UNIVERSITÉ DE GRENOBLE

Distributed Model Predictive Control for energy management in buildings

Ph.D. thesis presented by:

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Patrick Béguery - Schneider-Electric / Strategy & Innovation

November 29th 2012

Schneider Electric

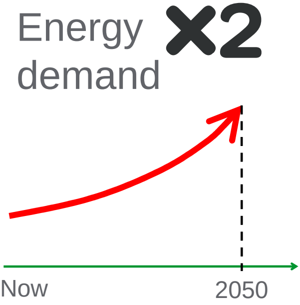
homes

gipsa-lab

Introduction

Energy consumption in the world - the facts

The challenge ...



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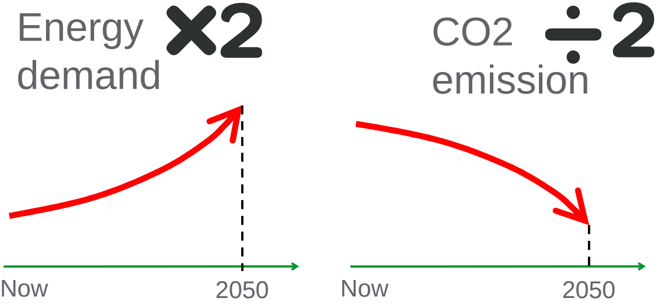

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Introduction

Energy consumption in the world - the facts

The challenge ...

Energy demand ×2

CO2 emission ÷2

=

×4 More efficient

5

Introduction

Energy consumption in the world - the facts

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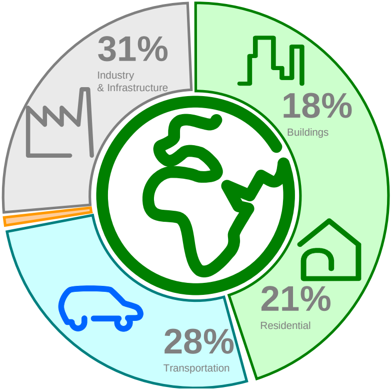
Energy consumption in the world - the facts



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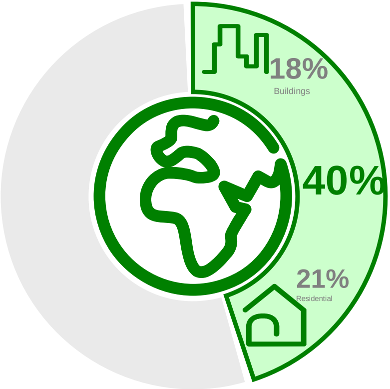
Energy consumption in the world - the facts

1. **40 %** of world-wide primary energy consumption is due to buildings



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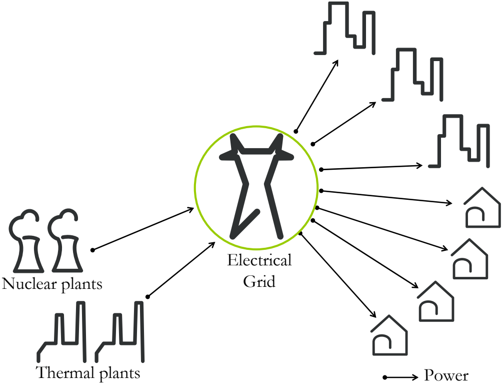
Towards smart grid



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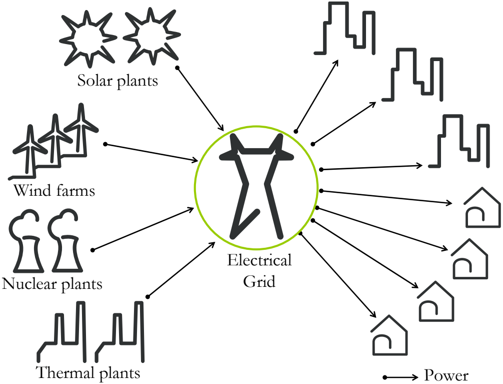

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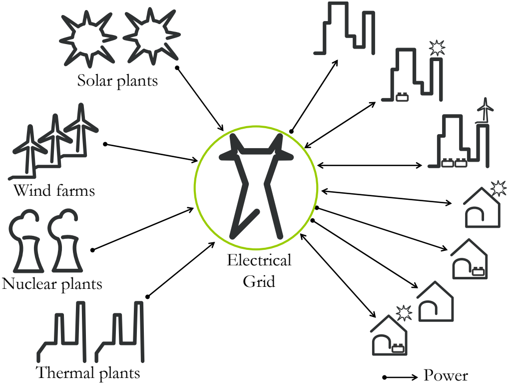

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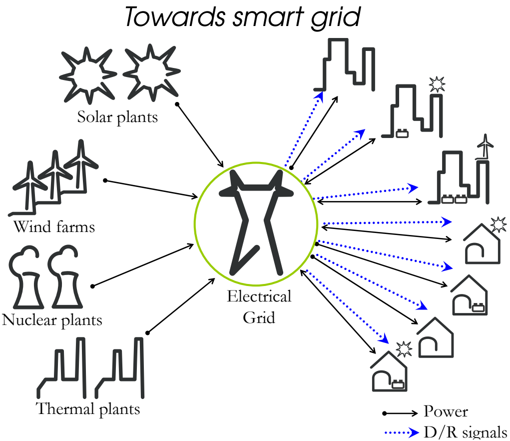

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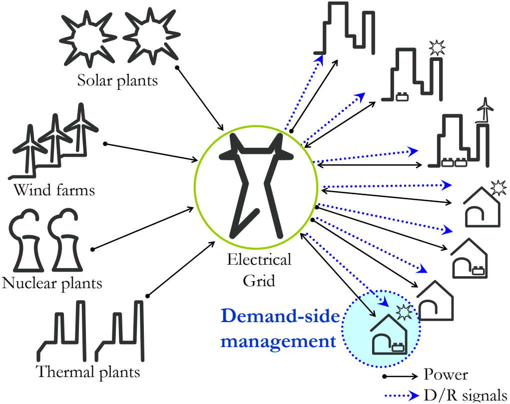
Energy consumption in the world - the facts

1. **40 %** of world-wide primary energy consumption is due to buildings
2. Buildings play a key role in smart grid



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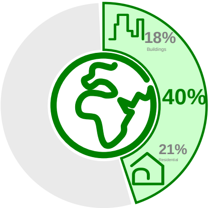

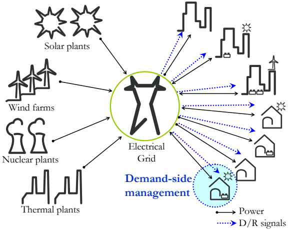

Objectives

1. Reduce Buildings energy consumption
2. Make them smart grid ready

The HOMES program

Largest funded program on buildings **active energy efficiency** in Europe ...

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The HOMES program

Largest funded program on buildings **active energy efficiency** in Europe ...

"Equip each building with Active Energy Efficiency solutions, to achieve the best possible energy performance"

September 2008 > September 2012
26 Work Packages – 80 M€
39 M€ funded by OSEO (French Agency) incl. Schneider 26 M€

Thesis objectives

Design **control algorithms** able to improve energy management in buildings

1. **Reduce energy** and **maintain comfort**
2. Make buildings "**smart grid ready**" (variable energy prices, power limitations)
3. Design **generic**, **scalable** and **modular** solutions

Distributed Model Predictive control for energy management in buildings

1. MPC for energy management in buildings
2. Zone Model Predictive Control
3. Distributed Model Predictive Control
4. Conclusion

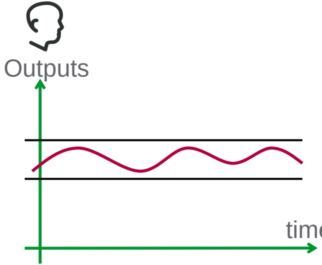
Energy management in buildings

An introduction

Comfort indicator + **Energy criterion**

Ensure comfort by mainting outputs in a given set

Find the best way to achieve comfort given constraints on inputs



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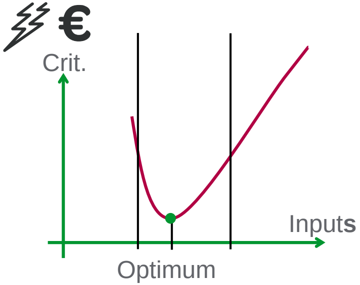

Conventional control in buildings

Rule-based control

Rule-based control

`Rule1:` *if* `condition[params]` *then* `action[params]`
`Rule2:` *if* `condition[params]` *then* `action[params]`
...

Many issues

- Coherence of the process of decision
- Parameters tuning ?
- **complex situations** ?

Conventional control in buildings

Rule-based control

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Rule1: *if* condition[params] *then* action[params]
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...

Many issues

- Coherence of the process of decision
- Parameters tuning ?
- **complex situations** ?

To sum up ...

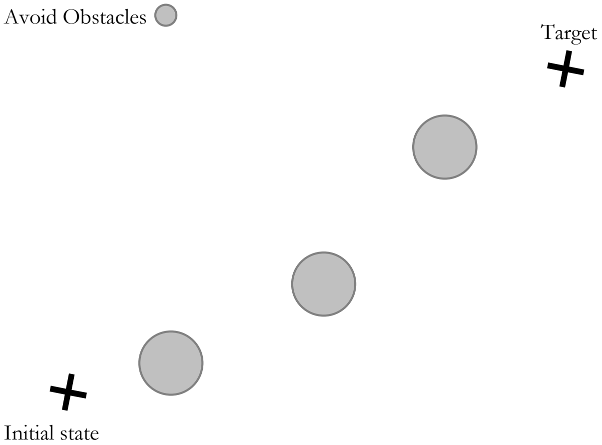
- Difficult to generalize
- Must be fully adapted for a given scenario
- Difficult to handle economical objectives
- Difficult to ensure coherence of the decision
- **Extremely simple to implement on BEMS !**

Model Predictive Control (I)

An intuitive concept...

A simplistic example

minimize path length and avoid obstacles



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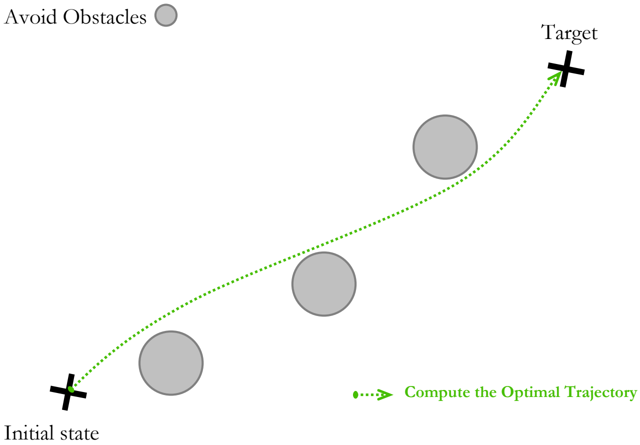

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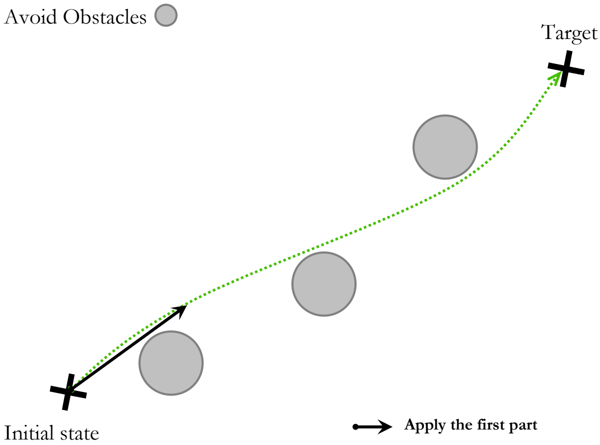

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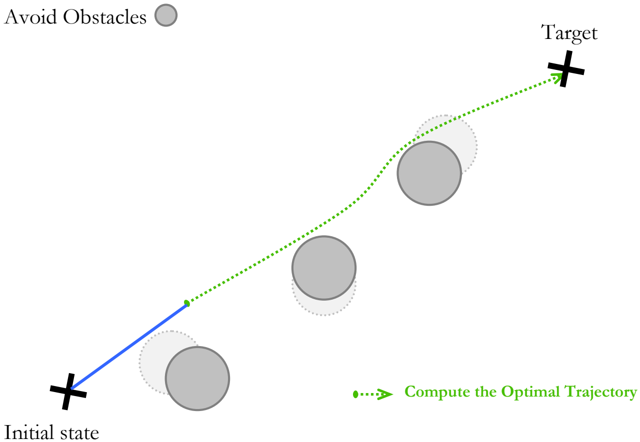

