Stochastic model-predictive control of district-scale building energy systems using SpineOpt

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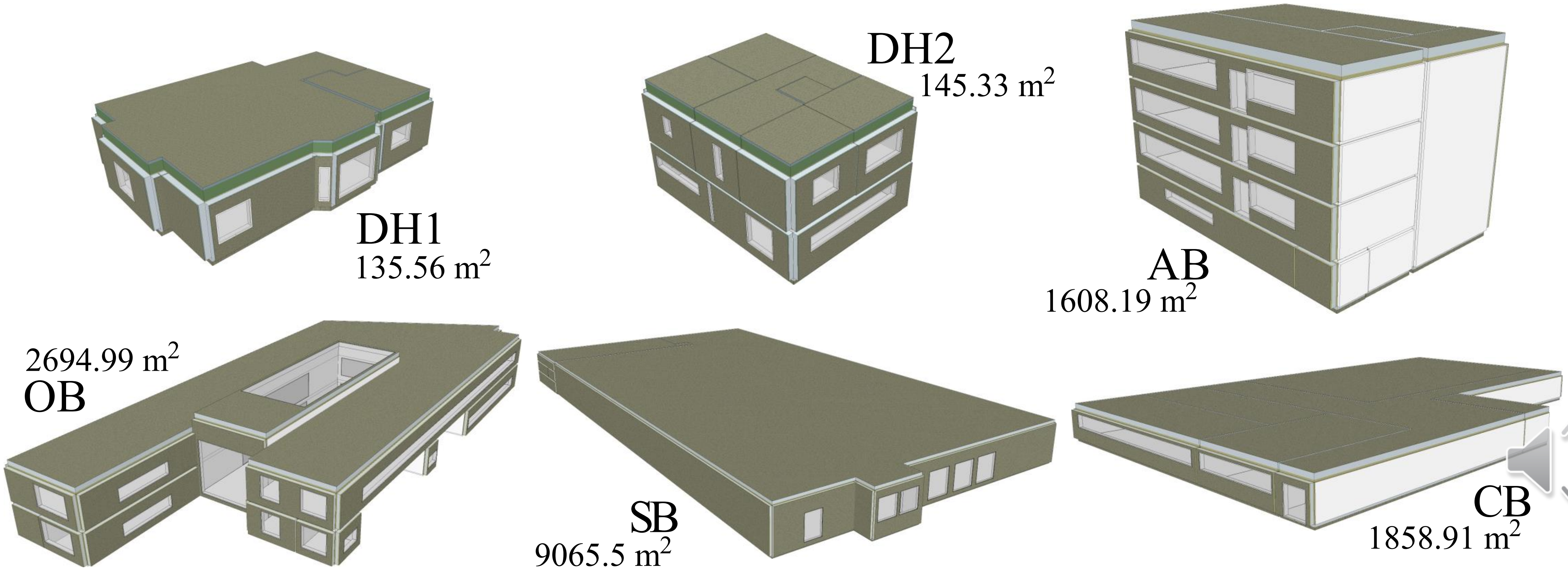
Motivation, aims and objectives

1. In order to understand the wider role of building-level demand-side management, it needs to be depicted in energy-market-scale models.
2. Unfortunately, hourly building-stock-scale models are extremely difficult to validate, as there are practically no measurements to compare against.
3. **Thus, this work aims to provide a proof-of-concept that energy-market-scale models such as SpineOpt can reasonably depict building- or district-level flexibility.**

Imaginary district of 6 buildings based on the examples in the old IDA ESBO v1.13



