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# Adaptive data-driven predictive control of buildings

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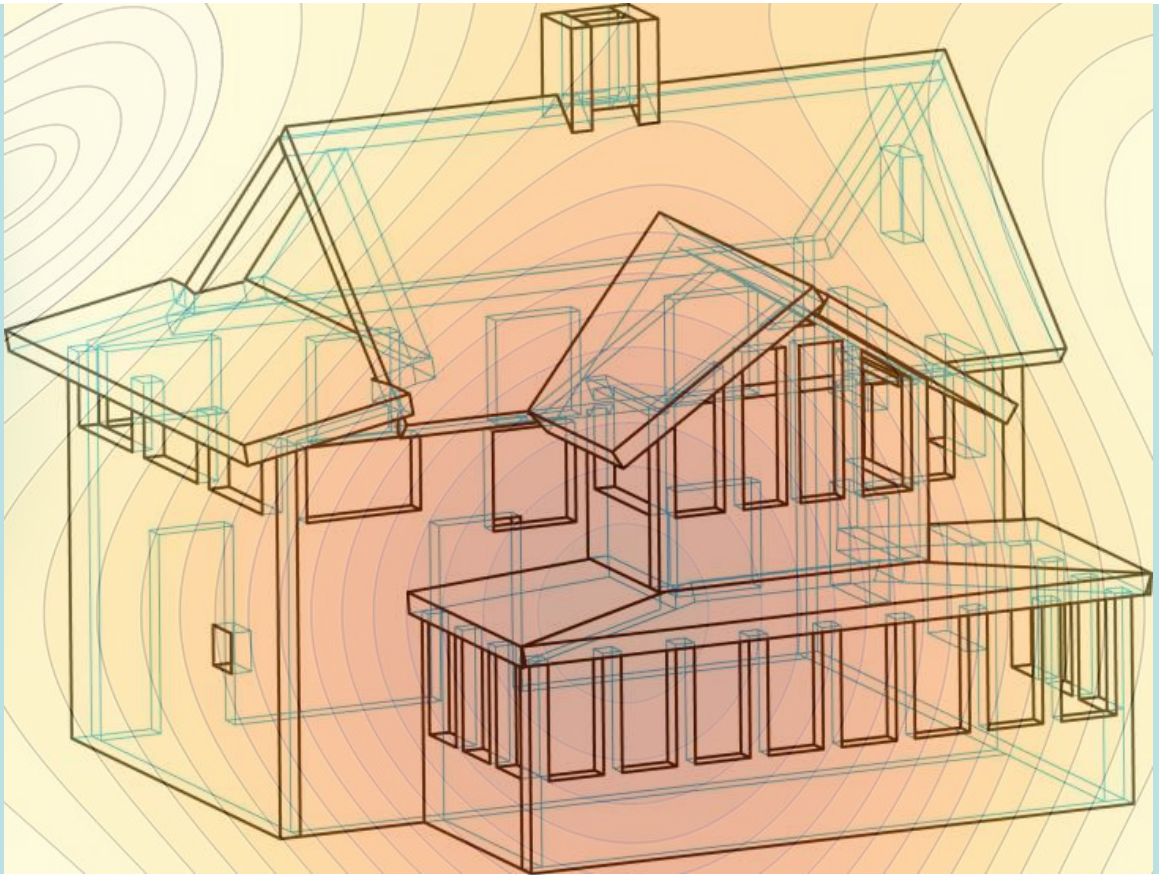
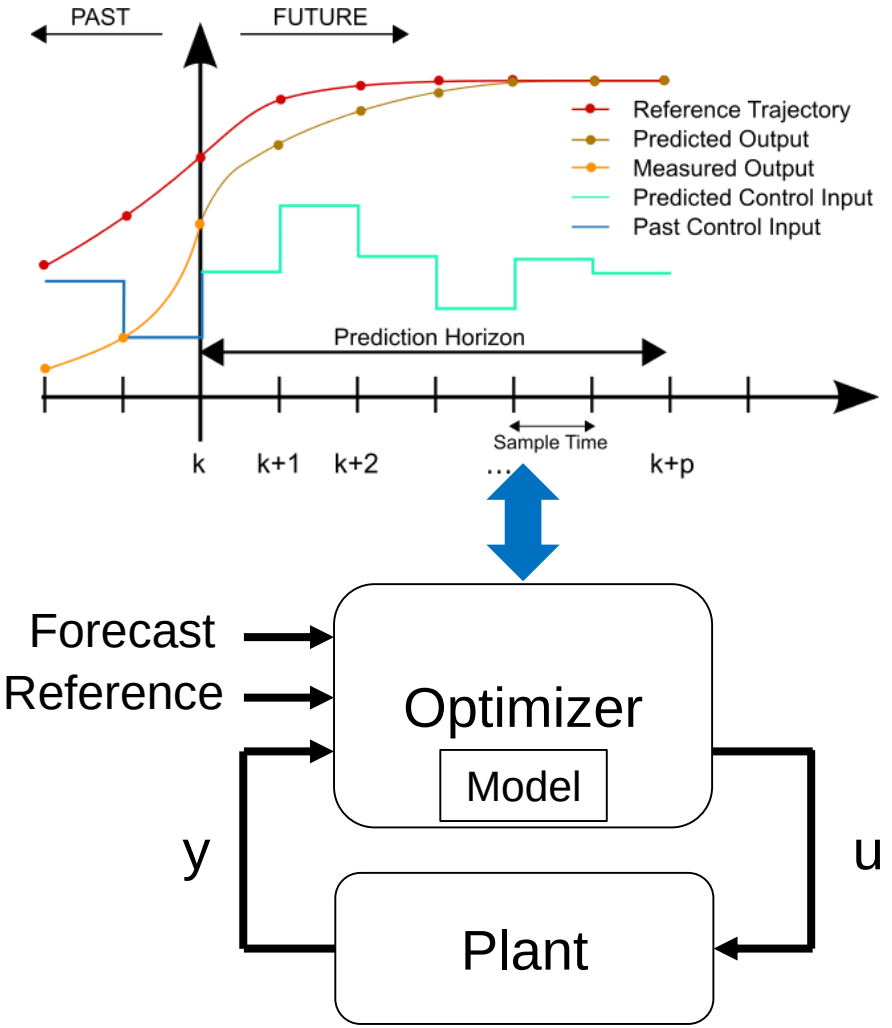


