DISTRHEAT

Digital intelligent and scalable control for renewables in heating networks

Deliverable 5.2

Report on the experience with optimization strategy and the use of pipelines and buildings as heat storage

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Authored by:	September 29th, 2023	Avinash Renuke, Joakim Örneskans, Mathilda Cederbladh, Stavros Vouros	Mälardalen University
Reviewed by:	September 29th, 2023	Konstantinos Kyprianidis	Mälardalen University
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Executive summary

A strategy for optimally using thermal loads in district heating substations is developed. The strategy is evaluated through simulation using real operator's data from two large-scale substations in Västerås. The capability of optimally managing thermal loads across the entire network of Västerås is also explored. The energy savings out of this approach are quantified.

1. Introduction

Presently, district heating networks present significant thermal variations and peaks that stretch the power plant, therefore affecting operational stability, economy, as well as environmental impact. Still, there is a high potential for exploiting excess thermal loads and optimally managing for improving the operation. Operational flexibility comes together with compromise in comfort levels for the end-users. Therefore, identifying the best tradeoffs and developing optimal strategies will unleash the potential of district heating sector without the need of new investments.

2. Optimization strategy for building

2.1. Control scheme for managing building thermal loads

A control scheme for optimal management of building thermal loads is developed (Cederbladh et al., 2023). Indoor temperature is allowed to vary with designated limits around an average setpoint, aiming at minimizing the variation in heat supply per hour. The concept of "peak shaving" yields lower variations in building heat loads which allow for better stability for the network. Furthermore, it enables a steadier operation for the central power plant which otherwise would be stretched during peak periods.

