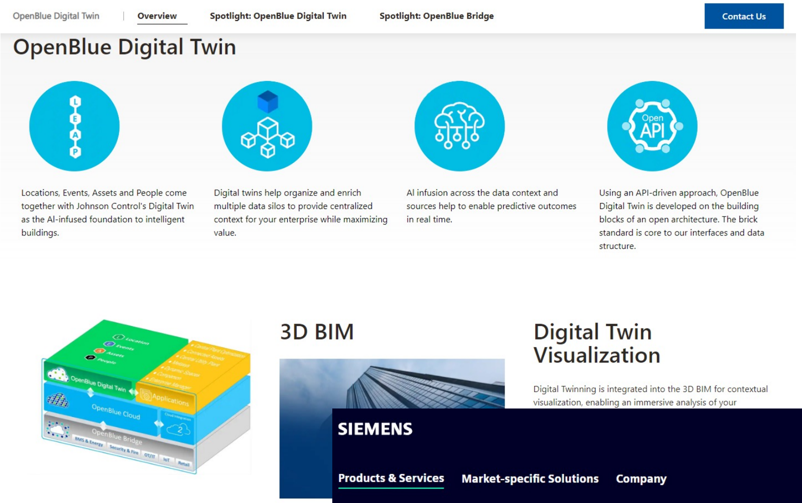
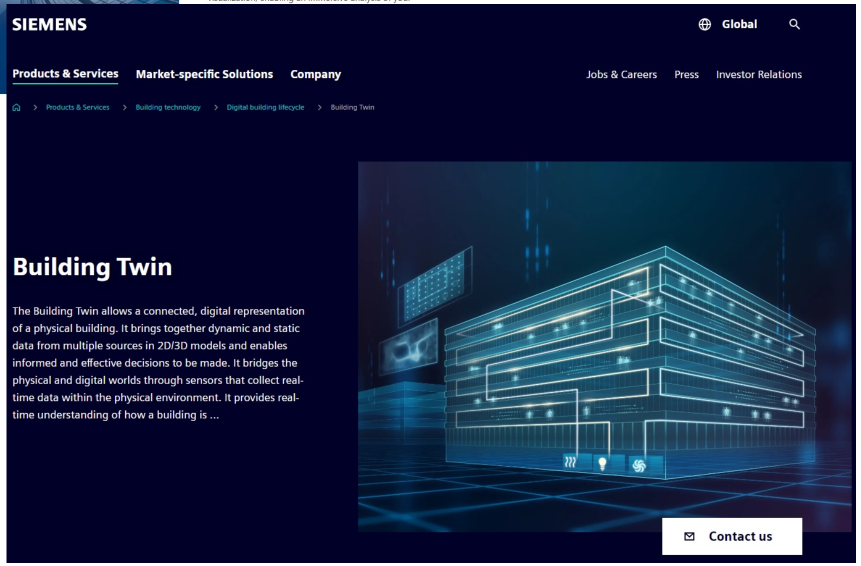
Application-oriented performance evaluation of digital twins for buildings

Sicheng Zhan
szhan@nus.edu.sg

NUS National University of Singapore

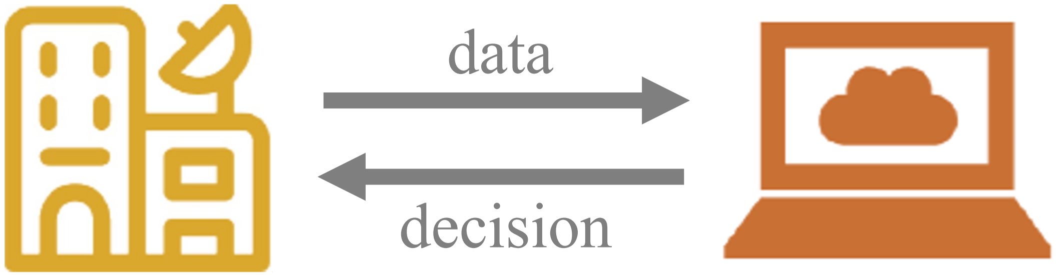




Existing digital twin solutions

- 3D BIM model
- Data acquisition
- Data visualization
- Energy prediction & evaluation

Digital twins: Computational models that replicate the behaviour of real-world systems, conducting virtual experiments in unseen scenarios and supporting decision-making



