IEA HPT Annex 52 - Long-term performance monitoring of GSHP systems for commercial, institutional and multi-family buildings

Case study report for the Xylem HT-BTES plant in Emmaboda, Sweden

Efficiency by using heat pumps for extraction of stored heat

Olof Andersson

Leif Rydell

Niklas Håkansson

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Preface

This report is part of the work within IEA HPT Annex 52 - *IEA HPT Annex 52 - Long-term performance monitoring of GSHP systems for commercial, institutional and multi-family buildings*, with project period January 1st 2018 to December 31 2021. Annex 52 Operating Agent is Sweden.

Annex 52 aims to survey and create a library of quality long-term measurements of GSHP system performance for commercial, institutional and multi-family buildings. While previous work will be surveyed, the emphasis of the annex is on recent and current measurements. The annex also aims to refine and extend current methodology to better characterize GSHP system performance serving commercial, institutional and multi-family buildings with the full range of features shown on the market, and to provide a set of benchmarks for comparisons of such GSHP systems around the world.

The results from the annex will help building owners, designers and technicians evaluate, compare and optimize GSHP systems. It will also provide useful guidance to manufacturers of instrumentation and GSHP system components, and developers of tools for monitoring, controlling and fault detection/ diagnosis. This will lead to energy and cost savings.

This report has been worked out by:

Olof Andersson, Geostrata HB was the formal project leader of DP2. He designed the BTES storage and has followed up the performance of system from the early start in 2010.

Leif Rydell, Reikab AB was the former operating manager of energy systems at Xylem. He was responsible for operation of the BTES system during his employment up till 2019.

Niklas Håkansson, Xylem Water Solutions, is the current operating manager of the energy systems, at Xylem Emmaboda. He has provided the data for the project since 2019.

The work that led to this report has been funded by Swedish Energy Agency, Xylem Water Solutions, Geostrata HB and Reikab AB.

Summary

The Xylem industry in Emmaboda is a manufactory of pumps also known Flygt. The industrial area covers some 330 000 m^2 of which 110 000 m^2 are workshops and other buildings. It also contains a foundry with a couple of melting ovens that produce a lot of waste heat. There are also a large number of other heat sources that are linked to an internal heating system, partly applied with heat pumps to capture and utilize low temperate waste heat as well.

In order to increase the waste heat recovery, HT-BTES (High Temperature Borehole Thermal Energy Storage) for seasonal storage was constructed and put into operation in 2010. It consists of 140 boreholes, 150 m deep. As BHE (Borehole Heat Exchanger) a coaxial solution is used that makes the heat carrier having a direct contact with the bedrock. It also makes it possible to have reversed flow for thermal stratification of stored heat.

The hydraulic contact with the bedrock makes the heat carrier pressure being controlled by the of the groundwater level. This means that the fluid is circulated under vacuum pressure (approx. -35 kPa) that caused technical problems with gas and cavitation the first years of operation.

After 4 years the storage temperature reached approx. +45°C where it stayed up till summer 2018 even if considerable amount of heat was stored. The main reason for the lack of temperature increase was probably that the heat spread sideways and caused larger heat losses than expected. Even worse, not much heat could be recovered due to a considerable lower temperature than designed.

To increase the heat extraction from the storage a set of heat pumps was installed with a maximum capacity of 800 kW. The heat pump system was taken into operation in September 1, 2018 and has now been monitored for three full years (up till August 31, 2021). During this period 7120 MWh of waste heat was stored, and the heat pump system produced 7 340 MWh of which 5 900 MWh came from the storage. Electricity used for the heat pumps amounts to 1 440 MWh. This means a COP of slightly above 5.0 as an average.

The COP for direct use of waste heat that consists of a mixture with direct heat exchanging and capture by heat pumps has been calculated to approx. 7.0.

The SPF0 for heating and cooling, injected and extracted heat from BTES, is approx. 160, while SPF1 for heating, electricity for waste heat capture included, comes out with 3,9 and SPF2, with all circulation pumps in the heating system included, 3.8.

The SPF1 for cooling is just above 13, and SPF2, with circulation pumps included, approx.12.

The Annex 52 boundary schema is not truly applicable for the type of energy flows represented by Xylem. For this reason the boundaries has been simplified and higher levels than SPF2 excluded.

The most important lessons learnt are:

- This type of BTES systems works excellent for process cooling
- Desired storage temperature was not reached, mainly due to heat losses sideways
- Extraction temperature drops quickly to an unusable temperature level
- A heat pump system for a heat extraction makes the storage work both ways and should have been considered, or prepared for, already at the design stage in 2009.
- Coaxial borehole heat exchangers of the type used for Xylem have low thermal resistance and allow thermal stratification. However, vacuum pressure at circulation may create serious technical problems.

Contents

BACKGROUND

The building

Xylem Water Solutions, former Flygt AB and ITT Flygt, is one of the leading manufacturers of submersible pumps and mixers in the world. The industrial plant in Emmaboda, Sweden, is the largest one. The location is shown in figure 1. It's the working place for approx.1 200 people.

Figure 1: *Location of Xylem Emmaboda and the main office building (Photo: QTF Sweden AB).*

The industry area covers 330 000 m^2 of which 110 000 m^2 are occupied by building's with different functions. Except for the main office building there are workshops of different kinds, and a foundry, see Figure 2. Practically all components for pumps or mixers are fabricated on place.

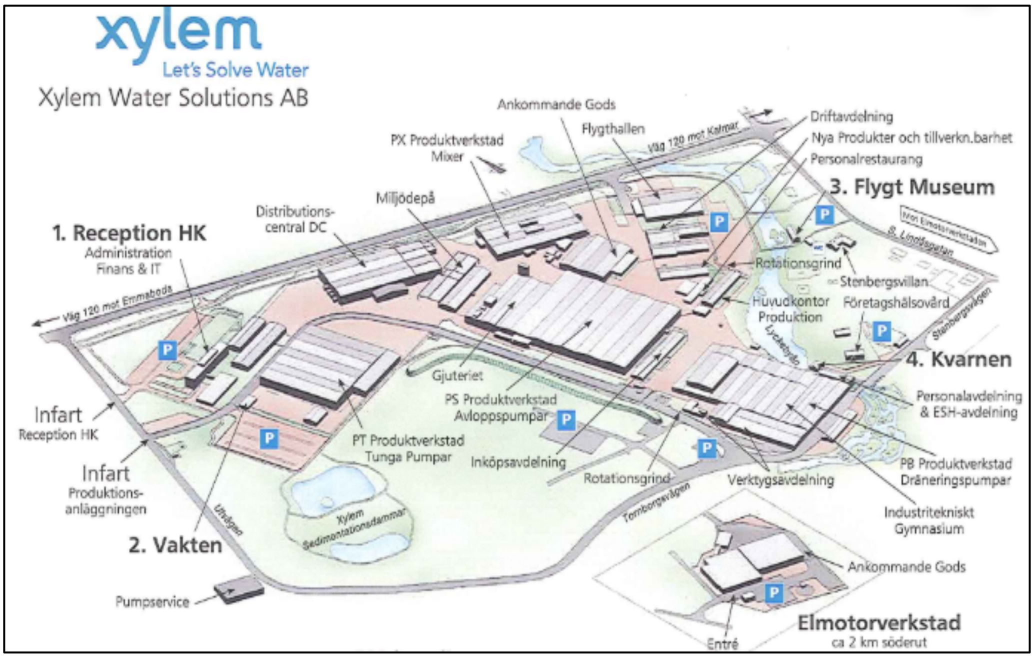


Figure 2: *The industrial area has different types and functions of buildings*.

For space heating the industrial area has an internal heating grid primarily supplied with waste heat from the cooling processes and secondary by an external district heating net.

In order to increase the utilization of waste heat HT BTES (High Temperature Borehole Thermal Energy Storage) was constructed and put into operation during the summer 2010. This way the amount of bought district heat was expected to decrease and less heat disposed to the atmosphere through the cooling tower. The concept is illustrated in Figure 3.

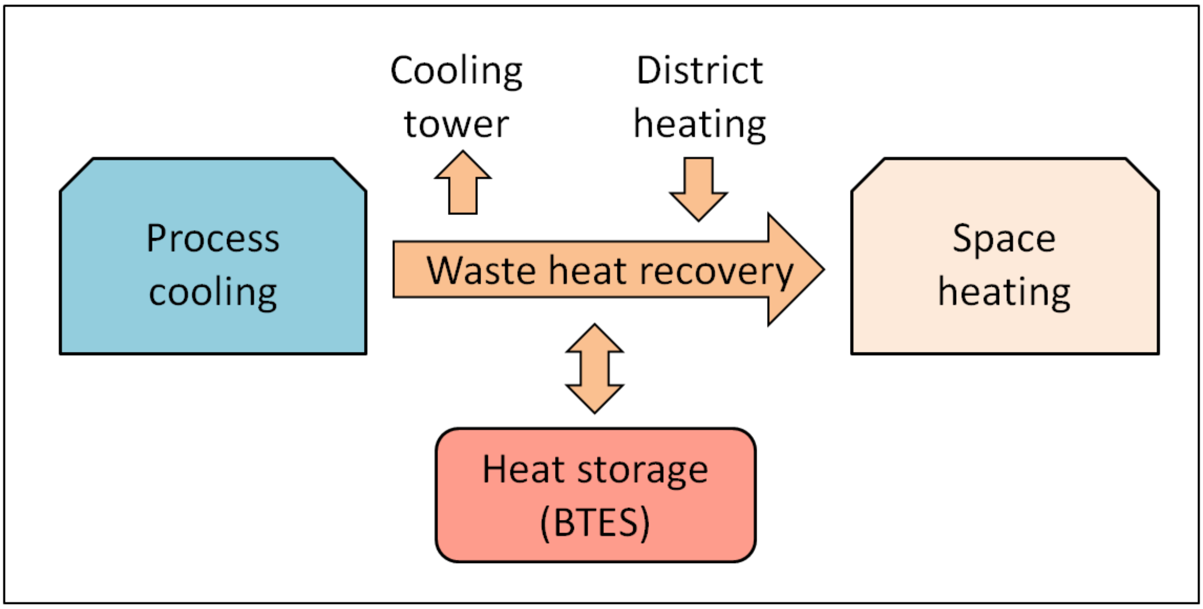


Figure 3: Concept using BTES for seasonal storage of waste heat and this way replace bought district heat and relief operation of the cooling tower.

The HT-BTES concept was realized in 2009-2010 and was evaluated the first time after 5 years of operation (Nordell at al 2016). In this evaluation it was suggested to add a heat pump system to the storage in order to have a more efficient heat extraction.

In 2018 the heat pump system for extraction of stored heat was installed. It was taken into operation Sept 1, 2018. In this case study the results of the system performance are presented covering three full heating seasons compared to the storage performance a couple of years prior to the heat pump installation, see Table 1.

Table 1 Summary of the building features

Location	Emmaboda
Year of building construction	Mayor part of buildings >30 years
Ground source system operation start date	Late summer 2010
Building Type	Mainly workshops
Building floor area	110 000 m²
Analyzed monitoring period	Sept 01, 2016- Aug 31, 2021
Unique features of the system	Borehole Thermal Energy Storage (BTES) used for both heating and process cooling

The overall system configuration for the Xylem industry buildings is given in Table 2.

