Human behavior and social interactions in complex environments: The case study of the KTH Live-In Lab

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Modeling Behavior in Complex Environments

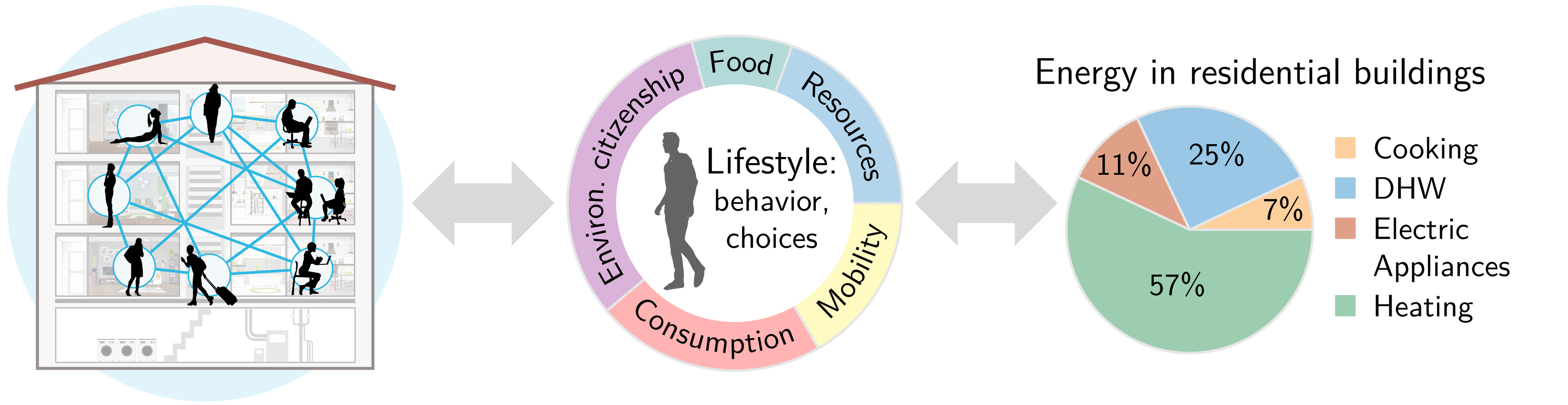
Context New urban cities and residential buildings are examples of complex cyber-physical-human systems (CPHS)

Challenges Limited comprehension of bidirectional interactions between humans and environmental conditions

Research directions

- What influences occupants' behavior pattern related to window operation in buildings?
- Can sustainable behaviors diffuse within social groups?
- How can ultimately the understanding of behavioral dynamics trigger energy efficiency?

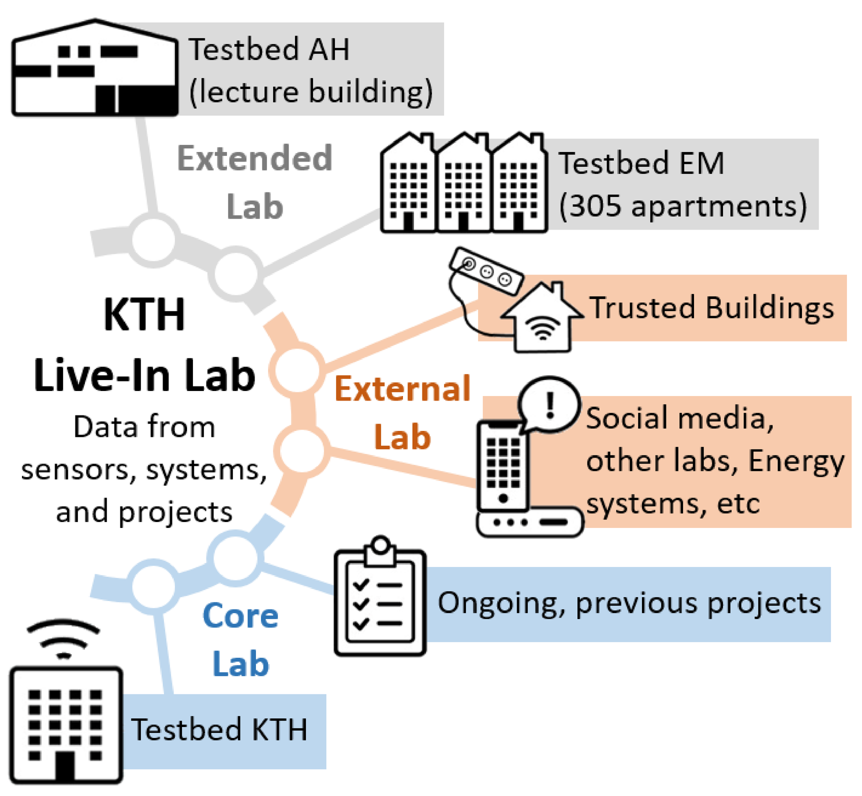
ML, data-driven control methods, social network dynamics and control, surveys and experimental campaigns,..