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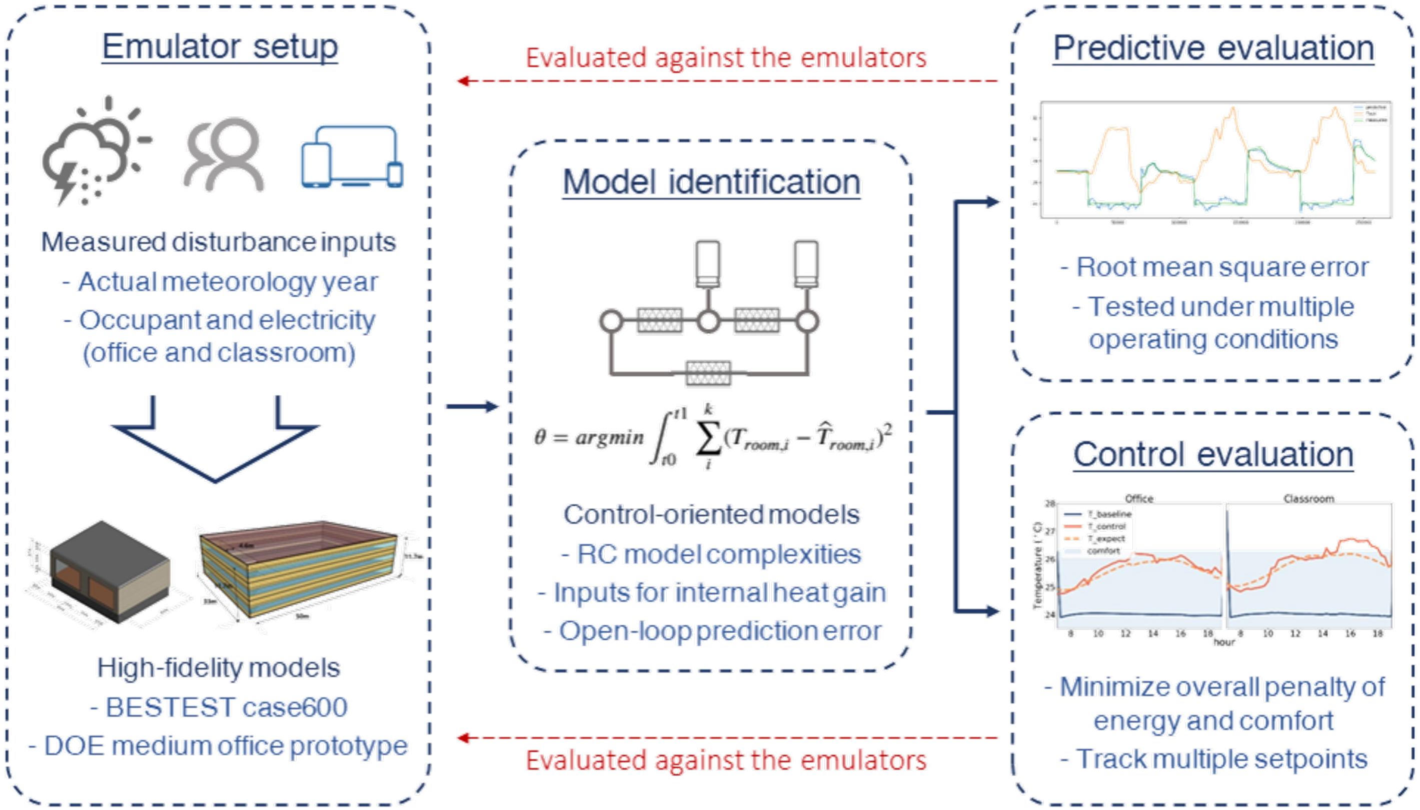
How to guarantee the reliability before implementation?

Resistor-capacitor model for control



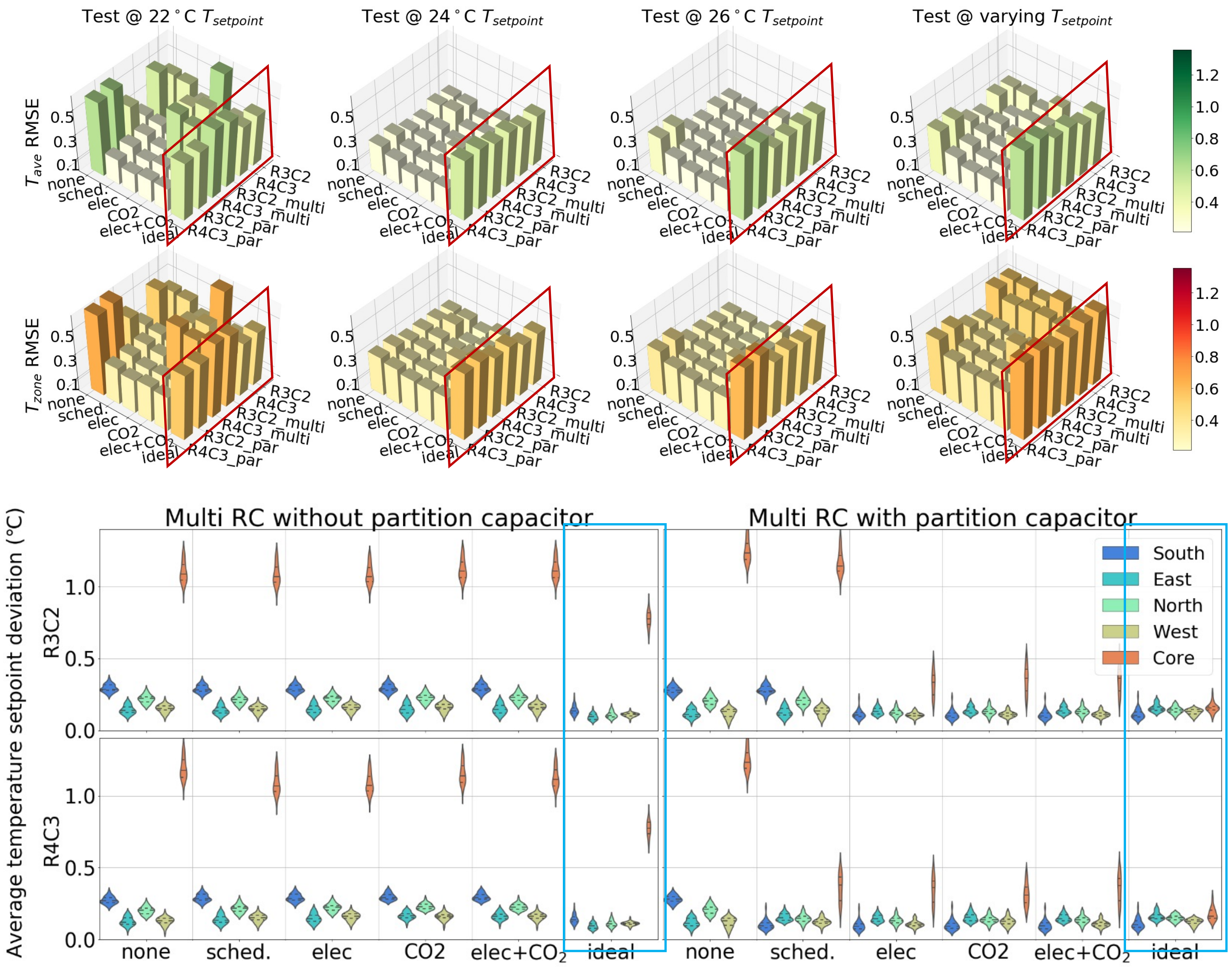
- Increasing RC model complexity
- Identified with the same dataset through non-linear programming