Table 2 Summary of the system configuration

Heat distribution	Local heating grid
Cooling distribution	Local cooling grid and the heating grid for BTES
Domestic hot water (DHW) production by system	Spottily from the local heating grid
Supplementary heat for space heating	District heat
Supplementary heat for DHW	None
Supplementary cooling	Cooling tower
Nominal capacity of supplementary heating for space heating	5 000 kW
Nominal capacity of supplementary heating for DHW	None
Nominal capacity of supplementary cooling	1 500 kW
Heating load (average for the monitored period)	11 000 MWh/year (100 kWh/m^2,y)
Process cooling load (rough estimate)	9 000 MWh/year
DHW	Not monitored (insignificant)
Heat pump type, BTES system	Water-to-water
Heat pump type, Waste heat capture	Water to water and air to water
Reversible	No
Compressor type, BTES HP system	2 x scroll
Speeds	Variable speed
Compressor type, Waste heat capture HP:s	Mainly piston, a few screws
Number of heat pumps	11
Nominal total heat pump heating capacity, BTES system	480 kW_{th}
Nominal total heat pump heating capacity, Waste heat capture	1 525 kW_{th}
Nominal total heat pump heating capacity available for DHW	NA
Nominal total heat pump cooling capacity [kW_{th}]	1 140 kW_{th}
Nominal cooling capacity BTES system (at delta T 10ºC)	800 kW_{th}
Refrigerant, BTES HP system	R410A
Refrigerant, Waste heat capture HP:s	Mainly R134a

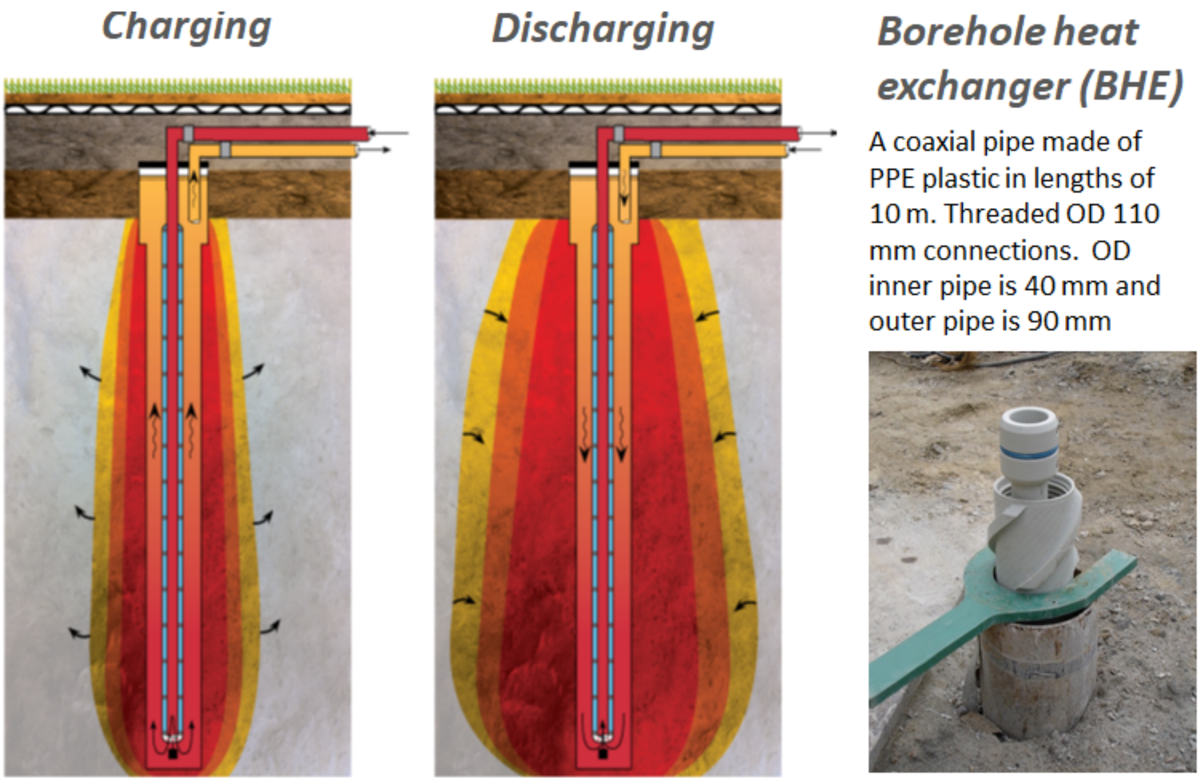
The ground source system

The HT-BTES consists of 140 boreholes, 150 m deep and with a c/c-distance of 4 m. It is located on a flat grass surface just outside the factory area and has a rectangular shape measuring 60 x 40 m. It was constructed during the winter of 2009-2010.

The boreholes have steel casing (OD 140 mm) through the overburden, in average 9 m in length. In the rock that consists of granodiorite the dimension of the boreholes are in general 115 mm. The drilling method was hammer drilling with compressed air and a down-the-hole hammer.

A type of coaxial Borehole Heat Exchangers (BHE) was developed in the project. The BHE consist of double pipes with intermediate insulation consisting of non-convective water, kept in place by swelling rubber rings. The BHE was installed in lengths of 10 m with threaded connections, see Figure 4.

An advantage using this type of BHE is that it allows for bidirectional flow. Thus, the highest storage temperature can always be located at the bottom of the storage, see Figure 4. Another advantage is that the thermal resistance is significantly less compared to conventional U-pipes. The latter option usually has a value around 0.08 K(W/m). The resistance of the coaxial heat exchanger was measured by a thermal response test to be 0.02 K(W/m). The test also indicated a borehole thermal conductivity close to 3.0 W/m,K



A coaxial pipe made of PPE plastic in lengths of 10 m. Threaded OD 110 mm connections. OD inner pipe is 40 mm and outer pipe is 90 mm

Figure 4: Coaxial borehole heat exchanger with dual flow function. The flow is reversed when discharging compared to charging. Thus, the temperature is always the warmest at the bottom of the storage which reduces heat losses and provides the highest possible temperature at extraction of heat (Photo: Olof Andersson).

The boreholes are divided into seven sections (A-G) with 20 holes in each, see Figure 5. The three inner sections are thought to have the highest temperature and the four outer ones to act as a buffer zone with slightly lower temperatures. The idea behind this lay-out is to adjust the extraction temperature to fit the demand. To achieve this function control valves are placed on the assembly pipes in the storage central, as shown in the figure.

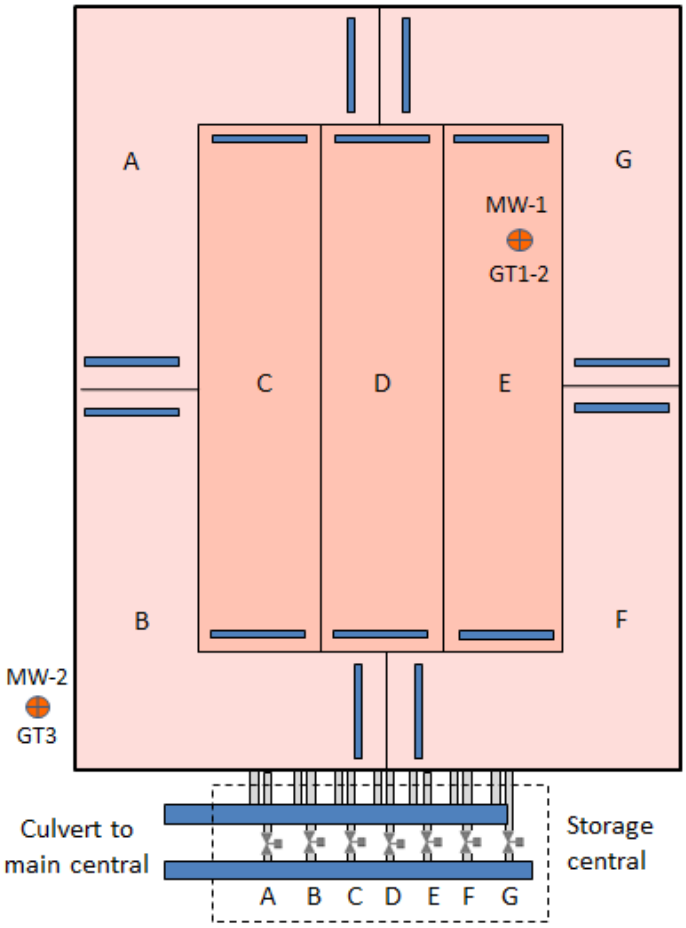


Figure 5: Design of the borehole storage with seven sections (A-F). Each section has 20 boreholes of which two are in series. The boreholes are connected with OD 40 pipes, and ends up to OD 90 field manifolds at both section ends (blue). Finally the field manifolds connects to larger manifolds in the storage central. MW: Monitoring well. GT: Temperature sensor

The boreholes are assembled by a horizontal pipe system (OD 40 mm) connected to the boreholes by fusion welded sleeves. All pipes used in the storage design are made of thermal resistant PPE-plastic. The pipe system, before it was covered is shown on the photo, Figure 6.

After the pipe system was filled with water and tested concerning its hydraulic function it was covered by sand (200 mm), with a plastic sheet on top. Then a layer of foam glass (400 mm) was placed on the plastic sheet with a geotextile on top. Finally a layer of topsoil (300 mm) was used, which now is forming a natural lawn.

Figure 6: Photo from the summer 2010 showing the horizontal pipe system (gray) on top on sand. The blue colored pipes on the surface are field manifolds and in mid bottom one out of two main manifolds, now placed in the storage technical room.(Photo: Leif Rydell)

The BTES system is connected to internal space heating grid by a large heat exchanger (HEX) designed for exchange of some 1 000 kW. On the storage side the heat carrier (water) is circulated and on the other side the internal space heating system. The flow on the storage side can be reversed to allow the two different modes of operation, charging and discharging. The principal flowchart covering the total heating and cooling system is shown in Figure 7.

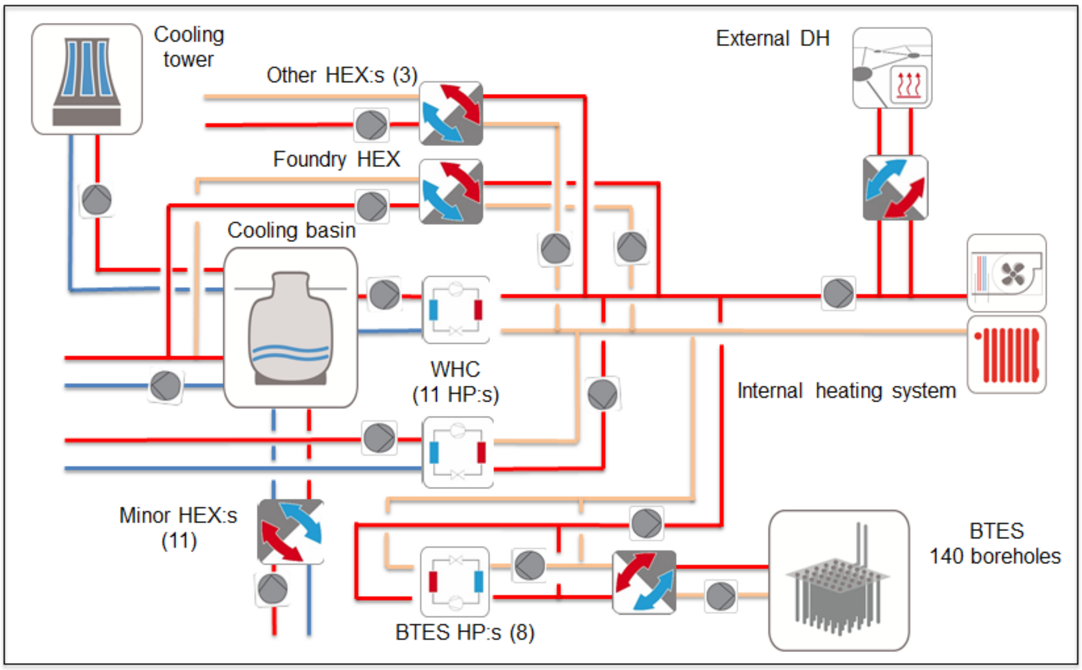


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Figure 7: Principal flow chart with BTES as a seasonal storage of waste heat from process cooling

The flow chart shows how excess heat from the cooling processes directly or by means of 11 heat pumps (WHC) is stored in BTES and with lack of heat in the internal space heating system is recovered. The eight BTES heat pumps were added in September 2018.

Waste heat from the process cooling system is captured from a number of heat exchangers and heat pumps and is directly used during the space heating season. When not being used directly this heat is stored in the BTES.

