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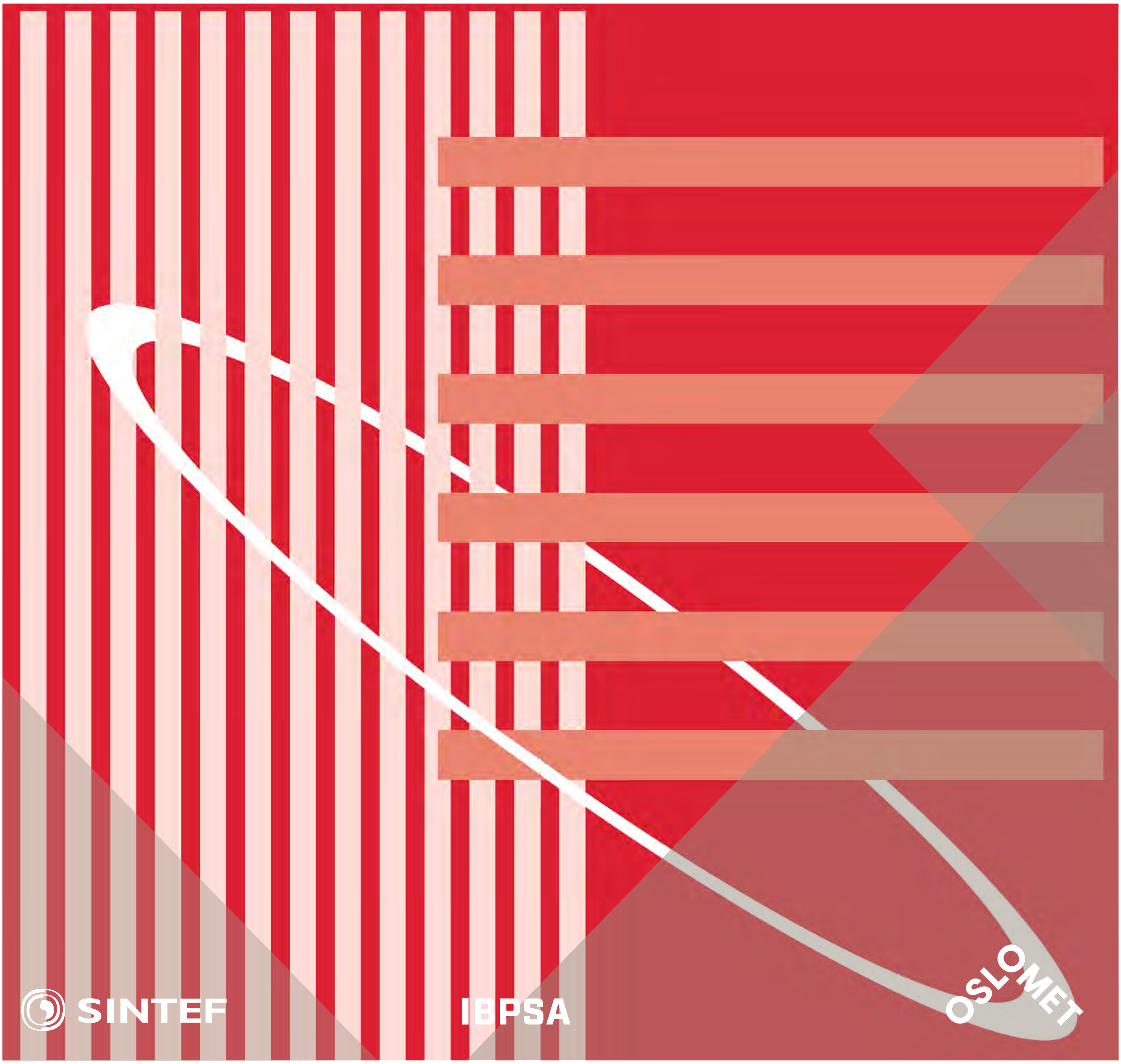

SINTEF Proceedings

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Integration of a high-temperature borehole thermal energy storage in a local heating grid for a neighborhood

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Abstract

A borehole thermal energy storage (BTES) will be built in a refurbished residential district in Oslo, Norway. The new heating demand for the neighborhood is estimated to be 26 GWh/year. To partially meet this heating demand, excess heat from a waste incineration plant will be stored in a BTES. The stored thermal energy can be used as a heat source in winter. A local heating grid connects the heat storage with a district heating grid.

A Modelica model of the BTES system has been created using the results from a design study. Several cases were investigated where the use of the BTES was limited to periods with peaked heating demand. Fluctuating seasonal district heating prices were considered to highlight the economic benefits.