$$\theta = argmin \int_{t0}^{t1} \sum_{i}^{k} (T_{room,i} - \hat{T}_{room,i})^2 dt$$

$$s.t. \quad \hat{T}_{room} = f(x, u, d, \theta)$$

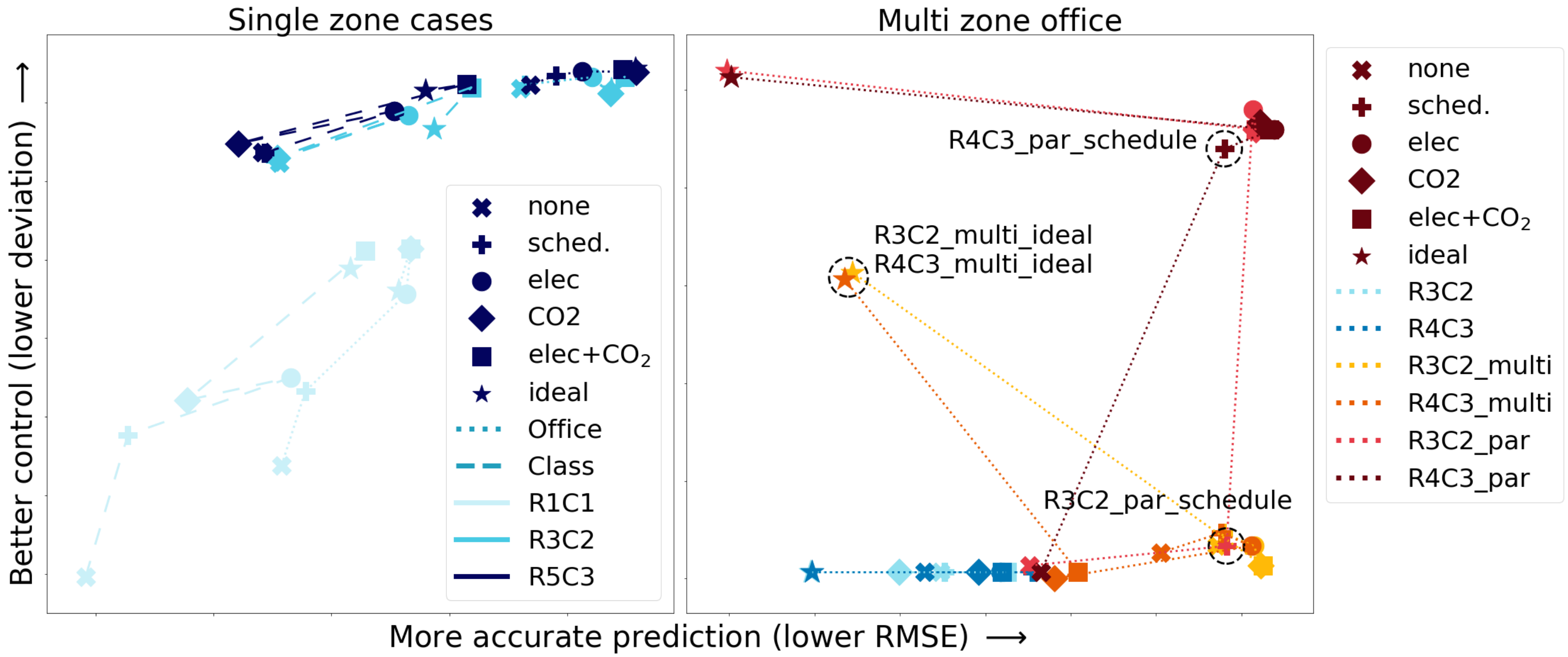
$$\theta^{lb} \leq \theta \leq \theta^{ub}$$

- Prediction under different conditions (extrapolation capability)
- Virtual control experiments on high fidelity models



