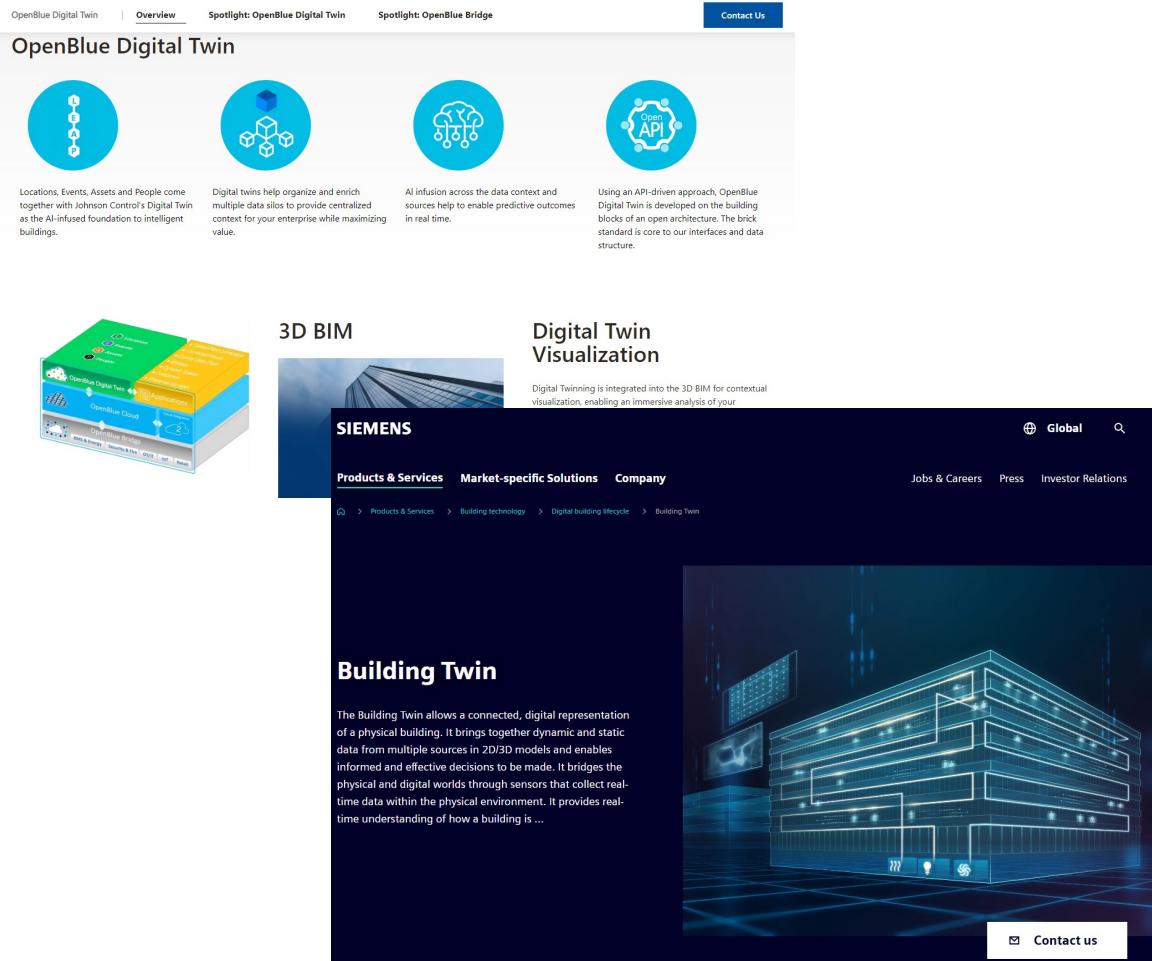


Application-oriented performance evaluation of digital twins for buildings

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The screenshot displays the OpenBlue Digital Twin website. At the top, there are four circular icons representing different components: a network of nodes, a digital twin model, AI integration, and an API interface. Below these are four descriptive text boxes:

- Locations, Events, Assets and People come together with Johnson Controls' Digital Twin as the AI-infused foundation to intelligent buildings.
- Digital twins help organize and enrich multiple data silos to provide centralized context for your enterprise while maximizing value.
- AI infusion across the data context and sources help to enable predictive outcomes in real time.
- Using an API-driven approach, OpenBlue Digital Twin is developed on the building blocks of an open architecture. The brick standard is core to our interfaces and data structure.

Below this section, there are two main visual components:

- 3D BIM:** A diagram illustrating the integration of various digital components into a 3D BIM model, including OpenBlue Digital Twin, OpenBlue Cloud, OpenBlue Bridge, and other systems.
- Digital Twin Visualization:** A screenshot of the Siemens website under the 'Digital Twin Visualization' heading, showing a building's facade with a digital overlay of data points and connectivity.

At the bottom left, there is a section titled "Building Twin" with a detailed description of its function and benefits. On the right side, there is a large, stylized 3D rendering of a building's structure with glowing blue highlights, representing the digital twin visualization.