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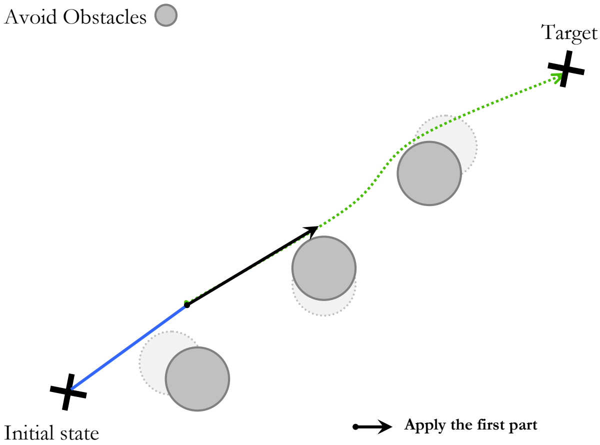

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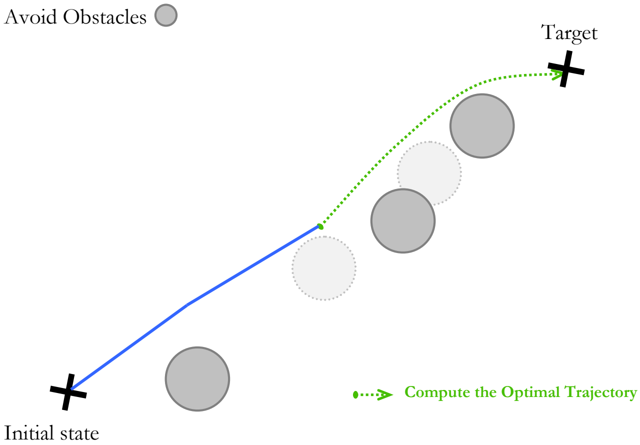

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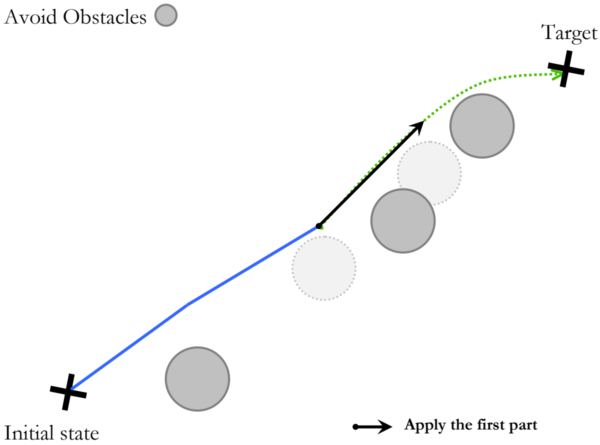

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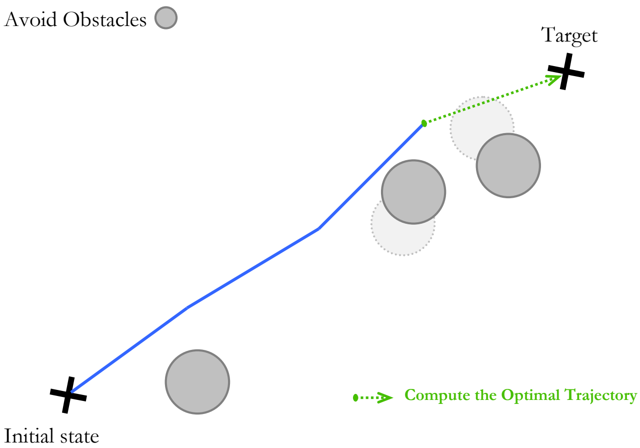

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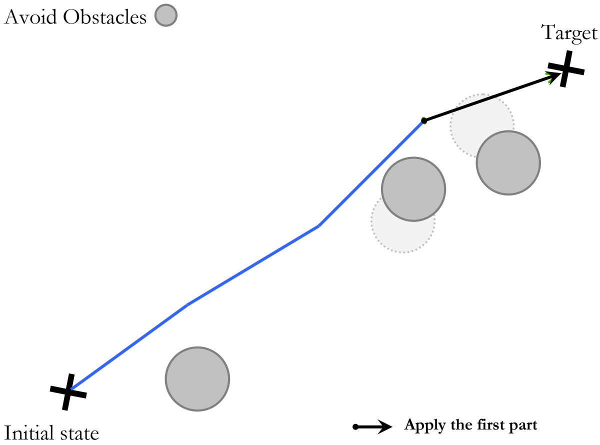

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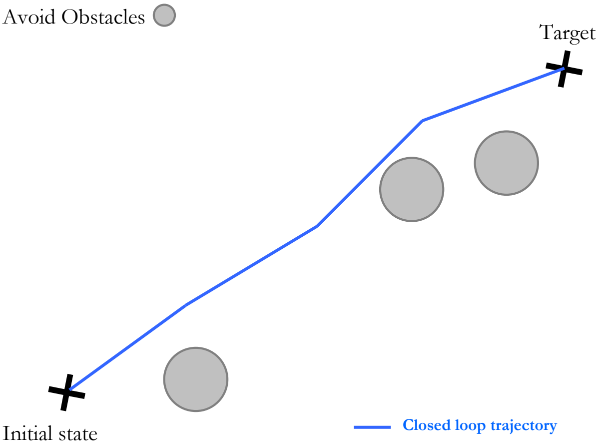

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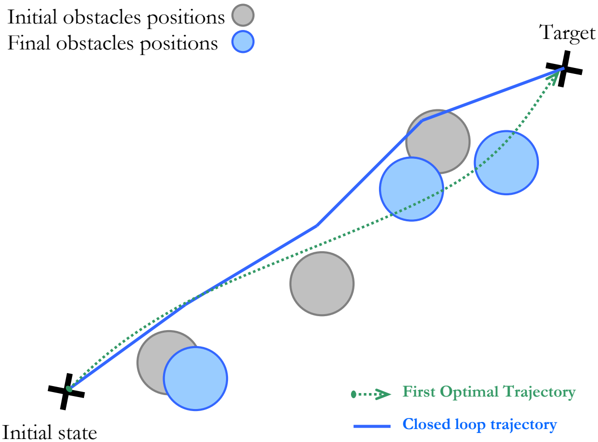

Model Predictive Control (II)

Receding Horizon Principle

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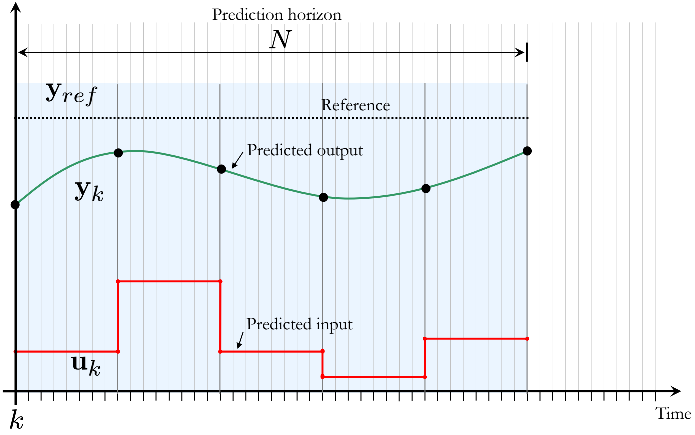


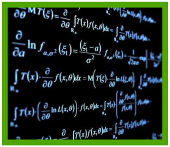
Why Model Predictive Control in buildings?

- Thermal inertia
- Coupled dynamics
- Constraints (comfort, actuators, power consumption, etc.)
- Multi-source: several power sources (thermal, electrical, etc.)
- Economic objectives (varying energy tariffs)

MPC for building Energy management

The ingredients ...

Model



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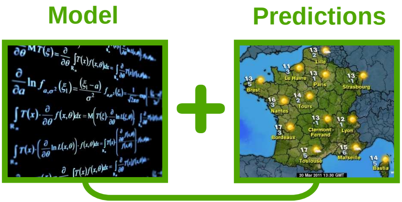

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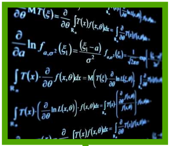

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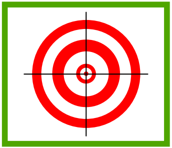
Predictions

+

Objective



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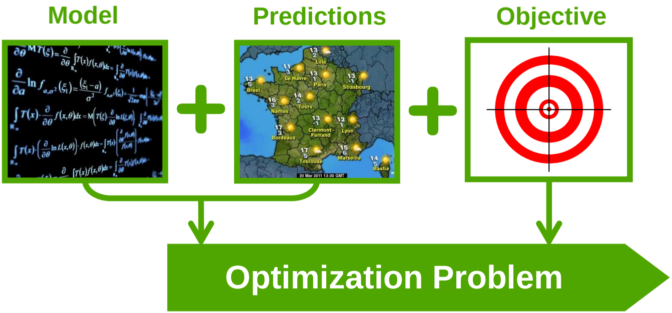

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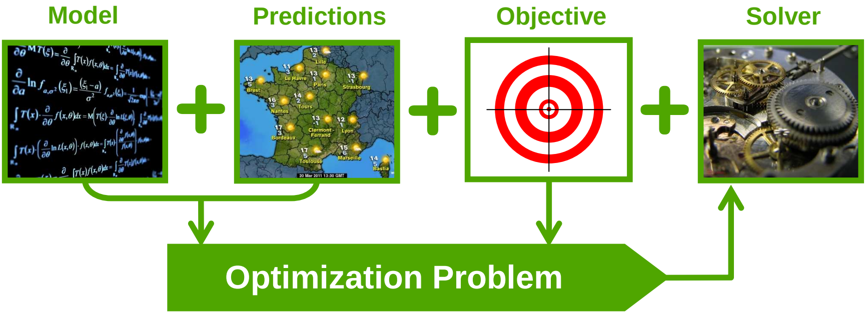

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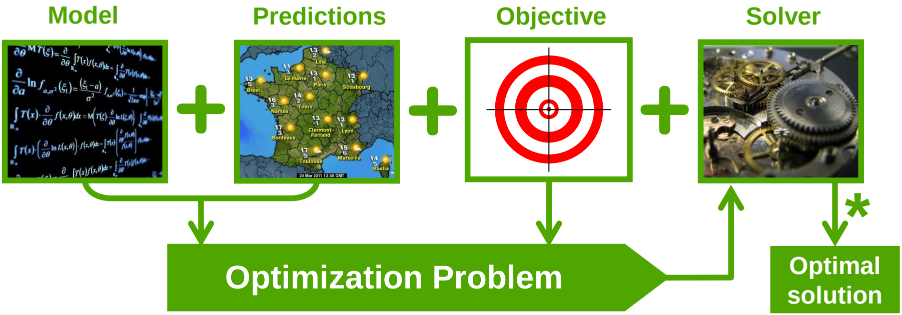
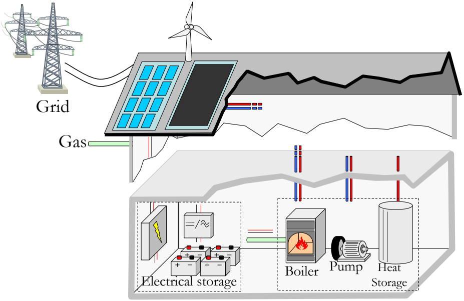


Building control layers

Decomposition approach



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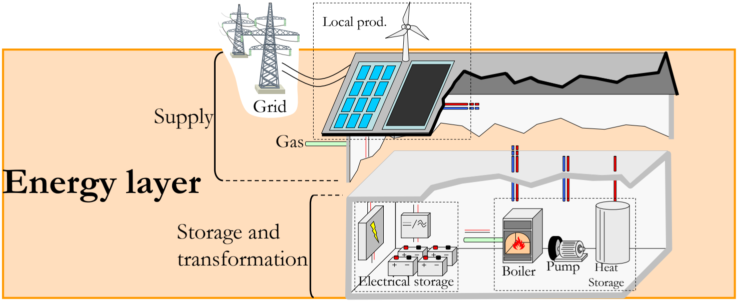

