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Data-driven assessment for the supervision of District Heating Networks

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Abstract

There is an ongoing trend towards temperature reduction in District Heating Networks, allowing for the reduction of distribution heat loss and enabling the integration of low exergy heat production systems. There is a clear scientific consensus on the improved sustainability of such systems. However, there is not sufficient knowledge on how to deliver a successful transition to a low temperature District Heating system, while ensuring the operational levels of the existing system. This paper presents the experience on the progressive temperature reduction of a district heating subnetwork over the 2018–2021 period in Tartu, Estonia. Data from heat meters is extensively used to assess the capacity of substations and network branches to deliver the required heat and quality levels. Faulty substations are identified for targeted assessment and improvement works. Several substations have been identified as missing some of the performance criteria. This has led to further analysis, closer supervision and interventions in the operational conditions of the network. This is an ongoing process, expected to remain in the established procedures of the DH network operator. At the end of the process, a temperature reduction of 7 °C has shown an improvement of 4.8% in network heat loss.

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Keywords: District Heating; Energy System; Low temperature district heating; Temperature reduction; Case study; Network Operation; Heat supply; Infrastructure improvement; Thermal substation; Heat Meter

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1. Introduction

District Heating (DH) Systems are key infrastructures that deliver heat to 13% of European households and businesses [1]. In line with many other policies and measures targeted at improving the efficiency of energy systems,

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there is a clear improvement potential in these systems linked to the reduction of the operational temperatures in these networks [2].

Temperature levels in these networks are defined as a result of a techno-economic optimization linking heat delivery capacity, compatibility with heating systems at building level, compliance with Domestic Hot Water (DHW) production regulations (threshold temperature levels to avoid legionella), pumping costs, and pipe dimensions.

Networks are typically designed based on several typical operational conditions:

- Warm periods, with ambient temperature in excess of a certain value. In these periods, stable supply temperature levels are prescribed.
- Cold periods, one or more operational conditions are defined at lower temperature levels. In these periods, greater supply temperatures are prescribed. At these operational conditions, building substations capture greater energy (due to greater supply temperature levels), with limited increase in flow.
- In all cases, minimum supply–return temperature differences are prescribed. This is done to keep pumping (electricity) costs controlled and ensure the service to all consumers.

Altogether, this results in supply and return temperature levels as prescribed in Fig. 1. Once specified, these levels are established in contractual documents. So that, the DH provider delivers heat at temperature levels not lower than the established supply temperature, and that customers cool-down the circulated water below the established return temperature. The first condition ensures that a sufficient heating capacity is delivered to the customer, while the second one ensures that building-levels systems are properly operated to limit water flow and pumping costs.

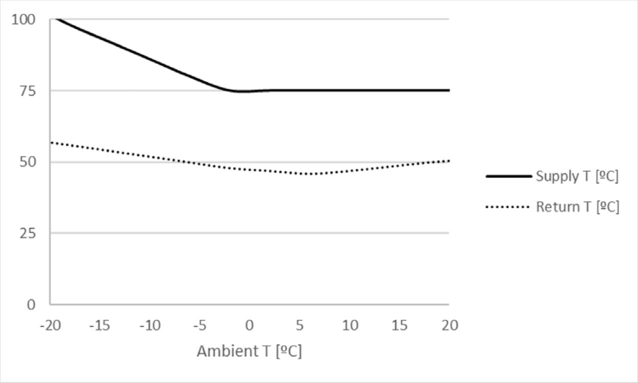

Fig. 1. Supply and Return temperature levels at various ambient temperature levels prior to the temperature reduction.

Once established, changes to operational conditions are limited by the contractual conditions, and physical limitations in all pieces of equipment in the network. Furthermore, typically substations are owned and operated by customers, with long service life. This limits the capacity of DH operators to re-specify equipment and modify the operation criteria in the short term.

Although the physical configuration of the network needs to be kept quite stable, it is known that engineering design and sizing criteria commonly results in oversized systems with spare capacity. In this context, it is possible to optimize system operation without relevant physical modifications.

