DISTRHEAT

Digital intelligent and scalable control for renewables in heating networks

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Report on the development of the physical model of district heating network

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Executive summary

This document describes the development of the dynamic model for the district heating network of Västerås, Sweden. A characterization of the network is provided, in terms of energy requirements, topology, length, and time delays. A brief description of the dynamic model development is following, describing the principal operating parameters. A verification of the model is carried out with respect to measured data from all the main pumping stations of the network. Aspects related to future use of the model are discussed.

1. Introduction

A physics-based model has been developed representative of the large-scale district heating network of Västerås, Sweden. The model has been built based on historic data from the plant and network operation. Dynamic heat and mass transfer equations have been employed for capturing the inherent time delays as well as temperature and mass variations of the network. The model accurately replicates the behavior of the network for the purpose of model-in-the-loop control and optimization.

2. Model description

2.1. Network characterization

The network of Västerås is operated by Mälarenergi AB and is rated at a connectivity of 98%. The network is managing more than 1800GWh of heat annually. The combined heat and power (CHP) plant is supplying six outlying regions at varying distances. A simplified representation of the network is provided in Fig. 1.

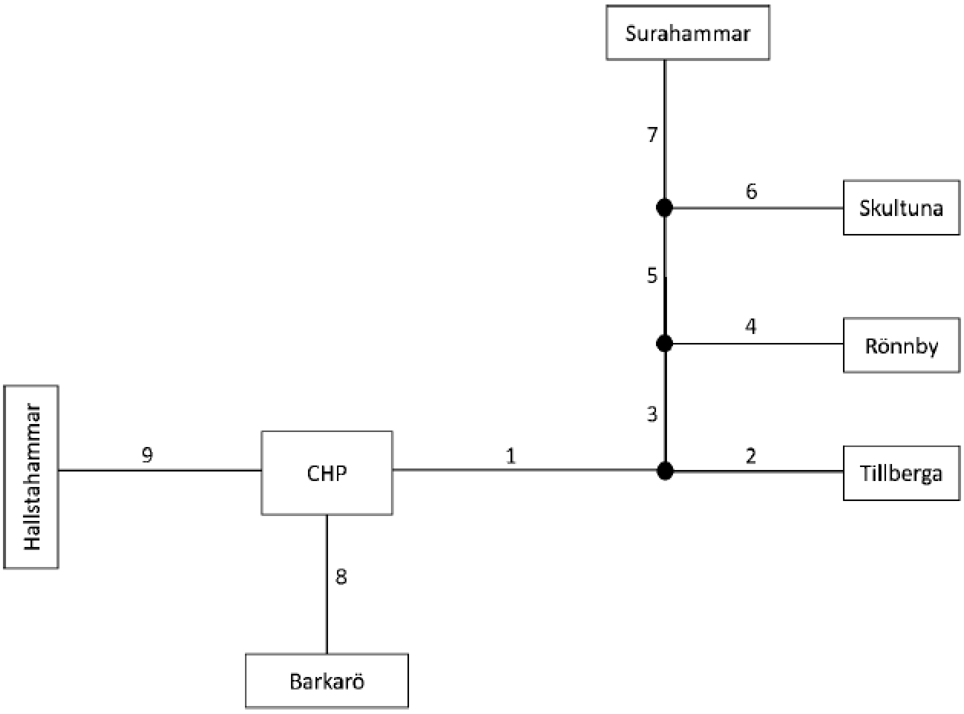

Figure 1: Overview of main branches in the district heating network (Zimmerman et al., 2019).

A common supply temperature and mass flow is leaving the CHP. Depending on the distance of each region, different temperatures will reach at the regions. The mass flow that goes through each region is controlled at corresponding pumping stations. The control of mass flow is based on the back pressure that each pumping station is exerting by the substations. A representative distribution of time delays for the Tillberga area as function of time is provided in Fig. 2.