Introduction

With consideration of increasing consumption and depleting fossil-based fuels, the future will most likely bring increased energy prices and both short and long-term energy insecurities. There is a need for better utilization of energy to reach the goals for reducing greenhouse gas emissions. In this context, the future is not just about how energy can be produced as efficient and clean as possible, but also about how to handle the energy that has already been produced. In future neighborhoods, both thermal and electric energy can be managed in a flexible way to achieve reduced power peaks, reduced energy use, reduced CO2-emissions and increased self-consumption of locally produced energy [Jensen17].

For many sites, a seasonal mismatch is at hand between the available waste heat and the heat demand. Typical examples are waste incineration plants with generally uniform amounts of waste heat throughout the year. As waste cannot be stored for several months, it needs to be incinerated in summer as well, leading to great amounts of surplus waste heat available in summer months, while heating demand is greatest during winter. In order to shift heat potentials from summer to winter and thereby enabling the feed-in of otherwise wasted surplus heat in an economically attractive way, this study investigates the storage of waste heat to meet the heat demand for a neighborhood, with the help of a largescale high-temperature borehole thermal energy storage (BTES).

For 4th generation district heating grids, waste heat integration is expected to be a common design element. Integration of waste heat into these grids is technically feasible, as many practical examples were already successfully demonstrated in 2nd/3rd generation grids [Lund14]. However, significant thermal capacities still remain unused due to the required high supply temperatures for 2nd/3rd generation district heating grids.

In this context this study focuses on the case study of Furuset (Oslo, Norway) to explore potentials to improve the local heat supply by using waste heat from a local incineration plant as an additional energy source. The heat is stored in a BTES in summer, and different control strategies for discharging cycles will be highlighted with regard to efficient utilization of the stored heat in winter.

Based on available information about the Furuset area and the plan for the future district heating system, a system model for dynamic simulations of the micro energy grid in Furuset was built to investigate the thermal interaction between the borehole park as a heat source, and the buildings as a heat sink. The focus of the study lies on the evaluation of various operation and control strategies.

Borehole thermal energy storage

A BTES stores large amounts of waste heat for later use to solve the temporary mismatch between energy production and demand. The natural heat capacity in a large volume of underground soil or rock is used to store thermal energy. The subsurface is heated by circulating a fluid like water or brine in a closed system with vertical boreholes that are typically 20 – 200 m deep, filled with a plastic pipe and grouting [Tabares-Velasco17]. Drawbacks of BTES systems are generally slow response and high thermal losses. The slow response is due to a relatively low heat transfer rate between the ground and the heat transfer fluid. Thermal losses for BTES systems are usually in the order of 30 % [Sibbitt15], depending on the shape of the storage volume and the borehole arrangement.

Storage temperatures for regular BTES range between 30 – 60 °C during charging and discharging, with up to 70 – 90°C for high-temperature borehole thermal energy storages [Sibbitt15]. A start-up period of a few years should be expected to heat up the storage and the surroundings for the design system temperature to be reached [Tabares-Velasco17]. The application of BTES has mostly been designed for use in larger building complexes, neighborhoods or as part of district heating grids [Gehlin19].

Existing high temperature BTES systems

Two well-documented cases for high-temperature BTES systems that are well-proven and in operation for several years are integrated in the Drake Landing Solar Community in Canada and at the Emmaboda site in Sweden.

In Drake Landing, heat for 52 high energy-efficiency houses is provided through an integrated system combining solar thermal collectors and a BTES. The BTES system is composed of 144 boreholes with a depth of 35 m [Sibbitt12]. The BTES is connected to solar collectors, auxiliary boilers and two water tanks for short-term storage. The water tanks are used as a buffer between the collector loop, the heating grid, and the BTES field, charging and discharging thermal energy as required to balance both the variations in energy demand and power consumption. The injection and withdrawal temperatures vary from 80 °C to 30 °C. The BTES is providing more than 90 % of the total annual heating demand, which is achieved through a combination of direct use from the solar collectors and indirect use of the stored solar heat in the BTES. The coefficient of performance is over 30. Consistent retrieving efficiencies of above 95 % were achieved for the period 2012 – 2016, with overall ten years of reliable operation with no unscheduled interruptions related to heating delivery operation [Sibbitt12].

The high-temperature BTES in Emmaboda (Sweden) was put in operation in 2010 and consists of 140 boreholes with a depth of 150 m. The system is charged with industrial waste heat from an aluminum foundry. The overall activity at the foundry is rather energy intensive with 45,000 MWh of electricity and 5000 MWh of district heating being purchased for the site annually. The BTES is used to store heat generated in summer when the plant has no heating demand, and to use it in winter to reduce purchased district heating for the site [Nordell15]. The highest achieved values for heat injection and extraction were 2200 MWh and 400 MWh, respectively, yielding a BTES efficiency of 19 % [Nilsson19].

Although the geological conditions in Norway are generally favorable for high-temperature BTES systems [Ramstad17], there is still a lack of integrated high-temperature BTES systems that are in operation. One of the first high-temperature BTES systems in Norway is planned to be built at Furuset in Oslo.