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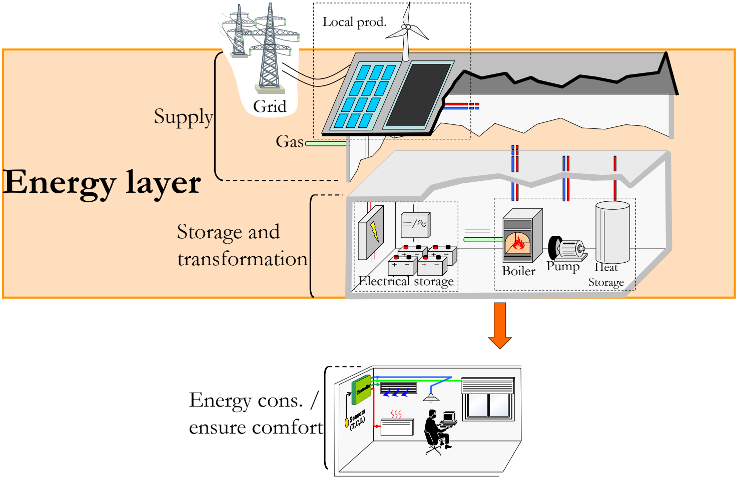

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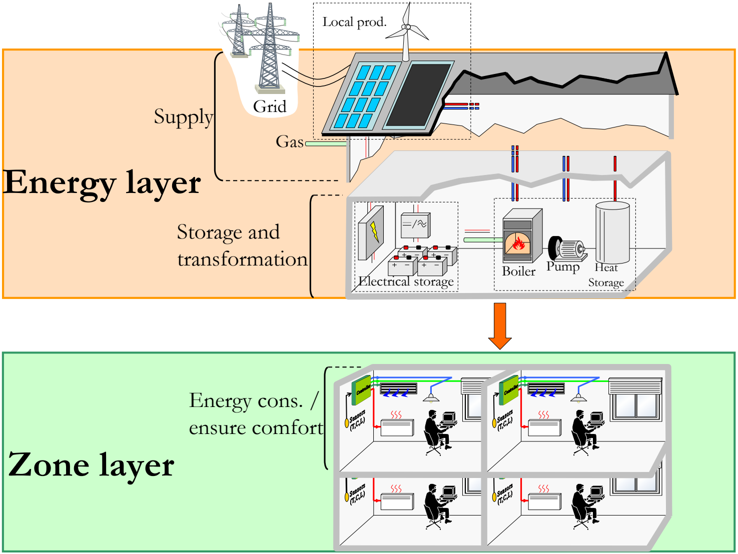

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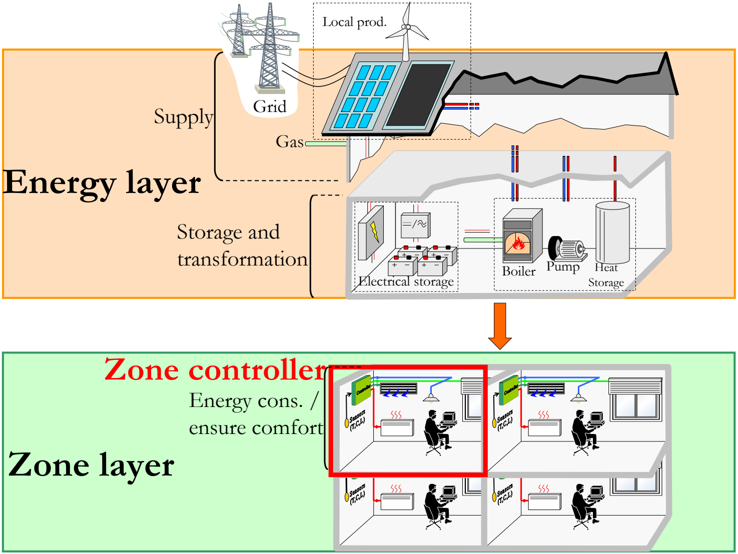

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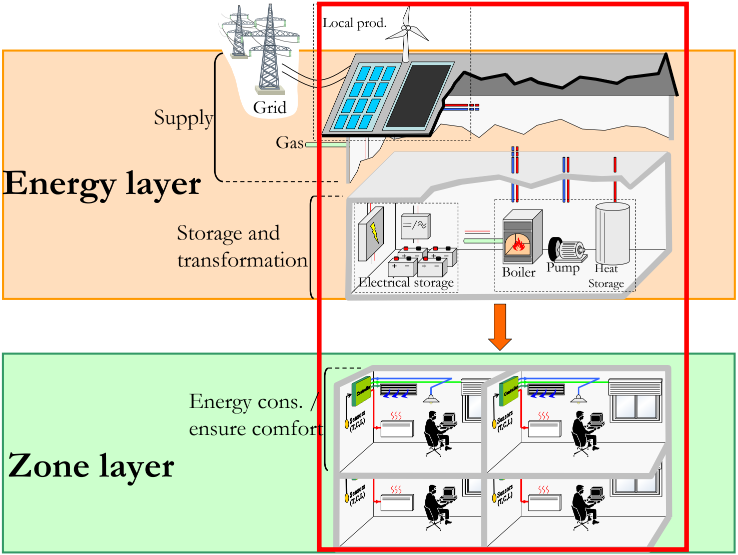

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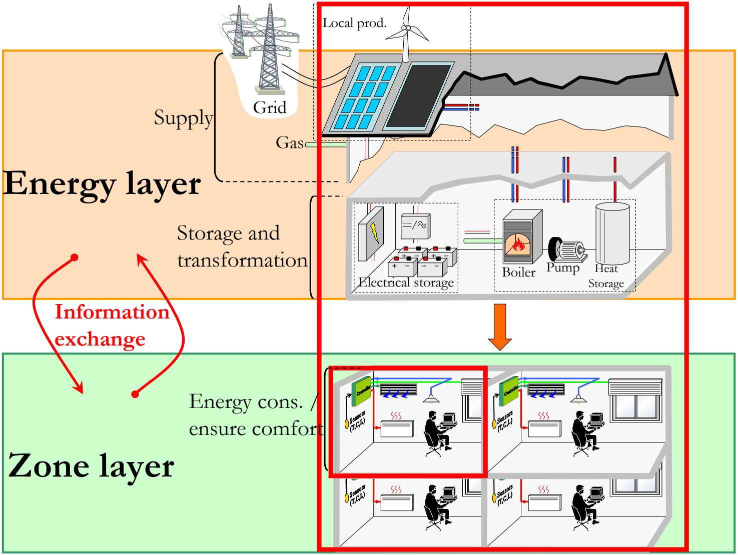


Distributed Model Predictive control for energy management in buildings

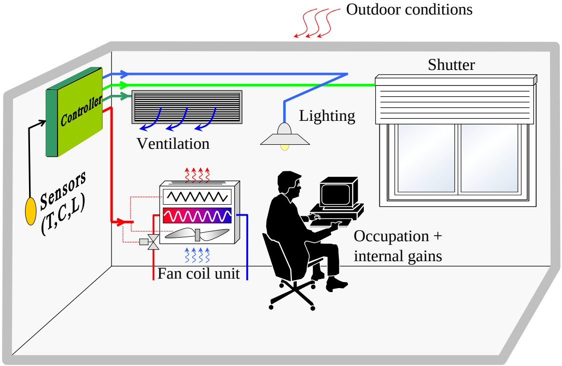
Zone Model Predictive Control

zone presentation

Objective

(a) Control comfort parameters (temperature, CO_2 level, lighting),

(b) Minimize operational costs (energy, invoice).



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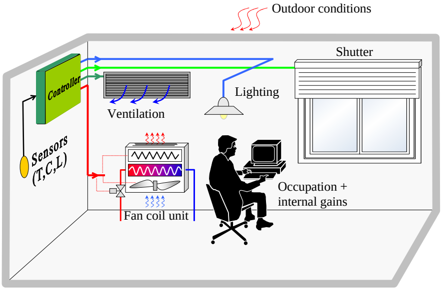
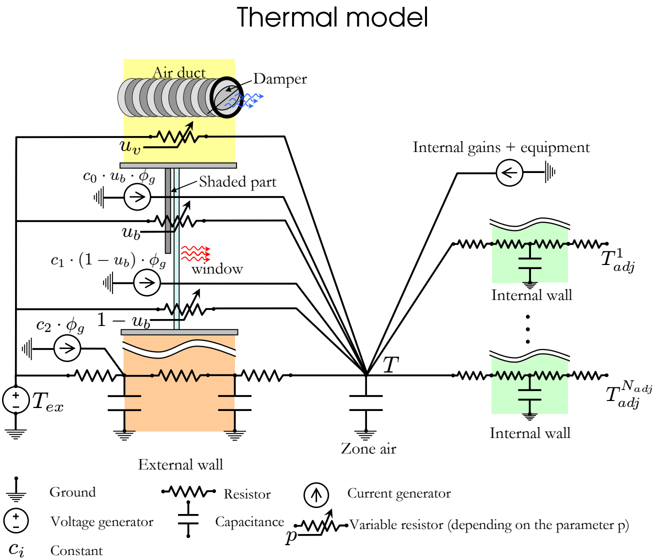


Variables	Description	Unit
u_w	FCU valve opening	$[-]$
u_f	FCU fan speed	$[-]$
u_h	Elec. heating control	$[-]$
u_v	Ventilation control	$[-]$
u_l	Lighting control	$[-]$
$\{u_b^i\}_{i=1,\ldots,N_f}$	Blind ctrl facade i	$[-]$
T_w	Inlet FCU water temp.	$[^oC]$
T_{ex}	Outdoor temperature	$[^oC]$
T_{adj}	Adjacent zones temp.	$[^oC]$
$\{\phi_g^i\}_{i=1,\ldots,N_f}$	Global irr. flux facade i	$[\frac{W}{m^2}]$
Occ	Number of occupants	$[-]$
C_{ex}	Outdoor CO_2 level	$[ppm]$
T	Indoor air temperature	$[^oC]$
C	Indoor CO_2 level	$[ppm]$
L	Indoor illuminance	$[Lux]$

Description of Input/Output and exogenous variables

Zone Modeling

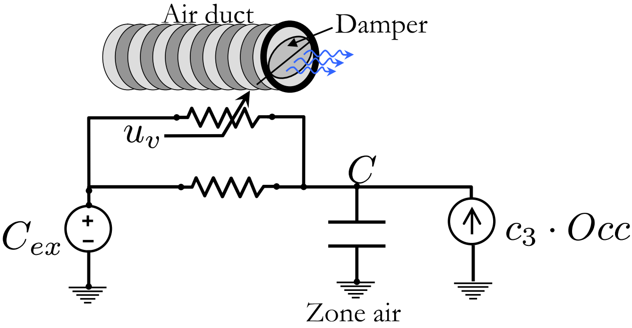
electrical analogy



Zone Modeling

electrical analogy

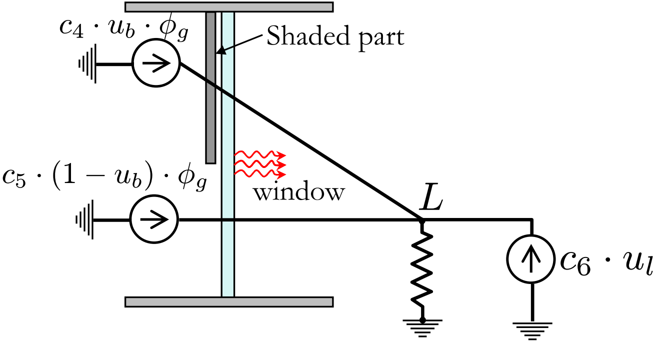
CO_2 accumulation model



Zone Modeling

electrical analogy

Indoor illuminance model



Zone Model

Bilinear state-space representation

Zone model - bilinear system

$$\begin{cases} x^+ & = & A \cdot x + \left[B(y, w)\right] \cdot u + F \cdot w \\ y & = & C \cdot x + [D(w)] \cdot u \end{cases}$$

- x state, y output, w disturbance, u input.
- The matrices $[B(y, w)]$ and $[D(w)]$ are affine in their arguments.

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Simulator form

$$\mathbf{y}_k := \mathcal{Z}(\mathbf{u}_k, \mathbf{w}_k, x_k)$$

boldfaced vectors are predicted profiles (e.g. $\mathbf{u}_k := [u_k^T, u_{k+1}^T, u_{k+N-1}^T]^T$).

