ISEC 2024 – 3rd International Sustainable Energy Conference
Future District Heating and Cooling
https://doi.org/10.52825/isec.v1i.1047

Published: 18 Apr. 2024

Decreasing the Return Temperature in District Heating Networks Thanks to a Switch to Alternative Substation Architectures

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Abstract. District heating networks (DHN) are key systems for managing heating and reducing carbon emissions at a large scale. Therefore, increasing their efficiency is a key to reduce climate change. DHNs with centralized production are supplying hot water to building substations (interface between the DHN and the buildings) for domestic hot water (DHW) production and space heating (SH) using heat exchangers. Colder water is returned to the centralized district heating system by the return pipe. One of the crucial factors to improve the efficiency of DHNs is to decrease the return temperature in the network to keep the same amount of energy transferred to the buildings while reducing the thermal losses and the flow rate, leading to more savings. In this paper, we model and simulate two of the most common DHN substation architectures used in a typical third-generation DHN to identify their flaws and propose new district heating substation architectures that can increase the DHN efficiency. The main result from our study is the consistent reduction in the average return temperature across all scenarios when implementing our proposed architectures. The reduction ranged between 3.7 °C and 10.2 °C. We also found that the lower the heating temperature, the greater the reduction. This is particularly beneficial as buildings are increasingly equipped with low-temperature heating systems, especially new constructions. Moreover, these architectures showed optimal efficiency with new buildings that have a high water heating demand compared to heating demand. This is due to the higher impact of cold water preheating.

Keywords: District Heating Networks, Substation Architectures, Return Temperature, Pre-Heating, Efficiency

1. Introduction

District heating networks (DHNs) are composed of insulated pipes used to deliver heat from one or several heat sources to multiple buildings. The connection between the network and the building is made by substations. A substation in a DHN is primarily composed of one or two heat exchangers to transfers the heat from the network to the building's heating and domestic hot water (DHW) production system. These substations are key components of the network.

DHNs play a pivotal role in national energy strategies due to their efficiency and capacity for large-scale heat distribution [1], [2]. They are particularly significant in the context of renewable energy integration and CO2 reduction. DHN can use heat sources unavailable at a buildings scale as CHP, waste heat from industry or heat from domestic waste combustion. Moreover, the sharing of the heat sources, increase their efficiency and lead to better maintenance and therefore reduce the carbon footprint of heating. It can also easily integrate flexible energy from renewable sources as solar and make this technology available for cities' buildings.

DHN can be classified into different generations, depending on their supply temperature, energy source, and distribution technology [3]. The first generation used steam as the medium, with supply temperatures above 100°C. This generation was common in the US and some European countries in the late 19th and early 20th century, but it had low efficiency and high heat losses. The second generation switched to pressurized hot water as the medium, with supply temperatures between 80°C and 120°C. The distribution pipes were made of steel, with improved insulation. This generation was dominant in Europe and the former Soviet Union in the mid-20th century, but it still had high environmental impact and low flexibility. The third generation reduced the supply temperature to between 60°C and 100°C, and increased the use of renewable and waste heat sources, such as biomass, geothermal, solar thermal, and combined heat and power (CHP). The distribution pipes were made of pre-insulated steel or plastic, with lower heat losses and better durability. This generation is still widely used in many countries, especially in Northern Europe, and it has higher efficiency and lower emissions than the previous generations. This is the most common generation. The fourth generation further lowered the supply temperature to between 40°C and 60°C, and integrated more diverse and flexible energy sources, such as heat pumps, thermal storage, and smart grids. The distribution pipes were made of plastic, with minimal heat losses and high adaptability. This generation is considered the state of the art for district heating, and it can achieve near-zero carbon emissions and high customer satisfaction. In this article, we focus on third generation DHN, but the strategy could be applied to second and fourth generation with additional studies.

