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Potential of residential buildings as thermal energy storage in district heating systems – Results from a pilot test

Johan Kensby *, Anders Trüschel, Jan-Olof Dalenbäck

Division of Building Services Engineering, Department of Energy and Environment, Chalmers University of Technology, Gothenburg, Sweden

HIGHLIGHTS

- Pilot test of five residential building potentials as thermal energy storage was conducted.
- Five different charge cycles were tested during a total of 52 weeks.
- Storage capacity up to a degree hour amount of 63 °Ch was tested.
- The variation in indoor temperature caused by the test was less than ±0.5 °C.
- A fixed time constant is not accurate enough to describe indoor temperature variation.

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ABSTRACT

Heat demand in a district heating system can have a significant variation within 1 day, which produces problematic conditions for efficient heat generation. Short-term thermal energy storage can decrease this daily variation and make the conditions for generating heat more favorable. By periodically overheating and underheating buildings, causing small variations in indoor temperature, building thermal inertia can be utilized for thermal energy storage. This study presents the results from a pilot test where the potential to function as thermal energy storage was tested for five multifamily residential buildings in Gothenburg, Sweden. The signals from the outdoor temperature sensors were adjusted in different cycles during a total of 52 weeks. The delivered heat and indoor temperature were measured during the test. The results indicate that heavy buildings, with a structural core of concrete, can tolerate relatively large variations in heat deliveries while still maintaining a good indoor climate. The study also demonstrated that a fixed time constant is not accurate enough to describe the variations in indoor temperature caused by the utilization of the buildings as short-term thermal energy storage. Degree hours is instead proposed as a simple yet adequate measurement for the thermal energy storage capacity in buildings. Storing 0.1 kW h/$m^2_{floor\ area}$ of heat will very rarely cause variations in indoor temperature larger than ±0.5 °C in a heavy building.

1. Introduction

Heat demand in district heating (DH) systems is mainly dependent on outdoor temperature, but behavioral factors such as domestic hot water usage also have a substantial contribution. In climate conditions with large differences in outdoor temperature between day and night, there is often a significant peak in heat demand during the night. If the outdoor temperature fluctuations are minor, peaks in heat load commonly occur during the morning and evening when the need for hot tap water is large. Factors such as those mentioned can cause significant variation in heat demand in a DH system, as shown in an example from Gothenburg in Fig. 1. The figure shows one typical winter week with frequent variations in the magnitude of 100 MW during only a few hours. This produces problematic conditions for heat generation, and it can be difficult to generate the heat required in an efficient way. Several daily starts and stops of heat-only boilers (HOBs) are required to meet the varying heat demand in many DH systems. The many starts and stops increase the heat losses and lower the efficiency of the boilers. It is also common that the boilers that operate on the margin run on fossil fuels, which involves high costs and a high environmental impact. A study of how large the daily variations are in Swedish district heating systems can be found in [1].

* Corresponding author. Address: Division of Building Services Engineering, Department of Energy and Environment, Chalmers University of Technology, Maskingränd 2 Floor 3, 41296 Göteborg, Sweden. Tel.: +46 706531373.

E-mail address: johan.kensby@chalmers.se (J. Kensby).

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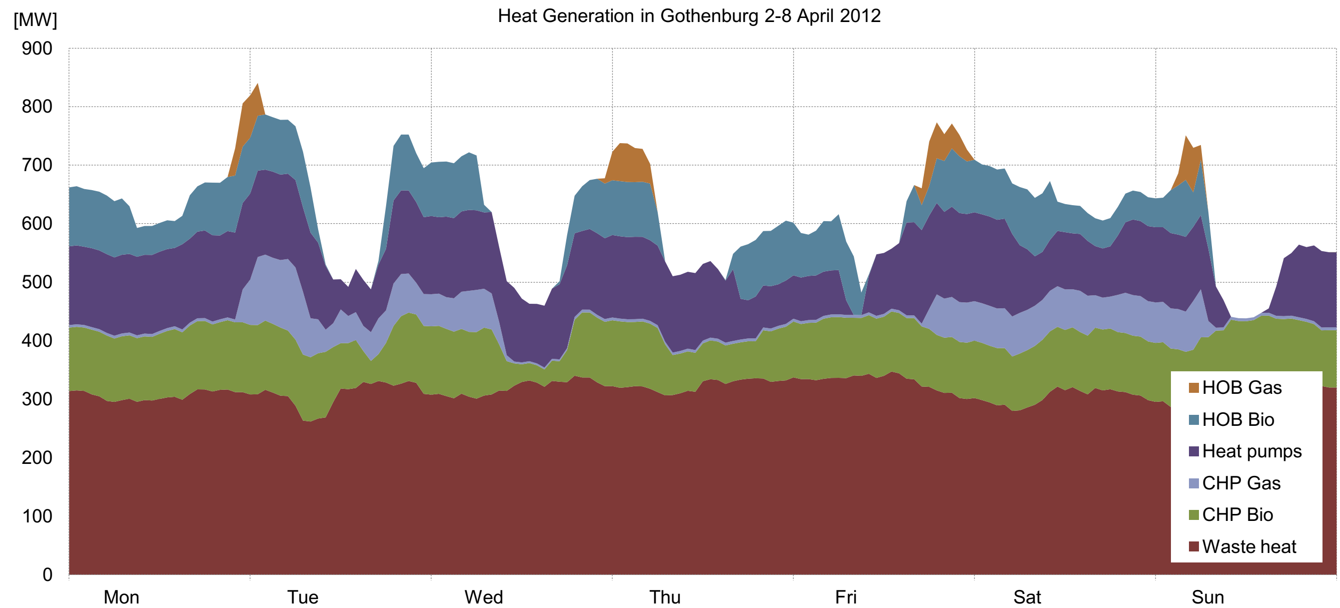