# Model Predictive Control (MPC)

- Classical control corrects an error once it occurs
- MPC can act preemptively
- It optimizes a performance measurement (setpoint deviation, power consumption, …) over a planning horizon
- It can integrate state and control constraints, and external forecasts
- For compex systems, it is often easier to tune than classical controllers



# Models and optimizations

## Model

$x_{k+1} = Ax_k + Bu_k$

$y_k \quad = Cx_k + Du_k$ (Convenient case: $y = x$)

Chaining the equations:

$$
\begin{aligned}
x_0 &= x_0 \\
x_1 &= Ax_0 + Bu_0 \\
x_2 &= Ax_1 + Bu_1 \\
&= A(Ax_0 + Bu_0) + Bu_1 \\
&= A^2x_0 + ABu_0 + Bu_1 \\
x_3 &= Ax_2 + \cdots \\
X &= \mathcal{A}x_0 + \mathcal{B}U = f(U)
\end{aligned}
$$

## Optimization

Cost function: $\min_U J(X, U)$

Calculate optimal chain of control commands $U^*$ and system states $X^*$ that minimize the cost $J(X, U)$.

## Why Model Predictive Control of buildings?

- Buildings have slow reaction times in the range of hours
- They are influenced by forecastable disturbances (weather)
- This makes them an ideal application for MPC
  - Current main application in industry: Chemical reactors
- Common optimization goals: Minimize energy consumption, maximize thermal comfort, demand response, etc.
- Demand response requires a prediction of the energy consumption to trade with the grid operator

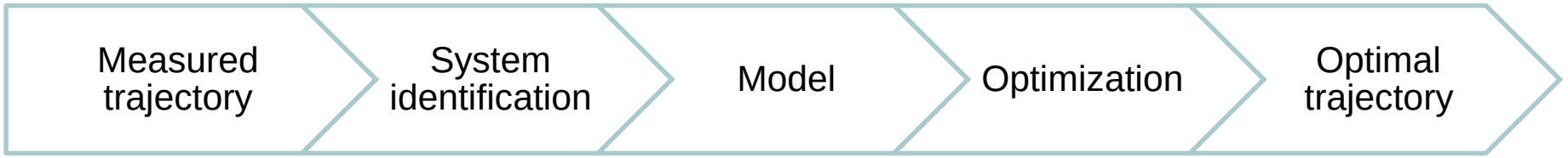
## Why adaptive data-driven predictive control of buildings?