The BTES system was designed for a maximum flow rate of 25 l/s able to store 3,600 MWh/a at a maximum supply temperature of 70ºC. It was expected to reach a charging temperature of +60ºC at the end of summer and a discharging temperature of +40ºC at the end of the space heating season. However, in practice these figures have never been achieved. The actual storage capacity after the heat pump system installation is given in Table 3.

Table 3: Summary of the BTES storage system configuration

Heat distribution Distribution temperature	To the factory internal heating system 40-60°C
Cooling distribution Distribution temperature	To the factory internal cooling system 20-45ºC
Supplementary heat for space heating	External district heat
Supplementary cooling	Cooling tower
Nominal capacity of supplementary heating for space heating	5 000 kW (linked to internal heating system)
Nominal capacity of supplementary cooling	2 000 kW (cooling tower)
Heating load BTES HP system (average 3 years)	2 445 MWh/year
Cooling load BTES HEX (average 3 years)	2 370 MWh/year
Heat pump type BTES HP-system	Water-to-water
Reversible	No
Compressor type	2 x scroll
Speeds	Variable speed
Number of heat pumps	8 in parallel
Nominal total heat pump heating capacity	480 kW (0/55ºC)
Operating heat pump capacity	800 kW (28/55ºC)
Refrigerant	R410A

In the Tables 4 and 5 the basic data regarding the BTES system are summarized.

Table 4: Summary of the ground source and sink

Ground source	Vertical boreholes
Loop type	Coaxial, half open
Ground composition	Granodiorite
Groundwater level [m]	Approx. 3,5 m below surface (stable over the year)
Annual mean air temperature (average 20 years)	8°C
Undisturbed ground temperature (measured)	8,5°C
Design ground thermal conductivity (TRT measured)	2,9 W/m,K
Specific ground heat capacity (estimated)	$2.5\ \mathrm{MJ/(m^3 \cdot K)}$
Minimum ground heat exchanger exiting fluid temperature	25°C
Maximum ground heat exchanger exiting fluid temperature	60°C

Table 5: Summary of the ground heat exchanger

Number of boreholes	140
Borehole length	150 m
Total borehole length	21 000 m
Average distance between boreholes	4 m
Borehole geometric distribution	Rectangular
Borehole diameter	115 mm
Borehole filling material	Groundwater
Borehole heat exchanger type	Coaxial (pipe in pipe), open to the bedrock
Design Effective thermal resistance per unit length	0,02 Km/W (TRT measured)
Source side pipe characteristics	PEE OD40 PN10
Source side brine type	Water
Source side brine flow in operation	9-21 l/s (most commonly 18 l/s)

Monitoring

The insulating efficiency is measured with temperature sensors under and above the foam glass and in the upper part of the topsoil. For measuring the storage temperature there are two monitoring wells (MW), one inside and one a few meters outside the storage. In these wells temperature sensors are installed (GT1-3 in Figure 5). Furthermore, supply and return temperatures to and from each of the sections are measured, as well as the pressure in the two assembly pipes in the storage central.

From the main technical central, about 200 m from the storage, the heat carrier is circulated via a steel culvert using a frequency controlled circulation pump. Heat is supplied or extracted from the storage via a heat exchanger (HEX) that on the secondary side is connected to Xylem's internal heating grid. In the system there are sensors for instantaneous measurement of temperatures, flow and pressure, see Figure 8. In addition, electricity consumption for the heat pumps and the circulation pumps each side of the HEX.

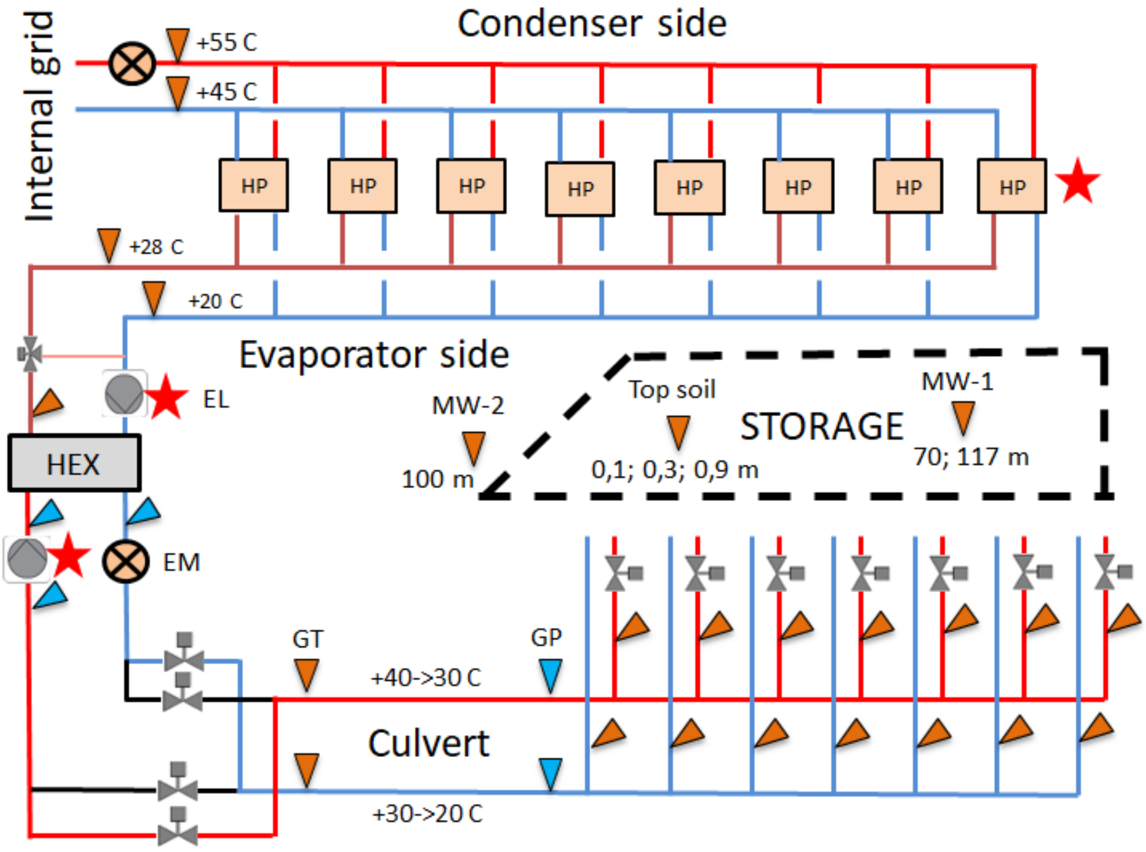

Figure 8: Simplified flowchart for heat extraction with sensors for energy measurement (EM), system pressure (GP) and temperatures (GT). In addition, electricity (red star) consumption is measured for heat pumps and circulation pumps

Performance metrics

For an industry with a BTES storage like Xylem has a complex flow of heat and cold and may not fit very well for boundary definitions. In this case the storage works both for cooling and heat extraction. The efficiency of the storage itself in terms of stored heat divided by recovered heat over a single year has been measured, but will not reflect the actual losses from the storage. The fact that a huge amount of heat has been stored for a number of years prior to the extraction such a calculation cannot be done. Still, the efficiency of the storage in terms of heat losses has been theoretically estimated to be in the order of 30 % (Nordell et al 2016).

By measuring heat produced from the storage and the electricity used for the circulation pump the Annex 52 system boundary H0 can be defined. By adding the electricity used for all heat pumps that produce heat to the internal heating grid the system boundary SPF1 can be defined and properly calculated. In this case a specific COP for the waste heat capture has been calculated based on measurements with the ClimaCheck method on six of these heat pumps (Carlsson 2015). By adding waste heat captured by direct heat exchanging and apply these mix for the season 2018/19 (Rao 2019) the resulting COP was found to be just above 7,0.

The boundary SPF2 is estimated adding electricity for all the circulation pumps on both sides of heat pumps and heat exchangers, as shown in figure 9. There are no reliable data for calculation of the boundary levels 3-5.

The boundaries suggested for Xylem is illustrated in Figure 9 and may serve as a boundary system for similar industries.

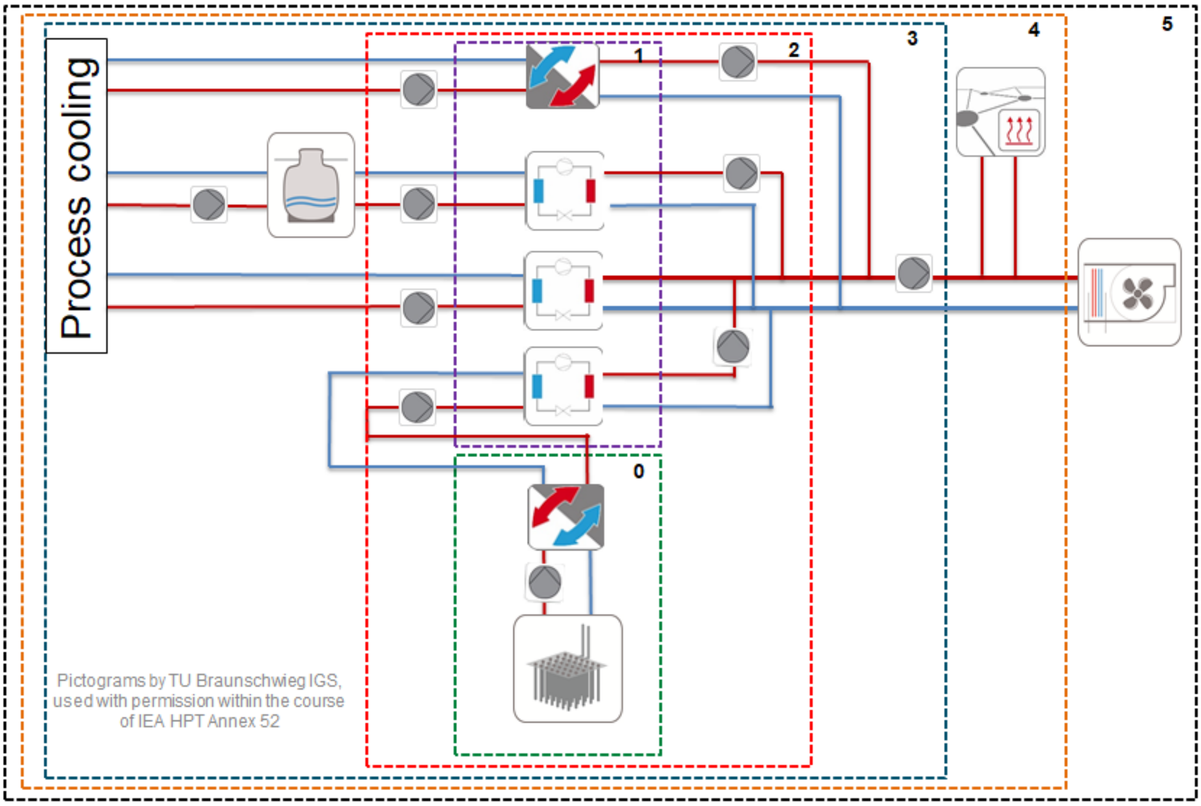

Figure 9: Proposed system boundaries for an industry with waste heat recovery from different sources and equipped with a seasonal underground storage

The boundaries for cooling are similar to that for heating, see Figure 10.