Existing digital twin solutions

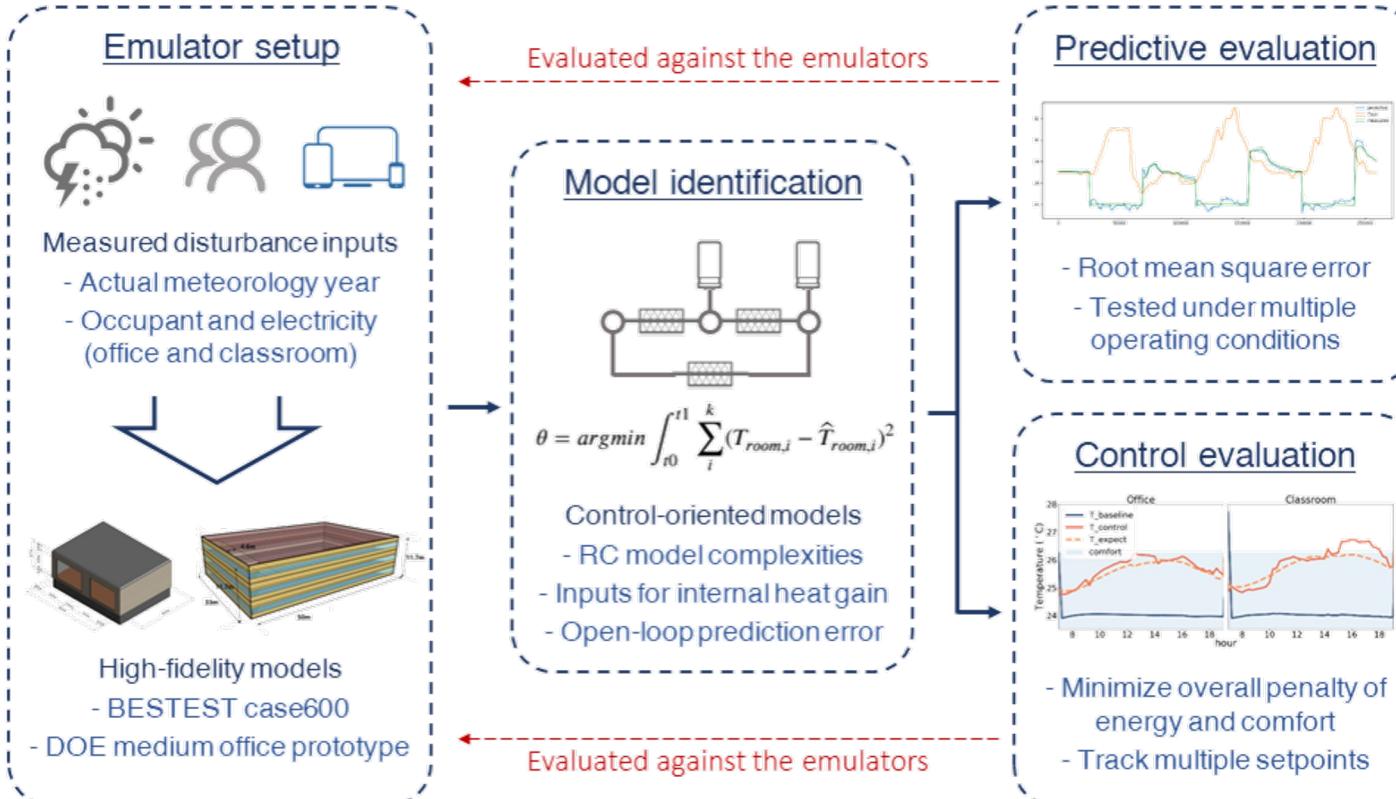
- 3D BIM model
- Data acquisition
- Data visualization
- Energy prediction & evaluation

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



How to guarantee
the reliability before
implementation?