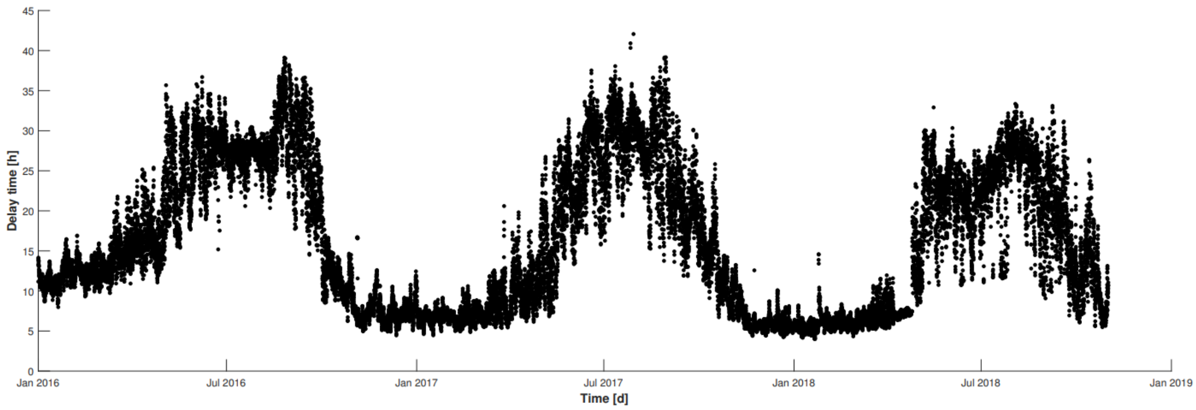

Figure 2: Seasonal variation in time delay for heat supply to the Tillberga area (Zimmerman et al., 2019).

2.2. Network model

A dynamic representation of the convective heat transfer phenomena along the network has been developed. The temperature of water exiting the pipes is a function of supply temperature from CHP, water mass flow and heat losses. Heat losses are calculated based on estimations of the pipe heat transfer coefficient, dimensions, and outdoor temperature. Heat transfer coefficient is estimated using the pipe sizing, material properties and insulation properties. Time delays are calculated based on the pipe dimensions and the time-varying mass flow. The time delays for the 9 main distribution lines in the Västerås network are presented in Fig. 3.