One of the key factors influencing the efficiency of DHNs is the return temperature [4]. Reducing the return temperature of the DHN means increasing the difference between the supply and return temperatures, also known as the delta T. This can have several benefits for the performance, efficiency, and sustainability such as:

- Pump efficiency [5]: with an increased delta T, the flow rate can be lowered, which decreases the energy required to pump the water. This results in lower operational costs and energy consumption.
- Decreased thermal losses on the return path [6], [7]: a lower return temperature means a lower average temperature in the network, which reduces the heat losses to the surroundings. This can save energy and money, as well as lower the environmental impact of the system.
- Heat sources efficiency [8]: Heat production systems, such as boilers and combined heat and power (CHP) plants, operate more efficiently at lower temperatures. This is partly due to the potential for condensation of flue gases, which recovers additional heat and further boosts system efficiency
- Integration of new sources [9]: lower return temperatures facilitate the incorporation of renewable heat sources, such as geothermal or solar thermal energy, which typically operate at lower temperatures compared to traditional fossil fuel-based sources.
- Enhanced system capacity: by operating at a lower return temperature, the existing network can potentially carry more heat without the need for significant infrastructure upgrades, thus improving the capacity and reach of the DHN.
- The economic value of reduced return temperature can vary from 0.05 to 0.5 €/MWh/°C, highlighting the financial incentive for optimizing return temperatures [6].

The return temperature of a DHN is dependent on the outlet temperatures of its substations, which in turn are influenced by the network substation's architecture and the buildings heating systems temperatures. Therefore, improving the architecture of these substations could potentially decrease return temperatures, leading to more efficient and sustainable heat networks.

2. Methods

2.1 Simulations conditions

The main objective of this study was to compare the performance of different substation architectures for DHN in terms of return temperature. The lower the return temperature, the better the performance of the network.

To evaluate the return temperature of a substation, we used a weighted average of the outlet temperatures of the heat exchangers that connect the substations to the distribution network, as shown in equation (1):

$$\bar{T}_{return} = \frac{\int_{period} T_{return}(t) * \dot{m}(t)dt}{\int_{period} \dot{m}(t)dt} \tag{1}$$

where :

- $\bar{T}_{return}$ is the average return temperature from the substation over the considered period,
- $\dot{m}(t)$ is the mass flow rate supplied by the distribution network to the substation at time t
- $T_{return}(t)$ is the return temperature measured at the outlet of the substation at time t.

We considered two periods for the comparison: the heating season (from September 30th to May 14th) and the whole year.

We simulated a third generation DHN with a supply temperature that follows the weather compensation shown in Figure 1. The weather compensation is a function of the outdoor temperature, such that the supply temperature is 95°C at -7°C, 50°C at 18°C, but cannot be lower than 65°C (Figure 1).

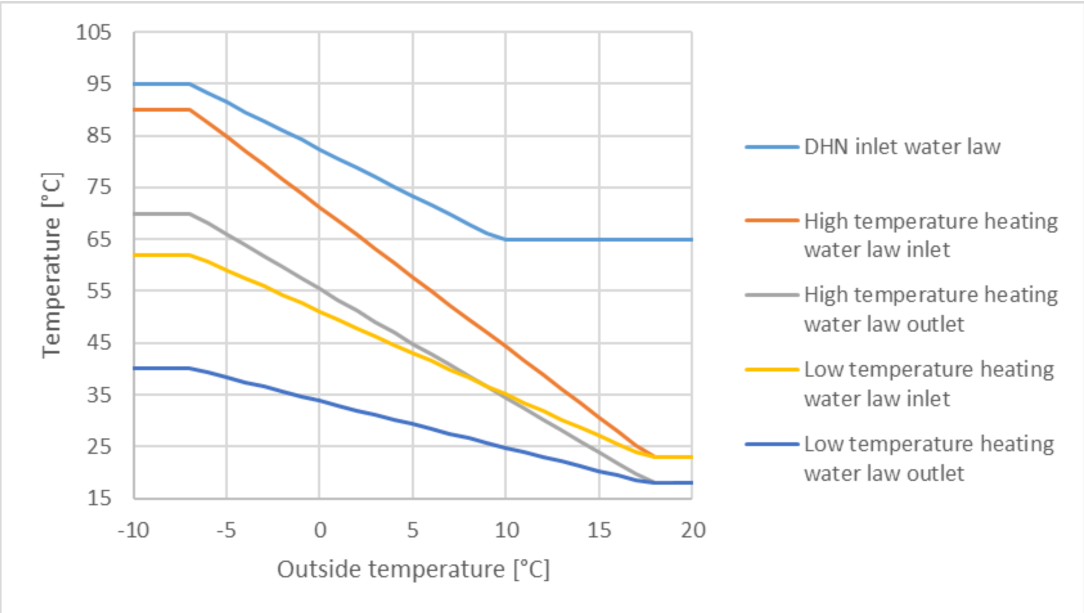

Figure 1. *DHN supply temperature, heating supply and return temperature for high and low temperature heating systems according to the outside temperature*