The Furuset case

The site in Furuset is a pilot area within the research center ZEN (Zero Emission Neighborhoods in smart cities) [Baer18]. Furuset is a multi-functional local neighborhood center in the eastern part of Oslo which incorporates about 3.800 residential units from the 1970s. The Furuset project aims to physically upgrade the district towards high environmental ambitions. The renewal includes the whole infrastructure and is taking energy, waste, water, traffic and social issues into consideration.

The development of a micro energy system aims to establish a local energy system with zero-emissions. Furuset lies within the concession area of a local district heating provider. Estimated timeframe for completion is 2030 [Baer18].

The planned micro-energy system in Furuset is depicted in figure 1. It will be used to connect a high-temperature BTES, solar panels and batteries with a local district heating grid to reduce peak loads.

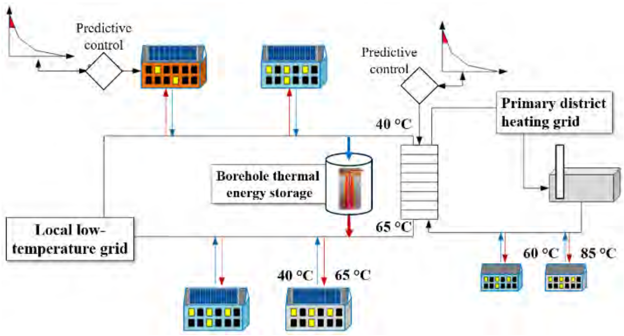

Figure 1: The planned micro energy system in Furuset

The utilization of a BTES is a promising approach to store surplus heat during summer from the local nearby waste incineration plant in Klemetsrud for heating purposes in winter, thus getting a step closer to establish a local energy system with zero-emissions. The stored surplus heat can be used for either direct use in the local thermal grid or as a heat source for a heat pump.

To investigate the dynamic interaction between the BTES, the incineration plant, Furuset's micro energy system and the primary district heating grid, a Modelica-based model was created. With help of the model, several BTES operation cases and control strategies can be assessed to guarantee the most efficient utilization of the stored heat. Both the model and the system design parameters that are used in the model are presented in the following sections.

Dynamic simulation model

A simplified version of Furuset's micro energy system from figure 1 is modelled using the Modelica language. A borehole field model is available in the open-source buildings simulation library IBPSA [Wetter14], which was modified and configured to fit the Furuset design. The Modelica model (figure 2) uses the system design parameters from the following section.

As the Furuset borehole park is planned to be an extensive site with 440 boreholes thermally interacting with each other and the ground, the borehole model needs to provide the possibility for the simulation of both short-term transient thermal effects within the boreholes and long-term thermal interactions within the overall bore field.

A common strategy for the simulation of BTES is to use separate models to evaluate heat transfer inside and around the boreholes, with the borehole wall temperature acting as an interface between the models [Cimmino19a].

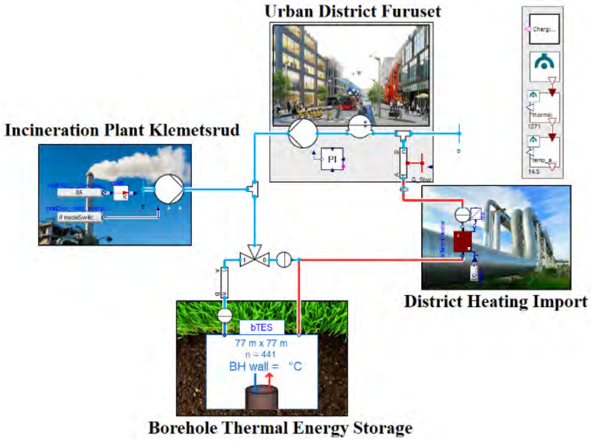

Figure 2: A simplified overview of the modelled micro energy system in Furuset

In general, the borefield model is constructed in two main parts: the borehole and the ground heat transfer. The thermal behavior between the pipes and borehole wall are modeled as a resistance-capacitance network [Bauer11]. Fluid and ground temperatures are predicted by temporally superimposing g-functions, which are step-response functions that estimate the relation between the heat injection rate in the bore field and the resulted average temperature variation at the borehole walls [Eskilon87]. The g-function of a particular bore field needs to be superimposed in time to obtain the effective borehole wall temperature variation due to variable heat extraction rates.

The heat interaction between the particular boreholes is therefore restricted to parallel feeding of the boreholes, as the same borehole wall temperature needs to be assumed at each depth. The ground temperature response model only computes the average borehole wall temperature for all boreholes combined. Except for various first results as for example stated in [Cimmino2019b], there is currently no modelling approach reported that is capable of considering both serial and parallel operation of a borehole park for long-term dynamic simulations. The results of this study shall therefore be assessed in consideration of the usage of a parallel connection setup.