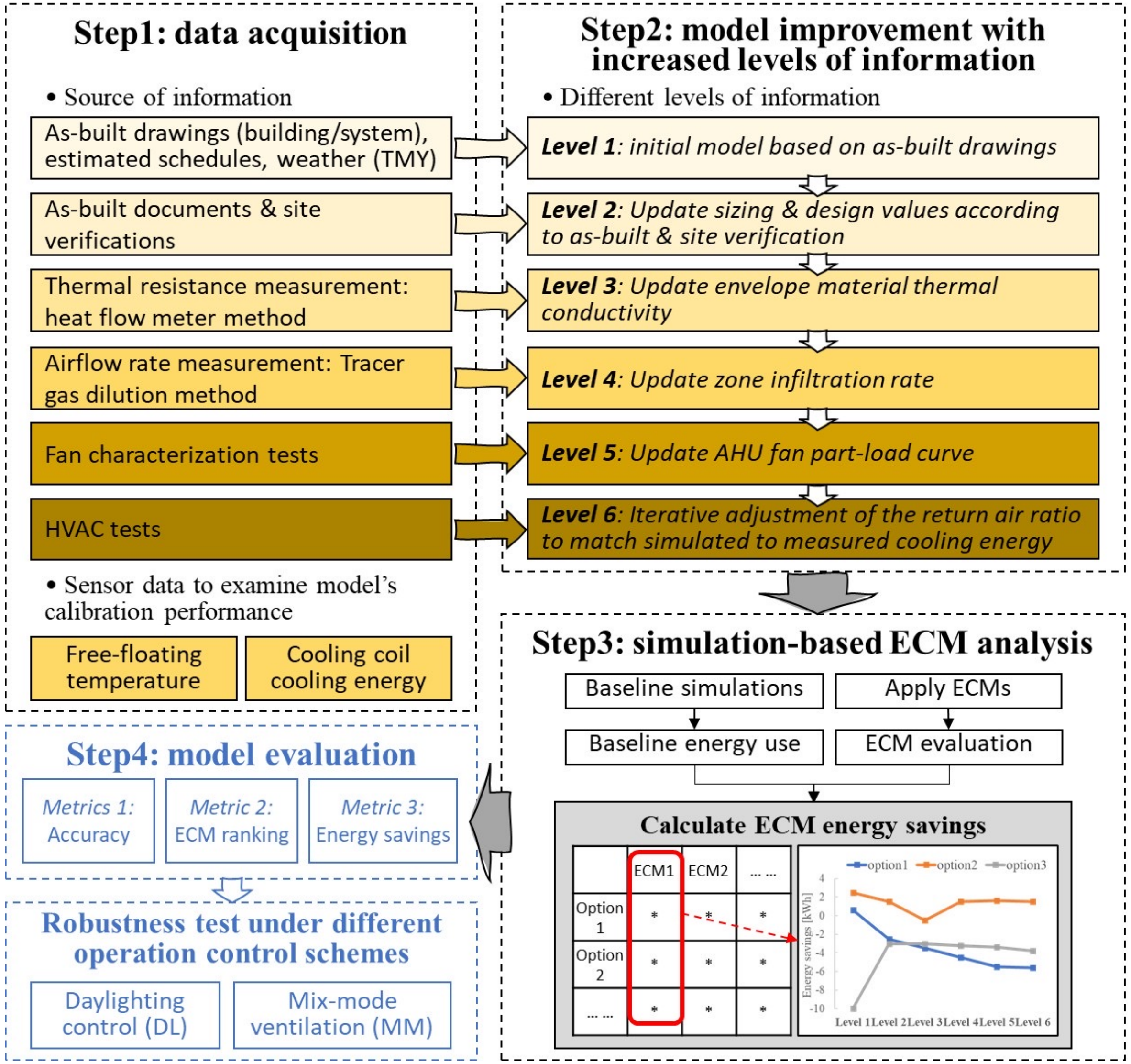
- The identification underestimate partition capacitor for lower RMSE
  - NOT detected by prediction tests
  - Yielded control deviations

- More representative input resulted in larger prediction error but better control



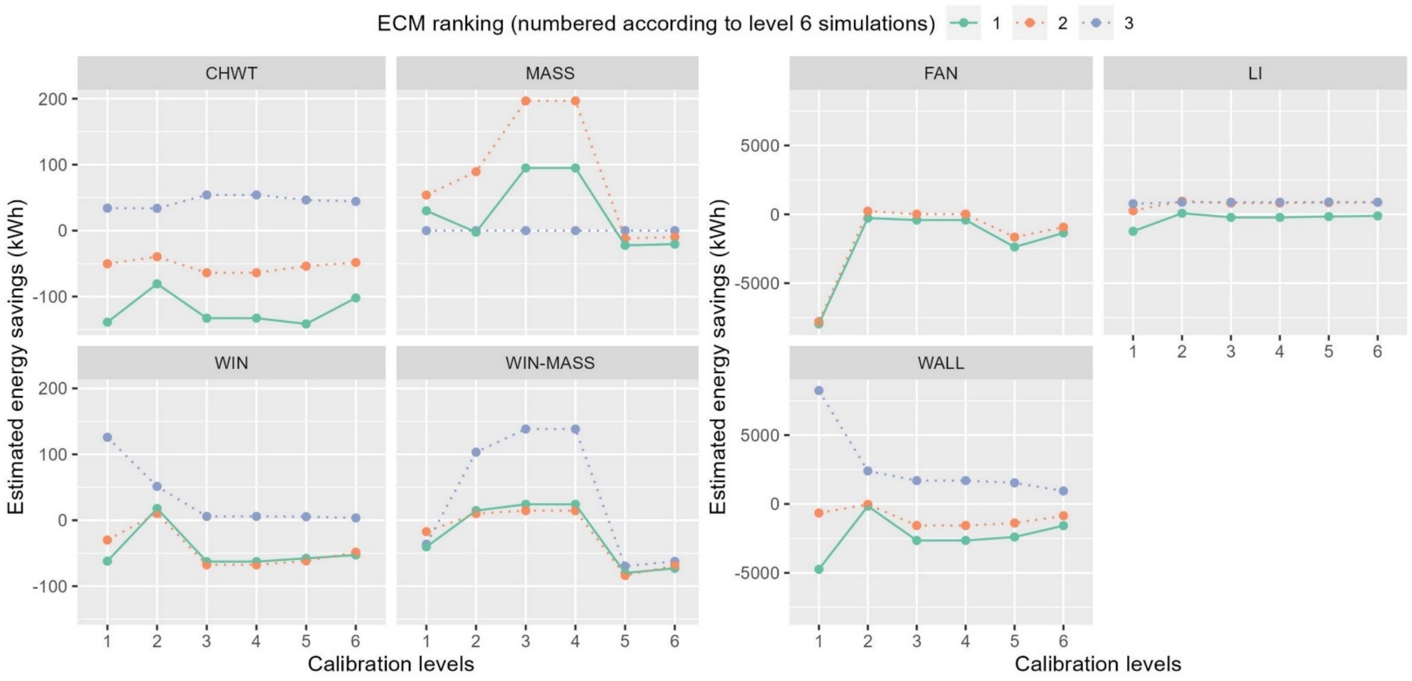
- Lower prediction error means better control for simple dynamics
- For complex buildings, only led to better control with adequate model
- Critical physical component should be preserved (partition capacitor here)