Example: Design of energy-efficient buildings

- **Why?** Buildings are estimated to account for ≈ 30%-40% of overall energy use and ≈ 40% of CO_2 emissions (IEA;Our World in Data;Itard, *OTB Rep* (2008))
- **Modeling challenges** include accounting for observed discrepancy between:
  1. Predicted and measured building performance (EPG) ⇐ *occupant behavior*
  2. Surveyed and measured occupants behaviors and attitudes ⇐ *social influence*

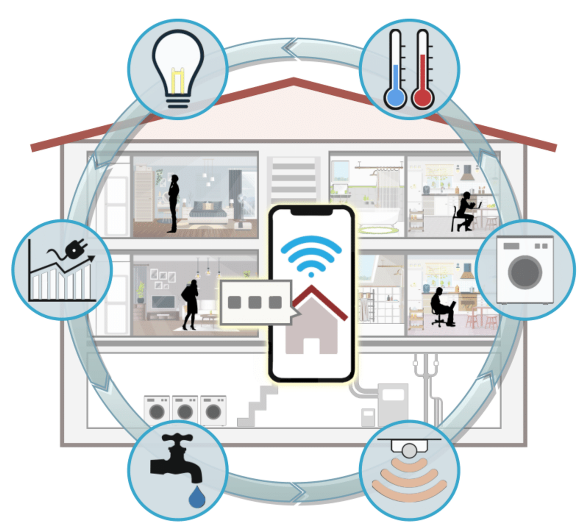
KTH Live-in-Lab: Example of CPHS Environment



State-of-the-art platform of building testbeds:

- Real-world experiments
- Collaboration platform & Multidisplinary research
- Flexible structure
- Multiple sensors: occupancy, ambient (T_{in}, T_{out}, CO_2, RH), energy/water/electricity meters

CPHS environment, which combines:
(CP) KTH Live-In Lab buildings and datapool
(H) KTH Live-In Lab tenants



liveinlab.kth.se/en
Molinari M et al., *Applied Energy* (2023)
Rolando D et al., *Energies* (2022)