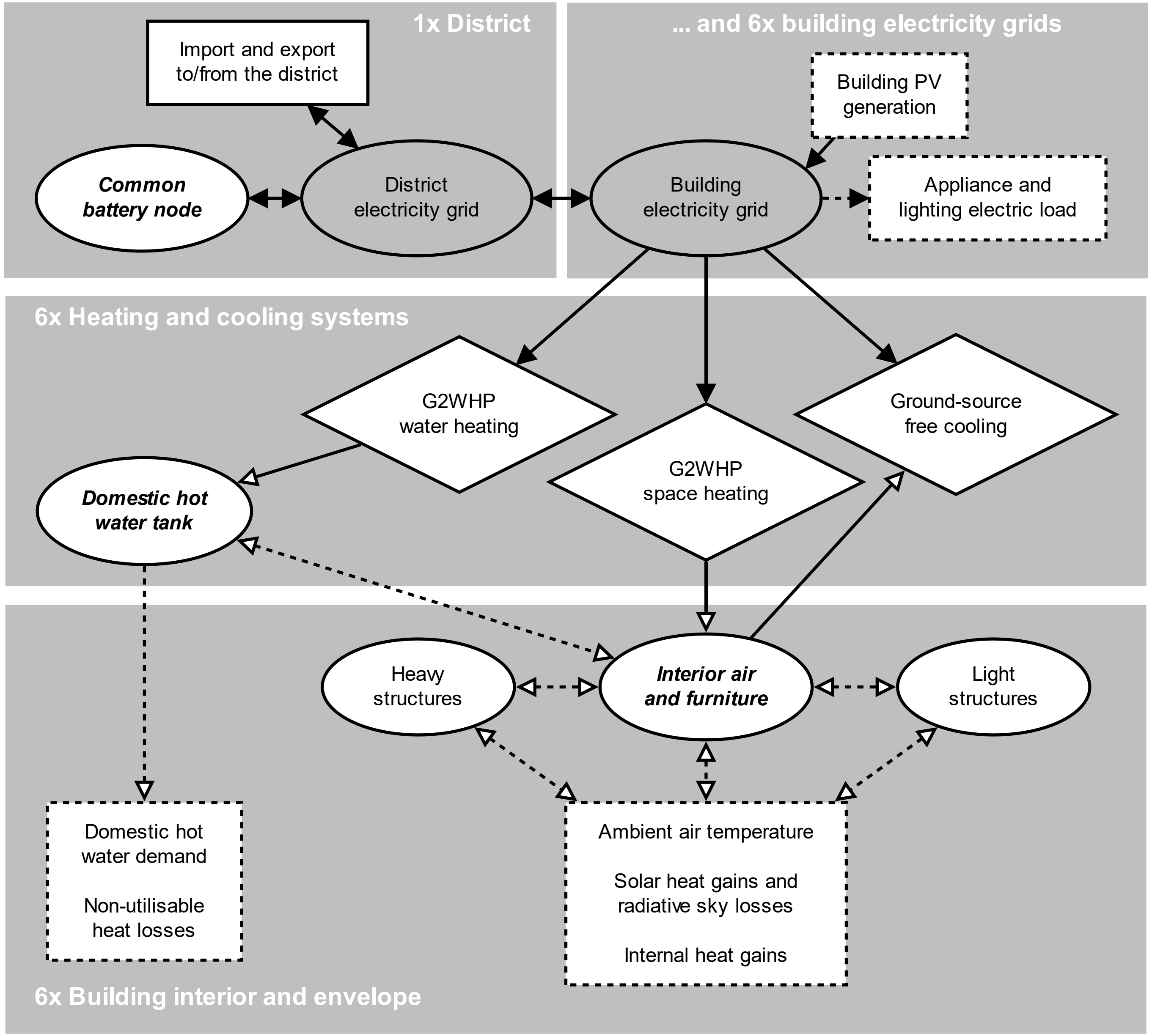
Methodology in a nutshell

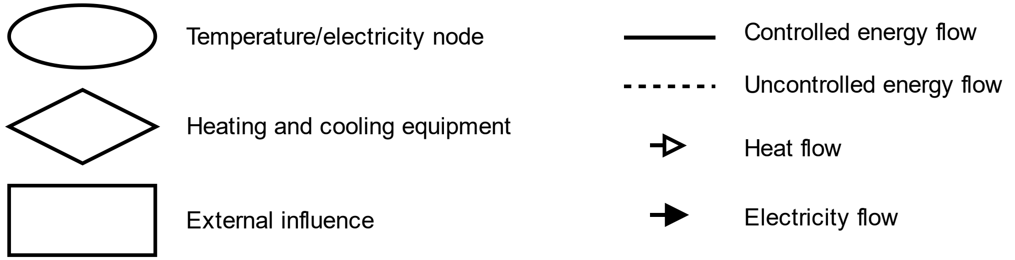
ArchetypeBuildingModel.jl

- A tool for aggregating building stock statistics into desired synthetic average archetype building RC-models for energy market modelling.
- **Used to generate the building RC-models for SpineOpt.**