We simulated two types of buildings with 100 dwellings each: an old building with high-temperature heating and a new building with low-temperature heating. For high-temperature profiles, the supply temperatures range from 23°C (for an outdoor temperature of 18°C) to 90°C (at -7°C), while the return temperatures range from 18°C to 70 °C (for the same outdoor temperatures). For low-temperature heating system, the supply temperatures range from 62°C to 23 °C (for an outdoor temperature of respectively -7°C and 18°C), while the return temperatures range from 40°C to 18 °C for the same outside temperature (Figure 1).

The heating energy demand is 522.5 MWh/year for the old building and 240 MWh/year for the new building. The hourly demand is determined by the degree-days with a base temperature of 18°C for the old building and 14°C for the new building. The climate data used is from Le Bourget (Paris region) in 2012.

For the DHW consumption, both buildings have the same: 25 m3/year/dwelling with a recirculation loop. The supply temperature of the recirculation loop (and the DHW) is 57°C and the return temperature is 52°C. The cold water temperature from the city network is 15°C throughout the year. The cold water consumption profiles used are those defined by COSTIC [10].

The total energy consumed for the DHW production (draw-off) is 122 MWh for both type of buildings and the recirculation loop energy is 128 MWh for the old building and 90.5 MWh for the new building.

We simulated two types of substation architectures: series and parallel. For each type of architecture, we simulated a classic and an improved version, with each one having an instantaneous (direct DHW production) variant and an accumulation (with DHW storage) variant (Figure 2). The architectures with accumulation have a 3000-liter DHW tank. The charging pump of the DHW tank has a regulation that activates when the temperature of the tank is too low. The heat exchangers are sized to have a pinch of 2 °C when the maximum power is transferred (with an additional safety factor of 10 %).

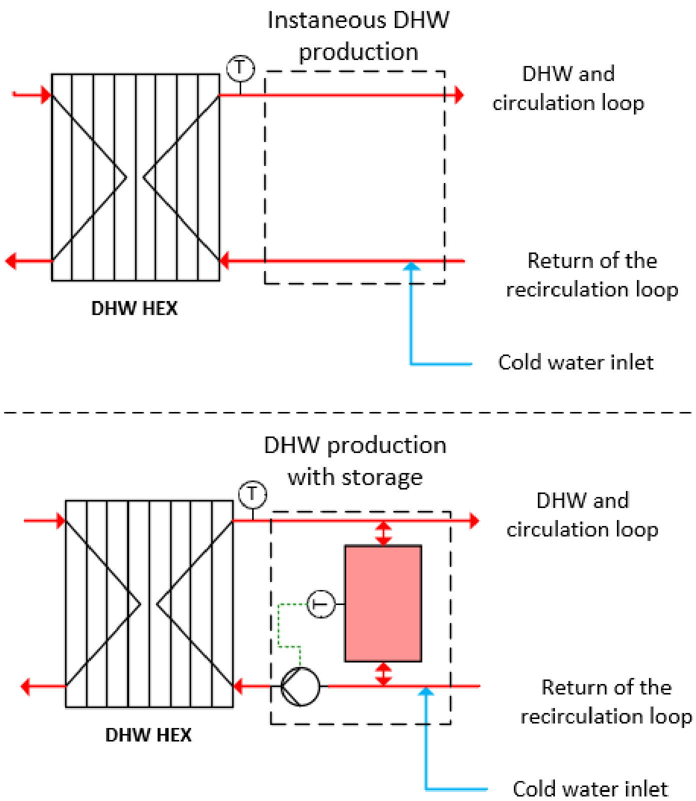

Figure 2. *Schematic description of the two domestic hot water productions systems : instantaneous and accumulation*

2.2 Series architectures

2.2.1 Classic

The classic series architecture consists of two heat exchangers (Figure 3). The first heat exchanger is responsible for heating and supplying heat for the DHW heat exchanger. The weather compensation of the fluid leaving this exchanger follows the heating system weather compensation but always remains above 62 °C to allow the production of DHW.

A second heat exchanger is used for the production of DHW. A three-way valve upstream of the DHW exchanger allows the regulation of the secondary side fluid temperature. On the secondary side of the DHW heat exchanger, both variant for DHW production will be studied : instantaneous and accumulation.

