CPS Medium: Physics-informed Learning and Control of Passive and Hybrid Conditioning Systems in Buildings

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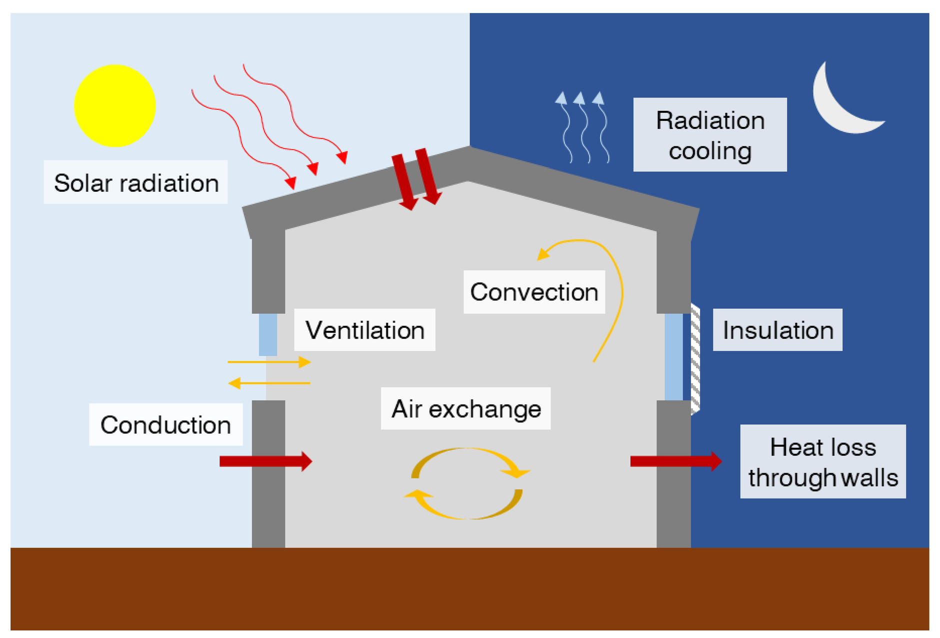
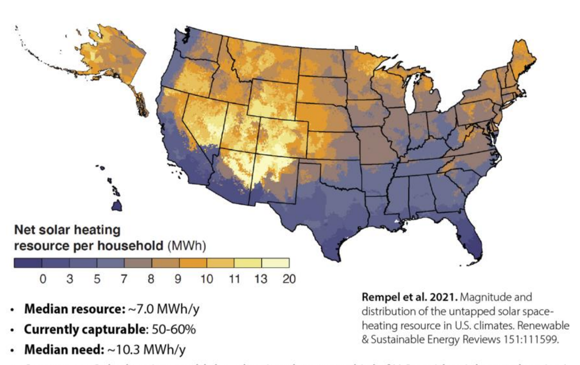
Goal: Design model-based and data-driven strategies for controlling passive and hybrid (active + passive) building conditioning systems



Motivation: Harnessing passive climatic resources for heating and cooling in buildings will provide significant energy savings



