Model-based Building Energy Management System with User Feedback in the Loop

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Area 2.2 Automation and Control

Motivation

Buildings consume 30% of the world's final energy and contribute 19% to indirect emissions, see [1]. Air-conditioned offices have a high energy footprint. Retrofitting buildings with predictive control strategies can lower energy demand and increase comfort by considering future weather. Infrastructure and user feedback are challenges in achieving these goals.

Energy Management System

Optimization-based energy management systems (EMS) are a high-level control approach for energy systems like district heating networks [2]. A descriptive model and objective function are required to solve an optimization problem and apply the resulting schedule in a receding horizon fashion. EMS for buildings require **a simplified model of each thermal zone**, and the objective function includes costs for heating and cooling, virtual costs, and a comfort model. **Feedback from users** is necessary since thermal comfort varies among individuals.

Building Model

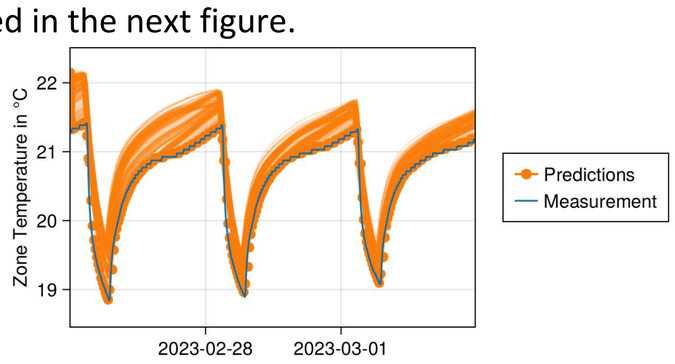
For the model of the thermal zones, a **grey-box approach** is used

$$\frac{dT_\mathrm{z}}{dt} = k_{\mathrm{w,z}}(T_\mathrm{w} - T_\mathrm{zone}) + k_{\mathrm{floor,z}}(T_\mathrm{floor} - T_\mathrm{z}) + \boldsymbol{k}_{sol}^T \boldsymbol{I}_\mathrm{g} + d$$

$$\frac{dT_\mathrm{w}}{dt} = k_{z,floor}(T_z - T_\mathrm{w}) + k_{\mathrm{amb,w}}(T_\mathrm{amb} - T_\mathrm{w})$$

$$\frac{dT_\mathrm{active}}{dt} = k_{\mathrm{z,active}}(T_\mathrm{z} - T_\mathrm{active}) + k_\mathrm{h}(T_\mathrm{feed} - T_\mathrm{active})u_\mathrm{h} + k_\mathrm{c}(T_\mathrm{feed} - T_{active})u_\mathrm{c}$$

where T_z, T_w and T_active is the temperature of the zone, the wall and the active element, respectively. As external influences the ambient temperature, solar radiation and internal loads are considered. An **unscented Kalman filter (UKF)** handles the simultaneous state and parameter estimation. The quality of the prediction is depicted in the next figure.



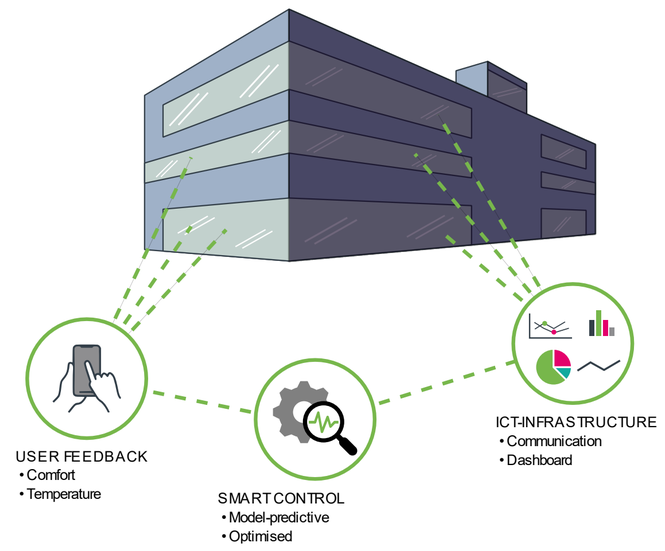
Predicted zone temperature for the cellar for the next 48 h, with a dot indicating the now-cast. Each morning the ventilation is switched on for 3 h, resulting in a considerable drop of the temperature.

User Feedback Integration

A model-based approach is used for incorporating the user feedback in the EMS. A comfort model is calibrated, based on the actual users. For this, a simple **web-based feedback system**, with a five-point Likert scale (“much too cold”, “too cold”, “pleasant”, “too warm” “much too warm”), is used. The feedback is viewed as measurements from the internal comfort model, and an UKF updates its parameters.

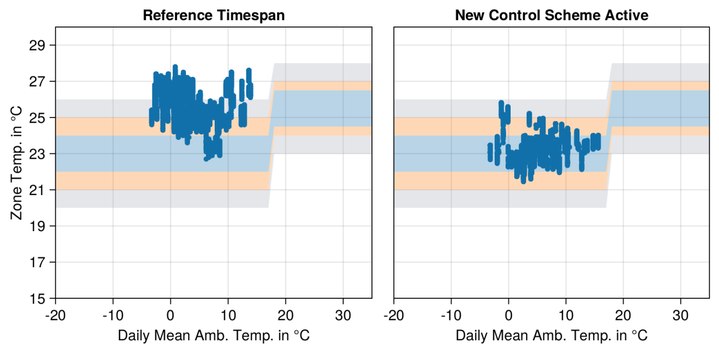
Case Study

As a case study an **office building at the INNOVATION DISTRICT Inffeld**[3] is considered. The proposed Predictive control strategy, together with the user feedback is implemented. A central information and communication technology (ICT) handles all communication with the building automation system.



Schematic view of the building energy management system for Inffeldgasse 21b. The main components are the EMS, the user feedback integration and the ICT-infrastructure.

Each floor is actuated with only one valve and the temperature measurements from only one sensor per floor are collected. The combination with the user feedback is especially helpful in this case, since the feedback can be viewed as qualitative measurement, functioning as additional feedback in the control loop. The control scheme is running since 2022-11-20. A comparison of the zone temperature of the first floor is depicted next.



Zone temperature of the first floor for the new control scheme and a reference timespan (same timespan the year before) with the old control scheme.

The zone temperature shows **less overheating** (23 - 25°C vs. 25 - 27°C) with the new control scheme as in the reference timespan.

Conclusion

- A prediction control scheme for thermal control of office buildings is implemented.
- The UKF-based approach for the parameter estimation minimizes the needed commissioning effort of the system.
- Model-based handling of user feedback ensures that the wellbeing of the users is considered explicitly in the control scheme.

Literature

[1] IEA, “Buildings,” 2022. [Online]. Available: https://www.iea.org/reports/buildings.
[2] V. Kaisermayer, J. Binder, D. Muschick, G. Beck, W. Rosegger, M. Horn, M. Gölles, J. Kelz and I. Leusbrock, “Smart control of interconnected district heating networks on the example of “100% Renewable District Heating Leibnitz”,” Smart Energy, vol. 6, 5 2022.
[3] https://www.tugraz.at/tu-graz/universitaet/klimaneutrale-tu-graz/innovation-district-inffeld

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