- Buildings complex and individual
- Their thermal behavior can change over time
- Industry doesn't want to spend the work hours to make and maintain a model

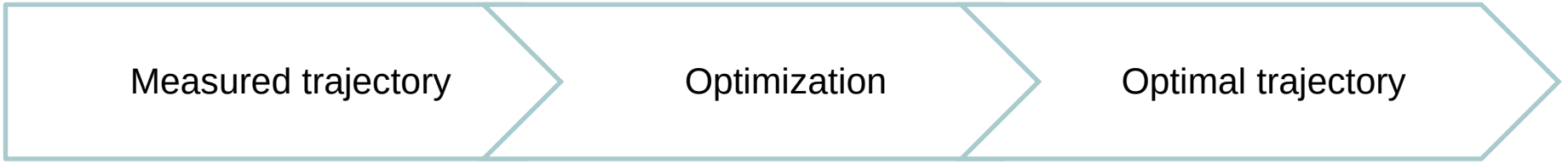
## Conventional MPC vs data-enabled predictive control (DeePC)

- Data-enabled predictive control skips the model building step
- This may help avoid problems due to ill-chosen model structures
- First proposed (and named) by Coulson et al. in 2019

Conventional MPC:



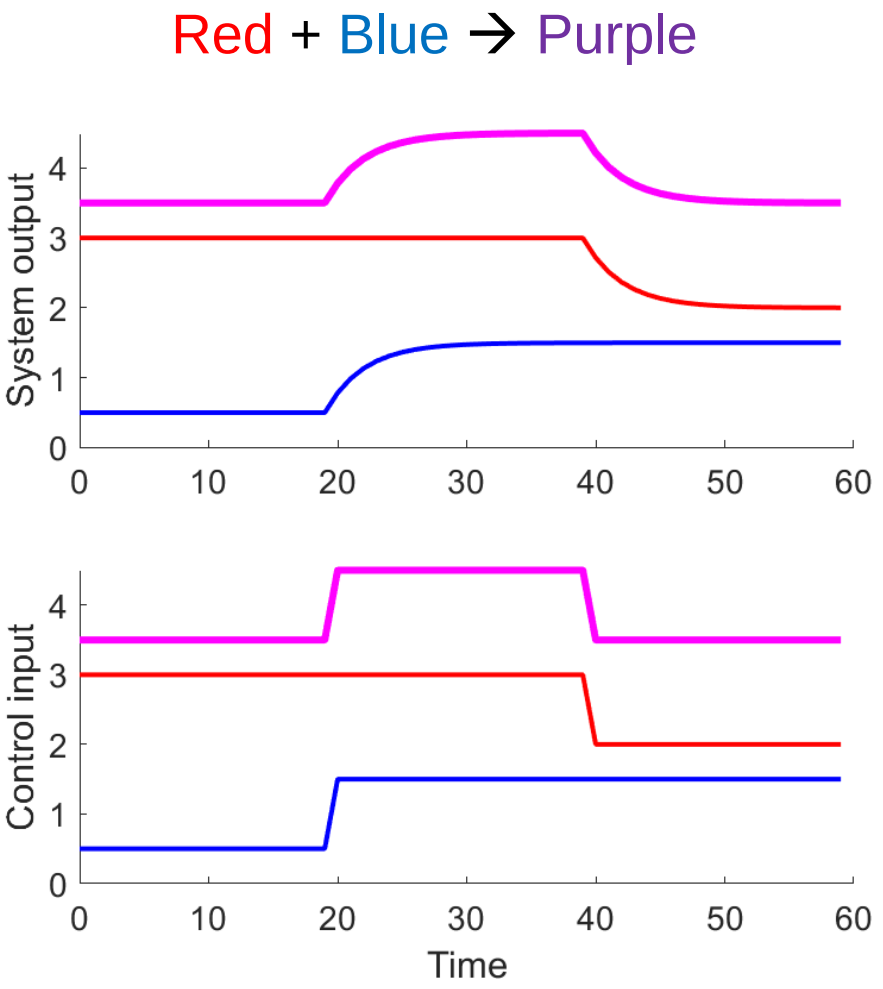

DeePC:




Coulson et al. – Data-enabled predictive control: In the shallows of the DeePC (European Control Conference, 2019)

## The principle of DeePC visualized

- For a linear, time-invariant system, measured trajectories can be combined to generate new possible trajectories.
- If the set of measured trajectories is sufficiently rich, any possible trajectory can be generated (Willems' fundamental lemma)
- Finding the right combination of trajectories replaces the model in the optimization