System design parameters

The heat demand for Furuset is estimated based on the expected building mass in 2030. A typical temperature profile for Oslo is used as a base to generate thermal load profiles from a database that contains various large sets of heat load measurements from different building categories and energy efficiency levels. The heating demand includes both space heating und domestic hot water heating. It is mapped based on estimated floor space as well as the age and type of both new and old buildings in the neighborhood [Lindberg13]. As illustrated in figure 3, the maximum value for the heat demand is estimated to be 10.1 MW while the aggregated yearly heating demand is 26 GWh. The Modelica model applies this heat demand profile directly as a heat sink.

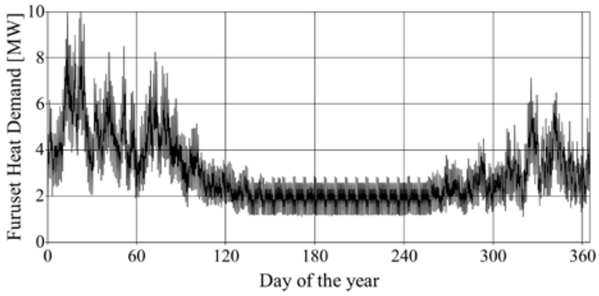

Figure 3: The estimated heat demand profile for Furuset

In addition to the estimated heat demand profile for Furuset, further design parameters are provided by a design study conducted by [Tvärne18]. The supply and return temperatures in the micro energy system are planned to be 65 and 40 °C, respectively. The preliminary design of the high temperature BTES was concluded to consist of 440 boreholes, each 180 m deep with a 3.7 m distance between the boreholes, arranged in a cylindrical shape with both parallel and serial water flow. Further design parameters are summarized in table 1.

Table 1: Design parameters for the planned BTES system in Furuset [Tvärne18][Zari16]

Charging temperature in summer	87 – 90 °C
Mass flow rate in summer/winter	200 m^3/h, 1100 m^3/h (55 – 305 kg/s)
Pipe material	U-pipe, type PE100-RT, HDPE ISO 24033 Type II (0.42 W/mK, 0.941 g/cm^3)
Borehole thermal resistance	0,12 - 0,26 Km/W
Rock type	Granodiorite/Gneiss,
Rock density	2.65 g/cm^3
Rock heat capacity	770–979 J/kg K
Rock thermal conductivity	2.7–3.1 W/m K

As for the waste heat quantification, the design study estimates excess heat in the range of 40 MW from the incineration plant in Klemetsrud being available during the summer months June, July and August. During these three months, the BTES system will only be operated in charging mode. Starting from September, the BTES can be used to provide heat to the micro-energy system of Furuset. The maximum charging (injection) and discharging (extraction) effect for the BTES is estimated to be 12 MW and 4 MW, respectively. The total amount of required thermal energy for charging is 13 GWh/year. With an estimated heat loss value of 27 %, 9.5 GWh of heat can be provided per year to Furuset. However, these values only apply for a BTES in equilibrium state, after several years of charging. Table 2 and figure 4 show that a larger amount of heat is needed especially in the very first year of operation:

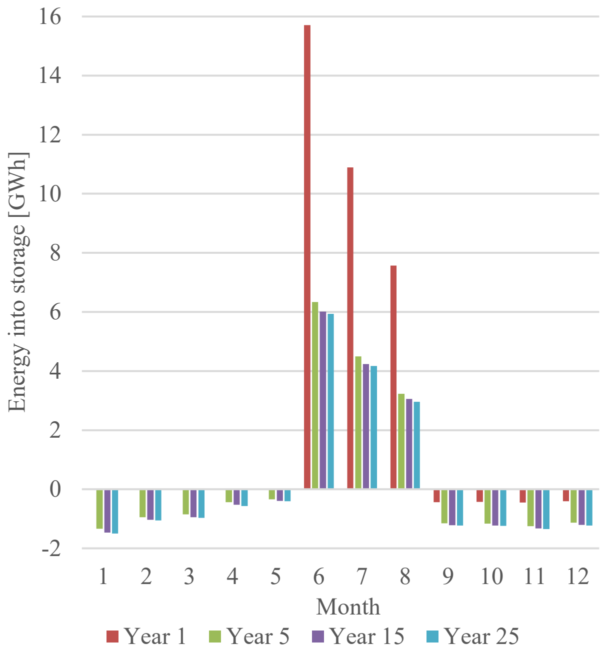

Figure 4: Estimated monthly heat for charging and discharging the BTES for several years of operation [Tvärne18]

After five years of operation (green bars in figure 4), the heat losses have stabilized and the BTES can be used with balanced charging and discharging cycles, as the amount of heat being injected and extracted from the BTES is already close to the equilibrium values that would be reached after 25 years of operation (purple bars in figure 4). In an equilibrium operation, roughly 13 GWh are being charged into the BTES during the three summer months, while 9.5 GWh are being discharged during the remaining months, as summarized in table 2.

