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Towards Reliable Digital Twin Applications in Buildings: a Data Perspective

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Digital twins in the building industry

OpenBlue Digital Twin | Overview | Spotlight: OpenBlue Digital Twin | Spotlight: OpenBlue Bridge | Contact Us

OpenBlue Digital Twin

- Locations, Events, Assets and People come together with Johnson Control's 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.



3D BIM

Digital Twin Visualization

Digital Twinning is integrated into the 3D BIM for contextual visualization, enabling an immersive analysis of your

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Building Twin

The Building Twin allows a connected, digital representation of a physical building. It brings together dynamic and static data from multiple sources in 2D/3D models and enables informed and effective decisions to be made. It bridges the physical and digital worlds through sensors that collect real-time data within the physical environment. It provides real-time understanding of how a building is ...

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Existing digital twin solutions

- 3D BIM model
- Data acquisition
- Data visualization
- Energy prediction & evaluation
- ❖ Energy conservation services V.S. scalable solution/product

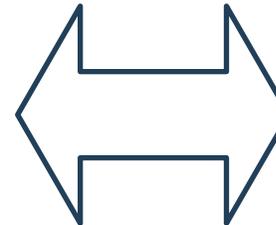
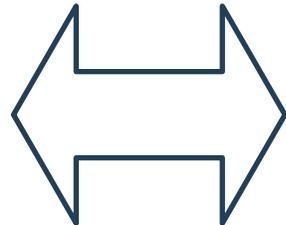
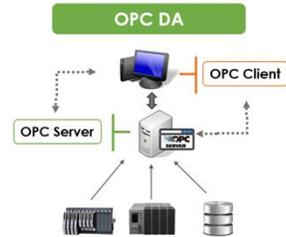
Digital twins in the building industry

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



Real-time data exchange

Web-based data acquisition and exchange



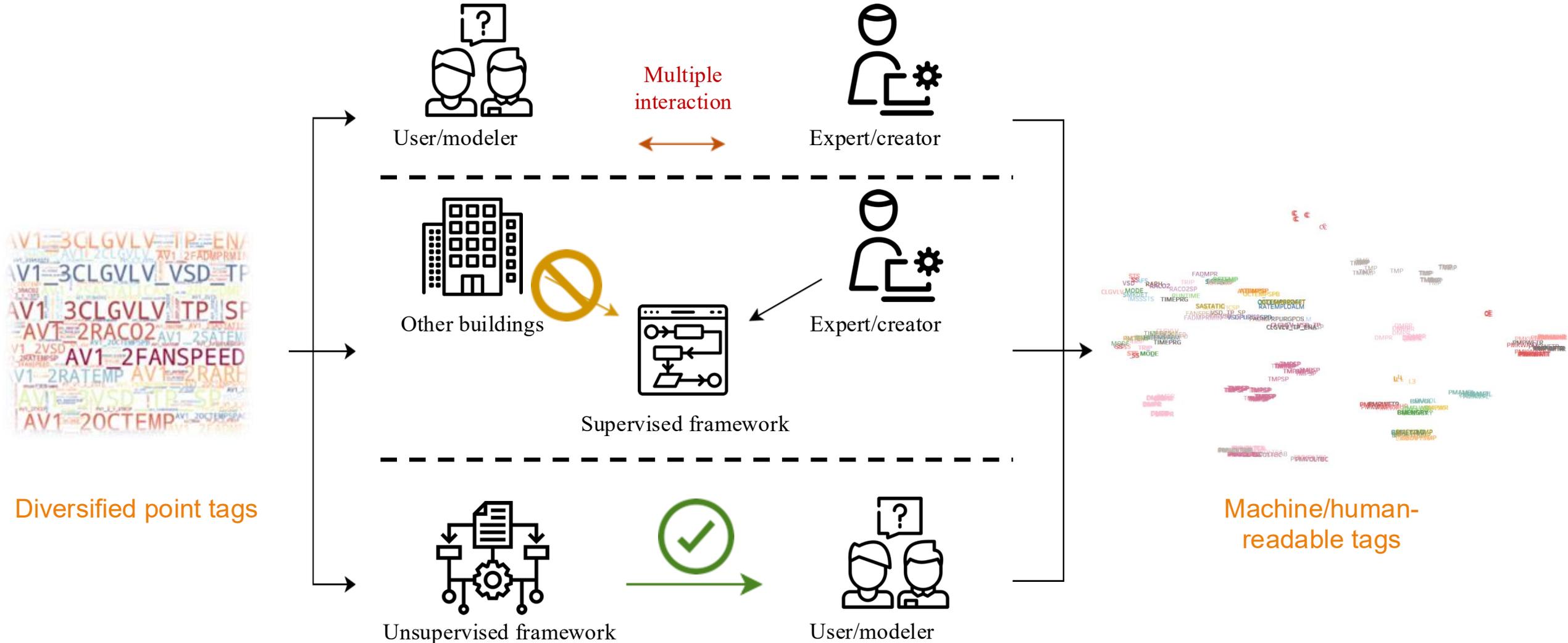
Buildings and building management systems

