DISTRHEAT

Digital intelligent and scalable control for renewables in heating networks

Deliverable 5.1

Report on the use of load model for normal cases to meet weather changes

September 25th, 2023

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Executive summary

The architecture of the control system designed in DISTRHEAT is described. The hardware and firmware employed for hosting the control algorithm are presented and aspects of connectivity and security are addressed. The system is demonstrated in a large-scale substation in the city of Västerås in Sweden. Demonstration results are presented and evaluated.

1. Introduction

Smart control solutions for the heating sector present high potential at simulation level. However, human factors are largely affecting the results in practice. At the same time, several limiting parameters can be showstoppers in the productionization process of such systems. Finally, stakeholders such as utility companies, housing companies, as well as end-users can better trust higher TRL solutions. For these reasons, a demonstration campaign is being carried out within DISTRHEAT to showcase the capabilities of the developed controller in real operating environment.

2. Control system description

2.1. Substation controller

A data-driven controller is developed incorporating the statistical load model described in Deliverable 4.2. The controller constitutes an optimization architecture featuring predictive and feedback stream, as illustrated in **Fig. 1**.

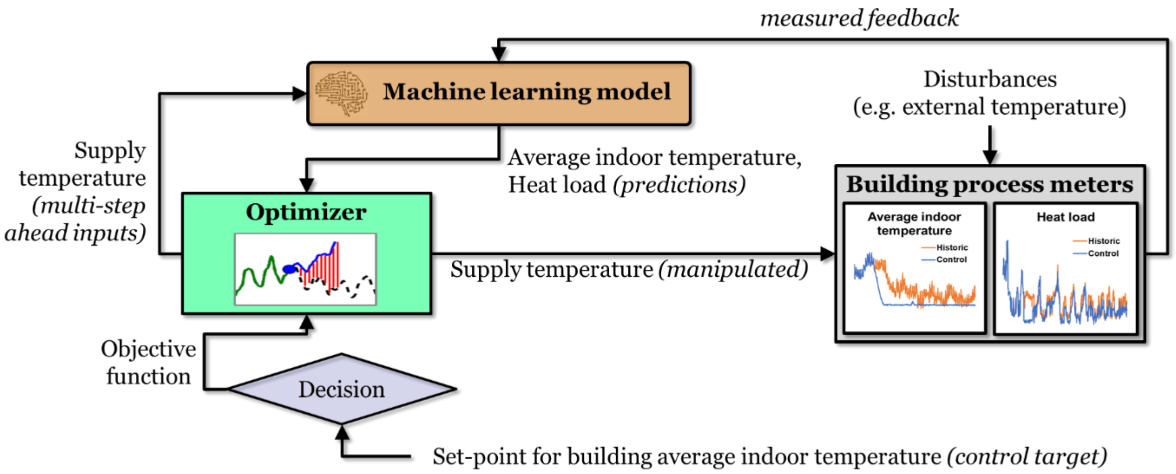

Figure 1: Architecture of the substation control scheme

The predictive stream is provided by the statistical load model, after integrating a weather forecast. Predictions for multi-step-ahead indoor temperature and heat load at the substation are fed into the optimizer. The optimizer converges when the designated indoor temperature profile is achieved. A control action is then instructed to the heating system, and this eventually reflects on the real indoor temperature and heat load in the facility. Measurements for all operating parameters return to the optimizer as feedback and new data for retraining the statistical model.

2.2. Hardware, interface, and security aspects

The XC05 Edge controller shown in **Fig. 2** is employed for hosting the control algorithm and interfacing with the demonstration facility. XC05 is developed by First Control in Sweden, and continuously improved during DISTRHEAT (Örneskans et al., 2023). XC05 is a full-size industrial control system, able to host robust adaptive control schemes, dynamic simulation using Modelica- or Python-based models. The platform provides a simple graphical programming interface and automatic local code generation. The hardware unit is based on a Raspberry pi 4 microcomputer which provides maximum development and operational flexibility at minimum market cost.

Figure 2: XC05 Edge controller

Interfacing of XC05 with industrial facilities can be implemented using all the standard industrial communication protocols such as Ethernet, CAN, WEB, RS232, 485, GSM, Siox, Modbus RTU and Modbus TPC/IP. To maintain security the XC05 is connected through a wired ethernet connection to the existing regulator through a local network. The IP-address is static and set by the owner of the equipment. The XC05 unit is also protected by an internal firewall and the only ports opened for inbound connections are the ones for programming and communicating with the XC05 unit.

