Long-term experimental study of price responsive predictive control in a real occupied single-family house with heat pump

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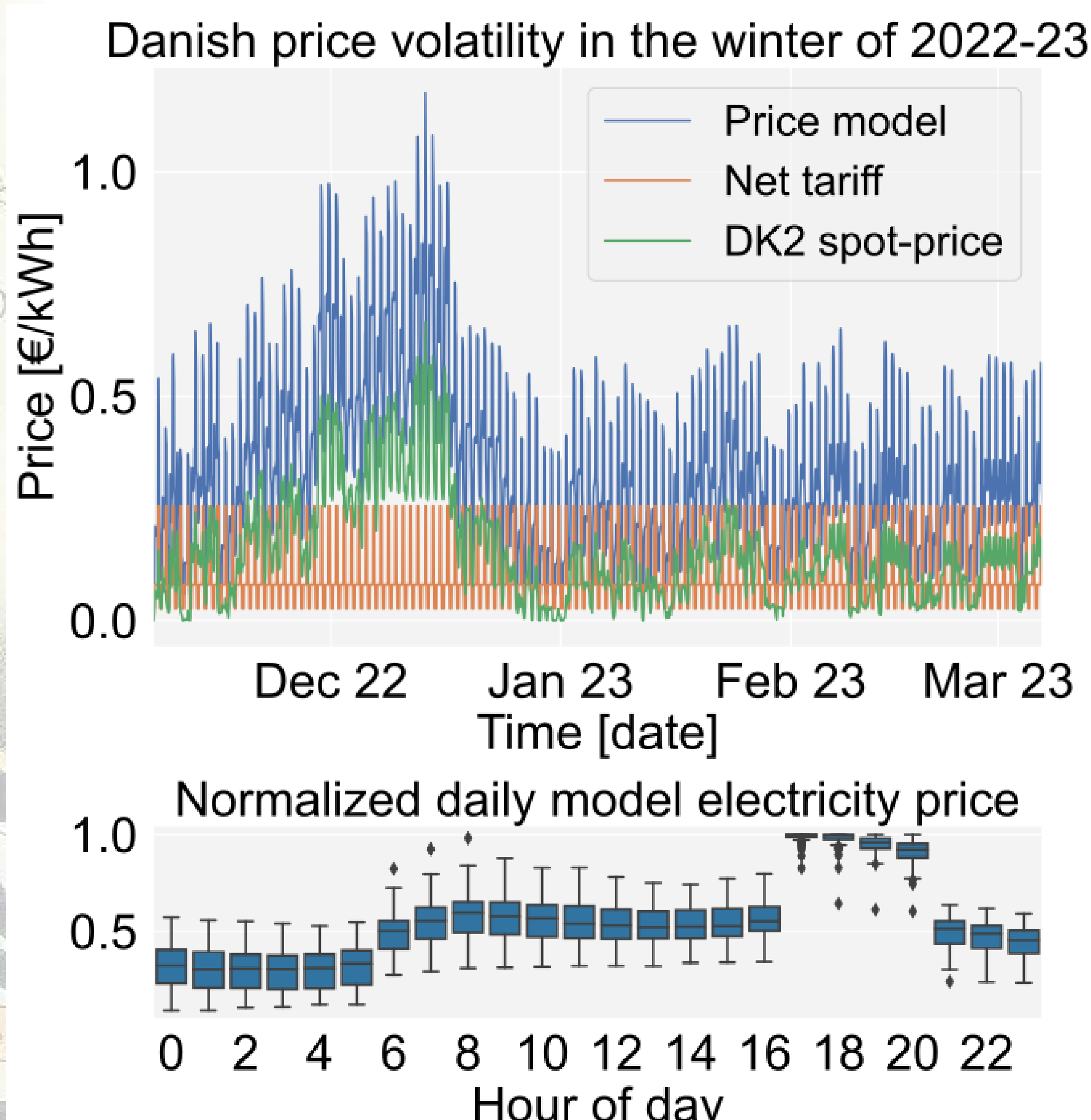
Overview

- Load shifting through demand side management
- *Four-month* experimental study in a near-zero emission *occupied* single-family house in Denmark.
- The control algorithm uses price signals, weather forecast, a single-zone building model, and a non-linear heat pump efficiency model.
- *Cost reduction* from the controller ranging from 2-17% depending on the chosen comfort level.
- Study carried out as part of the EUDP project "OpSys 2.0".