This type of substation has a high return temperature due to the direct mixing between the fluid exiting the DHW exchanger and the heating system return fluid.

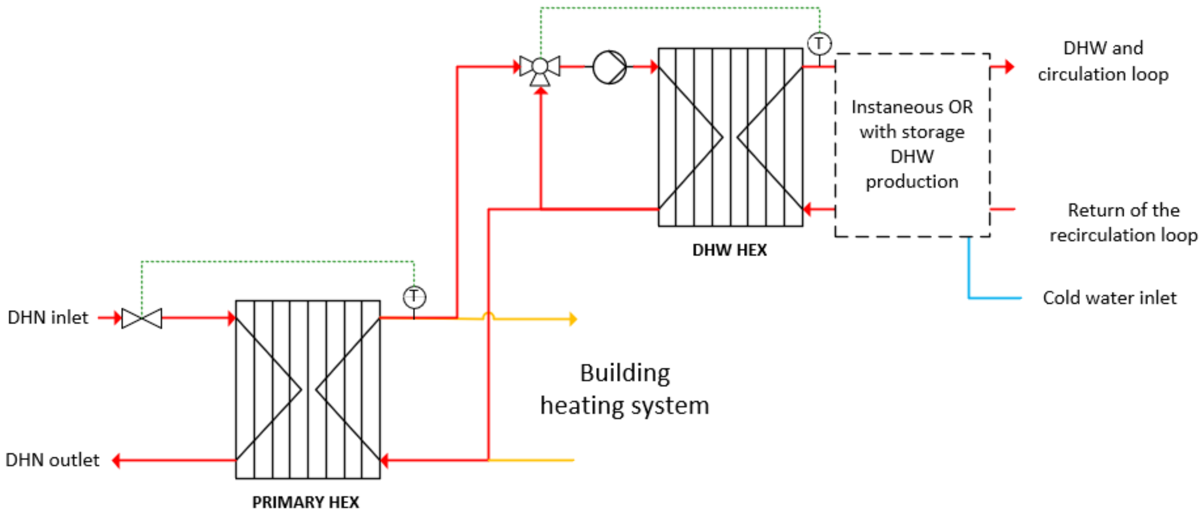

Figure 3. *Schematic description of the classic series architecture*

2.2.2 Improved

An improved version of the previous architecture is the series configuration with temperature depletion and preheating (Figure 4). In this case, a three-way valve allows the reuse of the water leaving the DHW exchanger for heating system if its temperature is high enough. A mix with water from the primary exchanger is also possible to adjust the temperature and respect the weather compensation. In series with the heating system, a preheating exchanger further reduces the return temperature and preheat cold water entering the DHW circuit. In this type of configuration, the return temperature is the lowest when there is an high DHW consumption (and thus an arrival of cold water from the city network).