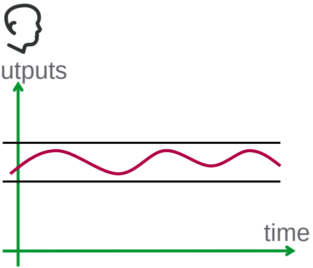
The control problem

problem description

Comfort indicator + **Energy criterion**

Ensure comfort by mainting outputs in a given set

Find the best way to achieve comfort given constraints on inputs



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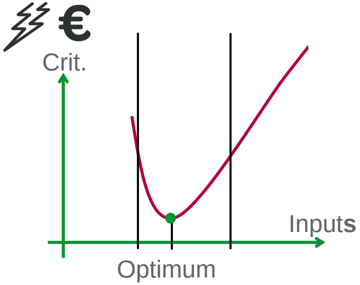
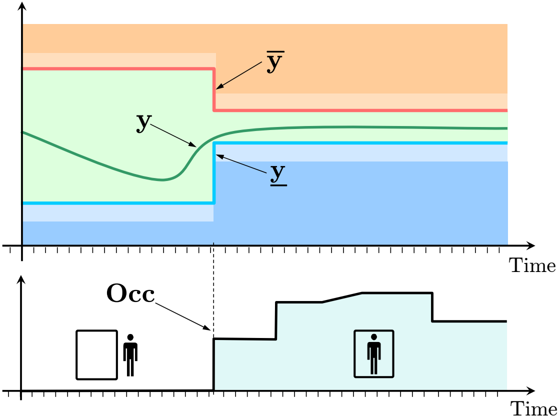


The control problem

The comfort indicator

- Comfort is only required during presence
- Comfort constraints are relaxed to ensure feasibility of the problem



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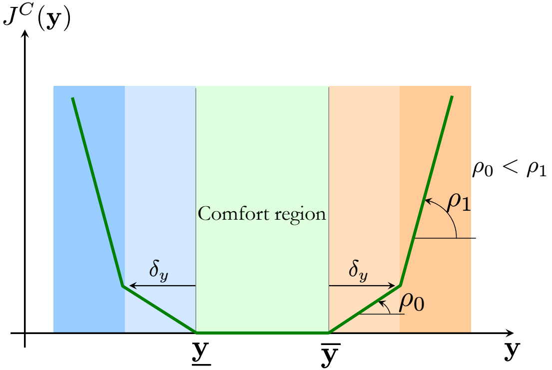

The control problem

Mathematical formulation

NMPC-related optimization problem

$$\underset{\mathbf{u}\in\mathbf{U}}{\textbf{Minimize}} \quad J := J^E(\mathbf{p}) + J^C(\mathbf{y}) \tag{1}$$

where:

- the boldfaced vectors stand for predicted profiles (e.g. $\mathbf{y} := [y_k^T, \ldots, y_{k+N-1}^T]^T$),
- $p \in \mathbb{R}^{n_p}$ is the power consumption,
- J^C is the discomfort criterion.
- J^E is the energy criterion.

The control problem

problem resolution

Optimization problem - explicit form:

$$\text{NLP}_k\text{: } \underset{\mathbf{u}_k,\boldsymbol{\delta}_0,\boldsymbol{\delta}_1,\boldsymbol{\delta}_d,\mathbf{y}_k}{\textbf{Minimize}} \; J_k(\mathbf{u}_k, \mathbf{y}_k \quad) \tag{2a}$$

Subject To :

$$[\Phi(\mathbf{y}_k \quad , \mathbf{w}_k)] \cdot \mathbf{u}_k + \delta_0^- + \delta_1^- \geq \underline{\mathbf{y}}_k - \Psi x_k - \Xi \mathbf{w}_k \tag{2b}$$

$$[\Phi(\mathbf{y}_k \quad , \mathbf{w}_k)] \cdot \mathbf{u}_k - \delta_0^+ - \delta_1^+ \leq \overline{\mathbf{y}}_k - \Psi x_k - \Xi \mathbf{w}_k \tag{2c}$$

$$\mathbf{D} \cdot \mathbf{u}_k - \delta_d^+ + \delta_d^- = \mathbf{a} \tag{2d}$$

$$\mathbf{0} \leq \mathbf{u}_k \leq \mathbf{1} \tag{2e}$$

$$\delta_0 \geq \mathbf{0}\,, \delta_d \geq \mathbf{0}\,,\; \mathbf{0} \leq \delta_1 \leq \begin{bmatrix} \boldsymbol{\delta}_y \\ \boldsymbol{\delta}_y \end{bmatrix} \tag{2f}$$

The control problem

problem resolution

Optimization problem - explicit form:

$$\text{NLP}_k: \underset{\mathbf{u}_k,\boldsymbol{\delta}_0,\boldsymbol{\delta}_1,\boldsymbol{\delta}_d,\mathbf{y}_k}{\textbf{Minimize}} \; J_k(\mathbf{u}_k, \mathbf{y}_k \quad) \tag{2a}$$

Subject To :

$$[\Phi(\mathbf{y}_k \quad, \mathbf{w}_k)] \cdot \mathbf{u}_k + \delta_0^- + \delta_1^- \geq \underline{\mathbf{y}}_k - \Psi x_k - \Xi \mathbf{w}_k \tag{2b}$$

$$[\Phi(\mathbf{y}_k \quad, \mathbf{w}_k)] \cdot \mathbf{u}_k - \delta_0^+ - \delta_1^+ \leq \overline{\mathbf{y}}_k - \Psi x_k - \Xi \mathbf{w}_k \tag{2c}$$

$$\mathbf{D} \cdot \mathbf{u}_k - \delta_d^+ + \delta_d^- = \mathbf{a} \tag{2d}$$

$$\mathbf{0} \leq \mathbf{u}_k \leq \mathbf{1} \tag{2e}$$

$$\delta_0 \geq \mathbf{0}\,, \delta_d \geq \mathbf{0}\,,\; \mathbf{0} \leq \delta_1 \leq \begin{bmatrix} \delta_y \\ \delta_y \end{bmatrix} \tag{2f}$$

Nonlinear optimization problem due the product terms $u \cdot y$

The control problem

problem resolution

Optimization problem - explicit form:

$$\text{LP}_k^{(s)}: \underset{\mathbf{u}_k, \boldsymbol{\delta}_0, \boldsymbol{\delta}_1, \boldsymbol{\delta}_d, \not{\mathbf{y}_k}}{\textbf{Minimize}} \; J_k(\mathbf{u}_k, {\mathbf{y}_k}^{(s)}) \tag{2a}$$

Subject To :

$$[\Phi({\mathbf{y}_k}^{(s)}, \mathbf{w}_k)] \cdot \mathbf{u}_k + \delta_0^- + \delta_1^- \geq \underline{\mathbf{y}}_k - \Psi x_k - \Xi \mathbf{w}_k \tag{2b}$$

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Update the output trajectory $\mathbf{y}_k^{(s)}$ by simulating the NL system:

$$\mathbf{y}_k^{(s+1)} = \mathcal{Z}(\mathbf{u}_k^{(s)}, \mathbf{w}_k, x_k)$$

The control problem

problem resolution

Optimization problem - explicit form:

$$\mathbf{u}_k^{(s)} \leftarrow \mathrm{LP}_k^{(s)}: \underset{\mathbf{u}_k,\boldsymbol{\delta}_0,\boldsymbol{\delta}_1,\boldsymbol{\delta}_d}{\textbf{Minimize}} \; J_k(\mathbf{u}_k, \mathbf{y}_k{}^{(s)}) \tag{2a}$$

Subject To :

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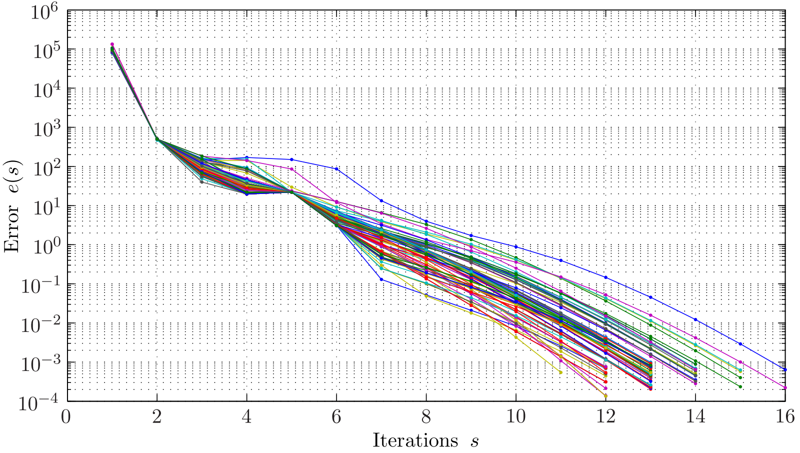
Update the output trajectory $\mathbf{y}_k^{(s)}$ by simulating the NL system:

$$\mathbf{y}_k^{(s+1)} = \mathcal{Z}(\mathbf{u}_k^{(s)}, \mathbf{w}_k, x_k)$$

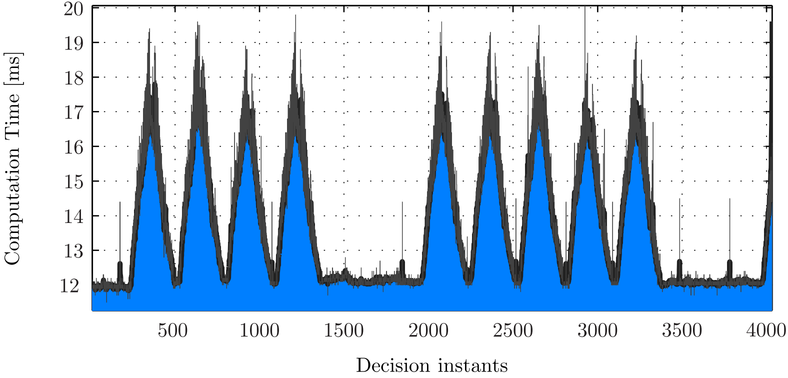
Fixed-point algorithm: $\mathbf{y}_k^{(s)} \xrightarrow{LP} \mathbf{u}_k^{(s)} \xrightarrow{SIM} \mathbf{y}_k^{(s+1)}$

Convergence analysis

- No formal convergence proof of the algorithm is provided,
- Run the algorithm starting from 100 random (unrealistic) initial guesses.



Computational burden



Computation time for $N = 720$, $N_u^{par} = 20$, $N_y^{par} = 20$ *(Intel® Xeon® @ 2.67 GHz, 3.48 Go RAM - ILOG CPLEX 12.1 for LPs)*

The case study

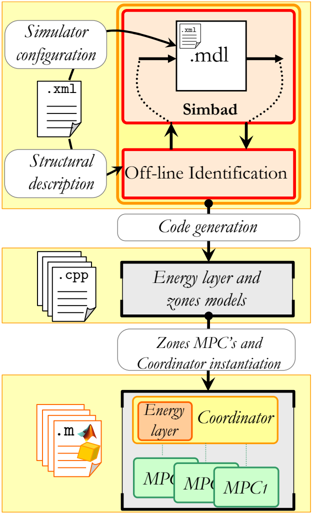
small business building

- Typical french small business building built in 2006, 20 zones, 540 (m^2),
- Electrical heater,
- Local dampers for ventilation control,
- Automated blinds,
- Location *Trappes* (near Paris),
- Modeled using the SIMBAD toolbox.

MPC integration in SIMBAD

Configuration step

1. Build the structure of the building (`.xml`),
2. Identify the dynamical models of each zone,
3. Generate automatically C code able for zones and energy layer representations,
4. Instantiate MPCs for the whole building (observers, powers estimators, available forecast, occupancy schedule, available equipments, etc.)



