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Intermittent Operations of District Heating Networks in Summer Months

A Showcase

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Abstract. In the OREWA project, optimization measures for existing heat networks were identified and assessed based on both economic and ecological considerations [1]. One of the focal investigations was the simulation of intermittent operational strategies tailored for the summer months. Next to the classic intermittent approach an innovative variation was explored, which involved the storage of hot water during intermediate phases in large central tanks to further minimize heat losses. Both the classic and innovative intermittent strategies showcased substantial reductions in network losses and energy consumption for circulation pumps. This research shows the melioration of heat network efficiency through a substantial reduction of summer heat losses for a network with a low heat demand density of 0.7 MWh/(m²·a).

Keywords: Heating Network, Optimization, Intermittent Operational Strategy, Reduction of Operational Costs

1 Intermittent Operation Strategies

One measure for reducing the average return and flow temperatures in heating networks is the intermittent operating strategy. For this purpose, buffer storage tanks must be installed at the consumers, from which the demand of the consumers can be covered temporarily while the heating network is not heated. This operating strategy has already been analysed by various authors [2,3]. The percentage thermal energy saving depends on the connection density and the type of consumer and lies between 0.4 % and 6 % in the mentioned studies. The results for the amortisation periods are, with one exception, beyond 20 years.

The exception is a study within the heat_portfolio project [3]. Rather than allowing the heating network to cool down, as intended during the rest phases of intermittent operation, colder water replaces the hot water in the pipes of the heating network. This is achieved by reversing the circulation in the heating network. The study conducted within the heat_portfolio project concluded that the measure would amortize within 13 years. However, it was noted that the cost calculation was not conducted in detail, given the complexity associated with implementing such a measure.

Ref. [4] studied in contrast to this investigation intermittent operation in a well-insulated heat network with diverse users (residential buildings, industry, etc). The decentralised storage tanks of the consumers were charged once a day. Two cases were considered: firstly, the flow temperature was increased in relation to continuous operation with a constant flow temperature in order to be able to use smaller decentralised storage tanks and, in the second case, larger storage tanks were charged with a lower flow temperature. Both approaches led to higher losses than with continuous supply with constant flow temperature. In the first case this was due to higher distribution losses and in the second case due to the high decentralised storage losses. These operating modes were therefore only recommended for low connection densities and/or low domestic hot water requirements.

2 Simulation Case Study

In this study, the feasibility of implementing an intermittent operational strategy for an existing heat network is investigated, focusing on scenarios where only single-family homes (SFH) with pure domestic hot water demand are supplied during the summer. To simulate this scenario of low demand (solely domestic hot water demand from SFH), the heat network system of the Effelter municipality was utilized. In Effelter, only domestic hot water demand for 34 SFH is provided during the summer. Additionally, to minimize heat network losses and utilize the waste heat from the biogas plant even during the summer, a wood chip drying facility is operated. The wood chip drying facility is disregarded for the investigation of the intermittent operational strategy, highlighting whether the measure proves to be economically feasible under ideal conditions. These ideal conditions include:

- Pure domestic hot water supply for SFH
- Low heat demand density
- High heat network losses

Two scenarios are examined, and the cost savings in terms of pump power demand and heat network losses compared to continuous operation in the summer are analysed. Table 1 depicts the scenarios under investigation.

Table 1. *Optimized operating strategy in summer for the heating network in the municipality of Effelter.*

Scenario	Description
Basis	Continuous operation of heating network
Classic intermittent	Charging of decentralized storages at customer; subsequent turn-off from network pump; natural cool down of network.
Innovative intermittent	Instead of the natural cool down with “Classic intermittent” the water within the network is exchanged with colder water to further minimize heat losses.

The district heating substations (DHS) must be equipped with buffer storage tanks for the implementation of this operational strategy. The volume of the buffer tanks is limited by the available space in the existing buildings. A maximum buffer tank volume of 1000 liters is estimated. The second criterion for determining the size of the storage volume is the number of residents in the household. It is advisable for the tanks to be equally depleted during periods without network operation. According to information provided by the project partner Enerpipe, a volume between 600 liters and 1000 liters is typically used for this operational strategy in SFH. Figure 1 depicts the DHS for the intermittent operational strategy.

