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# A novel heat pump-based energy recycling system of an industrial building utilizing waste heat flows and geothermal energy

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## Abstract

The energy efficiency improvement potential in industrial buildings is often significant, considering all unutilized waste heat flows. Cost efficient and innovative renovation concepts are needed for a good balance between cost savings and investment costs including energy grants for new energy systems. The paper presents a case study, motivated by financial savings and CO<sub>2</sub> emission reductions for an industrial building in Finland based on realized costs and measured energy consumption. The building belongs to a company with multiple industrial facilities in Finland and around the world and the company fulfils its energy program Mission to Zero, significantly reducing the carbon footprint of its buildings. The energy renovation concept studied in this study relies on a novel heat pump-based energy recycling system utilizing boreholes for thermal storage and free cooling. Sources for energy recycling are the cooling and pressurized air systems serving the production line. The long-term renovation plan is included to improve the overall cost efficiency. The energy concept is compared to the initial situation and a conventional ground source heat pump system utilizing free cooling from the boreholes. The measurements indicate that the performance, (SCOP 3.3) and heating energy covered by the heat pump system (about 97%), has been better than expected based on the energy calculations.

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*Keywords: ground source heat pump; energy recycling; hybrid heat pump system;*

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## 1. Introduction

The demand for energy efficiency measures in energy intensive industrial buildings is rising to cope with the rising energy prices and to meet the ambitious goals of leading companies to cut down the CO<sub>2</sub> emissions. A key issue is to find the most efficient measures to reach the goals with a decent price tag. However, some measures might even be free of charge such as set-point adjustments, which are important to trace before any major energy renovations are planned. Utilization of waste heat flows is on the contrary not free of charge but extensive utilization of waste heat flows in a heat pump-based energy recycling system will most likely pay itself back in 5 to 8 years depending on the system design. For the customer paying the investment, it is also important that the energy system will receive the maximum amount of government grants to produce a decent payback time. For example, in Finland 20 % lower investment costs can be achieved if energy system design fully complies with the grant requirements.

The ABB Group is an example of a leading industrial company that strives to significantly reduce its carbon footprint through its own energy efficiency program Mission to Zero. The investigated industrial building in this study, ABB assembly parts, is located near the Gulf of Finland in the city of Porvoo approximately 50 km from the Helsinki capital. It is characterized by both high heating and cooling demand, making it ideal for a heat pump-based energy recycling system. Firstly, to live up with the expectations, the objective was to design a cost-efficient hybrid heat pump system utilizing all feasible heat sources. Secondly, a high heating energy coverage rate (at least 95%) by the heat pump system should be reached.

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The investigated heat pump system in this paper, designed by the Granlund company, has been operational and monitored since November 2021. The objective of the presented study was to compare the installed hybrid heat pump system to a conventional ground source heat pump system utilizing free cooling as concerns the energy performance of the system and financial viability.

Energy recycling systems coupled with boreholes have been studied in the Nordic climate and a key dimensioning parameter is the relation between extracted heat from the ground and heat loaded into the ground and how it affects the average COP (Coefficient of Performance) in the long run [1]. For a pure ground source heat pump system, a conventional COP value to be used in energy calculations is 3.0 for a building in the cold climate (Nordic countries) and 3.6 in an average climate [2].

## 2. Methods

### 2.1. The investigated industrial building

The present study was made for an industrial building located in southern Finland as a part of an energy efficiency project carried out by Granlund Oy. The industrial building in question has high cooling demand all year round due to cooling intensive manufacturing process. The manufacturing line is operating from Monday to Friday implying that energy recycling from the cooling process is not available during the weekend. Another source for energy recycling in the building is heat from the pressurized air compressor also used from Monday to Friday. The original compressor (nominal motor power 75 kW) was air cooled but as a part of the energy efficiency project it was replaced with a liquid cooled version (nominal motor power 90 kW) suitable for the energy recycling system.

Heating consumption in the investigated building is mostly space and ventilation heating divided between the office and manufacturing parts of the building. The warehouse itself is energy intensive in terms of heating as the ventilation system and the circulation air heaters consume the most part of heating in the manufacturing area. Volume flow rates and heat recovery used in the ventilation system are 3 m<sup>3</sup>/s in the office region (plate heat exchanger for heat recovery) and approximately 12 m<sup>3</sup>/s in the manufacturing area (glycol-based heat recovery). The building is connected to the local district heating system and initial heating consumption before the heat pump project was approximately 960 MWh in 2019. Cooling is managed through two chiller units utilizing free cooling, one for the office area and the second for the manufacturing area. The cooling demand for the manufacturing part was estimated to be 840 MWh.

### 2.2. Description of the installed energy recycling system with boreholes

The installed heat pump system is a hybrid heat pump system consisting of energy recycling and boreholes. Boreholes are primarily used to support the energy recycling system especially during weekends when no recycling potential is available and to store unused heat from the energy recycling system into the ground. The borehole field is primarily charged during the summer months providing free cooling to the process cooling network. Free cooling is limited by the ground temperature and the cooling system temperature levels 8 / 13 °C, thus leading to a maximum brine temperature of 9 - 10 °C. However, the brine temperature supplied to the ground may increase even higher during the summer when the boreholes are charged with heat from the pressurized air compressors. A schematic drawing of the hybrid heat pump system is presented in Fig. 1.