With smart meters deployed to a great extent in electric networks, the last decade has seen a great progress in the deployment of smart heat meters in DH networks. This has resulted in several interesting applications. Lumbreras et al. [3,4] delivered an improved energy signature method linked to a decision tree model to predict heat loads in buildings by using smart heat meters. Lumbreras et al. [5], Johra et al. [6] and Gianniou et al. [7] developed clustering processes for pattern recognition in heating energy demands based on the same type of meters. Eriksson et al. [8] and Westermann et al. [9] developed improved energy signature methods for various applications in buildings. And Bergsteinsson et al. [10] presented the potentialities of using smart meter data as feedback signal for DH operation.

The aforementioned works have explored the use of heat meter data in many relevant fields of research in Building and District energy assessment and control. There is however a need to further explore the potentialities of these same pieces of equipment to support detailed engineering analysis of the spare capacity and operational excellence of networks to be operated at lower temperature conditions.

This work presents an analysis method to assess the operational fitness of building substations, where engineering criteria is massively deployed over heat meter data, and used to identify substations in sub-optimal conditions. This method is tested alongside a temperature reduction process in a DH subnetwork in Tartu (Estonia) and used to prescribe improvements to limiting substations.

2. District Heating Network

The DH network of Tartu, Estonia is owned and operated by GREN. The network operates between 75/45 °C and 110/60 °C. Temperature ranges and delivers up to 500GWh to more than 1500 consumers yearly. With 40–60 new connections to the grid per year, the consumers are collective housing (49%), industry and commercial buildings (33%) and individual housing (18%).

In this paper, data-driven assessment is performed over the subnetwork and consumer substations in the area of Tarkon-Tuglase. It comprises 5.34 km of network, serving more than 54 consumers, with some ongoing connections. Heat of up to 4.3 MW is delivered to buildings with different uses: residential, commercial, educational and offices. Fig. 2 and Table 1 present the basic information about this network.

Fig. 2. Distribution network in the Tarkon area.

Table 1. Characteristics of the DH subnetwork of Tarkon.

Characteristics of the DH subnetwork of Tarkon	
Point of consumption	54
Total consumption	8.2 GWh
Peak heat load	4.3 MW
Climatic zone	Warm-summer humid continental climate
Location	Tartu, northwest

3. Heat meter system & other data sources

The network is equipped with heat meters in all building substations. The accuracy of this devices is always higher than the one fixed in CEN EN-1434–1 [11] and the measuring error remains below 5%. An additional heat metering system is installed in the mixing chamber at the DH intake to the subnetwork. A schematic of the data sources in is shown in next Fig. 3. The following data is available at hourly aggregation intervals since the beginning of 2019 without relevant data loss:

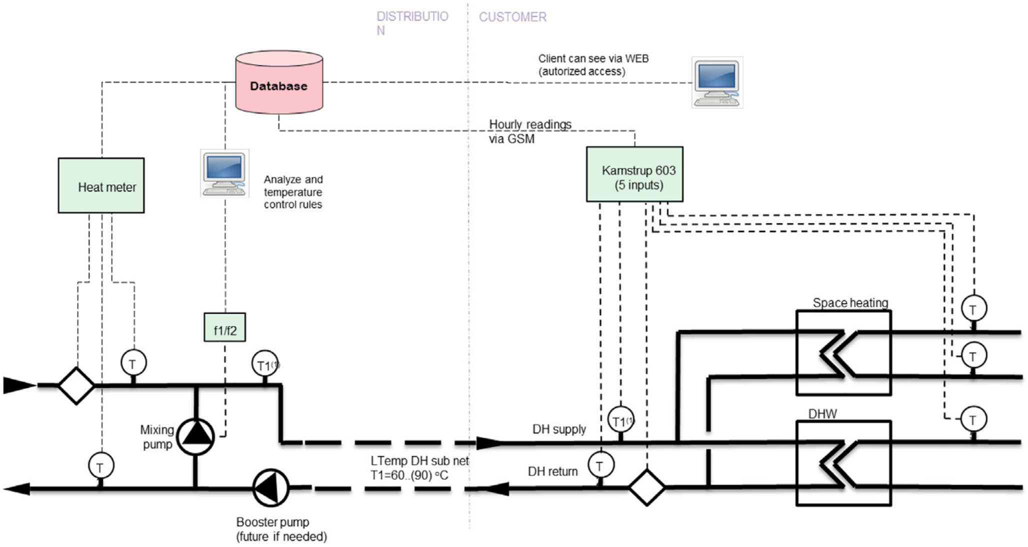

Fig. 3. Location and lay out of the smart energy meters in the DH in Tartu.