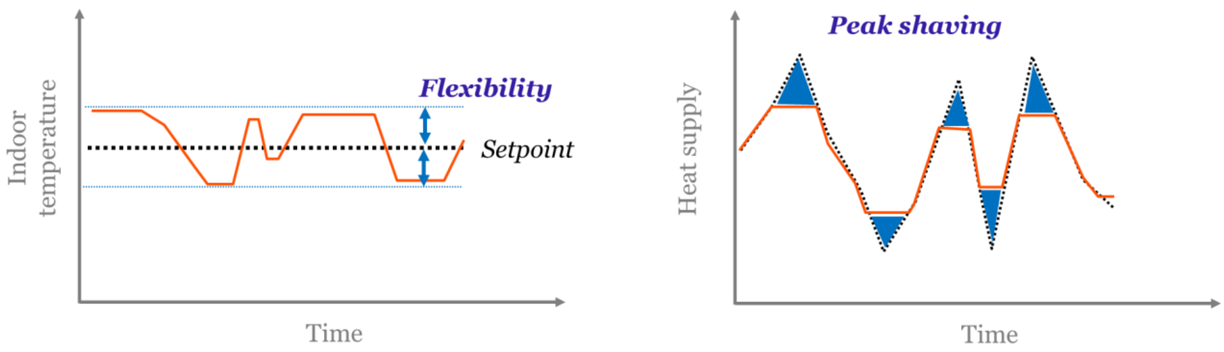

Figure 1: Concept of peak shaving using building thermal loads

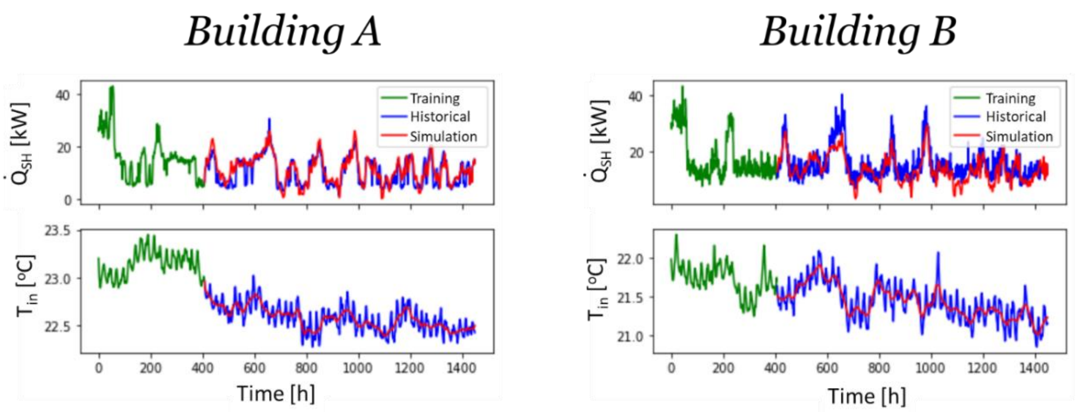

Figure 2: Validation of building model for two buildings in Västerås

A model is developed for capturing heat loads and indoor temperature, as well as heat stored in the building. The validity of the developed model is first confirmed for two residential buildings belonging to the large-scale network of Västerås. Historical data is used for training the model and a comparison between simulated and historical data is presented in Fig. 2. The accrued root mean squared error (RMSE) is 8% and 9% for building A and B, respectively. This accuracy is deemed adequate for the purpose of control and optimization.

2.2. Results for at building level

After validating the model, the peak shaving optimization algorithm is applied to both buildings, using the same models described in section 2.1. A setpoint and corresponding flexibility is assigned at 22+/-0.5 °C. The impact of optimization on both buildings is illustrated in Fig. 3.

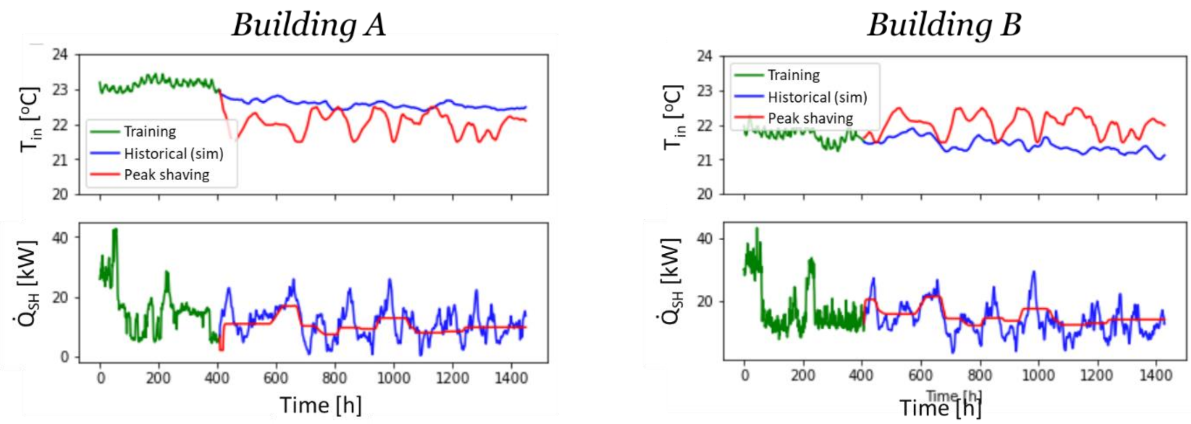

Figure 3: Optimization results at building level

It is shown that significant peak shaving can be achieved through allowing flexibility in the indoor temperature. Specifically, for building A, the maximum peak shaving is expressed as a drop from 26kW to 16kW of max heat load, between the historical and the optimized case. The corresponding energy delta for the monitored period is a saving (decrease) of 10%. This is of course due to lowering the average indoor temperature of the building, which historically was higher than 22°C. For building B, the maximum peak shaving is expressed as a drop from 29kW to 22kW of max heat load, between the historical and the optimized case. However, the corresponding energy delta is a penalty (increase) of 9%. This is because the historical average indoor temperature was lower than the intended 22°C.

Table 1: Impact of flexibility margins on peak shaving and energy deltas for building A

Flexibility *[°C]*	**Peak shaving** *[%]*	**Energy saving** *[%]*	**Average T_{in}** *[°C]*
±0.25	30	10	22
±0.50	35	10	22
±0.75	35	12	21.9
±1.00	36	9	22
±1.25	38	14	21.9
±1.50	40	7	22.2
±1.75	42	7	22.3
±2.00	45	6	22.3

A generalized view of flexibility margins on peak shaving, energy deltas, and average indoor temperature for building A is provided in Table 1. It can be concluded that flexibilities beyond

1 degree do not offer significant improvement in peak shaving, whilst at the same time energy savings are reducing. Similar peak shaving albeit with negative energy deltas are observed for building B.