Central data server

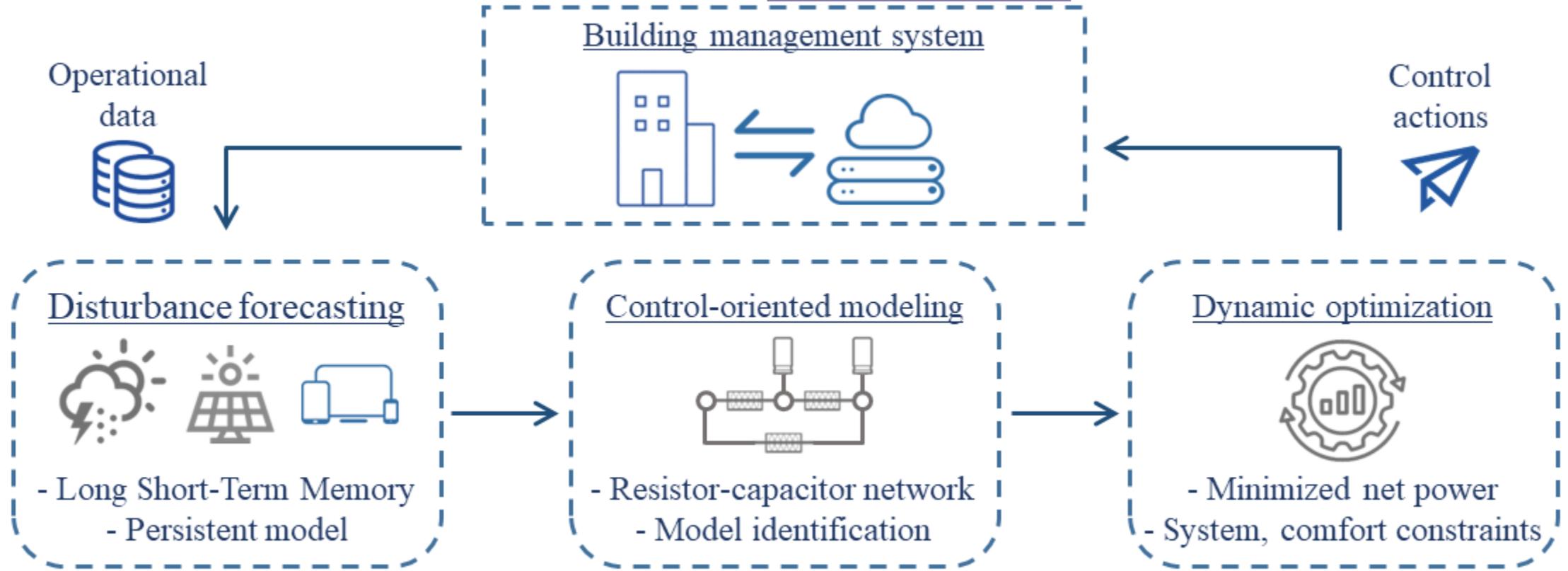
Restful API

Applications

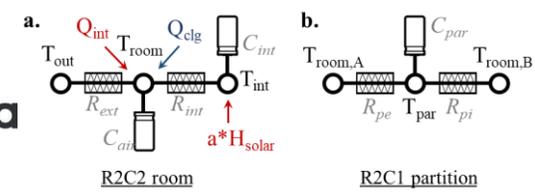
Automated tag recognition by unsupervised learning



Buildings as living labs



inputs: time, history
 lookback: 120min
 horizon: 60min



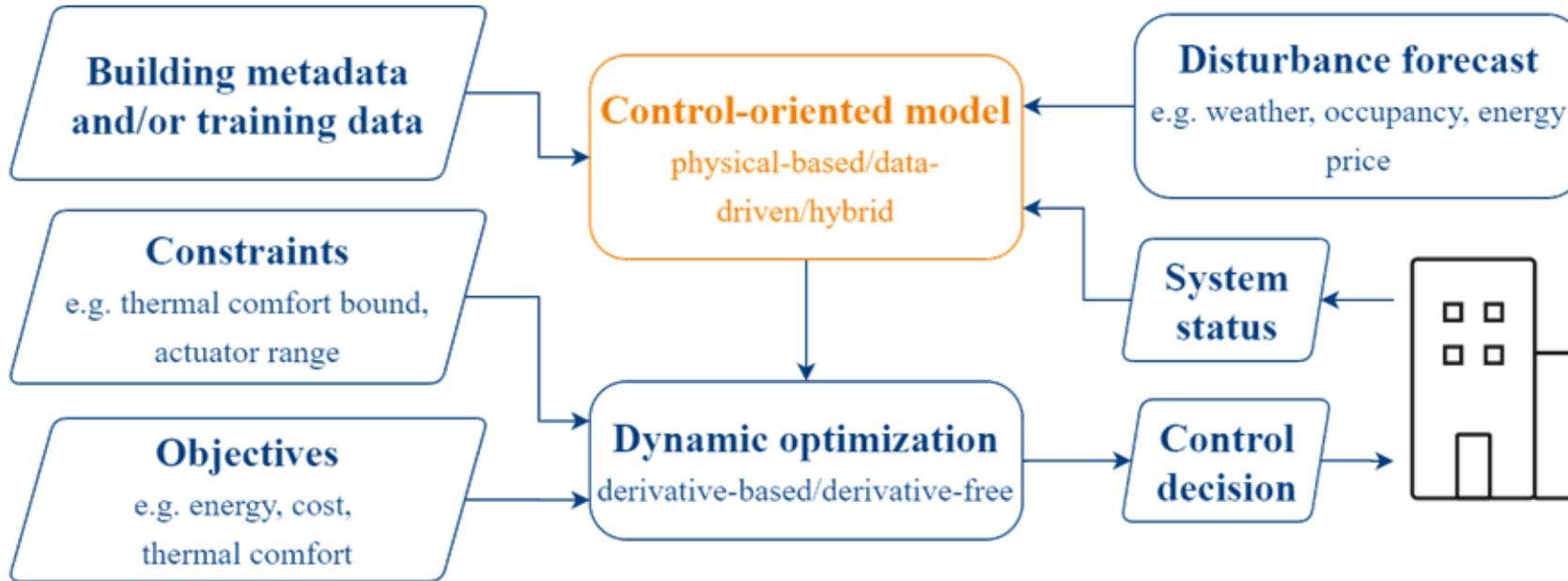
$$J = \int_{t_0}^{t_0+60min} (P_{PV} - P_{total})^2 + q_c \sum_i^k (T_{RM,i} - 26)^2$$