Resistor-capacitor model for control

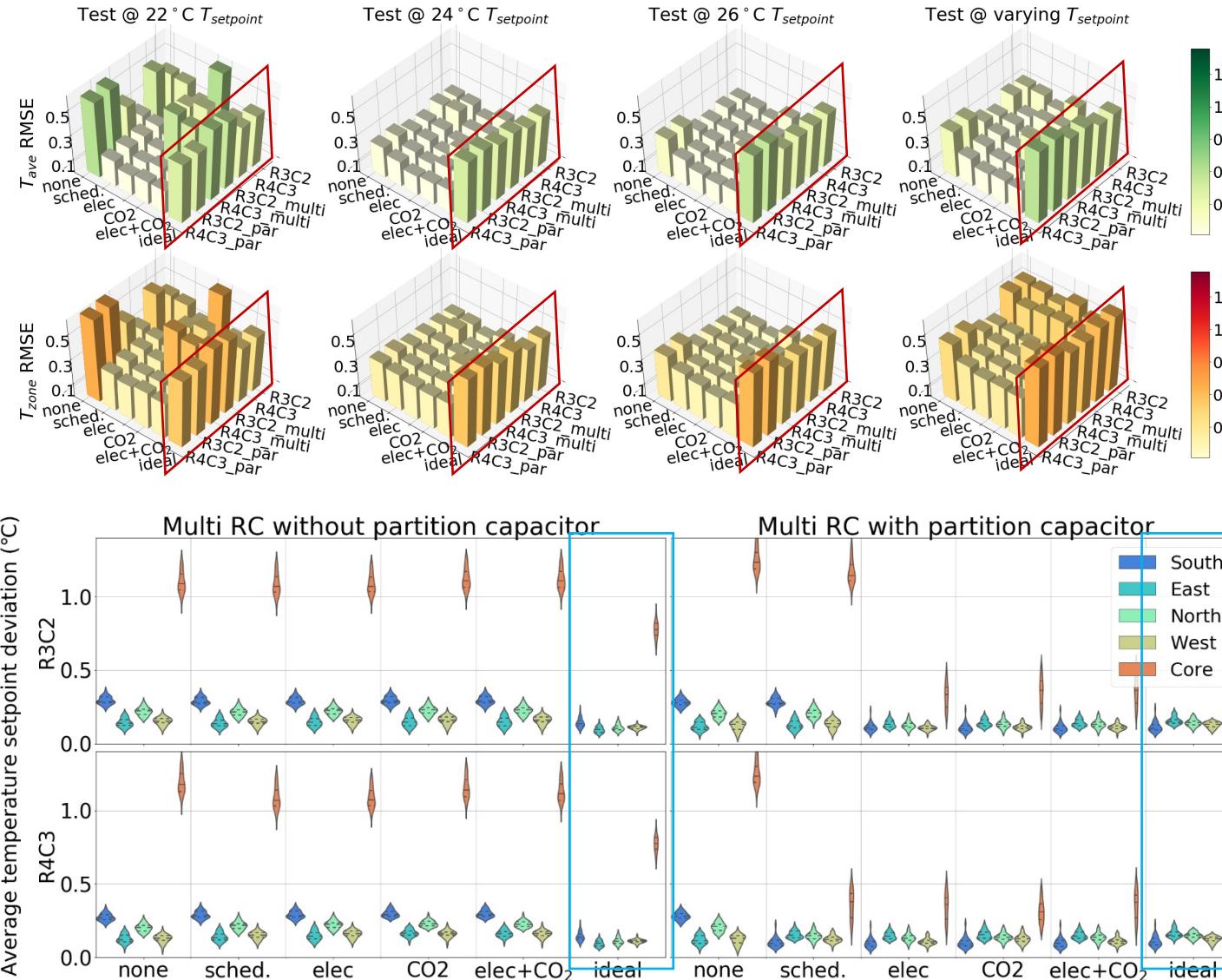


- Increasing RC model complexity

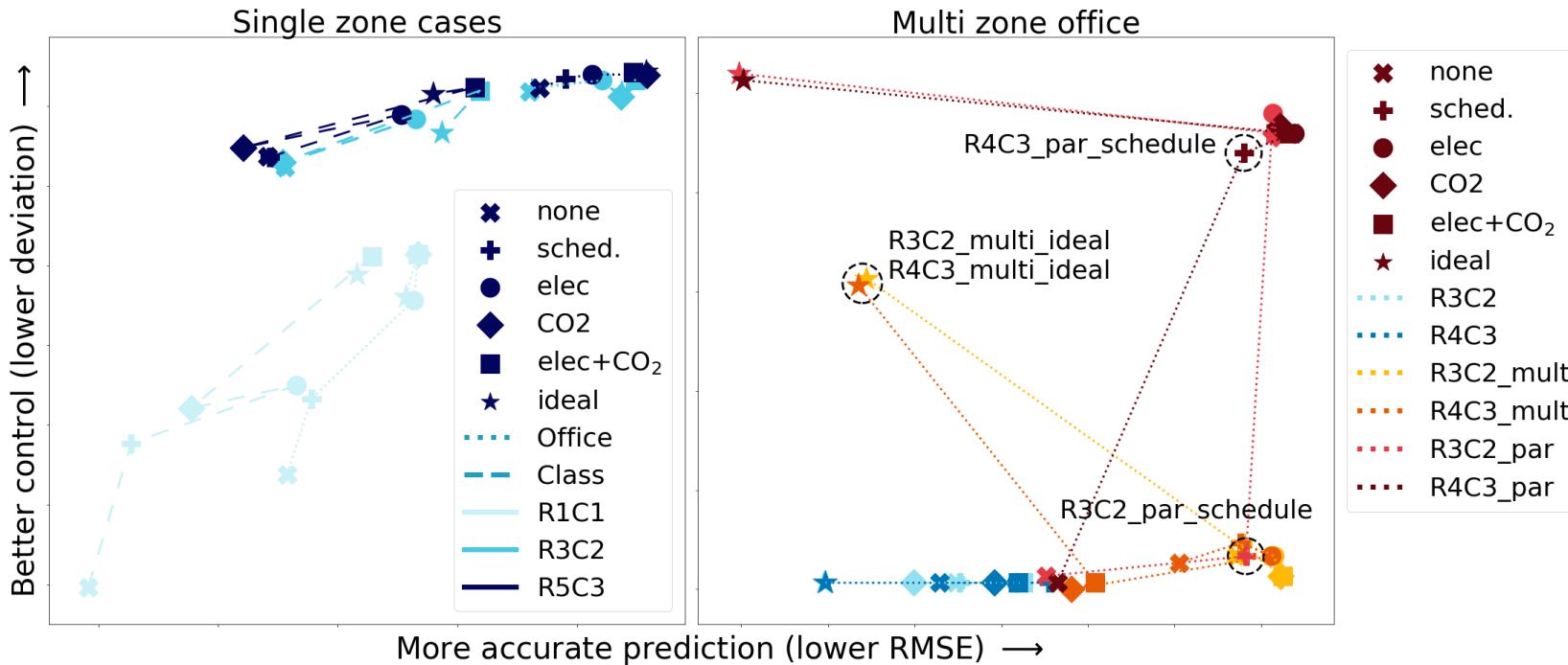
- Identified with the same dataset through non-linear programming

$$\theta = \operatorname{argmin} \int_{t0}^{t1} \sum_i^k (T_{room,i} - \hat{T}_{room,i})^2 dt$$
$$\text{s.t. } \hat{T}_{room} = f(x, u, d, \theta)$$
$$\theta^{lb} \leq \theta \leq \theta^{ub}$$

