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Lessons learned after one-year of use of a highly efficient neighbourhood in Norway

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Abstract. 2020Park is an innovative installation in Stavanger, Norway. This installation provides heating and cooling via a ground source heat pump (GSHP). The system combines eight 220m deep boreholes, with an air to brine heat exchanger and the heat from cooling 15 square meters of thermal photovoltaic cells (PVT). The GSHP has a rated coefficient of performance ranging from 2.8 to over 4 and can deliver 120kW of water-based heating at temperatures 50-60°C. The system is designed to deliver heating and, in reverse operation, cooling to offices, a playing ground, a supermarket and some shops.

Analysing measured data of one year of operation, this system shows a clear discrepancy between available heat for ground storage and required heating during cold periods. Due to the imbalance between needs, one would expect the temperature in the ground to drop and thus the temperature of the brine at the inlet of the heat pump. By using the extra heat sources, the inlet temperature to the GSHP is relatively constant and thus the system operates mostly in constant conditions yielding constant system COP. This solution is very interesting for highly efficient buildings and neighbourhood with unbalanced demands.

1. Introduction

Utilization of flexibility to support the decarbonisation of the supply of energy and energy system is one of the main notes of the Clean Energy Package of the European Union [1]. Buildings stand for 30 -40 % of the world's energy use and ventilation is responsible for a large share of buildings' total energy demands [2]. In Norway, about 80 % of the heating demands are covered by direct electricity or heat pumps [3]. The Norwegian parliament has set forth ambitions to reach 10 TWh absolute savings in existing buildings by 2030 [4]. The government aims to introduce a near-zero energy building (nZEB) standard by 2020 [5]. Thermal energy storage and renewable energy sources are the only way to meet the flexible energy efficient and low emission future requirements. The storage helps reducing power consumption and peak demands and enables efficient supply of thermal comfort with reduced CO₂ emissions and operation costs. Having efficient systems is the only way of achieving nZEB.

However, the demands of the newest building are changing with the tighter building envelopes [6,7]. Now the share of demands for heating is reducing in residences and hot water demands are relatively increasing. In offices the demands for heating are reduced and cooling demands increased because of the use of denser occupancy solutions, as the hot desk, and the higher number of computers and screens. Supermarkets have large amounts of waste heat that can be used for other heating purposes. Thus, when designing systems that supply heating and cooling in the newer nZEBs, old design rules of thumb cannot be used without any further consideration.



In this paper the thermal energy system supplying the heating and cooling demands of the 2020 Park are studied and analysed. The thermal energy supply system comprises a ground source heat pump (GSHP) with two parallel heat pumps and eight boreholes at 220m depth. In addition, two additional thermal systems are connected for ensuring constant inlet temperature to the GSHP. These are the cooling heat from PVT and an air to brine heat exchanger. The one-year measurement data has been studied with regards to the possibilities of low temperatures in the ground due to unbalanced demands and efficient supply of heating and cooling to the consumers via the heat pump.

2. System description

2020Park is a business building complex with an innovative thermal energy supply system situated in Stavanger Norway. The local heating network is provided via the thermal energy supply system and supplies heating and cooling to a total of 25 000 m². The building complex being supplied corresponds to an old brewery that was renovated according to the Norwegian standard of 2007 [8] (NB. Some areas are not renovated due to existing rental contracts that do not allow for intervention during the rental time). Most of the area corresponding to the building is dedicated to different uses. There are offices, a gym, some shops and a supermarket plus a playing ground. The demands from the different consumer types vary in size, temperature and time frame.

All the heating is provided to the different consumers at a maximum temperature of 40-50 °C. The system does not provide hot water and has no accumulation tanks to avoid legionella problems. Most of the heating is provided via water borne ventilation heating coils or radiators. The cooling is provided with temperature as high as possible to avoid condensation in the supply terminals and enable the provision via free cooling.

The heating and cooling system comprises eight ground source collectors. These have an average depth of 220m and are drilled in pairs. One collector is a vertical collector and in the same opening, a second collector drilled with an angle of 14 degrees' deviation from the vertical (as illustrated in Figure 1, right). This is done to reduce cost and used ground area, but unfortunately the boreholes may affect each other, and the extraction of heat/cool is reduced in such cases. The four pair of boreholes may affect each other resulting in reduced effectiveness.

