Karlsruhe Institute of Technology

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

Institute for Automation and Applied Informatics (IAI)

Building Modeling and Control for Occupant Thermal Comfort

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Motivation

- The electrification of the building heating sector contributes to the decarbonization efforts, under the condition that a significant proportion of the power grid consists of renewables.
- The integration of renewable energy sources into existing electricity grids presents a considerable challenge in terms of aligning power consumption with the intermittent nature of these energy sources.
- A reliable and easy-to-configure modular building model can not only perform detailed calculations and analyses of the thermodynamic behavior of a building, but also combine the energy systems of the building for energy management and co-simulation considering occupants' comfort.
- Advanced thermal controls, as part of demand response, have great potential to reduce energy consumption in buildings while maintaining occupant thermal comfort at desired levels.

Bottom-up Modular Modeling of Integrated Energy Districts

Modularized Generic Building White-Box Model with Electrical, Heat and Gas Grid Interfaces

- For simulation and analysis of district energy systems, it is critical to use generic, flexible, and reliable building models.
- The modular nature [1] of the white-box model makes it possible to extract and analyze detailed intermediate variables, which will greatly improve the compatibility of external controllers.
- The model contains a variety of indoor heating equipment, electrical equipment, gas equipment, and corresponding interfaces. By exporting the model to FMU format, the building model can be co-simulated with a variety of energy networks, including heat, power, and natural gas grids.

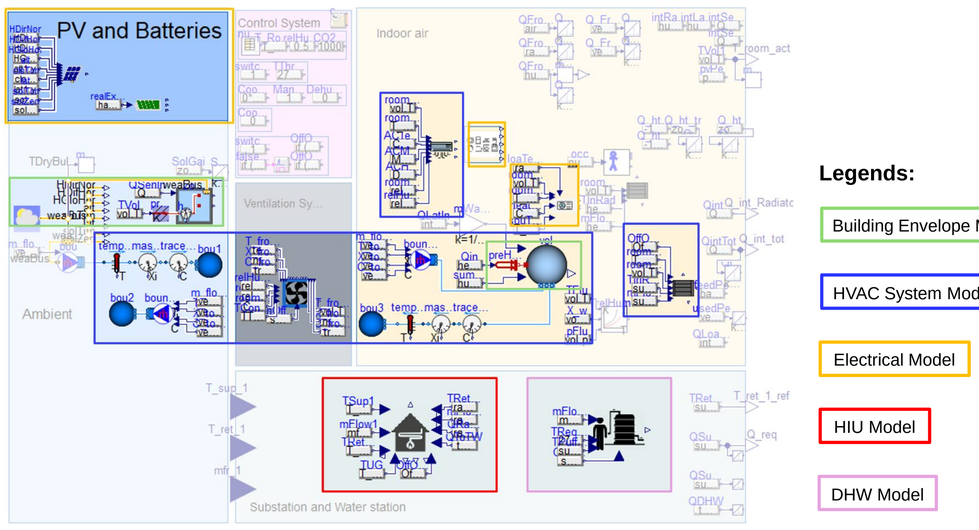

Figure 1: Generic modular white box building model using Modelica [2].

Modeling of District Heat and Low Voltage Grids with Multiple Heating Center Variants

- Simulation models of the heat grid pipelines, heating centers [3], heat interface units, power grid, and modular and highly parameterizable building models (shown in Fig. 1) are developed by using Modelica-based modeling.
- Economic and sustainable advices for heating center configuration from the perspective of the heat grid operator are provided.
- Through the coupling with the low-voltage power grid model, the behavior of the electricity consumption, solar power generation, and battery storage of district buildings can be reflected.

