,82 - 0,49	6,6	164	14,1	-141	0,16	1,37	0,10	75	10,3							0,03	6	-
	16 oct 2018		2,4	6,7	199	12,8	-57	0,19		0,00	84	1,1	-	5	0,425	3,46	3,88	18,20	< 0.01	9	-
7. Productieput 2 (koude bron)ondiepe peilbuis	22/23 june 2016	20 - 22	2,15 - 0,80	6,3	500	13,3	-49	0,13	2,00	0,00	112	2,5							0,02	56	-
	16 oct 2018		2,60	6,3	563	12,6	-34	0,05		0,00	162	4,2	-	13	0,632	4,86	8,32	60,32	< 0.01	64	-
8. Peilput 2 brede peilbuis	22/23 june 2016	156 - 161	0,97	6,7	402	16,0	-201	0,09	2,90	0,00	184	16,7							0,06	28	-
	16 oct 2018		1,55	6,9	267	13,4	-93	0,33		0,00	130	2,0	-	5	0,274	7,61	7,88	26,66	0,03	9	-
9. Peilput 2 smalle peilbuis	22/23 june 2016	64 - 99	1,90	7,0	310	13,2	-205	0,08	2,56	3,80	143	2,0							0,16	5	-
	16 oct 2018		1,47	6,8	190	13	-86	0,14		0,00	83	0,9	-	9	0,400	2,56	2,18	16,64	0,08	6	-

in decimal comma notation for use in Dutch language aerea!
blanc: not measured / analysed
- : not detected

Deltares
Enabling Delta Life

ARCADIS Design & Consultancy for natural and built assets

Sample	(IC) Br mg/l	(IC) Nitrate mg/l	(IC) Sulfate mg/l	(IC) Fosfate mg/l	(ICPOES) Mn mg/l	(ICPOES) Fe mg/l	*Total bacteria* gen copies/ml	*Dehalococcoides* gen copies/ml	*VC-reductase gen -vcrA-* gen copies/ml	*VC-reductase gen -bvcA-* gen copies/ml	*EtnET gen (VC-aerobe_* gen copies/ml	(GC-FID) Methane µg/L	(GC-FID) Ethene µg/L	(GC-FID) Ethane µg/L	(GC-FID) VC µg/L	(GC-FID) 1,1-DCA µg/L	(GC-FID) 1,2-DCA µg/L
1.Productieput 1 (warme bron) PP-D	-	-	1,2	-			7,95E+04	-	-	-		33	-	-	-	-	-
2.Productieput 1 (warme bron) PP-OD	0,22	-	56,9	-			2,87E+03	-	-	-	-		-	-	-	-	-
	0,13	-	7,2	-	0,15	50,4	1,16E+06	3,27E+02	4,86E+01	-	1,17E+02	849	-	-	-	-	-
3. Peilput 1 (nabij productieput 1) PB-A	0,20	-	39,8	-			3,26E+06	-	-	-	-	82	-	-	-	-	-
	0,11	-	6,3	-	0,15	37,9	7,45E+05	4,11E+01	5,64E+01	-	5,08E+01	793	-	-	-	-	-
4. Peilput 1 (nabij productieput 1) PB-B	-	-	19,9	-			1,51E+05	-	-	-	-	60	-	-	-	-	-
	-	-	11,1	-	0,04	19,3	5,03E+03	< 4	3,36E+01	-	1,52E+01	97	-	-	-	-	-
5. Peilput 1 (nabij productieput 1) PB-C	-	-	0,9	-			4,72E+04	-	-	-	-	292	-	-	-	-	-
	-	-	8,8	-	0,02	4,2	2,30E+06	9,06E+01	4,99E+01	-	1,19E+02	892	-	-	-	-	-
6. Productieput 2 (koude bron)diepe peilbuis	-	-	-	2,5			4,33E+06	-	-	-	-	145	-	-	24	-	-
	-	-	9,9	-	0,01	12,1	1,06E+04	< 4	3,72E+01	-	< 2	36	-	-	-	-	-
7. Productieput 2 (koude bron)ondiepe peilbuis	0,19	-	48,3	-			1,35E+06	-	-	-	-	35	-	-	-	-	-
	0,21	-	48,9	-	0,04	31,8	2,52E+05	< 4	7,92E+01	-	3,69E+01	151	-	-	-	-	-
8. Peilput 2 brede peilbuis	0,08	-	11,3	0,6			4,29E+06	-	-	-	1,71E+02	99	-	-	-	-	-
	< 0.08	-	6,5	-	0,09	6,4	2,40E+05	9,96E+01	4,87E+01	-	3,16E+01	1068	-	-	-	-	-
9. Peilput 2 smalle peilbuis	-	-	9,1	1,8			1,35E+03	-	-	-	-	-	-	-	-	-	-
	-	-	8,3	-	0,04	12,3	2,09E+05	9,78E+01	7,39E+01	-	2,68E+01	61.22	-	-	-	-	-

in decimal comma notation for use in Dutch lan
blanc: not measured / analysed
- : not detected

