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USING THERMAL STORAGES TO SOLVE THE MISMATCH BETWEEN WASTE HEAT FEED-IN AND HEAT DEMAND: A CASE STUDY OF A DISTRICT HEATING SYSTEM OF A UNIVERSITY CAMPUS

Haoran Li[1], Juan Hou[1], Natasa Nord[1*]

1 Department of Energy and Process Technology, Norwegian University of Science and Technology (NTNU), Kolbjørn Hejes vei 1 B, Trondheim 7491, Norway

ABSTRACT

Nowadays, the fundamental idea of district heating (DH) is to utilize local heat resources to satisfy local heat demands, otherwise those resources would be wasted. However, the mismatch between the achievable resources and fluctuating demand is challenging. This study analyzed the possibilities to solve this problem by introducing a short-term thermal storage and a seasonal thermal storage. A water tank (WT) and a borehole thermal storage (BTS) were chosen as the thermal storages. The DH system of a Norwegian university campus was selected as the case study. A high order system model was built in Modelica language. The results showed that the mismatch might be solved. The BTS brought about 3 GWh annual heat saving, and the WT brought about 110 kW average peak load shaving. However, around 0.8 GWh/year electricity was used by heat pump to recover the stored heat in the ground.

Keywords: 4th generation district heating, waste heat, ground source heat pump, seasonal thermal storage, water tank

1. INTRODUCTION

Nowadays, the fundamental idea of district heating (DH) is to utilize local heat resources to satisfy local heat demands, otherwise, those resources would be wasted. The suitable heat resources can be waste incineration, combustible renewables, geothermal energy, large solar collector fields, and waste heat from industry and other processes [1]. In 2014, renewables share 27% of European Union's DH supply, and the share of recycled waste heat share is 72% [2]. In the future, the share of recycled heat from combine heat and power plants will decrease, due to the increasing use of renewable power. However, waste heats from other sources bring huge potentials. To realize this idea, the current second or third generation DH system should transform into the 4th generation DH system. Characterized by flexible heat sources, low temperature, and smart management, the 4th generation DH system will show its energy and environment advantages in the coming years [1, 3]. However, the undergoing transformation has been facing many technical challenges [4, 5].

This study analyzed the challenge of harvesting waste heat from a data center. To solve the mismatch between the waste heat feed-in and heat demands, systems with thermal storages (TS) were investigated. A water tank (WT) and a borehole thermal storage (BTS) were chosen as the short-term TS and seasonal TS, respectively. The results of this study can provide guides for the development of the further DH system.

2. BACKGROUND

The DH system of a Norwegian university campus in Trondheim, Norway, was chosen as the case study. The topology of the network, the location of heat sources and buildings are presented in Fig 1.

The total building area of the campus is about 300,000 m^2. The main building function types are education, office, laboratory, and sport. Detail information of those buildings can be found in [6]. In the current situation, heat is delivered by two means: the main substation (MS) and a data center (DC). The MS obtains heat from the city DH system, and the DC recovers condensation heat from its cooling system. According to the measurement from June 2017 to May

2018, the total heat supply was 32.8 GWh, among them 77% came from the MS, and 23% came from the DC.

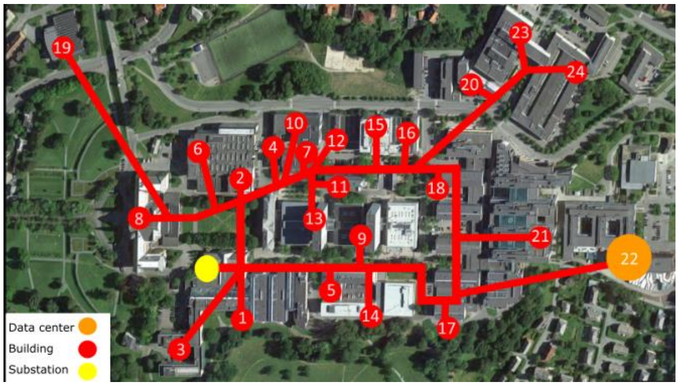

Fig 1 DH system of the university campus [7]

There was a mismatch between the waste heat feed-in and heat demands according to the measurement. As shown in Fig 2, the temperature difference between the supply and the return water of the secondary side of the MS showed negative values when the outdoor air temperature was above 7°C. This meant that the heat was transferred from the campus DH system to the city DH system. The reverse heat flow was caused by over waste heat feed-in.