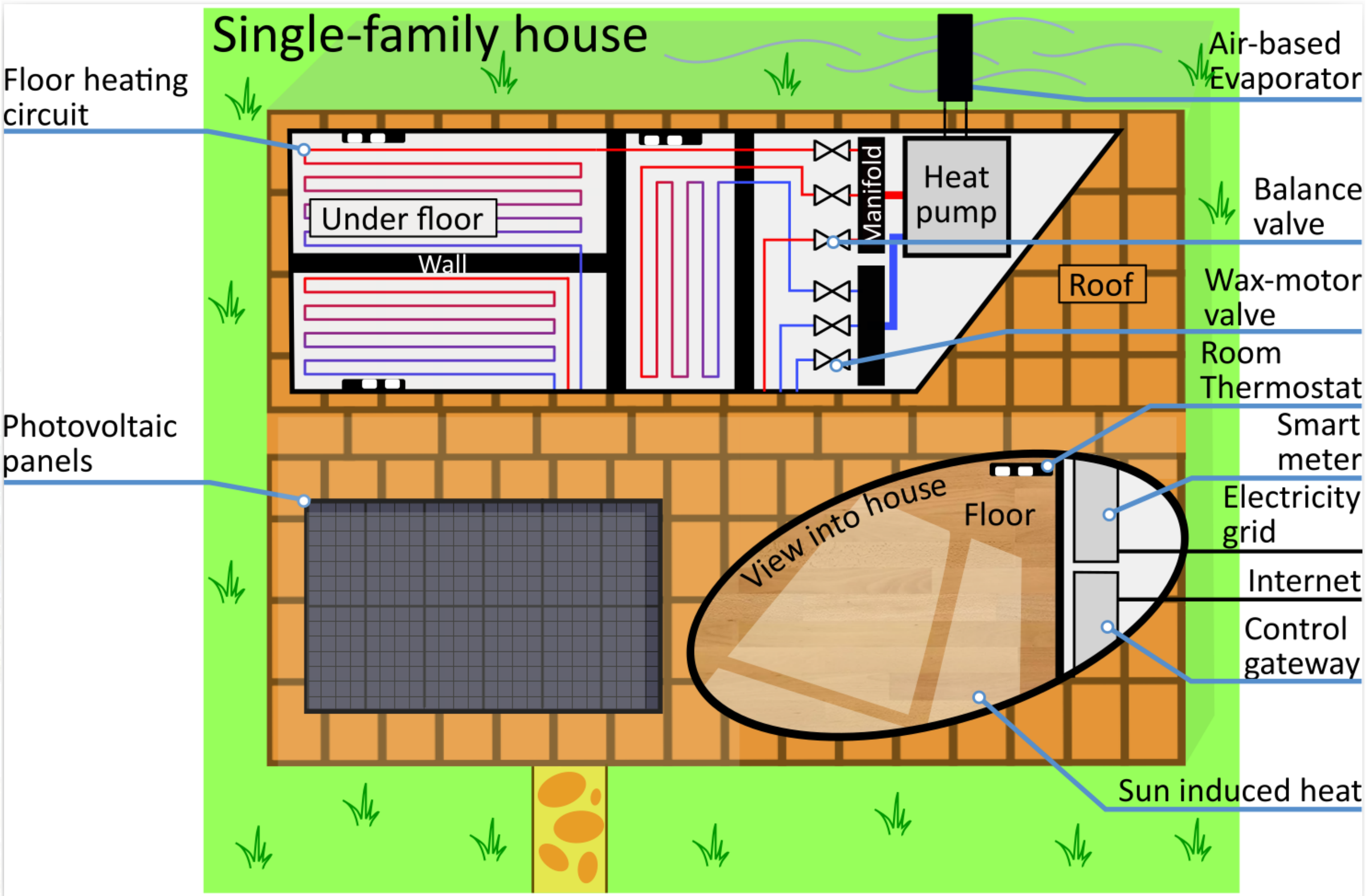
Outline

- Case study
- System setup
- Control architecture
- Main results
- Conclusion

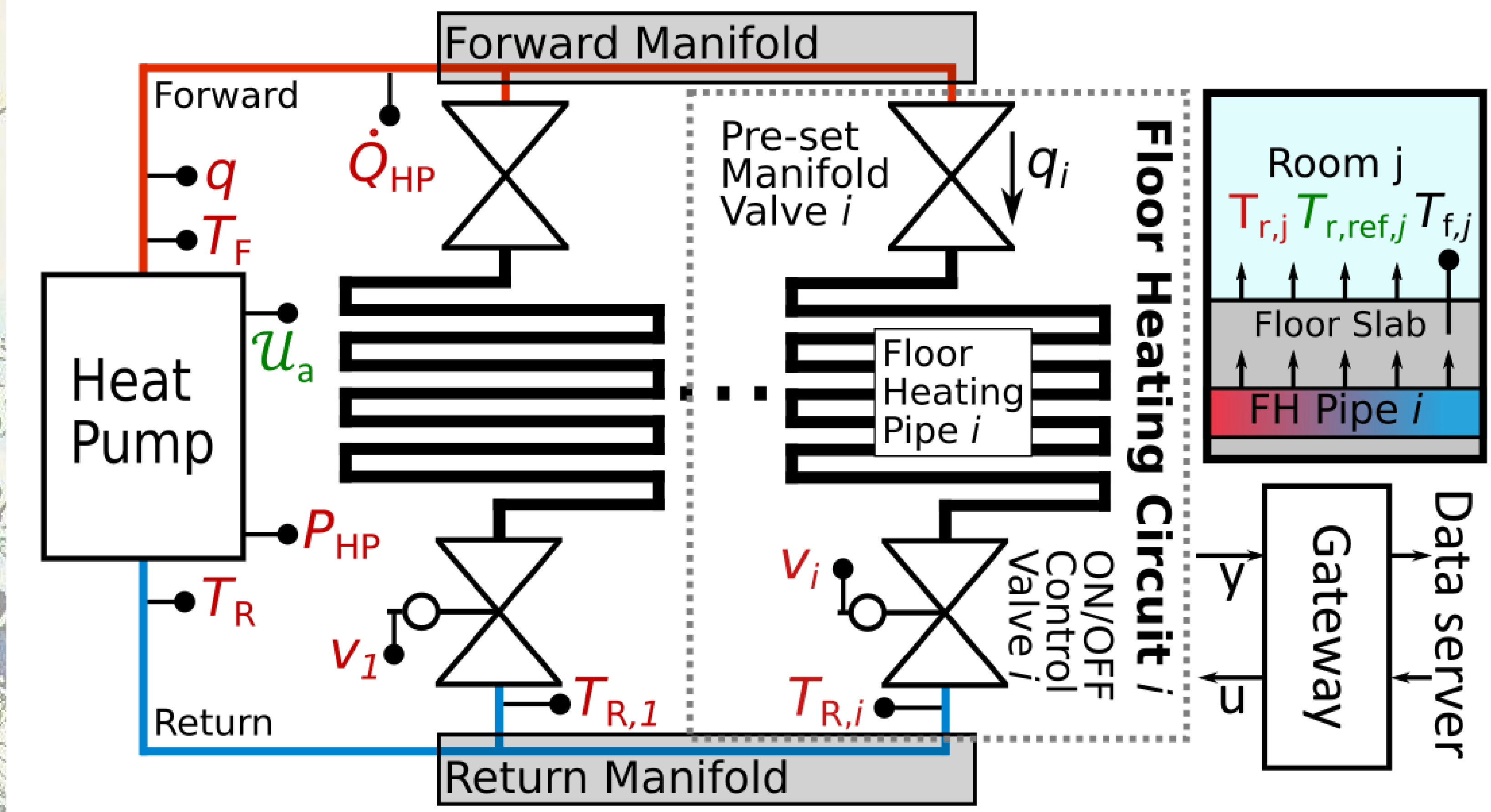
Why care about load shifting?