$$s.t. \quad \dot{V}_{SA,min,i} \leq \dot{V}_{SA,i} \leq \dot{V}_{SA,max,i}$$

$$25 \leq T_{RM,i} \leq 28$$

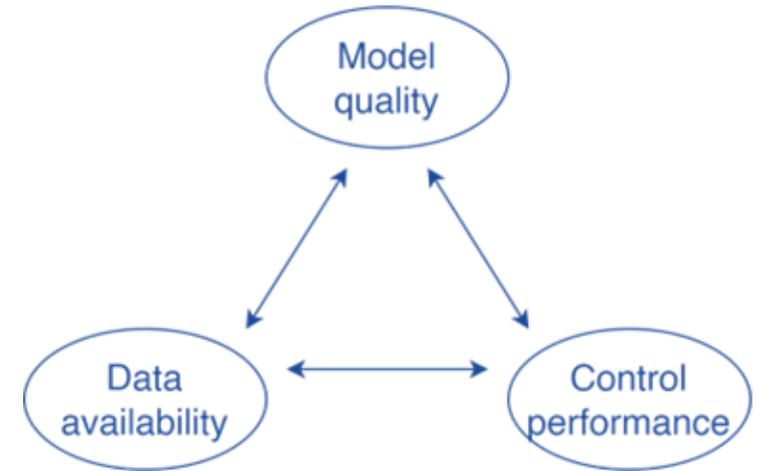
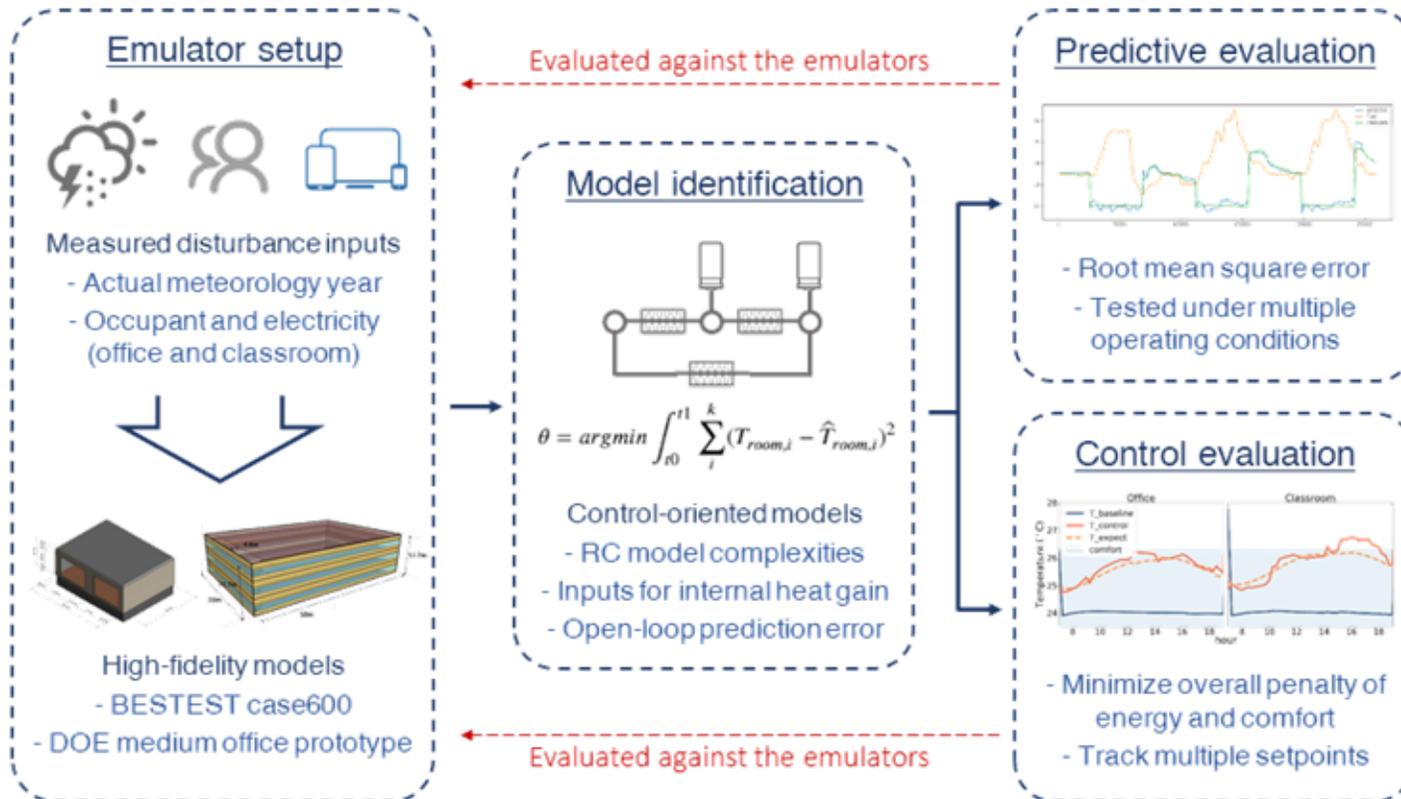
Impact of data on identification and optimization

MPC as an example



- Three main processes: disturbance forecast, **control-oriented model**, dynamic optimization
- Control-oriented model is the cornerstone, **data** required for model establishment
- Up to **70%** of total effort is attributed to model construction and calibration

Experimental design



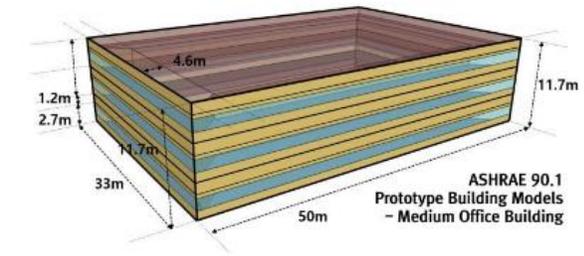
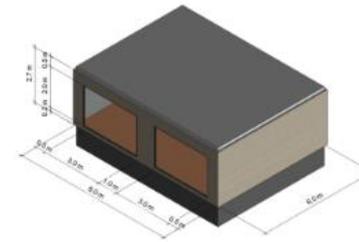
The relationship between data, model, and control?

- Virtual and actual testbeds
- Series of factorial experiments
- Quantified relationship

Emulator configurations

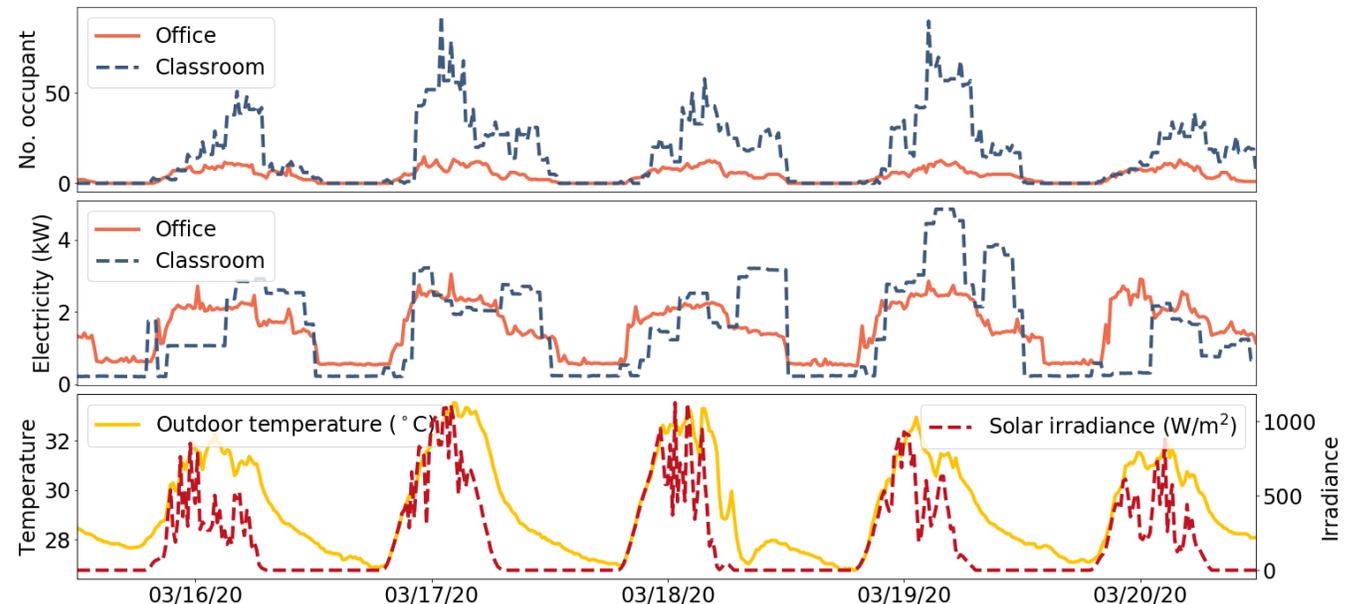
Single-zone experiment

- BESTEST Case 600
- Fan coil unit with PI local control
- No. occupant and electricity load from an actual office and classroom