3. Demonstration

3.1. Test facility

A full-scale demonstration is conducted integrating the systems described in the sections above. The large district heating network of the city of Västerås in Sweden ranges more than 800km of pipes and is handling more than 1800GWh of heat per year. The network of Västerås is operated by Mälarenergi. A large substation within this network has been selected as the test site for this demonstration. The substation comprises 8 residential buildings which in total host 87 apartments. The overall heat load for this substation can exceed 300kW at peak hours. The operation of the substation is illustrated in **Fig. 3**.

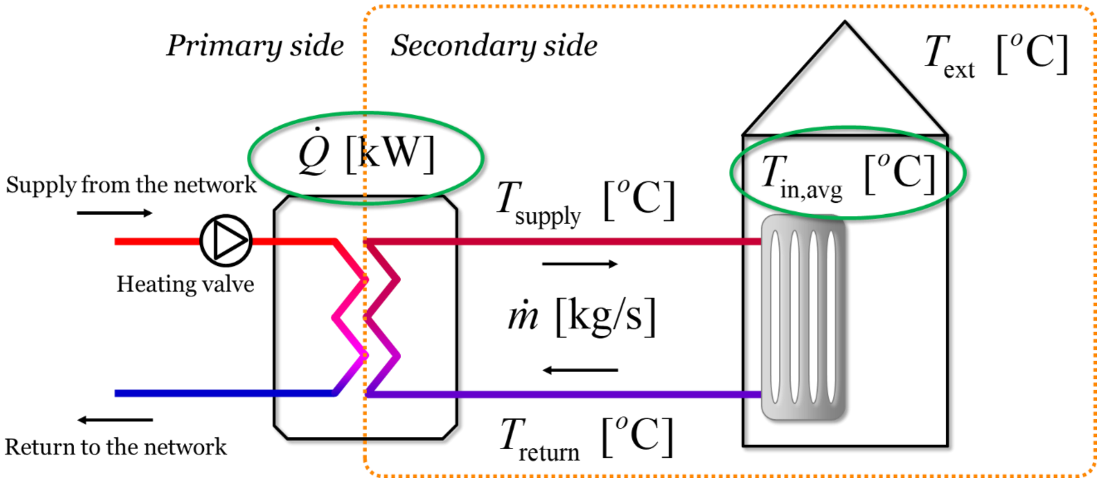

Figure 3: Illustration of the components of test case

A heating valve regulates the mass flow that arrives at the primary side of the heat exchanger within a simple programmable logical controller (PLC). The PLC runs against a linear heating curve that defines a supply temperature to the radiators as function of external temperature. No feedback on the indoor temperature or heat load is included in the traditional operation of this system.

The novel control method developed in DISTRHEAT is installed as an add-on to replace the simplified linear heating curve of the system. The controller learns adaptively from the existing data streams available in the substation and the apartments and provides optimal supply temperature setpoints for the PLC system that regulates the heating valve. In this way, indoor temperature and heat load become integral parts of the control scheme, whilst continuously learning from new data and adapting to changes in the weather but also the building thermal behavior.

Concurrently, no change or modification is required in the existing installation. The installation of the novel controller took less than 30 minutes to be up and running, from scratch. Also, no software tuning is required before the installation: the controller is installed and can learn the building behavior unsupervised. This depicts the scalability and “plug-and-play” dimension of the developed system.

3.2. Demonstration results

The demonstration was carried out during the month of February 2023. A consecutive test period of 2 weeks was monitored (Vouros and Renuke, 2023). The intended average indoor temperature setpoint was 21.5 ^{o}C. The external temperature, for a period of 40 days, including the test period, is presented in **Fig. 4.** The black part of the curve represents the test period while the gray part represents the period before and after the test, where the controller is not active. The highest external temperature recorded was +9^{o}C whilst the lowest was -8^{o}C, therefore providing an adequate range of variations for testing the impact of the controller on building heating performance.

The accrued indoor temperature profile is illustrated in **Fig. 5**. The controller was turned on February 6. Initially, the controller reduced the indoor temperature by 1 degree within a day, as was instructed by the building managers. Then it was able to maintain a consistent temperature of 21.5^{o}C within a range of +/-0.2 degrees. The controller was turned off on February 20 and indoor temperature started increasing again as it was not following the optimized control actions.

The corresponding heat load distribution is presented in **Fig. 6**. It is shown that the heat load is overall during the period that the controller was on. The overall energy savings in the 13-day period with control on and steady indoor temperature of 21.5^{o}C compared to the 13-day period prior to control onset, is 20%. The first day of controlling is excluded as it represents the initial transient of the controller until reaching the setpoint of 21.5^{o}C. It is noted that heat load and thermal energy deltas can be attributed to both varying indoor temperature as well as the external temperature. External temperature was higher on average during the control period. A normalized metric for thermal energy is derived through dividing with the external temperature delta with respect to a base value of 21.5^{o}C. In this way, energy deltas are decoupled from external temperature variations. In this case, normalized savings of 9% are calculated.