Case study: Modern low-energy single-family house

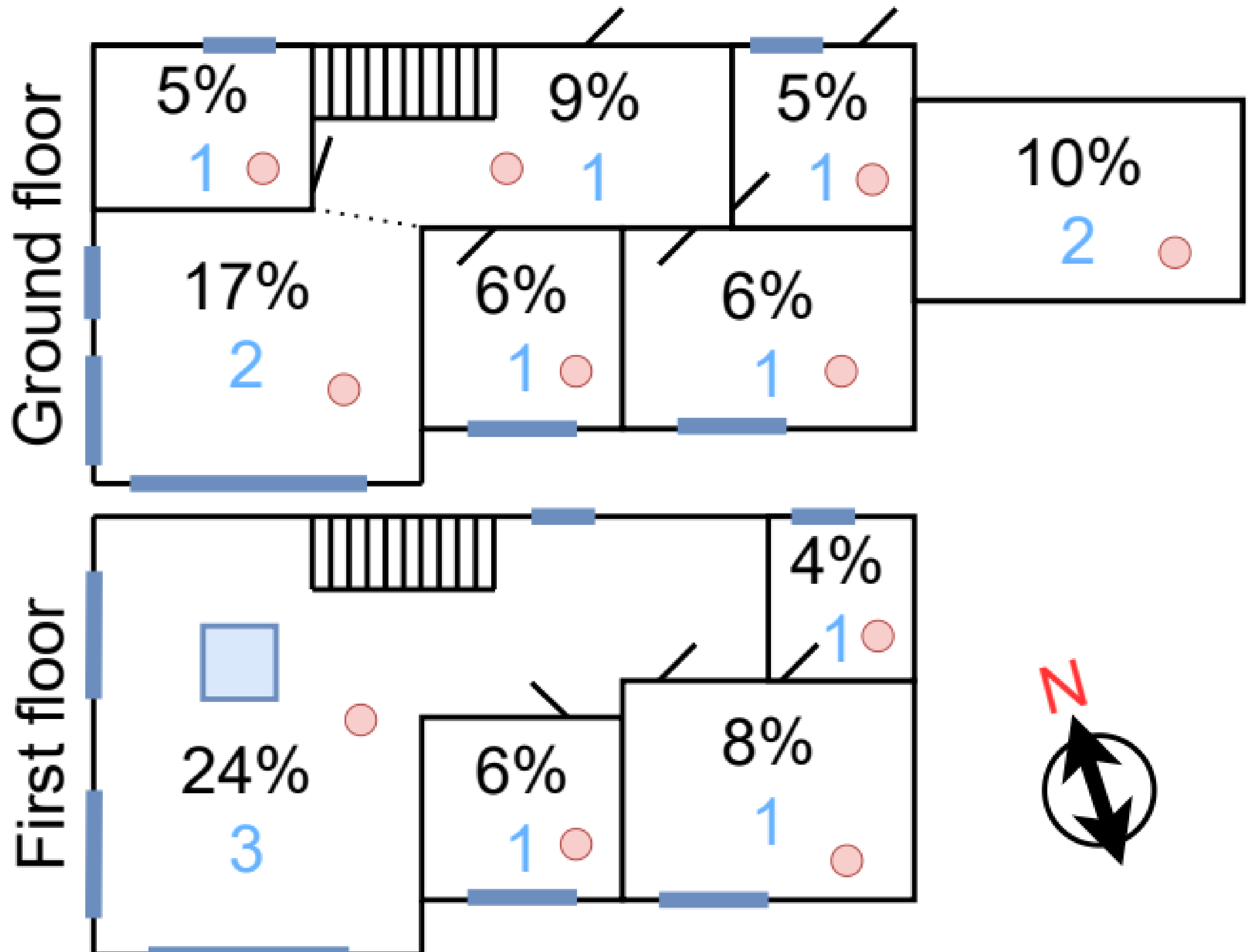


Heating system

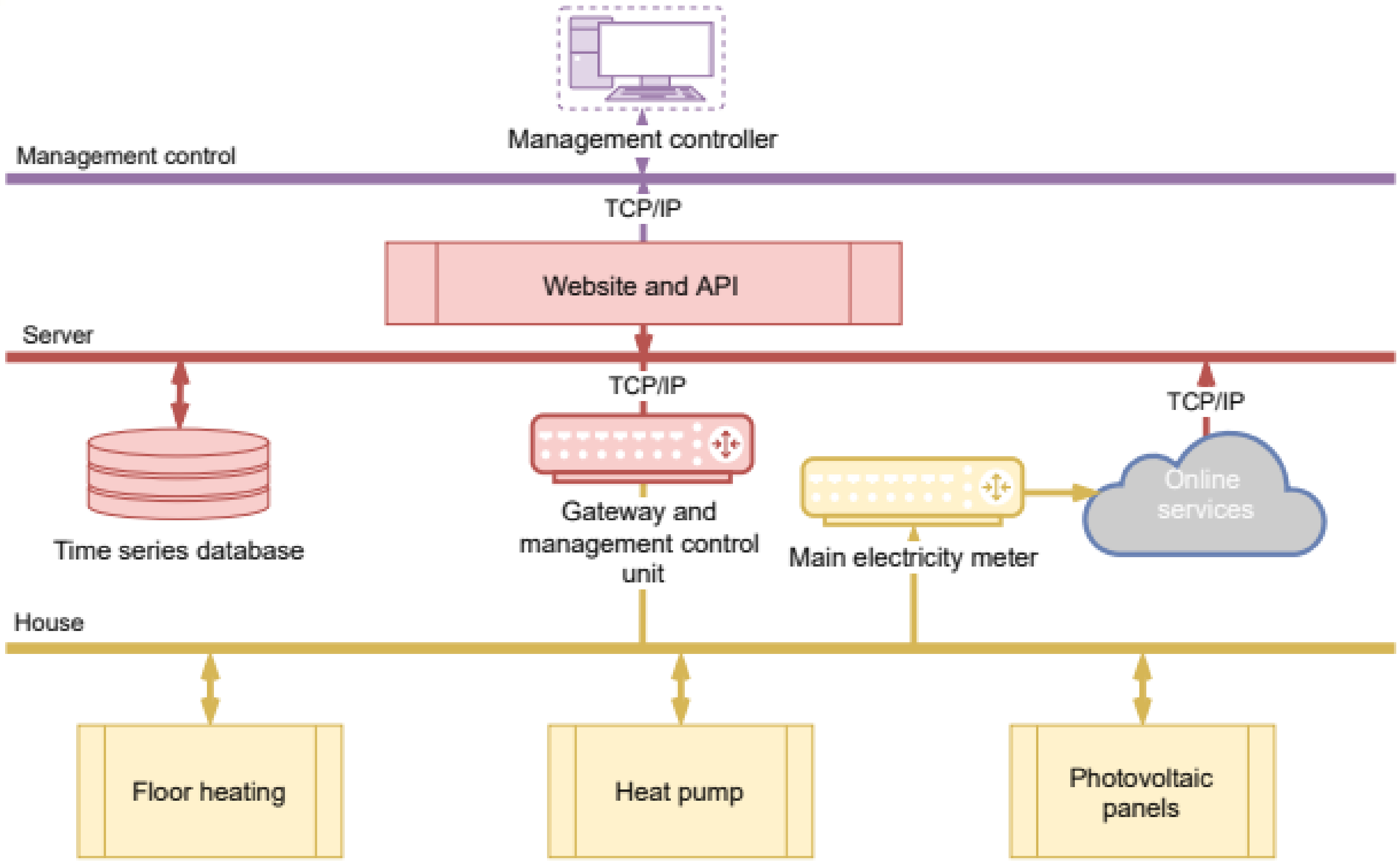


- Heat pump: Bosch Air/water, 7kW capacity
- Floor heating managed by Wavin controller – individual circuit flows governed by ON/OFF valves
- Photovoltaic panels on roof deliver up to 5.5 kW electric power, remaining electricity is supplied from electric grid