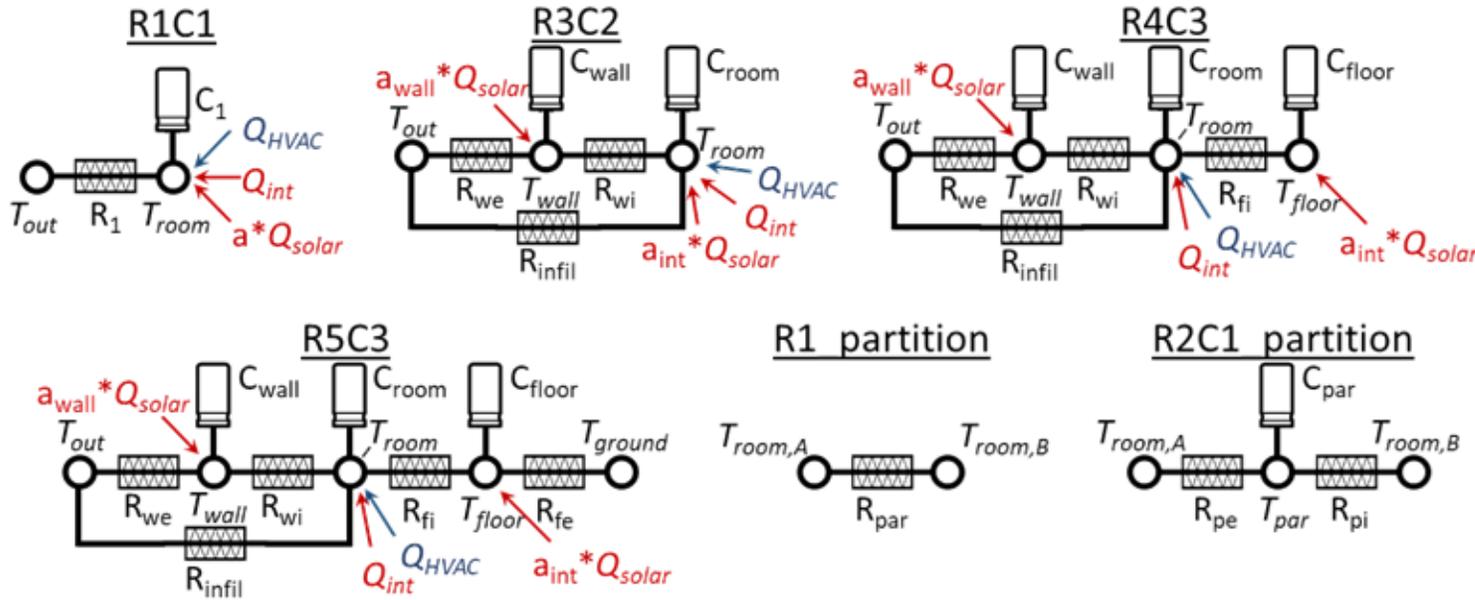


Multi-zone experiment

- A floor of DOE medium office
- Internal disturbance profiles randomly sampled for each room on each day



Model identification



- Increasing RC model complexity
- 6 alternative inputs for occupant-related disturbances
 - none, schedule, plug, CO₂, plug+CO₂, ideal

- Identified with the same dataset

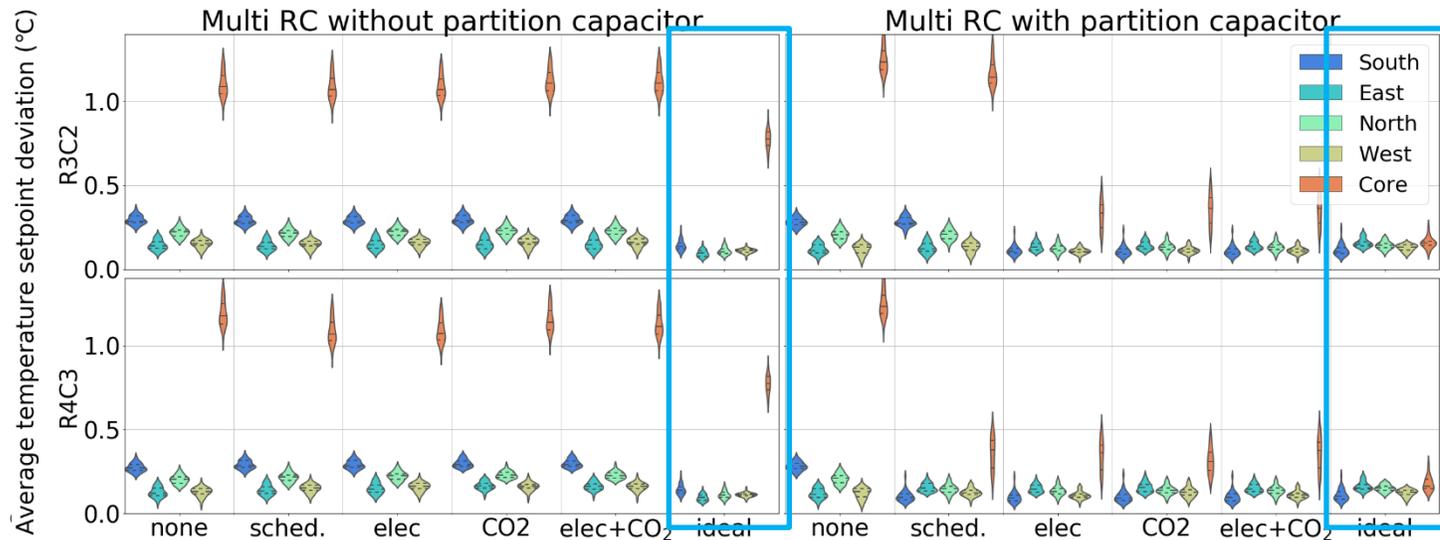
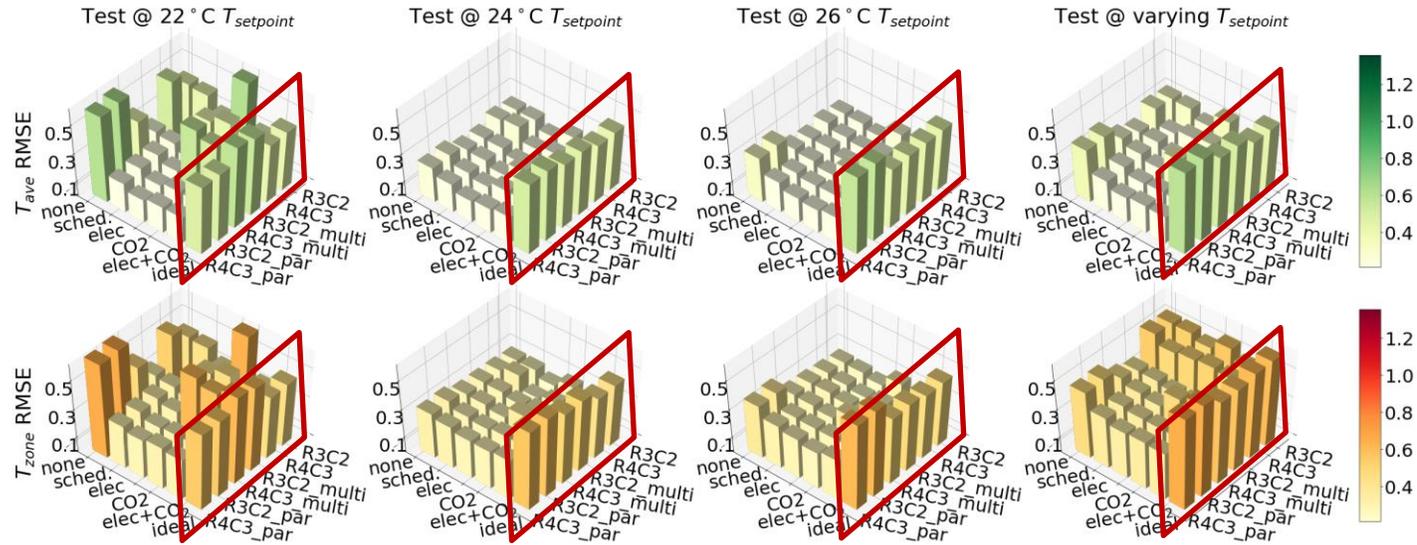
$$\theta = \operatorname{argmin} \int_{t_0}^{t_1} \sum_i^k (T_{room,i} - \hat{T}_{room,i})^2 dt$$