It is important to note that the overarching target of flexibility and peak shaving is not energy savings but reduction of positive and negative peak loads. Energy savings might or might not occur, and this depends on the variation of average indoor temperature as well as external temperature. However, reducing thermal peaks yields enhanced stability for the network and offloading of the central power plant during peak times.

3. Optimization strategy for network

3.1. Control scheme for managing network thermal loads

In this section, a control scheme for managing network thermal loads is developed (Renuke et al., 2023). At the network level control, the thermal load at the pumping station at the region of interest is considered for the optimization. AI/Machine learning models are used in order to predict future thermal loads. The model uses the historical measured data from the pumping stations and the weather conditions. The model adaptively trains the data and predicts the thermal load in the real-time scenario. Figure 4 shows the control scheme for managing network thermal loads. The predicted thermal loads at the pumping stations are used in the optimizer to optimize the supply temperature from the plant by keeping the return temperature in the line as a control target. The model basically estimates the heat losses in the network to get the optimized supply temperature from the plant.

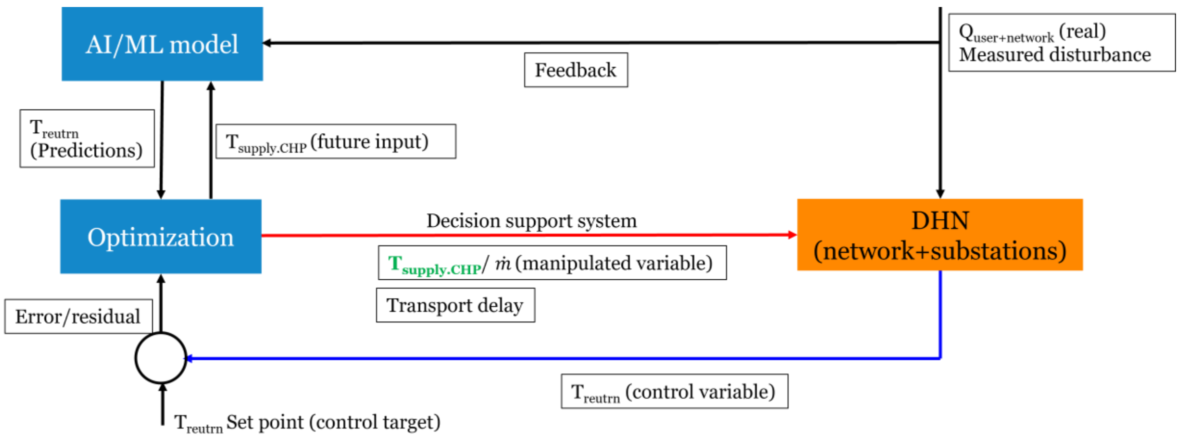

Figure 4: Control scheme for managing network thermal loads.

In the network control strategy, accurate prediction of thermal has a significant role to play in the optimization of the supply heat from the plant. The ML model developed hereby predicts the thermal loads within a required error margin as defined by ASHRAE 14 guidelines. Figure 5 shows the validation of the thermal load prediction ML model with the measured data.