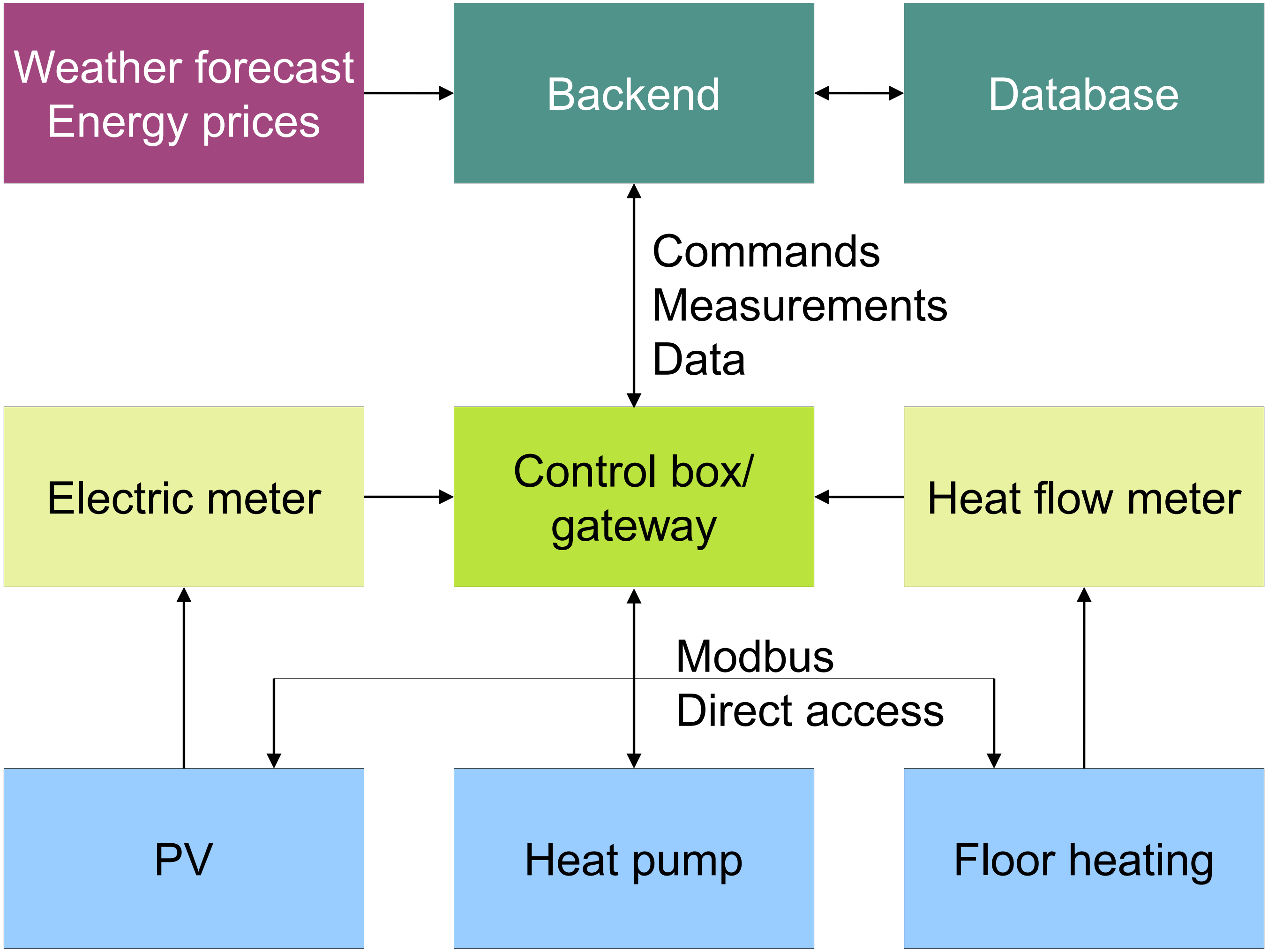
Floor layout



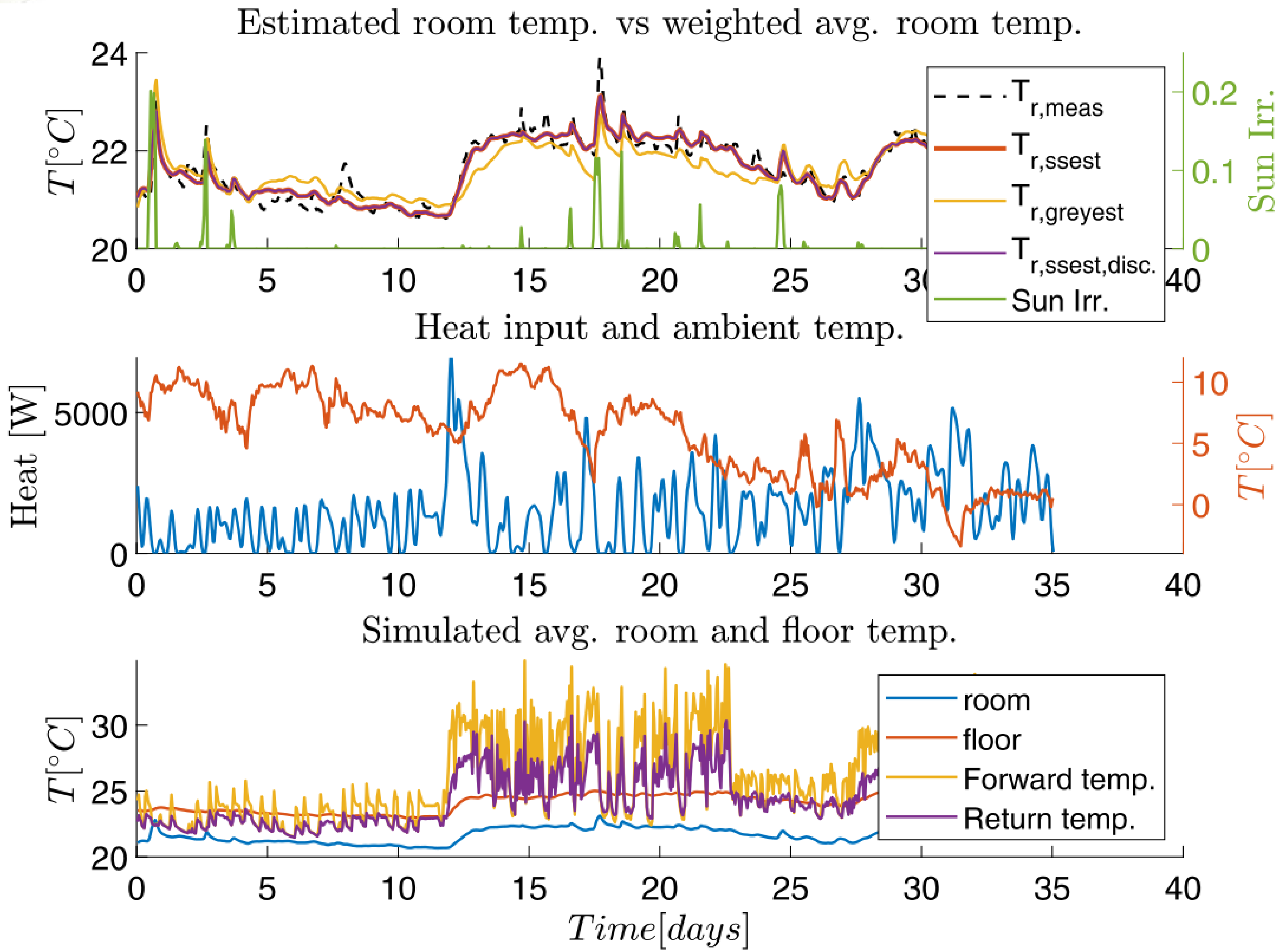
System setup – data management



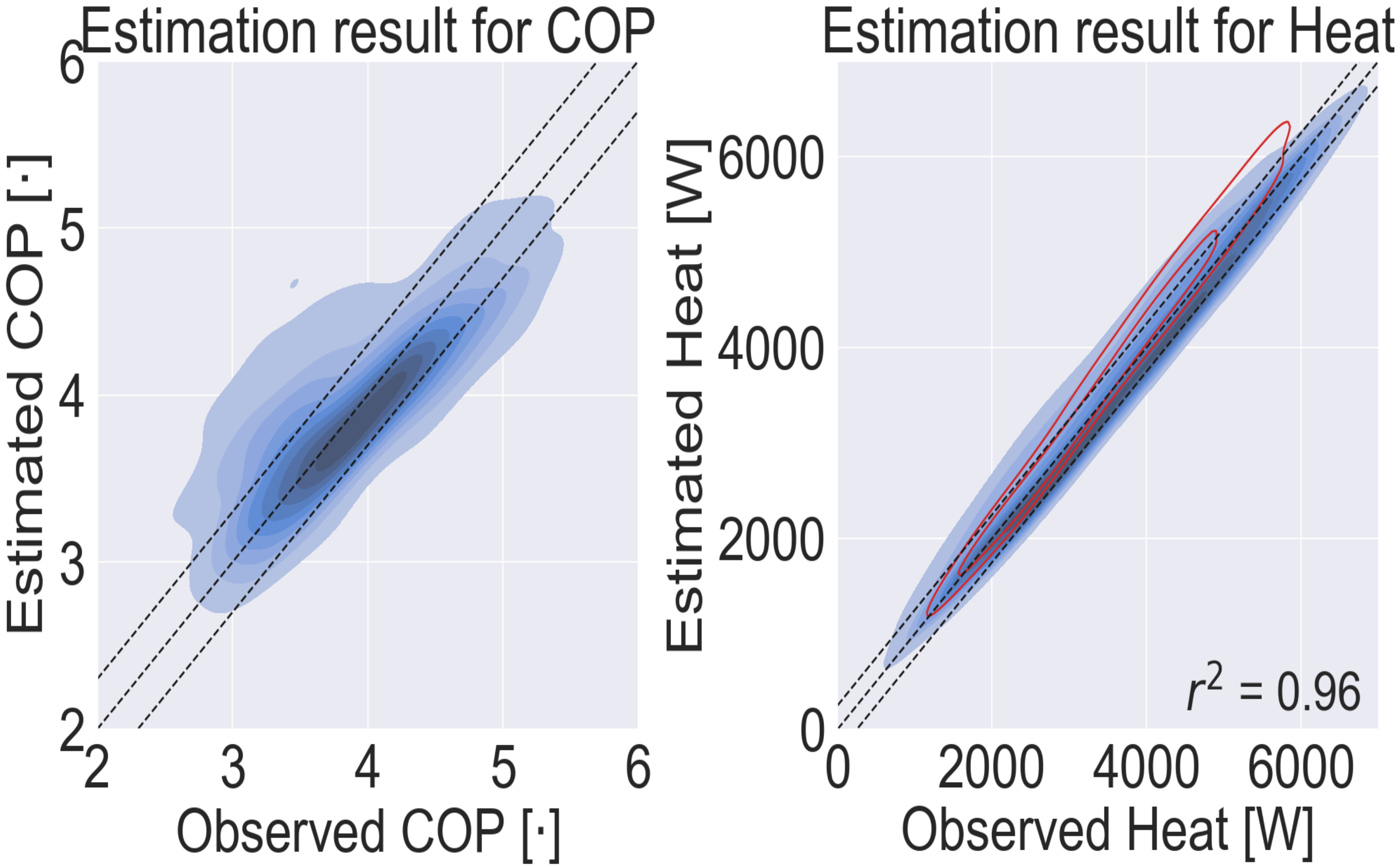
Communication infrastructure



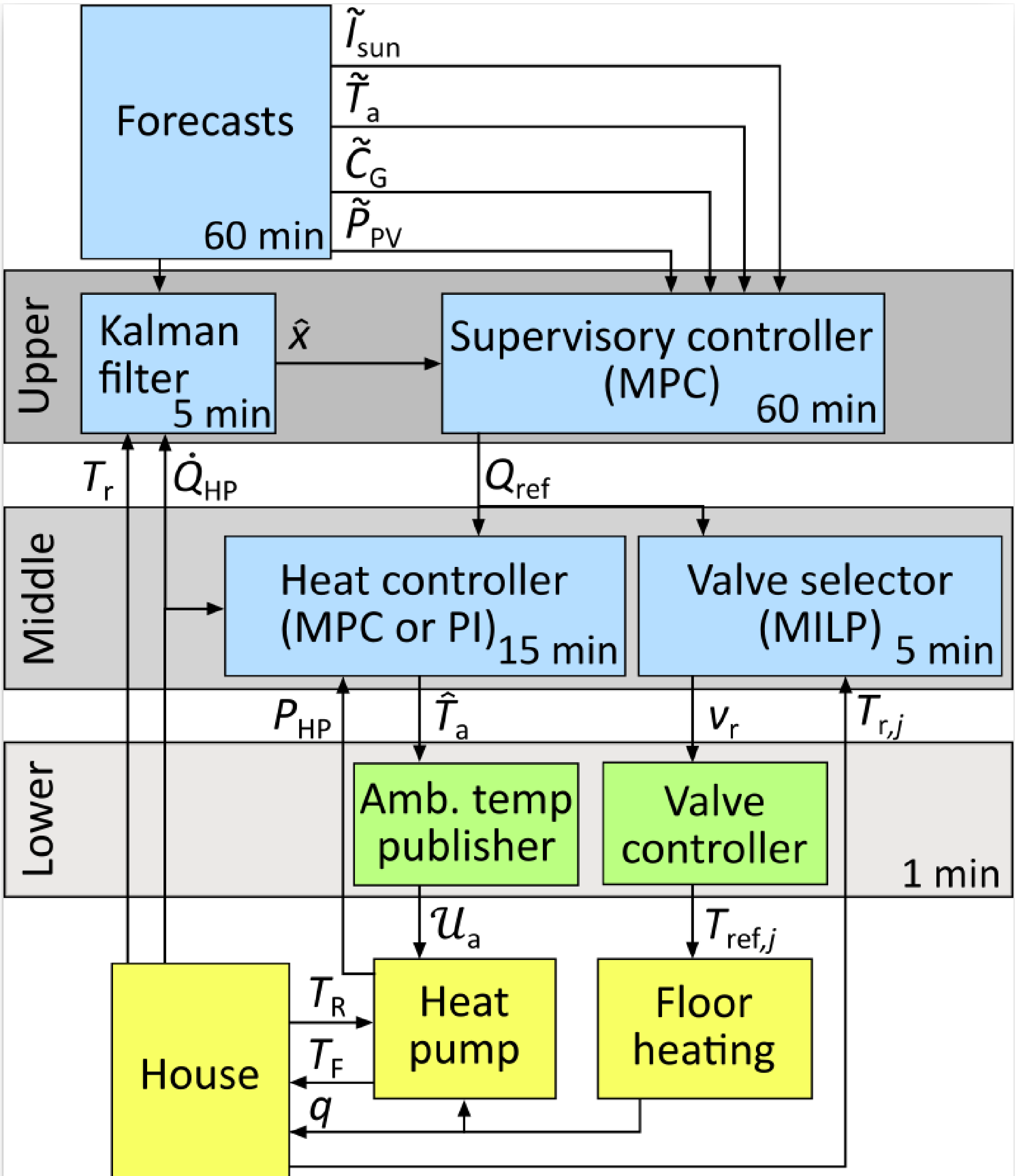