Energyplus for retrofit analysis



- An actual case study of evidence-based calibration
- the impact of different levels of information
- Robust evaluation in ECM analysis

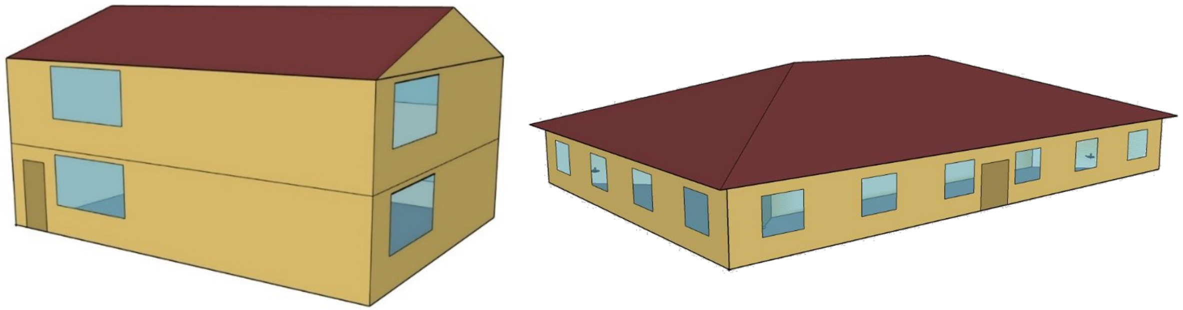
- More information gradually lowered CVRMSE
- Only matters for some design decisions
- Accurate estimation of energy saving requires information corresponding to the ECM

