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A Virtual Testbed for Robust and Reproducible Calibration of Building Energy Simulation Models

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The task of energy model calibration

$$\theta^* = arg\min_{\theta \in \Theta}(J(y, y^*))$$

Ground truth of model output(s)

$$s.t. \quad y = \mathcal{M}(x, u, \theta)$$

Model outputs

Model inputs

Disturbances

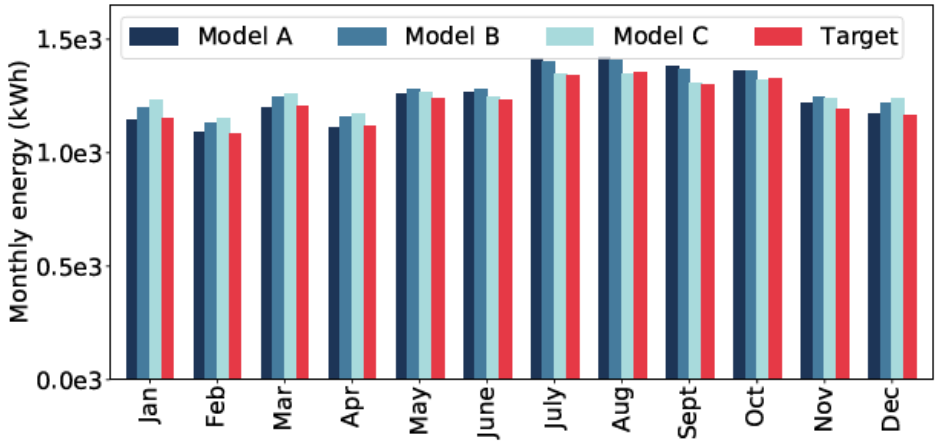
Model parameters

- Typical workflow:
  - Lack of robustness and reproducibility
  - Cannot guarantee model reliability

Misleading error metrics

- Mostly used CV(RMSE)
  - ASHRAE: monthly 15%, hourly 30%; IPMVP: 20%
  - For which output(s)?
  - Monthly bill can't suffice, how about smart meter?
- A simple case of the pitfall
  - Calibration of a single-family house in Hawaii
  - Electricity power density and nominal COP
  - Three models considered calibrated

CV(RMSE)	A	B	C
Monthly total	3.36%	3.96%	3.69%
Hourly total	19.98%	11.82%	16.16%



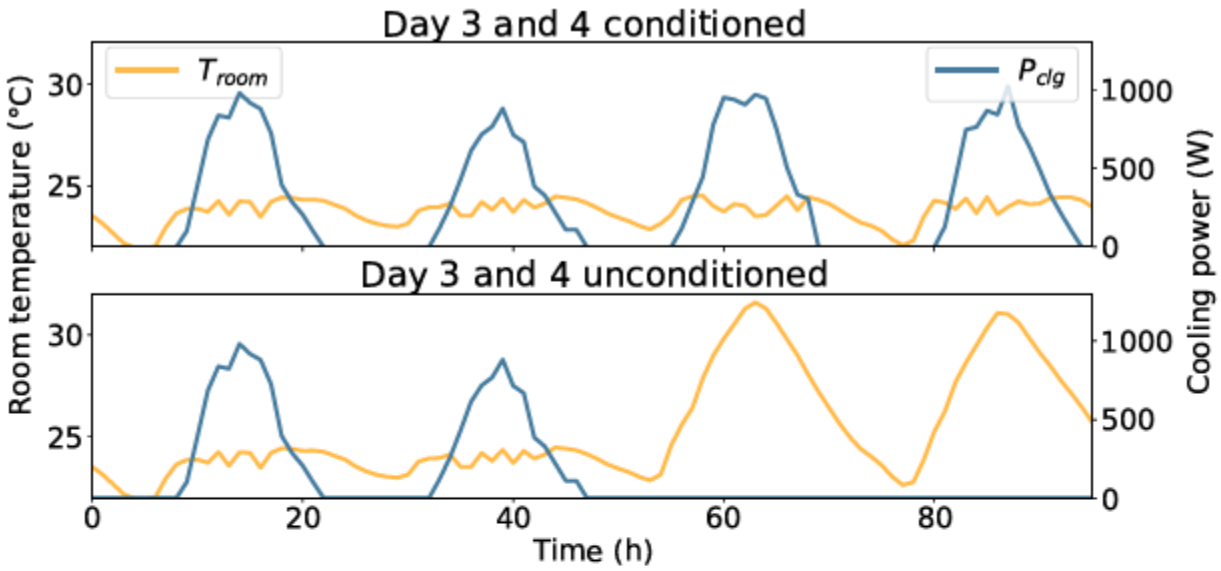
(a) Monthly total energy consumption.