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

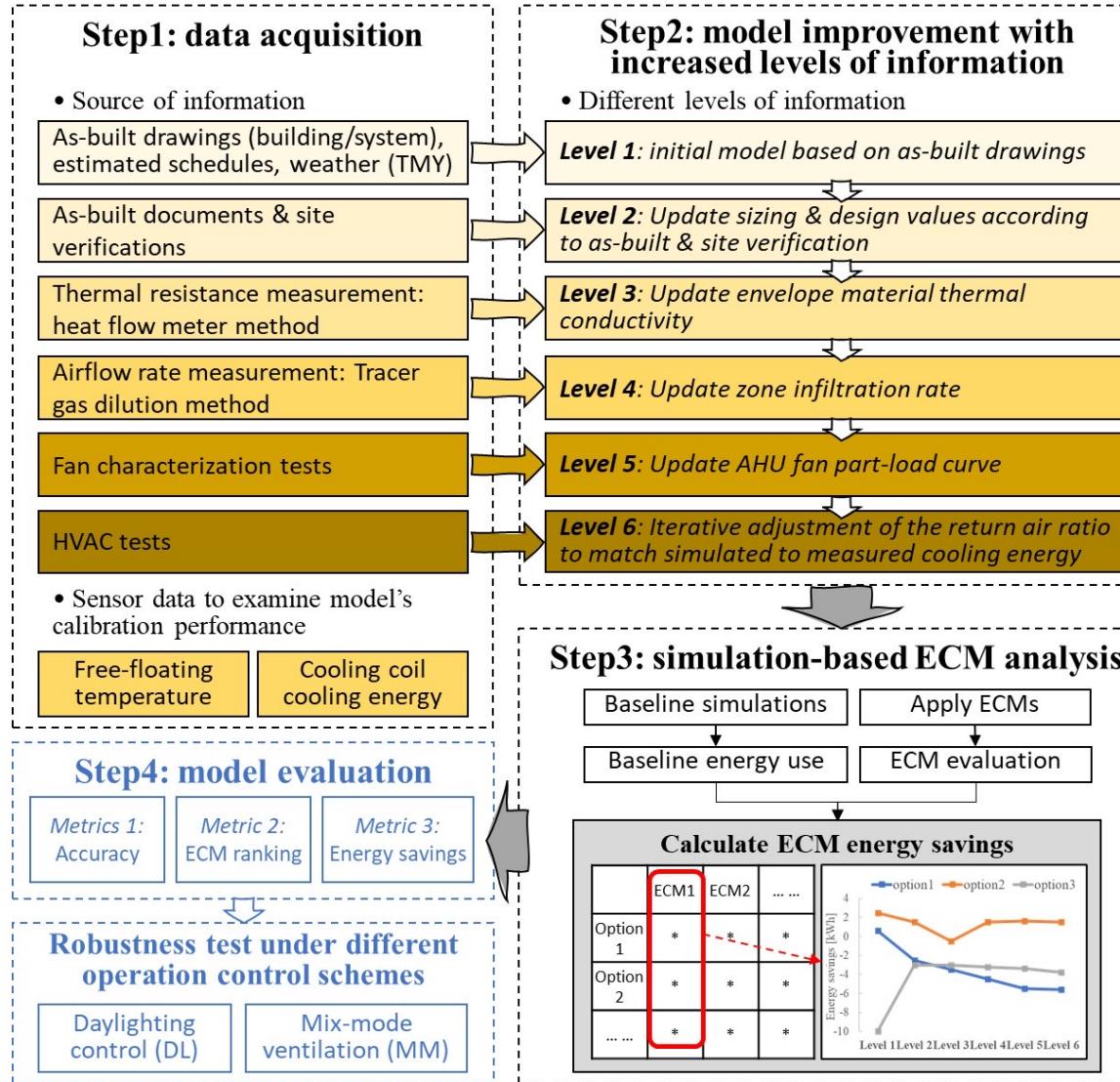


- The identification underestimate partition capacitor for lower RMSE
 - NOT detected by prediction tests
 - Yielded control deviations
- More representative input resulted in larger prediction error but better control



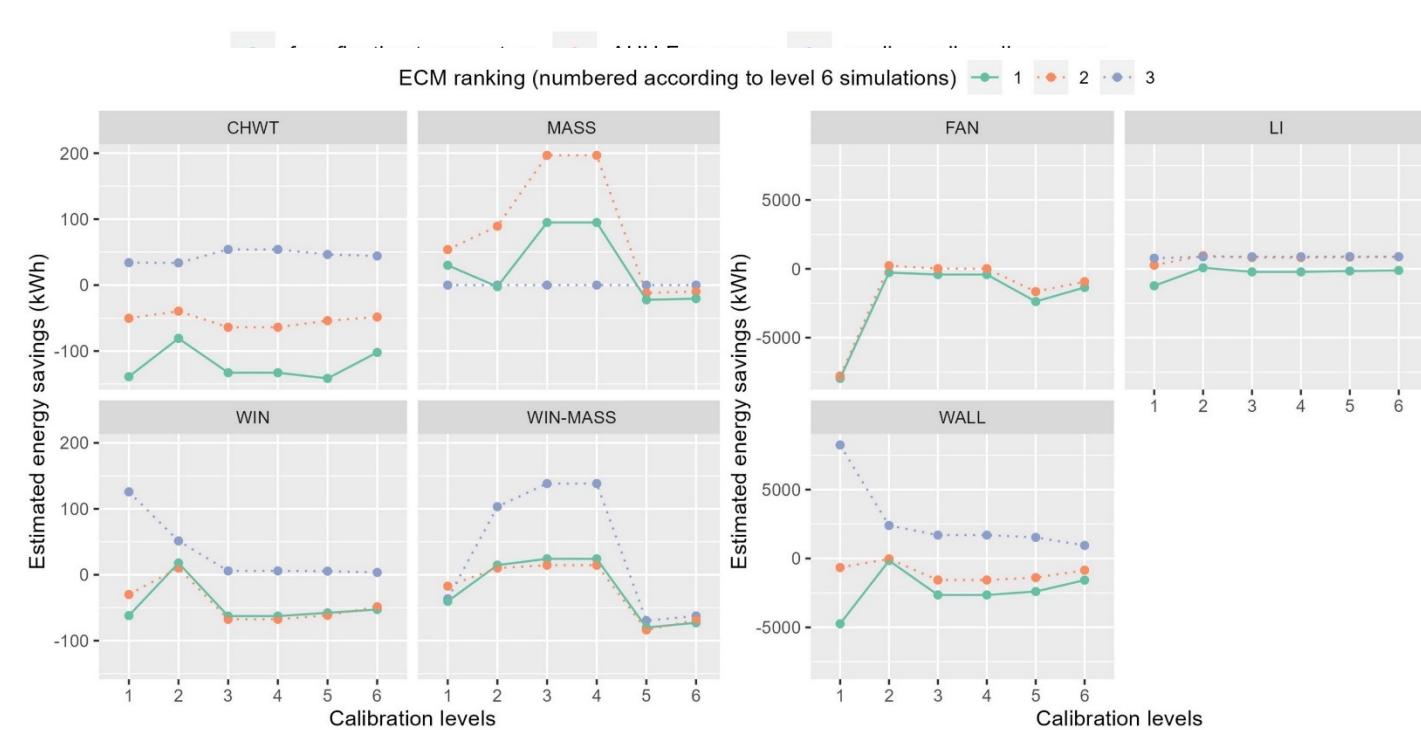
- Lower prediction error means better control for simple dynamics
- For complex buildings, only led to better control with **adequate model**
- **Critical physical component** should be preserved (partition capacitor here)