Table 2: Estimated aggregated heat for charging (three summer months) and discharging (nine winter months) the BTES for several years of operation [Tvärne18]

Season	Year 1 [GWh]	Year 5 [GWh]	Year 15 [GWh]	Year 25 [GWh]
Charging (Jun-Aug)	34.18	14.06	13.31	13.07
Discharging (Sep-May)	-1.72	-8.61	-9.35	-9.54

Case studies

A Modelica-based model was created towards results from the design study. To assess the most efficient utilization of the high temperature BTES with regards to lowering additional heating costs in form of imported district heat, several BTES operation cases and control strategies need to be evaluated. The first two cases *partial mass flow* and *complete mass flow* focus on general control strategies and the effect of mass flow control on the BTES performance.

The focus for case *September*, case *December*, case *peak 3.4* and case *peak 2.7* lies on discharging strategies, and how the BTES can most effectly reduce the overall energy cost in the micro energy system. With the help of peak shaving, the amount of imported district heating during periods of highest heating prices will be reduced. In all cases, comparisons between the modelled system performance results and the preliminary system performance results from the design study will be conducted.

Mass flow control cases

The first two sets of simulations focus on control strategies for operating the BTES. For the case *partial mass flow*, the BTES is operated to provide an outlet water temperature of 65 °C. To achieve this, the mass flow rate into the BTES is therefore limited and the rest of the flow is bypassed. Additional heat imported from the district heating grid is then used to heat the bypassed flow. The advantage of this approach is that the main district heating system can achieve lower return temperatures. For the case *complete mass flow*, the whole water mass flow which would be required to match the district's heat demand profile is pumped into the BTES, resulting in a lower water outlet temperature out of the BTES. In that case, the district heating system is used to lift the temperature up to the required 65 °C.

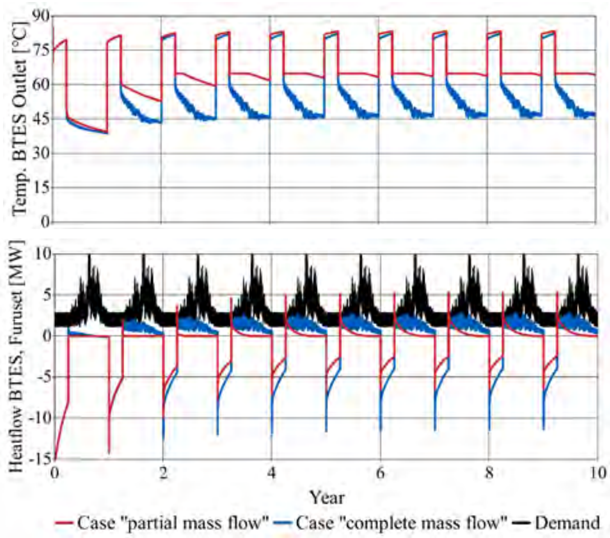

Figure 5: Comparison of two control strategies for BTES discharging over ten years of operation: (a) BTES outlet temperature; (b) heat flow rate into (negative value) and out of (positive value) the BTES in comparison to Furuset's heat demand

Figure 5a shows the BTES outlet temperature for ten years of operation with three months of charging followed by nine months of discharging. Figures 5b is comparing the heat flow rates from and into the BTES with the requested demand by the neighborhood. The modelled maximum charging power for the first year is 15 MW, while 12 MW were anticipated in the design study. The first year (i.e., the first three months) of charging was completed with 25 GWh of heat being stored in the ground, while the design study estimated 32 GWh. The deviation might result from the use of a parallel borehole configuration in the present model, while the design study suggested a serial connected setup, resulting in different values for the mass flow rate and overall heat losses.

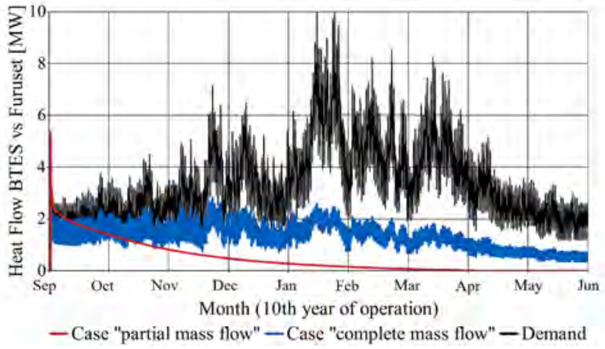

Figure 6: Comparison between Furuset's heat demand and the heat flow rate for the BTES, for nine months of BTES discharging, after ten years of operation

Figures 6 is zooming into figure 5b to focus on the tenth year of operation when an equilibrium operation point can be assumed after the initial years of charging the BTES. The nine discharging months are illustrated and the provided heat by the BTES for both two cases are depicted in comparison to the overall heat demand of the district. The difference between both curves yields therefore the amount of imported district heat to fully cover Furuset's heat demand.