Room temperature model fit



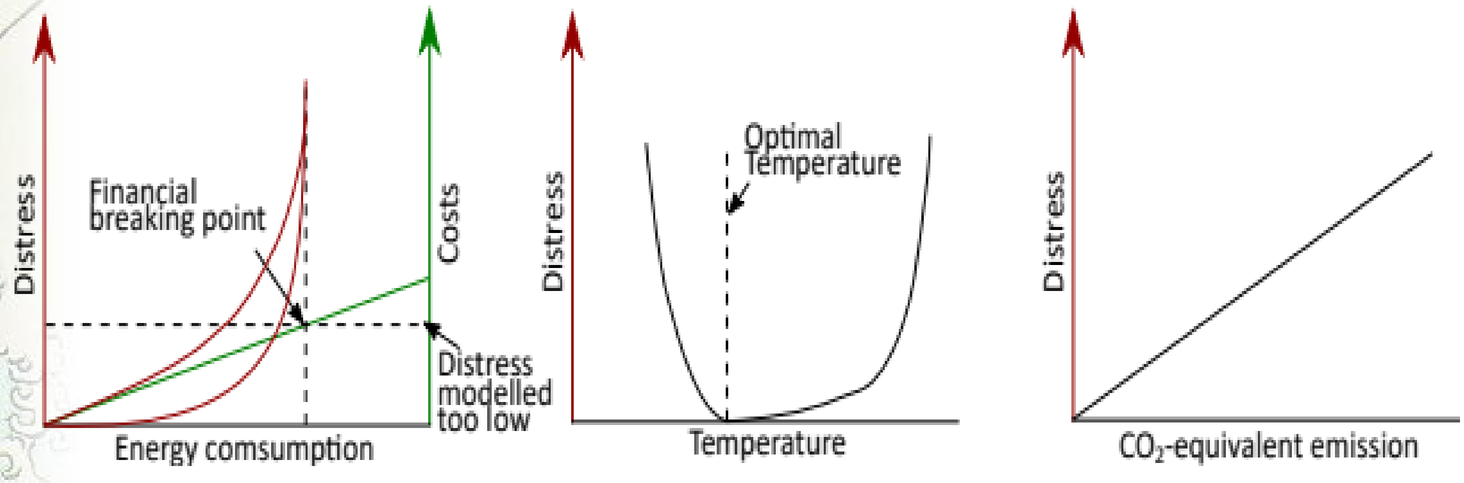
Heat pump model



Control architecture

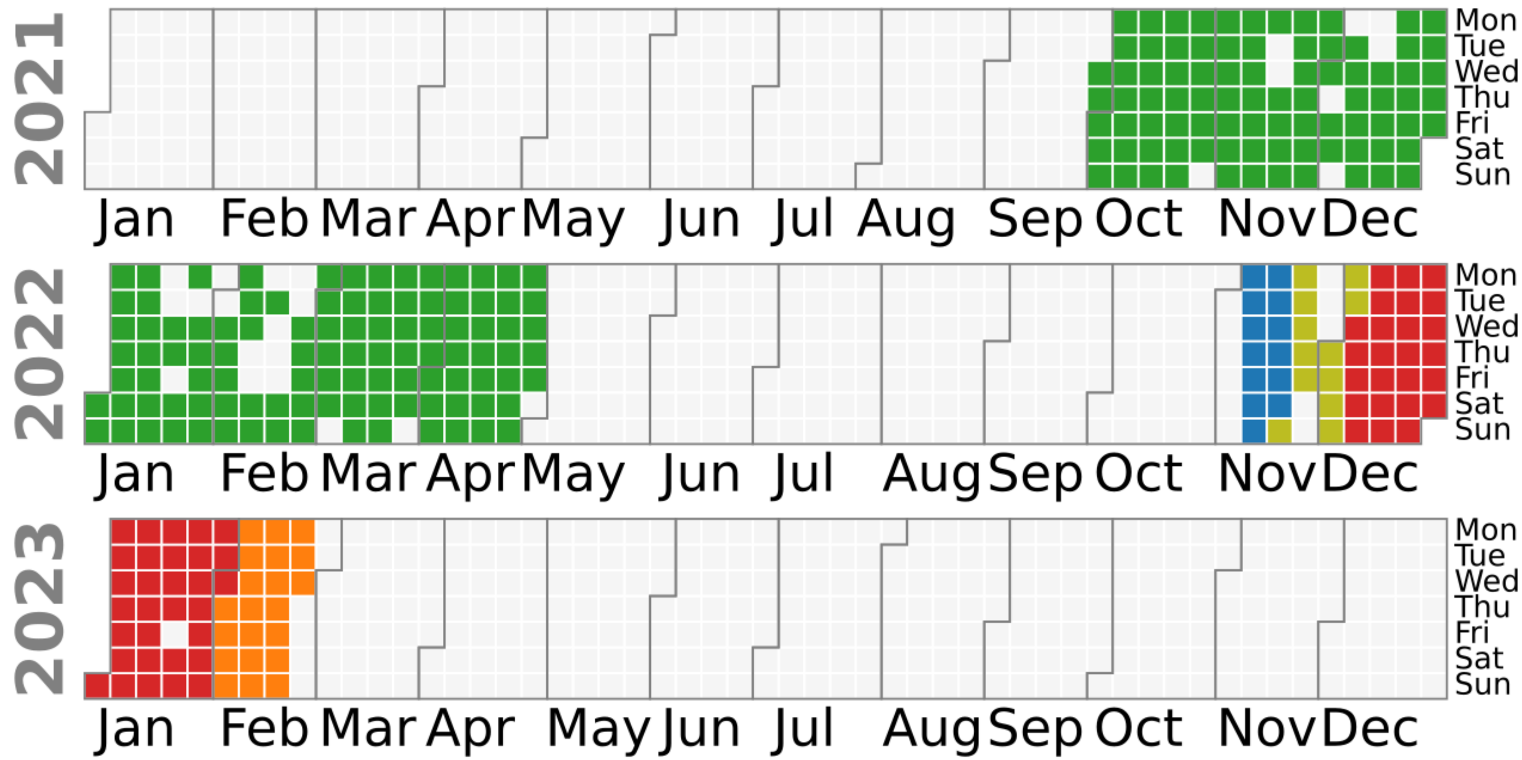


‘Tuning’ supervisory MPC



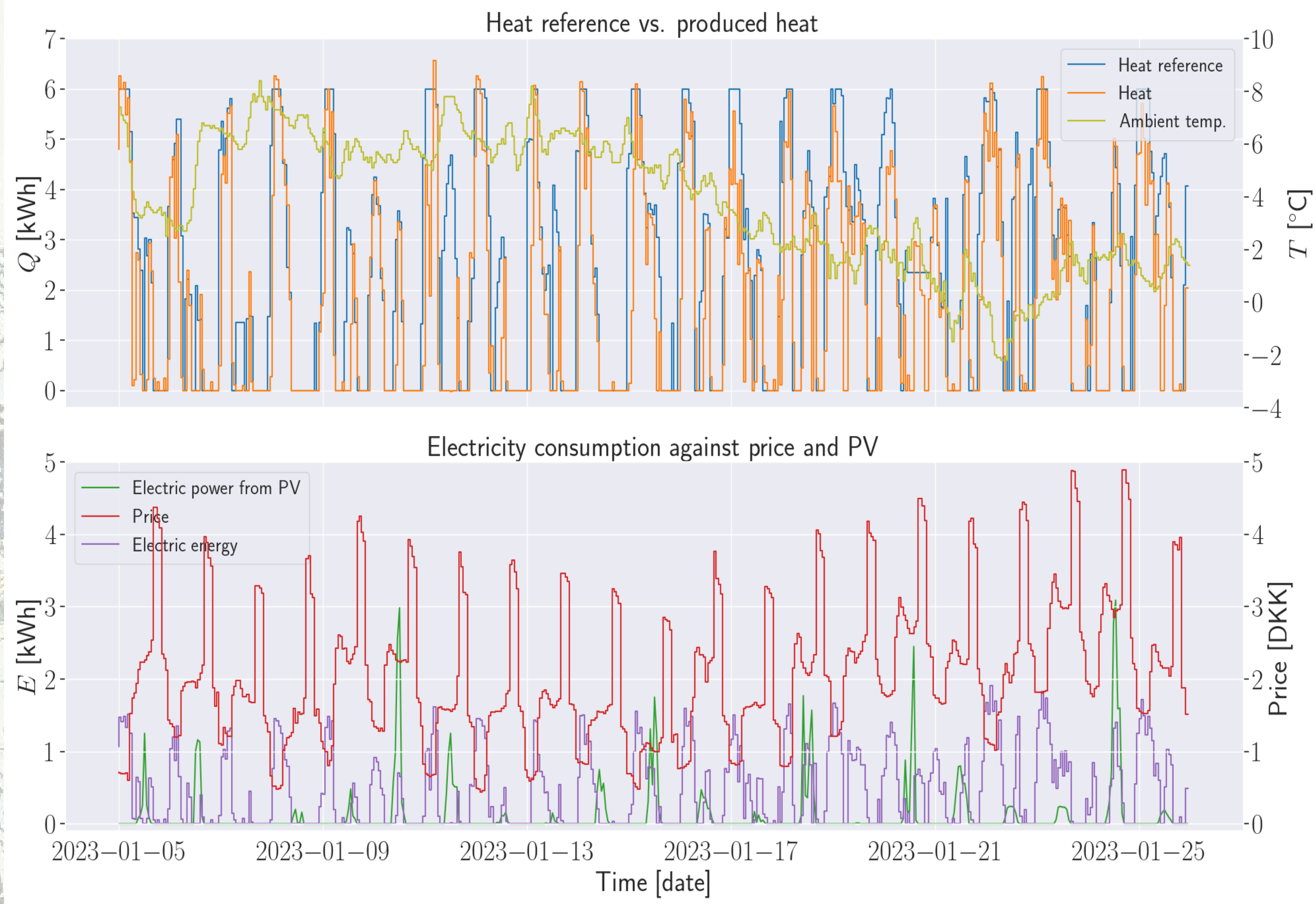
- The supervisory MPC solves a *Mixed Integer/Linear Programming* optimization problem based on a weighted sum of performance curves like the ones shown above.
- Instead of “comfort,” high values indicate “distress.”
- Lower-level controllers manage the actual flows, turning the heat pump ON/OFF, etc.

