Advanced Model Predictive Control for a sustainable built environment

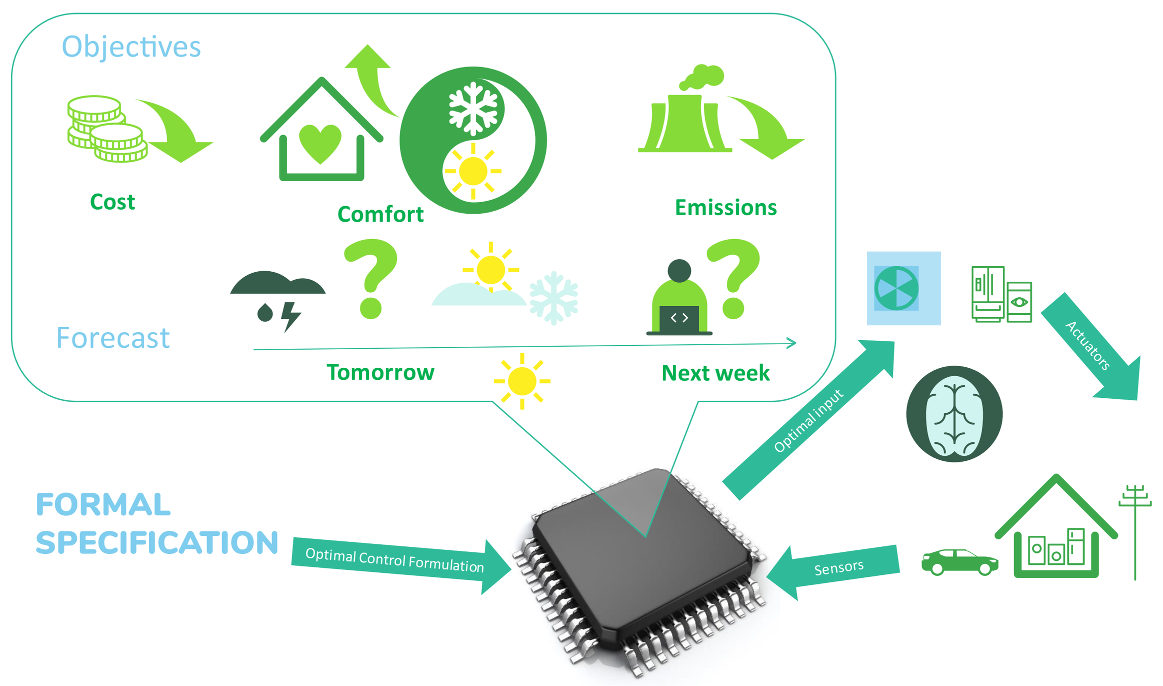
ACTIVE BUILDING CENTRE RESEARCH PROGRAMME

Introduction

Objective:
- **Minimise the cost of operation and carbon emissions of a building taking into account building dynamics and thermal comfort constraints**

Sources of uncertainty:
- Building parameters
- External signals
- Occupants

More predictive control for buildings



Learning controllers

- Step 1. Use **current knowledge** about the operating conditions and the building to devise a control strategy
- Step 2. **Apply the control strategy** proposed in Step 1
- Step 3 **Feed new knowledge and data** obtained from Step 2 **back** into the system to improve the control strategy

Methods:
- **Data-driven control**
- **Control co-design**
- **Robust control**

Data driven control

Objective:

Develop data-driven predictive controller that can handle the unknown disturbances and longer horizons

Challenges:
- **Sensitivity to uncertainty**
- **Overfitting when including unknowns**

Training data

$$\begin{pmatrix} U_p \\ Y_p \\ U_f \\ Y_f \end{pmatrix} g = \begin{pmatrix} u_{ini} \\ y_{ini} \\ u_f \\ y_f \end{pmatrix}$$