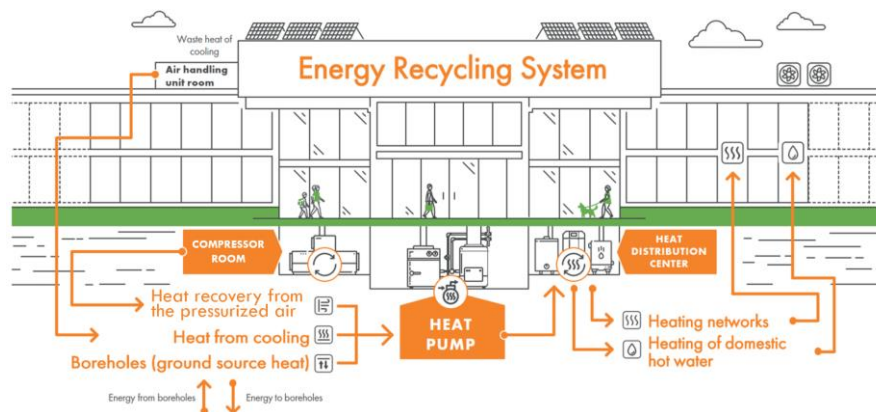


Fig. 1. Schematic drawing of the hybrid heat pump system.

Altogether three on-off controlled heat pump units are used in the heat pump system with a total heating capacity of about 330 kW. Buffer tanks were included in the heat pump system on the condenser side, 2 m<sup>3</sup> for space and ventilation heating and 2 m<sup>3</sup> for domestic hot water heating. On the evaporator side, the buffer tank was left out because the energy recycling potential was known to be almost constant during the workdays. Dimensioning parameters of the heat pump system are shown in Table 1.

Table 1. Dimensioning parameters of the heat pump system.

Parameter	Dimensioning data
Heat pump models	3x Gebwell Taurus EVI 110, 3x 104 kW at 5 / 45 °C ( $T_{e\_Out} / T_{c\_Out}$ )
Heat pumps for domestic hot water heating	One heat pump out of three working in alternating mode (domestic hot water / space heating)
Heat pump COP at rating points	4.0 at 5 / 45 °C and 2.6 at 5 / 65 °C ( $T_{e\_Out} / T_{c\_Out}$ )
Heat exchanger capacity for energy recycling from the cooling network	Dimensioning heating capacity 100 kW at temperature levels 10 / 5 °C on the brine side
Heat exchanger capacity for energy recycling from the pressurized air compressors	Dimensioning heating capacity 60 kW at temperature levels 20 / 5 °C on the brine side
Borehole field	18 pcs of boreholes in two rows, depth 250 m and distance between the holes 20 m
Heating system setpoint curve for the supply water temperature (targeted design values)	Supply water temperature at -29 °C: 66 °C, supply water temperature at 0 °C: 46 °C * <sup>1</sup> )

\*<sup>1</sup>) The actual heating curve in the building automation system was higher at 0 °C, approximately 52 °C.

The chosen heat pumps are on-off controlled with two compressors per heat pump, altogether 6 compressors in the whole system. All heat pumps take advantage of superheating of the refrigerant R410A to produce small fractions of domestic hot water at a high COP value. Domestic hot water is produced separately with one of the heat pumps particularly during the summer months. The borehole field, 18 x 250 meters, was sized based on the heating capacity requirements especially during the weekends when no energy recycling is available. Despite of heating capacity-based dimensioning of the borehole field, temperature is still very stable from year to year due to balanced extraction and loading of the boreholes.

Compared to a conventional heat pump system utilizing geothermal energy, the most significant difference is energy recycling from the pressurized air compressors and loading of unused heat in the ground to stabilize the temperature profile in the borehole field. Energy recycling from the cooling networks and free cooling from the ground can be seen as the conventional approach in the Nordic countries. The existing chiller is used as backup whenever the heat pumps are not able to recycle heat from the cooling network to the heating networks or when the free cooling capacity from the ground is insufficient.

### 2.3. Simulation model for the hybrid heat pump system

The energy system simulations were performed with the energy simulation tool IDA ICE 4.8.2 (Indoor Climate and Energy) in combination with its ESBO plant interface (Early Stage Building Optimization) for simulation of energy systems. IDA ICE is especially used in the Nordic countries for building energy simulation purposes and it is extensively validated in previous studies [3-7]. In this work the original ESBO plant model for energy system simulations has been reworked to match more closely the real heat pump system. Moreover, the original heat pump model has been replaced by a parametric heat pump model working accurately based on performance data given for a specific heat pump model at all possible operation points as also parametrized in [1]. Measurement data from the heat pump manufacturer Gebwell (heating capacity and COP at different operation points) was used in the simulation model describing the Taurus EVI 110 heat pump. Despite of the real on-off controlled compressors in the heat pump, the part load behaviour of the heat pump

was modelled in line with the standard EN 14825 degradation coefficient  $C_c$  [8], with a given value of  $C_c = 0.97$ . The same modelling approach is also used in the original heat pump model included in IDA ICE.

It has been shown that the original heat pump model in IDA ICE can be used quite accurately within an error of  $\pm 1\%$  in energy system simulations if the heat pump is calibrated using 7 calibration parameters against measured data [9].