Figure 6 shows that the case *partial mass flow* is not capable of providing sufficient heat to the neighborhood, especially during the periods of peaked demand in January/February. The integrated values yield that in case *partial mass flow* only 7.1 GWh of heat is stored in the BTES during summer and 3.2 GWh are being discharged during the rest of the year. For case *complete mass flow*, 12.1 GWh are charged and 8.9 GWh are discharged, which meets the estimated values from the design study, as stated in table 2 and figure 4. It can be therefore concluded that only case *complete mass flow* is able to reproduce realistic BTES operation, and the BTES system should be operated with higher mass flow rates with less consideration of the BTES outlet temperature.

In case *partial mass flow*, even ten years of BTES operation are apparently not sufficient to provide an outlet temperature of 65 °C with reasonable amounts of mass flow rates, which ultimately results in highly increased imported district heat. This cannot be justified by the lower return temperature in the district heating grid, and it can be therefore recommended to control the BTES with an increased mass flow rate and accepting slightly lower outlet temperatures. In that case, more heat can be retrieved compared with an outlet temperature-controlled BTES system. It shall be however noted that a proper consideration of the pressure loss within the BTES will most likely lead to a more beneficial assessment of the *partial mass flow* case.

However, as shown in figure 6, both operation cases are only covering 2 % (case *partial mass flow*) and 26 % (case *complete mass flow*) of the highest peak load in January. Most of the peak loads are being covered in the beginning of the discharging season in September/October, when import from the district heating grid is not as costly as during winter months. The next cases will therefore focus on reducing the highest peak loads during winter.

Peak shaving cases

For the next cases, the BTES will be mainly used to reduce the amount of imported district heating especially during the most costly time periods of peaked heat demand. To better evaluate the economic benefit when a BTES is applied to reduced transient peak demands, the price for imported heat from the district heating grid needs to be considered. The real economic benefit of this system is a function of the marginal energy production cost for the district heating company. However, this information is considered trade secret and is therefore not publically available. Instead, a comparison of the following cases is performed with a standard pricing scheme for industrial costumers.

The district heating price is typically added together from three terms: a fixed base term, an energy term and a term for the maximum peak demand per month. Up-to-date values for these terms for 2019/2020 for industrial end-users were taken from a local district heating provider in Oslo [Fortum20]. The basic term is 3000 NOK/year, and the remaining monthly terms are summarized in table 3.

Table 3: District heating prices for industry in Oslo, 2019/2020 [Fortum20]

Month	Energy Term [NOK/kWh]	Maximum Demand Term [NOK/kW/month]
January	0.5103	150
February	0.3992	150
March	0.3640	80
April	0.2954	23
May	0.6172	23
June	0.5253	23
July	0.5559	23
August	0.5697	23
September	0.5270	23
October	0.6005	23
November	0.6868	80
December	0.6425	150

The highly increased pricing for district heat import is especially apparent during the winter months of December, January and February. The explicit utilization of the stored heat from summer during these particular months offers therefore the highest possible savings. In the following, four control strategies for an efficient usage of the BTES during peaked demand will be compared. It shall be noted, that based on the results from the previous section, the BTES is supplied with an on/off control for the mass flow in all four cases: If stored heat from the BTES is requested, the complete required mass flow needed to meet the heat demand of the neighborhood is pumped into the BTES, as a partial bypass was considered to be energetically less favorable.

The first case *September* corresponds to the *complete mass flow* case from the previous section, as the BTES discharging starts right after the end of the charging period and lasts for nine months.

For case *December*, a shorter overall discharging period is investigated. The start of BTES discharging is shifted to the beginning of December, when the import of district heat becomes most costly. Therefore, the BTES is completely bypassed for the first three months September, October and November, and the heat demand for the neighborhood is entirely provided by district heating during the first months.

In the last two cases, *peak 2.7* and *peak 3.4*, the BTES will only be utilized when the neighborhood's heating demand surpasses a specific threshold. The threshold for case *peak 3.4* is set to 3.4 MW to concentrate the utilization of the BTES to periods with highest heating demand. The import from the district heating grid will therefore cover all heating demand under this threshold, while the BTES is providing any heat demand surpassing the 3.4 MW threshold. The shaved off peaks are illustrated in figure 7:

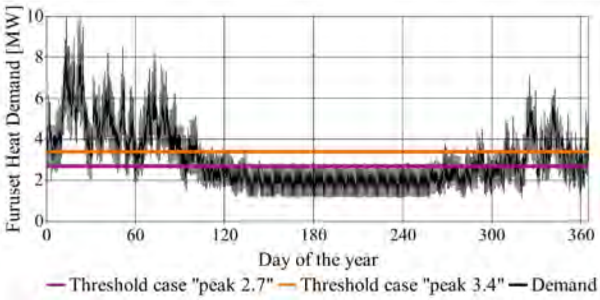

Figure 7: Visualization of both peak shaving thresholds in comparison to Furuset's heat demand profile