Experiment and benchmark days

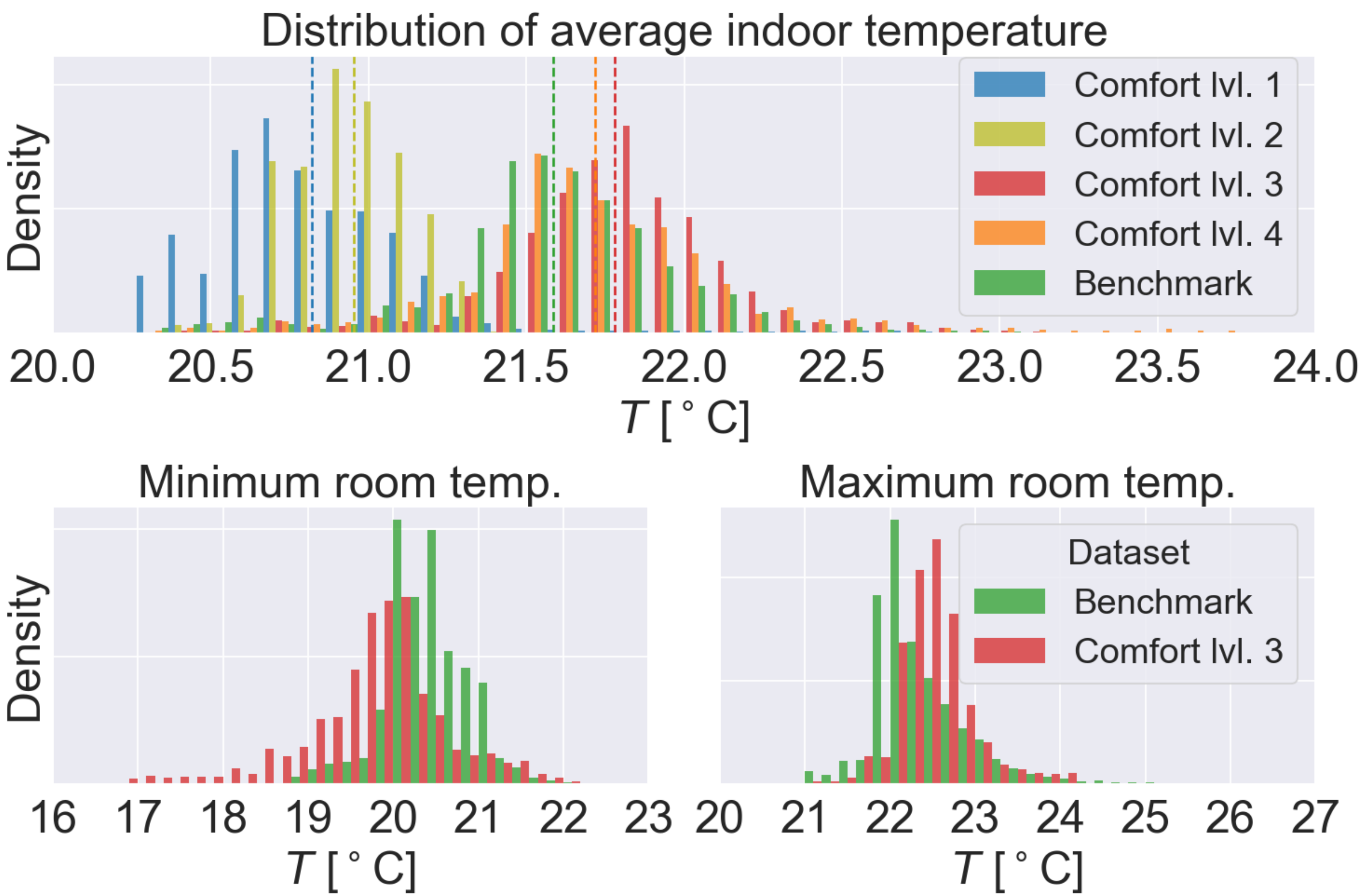


Green – benchmark
Blue – Comfort level 1
Yellow – Comfort level 2
Red – Comfort level 3
Orange – Comfort level 4