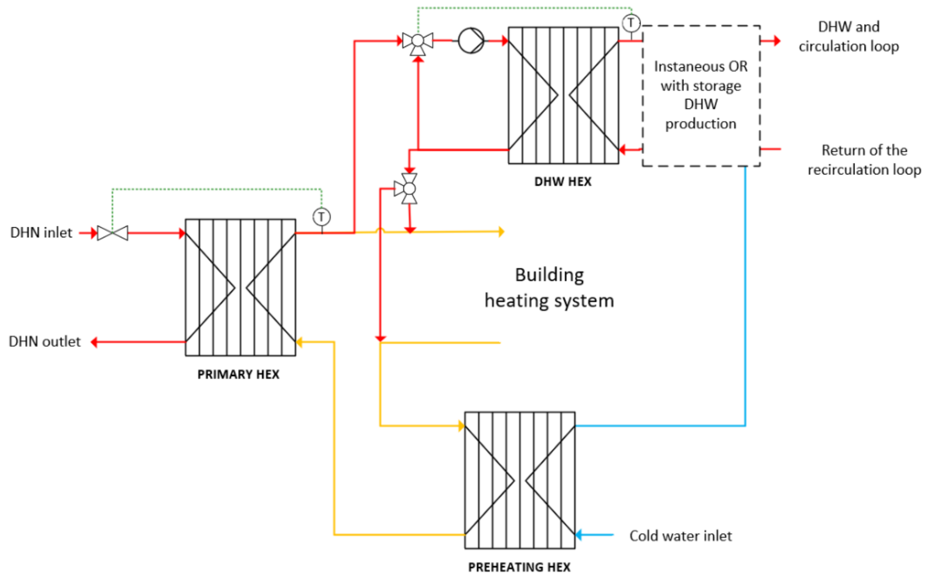

Figure 4. *Schematic description of the improved series architecture*

2.3 Parallel architectures

2.3.1 Classic

The classic parallel architecture is where the DHW production exchanger and the heating are in parallel (Figure 5). Two two-way valves allow the regulation of the supply temperature for the DHW and the heating systems. This type of substation can have low temperatures when there are no DHW demands and a low-temperature heating, but most of the time, the DHW demand leads to high return temperatures. This architecture is widely used due to its simplicity and efficiency in managing temperature regulation.

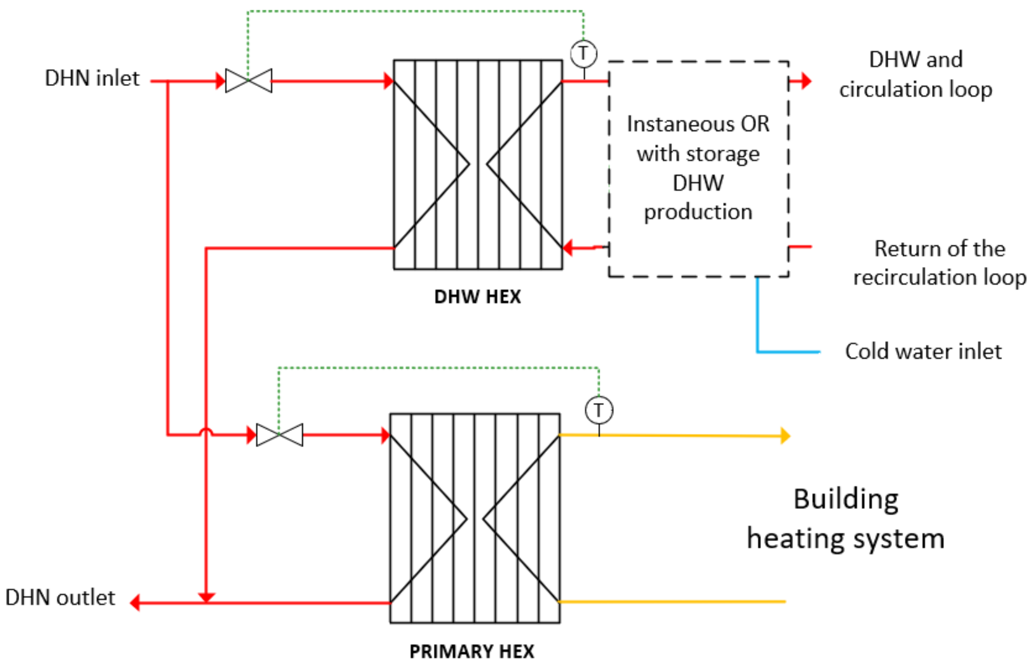

Figure 5. *Schematic description of the classic parallel architecture*

2.3.2 Improved

The enhanced parallel configuration is an improvement over the classic version (Figure 6). In this setup, all the water exiting the DHW exchanger is directed into the heating exchanger. A two-way valve allows the addition of water directly from the network inlet to increase the temperature if it is too low. After exiting the heating exchanger, the fluid passes through a preheating exchanger which preheats the cold water when there is a DHW draw-off. This configuration optimizes the use of heat and ensures efficient temperature regulation.