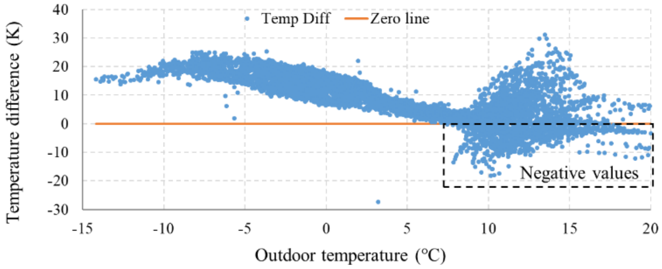

Fig 2 The measured water temperature difference of the secondary side of the MS

The short-term mismatch for a typical week is shown in Fig 3. During the periods with over waste heat feed-in, the reverse heat flow could be considered as heat loss for the campus DH system. In contrast, for the periods with insufficient waste heat feed-in, the deficit would be supplemented by the MS. Introducing a short-term TS can be one way to solve the short-term mismatch.

The net value of the over heat feed-in (over waste heat feed-in minus deficit in Fig 3) for a typical week was 0.02 GWh. In addition, the period with the over waste heat feed-in lasted for about half a year as shown in Fig 4. The long-term duration of the over heat feed-in makes it reasonable to introduce a seasonal TS.

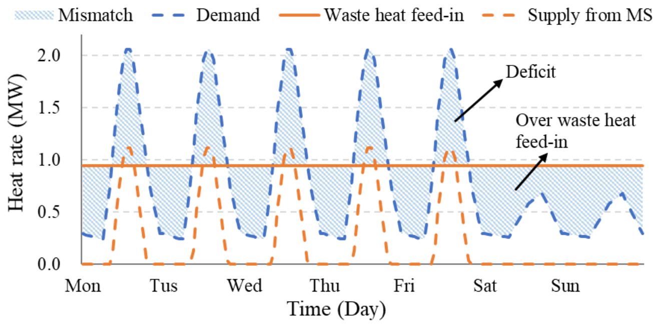

Fig 3 Heat balance for a typical week when the outdoor air temperature is above 7°C

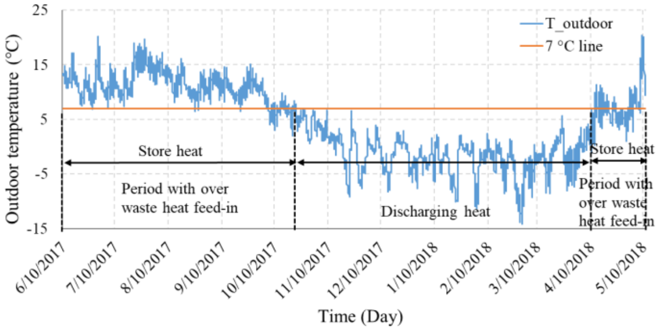

Fig 4 The measured outdoor air temperature and the period with over waste heat feed-in

3. METHODOLOGY

3.1 *Simulation tool*

The DH system model of the campus was built based on Modelica language [8]. Compared with other widely used tools such as Simulink, TRNSYS, and IDA ICE, Modelica presents the highest fidelity for DH system simulation [9]. Dymola [10] was used as the simulation environment. The libraries from IBPSA Project 1 [11] were selected to build the model.

3.2 *Scenarios and model*

Four scenarios with different system design were investigated. Detailed description about the scenarios is given in Table 1.

Table 1. System description of different scenarios

Scenarios	Short-term TS	Seasonal TS
NoShortNoSeasonal	-	-
WithShortNoSeasonal	WT	-
NoShortWithSeasonal	-	BTS
WithShortWithSeasonal	WT	BTS

Note. '-' refers to not exist.

The model structures of the scenarios in Table 1 are presented in Fig 5. The scenario 'NoShortNoSeasonal' was the reference scenario of this study, which was similar with the current situation of the DH system.

For all the scenarios, the way of waste heat feed-in was from return to return, which meant that the water from the return pipes of the DH system went through the condensation side of heat pumps (HP), and it went back to the return pipes after collecting the condensation heat. The return water would be further heated by the MS before it became the supply water of the system. The idea of the connection the return to return was to utilize the high supply temperature from the city DH system, while at the same time ensured a high coefficient of performance for HPs.

For the scenarios without the BTS, the cooling tower (CT) would exhaust the over heat of the DH system and decrease the cooling water temperature of the HP in the DC. In that way, the safety operation of the HP would be ensured. The function of the WT was peak load shaving. Heat would be stored during the low demand hours and used during the peak load hours.