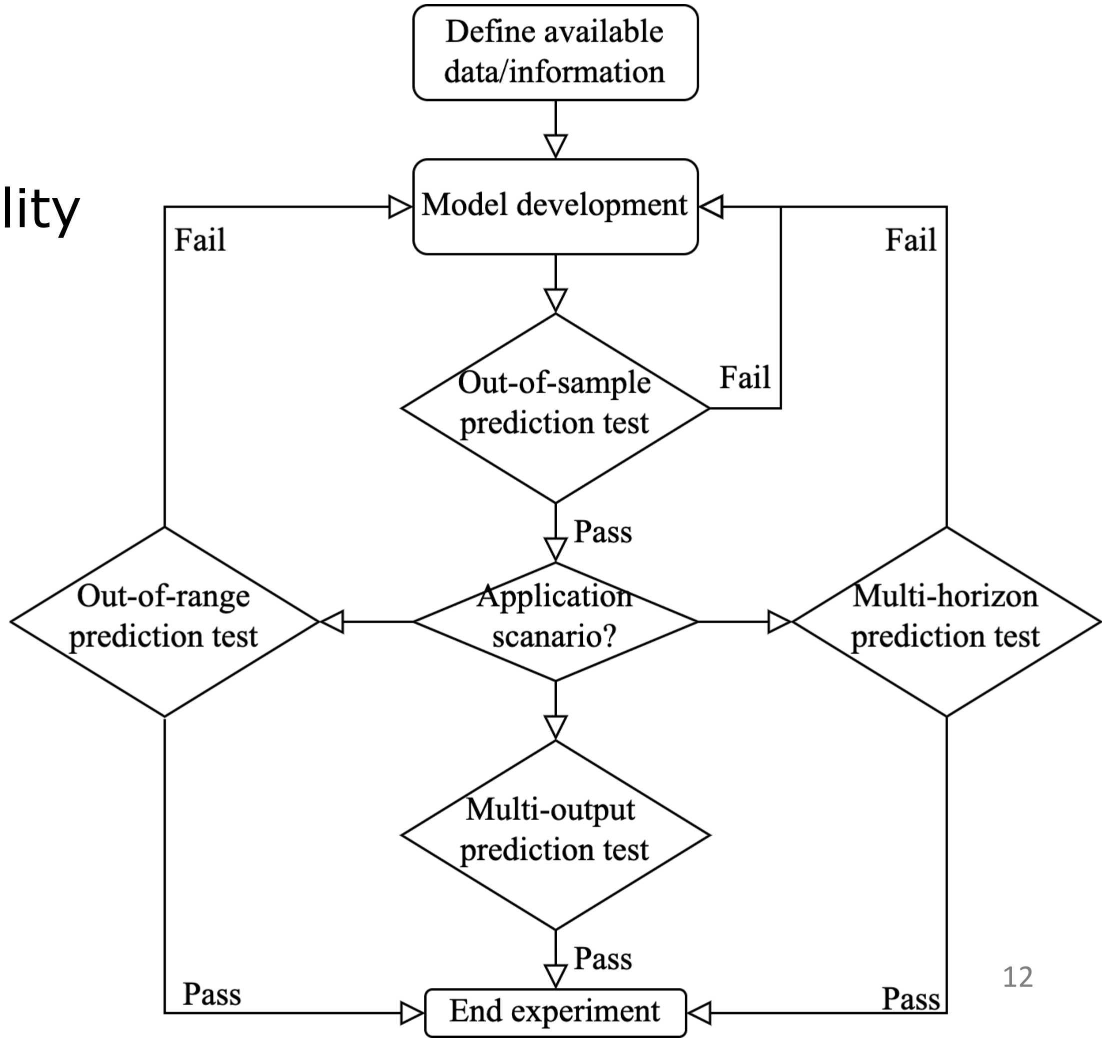


Co-simulation for every building is impractical

Prediction/extrapolation capability is the key

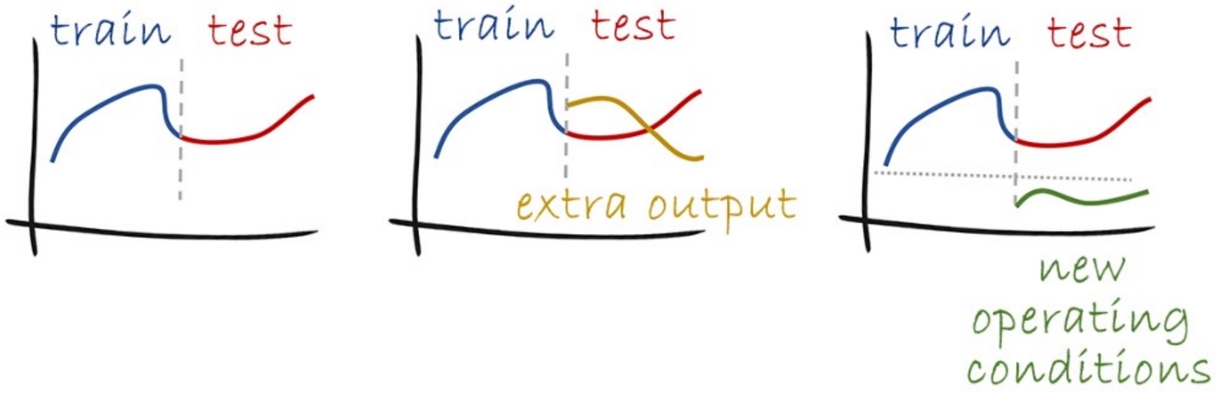
- A testing framework for digital twins
  - Based on a virtual testbed
  - Emulator as the actual building, higher-fidelity than its twins
  - Reproducibility
    - Single-family house/small office
    - Different climate zone (IECC envelope)

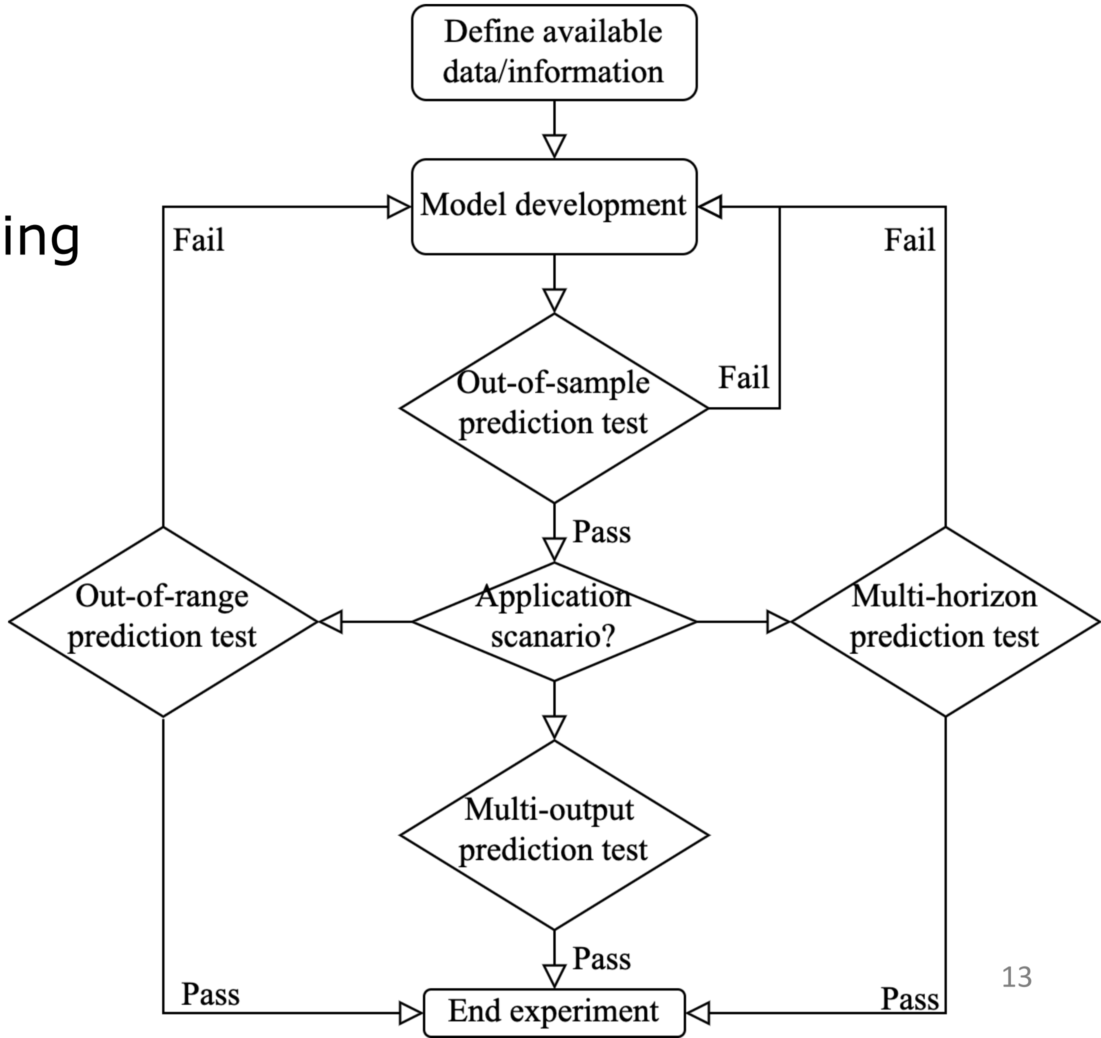




Prediction/extrapolation capability is the key

- Out of sample as a must
- Optional more demanding tests, e.g. multi-horizon/resolution
- Ability to generate application-oriented testing data (python script)