Energyplus for retrofit analysis



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

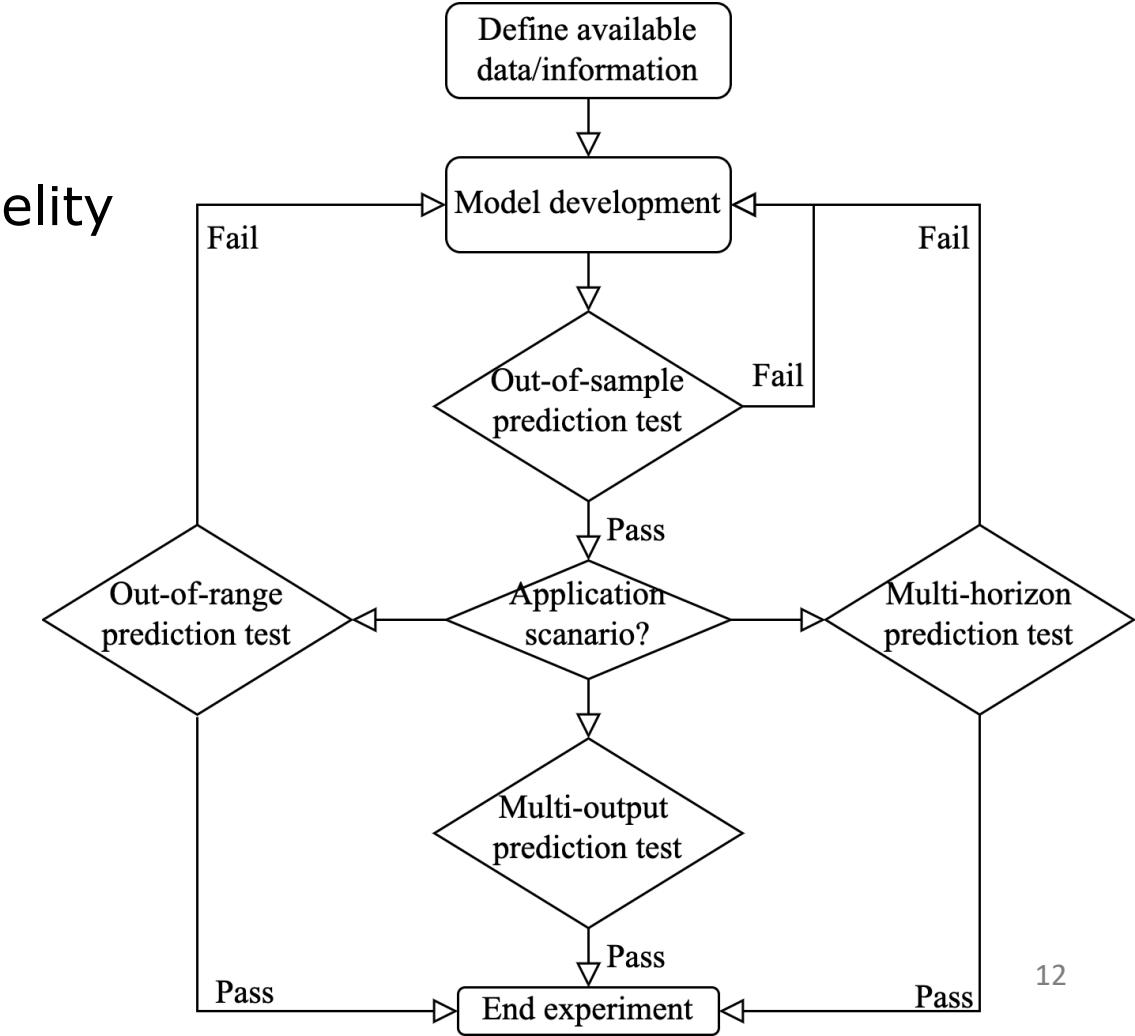
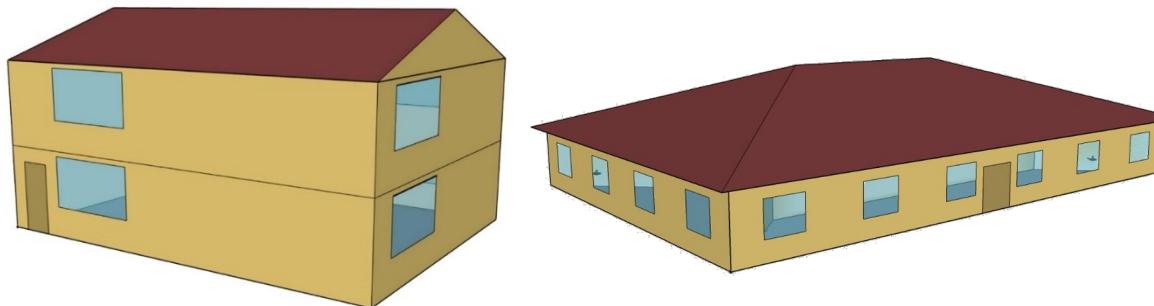
- More information gradually lowered CVRMSE
- Only matters for some design decisions
- Accurate estimation of energy saving requires information corresponding to the ECM