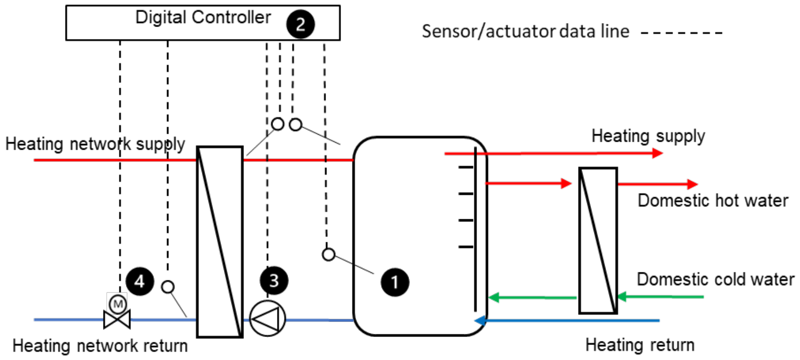

Figure 1. *DHS with buffer storage, motorized control valve, and digital controller.*

The DHS with buffer storage is equipped with a motorized control valve (4) and a digital controller (2) with a communication module. The temperature sensor (1), situated in the lower third of the tank, collects measurement data at 5-minute intervals and transmits it to the heating center through the digital controller (2). If the temperature at the sensor falls below 55 °C, the central circulation pump is activated. At this point, two-thirds of the tank still retain a temperature above 55 °C, allowing for continued heat supply while the heating network is warmed up and the tanks are recharged. Once the respective tank reaches the target temperature of 70 °C during recharging, it is disconnected from the heating network using the motorized control valve (4) and the pump in the intermediate circuit (3).

To estimate the charging frequency, an example calculation is performed for a buffer storage tank with a capacity of 1000 liters and a household of five people (see Table 2).

Table 2. *Example calculation for the expected charging interval of a decentralized buffer storage.*

Parameter	**Value**	**Unit**
Buffer volume	1000	l
Usable volume constrained by ramp up time of DHN	700	l
Temperature difference	15	K
Stored energy	12.2	kWh
Consumption of a 5-person household acc. to VDI 4655 [5]	6.8	kWh/day
Storage losses	2.2	kWh/day
Time span without loading	**1.3**	**days**

For a five-person household requiring 6.8 kWh/day of domestic hot water, the heating network can remain switched off for 1.3 days.

The concept for the classic intermittent scenario demands not only the installation of buffer storage substations at the customer´s premises. The communication technology between the individual substation and the heating centre as well as the central control logic also needs to be implemented.

In the innovative intermittent scenario, the classic intermittent mode of operation is supplemented by “cold flushing” of the heating network during periods of inactivity. Figure 2 shows the heating centre supplemented by the two central buffer storage tanks. The hot water (approx. 80 °C) is stored in the upper of the two buffer tanks and the medium-warm water (approx. 50 °C) is stored in the lower of the two buffer tanks.

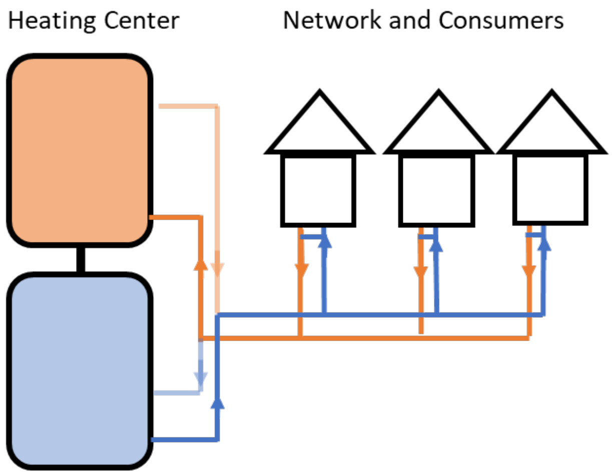

Figure 2. *Innovative intermittent operation with "cold flushing" of the heating network during periods of inactivity. The more transparent pipes at the heating center are used when the heating network is recharged with hot water.*

If the first decentralised buffer storage tank reports a recharge requirement, the central heating system is started up and the hot water from the upper storage tank is pumped into the heating network, while the second medium-warm central storage tank receives the water from the heating network that has cooled down over time. If the heating network is heated, all decentralised storage tanks are recharged. When the respective substation reports that it is fully charged, the valve at the access to the decentralised storage tank is closed and the water no longer flows through the storage tank of this substation, so that all decentralised storage tanks in the substation are gradually decoupled from the heating network. As soon as all decentralised storage tanks are fully charged, the lower central storage tank is connected to the flow of the heating network and the heating network is filled with medium-hot water. The warmer water is then fed back into the upper, hotter centralised storage tank. A temperature sensor in the return flow of the heating network indicates when the colder water has been distributed throughout the heating network. The charging process is then stopped. The central storage tanks must be able to hold approximately the volume of half to the entire heating network. The heating network volume is 11,000 litres. The heating center of the Effelter municipal heating network is equipped with two central storage tanks, each with a volume of 8 m³. The investigation of the operational strategy is being conducted using these tanks.

While the heating network and the heating center were modeled in Matlab/Simulink Simscape, the consumer model was written using the CARNOT toolbox implemented in Matlab/Simulink [6]. In this way, the advantages of each environment were used. A comprehensive description of the heat network in the Effelter municipality, as well as the simulation model and its validation, can be found in [7].