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

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

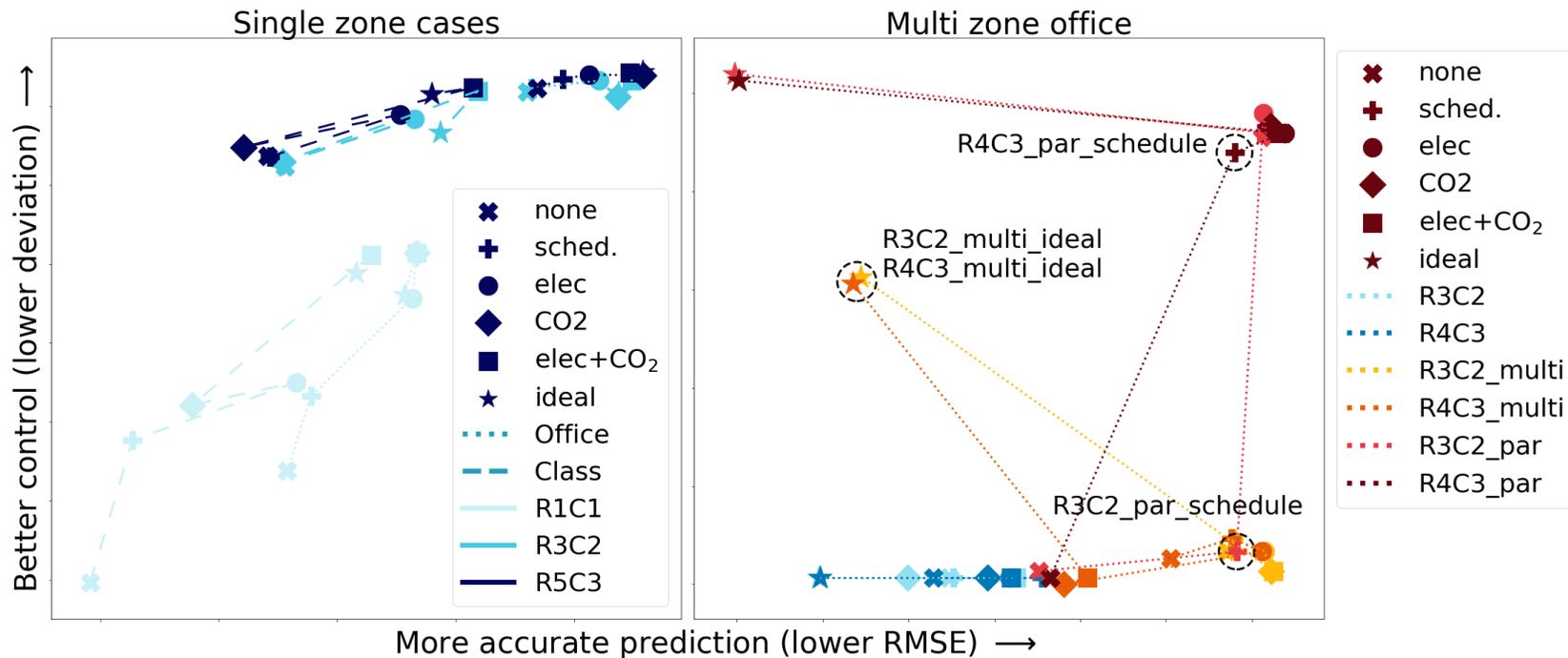
- Tested under different conditions (extrapolation capability)