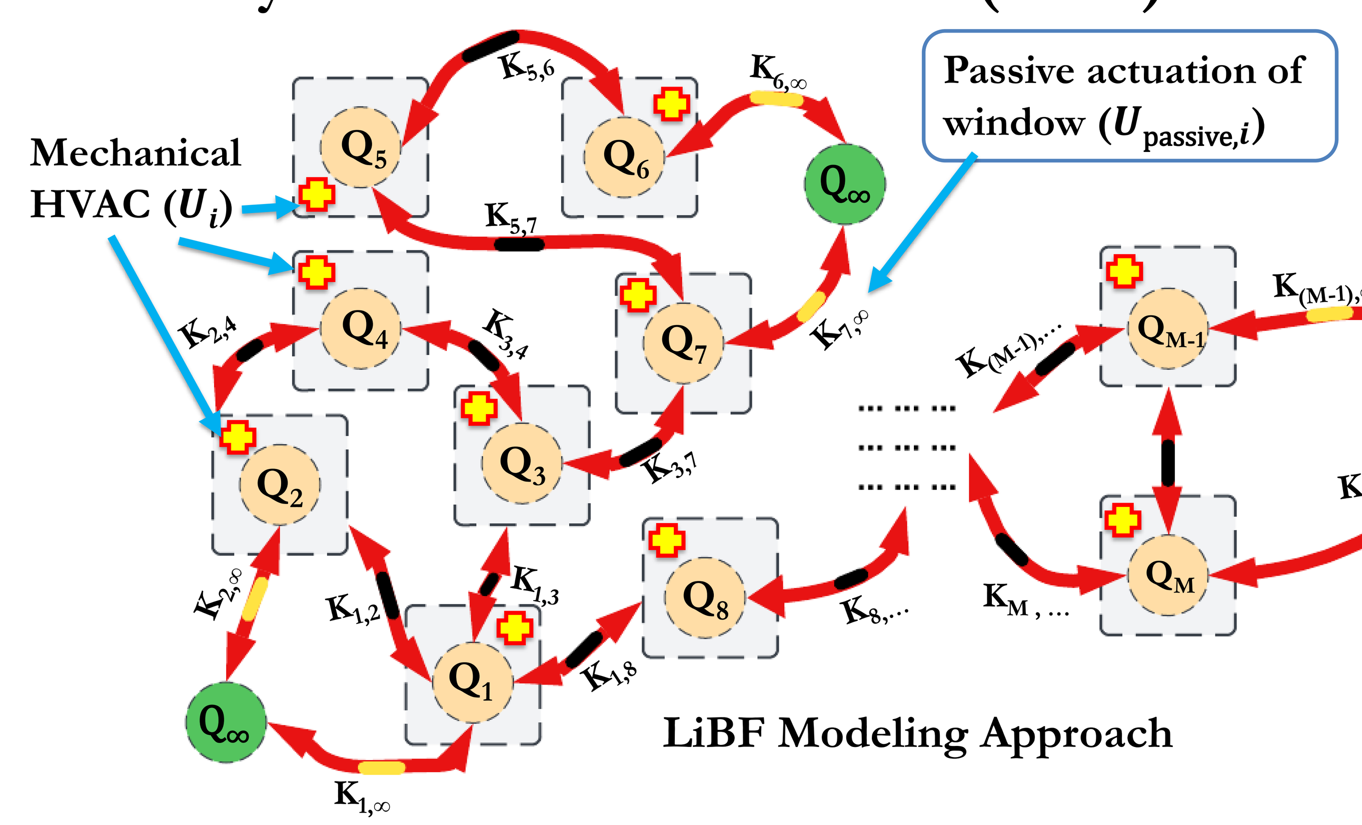
Challenges:

- Passive climatic resources such as available solar radiation, outside air (temperature and quality), etc. are time-varying and unpredictable: system must respond and adapt quickly.
- Control strategies must be climate-specific, portable across building types and layouts, and easily deployable for wide adoption.

Key innovation and approach:

- Novel graph-based model for these systems: combines physics-based knowledge (e.g., conservation laws) with data-driven approaches
- Exploit this unique model structure for both optimal control design as well as for providing certificates (e.g., stability, passivity, robustness to parameter variation)
- Incorporate learning, forecasts, and human intervention into control strategy

Locally-interactive Bilinear Flow(LiBF) Models for Hybrid Conditioning Systems



Q_∞ = Ambient State
Q_i = State of i^{th} Zone

$K_{ij}(\theta_{ij})$:= Flow Coefficient (thermal conductance between zone i and j).
θ_{ij} := Door Opening fraction

N_i : set of neighboring nodes for i^{th} node. For example, for Zone 1, the set of neighboring nodes will be, $N_1 = \{2, 3, 8, \infty\}$.

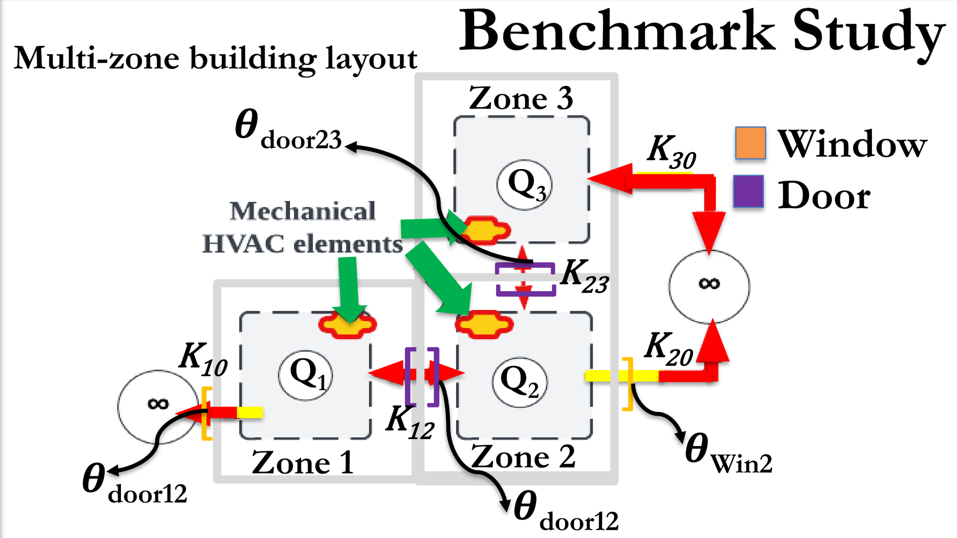
For i^{th} zone,
$U_{active,i}$ = Actuation of the active mechanical HVAC;
$U_{passive,i}$ = Actuation of natural air/heat flow.