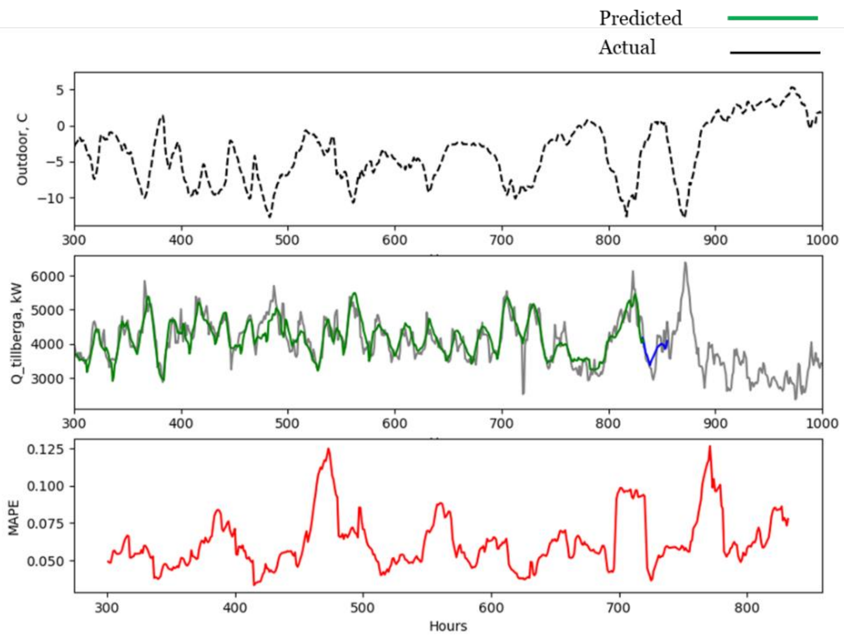

Figure 5: ML thermal load prediction model validation for the region of Tillberga with actual and predicted thermal loads with Mean Absolute Percentage Error (MAPE)

3.2. Results at network level

The control strategy is applied to the plant data for supply temperature optimization by controlling the return temperature setpoint after successful validation of the model. The optimization results are shown in Figure 7.

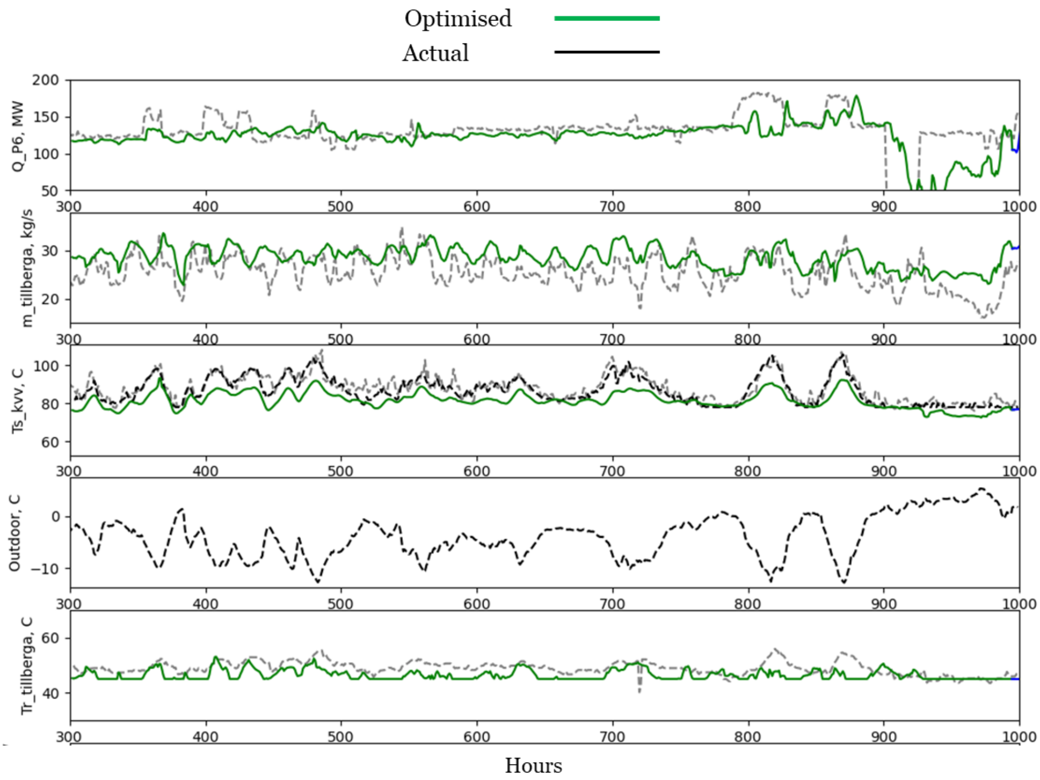

Figure 7: Plant supply temperature optimization for Tillberga region.

Figure 7 shows the optimized plant supply temperature for the region of Tillberga, mass flow through the network, impact on plant heat supplied to the network and return temperature. The optimized plant supply temperature is lower than the actual supply temperature which is based on the traditional approach. The reduction in supply temperature as high as 10 C is obtained through optimization, especially at the peaks. The lower supply temperature at the peaks would facilitate more electricity production from the plant or avoid switching on the additional boiler to achieve this peak temperature. The return temperature is seen to be lowered which as well was the control target in the optimization.