Multi-zone results



- 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

Summary of results

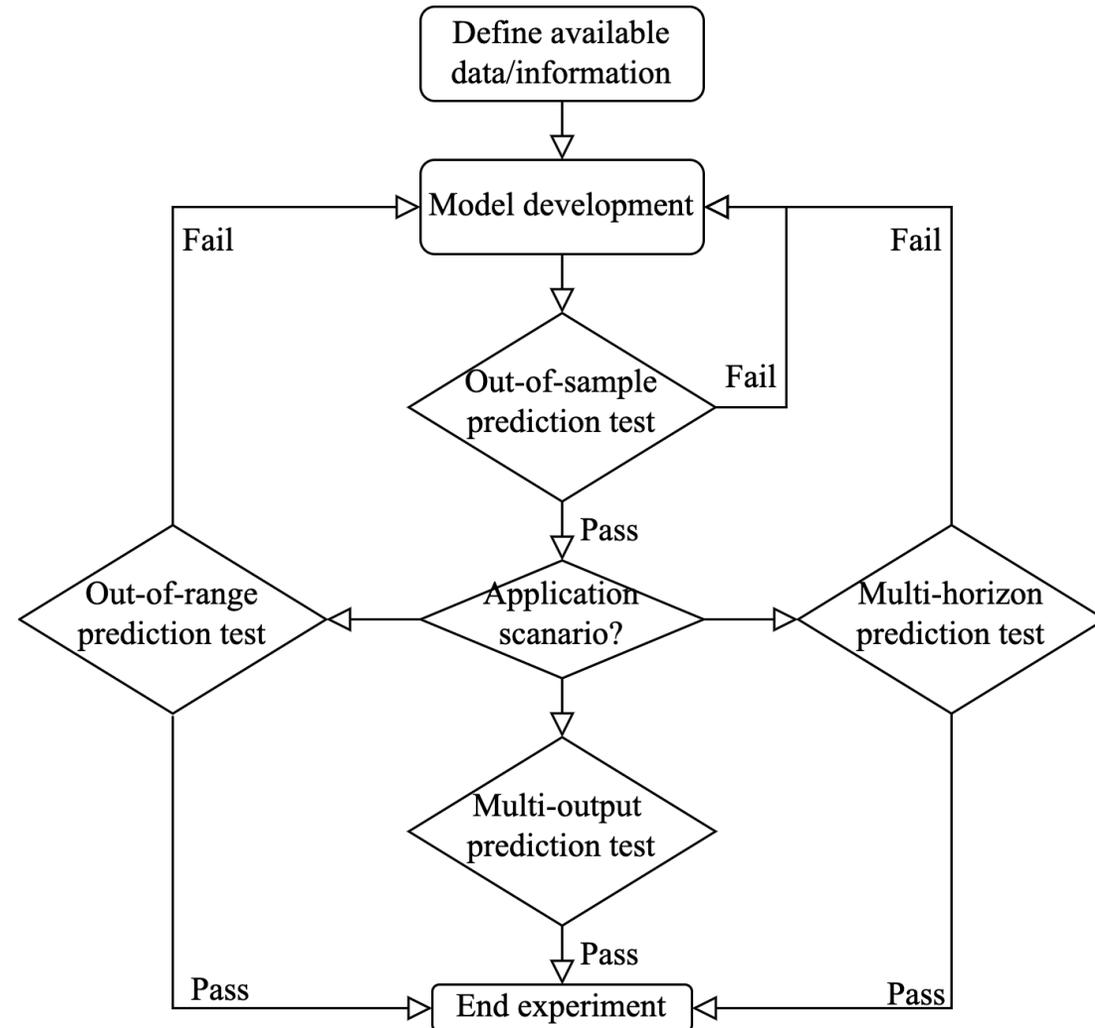
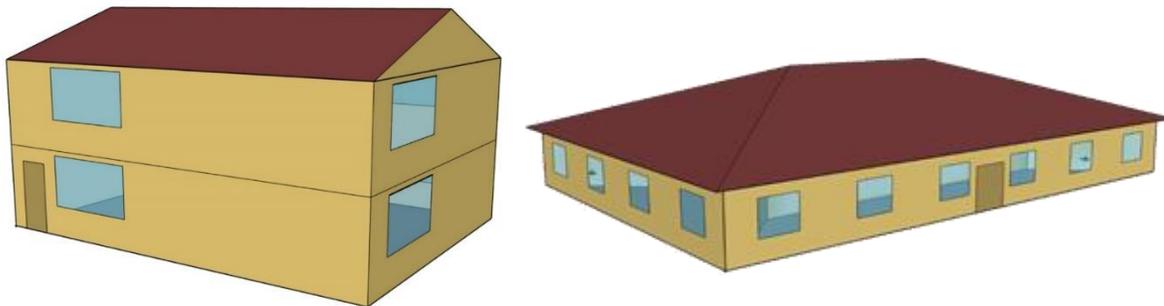


- Lower prediction error means better control for simple dynamics
- For complex buildings, only led to better control with **adequate model**
- **Critical physical component** should be preserved (partition capacitor here)

Co-simulation for every building is impractical

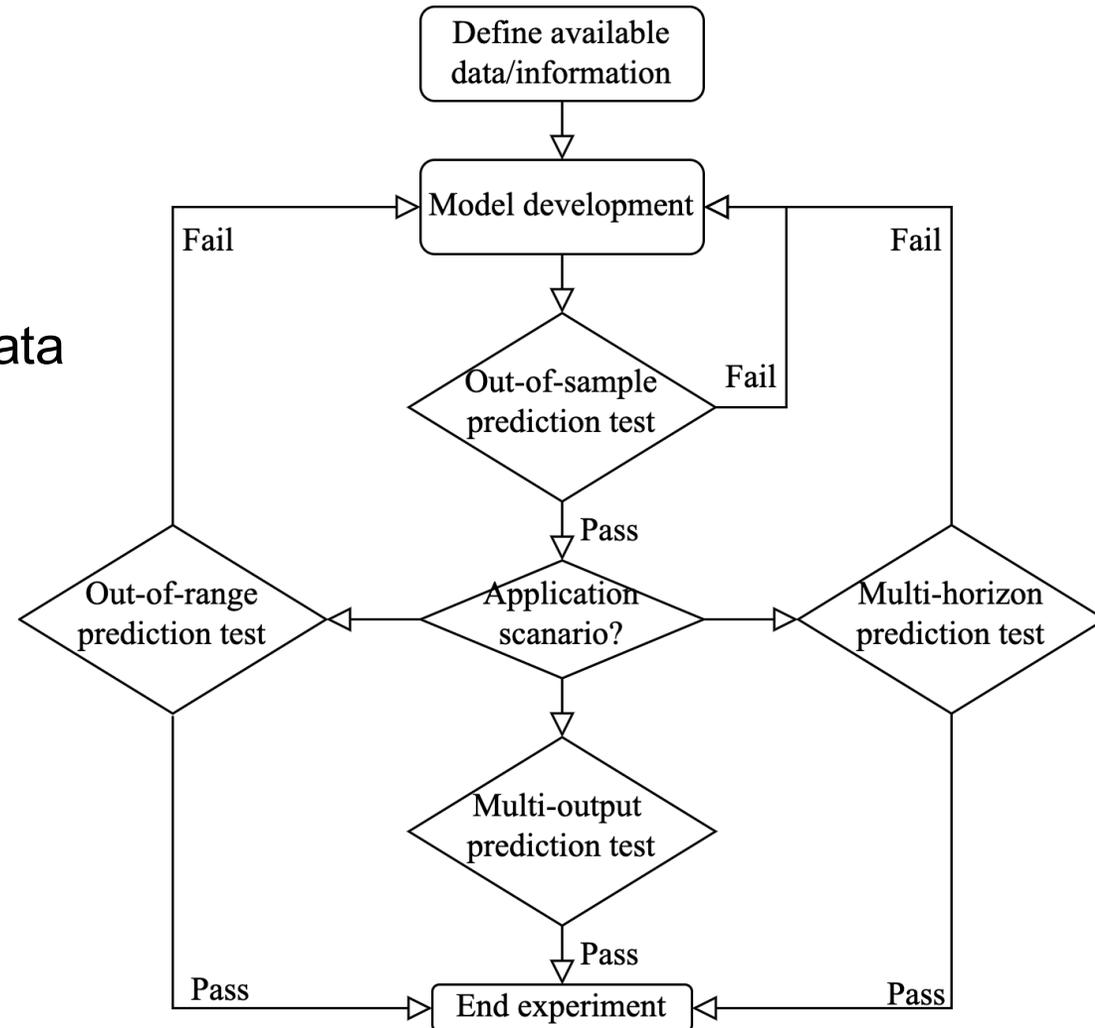
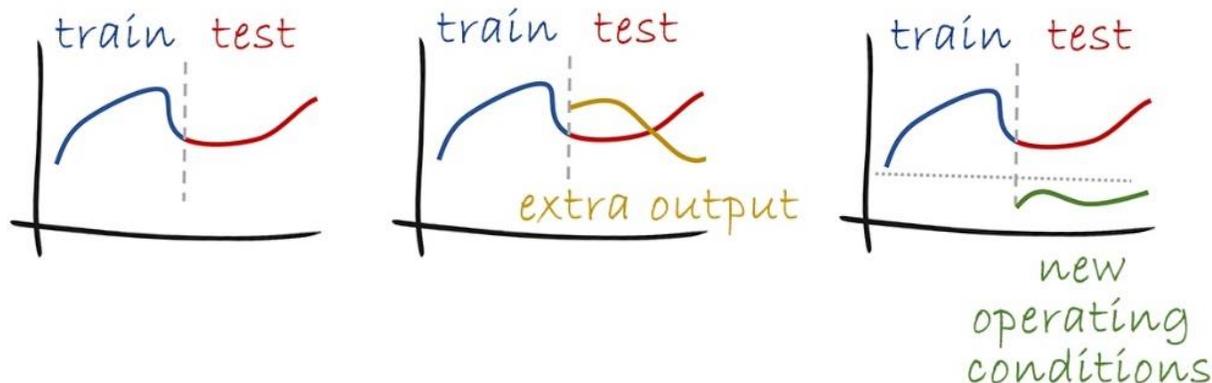
Prediction/extrapolation capability is the key