- Mixing chamber: Delivered energy, volumetric flow supply and return temperature.
- Individual substations (primary side): Delivered energy; volumetric flow, supply and return temperature.
- Individual substations (secondary side, heating): Supply and return temperature.
- Individual substations (secondary side, DHW): Supply temperature.

Weather data is taken from a well-established institutional data source from the University of Tartu Weather Station [12].

4. Temperature reduction process

The continuous monitoring of the network was initiated in 2019. And a temperature reduction process was initiated with the installation of a temperature reduction system that year. The reduction took place on 4 different phases as presented in Table 2.

Table 2. Steps for temperature reduction.

Period	Temperature reduction	Supply temperature (@ various ambient temperature levels)	Comments
01/01/2019 to 15/12/2019	N/A	80 °C (@-10 °C) 77 °C (@ 0 °C) 75 °C (@ > 10 °C)	Pre-intervention status
16/12/2019 to 21/06/2020	10 °C	70 °C (@-10 °C) 67 °C (@ 0 °C) 65 °C (@ > 10 °C)	Initial temperature reduction
22/06/2020 to 21/09/2020	12 °C	63 °C	Reduced temperature during summer season
21/09/2020 to 31/03/2021	10 °C	70 °C (@-10 °C) 67 °C (@ 0 °C) 65 °C (@ > 10 °C)	First full heating season at reduced temperature

5. Key performance criteria

From the DH Operator point of view, network performance criteria are assessed through energy and service quality metrics. Key items being as follows:

- **Distribution Heat Loss** reflects the amount of heat delivered injected in the network, but not transferred to the end customers. Heat loss ratios are highly dependent to network size and heat density, with values in the range of 8%–9% up to >20%. For this reason, the performance of this metric shall be defined as a reduction in this figure. Typical heat loss reduction levels in the range of 2%–3% would be considered as a success.
- **Quality of service.** Heat delivery to customers shall not be compromised by the temperature reduction process. This implies that, once corrected for climate, and use factors, the delivered heat should remain stable. At the same time, temperature constraints imposed by DHW heat production shall be fulfilled to ensure the safety of end users. DHW production temperature is prescribed at 55 °C in Estonia. Accounting for safety margins, the network shall deliver DHW temperature levels of 60 °C in the primary side of the substations at all times.
- **Pumping costs** need to be limited. This is commonly observed through the temperature response in the substations. Typically, this is particularly critical for cold periods, where pumping systems are operated at their most critical operational range. For ambient temperature levels below 0 °C, temperature reductions in substations shall be greater than 20 °C.

These criteria are established by each DH operator based on their knowledge of the network configurations, capacities and limitations; local and national regulations, and service agreements with customers.

6. Methodology

Data is gathered through automated processes from heat meters into a centralized database in hourly resolution. Weather data is downloaded with the same resolution from . Then the analysis procedures are executed for each substation by means of an automated process in python:

1. Values related to low load are disregarded. This is typically done considering a 1kWh threshold for single family houses and 5kWh for larger buildings.
2. Data is grouped at 5 °C intervals to get the necessary statistical information at each temperature slot.
3. Operation curves on Supply & return temperature, temperature response, distribution temperature loss, and supplied energy are computed over the statistical data.
4. To ensure DHW supply temperature is assessed at any time during mild periods (T>10 °C), statistical values for each hour are computed on the primary and secondary side of it.
5. The analysis is reported through a visual report and automated warnings of faulty/non-optimal substations. Warnings are generated if the Key Performance Criteria of Section 5 are not fulfilled more than 25% of the time.

This is performed for all the substations in the network and every step in the temperature reduction process. Fig. 4 presents key information of one substation.