The threshold for case *peak 2.7* was calculated considering the known heat demand profile, to ensure that all of the stored heat is utilized in the most efficient way: Since it was shown in table 2 that the BTES is capable to deliver at most 8 – 9 GWh per year, the integrated value for the particular shaved off peaks in the demand profile were set to 8 GWh, to theoretically approach an optimal and complete utilization of the stored heat by the end of the discharging season. With the given heat demand profile, the threshold was calculated to be 2.7 MW.

It shall be noted that this theoretical approach is only applicable because of the assumption of a known heat demand profile. In reality, the district's heat demand cannot be perfectly predicted, leading to a non-optimal usage of the BTES when the stored heat will either diminish before the end of the peaked heating season (overutilization of the BTES) or when valuable stored heat was not fully discharged during periods of peaked demand (underutilization of the BTES). In general, the prediction of future demands for optimal production planning is already well established in the operation of district heating grids, but not in connection with seasonal time horizons.

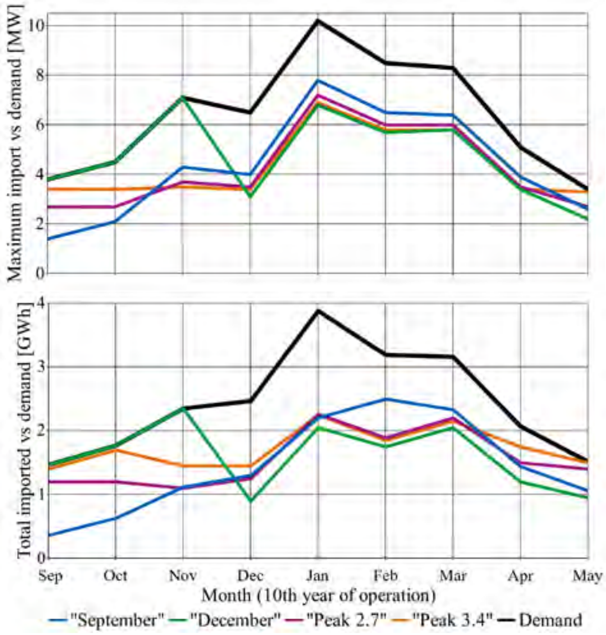

Figure 8: Four cases for peak heating reduction: (a) maximum peak values for Furuset's heating demand vs. imported district heat [MW], (b) overall heat demand of Furuset vs. imported heat from district heating [GWh]

Figure 8a illustrates how much heat in [MW] needs to be imported from the district heating grid for all four cases. Figure 8b illustrates the imported heat in [GWh]. As a comparison, the overall heat demand of Furuset is depicted as well. The difference between the black and the colored lines in figure 8 equals therefore the heat that is provided by the BTES. The bigger the difference between the black and the colored lines, the greater the cost reduction becomes due to reduced import of district heat.

Table 4 and table 5 summarize the reduction in peak heating in percent, both for the monthly maximum imported heat in [MW] and the overall imported heat in [GWh]. The second column in table 5 depicts Furuset's heat demand in [GWh] for each particular month of the discharging season. Without the utilization of any BTES, this amount of heat would be fully covered by import from the district heating grid. The sum for the nine discharging months equals to an annual heat demand of 21.9 GWh and is therefore slightly lower than the estimated 26 GWh from section "*System design parameters*", as the three summer months were excluded. During the summer months, it is assumed that the heat demand of Furuset is fully covered by available surplus heat from the incineration plant.

The amount of imported heat for case *December* equals the overall heat demand of the neighborhood in the first three months, since the BTES is not used before December. However, case *December* offers the biggest peak reductions for the remaining months, when most of the stored heat from summer is finally discharged, as illustrated in figure 8, table 4 and table 5.

Table 4: Furuset's maximum heat demand per month [MW] vs. the reduction of maximum imported heat from the district heating grid [in %] due to BTES usage

Month	Peak heat demand [MW]	Case peak 3.4 [%]	Case *peak 2.7* [%]	Case *Dec.* [%]	Case *Sept.* [%]
Sep	**3.78**	-10	-28.5	0	-63.3
Oct	**4.5**	-24.5	-40	0	-54.4
Nov	**7.15**	-51.7	-48.1	0	-39.7
Dec	**6.49**	-47.6	-46.4	-52.8	-38.2
Jan	**10.22**	-32.4	-29.6	-33.1	-24.1
Feb	**8.52**	-32.4	-29.4	-32.8	-23.8
Mar	**8.26**	-30.3	-27.4	-30.4	-22.1
Apr	**5.15**	-34	-31.4	-34.3	-24.9
May	**3.41**	-2.3	-20.8	-34.4	-24