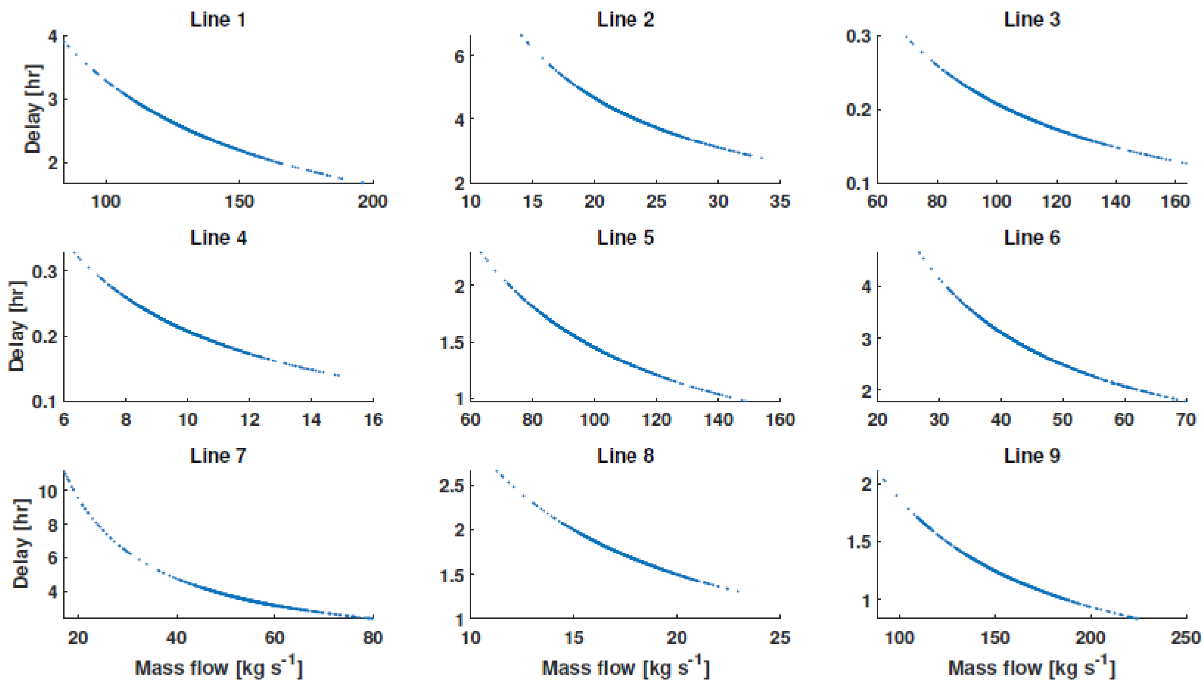

Figure 3: Time delays as function of mass flow rate in the major network distribution lines (Zimmerman et al., 2019).

3. Verification

The dynamic model is verified against measured data for the six main regions of the network. Figure 4 presents the distribution of supply temperatures at the six pumping stations. It is observed that the model is able to capture the governing amplitudes and frequencies at all regions. This verifies that heat losses along the network are properly modelled. The phase agreement between signals is good which depicts that time delays are accurately captured.

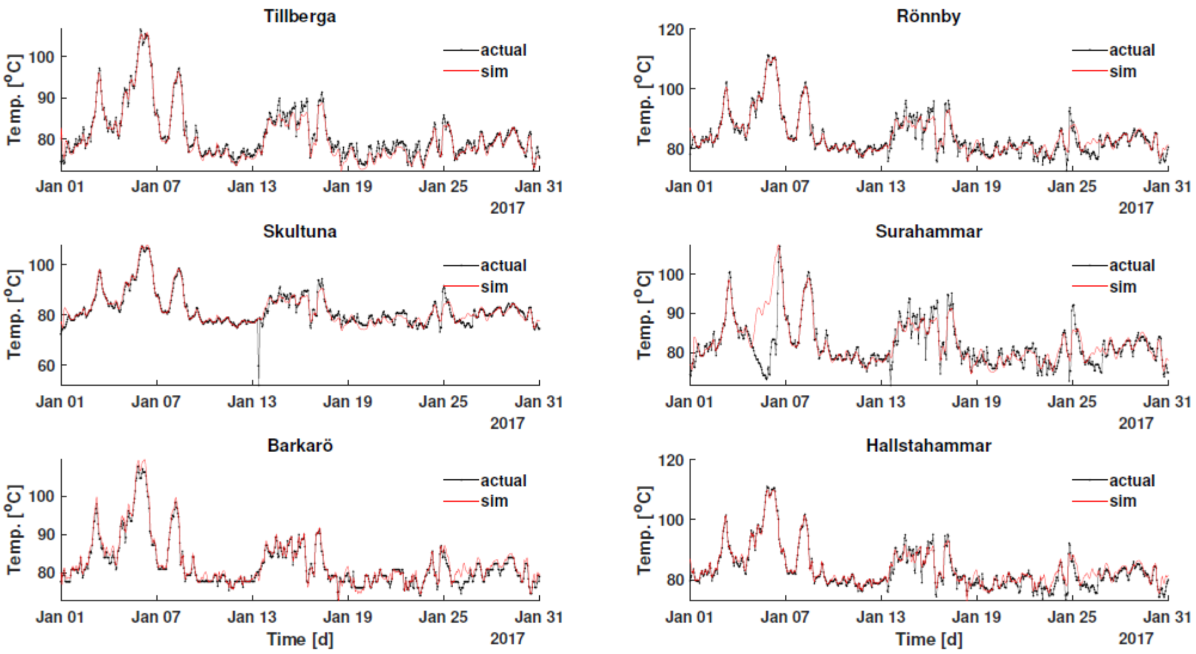

Figure 4: Distribution of supply temperature at the six major pumping stations of Västerås network: comparison between simulation results and measured data (Zimmerman et al., 2019).

