A bilevel approach to model-based control of supply temperature and velocity in district heating grids

Magnus Hamann Poulsen, Tobias Rønlev-Knudsen, Jan Kloppenborg Møller, Henrik Madsen, Tobias K. S. Ritschel

Department of Applied Mathematics and Computer Science, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark (e-mail: tobk@dtu.dk)

Abstract: District heating grids supply hot water to consumers through an interconnected grid of pipes in the ground. Typically, the water is supplied to the grid with a constant temperature regardless of the expected heat demands of the consumers. However, heating demands typically show clear diurnal patterns, and there is a significant potential to reduce the energy consumption of the heating plant in periods where demand is low. It is not straightforward to exploit this potential because of the significant time delays between the heating plant and the consumers. Furthermore, both the supply temperature and the supply velocity are manipulated variables, and the latter affects the time delays, which complicates the controller design. In this work, we use an energy balance based on convection and heat loss to describe the heat flow through a grid of pipes, and we use a finite volume method with upwinding to discretize the equations. The resulting model consists of linear parameter-varying ordinary differential equations where the system matrices only depend on the supply velocity. Therefore, we can derive an analytical control law for an offset-free (disturbance-adaptive) model predictive control (MPC) algorithm, and we use the stationary distribution of the resulting closed-loop system in a robust economic multi-stage real-time optimization algorithm to determine both the supply velocity and temperature setpoints for the MPC algorithm. Finally, we demonstrate the efficacy of the proposed approach in a numerical example involving the AROMA network.

Keywords: Model predictive control, real-time optimization, stochastic control, district heating, flexible operation.

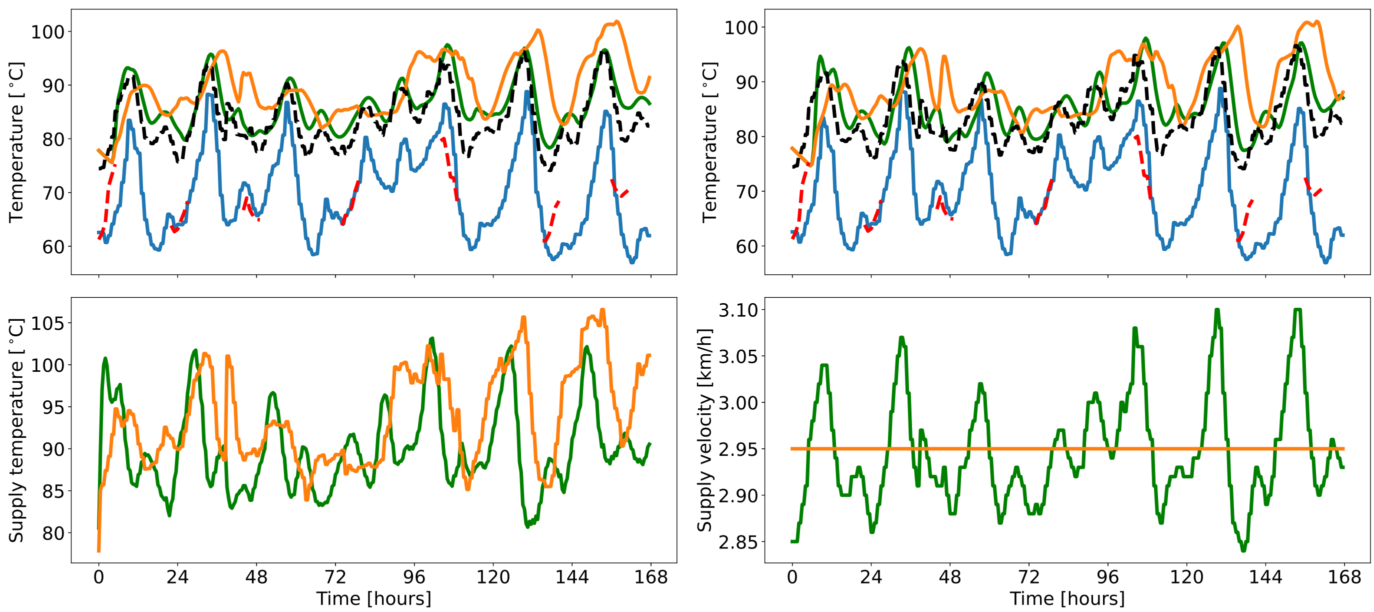

Fig. 1. Top row: The temperatures at the consumer nodes (i.e., the outputs) for the proposed approach (green) and for a rule-based reference control law (orange), a forecast-based lower bound (black), the forecasts that the black bounds are based on (red), and the consumers' required temperature (blue). Bottom row: The supply temperature and velocity for the proposed approach (green) and the rule-based control law (orange).

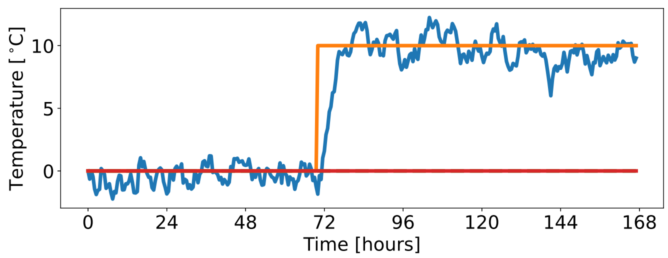

Fig. 2. The true (orange), nominal deterministic estimate (red), and adaptive estimate (blue) of the ambient temperature around the pipes.