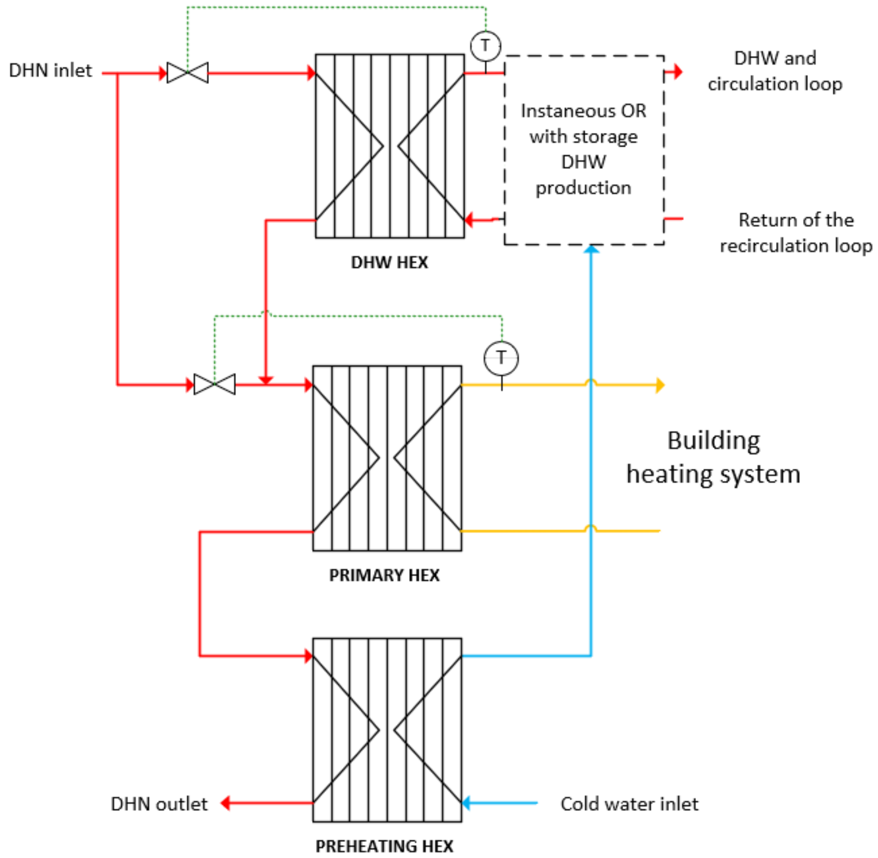

Figure 6. *Schematic description of the improved parallel architecture*

3. Results

The study conducted on new architectures for DHN substations has yielded promising results. The research demonstrates that these innovative designs significantly outperform the traditional configurations that are prevalent today. During the heating season (Table 1), the average temperature decrease observed was 6.9°C, while across the entire year (Table 2), the reduction averaged 6°C.

Notably, the minimum temperature decrease recorded was 3.7°C in a series configuration with accumulation DHW system and high-temperature heating systems throughout the year. On the opposite, the parallel configuration with DHW storage and low-temperature heating systems saw a decrease of up to 10.2°C during the heating period. Similarly, the parallel configuration with instant DHW production and low-temperature heating systems experienced a reduction of 9.3°C over the whole year.

The analysis further indicates that the improvements are more pronounced during the winter season with an average decrease of 6.9 °C in the heating season and 6 °C in the whole year.

The parallel configuration, in particular, showed a slightly larger average decrease in temperatures compared to the series configuration, with a 7°C reduction in the heating season and 6.3°C annually compared to 6.7 °C in the heating season and 5.8 °C annually for the series configuration.

Table 1. *Results in heating period*

	Series				Parallel			
	Instant		Storage		Instant		Storage	
	Classic	Improved	Classic	Improved	Classic	Improved	Classic	Improved
High temp	47,7	43,6	47,6	43,7	46,6	42,8	46,7	42,8
Low temp	41,4	31,8	41,2	32,0	39,1	29,1	39,4	29,2

Table 2. *Results in the whole year*

	Series				Parallel			
	Instant		Storage		Instant		Storage	
	Classic	Improved	Classic	Improved	Classic	Improved	Classic	Improved
High temp	48,2	44,2	48,0	44,4	47,0	43,0	47,1	43,4
Low temp	43,6	35,5	43,4	35,8	41,4	32,1	41,8	33,8

Moreover, the study found that low-temperature heating systems offer a significantly larger average improvement than high-temperature systems. The average reduction was 9.8°C in the heating season (Figure 7) and 8.2°C throughout the year (Figure 8) for low-temperature systems, as opposed to a 3.9°C reduction for high-temperature heating systems in both timeframes.

The data from the study is summarized in two tables and two figures, which detail the results for both the heating period and the entire year across different configurations and temperature settings. These tables highlight the effectiveness of the new substation architectures in optimizing the performance of district heating networks by substantially lowering return temperatures. The findings underscore the potential of parallel configurations and low-temperature heating systems in achieving significant improvements in energy efficiency.