A detailed insight into the full set of operating parameters about the area of Tillberga is provided in Fig. 5. It is observed that the model can adequately predict the heat propagating, and losses through the network over a distance of 14.5 km, in good agreement with the trends of the measured temperature. It is also possible to observe the distribution delay and losses since there is a noticeable shift in the temperature being supplied from the CHP and a 2–5K drop in the supplied temperature. The modelled vs. actual return temperature in Figure 5(b) is also within good agreement and is calculated using the load from Figure 5(c) and mass flow rate from Figure 5(d). The mass flow rate in Figure 4(d) is related to the delay time in distribution temperature, i.e., the amount of time it takes for the temperature leaving the CHP to arrive at Tillberga. During this period, the maximum and minimum observed flow rates are 33.5 and 14 kg/s with a corresponding delay of 4.4h and 10.4h, respectively.

Overall, the model is adequately capturing the dynamic response of the heat network. A reduced-order representation of the model will be used within a model-based control architecture (Saletti et al., 2021). The scope of the controller is to optimize the temperature supply from the power plan to satisfy the heat demands of the end users.

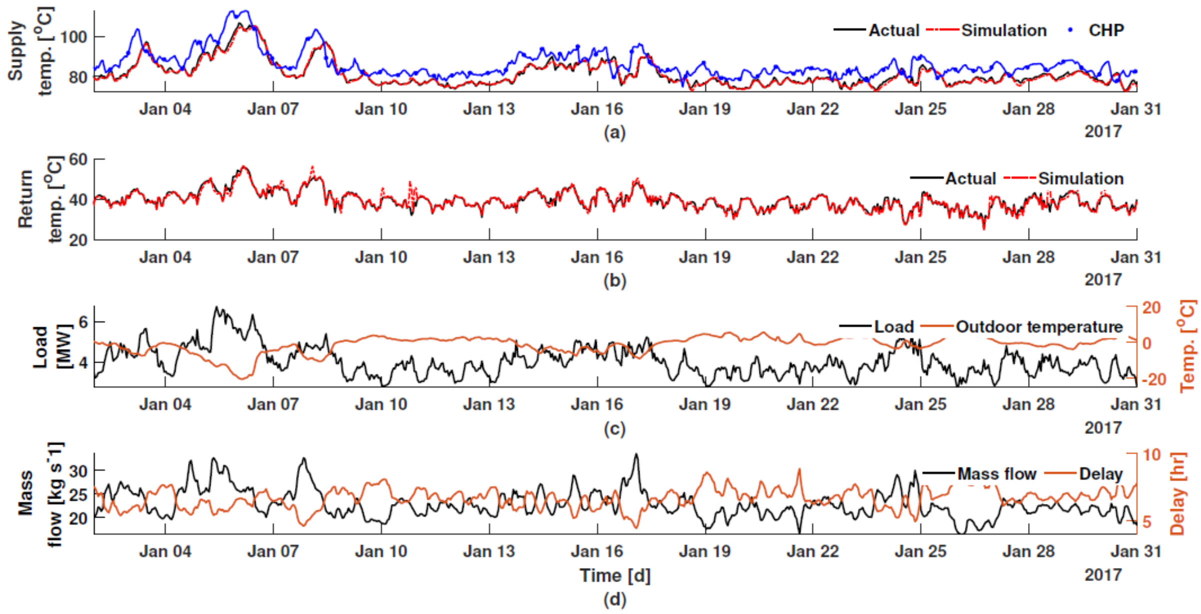

Figure 5: Verification of network heat propagation to Tillberga area: (a) supply temperature at CHP and supply temperature at the pumping station of Tillberga; (b) return temperature leaving Tillberga pumping station; (c) end-user heat load and outdoor temperature; (d) network mass flow rate and time delay (Zimmerman et al., 2019).

4. Conclusions

A physics-based dynamic model has been developed for the prediction of operating parameters in the district heating network of Västerås. The model has demonstrated sufficient accuracy with regards to measured data along the network. The generality of the model has been demonstrated for all the six major areas of the Västerås district heating network. Future use of the model involved order reduction and utilization into a model-based control scheme for optimal network management.

List of references

Zimmerman, N., Kyprianidis, K. and Lindberg, C.F., 2019. Achieving lower district heating network temperatures using feed-forward MPC. *Materials*, *12*(15), p.2465.

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