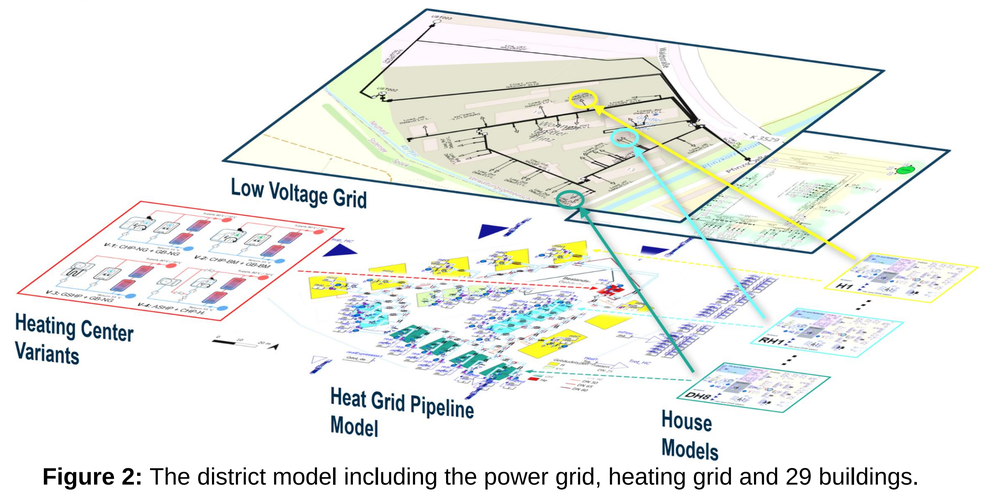

Figure 2: The district model including the power grid, heating grid and 29 buildings.

[1] Cheng, Haozhen, et al. "Economy and sustainability analysis with a novel modular configurable multi-modal white-box building model," ANNSIM'25, in print.

[2] Cheng, Haozhen, et al. "Construction and Control of Validated Highly Configurable Multi-Physics Building Models for the Sustainability Analysis of Multi-Energy Systems in a Co-Simulation Setup," SoutheastCon 2025, 2025.

[3] Cheng, Haozhen, et al. "New Co-Simulation Variants for Emissions and Cost Reduction of Sustainable District Heating Planning," 2024 IEEE PES 16th Asia-Pacific Power and Energy Engineering Conference (APPEEC), 2024.

Ensuring Thermal Comfort Within Demand Response

Grey-Box Models for Prediction and Testing of Thermal Building Control Algorithms

- The performance of predictive building models plays an important role in an effective model-predictive control (MPC) of indoor air temperature.
- The outside temperature, solar radiation, occupant behavior, opening of windows, etc. have a major influence on the prediction of the grey-box building models.
- An ensemble of grey-box building models is designed to improve the robustness against different user patterns (week and weekend) in commercial buildings.

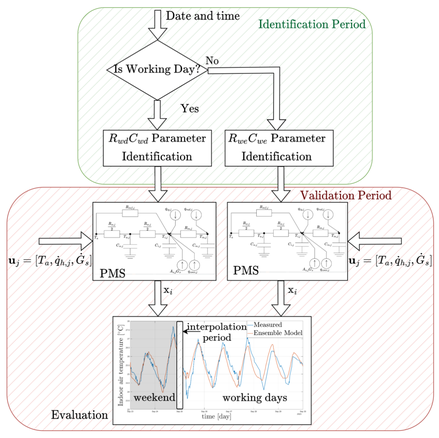

Figure 3: Identification and validation process of ensemble model [4].

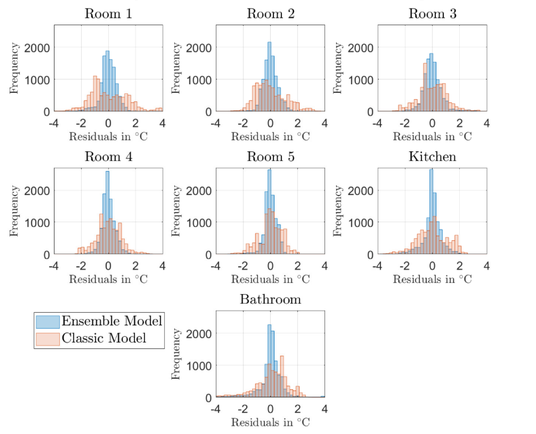

Figure 4: The residual histograms of classical and ensemble model for all rooms covered by study [4].