Co-simulation for every building is impractical

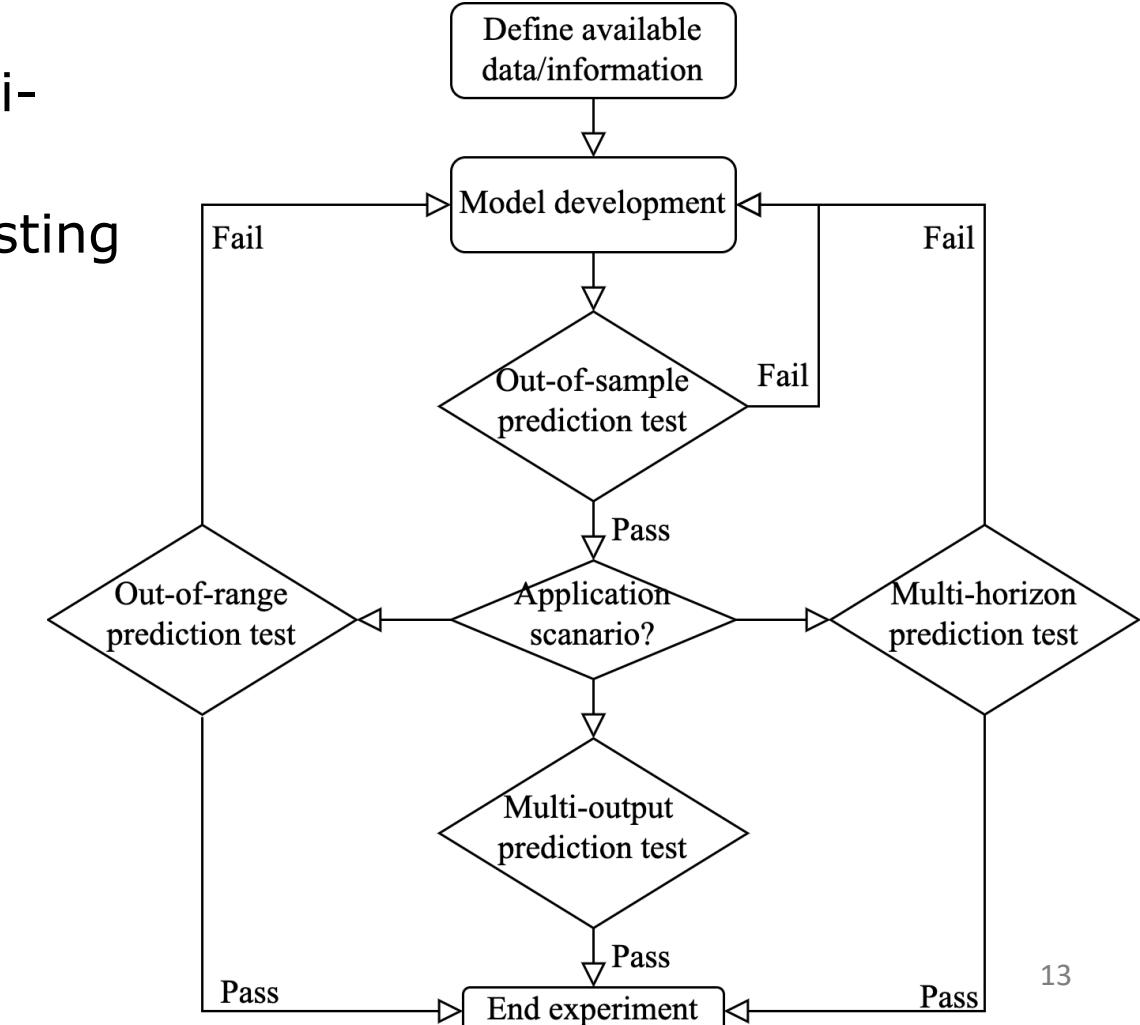
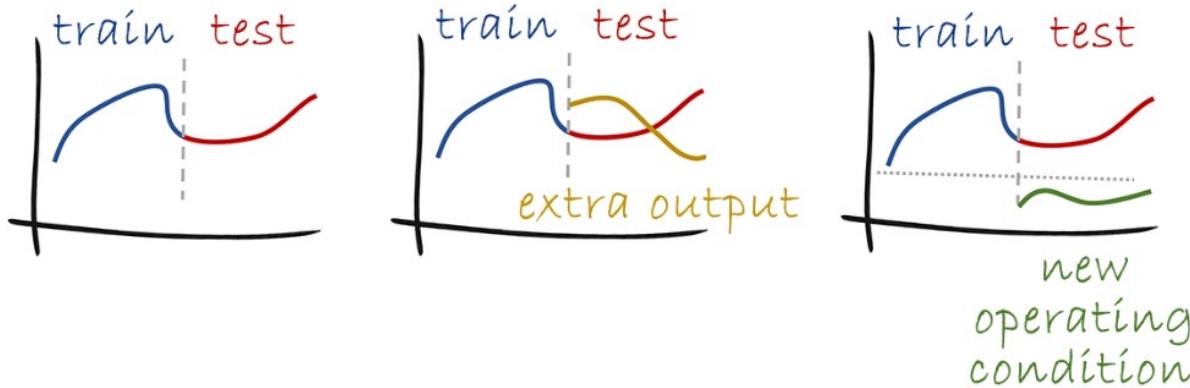
Prediction/extrapolation capability is the key