3 Results

An initial analysis was conducted to assess the influence of varying supply temperatures (specifically 80 °C and 90 °C) on the classic intermittent operational strategy. Employing a supply temperature of 90 °C expedited the heating of the tanks, resulting in extended periods of inactivity for the heating network and a 40 % reduction in pump electricity consumption. However, the higher network temperature increased heat network losses by 0.4 %. With the assumed energy prices of 60 Euros/MWh_{th} and 0.36 cents/kWh_{el}, the 90 °C supply temperature strategy proved to be more cost-effective.

The classic intermittent scenario with a flow temperature of 90 °C (lower operating costs) is now compared with the results from continuous operation. The result for continuous operation in summer without the wood chip drying system shows heat losses of 71 % with a pump power requirement of 460 kWh. The flow temperature of the heating network was 75 °C (see Table 3).

Table 3. *Comparison of the operating parameters for continuous and classic intermittent operation for the summer season.*

	Continuous	**Classical intermittent**	**Reduction**
Mean supply temperature	75 °C	90 °C	
Heat losses	70,6 %/-	53,3 %	
Heat losses absolute	68,0 MWh	56,2 MWh	17,3 %
Pumping energy	459,9 kWh	104,4 kWh	77,3 %

The system was simulated over seven days with hourly resolution and then extrapolated to the summer season. More heat is sold through the decentralized buffer storage tanks. This is partly because the buffer storage losses must also be compensated for and partly because the decentralized storage tanks must be charged at the beginning and are charged to varying degrees at the end of the simulation. The storage losses account for 6 MWh of the 26.6 MWh of heat sold in the season. This means that 24% of the heat purchased is of no use to consumers. The remaining 2 MWh, which is the difference between this, and the 19 MWh of heat sold in continuous operation, is due to the decentralized buffer storage tanks still charged at the end of the seven simulated days. The assessment of the intermittent operating strategy includes the saved heating network losses and the electricity savings. As SFHs with six residents are also connected to the heating network, the heating network has to be heated every 17 hours on average.

The heating network losses are 17.3 % lower with the classic intermittent operating strategy than with continuous operation. The reduction for electricity consumption is 77.3 %. From an energy point of view, this optimisation measure is recommended. Operating costs totalling 833 euros per year can be saved (see Table 4).

Table 4. *Annual operating cost savings through the classic and innovative intermittent operating strategy.*

Savings (regarding continuous operation)	**Classic intermittent**	**Innovative intermittent**	**Comparison of both scenarios**
Reduction of heat losses	17,3 %	17,7 %	+0,4 %
Saved electricity for pumping	77,3 % 355,4 kWh	58,9 % 270,8 kWh	-8,4 %

A comparison of the two intermittent operating modes shows that the heating network losses are reduced by a further 0.2 MWh per season due to the heating network with colder water (see Table 4). The electricity demand nearly doubles due to the innovative operation of the interim loading with colder water compared to classic intermittent.

As per the information provided by the project partner Enerpipe, outfitting a household with the substation buffer storage tank entails an approximate cost of 10,000 euros. Consequently, the optimization measure would not yield a return on investment if the buffer storage tanks needed to be procured initially. However, if the buffer storage tanks are already installed in the households and only the control system and communication modules in the substation require retrofitting, the measure is projected to amortize after 28 years (assuming a heat generation cost of 60 €/MWh and electricity cost of 0.36 €/kWh). Nevertheless, the advantages stemming from the communication capabilities of the substation, such as reduced maintenance costs and expedited fault detection, are not factored into the gains. These aspects serve to further decrease the 28-year amortization period.

4 Discussion

The study identified substantial heat loss reduction potential during summer months through classical intermittent district heating network operation. Furthermore, a decrease in pump electricity consumption was evaluated. These findings offer economic advantages, assuming the control system is the only implementation cost, and existing residential buffer storage can be utilized. The losses of decentral storages lead to higher sales for the operator, but higher costs for the customers. As the storage losses are less than half of the reduction of the network losses still an advantage of the total system can be achieved. However, under different conditions, the suggested operation may not be economically viable.

The innovative intermittent strategy does not reduce operational costs compared to the classical one but demands higher investment costs for the central buffer storages and the additional piping for cold flushing of the network and therefore cannot be recommended.

Data availability statement

Not applicable.

Author contributions

Anna Vannahme – Methodology, Investigation, Software, Visualization and Writing – original draft, Funding Acquisition, Project Administration

Simon Müller – Software, Conceptualization, Formal Analysis and Writing – review & editing.

David Schmitt – Supervision, Project Administration.

Thorsten Summ – Supervision, Project Administration

Christoph Trinkl – Project Administration, Funding Acquisition

Tobias Schrag – Conceptualization, Supervision and Writing – review & editing, Funding Acquisition

Competing interests

The authors declare that they have no competing interests.

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