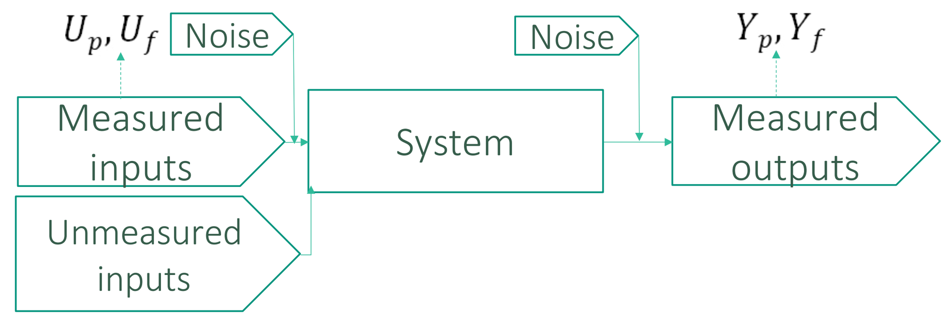
Recent input, Recent output, Predicted input, Predicted output

$$\min_g f(U_f g, Y_f g) + \lambda_{ini} \| Y_p g - y_{ini} \|_1$$

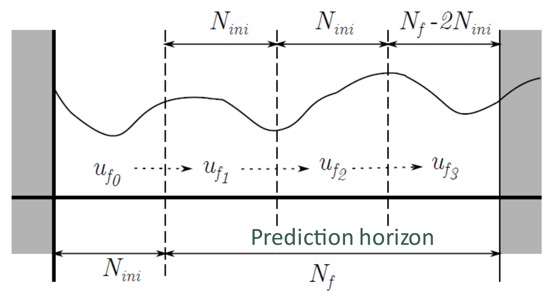
subject to:

$$U_p g = u_{ini}$$
$$U_f g \in U$$

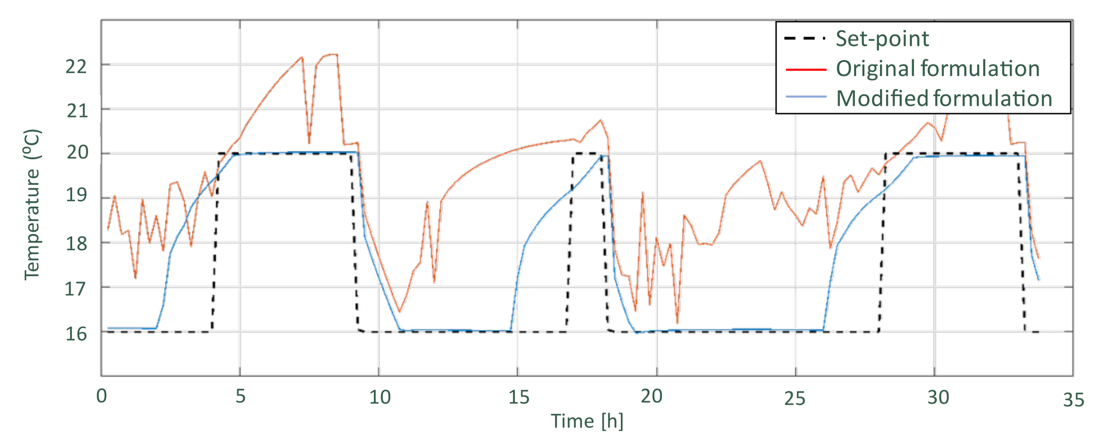
Relaxation weight



Proposed solution:
Modify data-driven approach by segmenting prediction horizon



Outcome:
- Significantly improved performance for longer horizons



Conclusions

Consequences of uncertainty:
- Higher cost of operation
- Dissatisfaction of occupants
- Unsatisfactory 'off the shelf' data-driven approaches

Improvements from proposed methods:
- Reduced modelling effort
- Higher efficiency
- Better performance
- Robust closed-loop operation
- Robust operation in worst-case scenarios