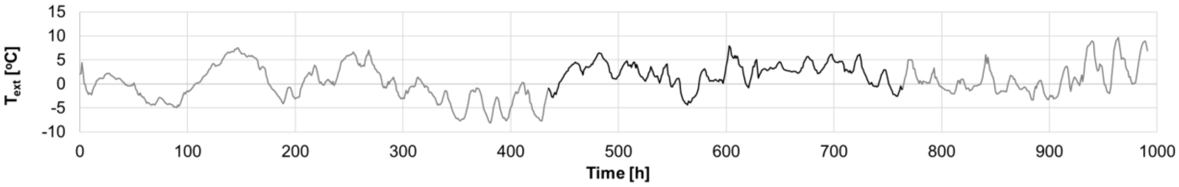

Figure 4: External temperature profile during the control demonstration

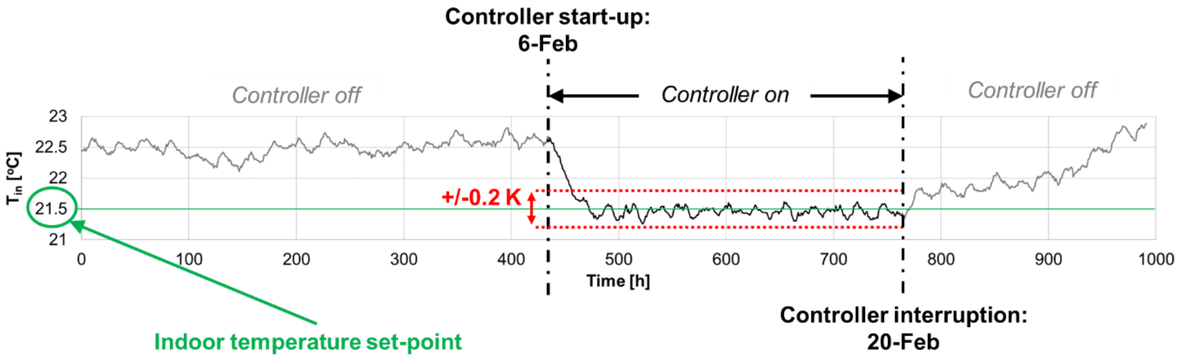

Figure 5: Indoor temperature profile during the control demonstration

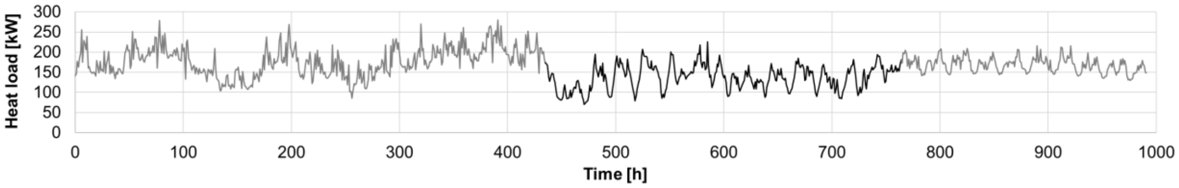

Figure 6: Heat load profile during the control demonstration

4. Conclusions

A flexible, robust, and plug-and-play controller has been developed for creating value out of already available data streams and optimal management in district heating substations. The controller has been proven able to manage a large-scale substation comprising 87 residential apartments and hosted under 8 buildings in the city of Västerås in Sweden. The controller was able to achieve the control targets for the entire period of testing whilst adapting to weather changes. For the case of examination, average indoor temperature was brought to the designated levels of thermal comfort whilst yielding a normalized energy saving of 9%. Most importantly, the proposed system provides controllability and forecasting ability to operators whilst offering enhanced thermal comfort to the end-users.

List of references

Joakim Örneskans, Konstantinos Kyprianidis, Stavros Vouros and Gunnar Bengtsson, 2023, “An Embedded Industrial Control Framework for Model Predictive Control of A District Heat Substation”, 64th International Conference of Scandinavian Simulation Society, Västerås, Sweden, September 26-27, 2023.

Stavros Vouros and Avinash Renuke, 2023, “Smart control in district heating: implementation, challenges, and opportunities”, 64th International Conference of Scandinavian Simulation Society, Västerås, Sweden, September 26-27, 2023.