- 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

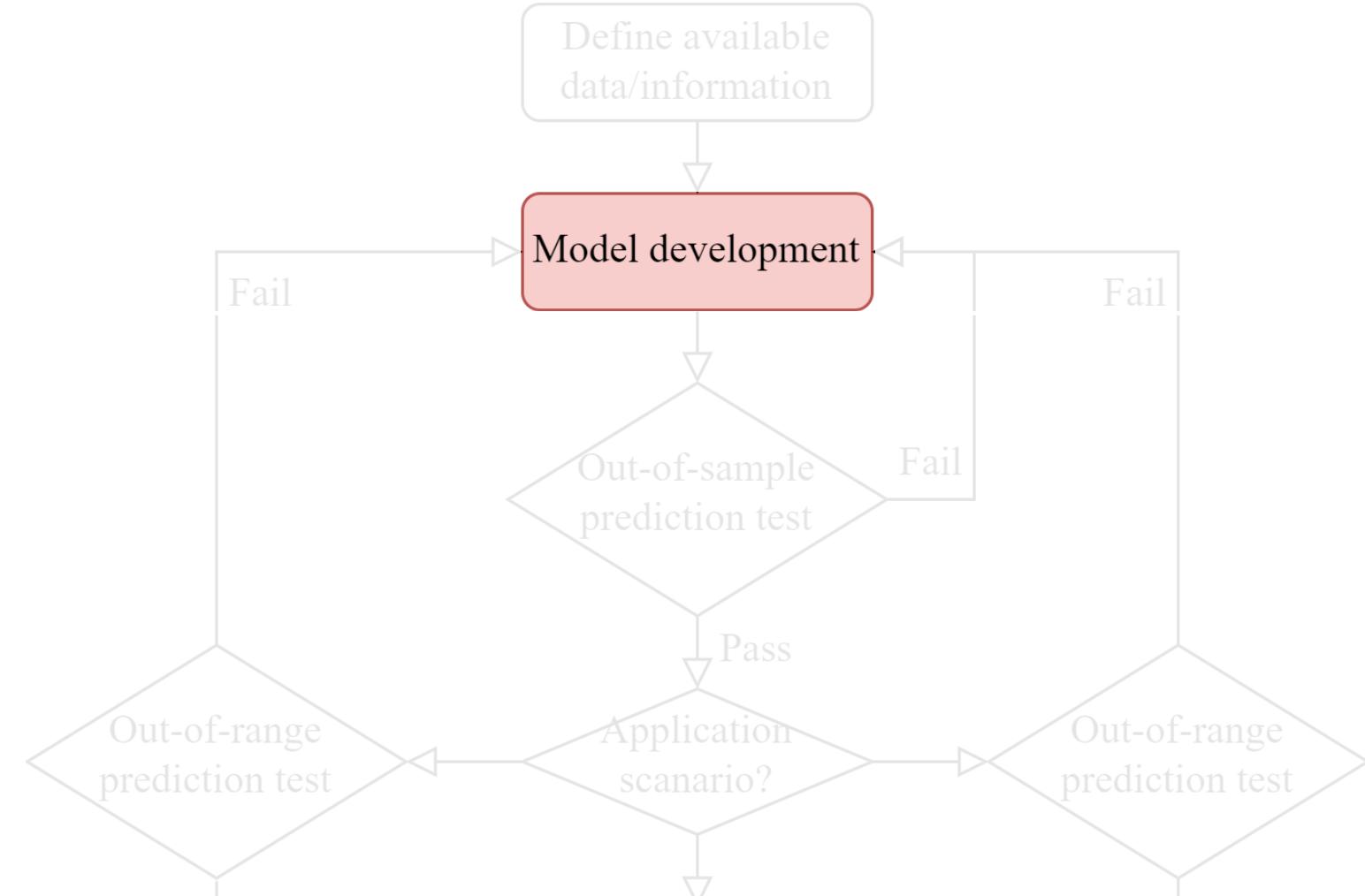
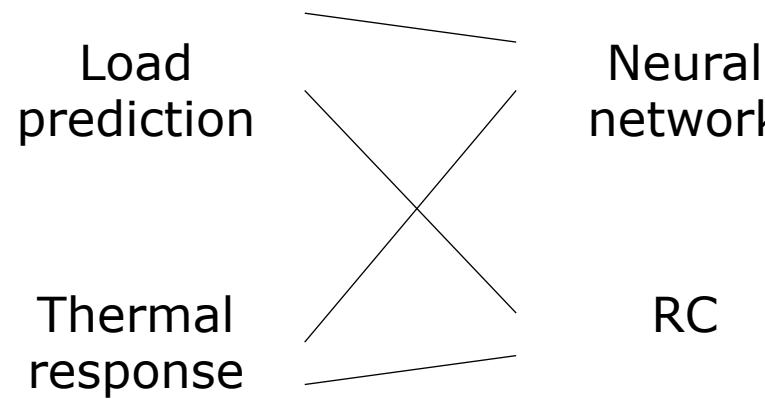
- Out of sample as a must
- Optional more demanding tests, e.g. multi-horizon/resolution
- Ability to generate application-oriented testing data (python script)