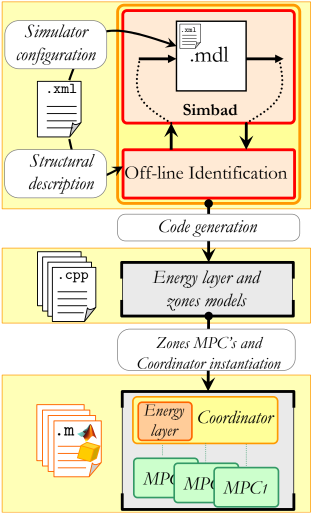
MPC integration in SIMBAD

Example: 20 zones building:

- ≈70 inputs / ≈60 outputs / ≈160 states

Simulation

- Refreshing period: 5 min.
- ≈ **2,102,400** optimization problems (600-900 d.v × 1000 con.) solved during the **whole year simulation**.
- Simulation time ≈ 18 (h)



MPC integration in SIMBAD

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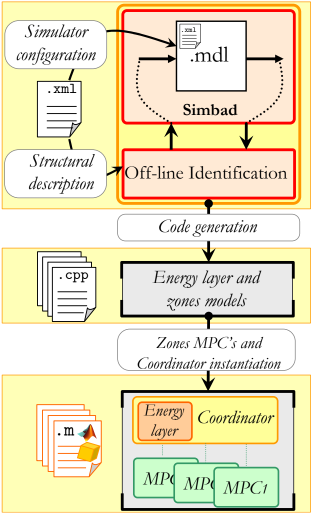

Simulation

- Refreshing period: 5 min.
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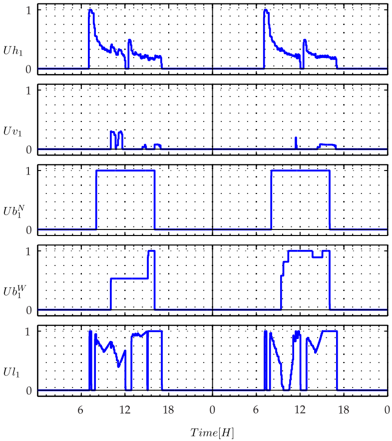
- Simulation time ≈ 18 (h)

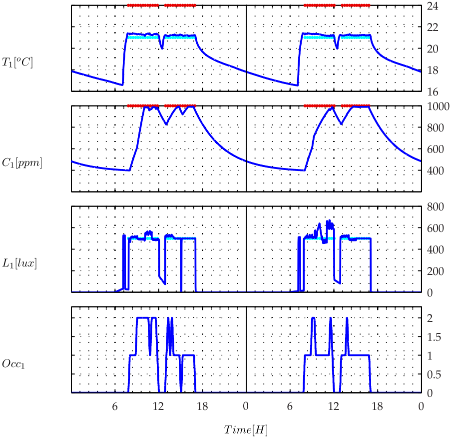
⟶ need for efficient code to perform a yearly simulation

- use of C code when appropriate
- vectorized m-code
- logical matrix indexation

Simulation results (I)

Zone MPC illustration- an office





48 (h) simulation - office # 1

Simulation results (II)

Yearly simulation results

1. Perfectly known forecast ($\alpha = 1$)
2. Errors on forecast ($\alpha = 0$)
3. Rule-based control

	Energy cons. (kWh/m^2/year)		
Rule based*	142		
MPC ($\alpha = 1$)	119 ($-$**16**%)		
MPC ($\alpha = 0$)	122 ($-$**14**%)		

Energy consumption / Comfort - Rule-based vs. MPC

*: more advanced RB control strategy (≈-50% compared to current practice)

Simulation results (II)

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Rule based*	142	91.6	
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Energy consumption / Comfort - Rule-based vs. MPC

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Simulation results (II)

Yearly simulation results

1. Perfectly known forecast ($\alpha = 1$)
2. Errors on forecast ($\alpha = 0$)
3. Rule-based control

	Energy cons. (kWh/m^2/year)	GTC (%)	TCV (k·^{O}C·h)
Rule based*	142	91.6	322
MPC ($\alpha = 1$)	119 ($-$**16**%)	91.8	295
MPC ($\alpha = 0$)	122 ($-$**14**%)	88.1	310

Energy consumption / Comfort - Rule-based vs. MPC

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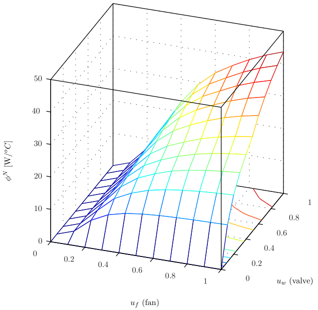
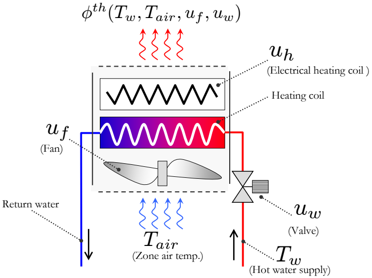
Other features (I)

Handling fan coil units

The FCU model is a static nonlinear heat emission characteristic:

$$\phi^{th}(u_w, u_f, T, T_w) = (T_w - T) \cdot \phi^N(u_w, u_f)$$





Thermal emission characteristic

Other features (I)

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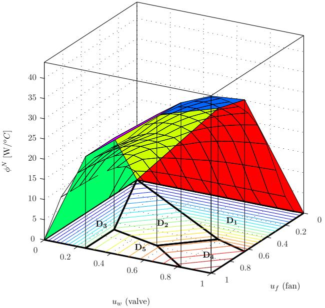
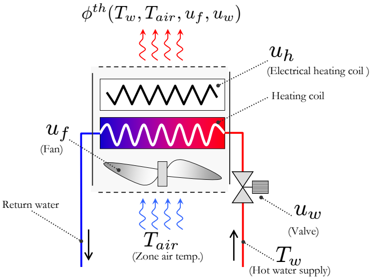




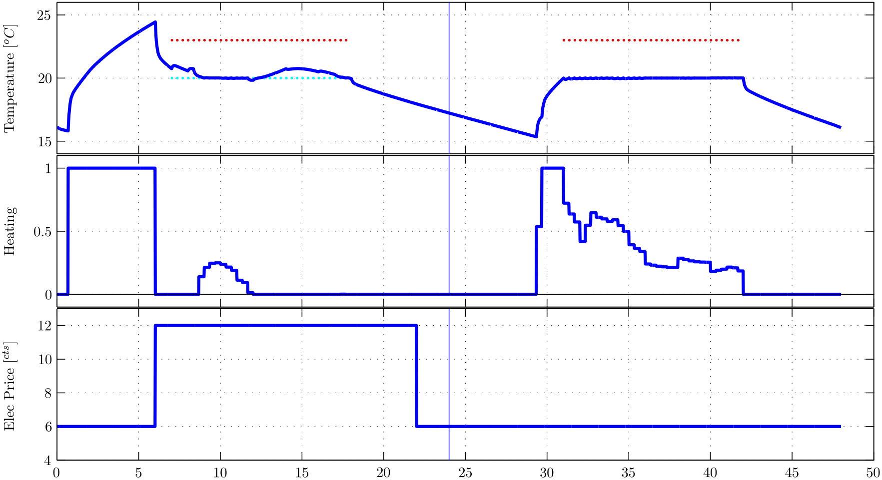
PWA approx.

Adapt the algorithm to handle FCUs and preserve the LP formulation

Other features (II)

variable energy prices

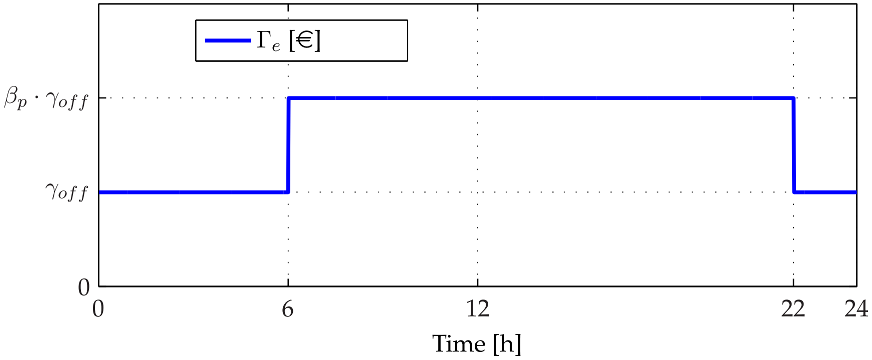
1. Preheat the first day during off-peak hours,
2. Optimal start the second day during on-peak hours,



Other features (II)

variable energy prices

Sensitivity of the solution to the ratio between high and low energy price periods (β_p)



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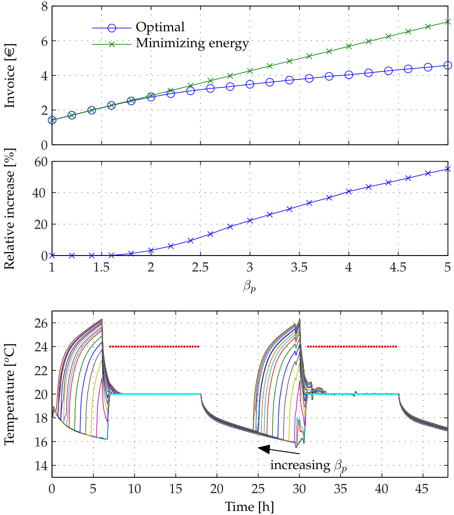
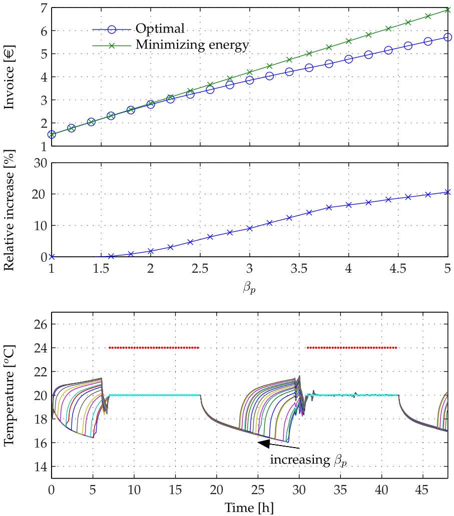


Other features (II)

variable energy prices

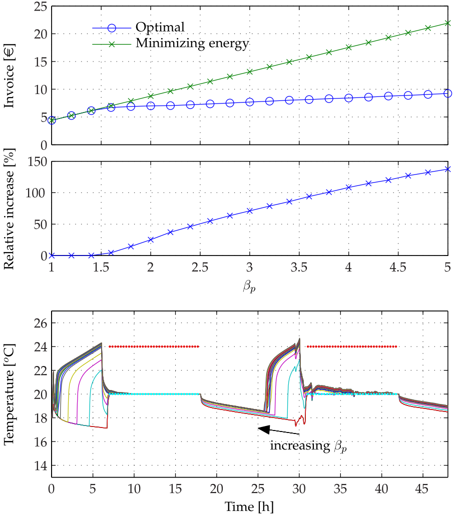
Heater half dimensioned



Other features (II)

variable energy prices

+ another zone (more inertia)



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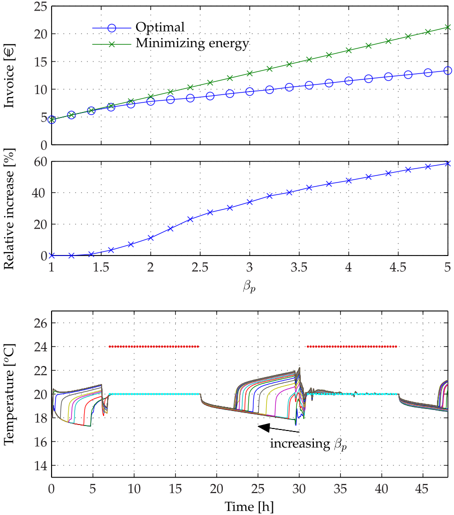

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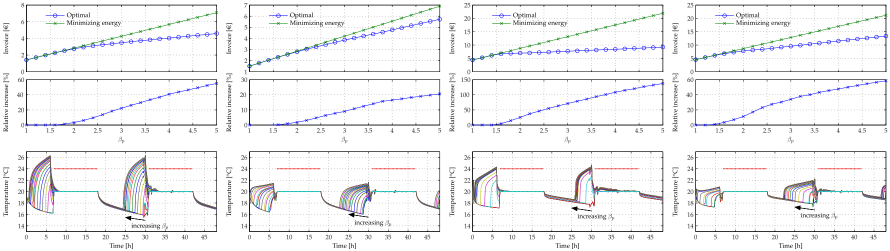

The optimal behavior is linked to the dynamical characteristics of each zone

Roombox implementation

Main features:

- Power output: lighting, shutters and blinds, HVAC
- Network connection to BMS
- Ethernet port for local PC
- Inputs for switches and window contacts 24 Vcc
- Output protection (SC protection, overload ...)