An overview of the customized energy system interface in IDA ICE is shown in Fig. 2 and the most important components of the model are numbered and explained below. Calculation of supplied and extracted heat to and from the energy model is done in dedicated macros, but in this context the details of the model are not discussed.

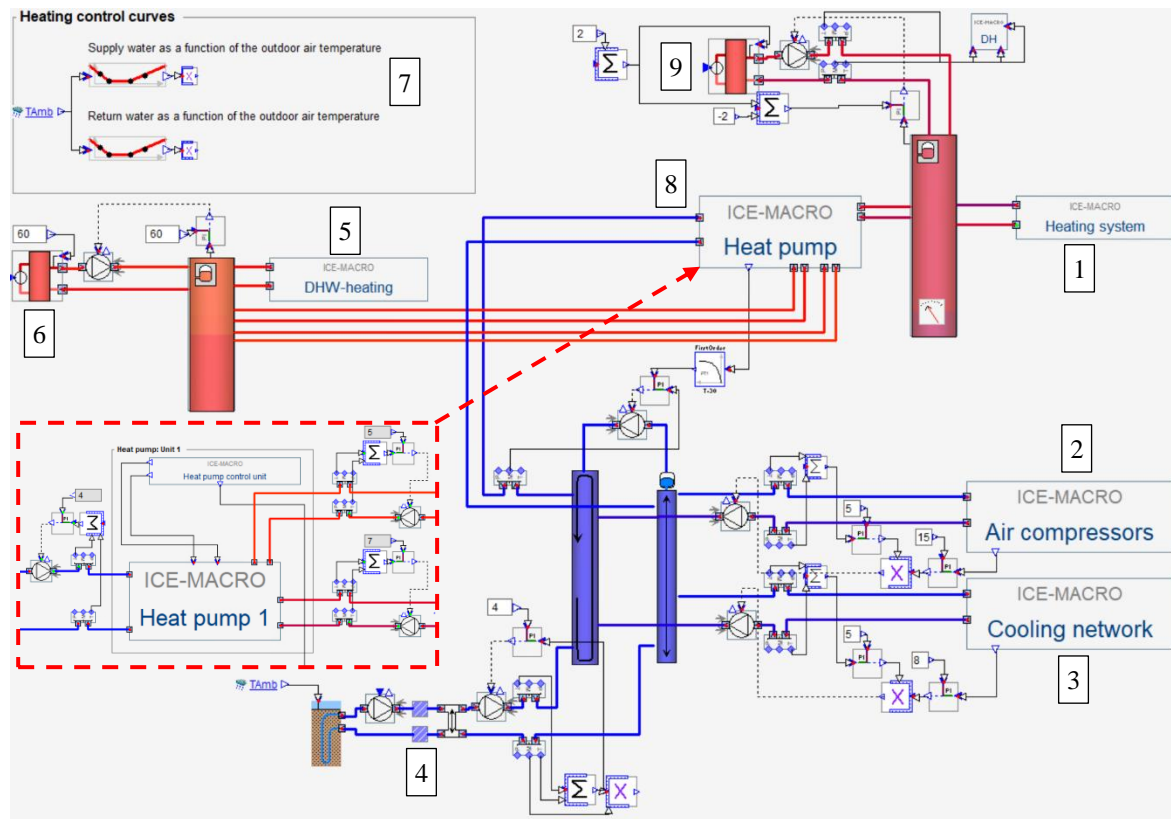


Fig. 2. The customized energy system interface in IDA ICE for energy system simulations.

Numbering and explanations referring to Fig. 2:

1. Space and ventilation heating systems in the building. Set points for the supply and return water temperature are given according to the heating control curves (7) and the measured heating power is used as input data.
2. Heat recovery from the pressurized air compressors including temperature control on the primary and secondary sides of the heat exchanger (brine / water). The measured heating power data of the compressors is used as input data.
3. Cooling network connected to the brine side with a heat exchanger including temperature controls. The measured and partly estimated cooling heating power data is used as input data.
4. Borehole field and its temperature control.
5. Consumption of domestic hot water. The estimated domestic hot water profile is used as input data.
6. Additional heating (district heating) supplied to the domestic hot water network if necessary.
7. Supply and return water set point curves as a function of the outdoor air temperature. The maximum supply water temperature is  $66\text{ }^{\circ}\text{C}$  at the outdoor air temperature of  $-28\text{ }^{\circ}\text{C}$ .
8. Parametric heat pump model and a snapshot of it showing its pipe connections. On the condenser side there are pipe connections for space heating and for super-heating supplied to the DHW tank. One of the three heat pumps is working in alternating mode (space heating / DHW heating) and therefore four hot pipes are connected to the DHW tank in the simulation model.
9. Additional heating (district heating) supplied to the space heating network if necessary.

Exemplified profiles for estimating the energy recycling potential are shown in Fig. 3 for cooling as well as for the pressurized air networks. The profiles were determined from the building automation system before the beginning of the heat pump project. Both energy recycling profiles are almost constant during workdays Monday to Friday. Heat recovery potential from the pressurized air compressors is 50 – 70 kW and heat to be recovered from the cooling network 100 – 140 kW. The energy simulations were performed based on measurement data from the original air-cooled compressors (motor power 75 kW), although it was known that the recoverable power from the new water-cooled versions (Atlas Copco GA90, motor power 90 kW) would be somewhat higher than before. The manufacturing line is closed from Friday evening to Monday morning, implying that the system works as a pure ground source heat pump system during weekends.

