



Buildings and a district heating network as thermal energy storages in the district heating system

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ABSTRACT

The aim of this article was to determine the energetic effect of use buildings and a district heating network as thermal energy storages to compensate the reduced heat output of the district heating system. Moreover, another so far underestimated values were analyzed, like the effect of the incidence of external temperature and duration of episodes with the lowest external temperatures on the heat output of the district heating system based on 63 heating seasons. Obtained results were presented for the reference district heating system in Poland.

According to the results, an average daily external temperature below -15°C occurred once per heating season and temperatures below -20°C occurred only once in four heating seasons.

The analysis shows that a temperature of -18°C can be adopted as the reference to determine the expected heat output in the DHS. On this basis the heat output can be reduced for central heating by 1%. The energetic effect of use buildings and a district heating network as thermal energy storages to compensate the reduced heat output of the district heating system was 16.2 MW. The achieved equivalent heat output was 93.2 MW. Considering all solutions, the heat output can be reduced for central heating by 14.8%.

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1. Introduction

One of the ways to decrease atmospheric pollution resulting from low-emissions (dispersed sources of low power) is the widespread use of district heating systems (DHSs). DHSs have high levels of efficiency and cause less pollution compared to dispersed sources [1,2]. Therefore, many recent studies concern making significant improvements in the DHSs.

In studies [3–6] authors indicate the need to reduce the high daily variations and the considerable difference between demand for heat output of DHS and heat load of connected buildings. Previous studies [7,8] indicated that avoiding daily heat load variations in DHSs and in substations will improve 3–6% of the annual heat supply in DHSs. On the basis of studies [9], it can be concluded that the above mentioned differences depend on a method of determination of heat output. Many current methods of determination of maximum heat output of DHS are based on the design values (contractual minimum value) of external temperature [10–12]. Therefore, the dependence of the regulated parameter like the network water temperature and water mass flow is commonly defined on the basis of external temperature [13,14]. It is noteworthy that

there were observed very rare occurrences of actual values of external temperature that are equal to or lower than the values of external design temperature during the heating season. Moreover, studies [15–19] have indicated that the decrease in the profitability of DHSs is an effect of oversized heat sources. This suggests that the optimal operation of heat sources in the DHS has been disturbed. This incompatibility is due to the lack of consideration in the present methods of determination of heat output of DHS such aspects as: the occurrence of multi-day episodes of external temperature; differences in construction technology and heat accumulation of buildings connected to DHS (thermomodernizations and new buildings with lower energy consumption requirements); heat accumulation in the district heating network.

Also, there was a lot of research on forecasting the heat load of the end-users [20–24]. However, the first step before those research should be to reduce the maximum heat output of oversized heat sources, that the forecasts could be made for the adjusted DHS. If so, the question may be asked: is it possible to reduce the maximum heat output? If the heat output will be reduced, another question may be asked: could a solution be proposed that will compensate the lack of heat output in case of unfavorable external temperature occurrence?

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Nomenclature

BHS	building heating system
CHP	combined heat and power
DHS	district heating system
DHN	district heating network
A	surface area, m ²
C _m	internal heat capacity of the building (J/K)
c _p	specific heat (J/(kg K))
K _j	internal heat capacity relative to the surface area of building element (J/(m ² K))
Q	heat (J/a)
$\dot{Q}$	thermal power (W)
T	temperature (K)
t	temperature (°C)
u	temperature reduction coefficient referring the heat exchanger operation (–)
V	capacity (m ³)

Greek symbols

α_o	relative flow of the water (–)
φ_o	relative heat demand (–)
Δ / δ	difference
ρ	density (kg/m ³)
τ	time (s)

Subscripts

0	initial
1	final
1n or 2n	supply or return of network
1i or 2i	supply or return of installation
A	accumulation
b	building
e	external
f	heated
int	internal
K	compensation
n	network
proj	design values that should be achieved
r	reduction
s	source

The value to which the heat output can be reduced with the possibility of its compensation will be called equivalent heat output.

A solution that can compensate the lack of heat output of DHS is heat storage technology.