- 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

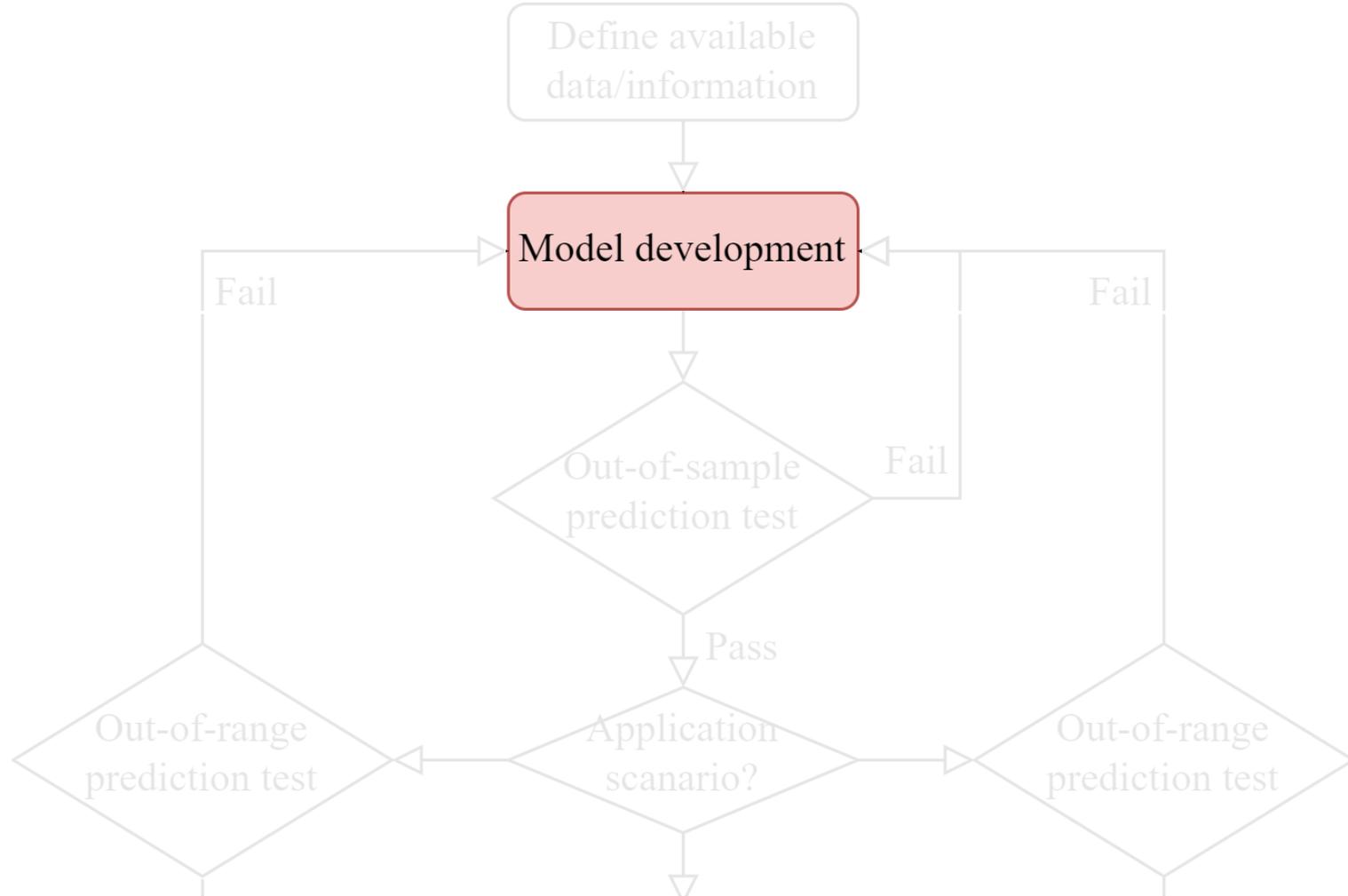
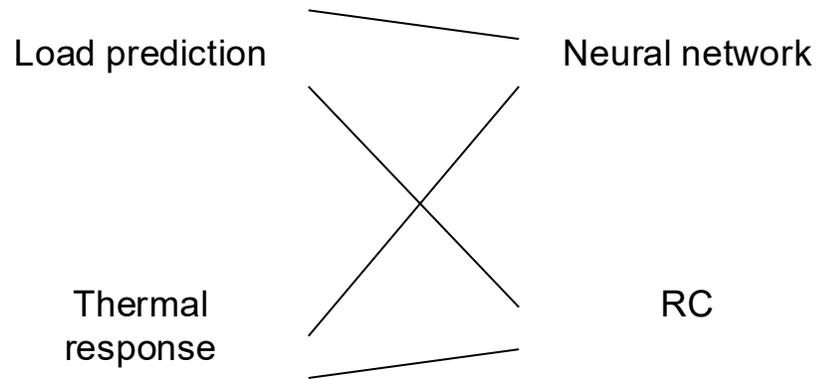
- Out of sample as a must
- Optional more demanding tests, e.g. multi-horizon/resolution
- Ability to generate application-oriented testing data (python script)



How “physical” does the model need to be?