The average plant supply temperature optimization results for the period of one month can be seen in Table 2. The control strategy at the network level not only reduces the peak supply temperature and return temperature, but it offers the advantages of energy savings by reducing the losses in the network.

Table 2: Plant supply temperature optimization results

	Historic supply	Optimized supply
Temp. Avg, C	87.9	81.5
Temp. Std, C	6.9	4.3
mass flow. avg, kg/s	25.5	28.5
mass flow. Std, kg/s	3.3	2.2

4. Architecture of a cloud-based integration

A holistic solution connecting central plants to pumping stations and individual substations is presented in Fig. 8. An architecture for a regional-level management of operational data based on cloud solutions is proposed. The network operational data is centrally stored at the utility company data centers and is exposed by an Hypertext Transfer Protocol (HTTP) application programming interface (API). To maintain security a dedicated desktop computer is given a static IP-address which is allowed to access the API using secret keys and SSL/TLS. A GET request is sent to the HTTP API which returns the desired data in JSON format which then is written to the local control algorithm application. The application processes the data and communicates the outcome back to the utility company with an HTTP PUT request.

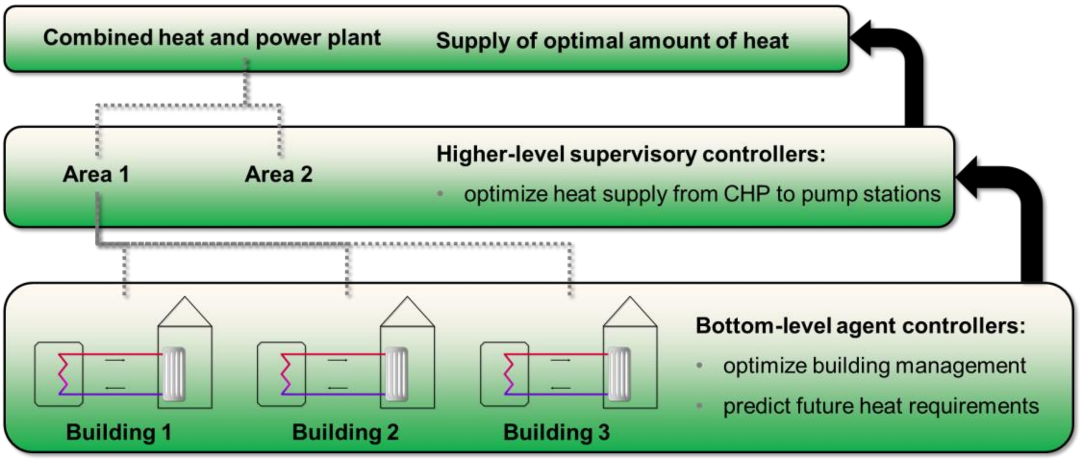

Figure 8: Integrated cloud-based optimization architecture

5. Conclusions

Optimal management of stored heat in buildings connected to the district heating network can yield peak shavings in the order of 35% through allowing a flexibility of +/-0.5K in the indoor temperature for the end-users. That can work as a bottom-up approach to thermal peak shaving to the benefit of the power plant, the network, the housing providers, and the end-users. Operational, environmental, and economic benefits are prominent. At network level, optimal management of heat through the pipes can offer a reduction in supply temperature by 6 degrees on average, which can offload the combined heat and power plant, and even allow more space for additional generation of electricity.

List of references

Mathilda Cederbladh, August Dahlberg, Stavros Vouros, Konstantinos Kyprianidis, Costanza Saletti and Mirko Morini, 2023, “Optimal flexibility for thermal peak shaving in district heating substations”, 64th International Conference of Scandinavian Simulation Society, Västerås, Sweden, September 26-27, 2023.

Avinash Renuke, Stavros Vouros and Konstantinos Kyprianidis, 2023, “Machine learning assisted adaptive heat load consumption forecasting in district heating network”, 64th International Conference of Scandinavian Simulation Society, Västerås, Sweden, September 26-27, 2023.