SpineOpt.jl

- A mixed-integer linear programming based energy system modelling framework for capacity expansion, unit commitment, and economic dispatch problems.
- **Used to solve the least-cost operation of the modelled district.**

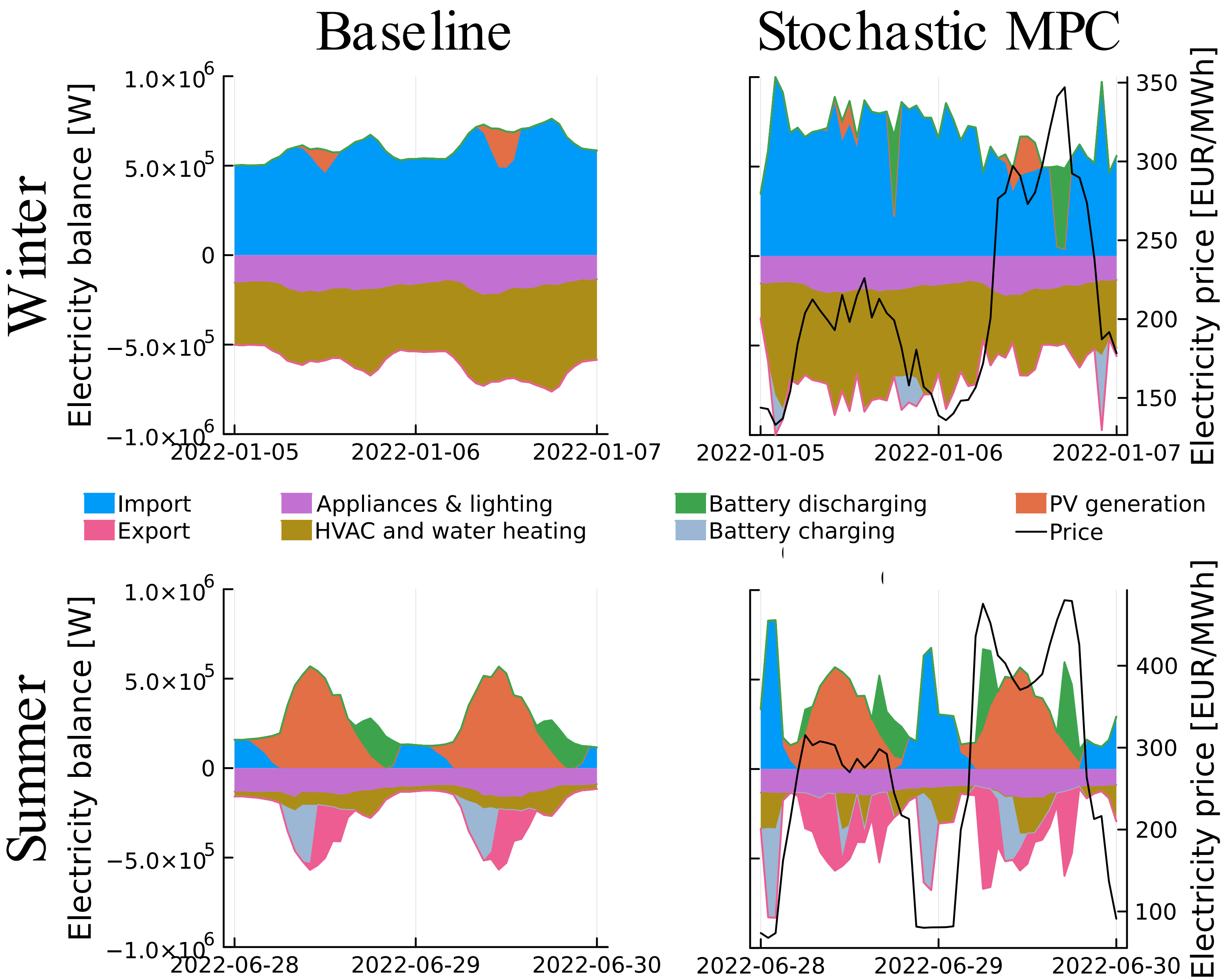




- Import/export power limited to 1 MW.
- 500 kW / 1 MWh battery, sized to cover the average appliance and lighting load for ~10 hours, with peak power 5x the average load.
- Total of ~680 kWp of PV, sized to cover the annual appliance and lighting load of each building.
- G2WHP using constant SPFs of 2.50 and 1.58 for space and water heating respectively.
- Ground-source free cooling using SPF of 30.

Table 1: Permitted temperature ranges in the model.

Indoor air	Range
Detached house 1 (DH1)	21–25°C
Detached house 2 (DH2)	21–25°C
Apartment block (AB)	21–25°C
Office building (OB)	21–25°C
Service building (SB)	18–25°C
Communal building (CB)	21–25°C
DHW tanks	60–90°C



- Hourly full-year rolling optimisation with 48-hour forecasts updated every 6 hours with day-ahead prices cleared according to NordPool conventions.

- The **Baseline** used a simple RBC, using the minimum amount of energy to maintain comfortable temperatures. The battery was charged with any excess PV generation, and discharged to meet demand whenever able. **Electricity prices were not considered in the baseline.**

- The **Stochastic MPC** used SpineOpt to minimize the expected net costs of electricity import/export to/from the district over optimistic, mean, and pessimistic forecasts for weather, prices, and load.

Table 2: Summary of the key results and their change relative to the Baseline for each MPC.