## PolyDome experiments: Setup

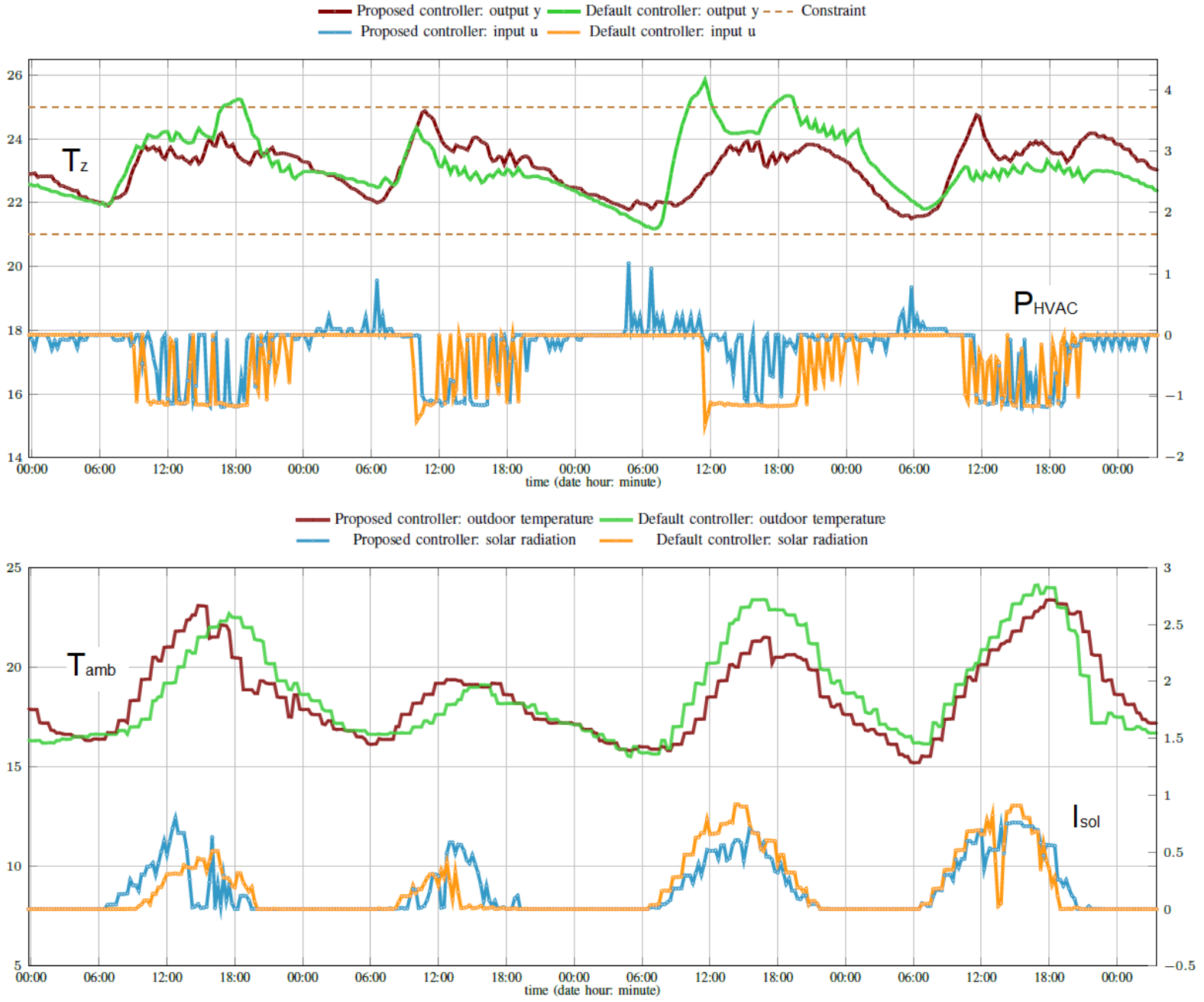
Building

- A 600 $m^2$ lighweight dome structure for teaching at EPFL
- Air-to-air heating and cooling

Control

- Robust bi-level formulation of DeePC
- Adaptive, using two days of data
- 2.5 h prediction horizon

Lian, Shi, Koch & Jones – Adaptive robust data-driven building control via bi-level reformulation: An experimental result (Preprint, 2022)


Proposed controller: output y
Default controller: output y
Constraint
Proposed controller: input u
Default controller: input u
$T_z$
$P_{HVAC}$
time (date hour: minute)
Proposed controller: outdoor temperature
Default controller: outdoor temperature
Proposed controller: solar radiation
Default controller: solar radiation
$T_{amb}$
$I_{sol}$
time (date hour: minute)

## Modeling field data: Setup

**Unpublished work removed!**

## Modeling field data: Results

**Unpublished work removed!**

## Discussion, conclusions and outlook

- Adaptive data-driven predictive control of buildings is feasible
- DeePC needs more investigation
  - First proposed 3 years ago, reference methods have existed for decades
- Ongoing research on DeePC theory:
  - Extension to noisy, non-linear and time-variant systems
  - Extension to continuous-time formulations
  - Extension to robust MPC
- Next step for me: Long-term simulations and experiments in buildings
  - Different formulations of DeePC

# Questions