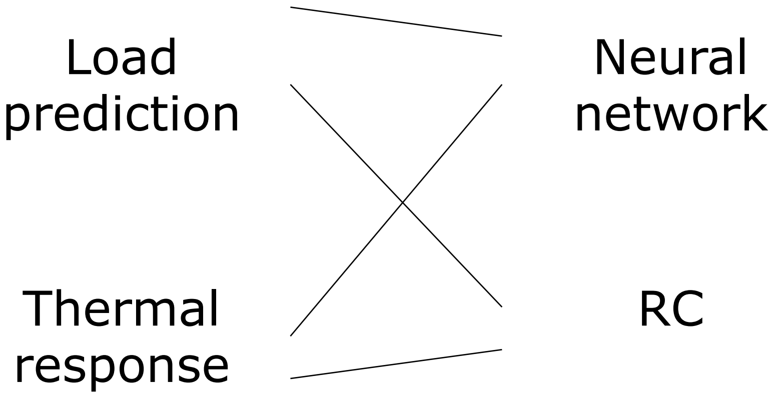


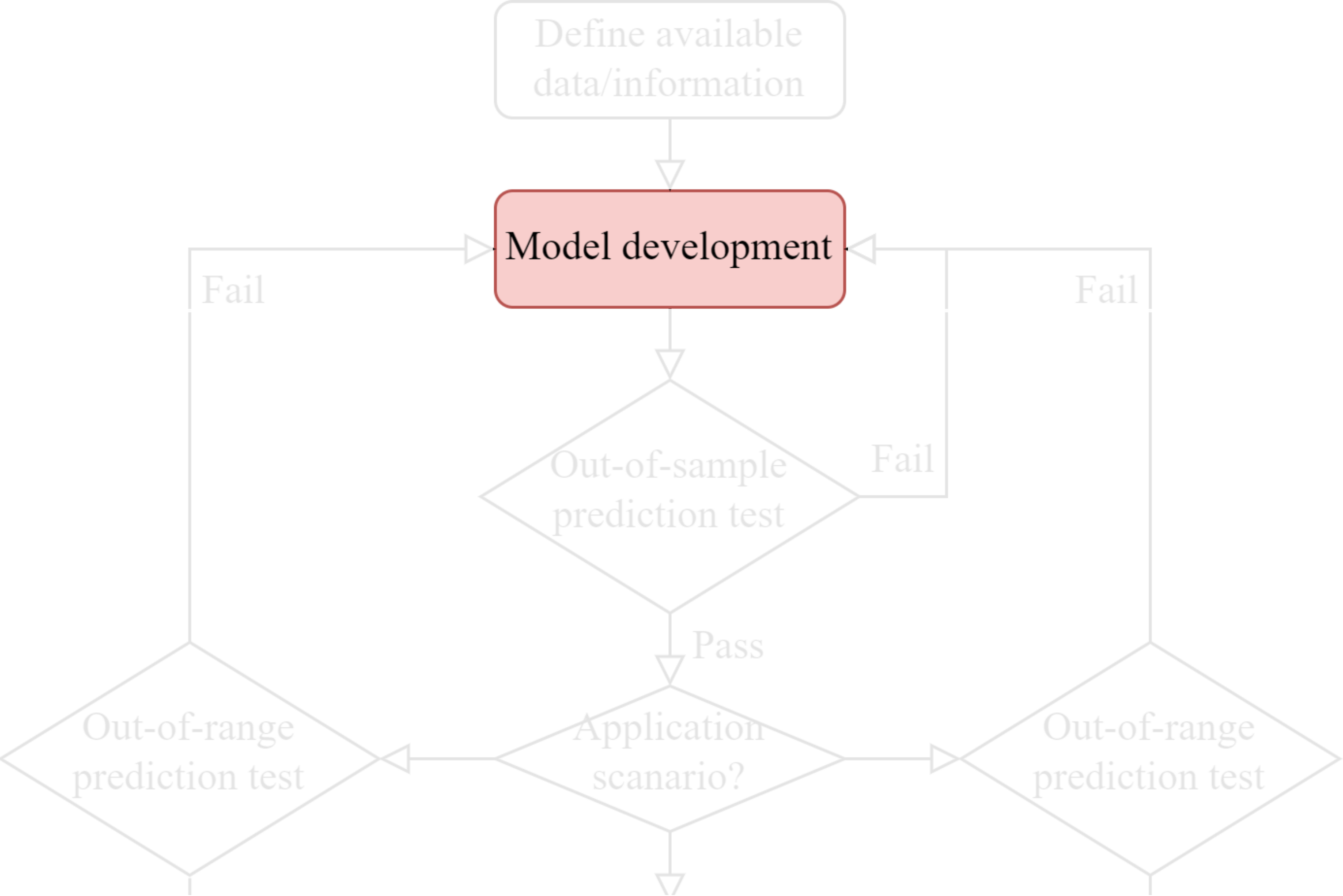


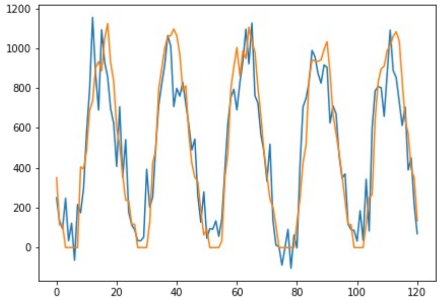
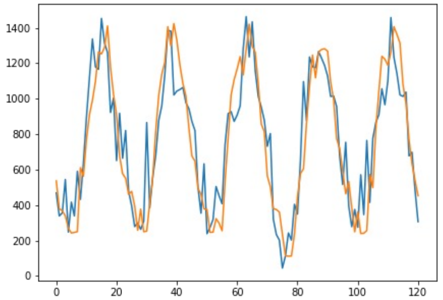
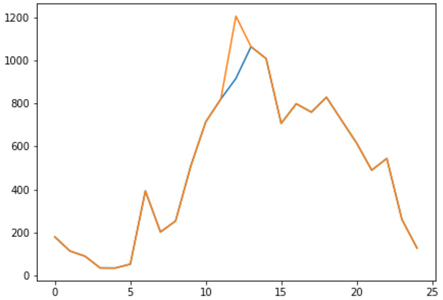
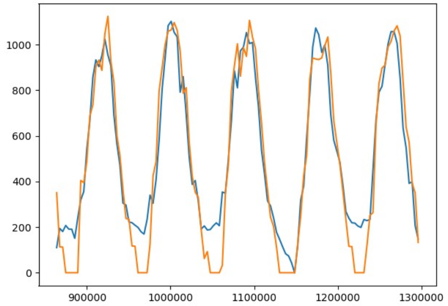
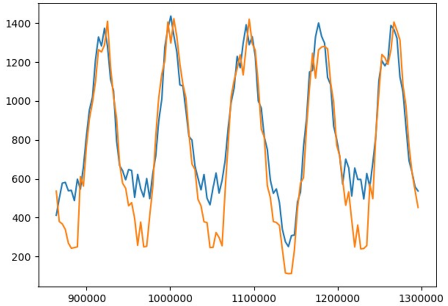
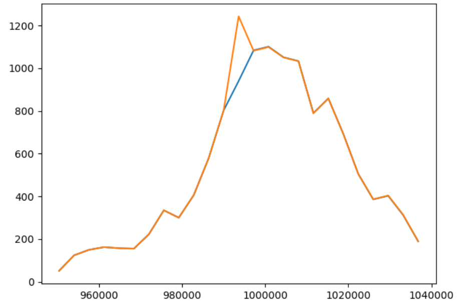
How "physical" does the model need to be?

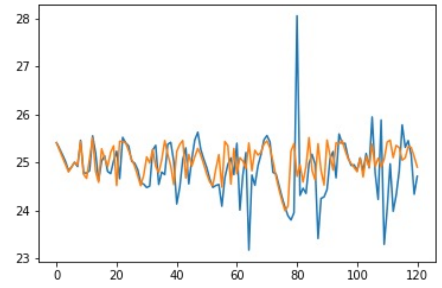
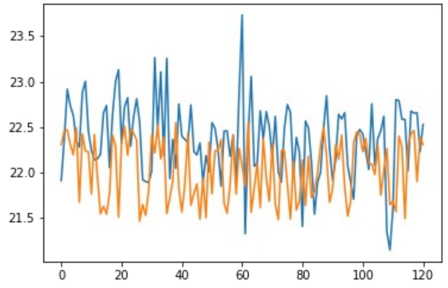
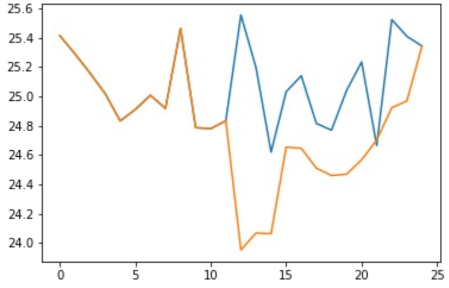
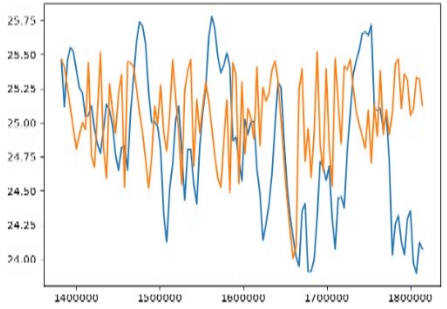
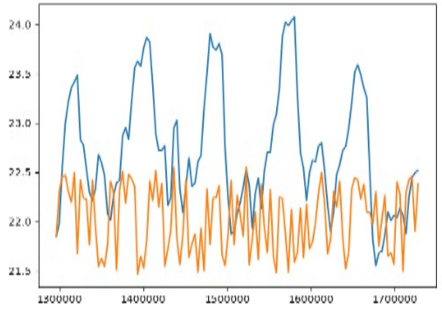
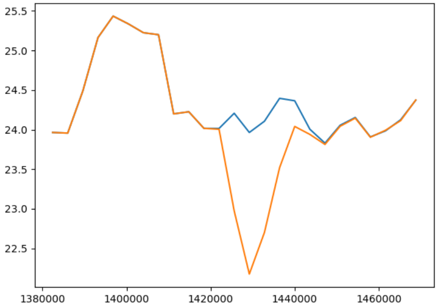
White/grey/black box

An example of pre-cooling





Load prediction	Out of sample test	Out of range test	Physical test
Neural network	 30.6%	 23.5%	 Failed
RC	 23.9%	 20.2%	 Failed

Thermal response	Out of sample test	Out of range test	Physical test
Neural network	 2.57%	 2.81%	 Failed
RC	 2.55%	 4.47%	 Passed

- Traditional error-based evaluation could be misleading
- Models need to be developed concerning the predictive scenarios
- More open questions to answer

Thank you!

https://jamescheng21.github.io/