Duration curves of the heating demand and energy recycling potential throughout the year are shown in Fig. 4. The duration curves for the heating demand are presented both without the ventilation adjustments (initial situation in the project planning phase) and with the adjustments to show the final situation.

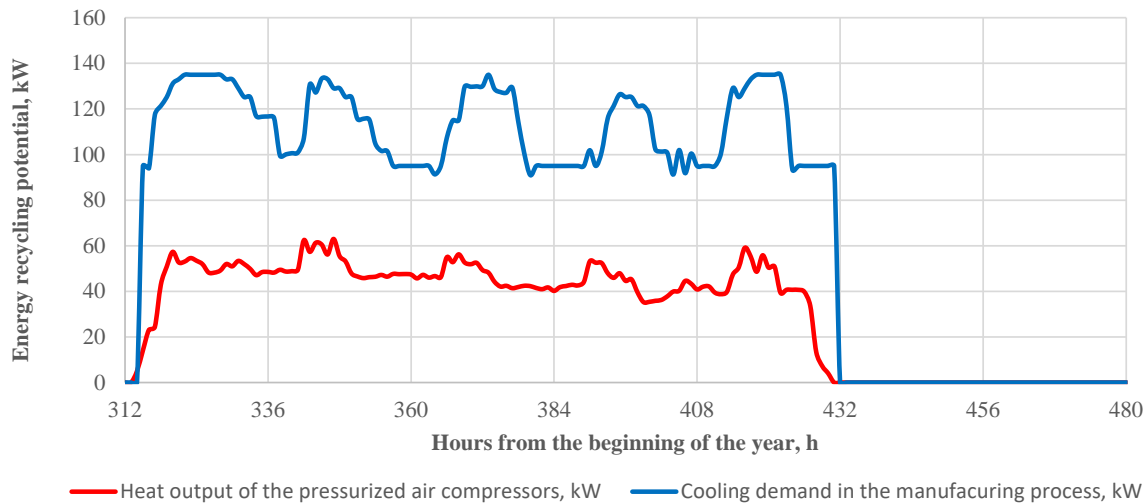


Fig. 3. Energy recycling profiles for one week during the heating season.

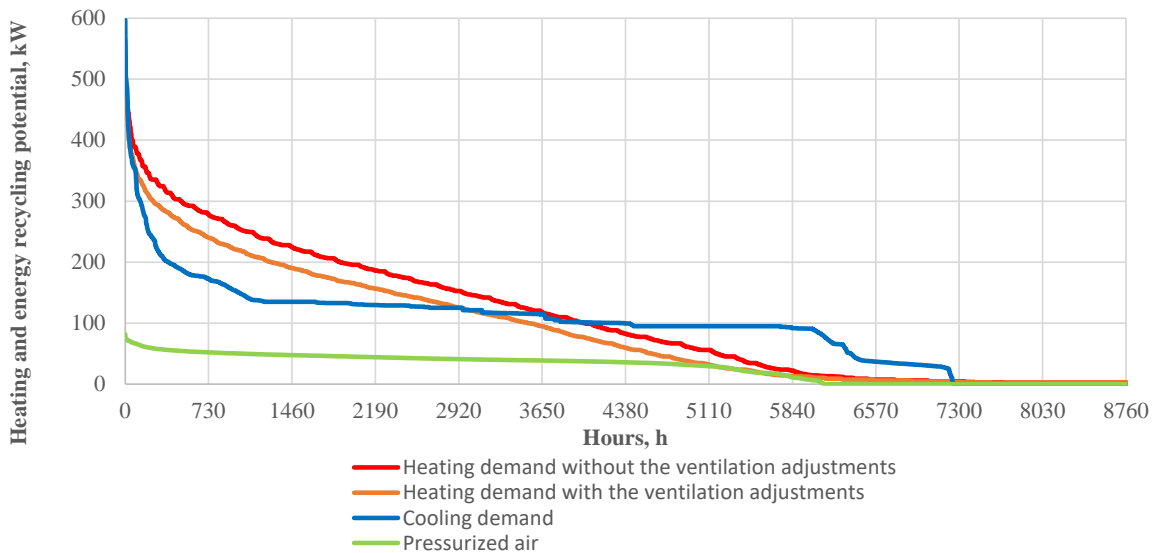


Fig. 4. Duration curves of the heating demand and energy recycling potential throughout the year.

The temperature profile in the borehole field was investigated in the GLHEPRO simulation software using the simulated heat extraction and loading profiles from the single year IDA ICE simulation. GLHEPRO is developed at the Oklahoma State University, and it has been validated against measured data from working ground heat exchangers [10] and compared with the ASHRAE Handbook method [11]. The GLHEPRO

simulations performed on a monthly level and for a period of 40 years will show if the dimensioning of the borehole field is sufficient.