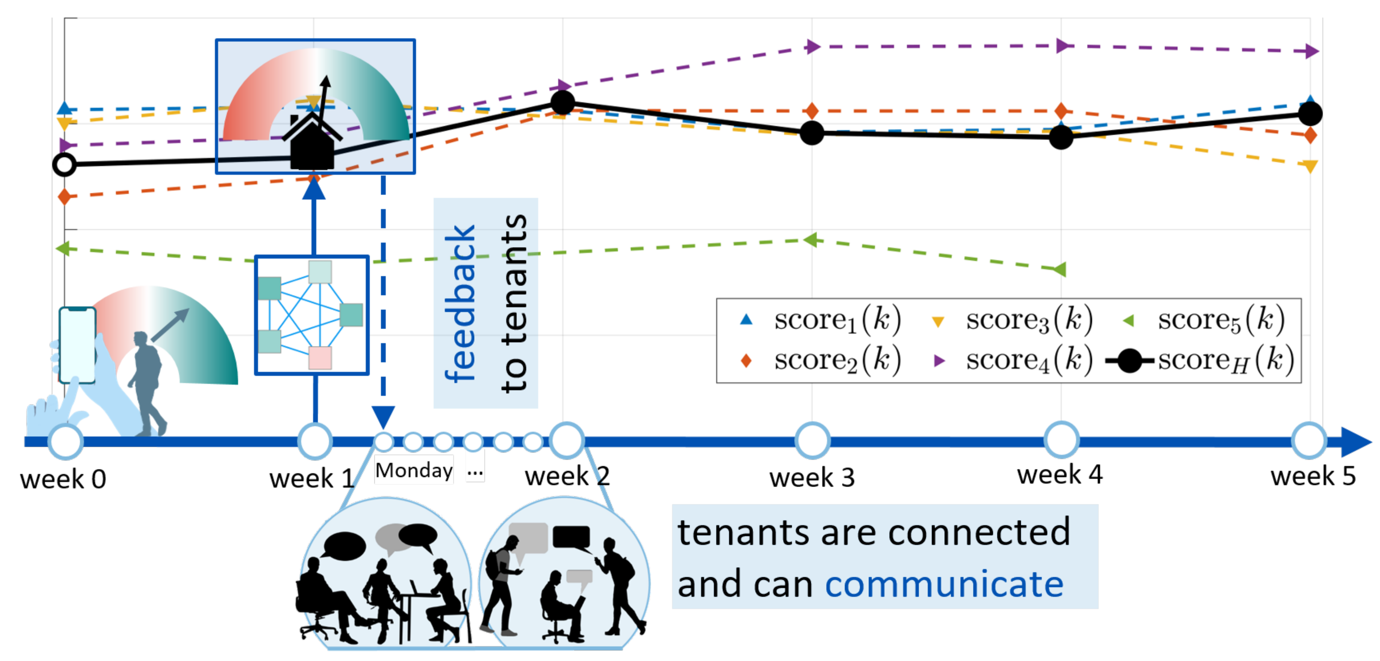
Social Interactions and Human Behavior

Aim Show that sustainable living can be promoted through digitalization of a household into a social network of interacting tenants

Approach Longitudinal experimental campaign, whose design is based on modeling household behaviors as a collective decision-making process

Interconnected tenants of KTH Live-In Lab as decision-makers: Reference state from survey on habits & environmental impact of lifestyle

Weekly monitored data on sustainability practices ⇒ Sustainability scores for each tenant and for the household



End of experimental campaign: Feedback from tenants

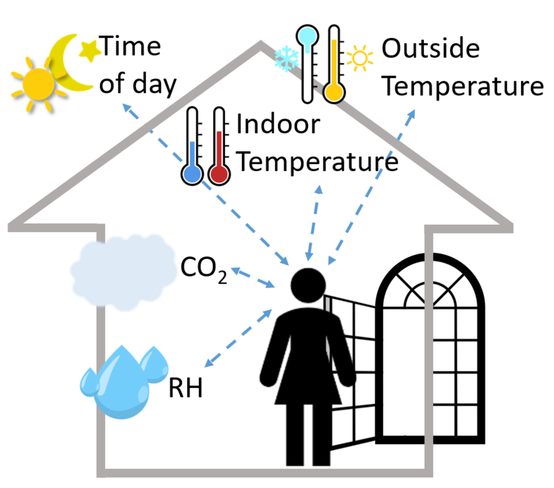
Environmental Drivers and Human Interaction

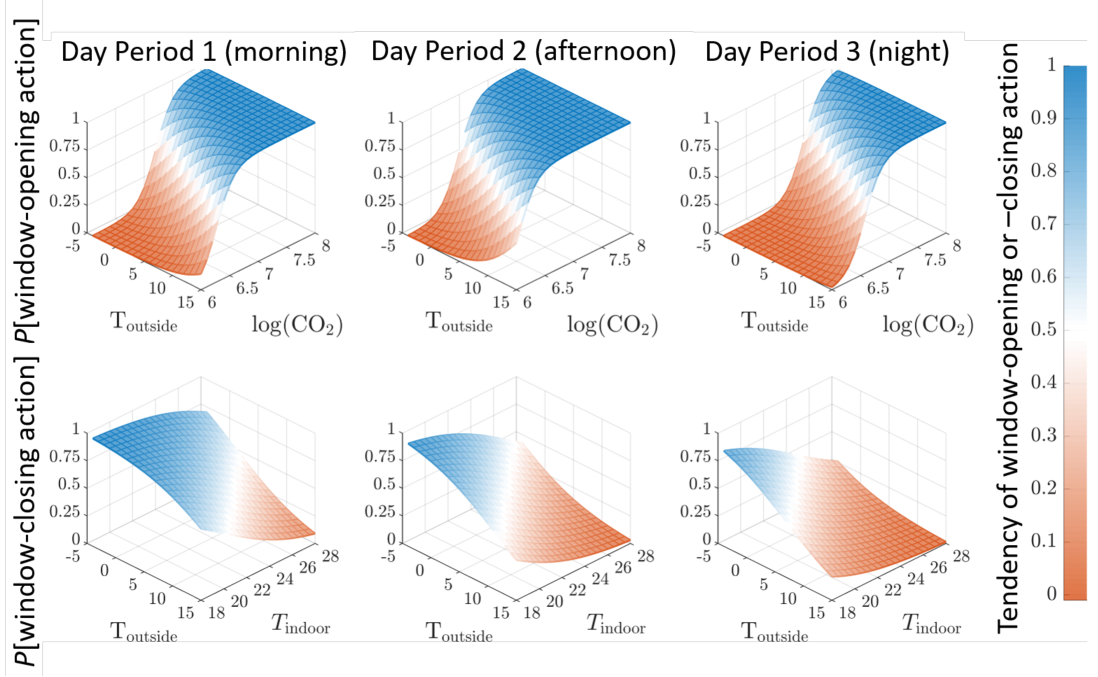
Aim Analyze physical environmental and categorical variables