Import & Export	Baseline	Perfect	Deterministic	Stochastic
Total import [MWh]	2340.33	2619.36 (11.92 %)	2625.22 (12.17 %)	2656.73 (13.52 %)
Total import costs [kEUR]	499.73	469.24 (-6.10 %)	469.86 (-5.98 %)	477.61 (-4.43 %)
Average import price [c/kWh]	21.35	17.91 (-16.10 %)	17.9 (-16.18 %)	17.98 (-15.81 %)
Total export [MWh]	146.54	320.94 (119.01 %)	321.13 (119.14 %)	319.56 (118.07 %)
Total export revenue [kEUR]	27.47	92.64 (237.27 %)	92.34 (236.17 %)	91.94 (234.70 %)
Average export price [c/kWh]	18.74	28.87 (54.00 %)	28.75 (53.40 %)	28.77 (53.48 %)
Total net costs [kEUR]	472.26	376.6 (-20.26 %)	377.52 (-20.06 %)	385.67 (-18.34 %)
Consumption & Generation				
Total heating electricity [MWh]	2177.23	2238.51 (2.81 %)	2244.41 (3.09 %)	2278.72 (4.66 %)
Total other electricity [MWh]	968.55	968.55 (0.00 %)	968.55 (0.00 %)	968.55 (0.00 %)
Total PV generation [MWh]	968.58	968.58 (0.00 %)	968.58 (0.00 %)	968.58 (0.00 %)
Total battery charging [MWh]	164.98	561.03 (240.06 %)	558.37 (238.45 %)	545.64 (230.74 %)
Total battery discharging [MWh]	148.39	503.97 (239.63 %)	501.56 (238.01 %)	490.07 (230.27 %)

1. **The total yearly net cost savings of ~18-20 % are in line with comprable literature.**
2. The rather extreme 2022 electricity price data causes the battery to exploit electricity price arbitrage for profits instead of prioritising self-consumption.

Conclusions

- **SpineOpt is viable for depicting optimal energy management of building energy systems on the district-scale.**
- Thus, city and nation-scale studies on the impacts of building-level flexibility are plausible, as the methodology can be scaled by using different numbers and types of archetype buildings.

Thank you for your attention!