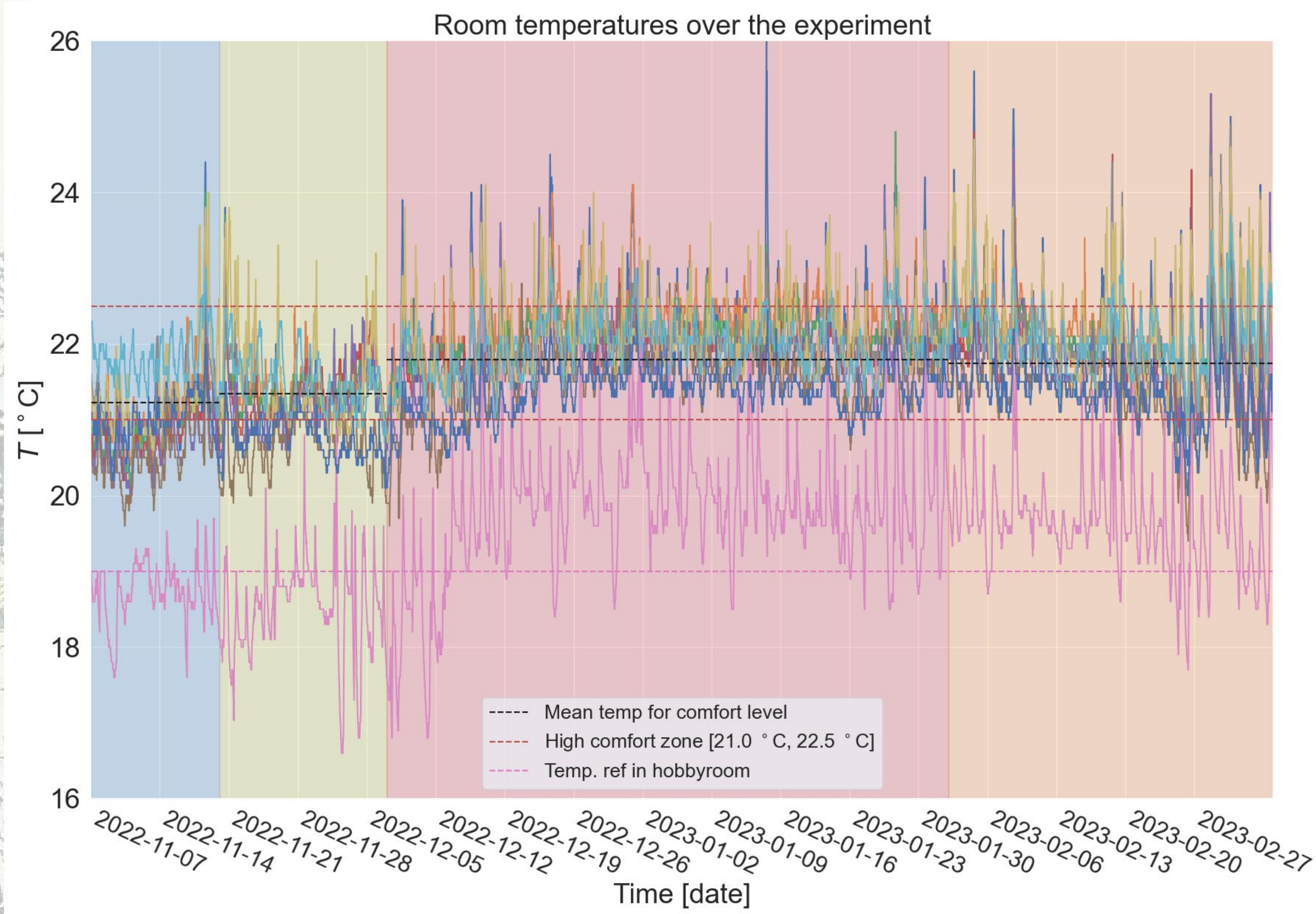
Control performance



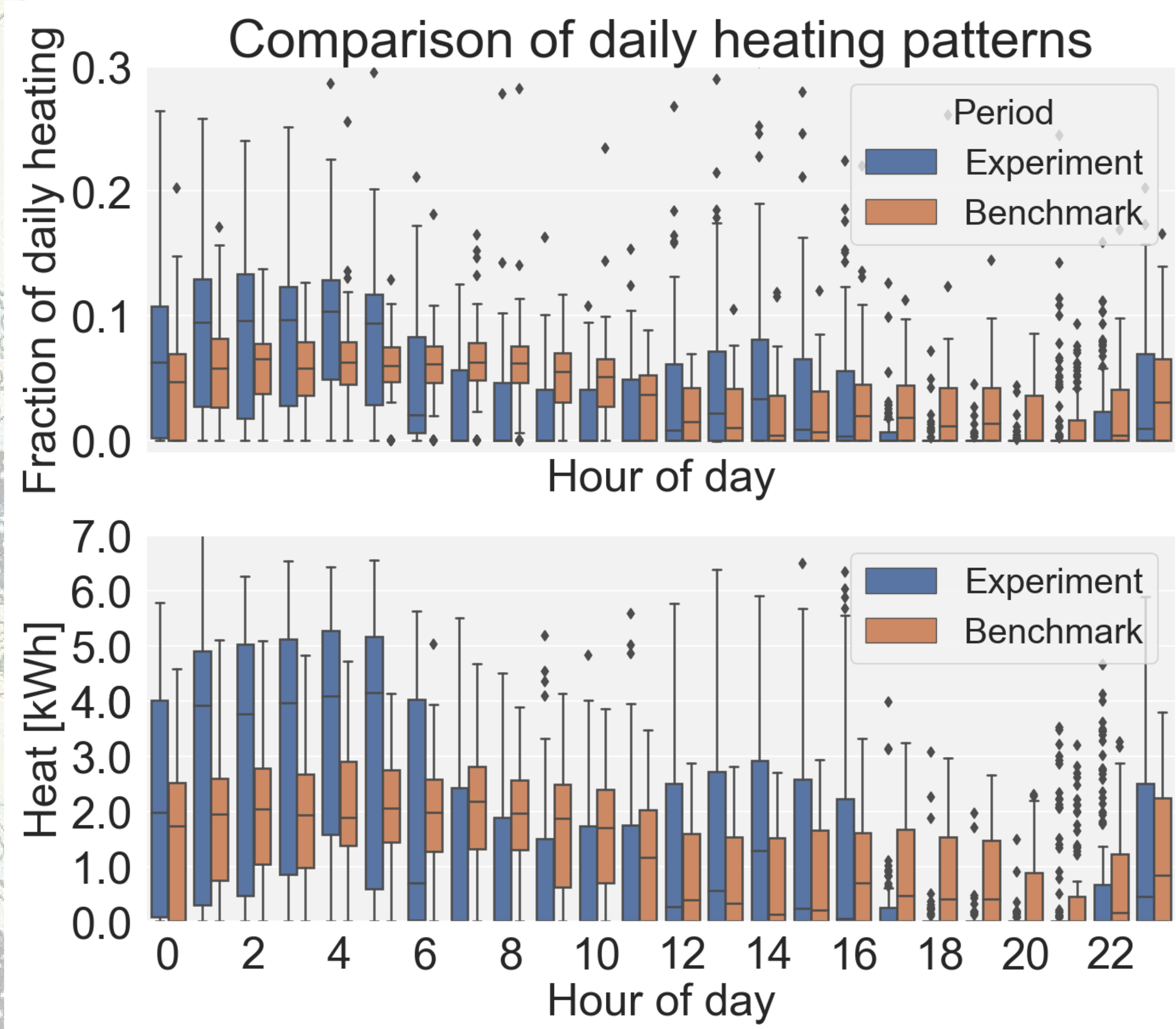
Control performance



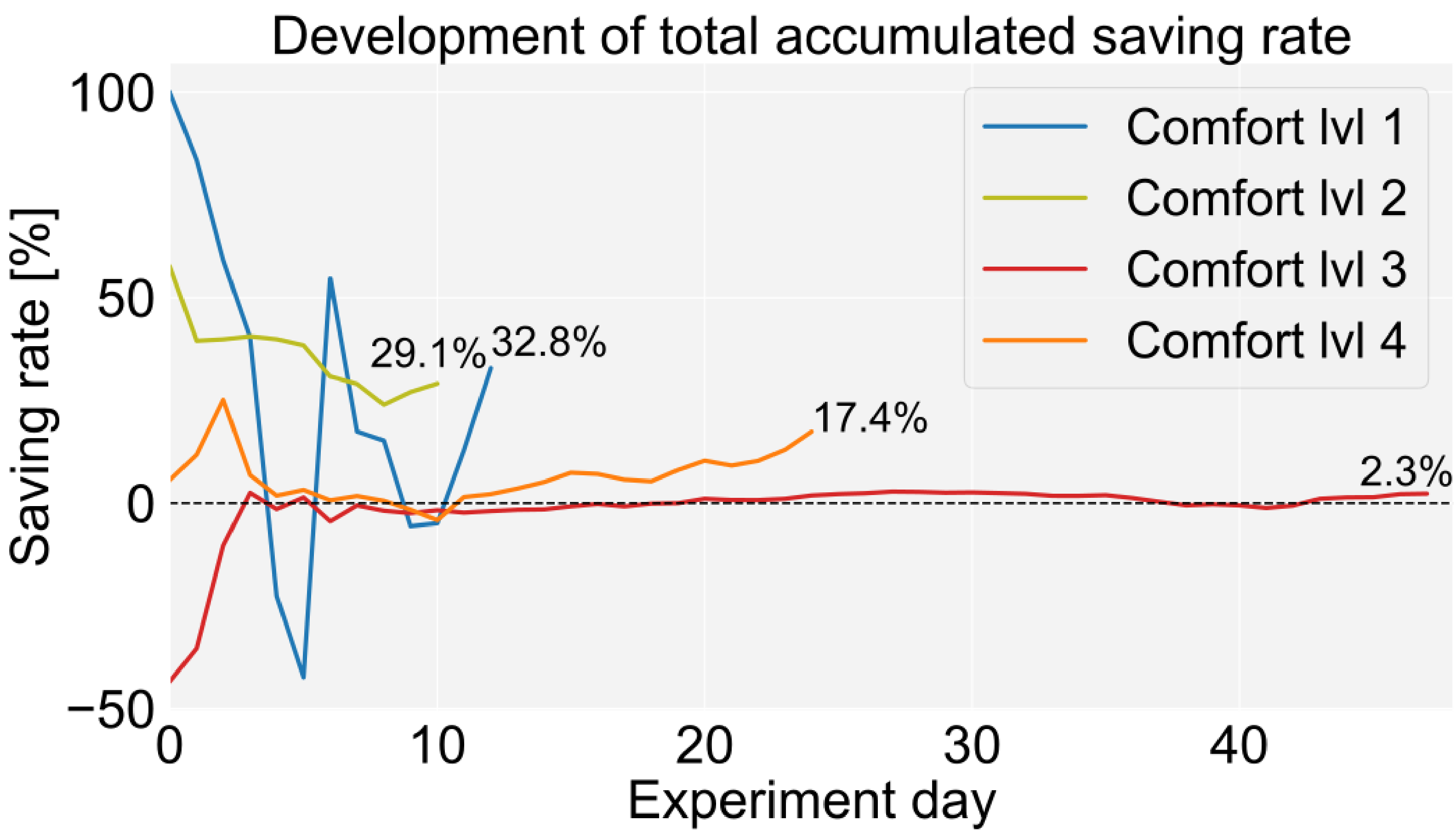
Long term performance



Benefit of using MPC?



Savings depend on comfort level



Nice percentage-wise savings ... but limited financial benefit

Comfort level	Average benchmark cost [€]	Exp. cost [€]	Reduction [€]	Saving rate [%]
1 (▲)	10.92	7.33	3.59	32.8
2 (▲)	49.84	35.34	14.50	29.1
3 (▲)	126.42	123.49	2.93	2.3
4 (▲)	42.65	35.23	7.42	17.4
3 and 4	169.07	158.72	10.35	6.1
All	229.83	201.39	28.43	12.4

Conclusion

- We presented a four-month experimental study in a near-zero emission occupied single-family house in Denmark.
- The control algorithm was able to provide energy savings by coordinating the available hardware, including running the heat pump closer to its COP optimum and exploiting the roof photovoltaic panels more efficiently.
- The cost reduction achieved was found to rang from 2-17% depending on the chosen comfort level.
- Crucially, the experiment did not result in any discernible discomfort to the occupants.