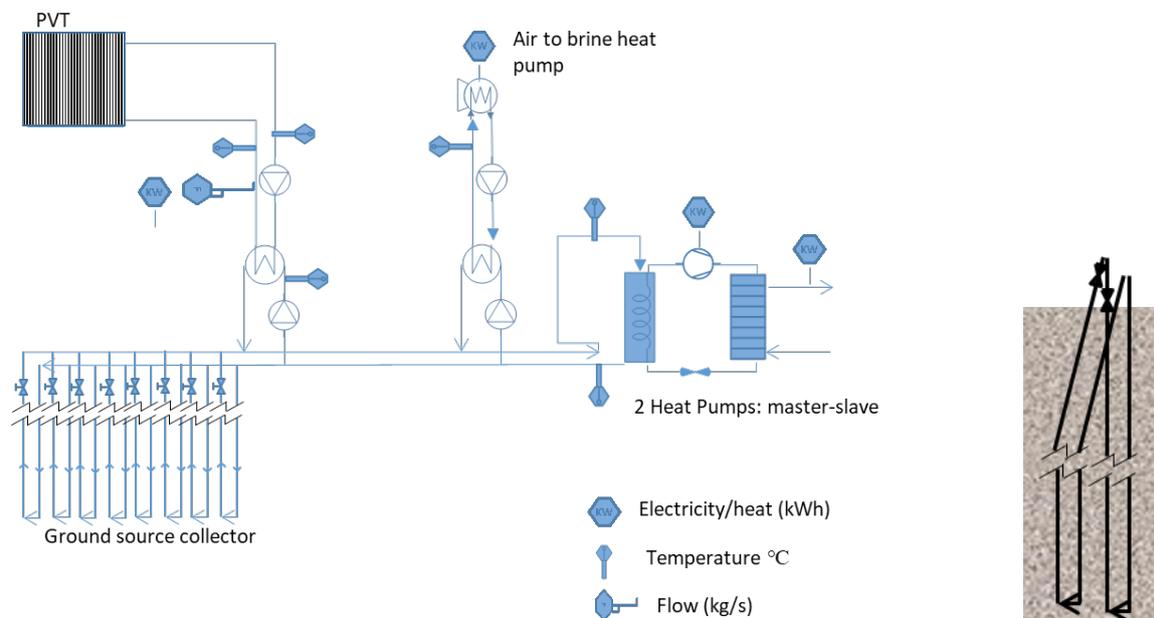


Figure 1. (left) Sketch thermal energy system, (right) sketch of the one pair of borehole collector

Regarding the thermal energy supply system (see figure 1, left), there are two ground source heat pump (GSHP) that are functioning as master and slave and can provide a total maximum heat supply of 120kW at 50°C to the consumers. Furthermore, the building has 15m² of PVT cells. The PVT has micro channels installed behind the PV cells to cool them down. This increases the production of electricity

and recovers heat from the ambient and the sun that can be used to increase the brine temperature from the borehole. Additionally, an air to brine heat exchanger (ASHX) is run when the outdoors air temperature exceeds 2 °C during heating season. This system is directly connected to the line from the ground collector after the PVT and enables a higher heat pump inlet temperature and to reduce the needed heat extracted from the ground. Additionally, for periods of high demands, the system is connected to district heating directly in the consumer side. Regarding measurements, the heat supplied from the PVT has only started to be measured recently and thus no measurements are available for the studied period. The electrical consumption of the air to brine heat pump and the two ground source heat pump compressors are monitored. The total supplied heat is monitored at hourly basis together with the main temperatures and flows of the system.

3. Results

2020Park has been under operation since 2017. Data were collected using two monitoring systems. The one from NIBE (provider of the GSHP) and Greentracker EMS for the whole system's energy demands. The reason for having both platforms is that one is due to simplicity, NIBE delivers their equipment with the follow up system and the cost of introducing these measurements in the Greentracker was not justified when the data could be accessed anyhow. The NIBE sensors are the default sensor provided by the heat pump. The data that has been analyzed is from the period March 2018 to March 2019 so that the in-regulation periods are not within the data analyzed.

3.1. System efficiency

The system COP is defined as the yearly energy factor in equation (1). A major source of uncertainty is in the method used to calculate the COP and the lack of measurements of the PVT (the PVT is measured but not logged and thus impossible to download). As a result, the calculated COP is somewhat higher than the real/effective value, thus the stated COP value has to be considered as a rough approximation.

$$\text{System COP} = \frac{\text{Delivered heating} + \text{Delivered Cooling}}{\text{Electricity compressor HP}_{\text{air source}} + \text{Electricity compressor HP}_{\text{GS}} + \text{Pump work PVT} + \text{GS pump work}} \quad (1)$$

Figure 2, at the left, shows an overview of the calculated system COP throughout the year. What stands out in the figure is that the highest COP is achieved in summer. During summer, the system delivers heating and cooling, which is seen from the higher brine temperatures during the summer in figure 2 (right). The cooling is mostly delivered via free cooling. During summer, the PVT is providing large amounts of heat, that could be used for regeneration of the ground, but owing to the connections of the system this cannot be used directly (see Figure 1). The heating demands during the summer period are related to the low night temperatures and the peak load at the start of the day start of the day.