Roombox

Schneider Electric

Roombox implementation

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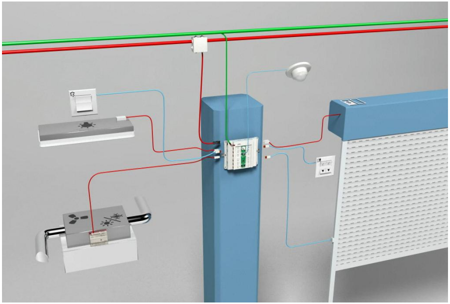


Roombox

Roombox implementation

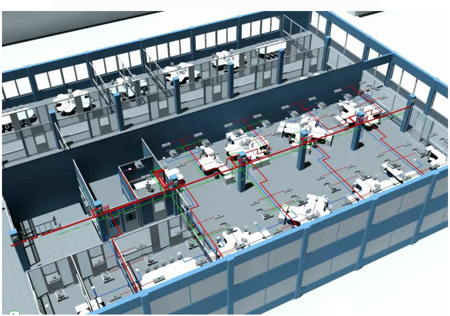
Objective

Implement the MPC algorithm on the Roombox →

- To study the real-time implementation
- To identify the main related issues

Validation

→ Virtual signals sent via the ethernet port (measures and forecast)



Roombox

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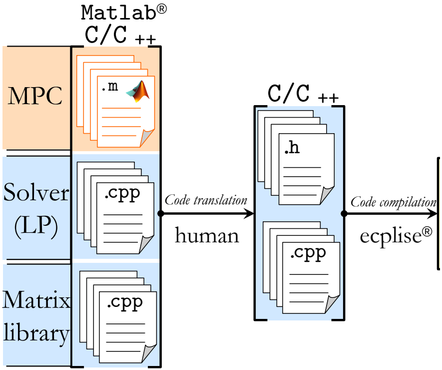


Roombox

Roombox implementation

Conditions

- Prediction horizon 12 h.
- sampling period 2 min.
- zone: $n_u = 6, n_y = 3$
- GLPK (GNU MILP solver)

Roombox Schneider Electric

Roombox implementation

Results

- ≈ 6 (s) / iteration
- 8.2 % of memory usage
- Able to run more than one thread of the algo. on one Roombox

Roombox

Distributed Model Predictive control for energy management in buildings

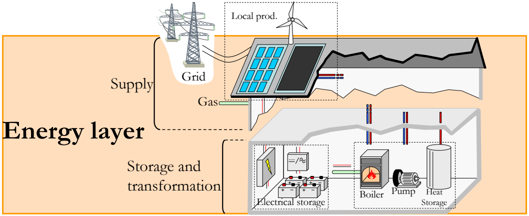
Building control layers

Decomposition approach

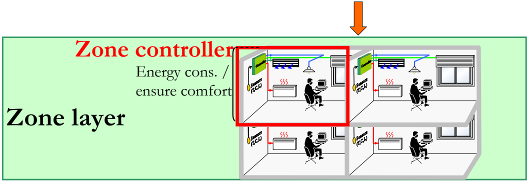
Objective

Coordinate the energy layer and the zone layer → Manage resource coupling constraints

- **Energy layer** → energy supply, storage and transformation



- **Zone layer** → consume energy to provide comfort



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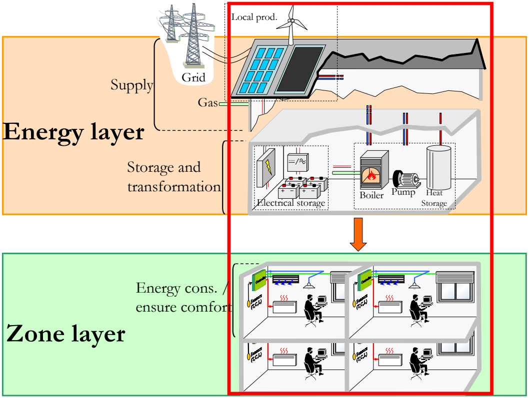

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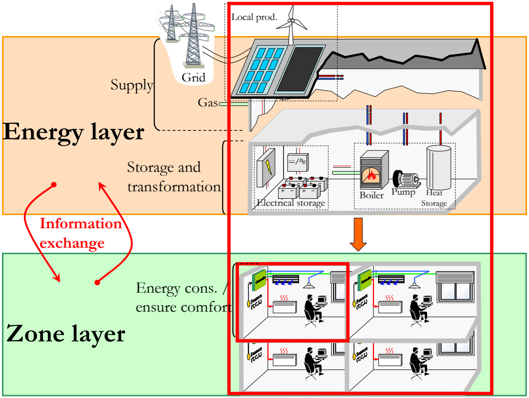
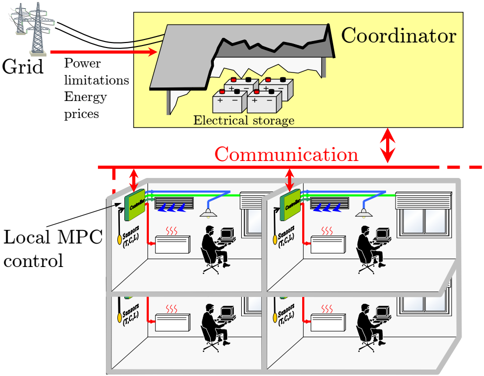


Handling coupling resource constraints



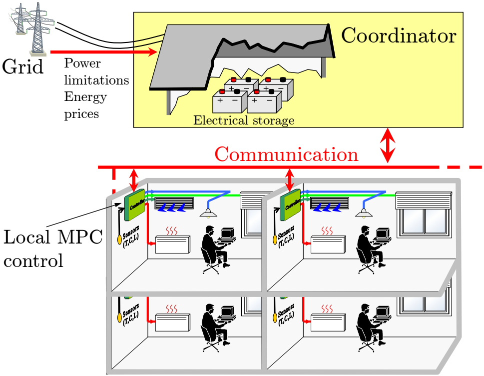
Objectives:

- Power limitation constraint on the whole building cons.

$$P_b^+ + \sum_{\ell \in Z} P_\ell \le \overline{P}_g$$

- Manage the storage capability (elec. battery)

Handling coupling resource constraints



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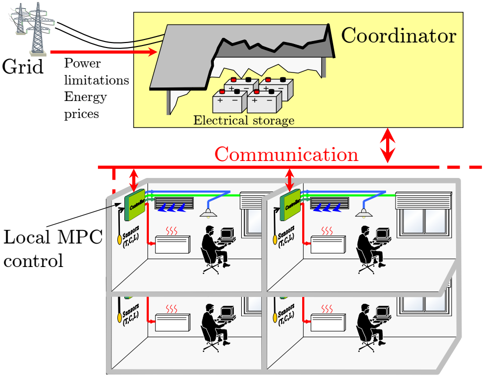

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Zone Predictive controller

Slight modifications ...

Each zone controller controls local variables

$$\text{MPC}_\ell \quad : \underset{\underline{\mathbf{z}}_\ell \leq \mathbf{z}_\ell \leq \overline{\mathbf{z}}_\ell}{\textbf{Minimize}} \; \mathbf{L}_\ell \cdot \mathbf{z}_\ell$$

Subject To:

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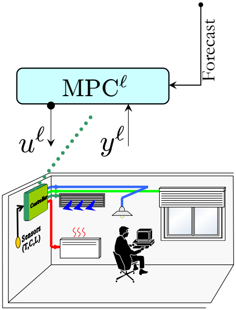

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Each zone controller controls local variables while meeting local constraints on resources:

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Subject To:

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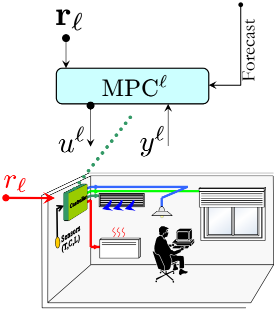
$$\mathbf{A}'_\ell \cdot \mathbf{z}_\ell \leq \mathbf{r}_\ell$$



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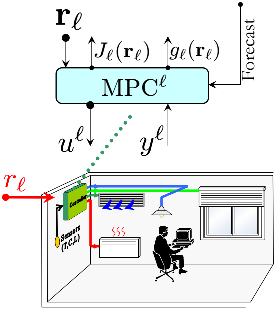
One gets:

$$(J_\ell, g_\ell) \leftarrow \text{MPC}_\ell(\mathbf{r}_\ell)$$

- $J_\ell := J_\ell(\mathbf{r}_\ell)$: optimal value
- $g_\ell := g_\ell(\mathbf{r}_\ell)$: sub-gradient at $\mathbf{r}_\ell$



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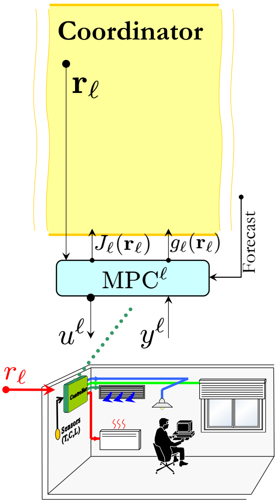
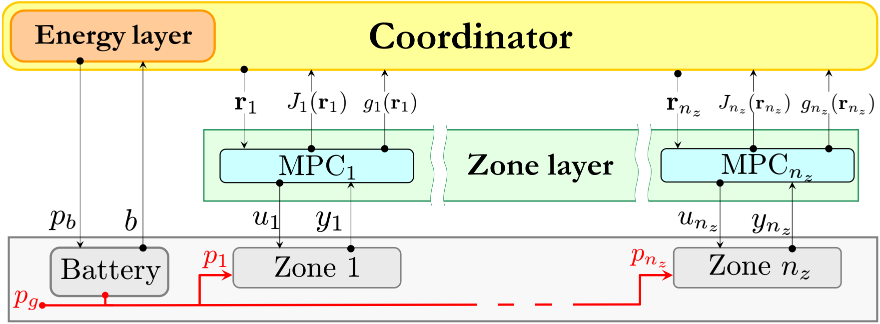


The coordination layer

At the coordination layer, the problem is the following:
How to affect optimally resource profiles r $:= \{\mathbf{r}_\ell\}_{\ell \in \mathbf{Z}}$ to minimize the total cost function ?



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$\rightarrow$ **Solve the master problem:**

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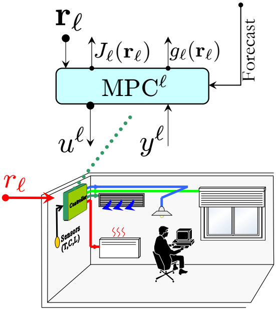
problem:
$\rightarrow$ J_ℓ **are not available !**
$\rightarrow$ **built-up approximations of** J_ℓ $\rightarrow$ **Bundle method**

The bundle method

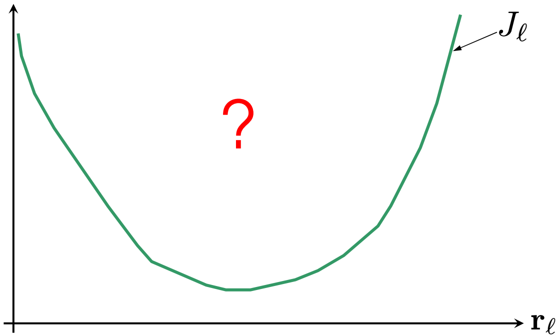
1. The coordinator affects local resources
2. Each zones gives:
   - The value of the cost function $J_\ell(\mathbf{r}_\ell)$
   - A sub-gradient $g_\ell(\mathbf{r}_\ell)$ (sensitivity)



The bundle method

Cutting plane approximation

Unknown at the coordination layer



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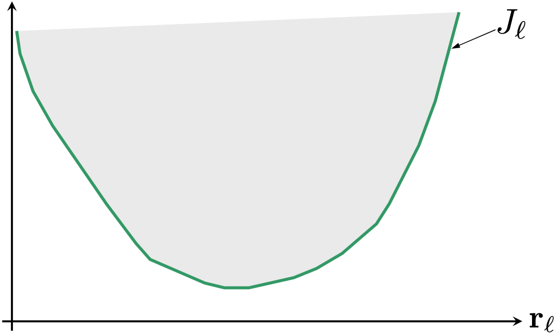

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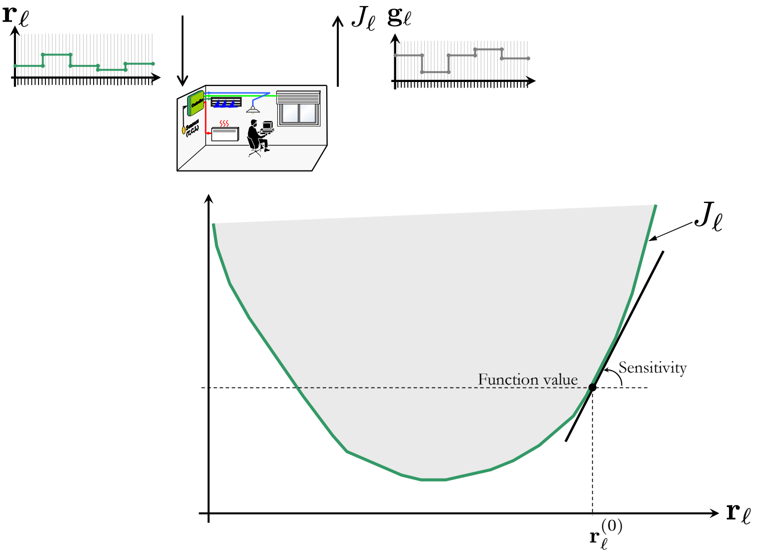