Europe-wide Use of Sustainable Energy from Aquifers

Sample	(GC-FID) 1,1,1-TCA µg/L	(GC-FID) Chloroethane µg/L	(GC-FID) 1,1-DCE µg/L	(GC-FID) cis-1,2-DCE µg/L	(GC-FID) trans-1,2-DCE µg/L	(GC-FID) TCE µg/L	(GC-FID) PCE µg/L	Benzene µg/L	Toluene µg/L	Ethyl-benzene µg/L	Xylenes µg/L	Naftalene µg/L	Mineral olie µg/L	(ICPMS) Li µg/L	(ICPMS) B µg/L	(ICPMS) Na µg/L	(ICPMS) Mg µg/L	(ICPMS) Al µg/L	(ICPMS) P µg/L	(ICPMS) K µg/L	(ICPMS) Ca µg/L	(ICPMS) Sc µg/L
1.Productieput 1 (warme bron) PP-D	-	-	-	-	-	-		-	5,6	-	-	-	-	6	43	3107	6257	-	795	6139	20808	0,47
2.Productieput 1 (warme bron) PP-OD	-	-	-	-	-	-		-	2,4	-	-	-	27	5	41	12416	11220	-	2289	5447	18009	0,47
	-	-	-	-	-	-	-	-	0,7	-	-	-	-	3,4								1,45
3. Peilput 1 (nabij productieput 1) PB-A	-	-	-	-	-	-		-	2,0	-	-	-	-	5	39	14196	10233	-	2505	5627	21376	0,48
	-	-	-	-	-	-	-	-	0,7	-	-	-	-	4,3								1,49
4. Peilput 1 (nabij productieput 1) PB-B	-	-	-	-	-	-		-	5,0	-	-	-	-	5	42	5480	2302	-	1327	2961	18715	0,47
	-	-	-	-	-	-	-	-	0,5	-	-	-	6,5	5,2								1,43
5. Peilput 1 (nabij productieput 1) PB-C	-	-	-	-	-	-		-	0,8	-	-	-	-	10	57	3128	9858	-	506	9320	26684	0,48
	-	-	-	-	-	-	-	-	-	-	-	-	-	13,0								1,70
6. Productieput 2 (koude bron)diepe peilbuis	-	-	-	-	-	-		-	0,9	-	-	-	-	16	32	4560	3639	-	1065	3673	14830	0,48
	-	-	-	-	-	-	-	-	-	-	-	-	-	5,8								1,43
7. Productieput 2 (koude bron)ondiepe peilbuis	-	-	-	-	-	-		0,3	4,7	-	-	-	-	6	24	8870	7877	-	2516	4969	50719	0,48
	-	-	-	-	-	-	-	-	-	-	-	-	5,6	7,5								1,50
8. Peilput 2 brede peilbuis	-	-	-	-	-	-		-	1,6	-	-	-	-	56	46	18425	9399	2	354	10525	43135	0,48
	-	-	-	-	-	-	-	-	-	-	-	-	-	10,7								1,63
9. Peilput 2 smalle peilbuis	-	-	-	-	-	-		-	3,6	-	-	-	-	6	31	33031	2561	-	1463	3329	19498	0,48
	-	-	-	-	-	-	-	-	-	-	-	-	-	6,3								1,32

in decimal comma notation for use in Dutch lan;
blanc: not measured / analysed
- : not detected