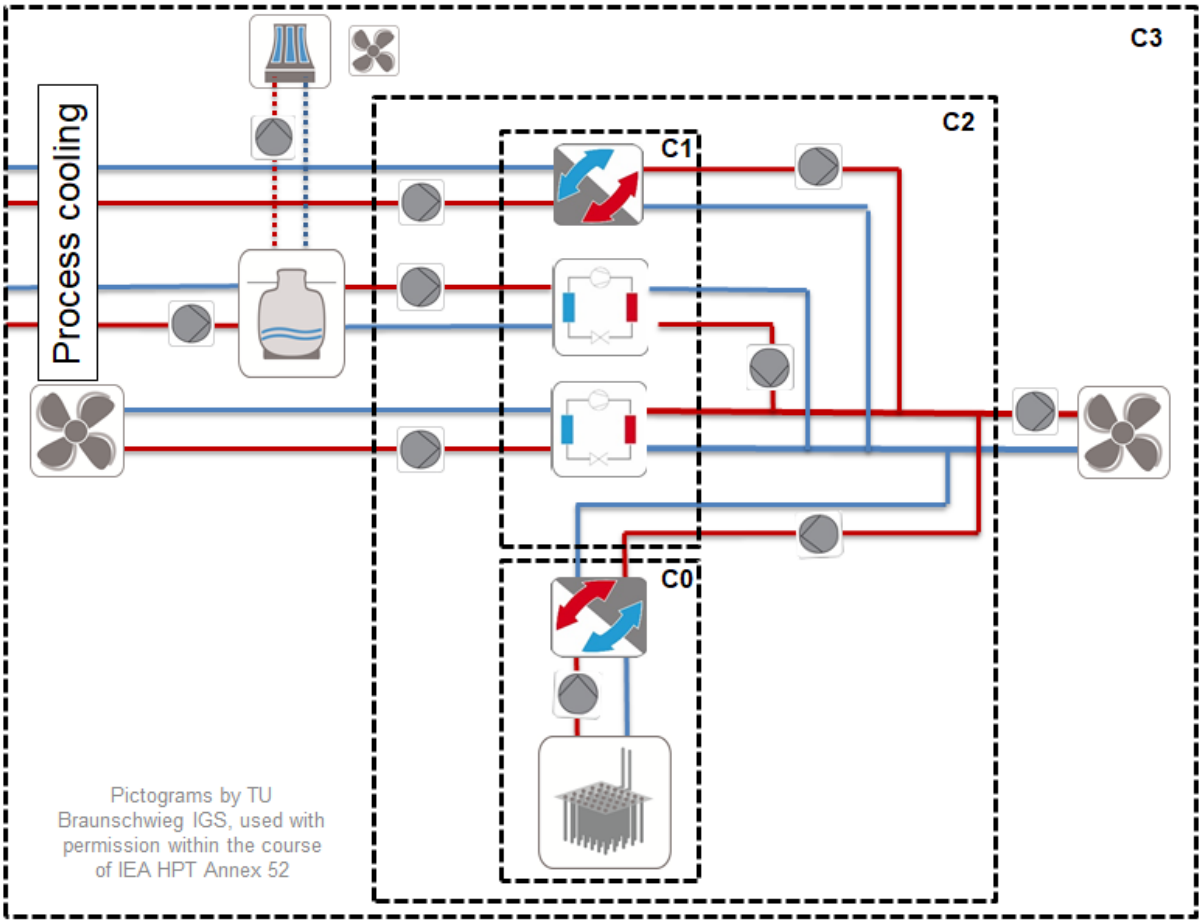

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Figure 10: Proposed system boundaries for cooling applied to an industry with process cooling combined with heat storage and equipped with a seasonal underground storage.

The boundaries for heating and cooling are simplified compared to the Annex 52 schema, and are defined in Table 6.

Table 6: Calculated system boundaries for the system according to the Annex 52 boundary schema.

Boundary description	HPT Annex 52 Boundary levels				
	H0/C0		H1/C1		H2/C2
Ground Source circulation pumps	X		X		X
All heat pump units, direct heat exchangers included			X		X
Circulation pumps for heat or cold distribution					X

PERFORMANCE MONITORING RESULTS

The monitoring results are focused on describing the differences prior to and after the installation of the BTES extraction heat pump system. The results cover the monitoring period September 1, 2016 to August 31 2021, of which the two first years are by heat exchanging only and last three years are with the extraction heat pump system taken into operation in September 2018.

Building heating and cooling loads

The flow of energy through a manufacturing industry like Xylem in Emmaboda is very complex. Basically a large amount of electricity is used for a number of manufacturing processes. Most of these processes are chilled with air or water, creating waste heat at different temperature levels. Some of the waste heat can be utilized for space heating directly during the winter, but in the summer it is disposed by cooling towers if not seasonally stored. In the Xylem case even low temperature sources are recovered by using heat pumps.

The load for heating is rather well known since peak loads are covered by external district heating. The load for cooling is mainly a function of production rate in the factories rather than the outdoor temperature. As illustrated in Figure 11, the load is therefore rather constant over the year. However, the load curve is in short terms quite peaky. For this reason peaks above 2 MW often occur. On the other hand much less cooling is needed during weekends and the summer vacation.

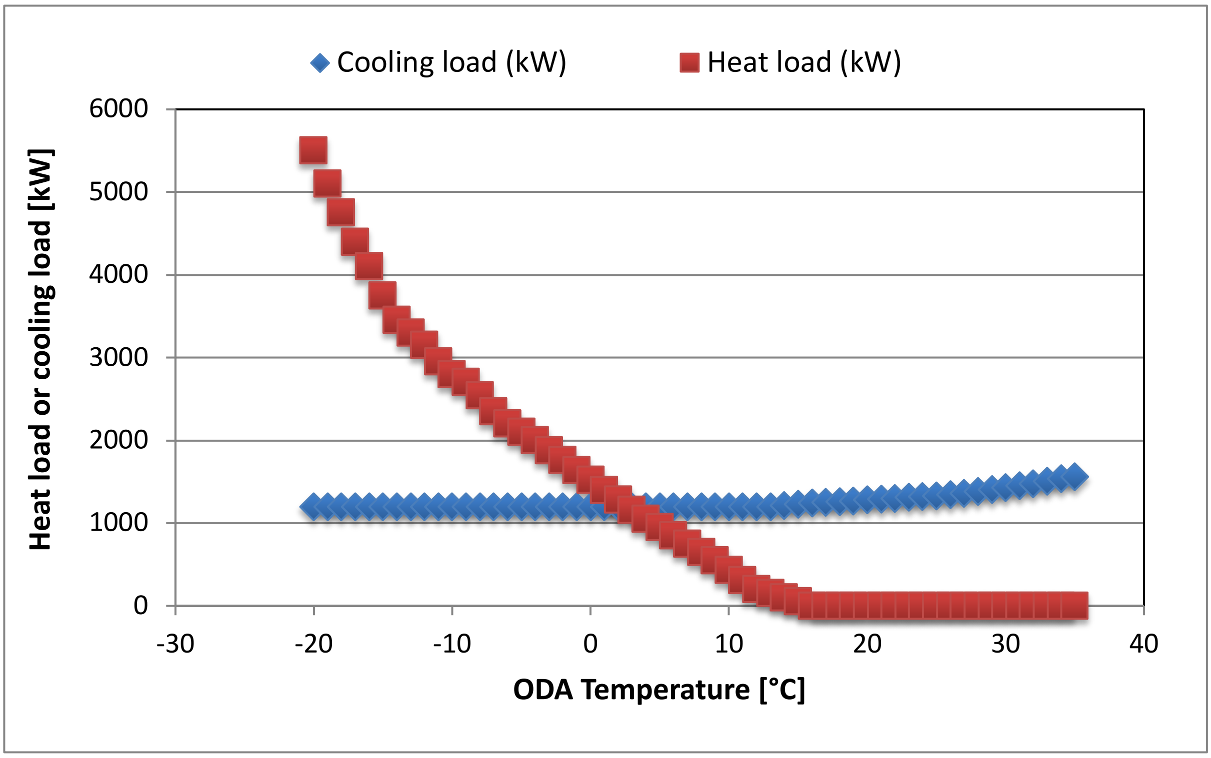

Figure 11: Energy signature for Xylem in Emmaboda

The overall heat demand varies with climate conditions and the amount of waste heat is a result of the production, measured as tons. During the last 20 years the production has been increased from 20 to

30 Mton/a. During the same period the heat demand has increased from some 11 to 13 GWh/a, and the directly used waste heat has increased from 1 to approx. 5 GWh/a. As shown in Figure 12 the externally provided district heat has gradually decreased from 9 to 3 GWh/a.

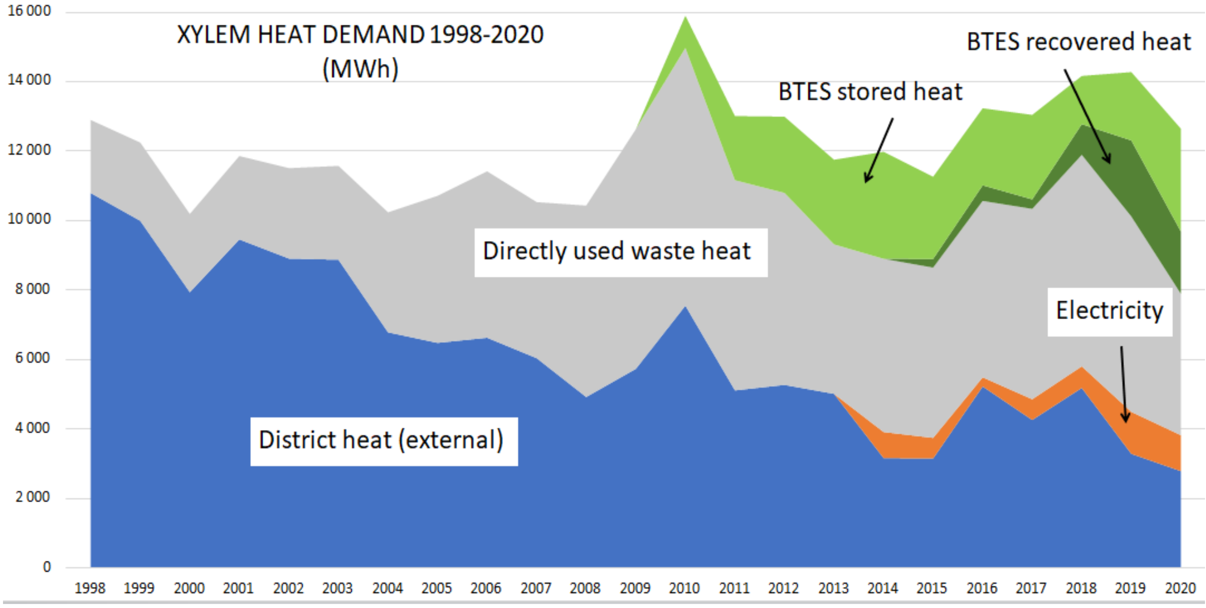

Figure12: Heat demand covered by different heat sources. Electricity shown is mainly for the heat pumps in the system

The annual heating and cooling load provided by the BTES the last five winter seasons, 2016/17 – 2020/21, is shown in Figure 13 and the background Figures in Table 7.