Control co design

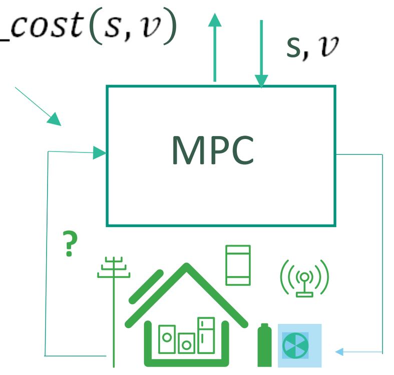
Objective:
Sizing under multi-year weather and price uncertainty considering
- Long samples of data
- High temporal resolution
- Closed-loop Model Predictive Control to counteract uncertainty

Challenges:
- **Difficult problem with high computational complexity**

Proposed solution:
Black-box optimization to avoid costly simulations

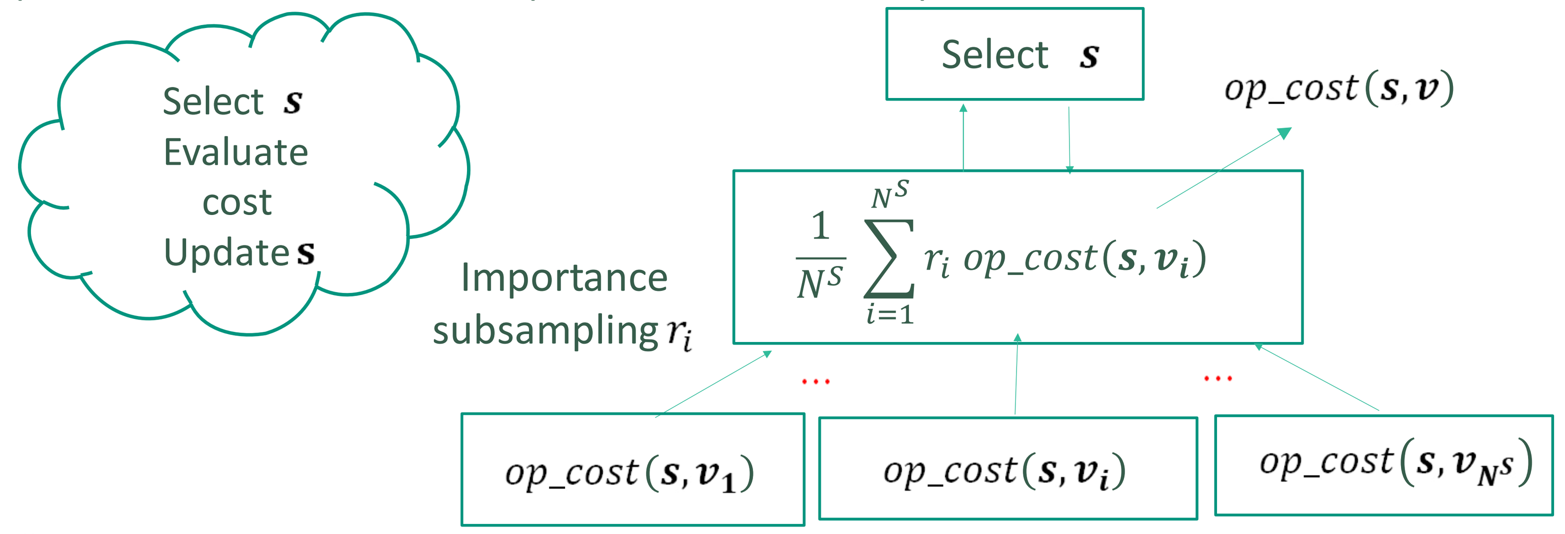
$\min_s \psi(s) + op\_cost(s, v)$
$\phi(s) \in \mathcal{C}$