### 3. Case study

#### 3.1. Simulation of the installed heat pump system and comparison to a conventional ground source heat pump system

The installed hybrid heat pump system was investigated using the energy system interface in IDA ICE described earlier. Attention was especially paid to the heat extraction and loading pattern of the borehole field and that all available heat is either recycled or stored in the ground. The target was to achieve a high heating energy coverage rate using the heat pump system, at least 95% in accordance with the ABB's energy program "Mission to Zero". Hourly simulation results shown in this paper are calculated based on the measured district heating consumption from 2019 without any ventilation adjustments to represent the initial situation at the project planning phase. The heat extraction and loading rates (kW) of the borehole field are presented in Fig. 5 for the installed system and for the conventional ground source heat pump system with free cooling.

Simulation results for the installed hybrid heat pump system show, that heat is mostly extracted from the borehole field during the weekends and heat is stored in the ground almost during the whole year with emphasis on the summer months. The peak heat extraction from the boreholes is about 38 W/m and loading 9 – 13 W/m depending on the ground temperature. The amount of heat stored in the ground is primarily limited by the temperature level of the liquid in the cooling network, but slightly more heat can still be stored in the ground from the pressurized air compressors if the free cooling mode is not available due to a high brine temperature. The rest of the cooling demand in the manufacturing area, which cannot be produced through energy recycling or by utilizing free cooling from the ground is covered by the existing chiller either as free or mechanical cooling.

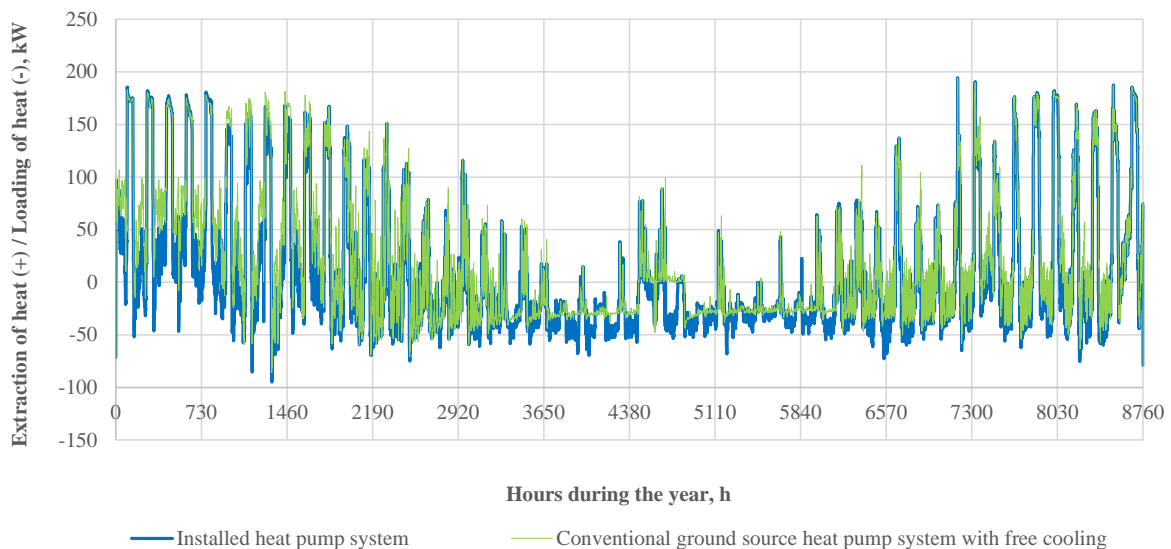


Fig 5. Net heat extraction rates (positive value) and loading rates (negative value) are shown on the left axis. The results shown with a thick blue line belong to the installed system and the results shown with a thin green line represent the conventional ground source heat pump system with free cooling.

An overview of the utilization of the installed hybrid heat pump system compared to the conventional ground source heat pump system with free cooling is presented in Table 2. The results are focusing on the energy balance of the borehole field and on the amount of free cooling available.

The energy simulations indicate that extensive loading of the ground comes at a price when it comes to the utilization of free cooling from the ground. Hence, 139 MWh less cooling energy (17% of the cooling demand) is utilized either through energy recycling or through free cooling from the ground. Considering possible free cooling with the existing chiller, the amount of compressor cooling is increased by 86 MWh (10% of the cooling demand). Altogether 103 MWh of more heat is still utilized in the installed energy system either through energy recycling or by loading the borehole field. From the numbers it can be observed that the

borehole field is almost fully charged bearing in mind the liquid temperatures in the cooling network (8 / 13 °C) and that all available heat from the pressurized air compressors is used in the energy system.

Table 2. Utilization of the hybrid heat pump system based on the energy simulations.

Investigated variable	Installed heat pump system (MWh)	Conventional heat pump system with free cooling (MWh)
Heat extraction from the boreholes	218 MWh	275 MWh
Heat loaded into the boreholes	170 MWh	124 MWh
Cooling energy utilized by the heat pump system	332 MWh	471 MWh
Heat from the pressurized air compressors utilized in the hybrid heat pump system	242 MWh	0 MWh

Monthly averaged liquid temperatures in the borehole field are compared in Fig. 6. for an anticipated life span of 40 years (480 months). The results shown with a thick blue line belong to the installed system and the results shown with a thin green line represent the conventional ground source heat pump system with free cooling. The number of boreholes is identical 18 x 250 m in both energy systems because dimensioning of the borehole field was made based on the required heat extraction rate (kW) and secondly to enable an adequate brine flow rate (dm<sup>3</sup>/s) on the evaporator side of the heat pumps. Dimensioning parameters of the borehole field are as follows: Heat conductivity of the ground 3.1 W/mK, undisturbed ground temperature 7.5 °C, collector pipe diameter DN45, borehole thermal resistance 0.12 K/(W/m) and distance between the boreholes 20 meters. Thermal response tests for the ground were not made during the project, implying that the parameters used in the calculation are commonly used in ground source heat pump applications.