Physics-informed Graph-based Model

$$C_i\dot{Q}_i = \sum_{j\in N_i} K_{ij}(\theta_{ij})(Q_j - Q_i) + B_i(U_{active,i})Q_i + B_{i\infty}(U_{passive,i})Q_\infty$$

Benchmark Study for Validating LiBF Modeling Approach

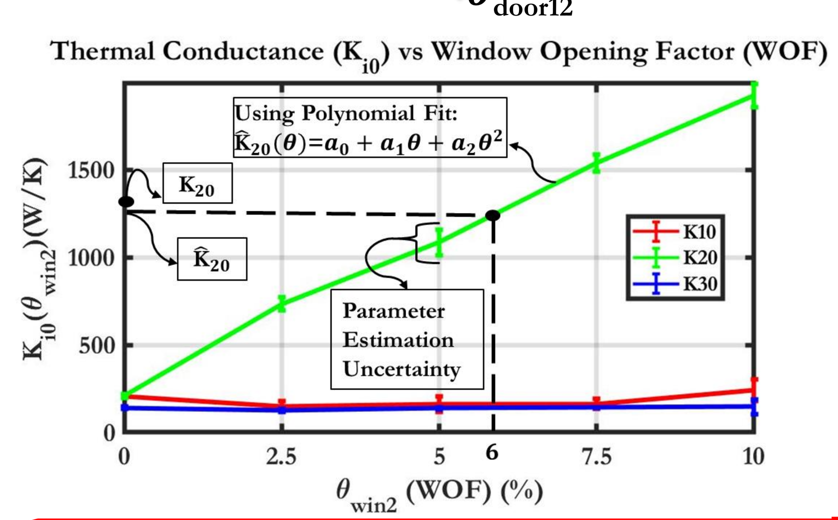
Multi-zone building layout

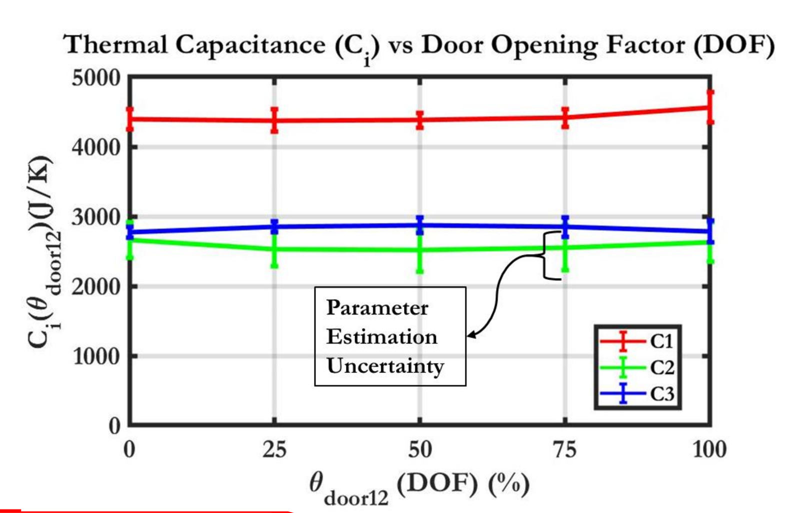


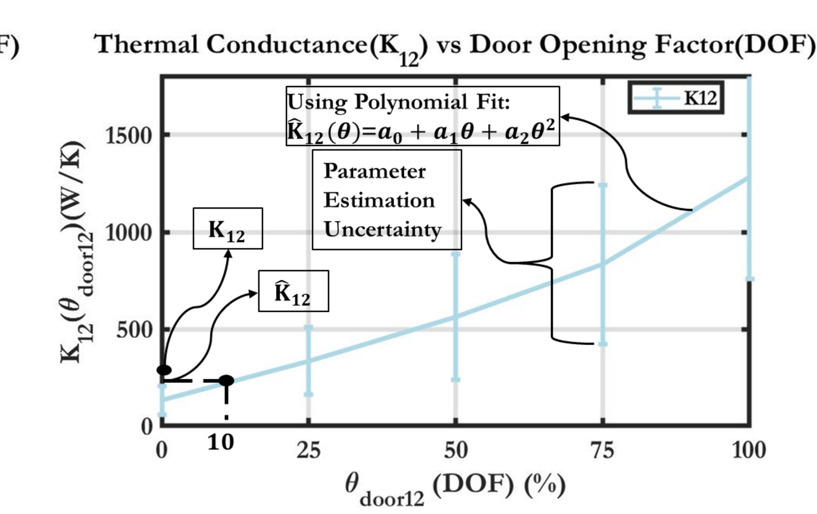
Model for the Multizone building

$$C_1\dot{T}_1 = K_{12}(\theta_{door12})(T_2 - T_1) + K_{10}(T_\infty - T_1) + U_1$$