Europe-wide Use of Sustainable Energy from Aquifers

E-USE (aq)

eit Climate-KIC

Sample	(ICPMS) Ti	(ICPMS) V	(ICPMS) Cr	(ICPMS) Mn	(ICPMS) Fe	(ICPMS) Co	(ICPMS) Ni	(ICPMS) Cu	(ICPMS) Zn	(ICPMS) Ga	(ICPMS) As	(ICPMS) Se	(ICPMS) Rb	(ICPMS) Sr	(ICPMS) Y	(ICPMS) Zr	(ICPMS) Nb	(ICPMS) Mo	(ICPMS) Ag	(ICPMS) Cd	(ICPMS) Sn	(ICPMS) Sb	(ICPMS) Te	(ICPMS) Cs	(ICPMS) Ba
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
1.Productieput 1 (warme bron) PP-D	42	-	-	28	10664	0,19	1,9	-	1585	-	0,9	-	3,8	117	0,22	1,89	-	0,57	-	0,067	2,0	1,50	0,018	0,014	5
2.Productieput 1 (warme bron) PP-OD	37	0,03	0,27	210	60865	0,42	2,7	-	11	-	1,4	-	6,6	81	0,26	1,90	-	0,29	-	0,029	0,8	0,70	0,015	0,014	94
		0,82	0,42	163		0,15	0,4	0,05	1,0		0,9	0,0	6,7	57	0,11	0,01	0,5	0,04		-	0,1	0,12		0,008	78
3. Peilput 1 (nabij productieput 1) PB-A	43	0,20	0,36	189	58379	0,24	2,1	-	2,4	-	0,4	-	7,0	65	0,28	1,90	-	0,19	-	-	0,3	0,35	0,015	0,019	105
		0,91	0,44	184		0,06	0,2	0,05	0,6		0,2	0,0	6,1	54	0,05	0,01	0,7	0,02		-	0,1	0,14		0,013	82
4. Peilput 1 (nabij productieput 1) PB-B	38	-	0,05	86	34291	0,46	2,2	-	2,8	-	0,9	-	2,8	75	0,27	1,89	-	0,19	-	-	-	0,21	0,012	0,011	13
		0,21	0,10	56		0,14	0,2	0,06	0,4		0,7	0,0	2,8	49	0,04	-0,04	0,5	0,05		-	0,1	0,12		0,009	6
5. Peilput 1 (nabij productieput 1) PB-C	55	-	-	37	6897	0,26	2,0	-	2,6	-	1,5	-	4,8	158	0,24	1,89	-	0,31	-	-	-	0,15	0,014	0,016	9
		0,07	-0,01	29		0,03	0,0	0,03	11,2		0,3	0,0	5,0	127	-	-0,03	0,2	0,07		-	0,0	0,05		0,011	5
6. Productieput 2 (koude bron)diepe peilbuis	32	-	-	17	7012	0,15	1,9	-	1,8	-	1,5	-	2,5	58	0,21	1,89	-	-	-	-	-	0,09	0,012	0,006	5
		0,07	0,03	21		0,01	0,0	0,04	2,0		2,1	0,0	2,4	72	-0,02	-0,04	0,1	0,08		-	0,0	0,04		0,007	1
7. Productieput 2 (koude bron)ondiepe peilbuis	92	-	0,28	76	34504	0,62	2,5	-	3,9	-	1,9	-	6,4	157	0,28	1,89	-	0,15	-	-	-	0,06	0,013	0,013	86
		0,40	0,45	52		0,17	0,3	0,14	1,3		1,2	0,1	7,2	183	0,08	-0,02	0,7	0,02		-	0,0	0,08		0,008	87
8. Peilput 2 brede peilbuis	78	0,75	0,13	394	213	0,30	2,2	-	2,6	-	1,6	0,17	5,6	196	0,35	1,92	-	-	-	-	-	-	0,015	0,008	30
		0,23	0,10	99		0,19	0,1	0,04	0,3		8,8	0,0	3,4	163	0,19	0,04	0,4	0,49		-	1,1	0,42		0,019	16
9. Peilput 2 smalle peilbuis	40	0,01	0,05	95	13077	0,31	2,1	-	2,7	-	3,1	-	2,8	69	0,24	1,90	-	0,89	-	-	-	-	0,012	0,011	10
		0,13	0,11	53		0,10	0,2	0,00	0,5		1,7	0,0	2,2	59	-0,01	-0,04	0,1	0,07		-	0,0	0,05		0,007	6

in decimal comma notation for use in Dutch lan;
blanc: not measured / analysed
 - : not detected