Many studies have focused on heat storage in the DHS. In the article [25] the authors reviewed currently used methods of DHS optimization together with the use of heat storage methods for this purpose. Studies [26] shows that methods of heat storage in DHSs can be divided into two types: diurnal storage and seasonal storage. There is widespread use in Scandinavia short term sensible storage tanks to cover peak demand periods, enabling the plant to be designed smaller and to run at full capacity [25]. A study [27], describes the solution of a multi-scale model of storage tanks. Their results showed that primary energy consumption can be reduced up to 12% and total costs can be reduced up to about 5% through the use of improved heat storage process. Other studies [28–31] describe distributed heat storages, and hourly, daily, weekly, and seasonal heat and cold storages, but using simulated conditions only.

Another division concerns the method of heat storage. The commonly used storage method is sensible heat storage, which can be divided into: hot water heat storage to store sensible heat [26],

gravel-water heat store – a pit filled with a gravel-water mixture [32], duct or borehole heat store, where heat is stored directly into the ground [33,34], aquifer heat store – below-ground layers of porous materials filled with groundwater [35]. This heat storage method requires considerable volume. Volume of gravel-water heat store should be 50% larger and volume of duct heat store should be 3–5 times larger than volume of hot water heat store [26]. According to studies [36–38] it was concluded that latent and chemical heat storage applications are at the stage of being laboratory-scale prototypes or pilot investments.

All of the above studies on heat storage have shown solutions requiring expansion of the DHS with additional elements (heat accumulators of different types), which entails considerable investment.

An alternative solution that does not require expansion of the DHS with additional elements can be the use of district heating network (DHN) to store heat, which has received much recent attention [39–41]. The maximal use of an existing DHN can avoid additional installation costs. In studies [40,41] was modeled the heat storage capacity of the DHN by capturing the quasi-dynamics of the pipeline temperature. However, study [42] indicates that heat storage is more feasible and operable to use buildings instead of the DHN. In study [43] authors pointed out there is a transmission delay in the DHN because of thermal inertia, which makes it unrealistic for a DHN to be used as a heat storage unit. And this is correct when it comes to heat storage in case of its uncontrolled surplus. However, in our research, DHN does not perform this function. In our research the supply temperature of DHN is increased intentionally and controlled when the external temperature is expected to drop below the external design temperature. Therefore, transmission delay is not a problem that we are trying to solve. It is enough that transmission delay will be known for a specific case of DHS. In that case it has to be added to the time that the source has to start increasing the supply temperature.

Other alternative solution that can be used without changes in DHS structure is heat storage in buildings connected to it. Heat storage in buildings is a known solution. However, almost all publications relate to the storage aspect itself, e.g. in building partitions filled with PCM [44,45]. The publications that treat buildings as heat storage for the DHS are rare. In studies [43] buildings have been used as a heat storage to maximize gains from wind farms connected to the CHP system. The change in the internal temperature in the building and the time of transmission delay were analyzed. These very interesting studies, however, aim to optimize the work of the CHP source, not to compensate for its reduced heat output. Other studies [46] on the potential use of residential buildings as thermal energy storage in DHSs was conducted. But, this study focused only on five buildings connected to a DHN and still it is not related to compensation of reduced heat output. Another studies [47] concern comparison of centralized storage vs. storage in thermal inertia of buildings. The total system yearly operating cost decreases by 1% when the thermal inertia of buildings and by 2% when the hot water tank was added to the DHS.

Based on the literature review, it can be concluded that DHS heat storage in buildings or in the DHN is not a well-known issue. It should be noted that the available literature does not combine two problems in one analysis – DHS heat storage in buildings and in the DHN together in one system. In Poland, over 50% of the total heat generated comes from DHSs. Therefore, the use of DHS heat storage in buildings and in the DHN seems to be particularly interesting, especially since it does not require DHS to be expanded with new elements. Based on that, the aim of this article was to determine the energetic effect of use buildings and the DHN as thermal energy storages to compensate the reduced heat output of the DHS.

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