Fig. 1. A total of 27 heat sources are grouped into six categories. During this week, the heat sources started and stopped 36 times. Heat-only boilers (HOBs) account for the majority of the starts and stops.

1.1. Benefits of short-term thermal energy storage

Access to short-term thermal energy storage (TES) can increase the overall efficiency for heat generation in DH systems. Short term can, in this case, be defined as normally a few hours, but up to a few days is also possible. The intent with a short-term TES is to generate more heat than the current heat load when it is favorable to generate heat. The heat is then stored and utilized when it is less favorable to generate heat. In this way, heat generation can be moved from peak load plants that run on fossil fuels to base load plants with better fuel economy and lower environmental impact. This decreases the variation in heat generation and reduces the number of daily starts and stops. The security of supply is also increased in DH systems with access to short-term TES, as the stored heat can be utilized in the case of an interrupted heat delivery.

DH systems with combined heat and power (CHP) have additional benefits from short-term TES. The electrical power generation can be decoupled from the heat load in the DH system, and thus, electricity can be generated when the electrical price is high and the heat can be stored and utilized when it is best needed [2,3]. The situation is similar for DH systems, which generate heat using heat pumps. With access to a short-term TES, the heat pumps can generate heat when the electrical price is low and then utilize the heat when there is a heat demand. Using these two strategies, DH systems can act as a balancing force for the electrical grid. The benefits from such systems will increase with expansion of solar and wind power, leading to larger variations in the electrical price. It might even become beneficial to use electrical boilers in DH systems to balance temporary grid electricity excess.

1.2. Strategies for short-term thermal energy storage

There are several strategies possible for short-term TES in district heating systems:

- Hot water storage tanks.
- Phase change materials (PCMs).
- Varying temperature in the DH network.
- Utilizing building thermal inertia.

Hot water storage tanks and phase change materials share a common feature in that they require an investment in the storage capacity in a district heating system; the storage capacity is not there by default. Hot water storage tanks are fairly common in Swedish district heating systems. Phase change materials are uncommon, but there are several technologies within this area that might be competitive alternatives [3,4].

It is common when varying the supply temperature in the DH network and utilizing building thermal inertia that the storage capacity is already present in DH systems. Investments in control equipment might be required to utilize this capacity. Varying temperature in the DH network can be utilized as there is a time delay between when the output temperature from a heating plant changes and when the temperature front reaches the customer. This possibility is utilized in many Swedish district heating systems, but the storage capacity is limited. There are also two significant drawbacks with this strategy: a temporary increase in supply temperature will decrease the efficiency of boilers and heat pumps, among other equipment, and also increase the risk of fatigue for the distribution pipes. The focus of this study was on utilizing the building thermal inertia as a form of short-term TES in district heating systems. This strategy is commonly included in the term demand side management (DSM). The storage potential can be utilized by periodically overheating and underheating buildings, producing small variations in indoor temperature. This strategy is uncommon and cooperation with customers is required, but the strategy has great potential and low cost.

1.3. Earlier work

Utilizing building thermal inertia as short-term TES in a district heating system is not a new concept. The oldest pilot test known to the authors is from 1982 [5]. The main aim for this test was to increase the supply security for the heat customers located farthest away from a heating plant in case of a shortage. Eighty residential and office buildings located in Stockholm, Sweden, participated, and their heat deliveries were remotely reduced by a control system. The magnitude and durations of the reduced heat deliveries