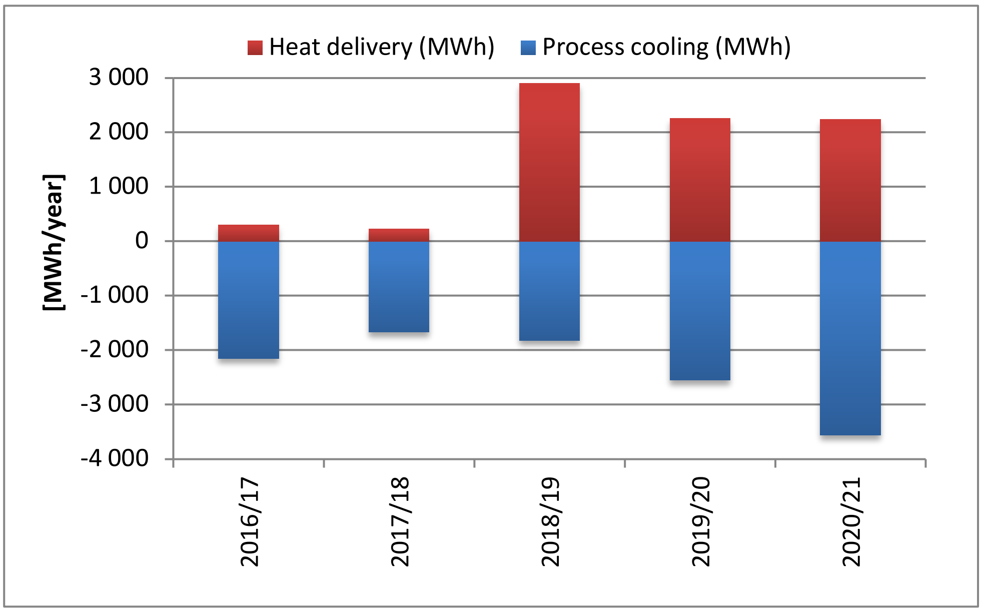

Figure 13: Annual heating and cooling provided by the BTES system

Table 7: Annual heating and cooling provided by the BTES system

Start of evaluation period	Sept 01 2016	Sept 01 2017	Sept 01 2018	Sept 01 2019	Sept 01 2020
End of evaluation period	**Aug 31 2017**	**Aug 31 2018**	**Aug 31 2019**	**Aug 31 2020**	**Aug 31 2021**
Building space heating load met by BTES system [MWh_{th}]	310	239	2 902	2 198	2 242
Industrial cooling load met by BTES system [MWh_{th}]	2153	1 667	1 606	2 164	3 349
Thermal energy extracted from the ground [MWh_{th}]	310	239	2 300	1 832	1 785
Thermal energy injected to the ground [MWh_{th}]	2153	1 667	1 818	2 550	3 556
Thermal balance ratio (extracted/rejected)	0,14	0,14	1,22	0,72	0,50
Heating load met by ground source (%)	2-3	2-3	24,5	20,8	22,6
Cooling load met by ground source (%),	No reliable data available, but > 50 %				

In Figure 14 the monthly load of heating and cooling provided by the BTES system is given. The heating demand reflects the winter climate conditions, such as a cold period Dec 2018-Jan 2019, see Table 8.

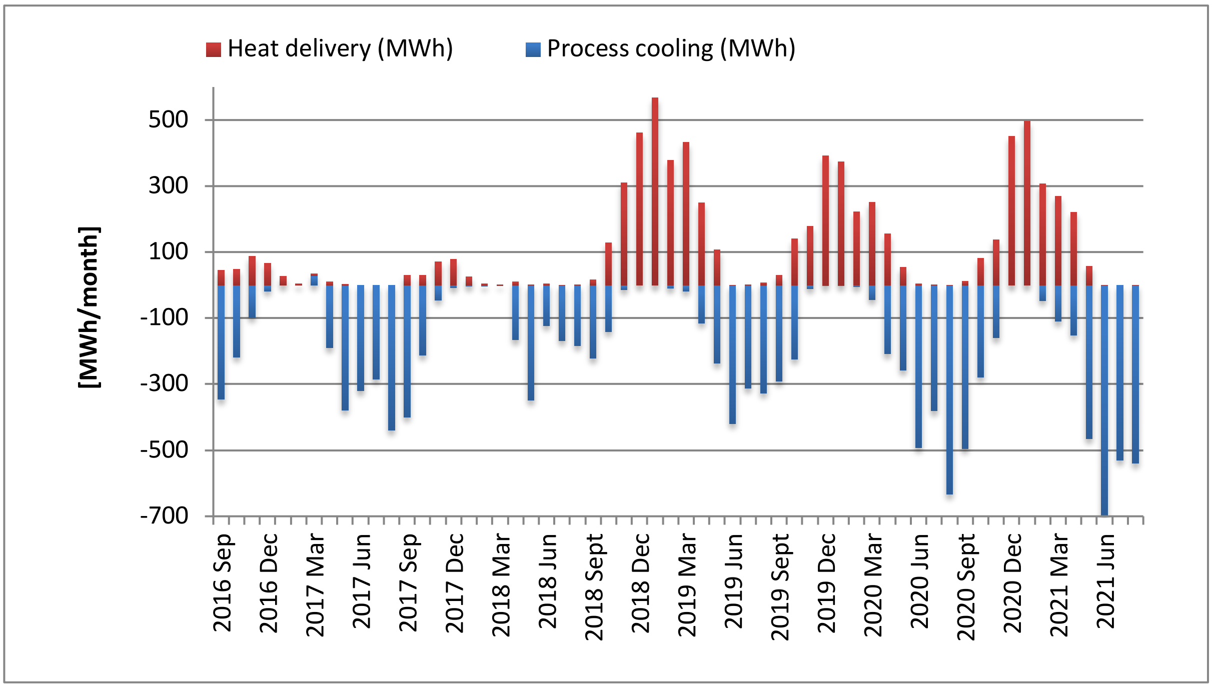

Figure 14: Monthly heating and cooling with the BTES system

Table 8: Average monthly temperature for the last three heating seasons

År	Okt	Nov	Dec	Jan	Feb	Ma	Apr
2018/19	8,2	3,9	1,8	-0,9	2,7	4,3	7,8
2019/20	7,6	4,0	2,4	4,4	3,3	3,5	7,2
2020/21	8,7	6,1	2,7	-1,6	-2,4	2,8	4,6

The figure also reflects the increased cooling capacity the last two years when the storage was cooled down by the increased extraction with the BTES heat pump system.

Ground heat exchanger performance

During the heating season heat is extracted and used for space heating. The entering and the exiting temperature vary depending on mode of operation and demand of heating and cooling. To understand the temperature curves given in Figure 15 the reversed flow shall be recognized between the two modes of operation.

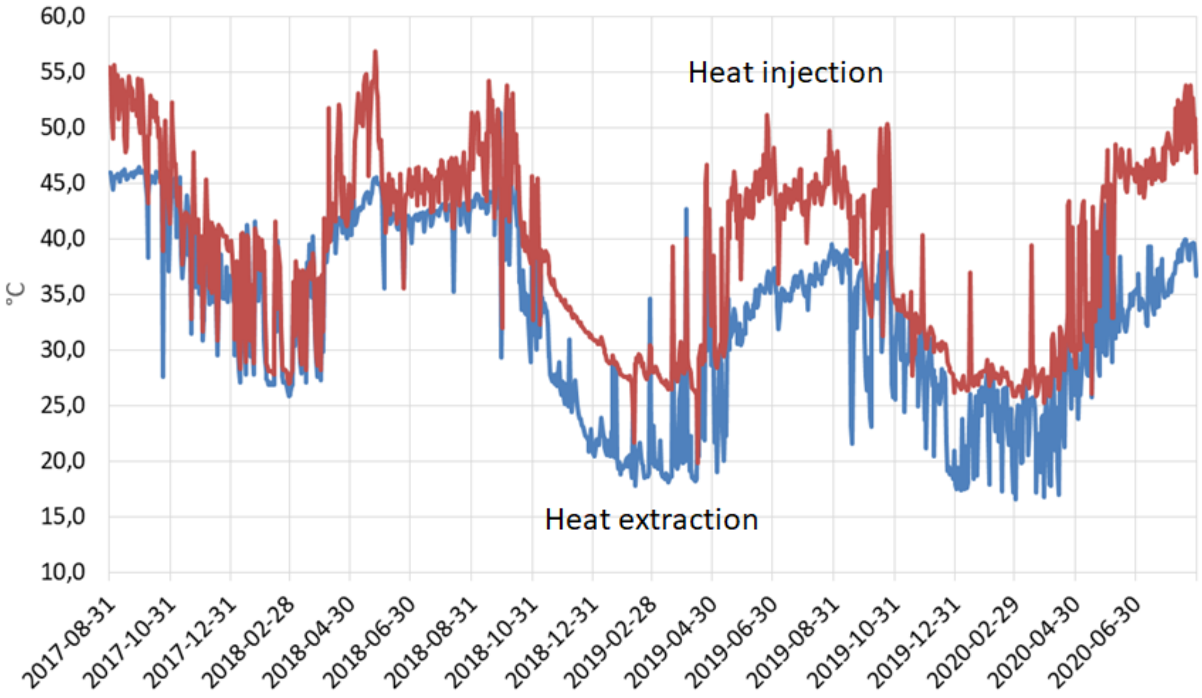

Figure 15: Entering and exiting temperatures over the years 2017-2020.

After the heat pump installation in Sept 2018 the delta T at heat extraction is around 8 °C, while during injection it's often 10°C or more. It can also be seen that heat extraction is interrupted by minor periods of injection, especially during autumn and spring. Furthermore, the heat injection temperature varies in the range of 45-55 °C and has become somewhat lower after the heat pump installation. The return temperature has dropped to be 20 °C or less at the end of the heating season since the heat pump installation.

The annual heat exchange during the monitoring period is shown in Figure 16. As shown in figure the cooling capacity of the storage has increased since the heat pump installation. This is due to the fact that the storage has gradually been cooled down as shown in Figure 17.

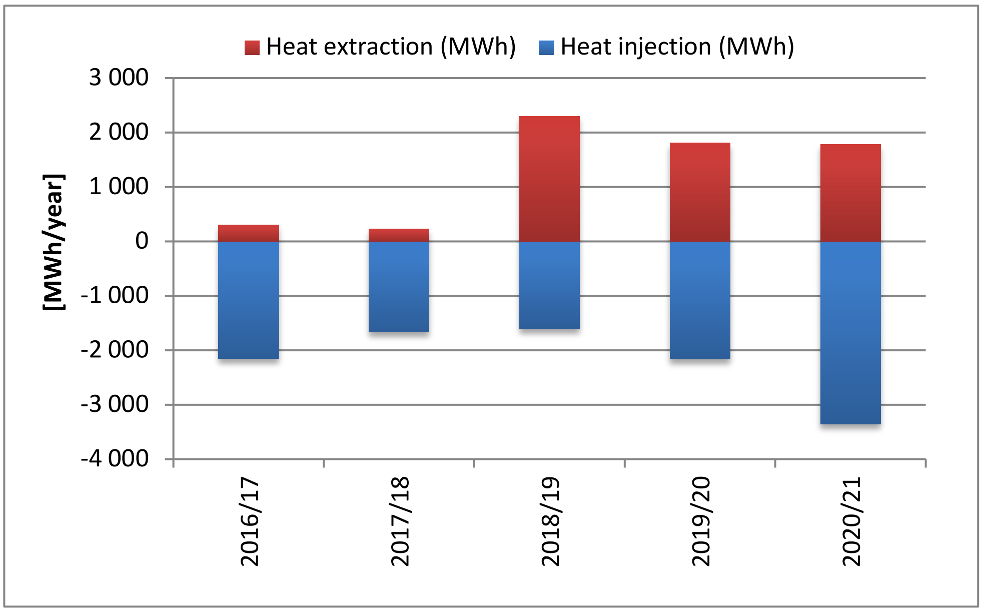

Figure 16: Annual ground heat exchange over the monitoring period

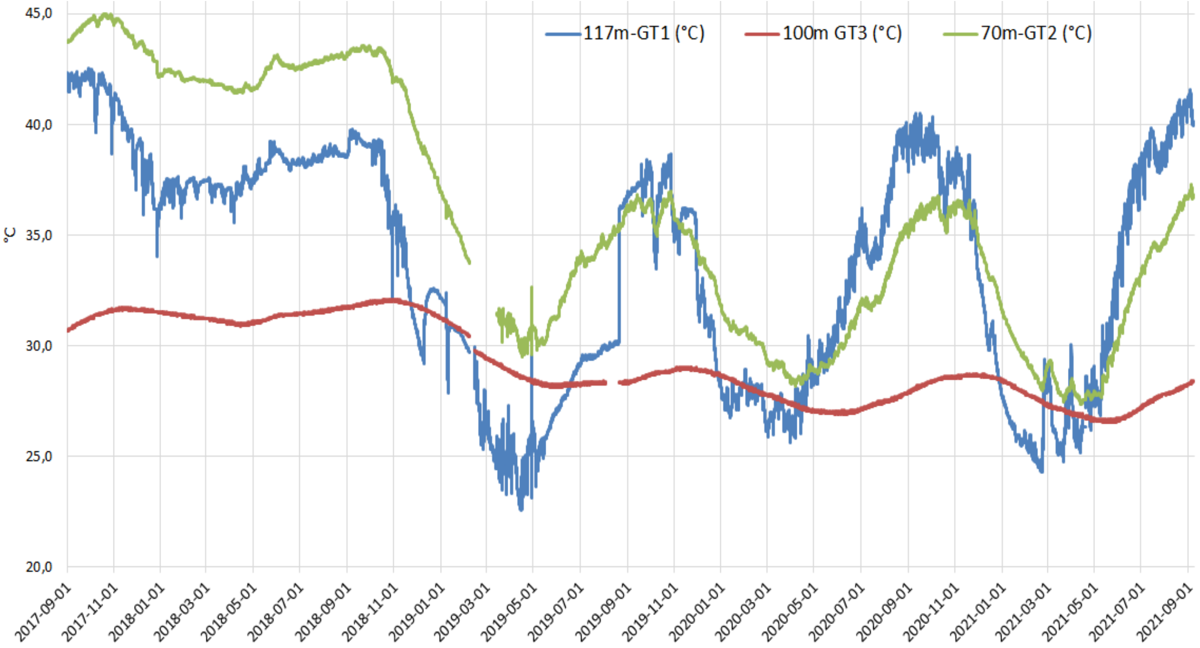

Figure 17: Temperature development inside and outside BTES. GT1-2 represents the inside of the storage and GT3 represents 10 m outside the storage.