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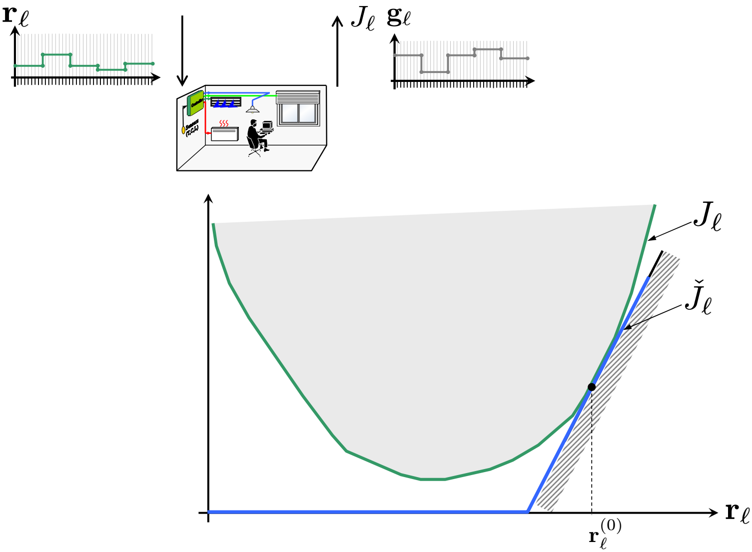

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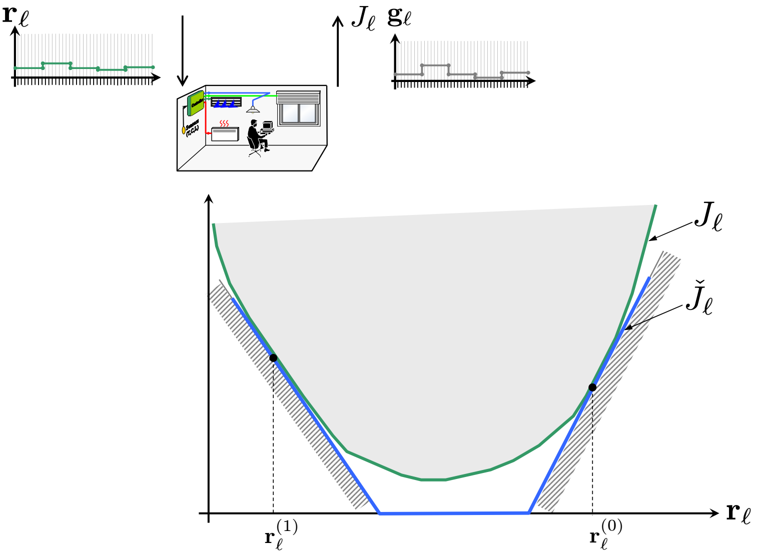

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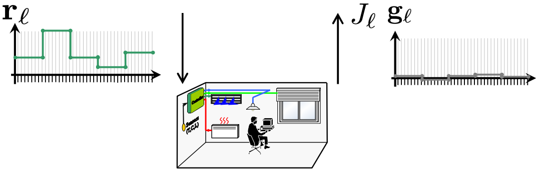

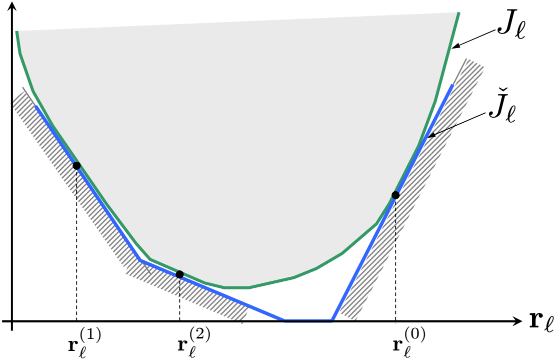

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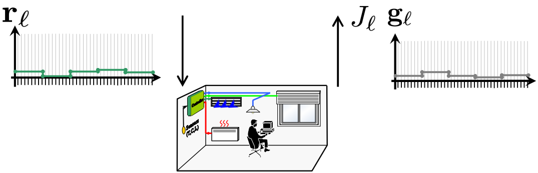
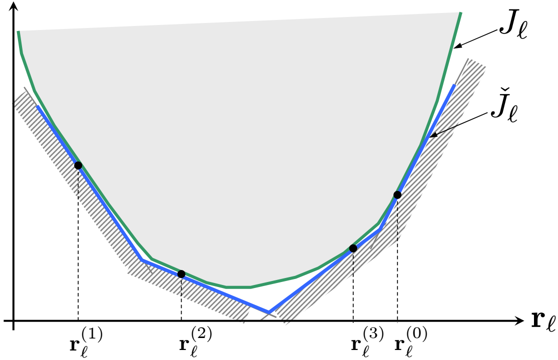
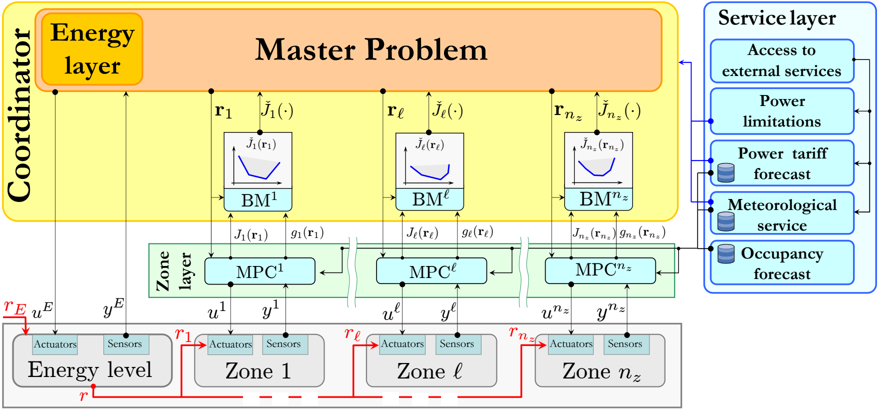




Distributed MPC scheme

- Process of decision is distributed among several agents
- The coordinator manages only the shared resources
- A restricted number of negotiation iterations is allowed



Now Distribute the optimization problem solving over time

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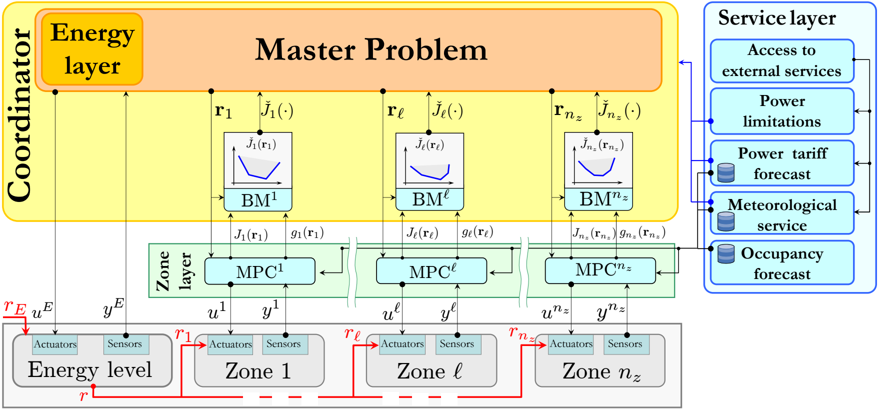

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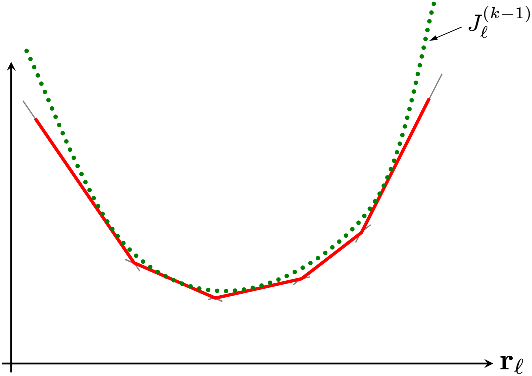
Distributing the optimization over time

The memory mechanism

The idea is simply to keep a certain part of the information (approximation) from one decision instant to next one...



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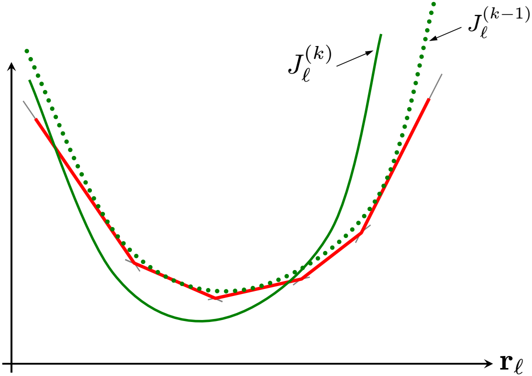

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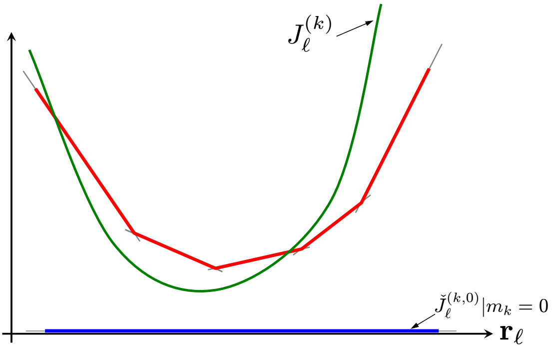

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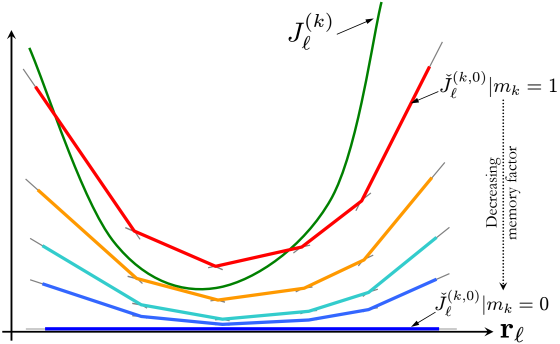
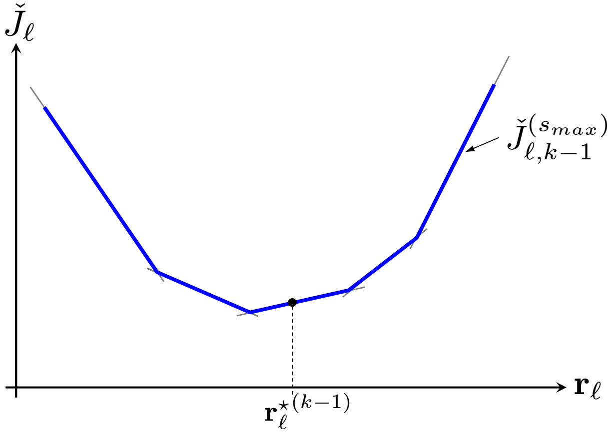


...by introducing a memory factor.