According to the simulation results, the monthly averaged temperatures in the borehole field fluctuate between 4 – 9 °C during the whole investigation period of 40 years. The temperature level in the conventional system is on the other hand constantly decreasing with same borehole dimensioning but it is still on the safe side regarding freezing. Without heat recovery from the air compressors, a constantly fluctuating temperature profile can be reached with free cooling only, but according to the simulations the energy system would need 8 – 10 additional boreholes (depth 250 m) to reach that level.

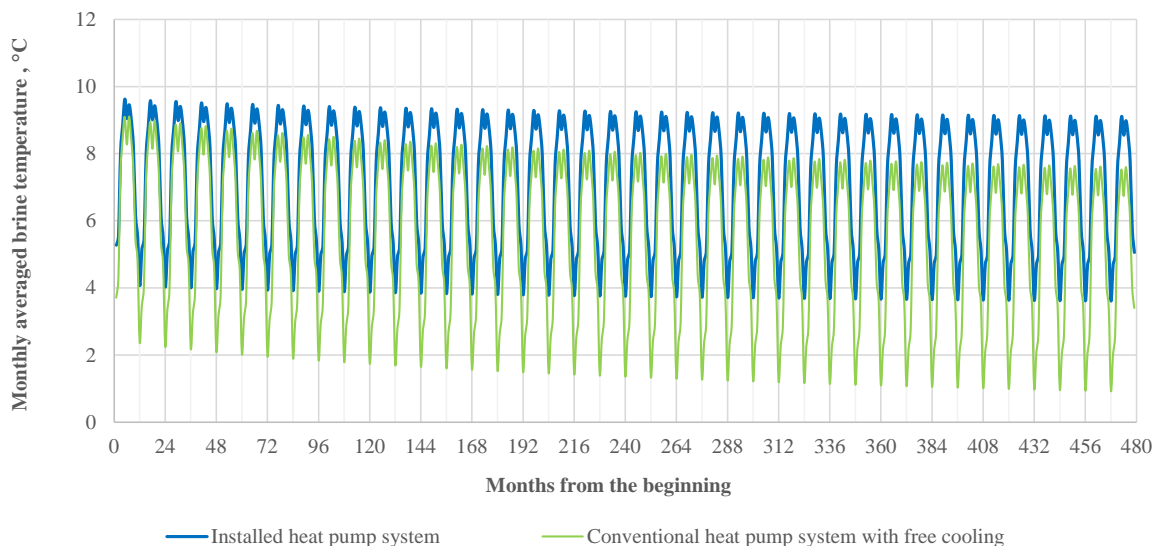


Fig 6. Monthly average liquid temperatures in the borehole field of the two compared energy systems.

The simulated seasonal coefficient of performance (SCOP) for the installed heat pump system is 3.19 and as seen from the monthly average liquid temperatures shown in Fig. 6, the SCOP will not decrease during the

lifecycle of the heat pump system. During the heating season the COP value fluctuates between about 3.5 during workdays and close to 3 during weekends when no energy recycling is available. The corresponding simulated SCOP for the conventional heat pump system with free cooling is 3.08 during the first year of operation and 3.04 on average.

### 3.2. Energy monitoring of the installed heat pump system

The installed heat pump system has been operational since November 2021 and its performance is monitored through a new building automation system interface provided by Schneider Electric. Key temperatures, status information of control valves as well as capacity data in the heat pump system are monitored at a time interval of 10 minutes. Measurements indicate that the building has consumed only 28 MWh of district heating since November 2021 and all additional heating took place in December 2021 and January 2022, approximately 80% in December and 20% in January. Compared to preliminary simulations performed in 2020, district heating consumption should have been approximately 34 MWh during the whole year when calculated with the measured district heating consumption data from 2019. During the year 2019 the amount of degree days (S17 degree day method) was 3419 in the Helsinki region and in 2021 correspondingly 3831. That is to say, the heating demand should be approximately 12% higher with the 2019 weather data compared to the year 2021. The before mentioned heating degree days are maintained by the Finnish Meteorological Institute [12].

An explanation to lower district heating consumption is that a schedule-based ventilation strategy has been deployed in the manufacturing spaces since mid-December 2021. A ventilation schedule with 100% air flow rate is used at workdays from 7 – 20 and a lower air flow rate of 67% of the nominal flow rate has been introduced to lower heating consumption at periods of absence. The operational hours of the ventilation unit serving the office region were also readjusted to further lower heating consumption. The adjustments to the ventilation system were proposed as a part of the energy efficiency project, leading to a 17% smaller heating energy consumption compared to measured consumption data from 2019. The total district heating consumption should have been higher if the ventilation system had operated as initially simulated, considering the ventilation adjustments at the end of 2021 and that 80% of the district heating was consumed during 2021. Measured consumption data from 2021 and the corresponding calculated data using district heating consumption from 2019 are compared in Table 3. DH in Table 3 stands for district heating.