Table 5: Furuset's monthly heat demand [GWh] vs. the heat import reduction [in %] due to BTES usage

Month	Heat demand [GWh]	Case *peak 3.4* [%]	Case *peak 2.7* [%]	Case *Dec.* [%]	Case *Sept.* [%]
Sep	**1.47**	-4.8	-18.4	0	-75.5
Oct	**1.77**	-4	-32.2	0	-64.4
Nov	**2.35**	-38.3	-53.2	0	-52.3
Dec	**2.47**	-41.3	-49.4	-63.6	-47.4
Jan	**3.88**	-42	-41.8	-47.2	-43.3
Feb	**3.19**	-42	-40.8	-45.1	-21.6
Mar	**3.16**	-32	-30.4	-35.1	-26.3
Apr	**2.07**	-15.5	-27.5	-42	-30.4
May	**1.52**	-1.3	-7.9	-37.5	-30.3

The effect of peak shaving is lowest for case *September*, especially during highest peak heating periods in winter, as the BTES is constantly being discharged and therefore not capable of providing enough heat during these periods. However, during the first four months and for the very last month, case *September* is capable to provide a larger reduction in heat import as both *peak* cases. This is due to the constant discharging of the BTES which leads to an increased utilization of most of the stored heat, while both *peak* cases appear to underutilize the stored heat:

The total amount of provided heat during the nine months is highest for case *September* (8.94 GWh), and especially case *peak 3.4* underutilizes the stored heat, as only 6.38 GWh of heat are being released in nine months, due to the restricted temporal utilization of the BTES in that case. Case *December* provides 7.39 GWh while case *peak 2.7* provides 7.88 GWh during nine months. The elaborate estimation of proper thresholds for peak shaving resulted therefore only in marginal efficiency improvements: Both *peak* cases provide approximately the same order of magnitude for peak reduction as case *December*, but especially for case *peak 3.4*, at the expense of overall utilization of stored heat potential.

Finally, with consideration of the amount of imported heat from figure 8 and the corresponding price terms from table 3, the overall costs for importing district heat result in: 10.04 MNOK for case *September*, 11.16 MNOK for case *December*, 10.48 MNOK for case *peak 2.7* and 11.26 MNOK for case *peak 3.4*. Without the utilization of BTES, the supply of Furuset's heat demand would be fully covered by import from the district heating grid, resulting in costs of 16.40 MNOK. Therefore, these costs can be reduced by 31.3 – 38.8 % when stored surplus heat from summer is utilized in winter.

It shall be noted that the consideration of a serial connected bore field will most likely result in higher outlet temperatures and therefore increased maximum power output from the storage, resulting in higher potential for cases that focus on peak heating thresholds such as the presented *peak* cases in this study.

Conclusion

BTES systems offer huge potential for storing surplus heat in summer for later use in winter. This simulation-based study was conducted with the help of a Modelica-based model, which utilized the results from a design study. The model was used in combination with aggregated heat demand profiles for a neighborhood in Oslo to get preliminary evaluations on the efficient integration of a BTES within a local micro energy system. The results showed that utilization of stored heat during periods of peaked heat demands provide great potential to reduce the costly heat import from district heating grids.

Two cases for testing general control strategies to discharge the BTES were investigated. Running all the water through the BTES resulted in a decreased borehole outlet temperature, and additional heat from the district heating grid was needed to lift the temperature to the required supply temperature. This operation mode was assessed to be energetically more efficient than the case with decreased water mass flow rates into the BTES, which lead to higher outlet temperatures but also more additional heat needed to be imported.

Several cases for temporally shifting the usage of the stored heat were investigated. It has been shown that with proper BTES utilization, the costs for importing district heat during periods of highest heating demand can be greatly decreased. Depending on the discharging case, the maximum heat demand was reduced by up to 53 % in winter. It was shown that the costs for importing district heat can be reduced by up to 39 % when stored surplus heat from summer is used in winter. The efficient utilization of the stored heat can be highly dependent on the anticipated heat demand profile for the district, as the threshold for starting the BTES discharge can be set too low (overutilization) or too high (underutilization).

In this context, heat demand profiles with more extreme peak demands could be analyzed in the future with their effect on an efficient utilization of the BTES. Furthermore, focus needs to be put on the usage of additional heaters: Heat pumps or electrical heaters can be assessed as an alternative to the import of district heating, and economic comparisons need to be drawn with consideration of both electricity prices and district heating prices. A proper consideration of pressure losses and pumping power as well as the integration of a BTES connected in serial configuration will further increase the quality of future studies on BTES integration: A storage in serial connection mode would reduce the heat losses to the ground in comparison to a parallel-connected BTES, and therefore increase the maximum power output.

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