White/grey/black box

An example of pre-cooling



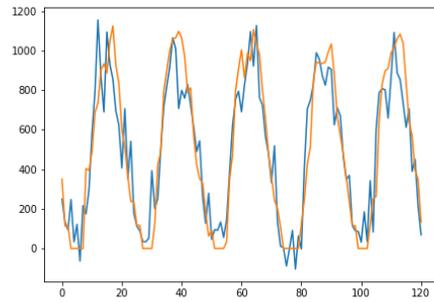
Load prediction

Out of sample test

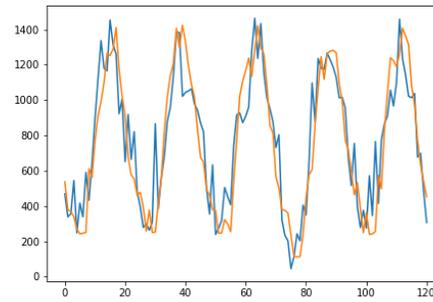
Out of range test

Physical test

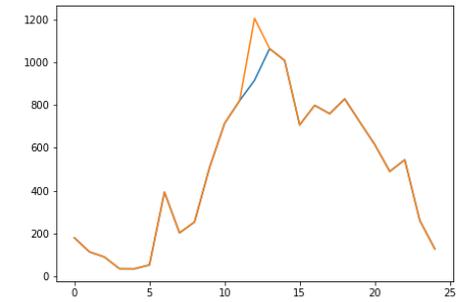
Neural network



30.6%

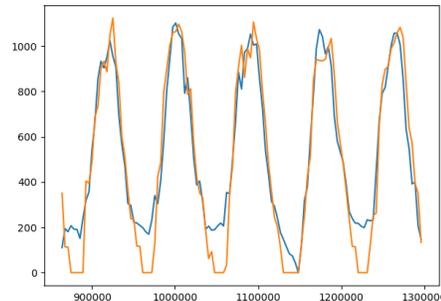


23.5%

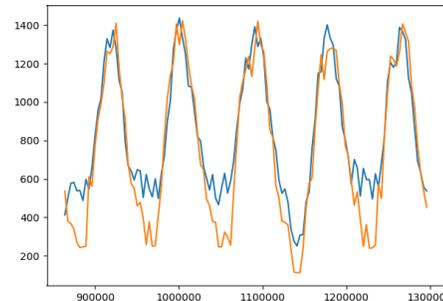


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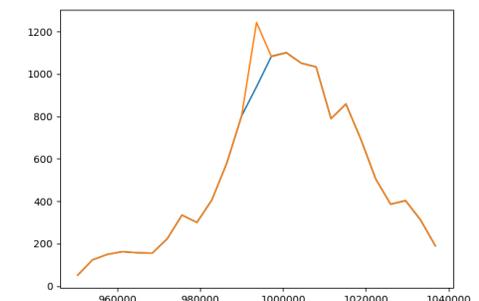
RC



23.9%



20.2%



Failed

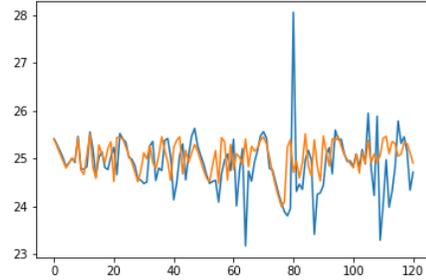
Thermal response

Out of sample test

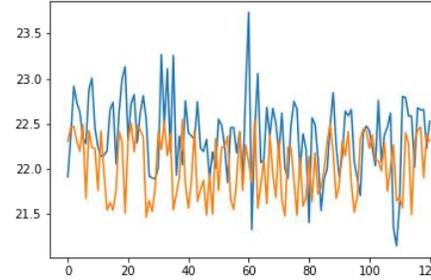
Out of range test

Physical test

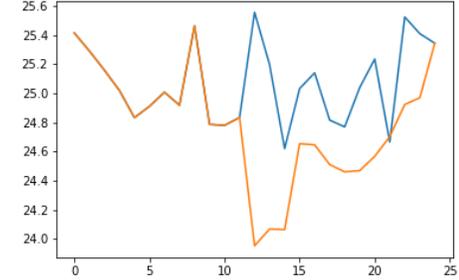
Neural network



2.57%

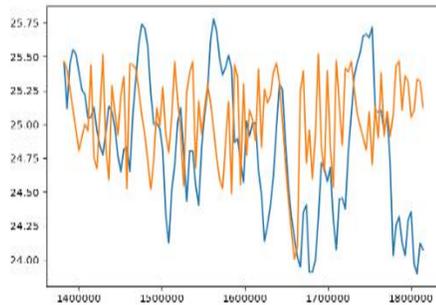


2.81%

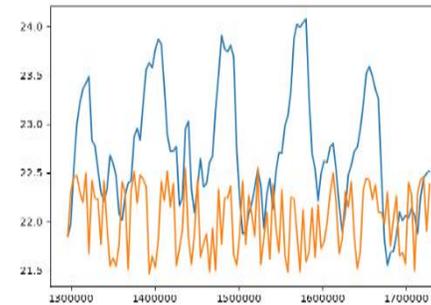


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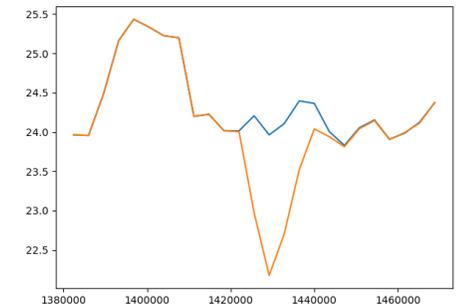
RC



2.55%



4.47%



Passed

Discussion

- Physical systems set the upper bound of energy performance, data availability determines the actual performance
- Traditional error-based evaluation could be misleading
- Data as the fuel: towards data-centric digital twins (strategic data acquisition for training and testing)
- Model developments need to cater for the downstream application (predictive scenario)

Thank you!

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