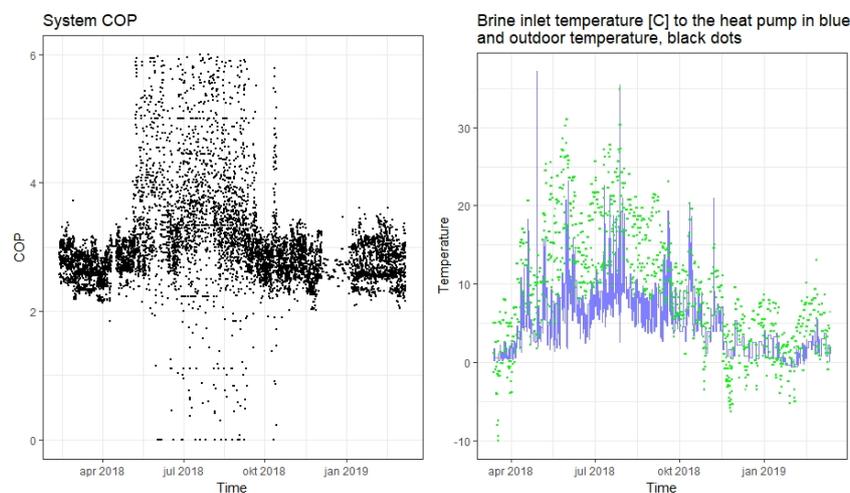


Figure 2. (Left) System COP, (Right) Comparison brine inlet temperature to the GSHP and the outdoor air temperature

3.2. Electrical demands

From figure 3, we can see that the GSHP is run throughout the year. During winter period the heat pumps are run at maximum and during summer at half capacity, one or both compressors. During summer, the ASHX is not run despite the air being above 2°C, to avoid over warming the brine and needing to run the heat pump as cooling machine instead of using it as free cooling. During winter, the ASHX is run very frequently. One could have expected, the correlation of the use of the ASHX with the increase COP to be larger. The low correlation here is somewhat counterintuitive, however, due to the difference of magnitude of both systems, the lower correlation can be justified.

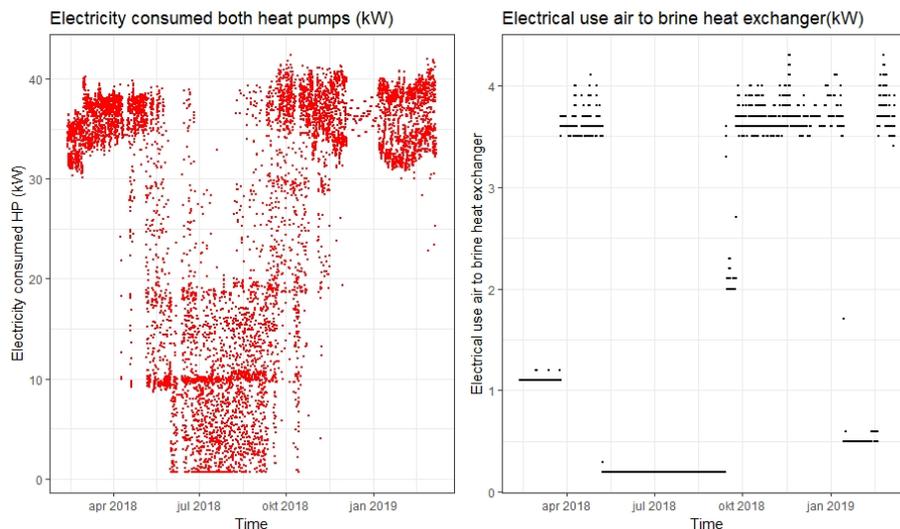


Figure 3. (Left) Electrical demand GSHP, (Right) Electrical demand ASHX

The most striking result to emerge from the data is how positively the use of the ASHX helps increasing the temperature in the supplied flow to the heat pump as figure 2 (right) shows, mostly from April to May and from October to November. During these periods the heating demands are high, but not all the heat is dragged from the ground. There is thus strong evidence that this is also positive to avoid the frost in the collector that would happen if all the heat has to be extracted from the ground. This finding is very important in cold climates as Norway where heating demands are important for many types of buildings.

If we turn to the delivered heating and cooling in figure 4, we see a clear imbalance between both demands. The system delivers heating that peaks at 120kW, the cooling is only 60kW. During the measured period, the heating demands are approximately 750 000kWh for heating and 37 000kWh for cooling. In this case, if all the heating was delivered only from the ground, the temperatures in the ground would have drop below freezing levels. However, the brine that enters the heat pump is always above the freezing level, enabling the high efficiency of the GSHP.