To understand the inside temperature record, the monitoring well inside the storage has a direct hydraulic contact with the heat carrier (Ramstad et al 2021). The fiber measurements reported in this study also caused interruptions/displacements seen in February and August 2019.

Heat pump performance

The BTES heat pump system was taken into operation in early September 2018. The system consists of 8 units in parallel and uses the BTES as a source of heat.

On the evaporator side the incoming temperature is set for +28°C.and outgoing for +20°C.   .

The condenser side the incoming temperature is set for 45°C and the outgoing for +55°C. However, the actual temperature demand for heating fluctuates as a function of the out-door temperature.

The heat pumps are specially designed regarding the unusual high evaporator temperature. (The normal maximum inlet temperature is maximized to +15°C).

The nominal capacity range as a function of incoming evaporator and the outgoing condenser temperature is shown in Figure 18 where the heat capacity, in this case 40 kW, is defined at 0 incoming and 35 outgoing temperature.

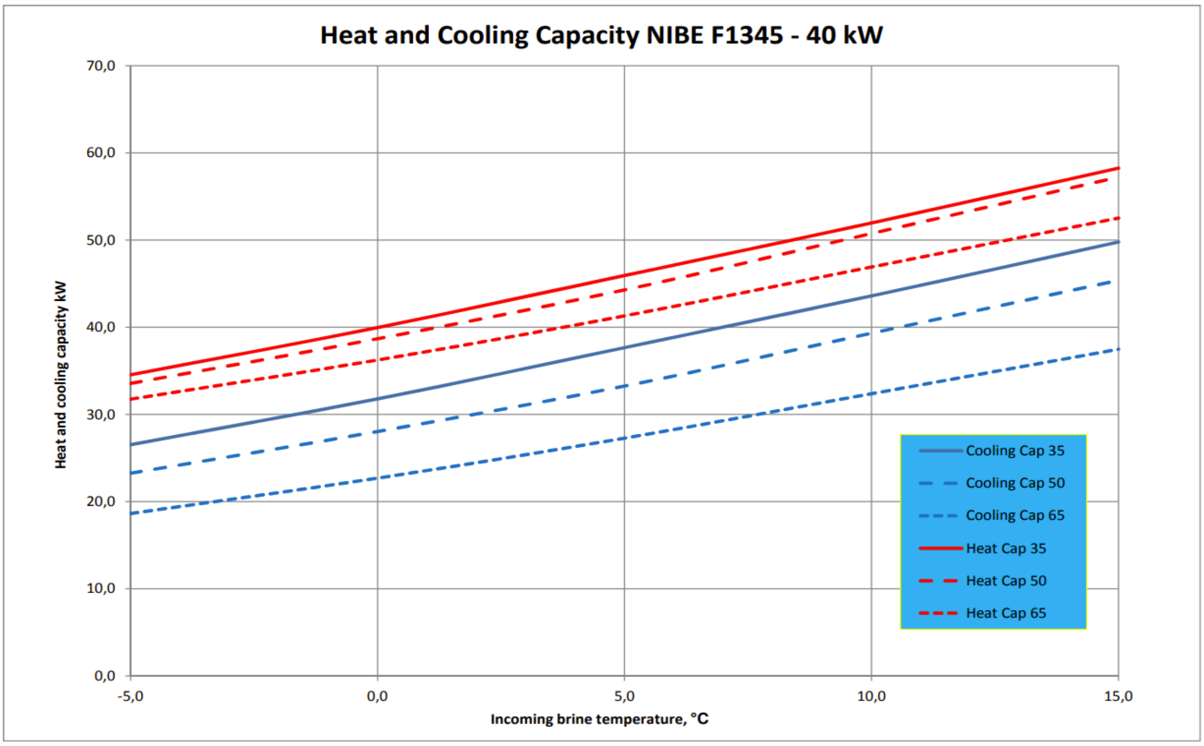

Figure 18: Heat pump capacity as a function of working temperatures (NIBE 2018)

In the case of Xylem the capacity is theoretically about 100 kW/unit at 28/55°C, or approx.800 kW all units together. This has also been confirmed with measurements in January 2019.

In Figure 19 the temperature on the evaporator side of the heat pump system is given for the first winter season. As can be seen the delta T is in the order of 8°C through the winter. It can also be seen that the incoming temperature is dropping a few degrees as the storage temperature is slowly decreasing towards the end of the heating season.

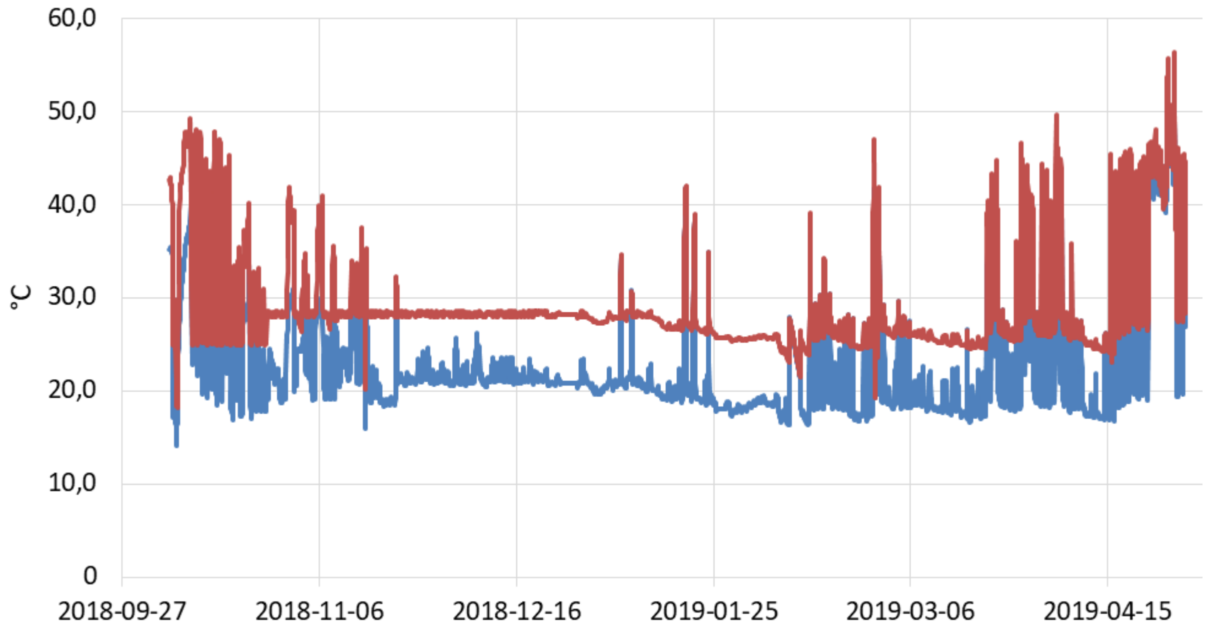

Figure 19: Incoming (red) and outgoing (blue) evaporator temperature the first heating season.

In Figure 20 the temperature on the condenser side is given for the heating season (2019/20). As can be seen the delta T vary due to supply temperature demand but is typically in the order of 10°C. It is also shown that the supply temperature typically is in the range of the set point, +55°C. However, occasionally supply temperature is +60°C or more the coldest days.

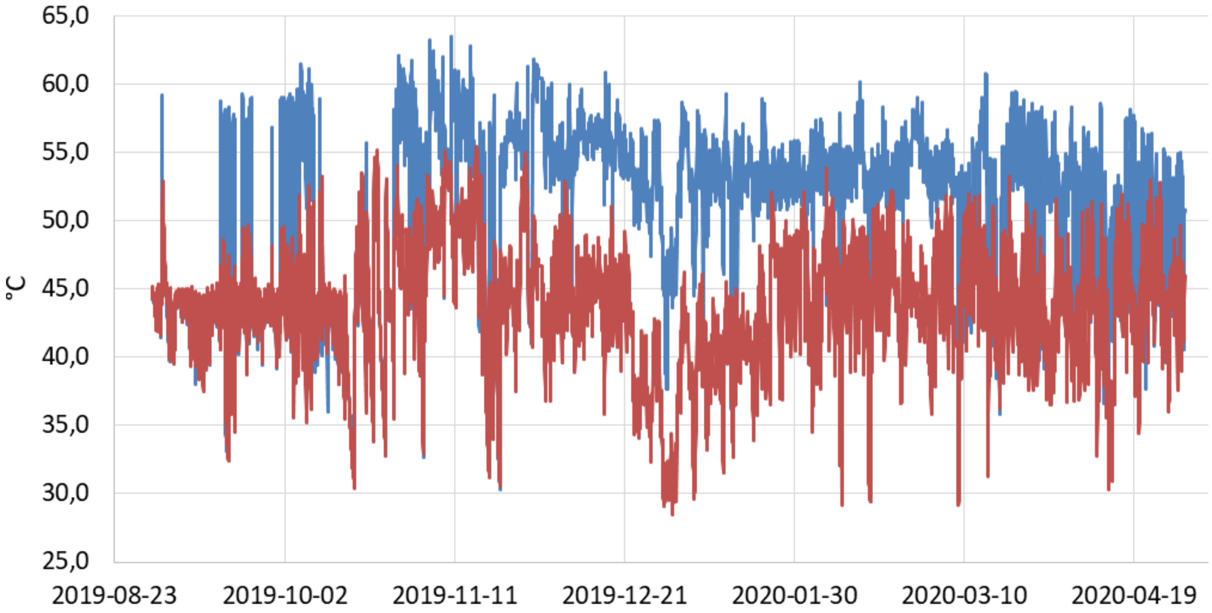

Figure 20: Incoming (red) and outgoing (blue) condenser temperature the second heating season.

The different winter conditions (see Table 8) also affect the seasonal COP of the heat pump system. The measured seasonal COP values are given in Figure 21 and the background values in Table 9.

The somewhat higher COP for 2019/21 is probably caused by a mild winter with a lower condenser temperature demand, see Table 8.