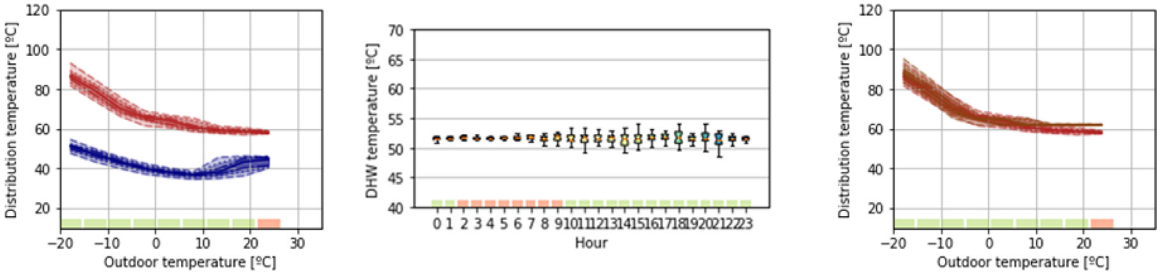

Fig. 4. Diagnosis of the operational excellence of consumer substations. Flow (red) and return (blue) temperature levels against ambient temperature (left); Hourly DHW supply temperature during low load conditions (center); and Flow temperature (red) vs DH supply temperature (brown) against ambient temperature (right).. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 3. Information about the data points.

Sequence	Period start	Period end	Number of substations fully monitored	Total data analyzed	Total data losses
1	01/01/2019	15/12/2019	47	8E5	0%
2	16/12/2019	21/06/2020	54	5E5	0%
3	22/06/2020	21/09/2020	49	2E5	0%
4	21/09/2020	31/03/2021	56	5E5	1.29% from one substation

Table 4. Area losses.

	Area total, MWh	To customers, MWh	Losses, MWh	Losses, %
Reference (2019)	8505.1	6991.3	1513.8	17.8%
2020	8267.2	7193.5	1073.7	13.0%
2021 (10month)	7713.6	6594.9	1118.7	14.5%

Table 5. Performance of substations.

Sequence	Substations not meeting the criteria. Absolute number (percentage)		
	DHW supply temperature at secondary side > 55 °C	Heat delivery temperature at 0 °C > 60	Temperature response at 0 °C > 20 °C
1	22 (43%)	4 (8%)	0 (0%)
2	22 (41%)	11 (20%)	10 (19%)
3	22 (45%)	0 (0%)	0 (0%)
4	31 (55%)	13 (29%)	5 (9%)

7. Results

The total data points analyzed adds up to 2E6 data points. Table 3 presents the information on the data analyzed per period and total data loss.

The data analysis also shows that temperature reduction has positive impact to losses. Table 4 shows that the total loss fraction has been reduced by 3.7% in absolute terms.

With regards to the actual performance of the DH system at consumer side along the temperature reduction process the following table presents the outcomes of the analysis. As it can be seen in Table 5, there is a number of faulty substations in the range of 8 to 55%, depending on the performance metric. The criteria for identifying such faults is that data in excess of 25% is below the required threshold. For the case of DHW supply temperature it is assessed independently for each hour in the day.

8. Conclusions & further work

The present work presents a temperature reduction process for the improvement of the energy efficiency of a DH network. This process has been accompanied with detailed monitoring and data analysis processes to ensure that the temperature reduction achieves the expected energy performance improvements while at the same time the performance delivered to the end user remains with sufficient quality.

A stepwise temperature reduction has been performed along a 2-year period. And a detailed data capture, processing and analysis process has been conducted. This has allowed to identify a number of substations close to their operational limits or requiring changes to the operational conditions in the network.

A continuous commissioning process, with assessments and interventions in every reduction steps has allowed to ensure that the system operation is still satisfactory even in the new supply temperature levels.

No major failure has been observed. Substations identified through the screening process have been found to be operating very close to the threshold criteria. As expected, most screened substations are buildings with relatively low load and/or located at the end of network branches. In the case of DHW supply temperature, underperformance has been tracked to specific peak load periods.

As a consequence of the analysis, the following interventions have been performed on a regular basis:

- Low DHW and DH temperature levels: Increase in DH flowrates and incorporation of thermostatic valves at the end of critical network branches.
- Low temperature response in substation: Communication with consumers to verify that the secondary-side control system meets the criteria established in the contract.

Altogether, this process has showcased the potential of data-driven approaches to the optimization of district heating infrastructure. Both at its main operational criteria and individual substations. Considering that the temperature reduction process waves away a large share of the original safety margin on behalf of efficiency, this data-driven supervision is meant to remain in the DH network to ensure that energy efficiency measures are compatible with satisfactory delivery of energy to customers.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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