Table 3. Measured heating consumption data compared to preliminary calculation data from 2019.

Consumption	Calculated value	Measured value
DH consumption without the heat pump system: 2019 measured data		956 MWh
Seasonal COP (SCOP) of the heat pump system: 2019 consumption data without ventilation adjustments	3.2	
DH consumption without the heat pump system: estimated consumption with ventilation adjustments (calculated based on the measured data from 2019)	796 MWh	
DH consumption with the heat pump system: 2019 consumption data without ventilation adjustments	34 MWh	
DH consumption with the heat pump system: 2019 consumption data with ventilation adjustments	12 MWh	
DH consumption with the heat pump system: 2021 actual consumption data		28 MWh
Heating energy produced by the heat pump system: 2021 actual consumption data		810 MWh
Seasonal COP (SCOP) of the heat pump system: 2021 actual consumption data		3.3

Energy simulations comparing the installed and the conventional heat pump system with free cooling indicate that there is only a minor difference of about 9 MWh in the district heating consumption in favour of the installed heat pump system (34 MWh compared to 43 MWh).

### 3.3. Analysis of life cycle costs and reductions of CO<sub>2</sub> emissions

The life cycle costs, and payback time of the hybrid heat pump system were investigated with a typical life span of 20 years including yearly maintenance costs and compressor renewals after 15 years of operation. All presented life cycle costs are proportioned to the initial state of the building: all heating energy is purchased from the district heating network and chillers with free cooling produce the cooling energy. Energy tariffs used in the calculation were gathered in November 2022, tariffs for district heating (energy tariff €/MWh and capacity fee €/kW) and the transfer fees for electricity (consumption related tariff €/MWh and power related fee €/kW). Especially the year 2022 has shown, that the electricity price has heavily fluctuated in Europe and the future is therefore difficult to predict. Due to the before mentioned uncertainties, the life cycle cost calculations were made based on two assumptions: 1. Energy tariff for electricity is 55 €/MWh without tax (assumption that the price will be stabilized to the same level as before the energy crisis in Europe) 2. Energy tariff for electricity is 80 €/MWh without tax (assumption that the price will not return to the same level during the upcoming decades). Hence, the total tariff in the first scenario is 84.7 €/MWh including the transfer fee, tax, and the energy tariff and 109.7 €/MWh respectively in the second scenario. An additional power fee of 2.4 €/kW/month is charged for the electrical power peak consumed every month. The district heating tariff is 68.2 €/MWh and the capacity fee is determined by  $2604.26 + Q \times 13.31$  €/kW, where Q stands for the peak capacity during one year. The CO<sub>2</sub> reduction potential of the installed heat pump system was determined using averaged emission factors for a district heating network and electricity generation in Finland. Emission factors used in the calculation are 177 kg CO<sub>2</sub>/MWh for district heating and 89 kg CO<sub>2</sub>/MWh for electricity production [13].

Life cycle cost savings, investment costs, payback time and reduction of CO<sub>2</sub> emissions compared to the initial state are presented in Table 4 using the electricity tariff 55 €/MWh. The calculation results are shown both for the installed heat pump system and the alternative conventional heat pump system with free cooling.

Table 4. Financial analysis of the heat pump system compared to the initial state of the building.

Variable	Installed heat pump system	Conventional heat pump system with free cooling
Investment cost	447 k€	442 k€
Savings in heating energy	34 MWh	43 MWh
Electricity consumption increased due to the heat pump system	166 MWh <sup>*1</sup>	149 MWh <sup>*2</sup>
Life cycle cost savings during a life span of 20 years with energy grants (-20% of the investment cost)	661 k€	663 k€
Payback time without energy grants	9.1 years	8.8 years
Payback time with energy grants (-20% of the investment cost)	7.3 years	7.1 years
Reduction of CO <sub>2</sub> emissions	148.5 ton CO <sub>2</sub> /year	148.5 ton CO <sub>2</sub> /year

<sup>\*1</sup>) The electricity consumption of the installed heat pump system is 280 MWh/year and electricity consumed by the chillers 155 MWh.

<sup>\*2</sup>) The electricity consumption of the installed heat pump system is 292MWh/year and electricity consumed by the chillers 126 MWh. The initial level electricity consumption of the chillers is 269 MWh without any heat pump system.

A higher electricity tariff of 109.7 €/MWh (scenario 2) compared to 55 €/MWh would increase the payback time by 0.6 years and reduce the life cycle cost savings by 75 k€ with energy grants (-20% of the investment cost).

## 4. Discussion

The investigated hybrid heat pump system in the industrial building owned by the ABB Group in Finland has been operational since November 2021 and monitoring of the system indicates that the performance has exceeded the expectations. The most obvious explanation for better performance compared to the energy

calculations shown in this paper is the ventilation adjustments in the manufacturing area lowering net heating energy consumption during off hours. The adjustments to the ventilation system were proposed as a part of the energy efficiency project but the heat pump system itself was dimensioned based on the original consumption profile of the building. A dimensioning approach on the safe side was chosen because it was unclear if the proposed changes would be implemented due to high quality requirements of contaminant removal from the air. Secondly, the safe side dimensioning approach was motivated by the fact that the operation line at the industrial building will most likely be active also during the weekends in the future. The extended operation time would noticeably increase the net heating consumption of the building, but then again also the energy recycling potential would increase leading to a better overall system performance. In the present situation the COP of the heat pump system is approximately 3.5 during workdays and close to 3 during weekends during the coldest winter months. With the extended operational hours in the future, the seasonal COP value (SCOP) would consequently be over 3.5 when the current value is 3.3.