Memory mechanism

Illustration

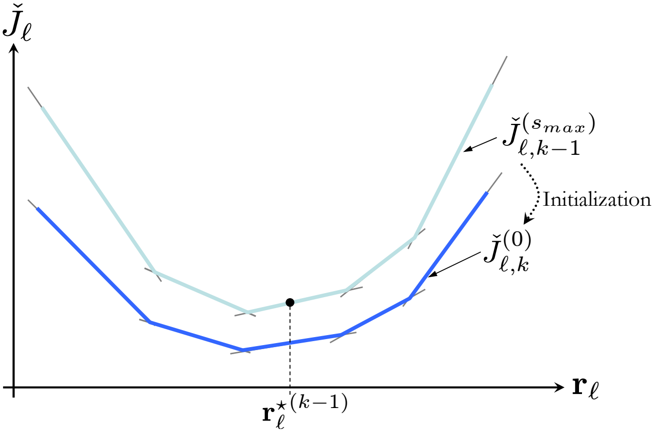
- $J_{\ell}^{(s_{max})}$ is given at decision instant $k-1$



Memory mechanism

Illustration

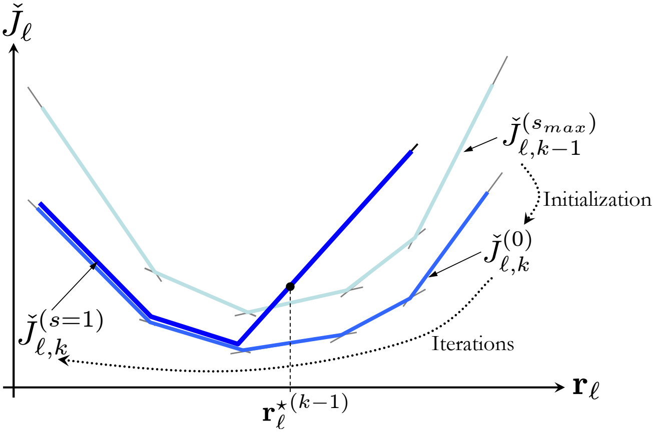
- Decrease it (memory factor $m_{\ell,k}$)



Memory mechanism

Illustration

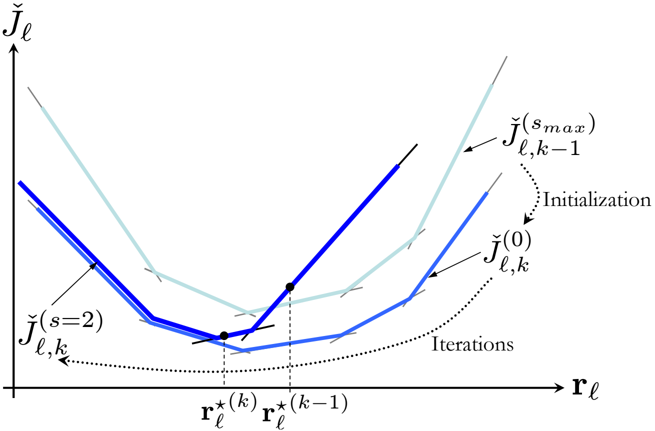
- First iteration (exchange between zone layer and coordinator)



Memory mechanism

Illustration

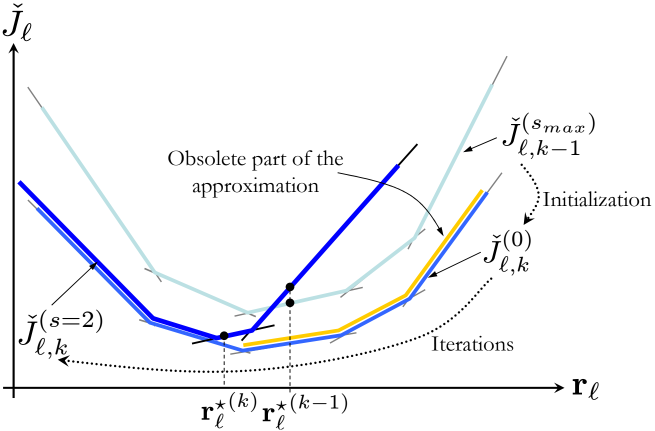
- Iterate (exchanges between zone layer and coordinator)



Memory mechanism

Illustration

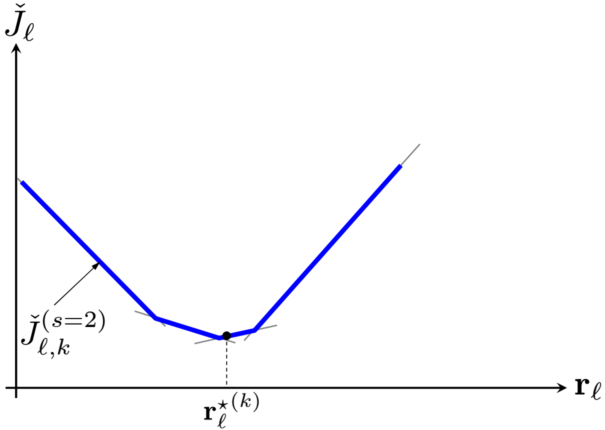
- One gets the latest approximation at decision instant *k*



Memory mechanism

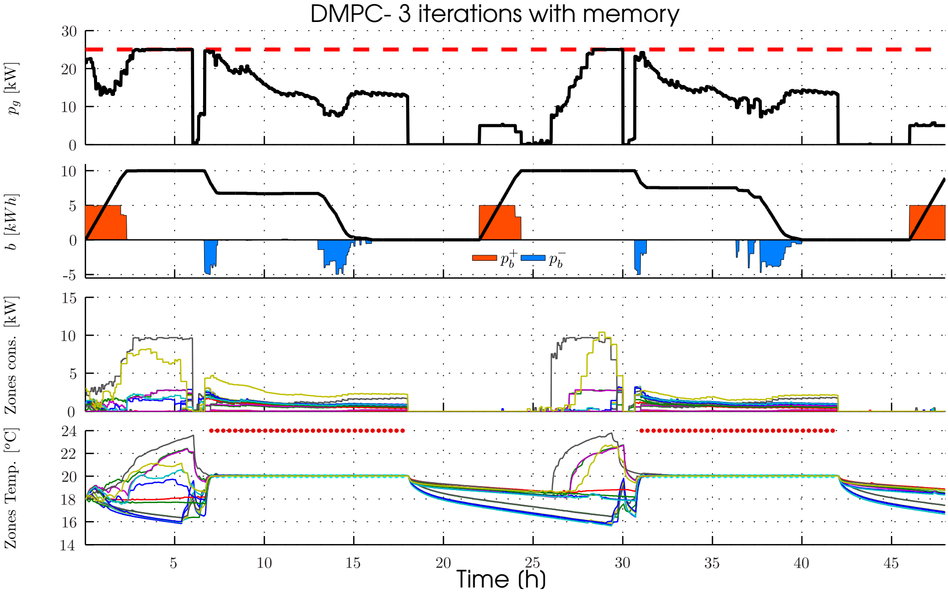
Illustration

- And so on ...



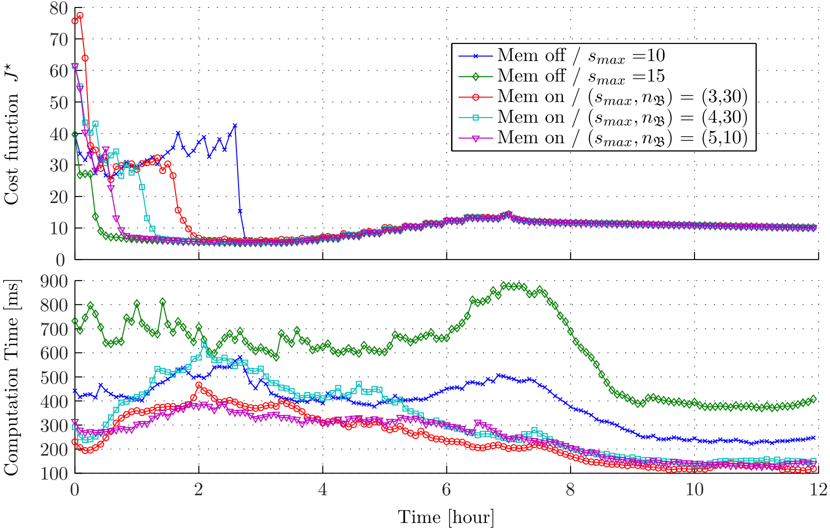
DMPC simulation

Closed-loop trajectories



Effect of the memory mechanism

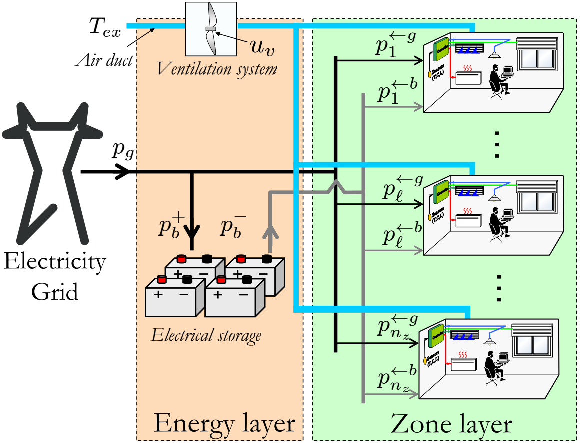
Achieve better solutions faster with memory !



Distributed Model Predictive Control

Other features

1. Handling shared variables
2. Including local production



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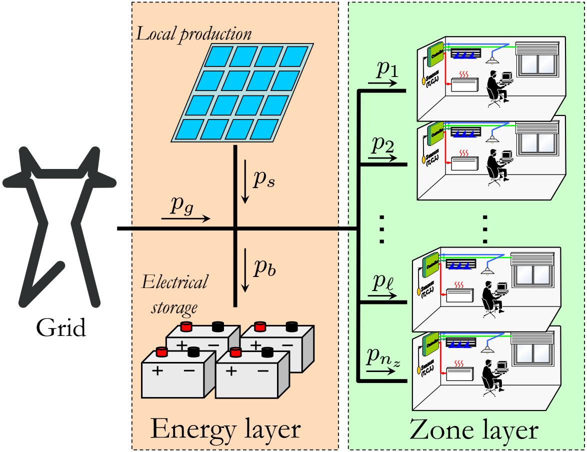
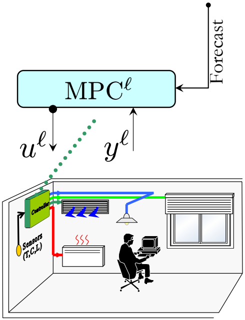


Distributed Model Predictive control for energy management in buildings

Conclusion

Summary

1. **Zone MPC design (Bilinear model, MIMO)**
   - generic framework
   - energy savings
   - Moderate computational burden
   - Real-time implementation



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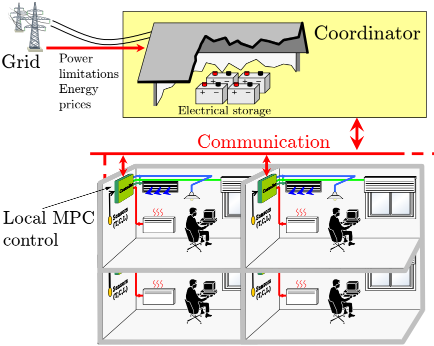

2. **Build a distributed solution based on local controllers**
   - Handle global power limitations (multi-sources)
   - Handle storage equipment
   - Manage shared actuators
   - Distributed-in-time optimization

Conclusion

Benefits

- A generic and coherent framework
- Modular $\rightarrow$ scalable, maintenance concerns
- Represents a good answer for smart-grid connectivity

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Issues

- Availability of the model of the building
- Availability of forecast
- Much more computationally demanding

For future ...

Projects

1. **First MPC prototype** in North-Andover (USA) starting in few weeks
2. Extend the current framework to manage **smart districts** (building $\leftarrow$ zone, district $\leftarrow$ building): **Ambassador** project (Europe)

For future ...

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but also ...

1. **Deployment tools** for large scale penetration
2. MPC **commissioning**
3. **Code certification** for large deployment

Acknowledgement

http://www.homesprogramme.com

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Publications I

Conferences

- M. Y. Lamoudi, M. Alamir, and P. Béguery. Distributed constrained model predictive control based on bundle method for building energy management. In 50th IEEE Conference on Decision and Control and European Control Conference- Orlando, 2011.
- M. Y. Lamoudi, M. Alamir, and P. Béguery. Unified NMPC for multi-variable control in smart buildings. In IFAC 18th World Congress, Milano, Itlay, 2011.
- M. Y. Lamoudi, M. Alamir, and P. Béguery. Model predictive control for energy management in buildings- part 1: zone model predictive control. In IFAC conference on Nonlinear Model Predictive Control, 2012.
- M. Y. Lamoudi, M. Alamir, and P. Béguery. Model predictive control for energy management in buildings- part 2: Distributed model predictive control. In IFAC conference on Nonlinear Model Predictive Control, 2012.
- M. Y. Lamoudi, P. Béguery, and M. Alamir. Use of simulation for the validation of a predictive control strategy. In 12th International IBPSA Conference , Sydney, Australia, 2011.

Publications II

- P. Béguery, M. Y. Lamoudi, O. Cottet, O. Jung, N. Couillaud, and D. Destruel. Simulation of smart buildings HOMES pilot sites. In 12th International IBPSA Conference , Sydney, Australia, 2011.

Book chapter

- M. Y. Lamoudi, M. Alamir, and P. Béguery. A distributed-in-time NMPC-based coordination mechanism for resource sharing problems. Chapter in Distributed Model Predictive Control made easy. Springer Verlag, 2012. (to appear)

Schneider-Electric white papers

- M. Y. Lamoudi, P. Béguery, O. Nilsson and B. Leida. Model Predictive Control - toward smarter energy management systems. White paper, Schneider-Electric, Jan. 2012.

Publications III

Patents

- M. Y. Lamoudi, P. Béguery, and M. Alamir. Procédé de commande pour gérer le confort d'une zone d'un bâtiment selon une approche multicritères et installation pour la mise en œuvre du procédé, 2011.
- C. Guyon, M. Y. Lamoudi and P. Béguery, Procédé et dispositif de répartition de flux d'énergie éléctrique et système électrique comportant un tel dispositif, 2012.

Thank you for your attention

Questions ?