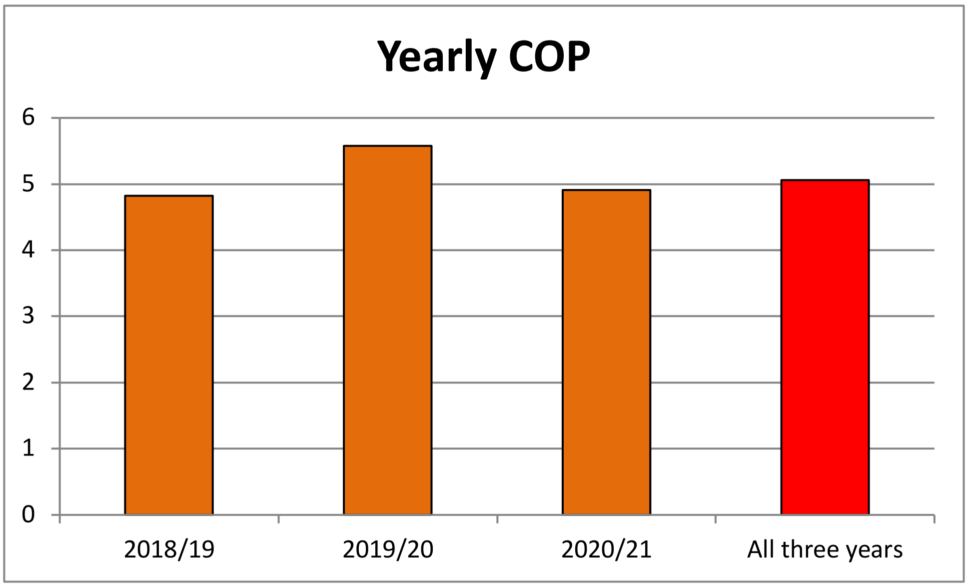

Figure 20: Yearly COP for the BTES heat pump system

Table 9: Heat produced and electricity used by the BTES heat pump system

Year	Heat (MWh)	Electricity (MWh)	COP
2018/19	2 902	602	4,82
2019/20	2 198	386	5,58
2020/21	2 242	457	4,91
All three years	**7 342**	**1 445**	**5,06**

The COP broken down into monthly values is shown in Figure 21. As shown in the figure the value for February 2021 sticks out with a much lower COP than normal. Also March and April show low values. The reason behind this is not clarified, but it draws down the seasonal COP for this heating season.

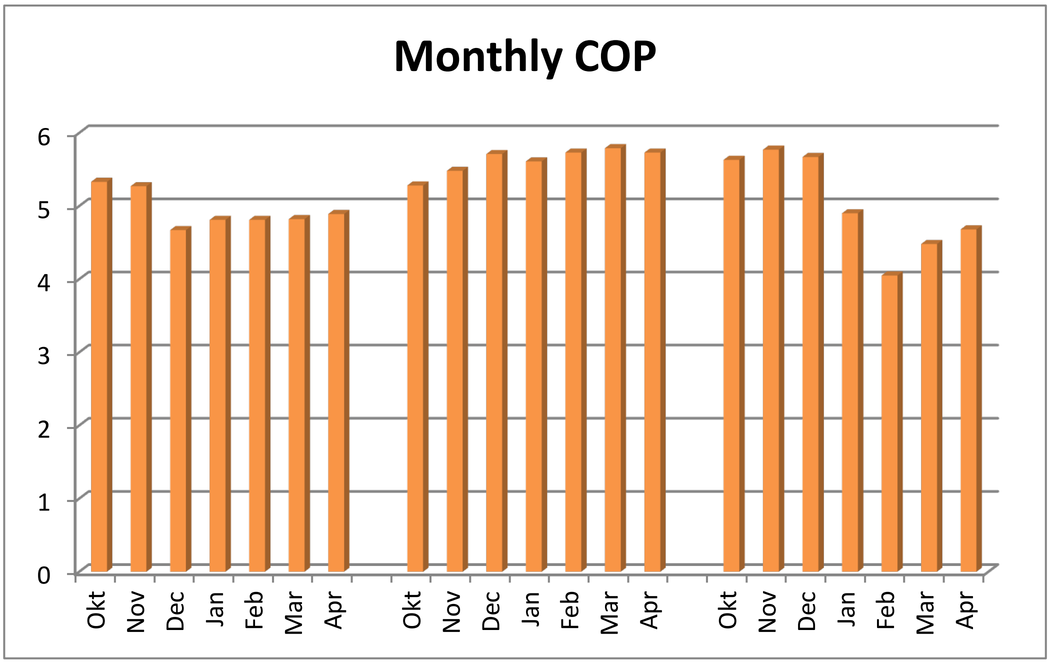

Fig 21: Monthly COP for the three heating seasons 2018/19, 2019/20 and 2020/21.

The lowering of the COP values at the end of season 2020/21 can be explained by a decreasing temperature on the evaporator side, see Figure 22. The drop of the incoming temperature down to +22°C was, at least partly, caused by a malfunction of the flow regulating valve.

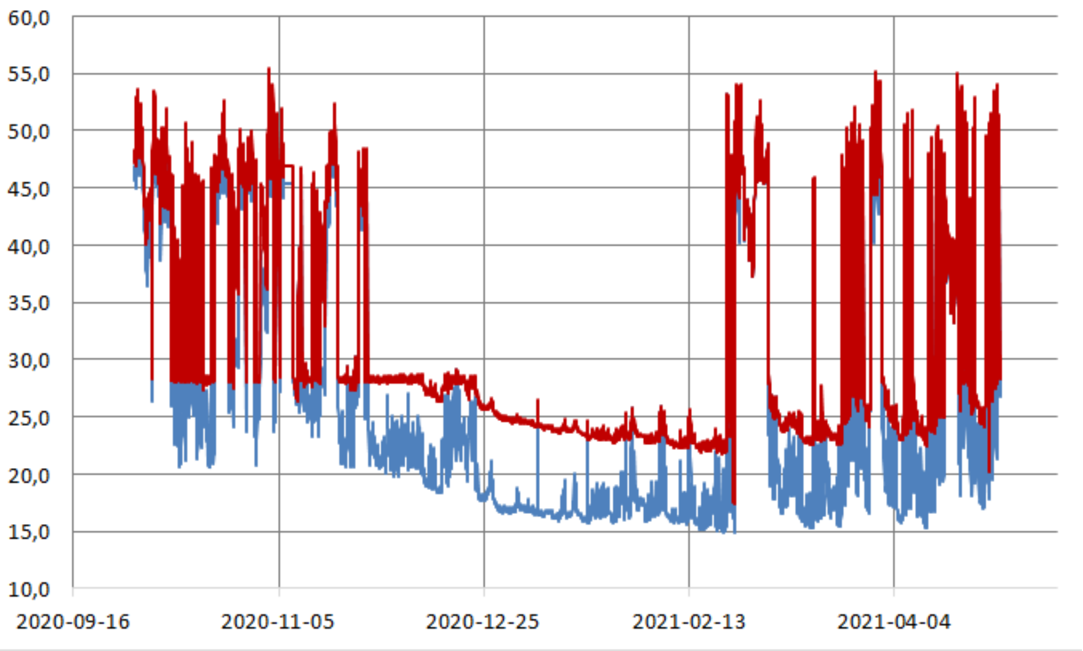

Figure 22: Incoming (red) and outgoing (blue) evaporator temperature the last heating season

The heat pump COP has been measured in January 2019. The results were used to optimize the performance with respect to incoming and outgoing temperatures. The

The method used was ClimaCheck and the results verify the monitored COP values. Furthermore the results indicate that a lowering of the incoming evaporator temperature will also significantly lower the COP.

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Overall system performance

For definition of the seasonal performance factors, see chapter “Performance metrics”.

The background values for calculation of SPF heating are given in Table 10 and for cooling in table 11 (WHC HP means Waste Heat Capture Heat Pumps).

Table 10: Values for calculation of yearly performance factor for heating

Year	BTES heat extraction	BTES CP Electricity	SPF0	BTES heat prod.	BTES HP Electricity	WHC HP Electricity	SPF1	Distr. pumps Electricity	SPF2
	(MWh)	(MWh)	(-)	(MWh)	(MWh)	(MWh)	(-)	(MWh)	(-)
2018/19	2 300	14	165	2 902	602	161	**3,74**	800	3,63
2019/20	1 812	12,7	143	2 198	386	127	**4,17**	544	4,04
2020/21	1 785	10,4	171	2 242	457	125	**3,78**	610	3,68
All three	**5 897**	**37,1**	**160**	**7 342**	**1 445**	**413**	**3,87**	**1 954**	**3,76**

Table 11: Values for calculation of yearly performance factor for cooling

Year	BTES heat injection	BTES CP Electricity	SPF0	WHC HP Electricity	SPF1	Distr. pumps Electricity	SPF2
	(MWh)	(MWh)	(-)	(MWh)	(-)	(MWh)	(-)
2018/19	1 606	9,3	173	112,4	13,2	135	11,9
2019/20	2 164	15,2	142	151,5	13	184	11,8
2020/21	3 349	19,7	170	234,4	13,2	281	11,9
All three	**7 119**	**44,2**	**161**	**498,3**	**13,1**	**599**	**11,9**

The SPF0 as defined in the Annex 52 schema is shown in Figure 23 and covers both heating and cooling (H/C)

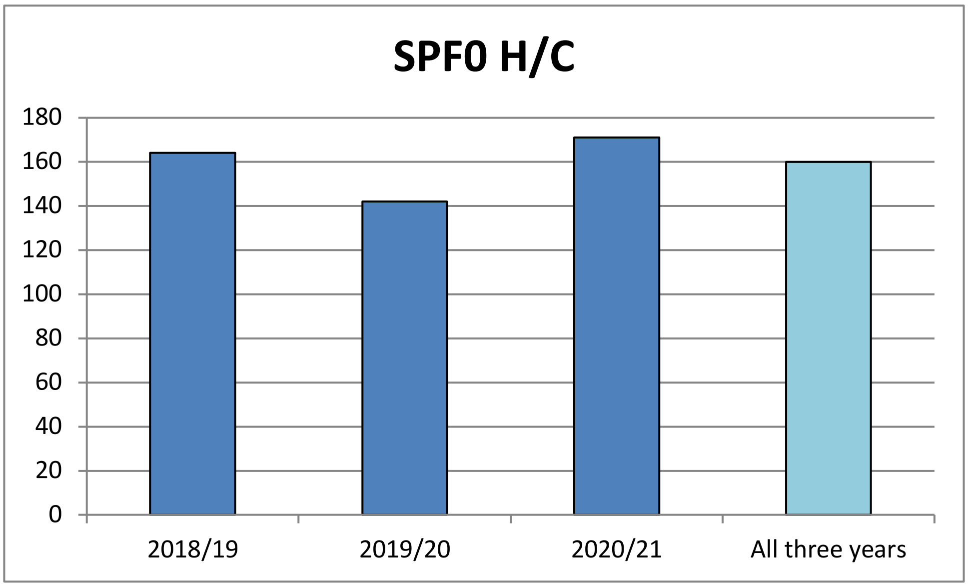

Figure 23: Yearly performance factor for heating and cooling

As a general remark, it has not been possible to distinguish the electricity for the BTES circulation pump into heating and cooling. In theory the value for extraction is probably somewhat larger than that for injection due to different viscosities.

The yearly values for SPF1-2 is shown in Table 12 and illustrated in Figure 24.