For the scenarios with the BTS, when the outdoor air temperature was above 7°C, the high return water temperature would first go through the BTS and be cooled, while heat would be stored in the ground. The cooled water would go to the DC afterwards. In those scenarios, the BTS replaced the CT as the condensation heat cooling system. When the outdoor air temperature was below 7 ℃, the return water went through the DC directly. In addition, the stored heat in the ground would be extracted and boosted by a HP for heating use.

4. RESULTS

The daily peak load shaving induced by the WT is presented in Fig 6 and Fig 7. Significant effects of peak load shaving can be observed for the scenarios both with and without the BTS. In addition, the peak load shaving patterns were similar for the scenarios with and without the BTS. The maximum and the average shaving values were 1 519 kW and 110 kW for the scenarios without the BTS, and 2 168 kW and 103 kW for the scenarios with the BTS.

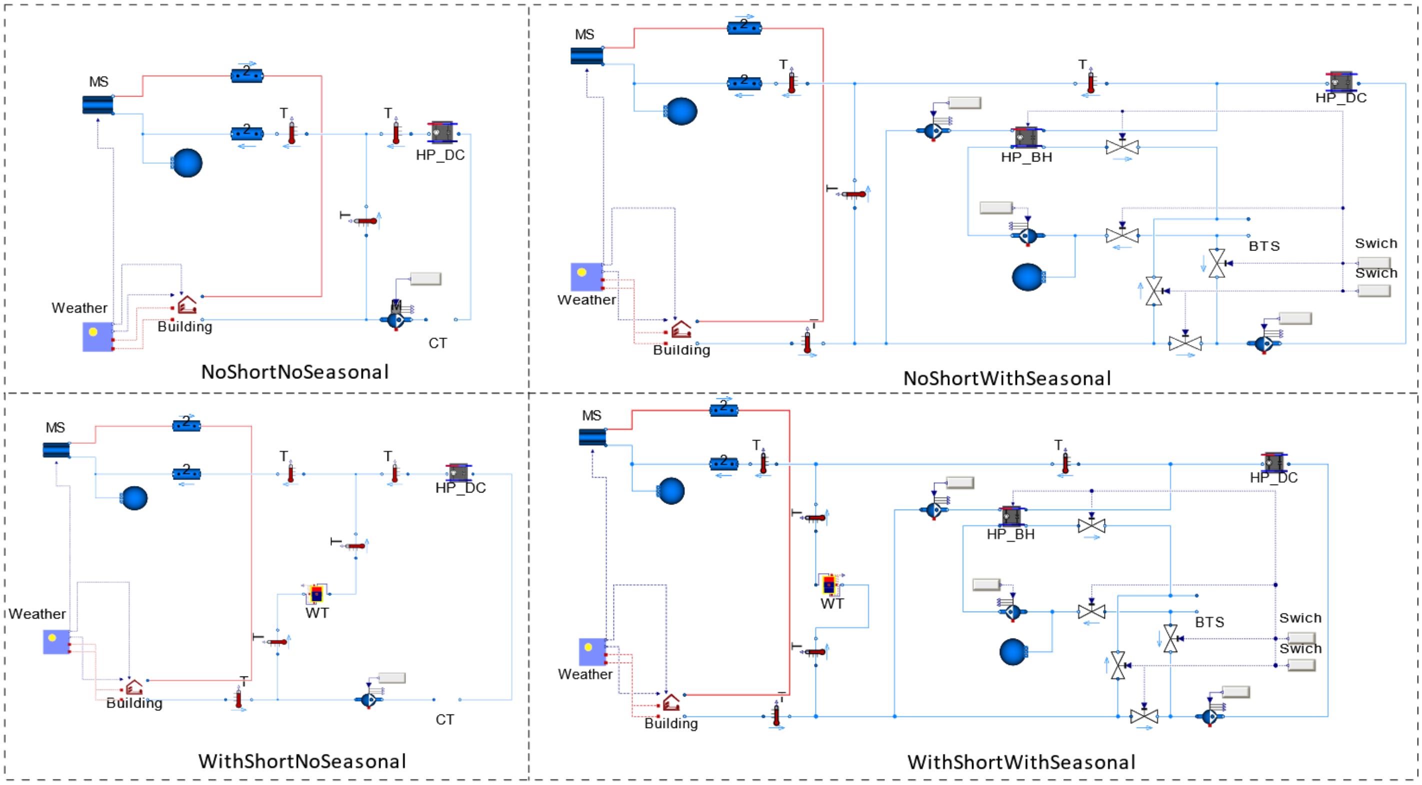

Fig 5 Model schematic of different scenarios

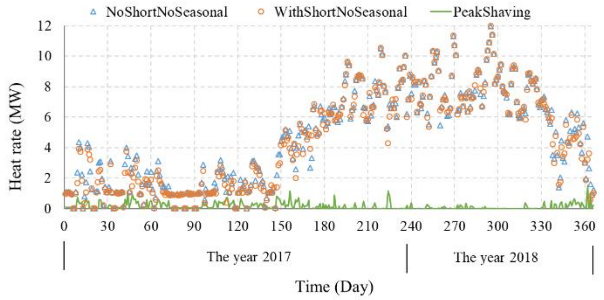

Fig 6 Daily peak load and peak load shaving due to the WT, for the scenarios without BTS

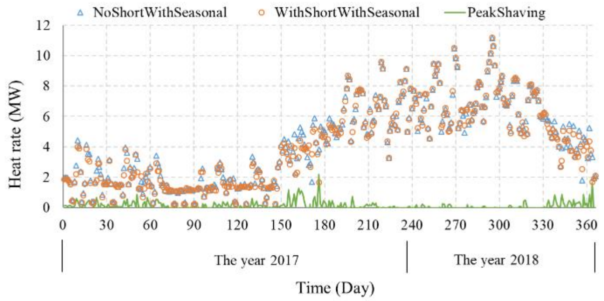

Fig 7 Daily peak load and peak load shaving due to the WT, for the scenarios with BTS

The seasonal mismatch was solved by introducing the BTS. As shown in Fig 8, about 0.8 GWh – 1.0 GWh heat was exhausted via the CT for the scenarios without the BTS. In contrast, no heat loss was found for the scenarios with the BTS.