Approach Selection of best fitting window-opening (window-closing) model, based on monitored data at KTH Live-In Lab (Oct-Dec 2020):

- Partition of window-opening (-closing) data: 20% (validation) - 80% (training)
- Selection of significant drivers: AIC (forward/backwards) with 10-fold CV
- Computation of best model (w. training data): Logistic Regression with selected drivers
- Model validation (w. validation data): Goodness of fit

$$\text{logit}(P[\text{opening/closing-window action}]) = \alpha_{DP} + \beta_{\log(CO_2)} x_{\log(CO_2)} + \beta_{RH} x_{RH} + \beta_{T_{in}} x_{T_{in}} + \beta_{T_{out}} x_{T_{out}}$$





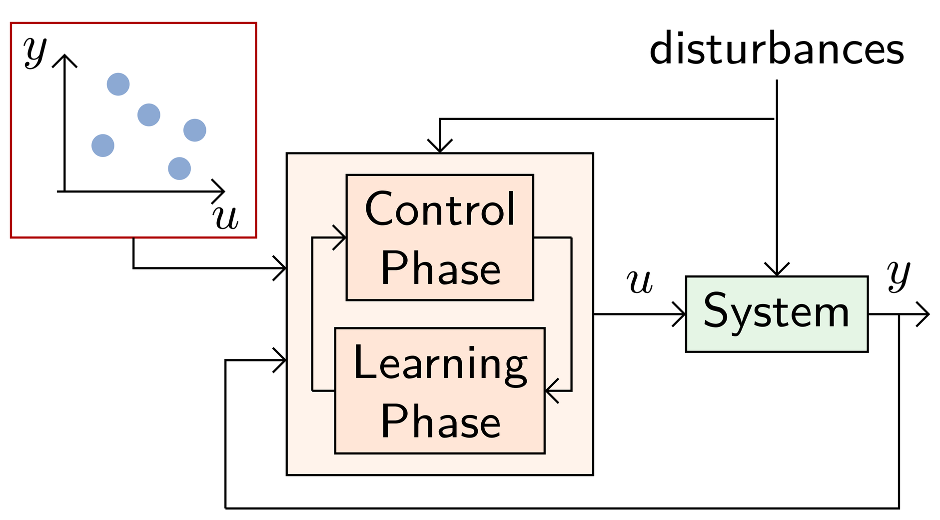
digital futures

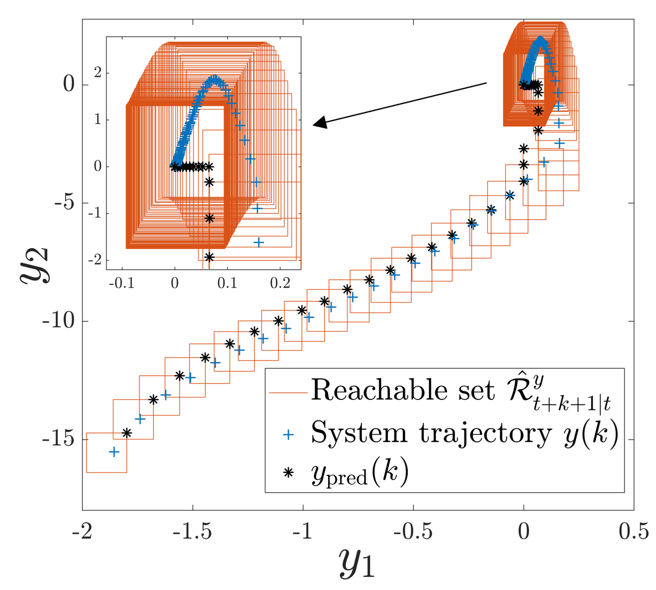
Improve Control Strategies in Smart Buildings

Aim Develop a cost-effective control strategy that achieves optimal performance and satisfies system constraints without relying on an accurate model of the dynamical system

Approach Robust data-driven predictive control to control unknown nonlinear systems under bounded process and measurement noise

- *Learning phase:* Implicit data-driven representation of unknown nonlinear system using zonotopes (finite horizon) and past input-output data
- *Control phase:* Nonlinear zonotopic predictive control (NZPC) to predict the reachable output set (finite horizon), by solving an optimal control problem





What influences occupants' behavior in residential buildings? An experimental study on window operation in the KTH Live-In Lab, M. Farjadnia, A. Fontan, A. Russo, K. H. Johansson, M. Molinari, submitted, 2023 CCTA
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