Table 12: Yearly values for the boundary levels SPF1 and 2 since the installation of the BTES heat pump system in 2018

Year	SPFH1	SPFH2	SPFC1	SPFC2
2018/19	4,29	3,63	13,2	11,9
2019/20	4,43	4,04	13	11,8
2020/21	4,24	3,68	13,2	11,9
2018-21	**4,31**	**3,76**	**13,1**	**11,9**

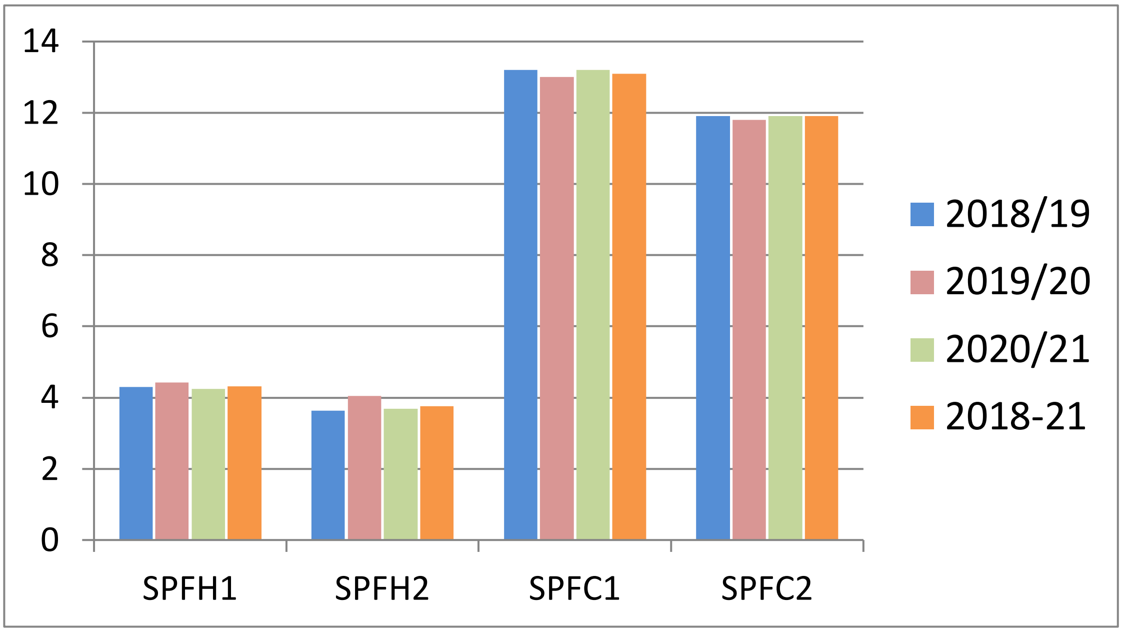

Figure 24: Yearly heating and cooling performance factors for the BTES heating and cooling system after the heat pump installation 2018.

LESSONS LEARNT

In general this type of BTES tends to be overestimated in terms of temperature at recovery of stored heat. Our assessment is that a heat pump system is needed to be able to make full use of the storage. However, it may be possible that HT- BTES would work with heat exchange alone, but in that case the injection temperature must be kept significantly higher than during extraction.

In the Xylem case, the temperature drop at extraction is illustrated in Figure 25.

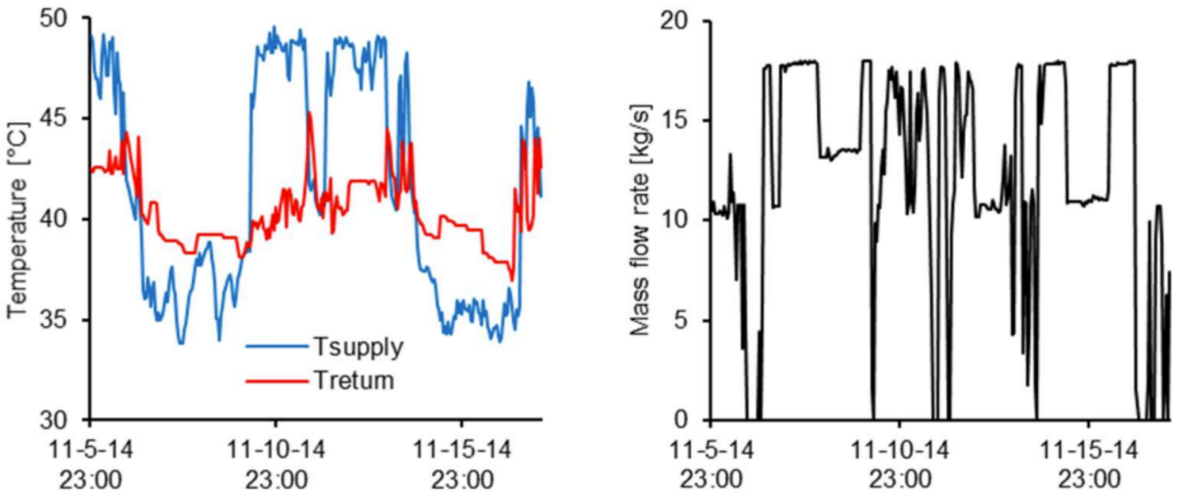

Figure 25: Injection of heat interrupted by two weekends of extraction in November 2014. To the right, corresponding flow rates (from Nilsson 2020)

The injection temperature shown is just below +50ºC. After switching to heat extraction the starting extraction temperature is about 7 degrees lower, but drops quickly to a level that is not useful for heating. By adding a heat pump at extraction this problem has proved to be overcome in the Xylem case.

The figure also demonstrates that the cooling capacity of the storage is at best after extraction of heat. From a cooling point of view it is therefore of great interest to lower the working temperature to level that is suitable for an effective waste heat injection and then use heat pumps at extraction. In the Xylem case this seems to be optimized around 40/25ºC.

The coaxial borehole heat exchanger has helped to obtain a thermally favorable temperature profile in the storage (Ramstad et al 2021). However, this advantage has not been sufficient to provide a temperature high enough when extracting the heat. It is therefore recommended to use conventional borehole heat exchangers (thermal resistant U-pipes) in a fully closed loop to avoid various technical problems with vacuum pressure in the loop. Even if now solved, these problems were major concerns the first years of operation.

Improvement measures

In the early start 2010 release of dissolved gas from the heat carrier became a major problem for circulation of the fluid. For this reason two vacuum pumps with magnetic valves were installed on the main manifolds in 2011. These are collecting and dispose most of the gas that are released.

The gas content has gradually dropped over the years but is still a factor that has to be monitored. In Figure 26 a sudden increase of collected gas in august 2019 is shown. This was caused by a leakage of in the magnetic valve and solved by adding a back valve.

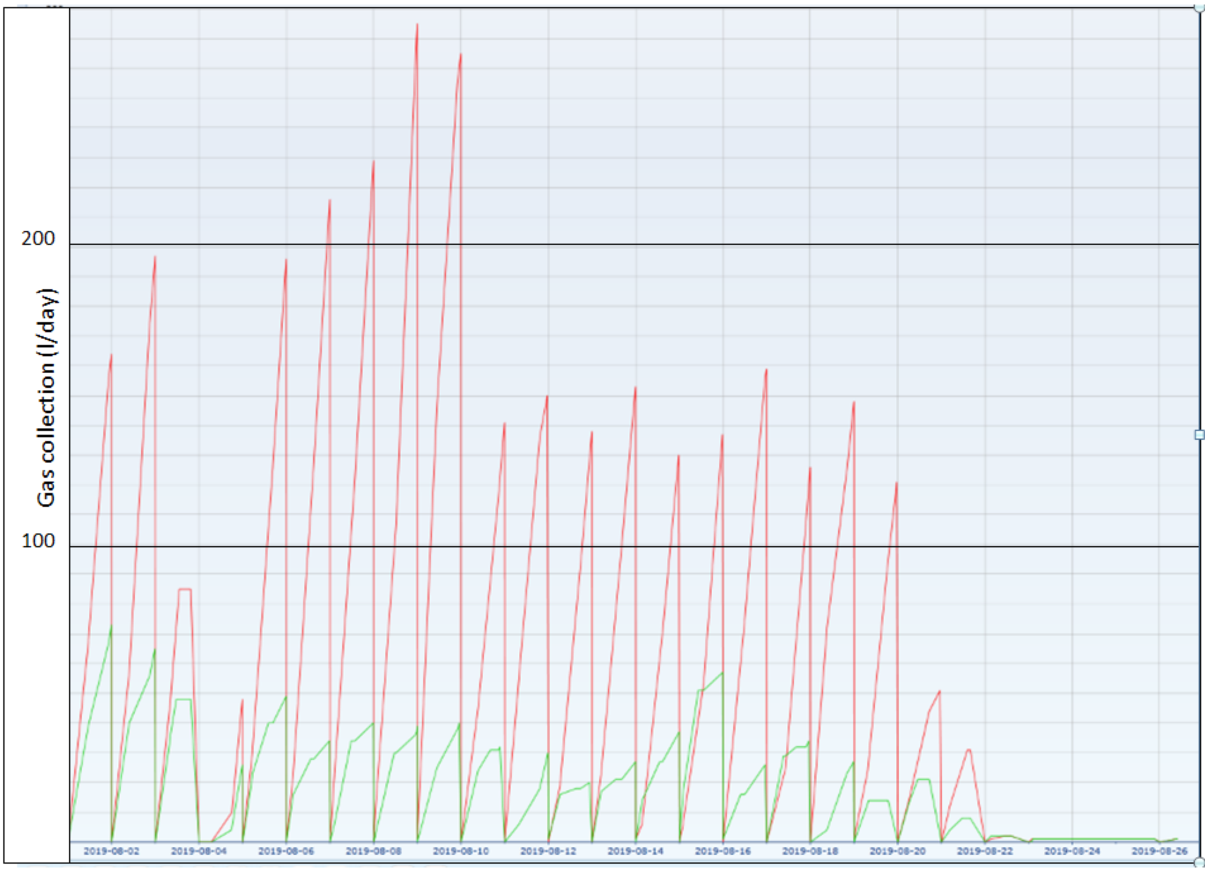

Figure 26: Diagram showing the measurement of released gas from the BTES heat carrier under a couple of weeks in August 2019. The red graph represents the extraction manifold, and the blue the injection manifold.

Due to vacuum pressure in the BTES loop and accumulated gas in the heat carrier the circulation pump was damaged by corrosion and cavitation, se Figure 27. A new somewhat smaller pump was replacing the damaged one in 2014.

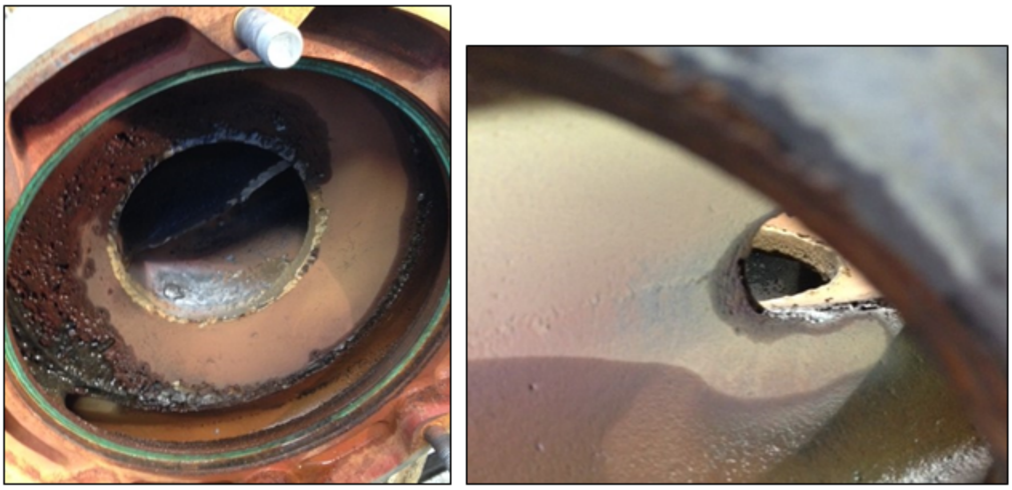

Figure 27: Corrosion and cavitation damages on the BTES circulation pump caused by vacuum pressure in the heat carrier loop.

In the early start corrosion products plugged the BTES heat exchanger that had to be cleaned a couple of times. The corrosion products were generated from general corrosion of the 200 m long steel culvert between the storage and the technical room, possibly also the borehole steel casings. Later on the heat exchanger started to leak caused by pitting corrosion, see Figure 28.

Figure 28: Left, general corrosion inside the culvert. Right, pitting corrosion on a heat exchanger plate (pink color)

The corrosion was caused by a high concentration of dissolved oxygen when filling the system with city water. The oxygen content is now continuously measured and kept under control. The plates of the heat exchanger have been replaced to a more resistant steel alloy.

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Project data access

Xylem Inc. owns the measurement data and has to be requested for access.

Project participants and their contribution

Instrumentation is a part of the comprehensive monitoring system at Xylem Emmaboda. Data from the system was made accessible for the project.

Data has been analyzed continuously by the authors since the start of the project and been presented at expert meetings.

This case study was written by O. Andersson with support from L. Rydell and N. Håkansson.

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