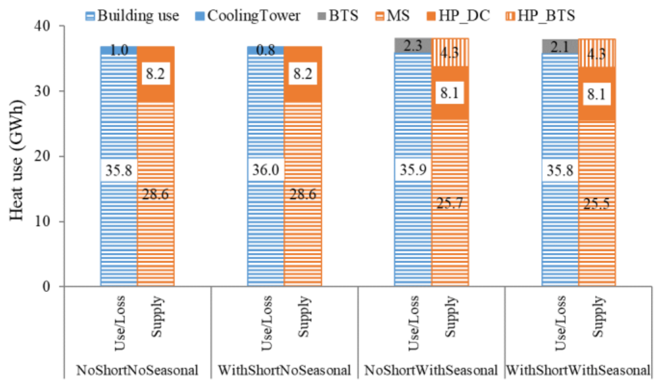

Fig 8 Annual heat use and heat supply for different scenarios

The heat supply from the MS could be reduced by introducing BTS. As shown in Fig 9, around 2.9 GWh – 3.0 GWh heat supply was saved. However, the electricity use increased around 0.8 GWh due to the HP of BTS.

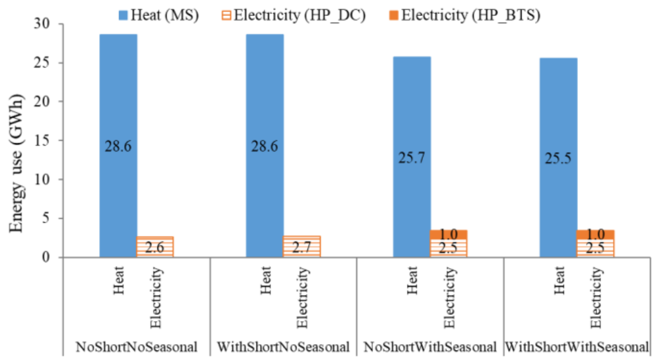

Fig 9 Annual heat and electricity use for different scenarios

5. CONCLUSIONS

The case study showed that the mismatch between waste heat feed-in and building heat demands could be solved by introducing TSs. The BTS brought about 3.0 GWh annual heat saving, and the WT brought about 110 kW average peak load shaving. However, about 0.8 GWh/year electricity was used for the HP of the BTS to recover the stored heat in the ground.

The research had some limitations. The sizing of the WT and BTS was conducted by the reference values from handbooks and engineering experience, optimal design analysis was not conducted. Meanwhile, the operation of the system was based on the rule of thumb, analyses of the optimal operation and control strategies were not conducted. More promising results might be achieved, if the optimal design, operation and control strategies were applied.

For the future work, more researches are needed for the optimal design, operation and control strategies. In addition, improving the heat storage efficiency is crucial for TSs.

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