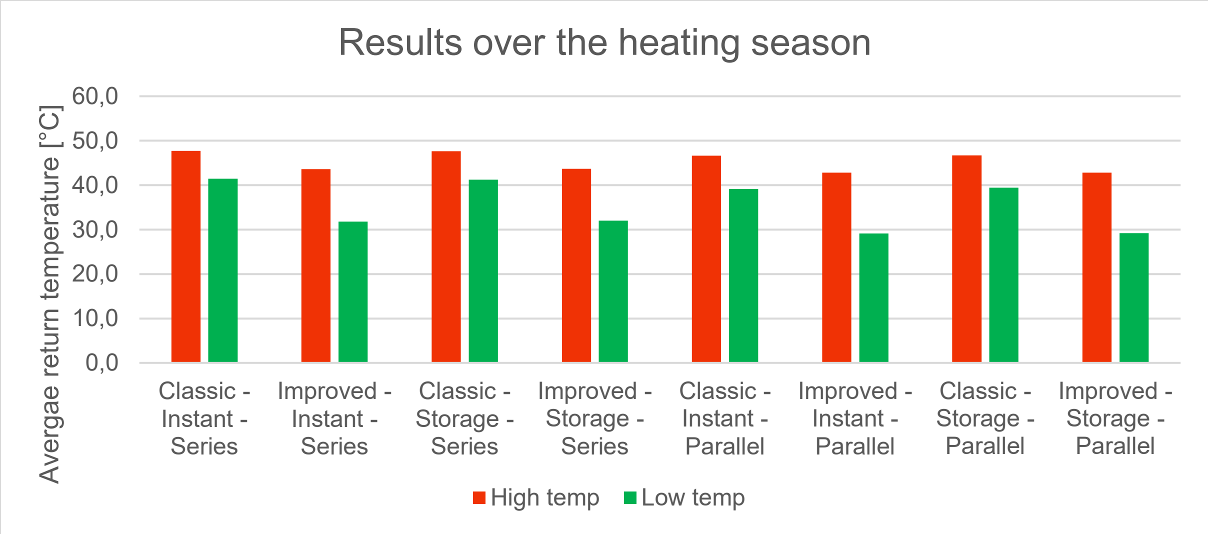

Figure 7. *Results of high and low temperature heating systems over the heating period*

Figure 8. *Results of high and low temperature heating systems over the whole year*

4. Discussion

In the current study, we explored two innovative methods to enhance the performance of heat network substations.

The first method involves utilizing the fluid exiting the DHW exchanger for heating purposes. This approach is particularly effective with low-temperature heating systems, where the primary fluid's exit temperature remains suitable for heating despite high DHW consumption. Additionally, low-temperature systems inherently contribute to a reduced substation outlet temperature due to their lower return temperatures.

The second method focuses on preheating the cold water entering the DHW production system with the fluid exiting the heating system. By implementing this technique, we can achieve a lower temperature of the fluid post-heating system, further optimizing the substation's performance.

Our findings indicate that these architectures yield the highest efficiency with low-temperature heating systems. In series configurations with high-temperature systems, the temperature of the fluid exiting the DHW exchanger often fail to reach the heating system's entry temperature, triggering a bypass more frequently. In parallel configurations, this by-pass doesn't exist, therefore the flow from the network inlet is increased to meet the temperature needs and leads to a higher mass flow rate and, consequently, a higher substation exit temperature.

The temperature decrease is notably more significant during the heating season than over the entire year. This is attributed to the heating systems' substantial role in lowering the preheating exchangers' entry temperature, thereby reducing the substation's exit temperature. The system's efficiency is maximized when there is concurrent DHW and heating demand.

While these methods are effective in reducing the return temperature of DHN substations, they are not without limitations. For instance, in parallel configurations, the entirety of the fluid exiting the DHW exchanger is directed into the heating exchangers, potentially causing high mass flow rates. To mitigate this, three-way valves could be installed to bypass the heating exchangers under certain conditions. Additionally, the proposed configurations involve reusing fluid from one exchanger to another, which, along with the introduction of a new exchanger, leads to increased pressure drops. This is particularly critical when a substation replaces a heating system like a gas boiler, where keep low pressure drops to maintain existing pumps is essential to control costs.

Furthermore, the cost implications of adding a new heat exchanger (the preheating exchanger) must be considered. Lastly, the proposed architectures necessitate the development of new control strategies, which may present challenges for implementation by personnel who are not adequately trained.

