Keywords: Optimal Control, Model Predictive Control, Large-scale Optimization, Data-driven modeling, Energy systems

AIRPORT ENERGY OPTIMIZATION WITH OPTIMAL CONTROL AND AI

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CONTEXT AND MOTIVATION

- Airports are highly energy-intensive infrastructures **+ HVAC** (*Heating Ventilation and Air Conditioning*) accounts for **~40% of total consumption**
- **PID** (*Proportional Integral Derivative*) controllers widely used to control the HVAC but are not so efficient because they :
  - Ignore energy use
  - Are sensitive to noise
  - Lack of predictive capacity
- There is a need for **adaptive** and **scalable** control methods
- **Challenges :**
  - Nonlinear dynamics
  - Large-scale systems
  - Random exogenous inputs

MODELING STRATEGIES

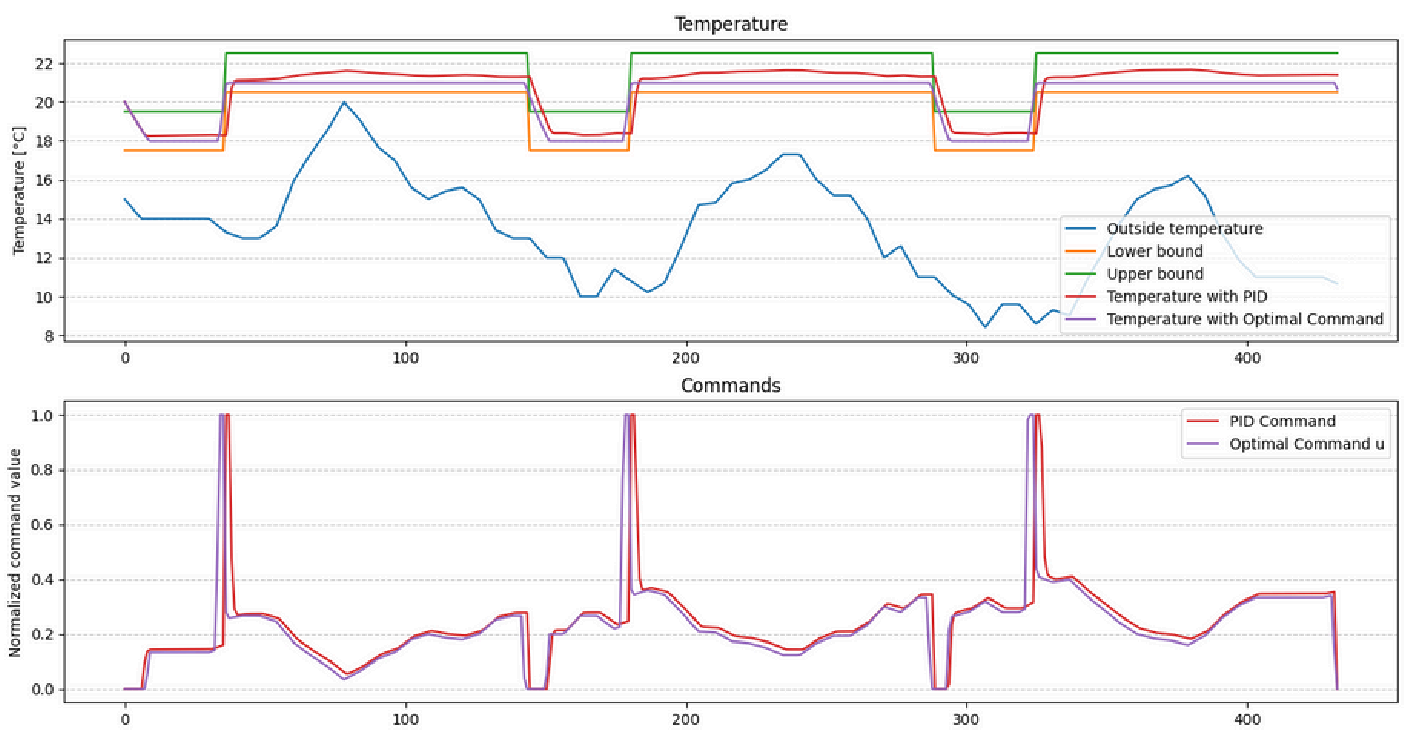
- **Cost function estimation :** parametric estimation of equipment consumption

$$\gamma^* \in \arg\min_{\gamma} \sum_{t=1}^{N} \left\{ E(\phi_t, u_t \to u_{t+1}) - g_\gamma(u_t, \Delta_t^{t+1} u, \phi_t) \right\}^2 + \lambda \mathcal{R}(\gamma)$$

- **Dynamics modeling :**
  - **Grey-box (ARX)** : interpretable, moderate accuracy
  - **Black-box (LSTM, GNN)** : nonlinear, spatio-temporal interactions
- **Uncertainty (passenger flows & weather) handling :**
  - Statistical approaches (distribution fitting, Gaussian Process)
  - **CVAE :** captures latent variability and generates conditional probabilistic forecasts