Deltares

ARCADIS Design & Consultancy for natural and built assets

Sample	(ICPMS) La µg/L	(ICPMS) Ce µg/L	(ICPMS) Pr µg/L	(ICPMS) Nd µg/L	(ICPMS) Sm µg/L	(ICPMS) Eu µg/L	(ICPMS) Gd µg/L	(ICPMS) Tb µg/L	(ICPMS) Dy µg/L	(ICPMS) Ho µg/L	(ICPMS) Er µg/L	(ICPMS) Tm µg/L	(ICPMS) Yb µg/L	(ICPMS) Lu µg/L	(ICPMS) Hf µg/L	(ICPMS) Ta µg/L	(ICPMS) Hg µg/L	(ICPMS) Tl µg/L	(ICPMS) Pb µg/L	(ICPMS) Th µg/L	(ICPMS) U µg/L
1.Productieput 1 (warme bron) PP-D	0,34	0,34	-	0,72	0	0,001	0,01	-	0	-	-	-	0,008	-	-	0,002	0,03	0,16	-	0,001	0,012
2.Productieput 1 (warme bron) PP-OD	0,35	0,36	-	0,74	0,01	0,006	0,02	-	0,01	-	0,00	-	0,011	-	-	0,002	0,02	-	-	0,002	0,010
	0,03	0,05	0,1	0,06	0,02	0,008	0,02	0,003	0,02	0,004	0,01	0,002	0,010	0,001	0,005	0,014	0,65	0,12	0,0140	0,004	0,008
3. Peilput 1 (nabij productieput 1) PB-A	0,36	0,39	-	0,75	0,01	0,008	0,02	-	0,01	-	0,01	-	0,013	-	-	0,002	0,02	-	-	0,002	0,011
	0,04	0,07	0,1	0,05	0,01	0,008	0,02	0,003	0,02	0,004	0,01	0,001	0,009	0,001	0,004	0,039	0,36	0,10	0,0192	0,003	0,009
4. Peilput 1 (nabij productieput 1) PB-B	0,35	0,37	-	0,74	0,01	0,003	0,02	-	0,01	-	0,00	-	0,011	-	-	0,002	-	-	-	0,002	0,011
	0,02	0,05	0,0	0,04	0,01	0,003	0,01	0,002	0,01	0,002	0,01	0,001	0,005	0,001	0,003	0,022	0,25	0,04	0,0003	0,002	0,005
5. Peilput 1 (nabij productieput 1) PB-C	0,34	0,36	-	0,73	0,00	0,002	0,01	-	0,00	-	0,00	-	0,009	-	-	0,002	-	-	-	0,002	0,059
	0,01	0,02	0,0	0,01	0,00	0,001	0,00	0,000	0,00	0,001	0,00	0,000	0,002	0,000	0,002	0,011	0,21	0,03	0,0006	0,001	0,004
6. Productieput 2 (koude bron)diepe peilbuis	0,34	0,34	-	0,72	0	0,001	0,01	-	-	-	-	-	0,008	-	-	0,002	-	-	-	0,002	0,005
	0,00	0,00	0,0	0,00	0,00	0,000	0,00	0,000	0,00	0,000	0,00	0,000	0,000	0,000	0,002	-	0,19	0,02	0,0019	0,001	-
7. Productieput 2 (koude bron)ondiepe peilbuis	0,35	0,37	-	0,74	0,01	0,006	0,02	-	0,01	-	0,00	-	0,012	-	-	0,002	-	-	-	0,002	0,011
	0,04	0,07	0,1	0,05	0,02	0,007	0,02	0,002	0,01	0,003	0,01	0,002	0,008	0,001	0,003	0,022	0,22	0,12	0,0335	0,002	0,010
8. Peilput 2 brede peilbuis	0,40	0,52	0,01	0,81	0,02	0,007	0,03	-	0,02	-	0,01	-	0,017	-	-	0,002	-	-	-	0,002	0,064
	0,13	0,16	0,0	0,04	0,02	0,009	0,01	0,007	0,01	0,006	0,01	0,003	0,008	0,003	0,004	0,011	0,19	0,09	0,0280	0,003	0,008
9. Peilput 2 smalle peilbuis	0,36	0,39	-	0,75	0,01	0,003	0,02	-	0,00	-	0,00	-	0,010	-	-	0,002	-	-	-	0,003	0,097
	0,02	0,04	0,0	0,02	0,01	0,002	0,01	0,001	0,00	0,001	0,00	0,000	0,002	-	0,001	0,000	0,14	0,02	0,0050	0,001	0,013

in decimal comma notation for use in Dutch lan

blanc: not measured / analysed

- : not detected