Identifiability issues

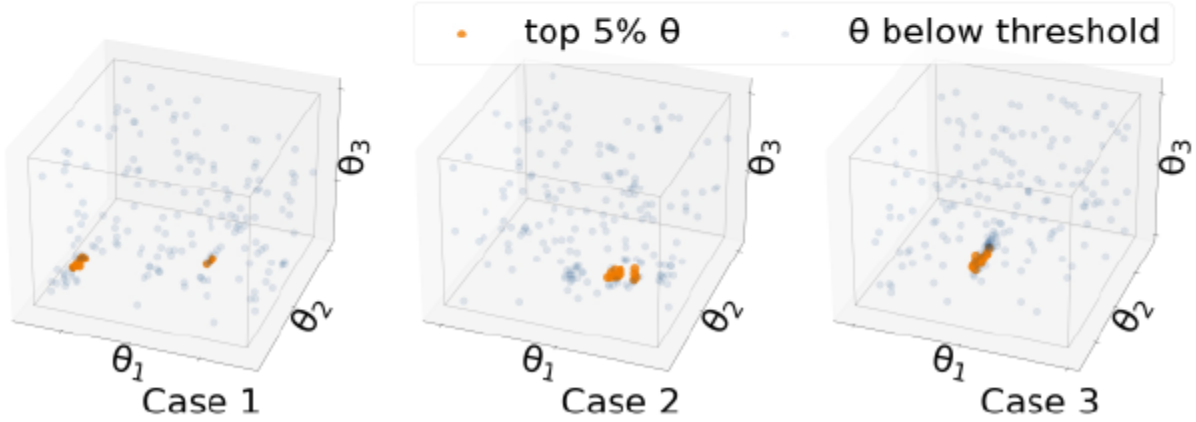
- No unique θ to minimize the error
  - Simple Bayesian Optimization example
  - SHGC, infiltration, and COP to calibrate

1. Cooling power when conditioned
2. Additional temperature data
3. Adjusted operations

✓ Properly define the problem
✓ Extra information needed
❖ Much more complicated in reality



(a) Results of two data generation schemes.



(b) Parameter space of three cases.

Inevitable model discrepancy

- Identifiable model ≠ correct parameters
  - The previous case 3 yielded parameters 10-20% off
  - More accurate annual prediction:
    - monthly CV(RMSE) of 1.54% and hourly of 11.77%
  - Many possible discrepancy sources in reality

Descriptive thermal properties

Steady-state v.s. real-time control

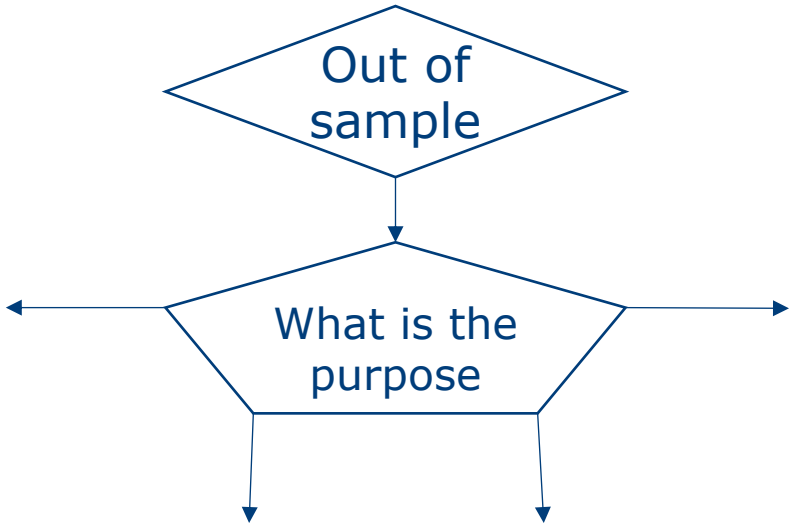
Heat transfer assumptions

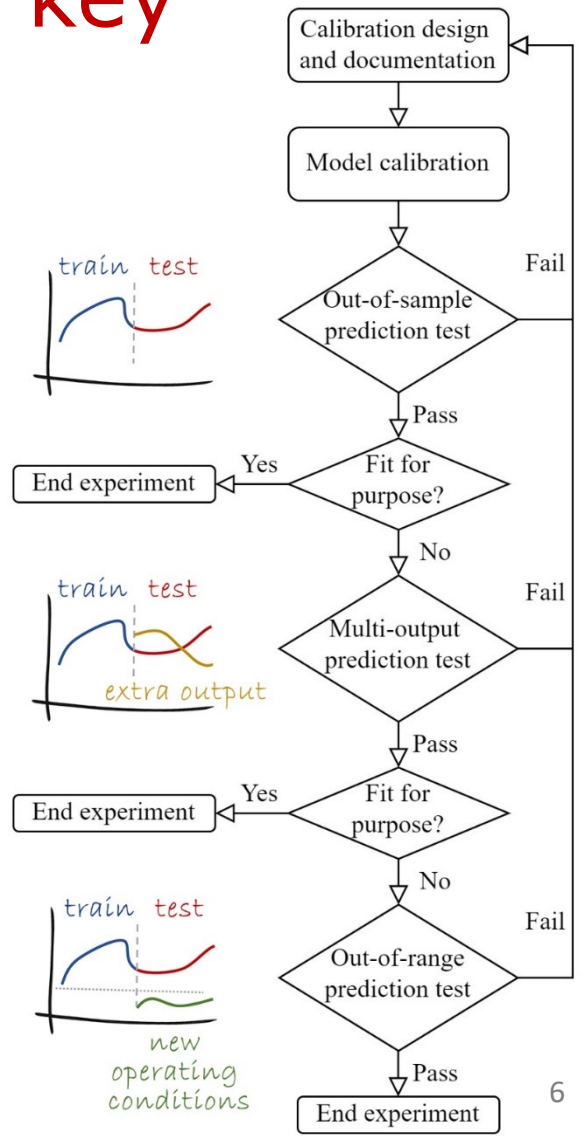
Electrical appliance usage

. . .