Compared to a conventional heat pump system with free cooling from the boreholes, the current situation reveals that the installed system is slightly over dimensioned proportioned to the net heating demand of the building. That is, the life cycle savings are even slightly higher in the conventional approach and same borehole dimensioning is applicable in both cases. From the design viewpoint, the pressurized air compressors would anyway have been replaced soon in the alternative approach by adding a separate liquid cooler on the roof of the building transferring waste heat into the outdoor air. Waste heat transfer into the outdoor air was, on the other hand, not in line with the ABB Group energy program Mission to Zero and secondly it was not a future proof solution bearing in mind the extended operational hours of the manufacturing line in the future. Hence, the conventional heat pump system (alternative approach) would have required more boreholes with a future proof dimensioning to cope with the increased heating demand, which then again would have influenced the profitability of the energy system negatively. The installed heat pump system can be seen as an encouraging example for other hybrid heat pump systems to be used within the ABB Group. In other industrial buildings a pure energy recycling system without boreholes might for instance be the only option due to strict ground water requirements in the area and in these cases an energy recycling system with a solid performance is the most valuable solution. For the investigated building ABB assembly parts in Finland, the use of a pure energy recycling system would have led to a decent heating energy coverage ratio of 63%.

The energy system simulation model in IDA ICE turned out to produce reasonable results compared to the measurements. The greatest uncertainties in the modelling relate to the borehole field, the properties of the ground and the amount of heat loaded into the borehole field by the new liquid cooled air compressors. Thermal response tests for the ground were not carried out during the project because the dimensioning on the energy system was known to be well on the safe side. The energy simulation of the borehole field was, on the contrary, made with conservative input parameters and the heat load of the air compressor was estimated based on measured data from the smaller old compressor (old compressor 75 kW and new compressor 90 kW). From this point of view, it was known that energy modelling would not overestimate the energy performance. The most significant uncertainties in heat pump modelling itself were found in the part load behaviour of the on-off controlled heat pumps at small loads and the effect on the average COP value.

## 5. Conclusions

The hybrid heat pump system investigated in this study was a part of the energy efficiency project carried out by the Granlund company to significantly improve the energy performance of an industrial building owned by the ABB Group in Finland. An incentive to the chosen design approach came from the ABB Group, aiming to significantly reduce the carbon footprint of its buildings in line with the energy program Mission to Zero. Monitoring of the installed heat pump system has revealed that the industrial building has been almost self-sufficient after the proposed adjustments to the ventilation system were made to lower the net heating consumption of the building. In fact, the hybrid heat pump system is for the present use of the building slightly over dimensioned and economically not the most feasible alternative compared to a conventional ground source heat pump system with free cooling. The system was on the contrary dimensioned for the future usage of the building when the manufacturing line is used every day instead of the present usage pattern from Monday to Friday. Hence, extensive energy recycling will pay itself well back in the future compared to a conventional heat pump system requiring more boreholes to cope with the increased heating demand.

The current design approach emphasises a good collaboration with the end user, understanding the current situation and future evolution. A key premise to success is to consider the long-term investment plan and include additional useful investments into the project, improving the overall cost efficiency of the project and making use of the energy grants for investments promoting the use of new energy technology. In this case the

existing air compressor was at the end of its life cycle, meaning that it should have been replaced anyway soon. The integration of the compressor to the energy system for energy recycling and loading the borehole field was a key measure in this project improving long-term energy efficiency of the heat pump system. A lesson learned was the importance of reducing unnecessary heating in the building, in this case unnecessary ventilation during off hours and dimensioning the heat pump system based on new heating consumption. The investigated heat pump system was dimensioned on the safe side based on the higher heating demand and by considering the future needs. Hence, the energy system could have been optimized slightly further and made somewhat cheaper but as a conclusion, it matches or even exceeds the expectations of the Abb's own energy program Mission to Zero. The energy recycling approach investigated in this study is applicable to all kinds of buildings, either as a pure energy recycling system or coupled with boreholes for additional heat extraction and buffering of waste heat into the ground. The system is also scalable in terms of heat pump capacity and the energy recycling sources and dimensioning of the system is tailored to match the consumption profiles of a specific building. The payback time of the investigated system is without energy grants approximately 9 years and with the energy grants in Finland (-20% of the investment cost) approximately 7 years. The energy performance of the energy recycling system could be optimized further based on the readings from the building automation system. With the present setpoints the supply water heating curve has been too high at warmer air temperatures, especially at 0 – 5 °C, over 50 °C. The temperature setpoint should according to the design parameters be more than 5 °C lower, implying that the seasonal COP (SCOP) could be close to 3.5 instead of the measured 3.3.

From the energy modelling point of view, the most important need for future research is to validate the energy system model used in the calculations especially at part loads but also on system level considering the operation of buffer tanks and mixing valves. The existing heat pump calculation models are generalized, and they are not related to a particular heat pump type, in this case to the on-off behaviour of the compressors.

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