Fuzzy Logic for Temperature Control

- Contrary to the MPC, the rule-based scheduler offers a model-free and forecast-free temperature control solutions. Due to its simplicity, it does not offer an optimal solution, but rather a "good enough" solution.
- Fuzzy Logic Control (FLC), as a rule-based controller, has the potential to improve thermal comfort in buildings while responding to dynamic electricity prices.
- The signals required by the controllers presented in Fig. [5] are: (i) current zone temperature, (ii) set point temperature, (iii) electricity price signal, (iv) coefficient of the performance (COP) of the heat pump.
- Comfort controller considers primarily the thermal comfort of the occupants, while economic combines primarily the COP of the heat pump and electrical prices to reduce the consumption and considers the thermal comfort secondarily.

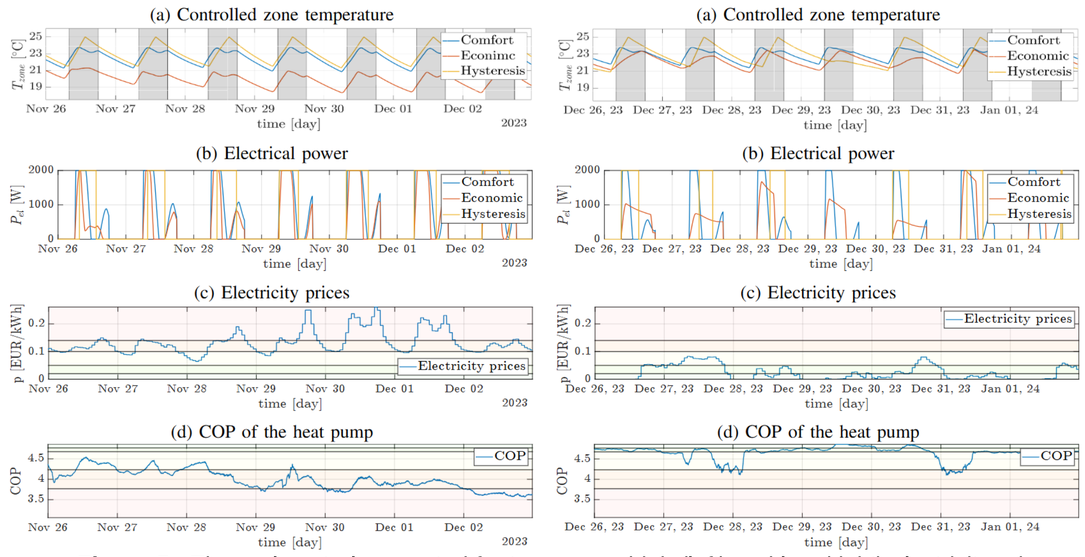

Figure 5: Thermal control presented for two cases: high (left) and low (right) electricity price signals. The efficiency of the heat pump is taken into account. Figure from [5].

[4] Kovačević, Jovana, et al. "Improving Reduced-Order Building Modeling: Integration of Occupant Patterns for Reducing Energy Consumption." Proceedings of the 15th ACM International Conference on Future and Sustainable Energy Systems. 2024.

[5] Kovačević, Jovana, et al. "A fuzzy logic approach for economic energy-efficient heat pump operation in thermal building control." 2024 IEEE PES Innovative Smart Grid Technologies Europe (ISGT EUROPE). IEEE, 2024.

Conclusion

- Incorporating electricity prices and heat pump energy efficiency into thermal building control strategies can have an impact on reducing electricity costs and electrical load when required.
- Combining controllers with validated multi-modal building models allows design and optimization of control strategies and building energy management systems.
- The effective combination of building models, energy network models and controllers can not only provide suggestions for improving residents' user comfort, but also provide guarantees for the efficient operation of the district's integrated energy system and energy management system.