Prediction/extrapolation capability is the key

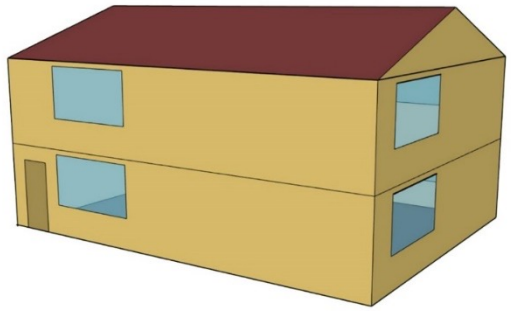
- A testing framework for calibrated models
  - Out of sample as a must
  - Optional more demanding tests
  - Other requirements, e.g. multi-horizon/resolution
  - Based on a virtual testbed

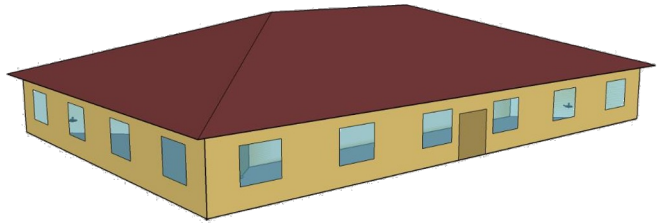


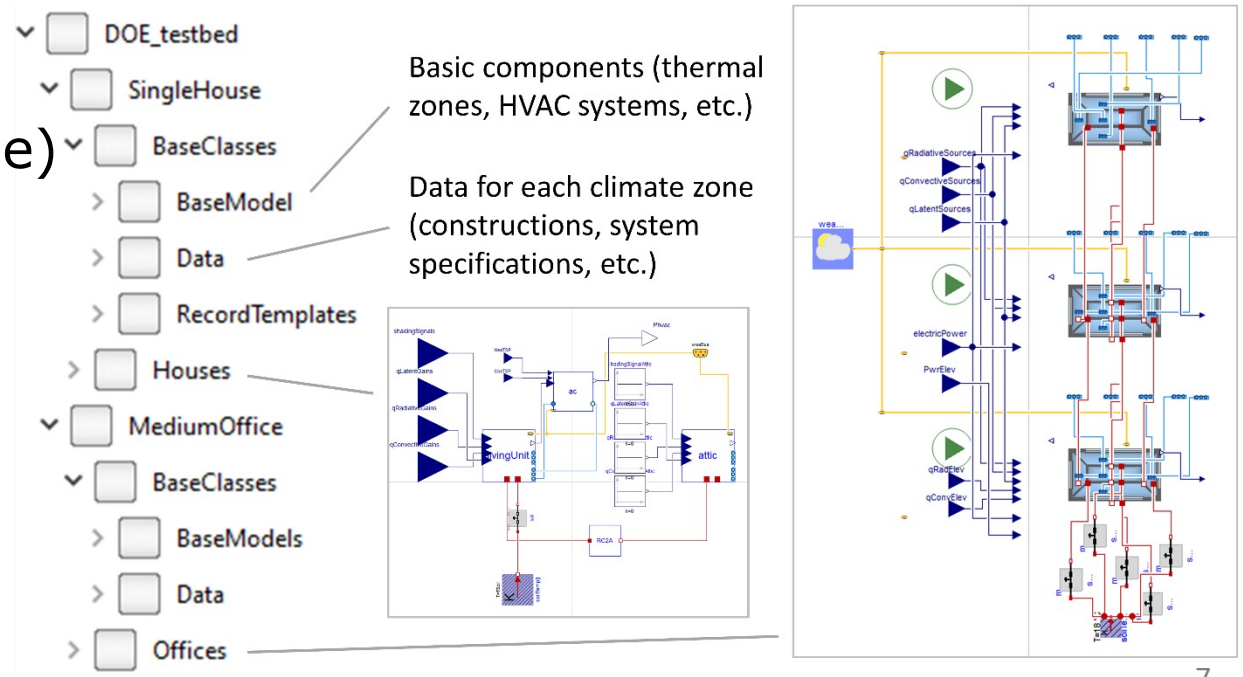


Virtual testbed

- Account for model discrepancy
  - Modelica as the emulator, other models to be calibrated
- Ability to generate fit-for-purpose testing data (python script)
- Reproducibility/transferability
  - Single-family house/small office
  - Different climate zone (IECC envelope)







Thank you!