Closed-loop optimal cost depending on size s, uncertainty v



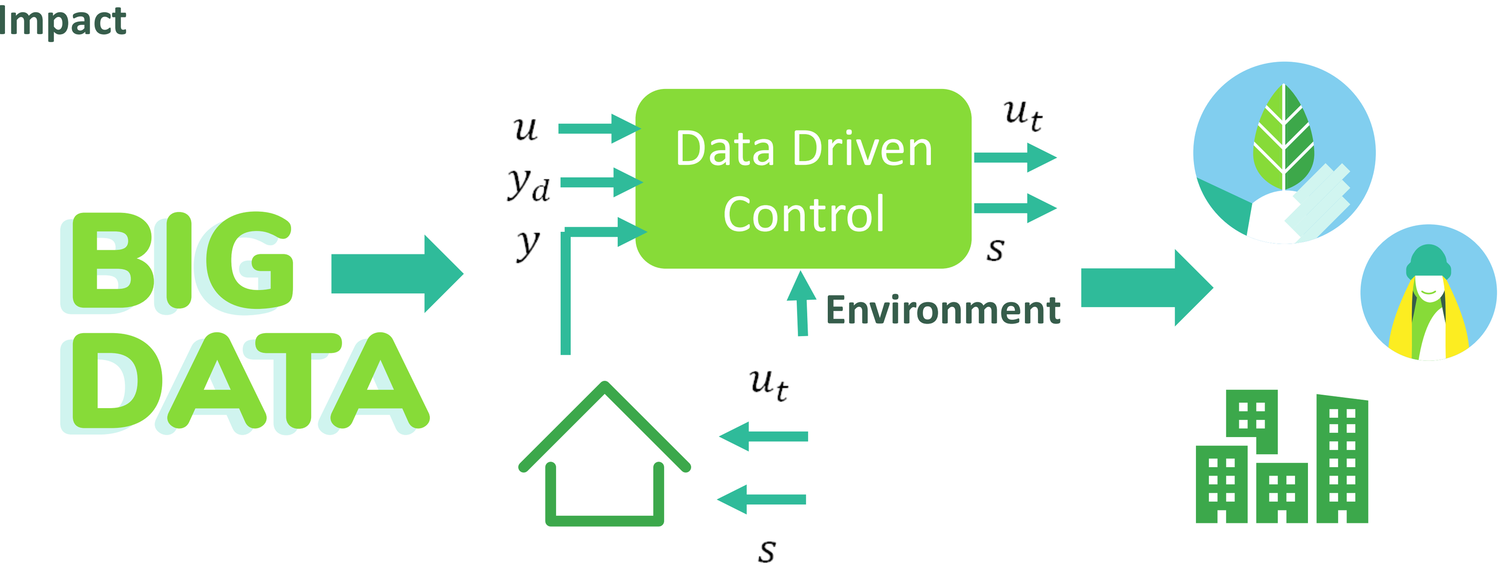
	Year Det	Blocks Det	Blocks v weather	Blocks v – weather, prices
Battery cap. (kWh)	7.88	0	0	60
Area PV (m^2)	89.62	89.62	89.62	89.62
Total Optimal Cost (£/y)	-476.6	-1137.9	-684.6	-2106.4

N_s scenarios – Algorithm Parallelization
Optimization across short samples of data – subsamples N^S of the full time series



Outcome
- Robust co-design framework considering optimised closed loop operations
- Algorithm to reduce computational burden – parallelization
- Design solution highly sensitive to uncertainty realization especially in prices

Impact



Robust control

Objective:

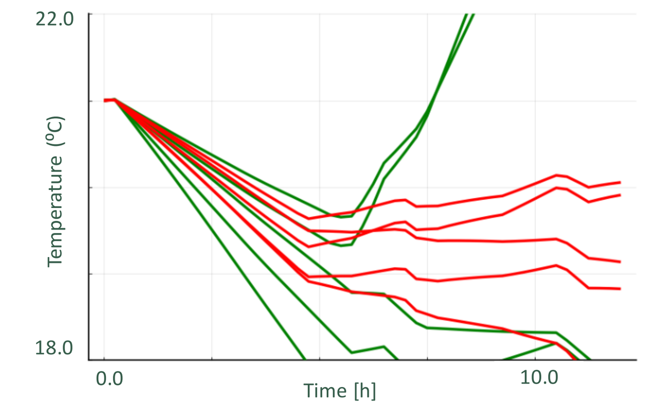
Find a solution such that the constraints are satisfied for every uncertainty.
For all ω, minimise

$$f_0(x, \omega)$$

subject to:

$$f_i(x, \omega) \le 0$$

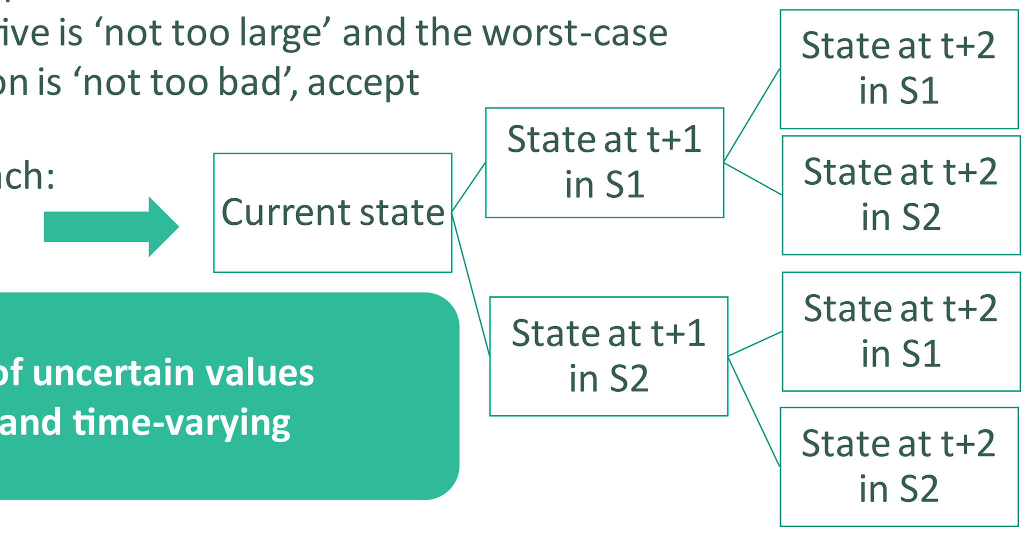
where $i = 1, \ldots, m$, $x \in \mathrm{R}^n$ - decision variable, $\omega = [\omega_j]_{j=1,\ldots,p}$ and $\omega_j \in [\omega_{\min}, \omega_{\max}] \in \mathrm{R}$ - parameter, f_i: $\mathrm{R}^n \times \mathrm{R}^p \to \mathrm{R}$



Red – robust, green – no robustness

Usual a posteriori approach:
- Solve the problem for the nominal value of uncertainty
- Analyse what happens for the nominal solution: if the worst-case objective is 'not too large' and the worst-case constraint violation is 'not too bad', accept

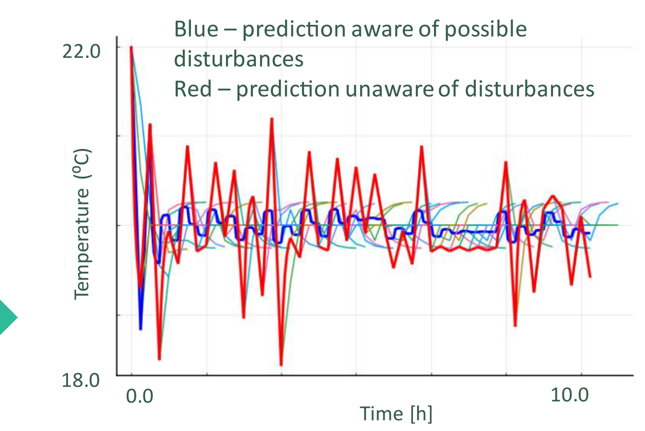
Usual a priori approach:



Challenges:
- **Infinite number of uncertain values**
- **Both parametric and time-varying uncertainty**

Proposed solution:
Our a priori approach:
- Use semi-infinite optimization to limit the number of scenarios

Outcome:
- Three times better performance
- Limited number of scenarios
- Uncertainty considered both in building parameters and external signals:
  - +/-1 in thermal mass
  - +/-6.5 C in external temperature



Future work
Papers:
- "Segmented-horizon data-driven predictive control for systems with unmeasured disturbance"
- "Integrated system and control design under uncertainty in closed loop operation"
- "Approximate local reduction methods for optimal control"

Collaborations
WP3, WP8, WP5

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