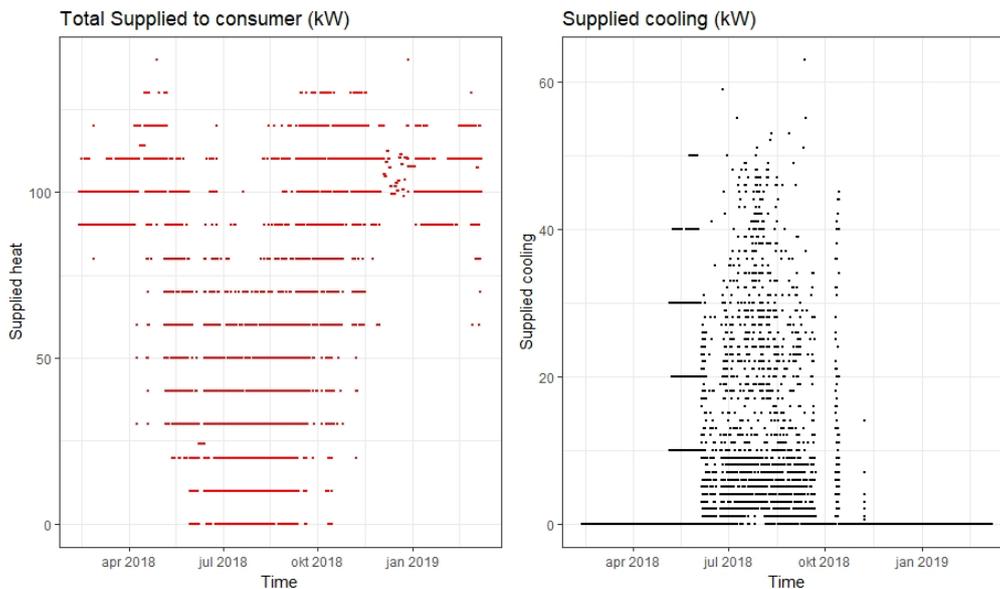


Figure 4. (Left) Delivered heating to consumers, (Right) Delivered cooling to consumers

4. Discussion

The average system performance during one year is 3.5, which is higher than many systems measured in Norway [9] but lower than the pilot buildings to which this installation intends to compare [10]. However, one has to bear in mind that this building complex has its building envelope renovated to a standard level lower than passive house or more recent standards.

This complex's thermal demands show a marked imbalance in heating and cooling demands. However, this cannot be observed looking at the inlet temperatures of the brine to the GSHP after getting unquantified heat from the PVT system and the air source heat exchanger. However, it is expected that the imbalance between heating and cooling will be more pronounced in the brine temperatures for coming years due to the limited time of operation of the GSHP so far. Care should be taken following up the brine temperatures, and strategies for more "charging" of the boreholes. Unfortunately, the monitoring system lacks some important parameters that should have been followed up to provide recommendations for improvements. Looking at the imbalance, given the use of extra heat sources, one could conclude that the temperature in the supplied brine to the heat pump is not varying so much. However, the temperature in the ground should have been monitored to be sure of not incurring in freezing of the ground. To account for the imbalance, solutions for storing larger amount of heat during the cooling season could be looked at, mostly given that the local distribution systems intend to provide heating and cooling to additional buildings. During summer, the air source heat exchanger is not operated to avoid raising the ground temperature, which seems to be a mistake, since charging is larger than discharging of the boreholes. Seasonal solutions such as PCM or thermochemical storage could have been considered to account for the future larger demands to avoid the investment in several extra systems. Employing more PVT in summer season could be a secondary source for heating during winter season. Water tanks could have been used as well as a short time response of the morning peaks. Additionally, given the small amount of cooling needed, it would probably be beneficial to increase the ground temperatures (recharging of the ground), even risking that the cooling has to be provided via the heat pump in cooling mode. Additional heat sources like the waste heat from the refrigeration at the supermarket could be used beneficially. However, nowadays there is no agreement between the heating provider company and the supermarket and the waste heat is used in the supermarket itself.

Further studies should be also done regarding the positioning of the boreholes. Due to the closeness of the pairs of boreholes, inter effects are expected. However, as the system is not recording the ground temperatures, this effect cannot be accounted for and in the future, more measurements should be done.

5. Conclusions

2020Park is a very innovative system that is a good example of solution to be used in future zero emission neighborhoods. In this case, all the buildings forming the neighborhood are placed in the same complex. A local heat distribution system covers the heating and cooling needs of all the connected consumers but without a third-party interaction. To achieve the Zero goal, the systems not only should be efficient, but also the interactions between heating and cooling producers via the local distribution systems have to be improved. 2020Park presents an efficient system in a not so efficient building envelope and thus it is representative and important as example to learn from for future constructions.

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