$$C_2\dot{T}_2 = K_{12}(\theta_{door12})(T_1 - T_2) + K_{23}(T_3 - T_2) + K_{20}(\theta_{win2})(T_\infty - T_2) + U_2$$
$$C_3\dot{T}_3 = K_{23}(\theta_{door23})(T_2 - T_3) + K_{30}(T_\infty - T_3) + U_3$$

T_i = Temperature of Zone i, T_∞ = Outdoor Temperature, U_i = i^{th} zone heat input

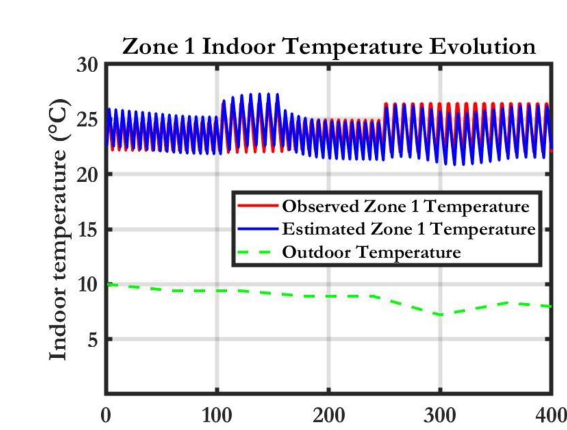


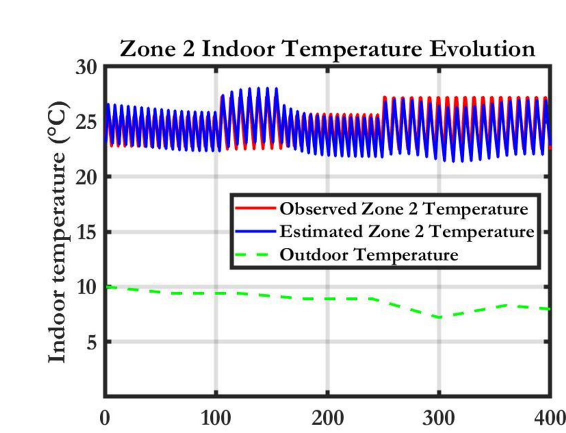




Key observations from study:

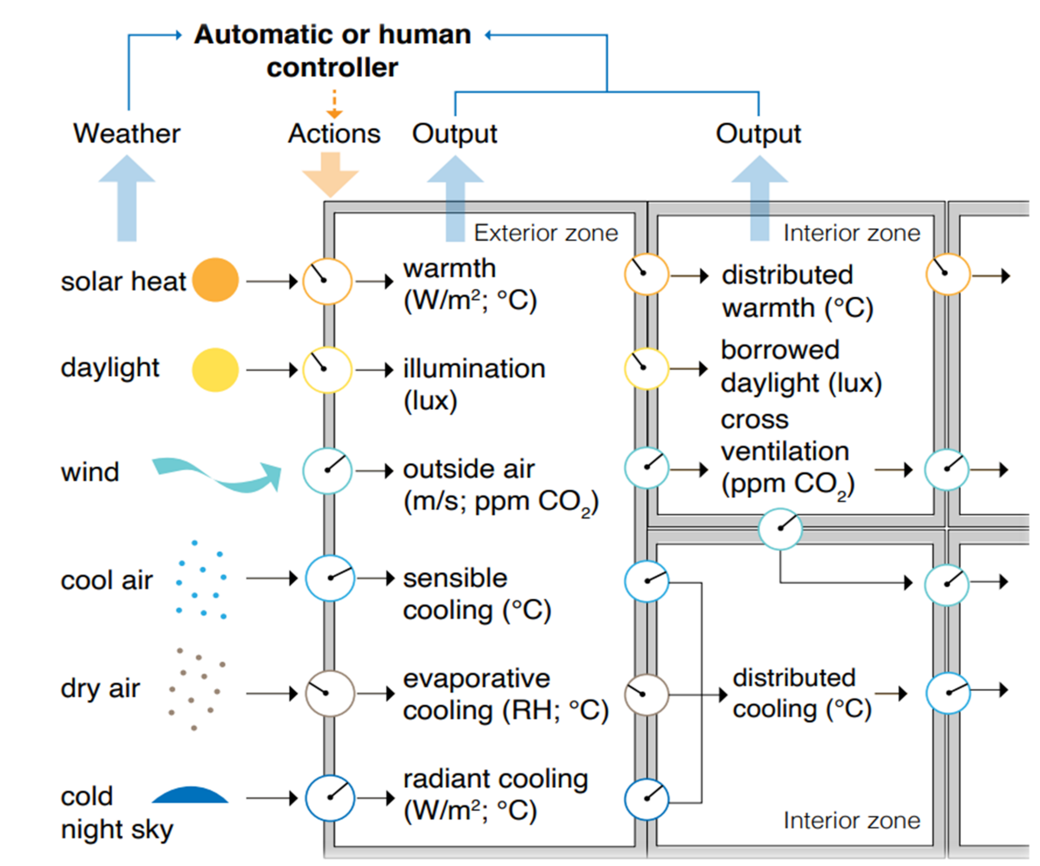
- ✓ LiBF model is able to capture the effect of passive controls (door and window opening factors)
- ✓ K_{20} increases as θ_{win2} increases (more passive resource harvesting), K_{10} and K_{30} remain unchanged with increasing θ_{win2}
- ✓ C_1, C_2, C_3 also unaffected by increasing θ_{door12}
- ✓ K_{12} increases as θ_{door12} increases (increased inter-zone coupling)



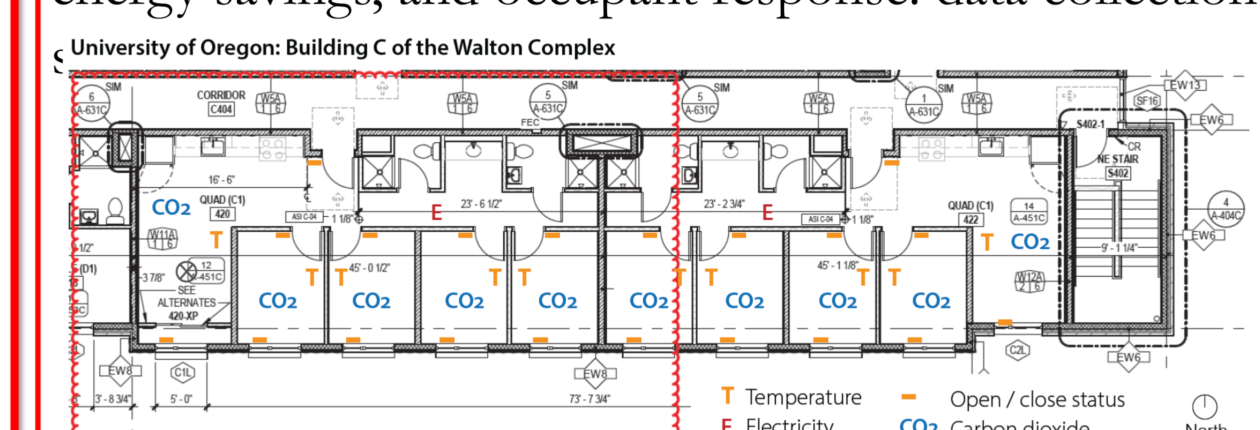


Validation: Zone 1, Zone 2 temperatures (compared against predictions from model)

Control of Passive & Hybrid Conditioning:



Validation Testbed (at Univ. of Oregon): Fully instrumented building with a digital twin (calibrated Energy Plus model) for modeling/control design, energy savings, and occupant response: data collection



Scientific Impact:

- New modeling paradigm for a broad class of CPS systems with coupled mass and heat transfer using graph-based locally interactive bilinear structure.
- Novel approaches for analysis and design of controllers that exploit this structure.

Broader Impacts:

- Adoption of passive mechanisms for heating, cooling and ventilation: increased energy savings
- Public perceptions about passive strategies influenced through outreach, awareness and education; and dissemination of research findings

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Table 1 : Change in conductance for different door/window opening fraction

[illegible]	[illegible]	[illegible]	[illegible]
18	4	30	12
10	3	11	14