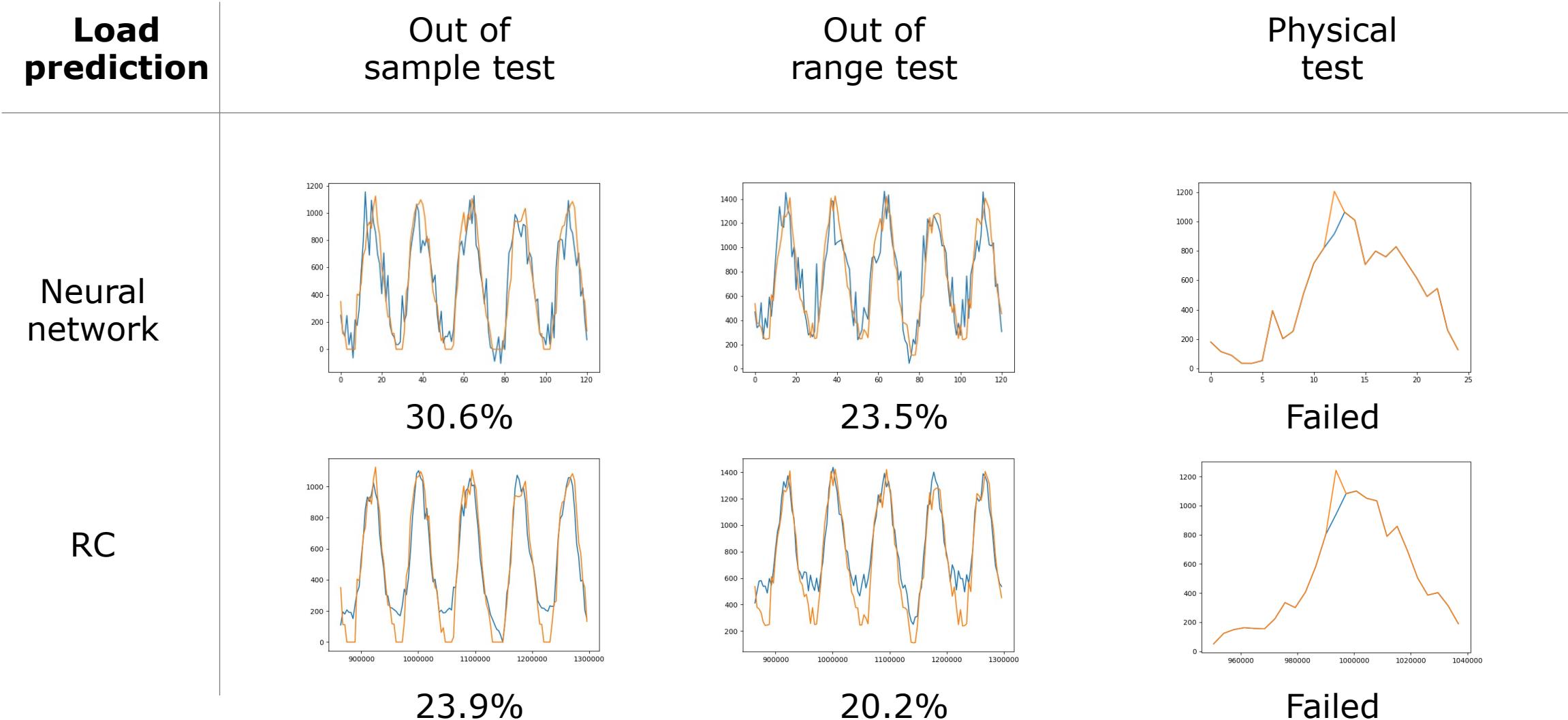


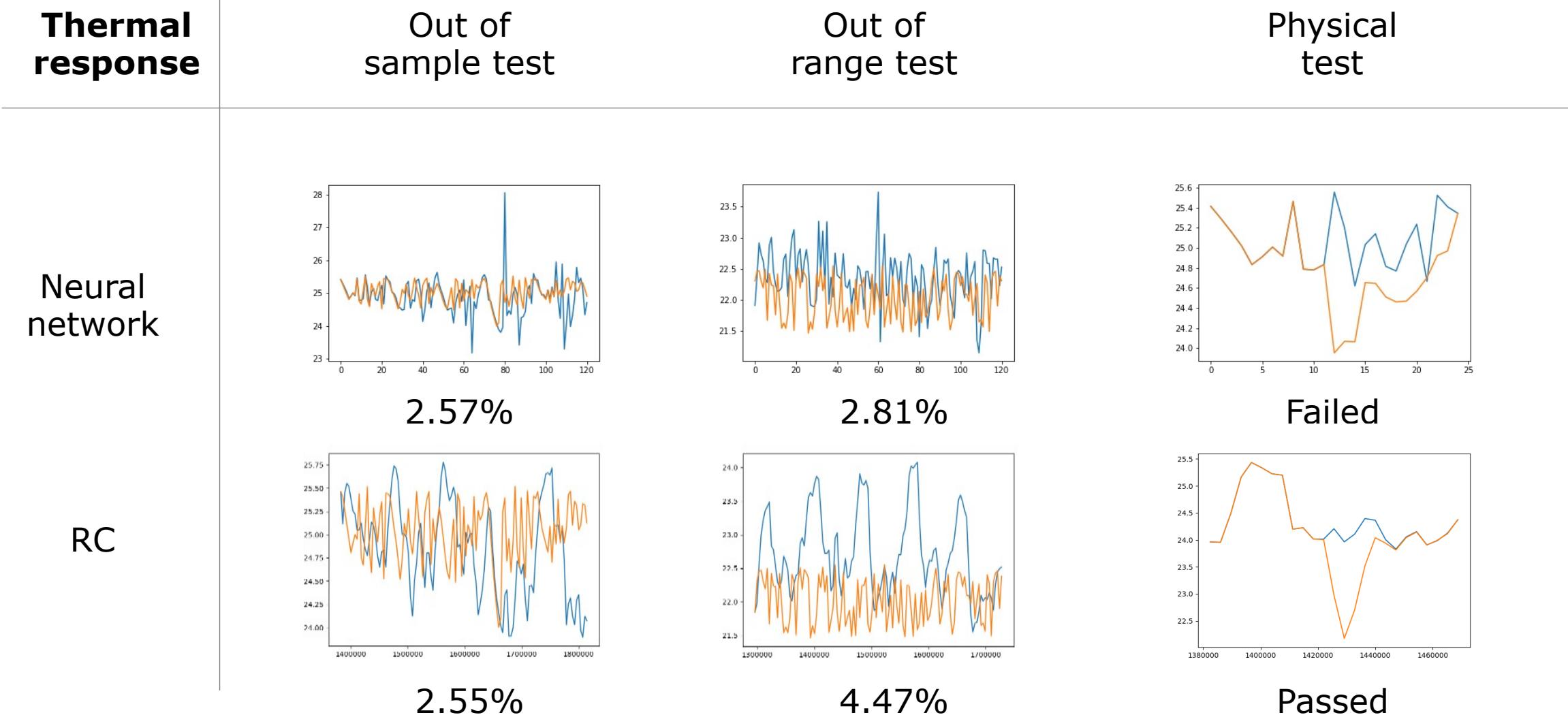
How “physical” does the model need to be?

White/grey/black box

An example of pre-cooling







- 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/>