These insights underscore the potential of the proposed methods to significantly improve the operational efficiency of DHN substations, albeit with careful consideration of the associated technical and economic factors.

5. Conclusion

In this study, we proposed two enhanced architectural designs for the most prevalent substation types in district heating networks. These designs were numerically tested across different building types to assess their adaptability and performance in varied contexts. The effectiveness of these architectures was gauged by the weighted average return temperature, factoring in the flow rate.

The innovative architectures employ dual strategies to lower the return temperature: leveraging the water exiting the DHW production system for heating when the temperature suffices, and preheating the incoming cold water with the fluid exiting the heating system to further reduce its temperature.

The findings reveal that both architectures significantly diminish the average return temperature, with reductions ranging from 3.7°C to a notable 10.2°C. These results suggest that adopting these architectures could substantially enhance the efficiency of heating networks, particularly with low-temperature heating systems and during the heating season.

Despite the encouraging outcomes, certain limitations were identified. Prior to widespread implementation, it is imperative to conduct comprehensive economic and hydraulic studies to ascertain the feasibility and long-term profitability of these architectures in substations.

In conclusion, while additional research is necessary to corroborate these preliminary findings, this study lays the groundwork for novel approaches to augment the efficiency of heating networks. The proposed architectures mark a significant step forward in this domain and hold the potential to markedly improve the energy performance of buildings.

Author contributions

Gaétan Chardon: Formal analysis, Writing – Original draft, Visualization

Rémi Patureau: Methodology, Software, Formal analysis, Writing - Review & Editing

Valentin Gavan: Conceptualization, Validation, Writing - Review & Editing, Supervision, Project administration, Funding acquisition

Competing interests

The authors declare that they have no competing interests.

References

[1] B. Möller and H. Lund, 'Conversion of individual natural gas to district heating: Geographical studies of supply costs and consequences for the Danish energy system', *Applied Energy*, vol. 87, no. 6, pp. 1846–1857, Jun. 2010, doi: 10.1016/j.apenergy.2009.12.001.

[2] H. Lund, B. Möller, B. V. Mathiesen, and A. Dyrelund, 'The role of district heating in future renewable energy systems', *Energy*, vol. 35, no. 3, pp. 1381–1390, Mar. 2010, doi: 10.1016/j.energy.2009.11.023.

[3] H. Lund *et al.*, '4th Generation District Heating (4GDH)', *Energy*, vol. 68, pp. 1–11, Apr. 2014, doi: 10.1016/j.energy.2014.02.089.

[4] F. Neirotti, M. Noussan, S. Riverso, and G. Manganini, 'Analysis of Different Strategies for Lowering the Operation Temperature in Existing District Heating Networks', *Energies*, vol. 12, no. 2, Art. no. 2, Jan. 2019, doi: 10.3390/en12020321.

[5] I. Sarbu and E. S. Valea, 'Energy Savings Potential for Pumping Water in District Heating Stations', *Sustainability*, vol. 7, no. 5, Art. no. 5, May 2015, doi: 10.3390/su7055705.

[6] S. Werner, 'District Heating and Cooling', Elsevier, 2013. Accessed: Feb. 27, 2024. [Online]. Available: https://urn.kb.se/resolve?urn=urn:nbn:se:hh:diva-24115. doi: https://doi.org/10.1016/B978-0-12-409548-9.01094-0.

[7] A. Poredoš and A. Kitanovski, 'Exergy loss as a basis for the price of thermal energy', *Energy Conversion and Management*, vol. 43, no. 16, pp. 2163–2173, Nov. 2002, doi: 10.1016/S0196-8904(01)00156-X.

[8] J. Oltmanns, M. Freystein, F. Dammel, and P. Stephan, 'Improving the operation of a district heating and a district cooling network', *Energy Procedia*, vol. 149, pp. 539–548, Sep. 2018, doi: 10.1016/j.egypro.2018.08.218.

[9] H. Li and N. Nord, 'Transition to the 4th generation district heating - possibilities, bottlenecks, and challenges', *Energy Procedia*, vol. 149, pp. 483–498, Sep. 2018, doi: 10.1016/j.egypro.2018.08.213.

[10] COSTIC, 'Guide technique - Les besoins d'eau chaude sanitaire en habtiat individuel et collectif'. 2016.