OPTIMAL CONTROL VS PID

We observe 5% energy savings on 3 days based on a RC-model



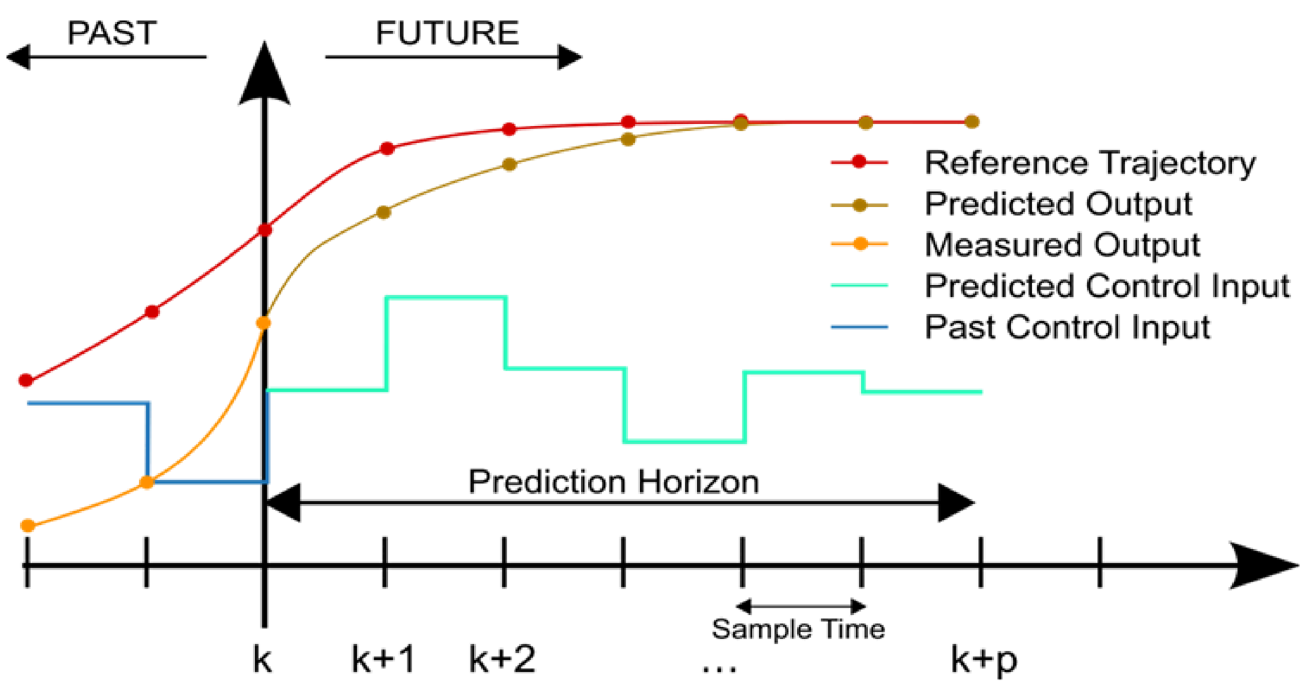
PROBLEM FORMULATION

- **Goal :** reduce energy consumption while keeping temperature and HVAC controls in admissible intervals
- **Controls** : valves opening in hydraulic systems, water pumps, fans speed, heat recovery wheels speed, temperature setpoints
- **Framework :** Constrained Rolling Horizon Optimal Control problem **~ Model Predictive Control**
- Can be solved via Sequential Quadratic Programming or Interior Point methods

$$\begin{aligned} \min_{\{u_{t+k}\}_{k=0}^{N-1}} \quad & \sum_{k=0}^{N-1} J(X_{t+k}, u_{t+k}) + \Psi(X_{t+N}) \\ \text{s.t.} \quad & \forall\, k \in \mathbb{N}_0^{N-1}, \\ & \begin{cases} X^i_{\min} \le X_{t+k} \le X^i_{\max} \\ u_{t+k} \in \mathbb{U} \\ X_{t+k+1} = f_\theta(X_{t:t+k}, u_{t:t+k}, z_{t:t+k}) + \epsilon_{t+k} \end{cases} \end{aligned}$$

Algorithm 1 Model Predictive Control (MPC)

Initialize state X_0
for $t = 0, 1, 2, \dots$ **do**
  Measure $\{X_{t-k}\}_{k=0}^{p}$
  Obtain optimal control sequence $\{u^*_{t+k}\}_{k=0}^{N-1}$ solving $(\mathcal{P})$
  Apply the control sequence $\{u^*_{t+k}\}_{k=0}^{N_c-1}$, with $N_c < N$
  Shift horizon forward
end for



PERSPECTIVES

- Extend dynamics modeling and controls to the full airport HVAC system
- Explore **robust** & **stochastic** MPC for uncertainty handling
- **Final objective :** adaptative model transferable across airports.