A Prototype for On-line Monitoring and Control of Energy Performance for Renewable Energy Buildings

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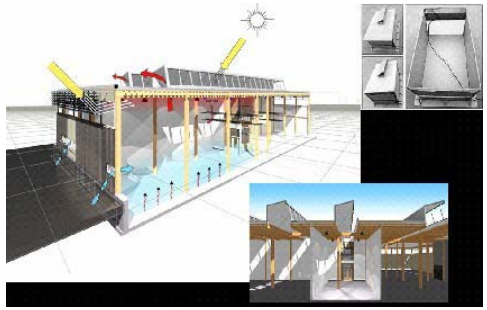

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CSTB
le futur en construction

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UPVD
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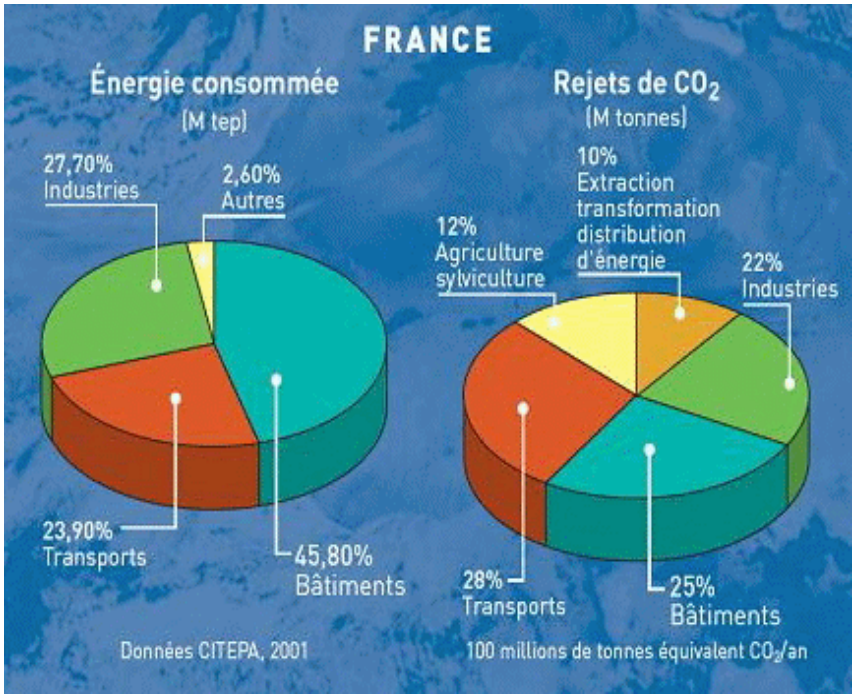
OUTLINE

- Introduction
- Energetic Performance of Buildings
  - ***Issues***
  - ***Indicators***
- A Prototype for Monitoring and Control
  - ***Instrumentation and Data Sets***
  - ***Hardware***
- Control and Optimization Algorithms
- Illustrative Example
  - ***Model Description***
  - ***Results and Discussion***
- Conclusions

Introduction

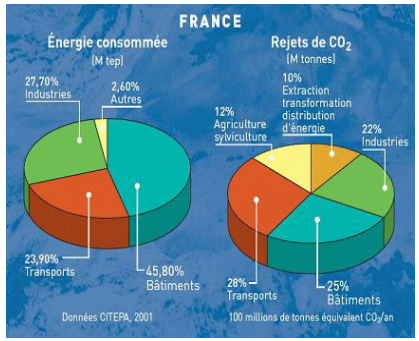
- In France 25% of GEG exhaustion and 46% of energy consumption ⇆ Buildings



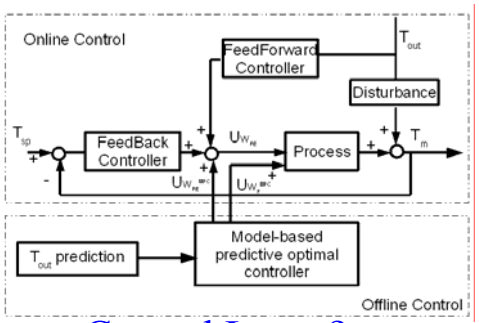
- Improving the energetic efficiency of buildings is a priority
- Develop the use of renewable energies
- Define ”a posteriori” indicators of energy performance
- Develop tools for monitoring, control and optimization of the use of renewable energies

Introduction

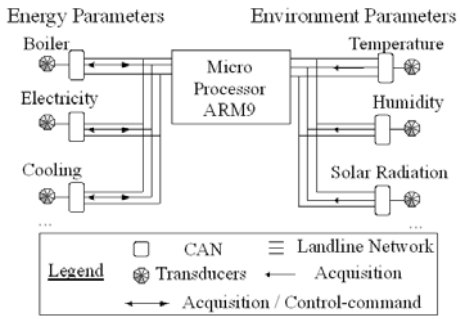
- Comprehensive Approach:
  - ***Indicator***
  - ***Sensors***
  - ***Electronics***
  - ***Control laws***



Performance Indicator ?



Control Laws ?



Electronics ?

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Energetic Performance of Buildings

- Multiplicity of Standards and labels (legal doc.):
  - ***Passiv Hause (Germany)***
  - ***Minergie (Switzerland)***
  - ***Effi-energie (France)***
  - …

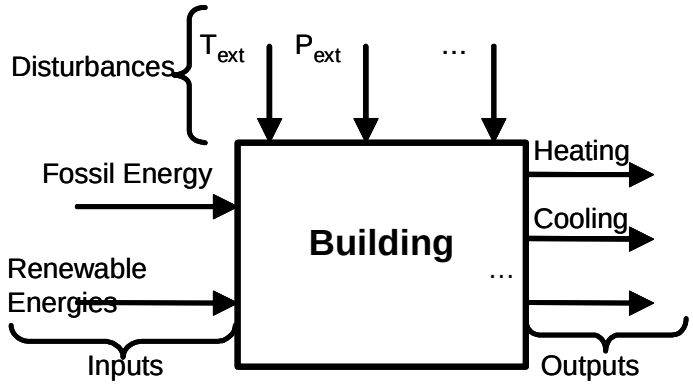
≠ different objectives

≠ ways for estimating energetic performance

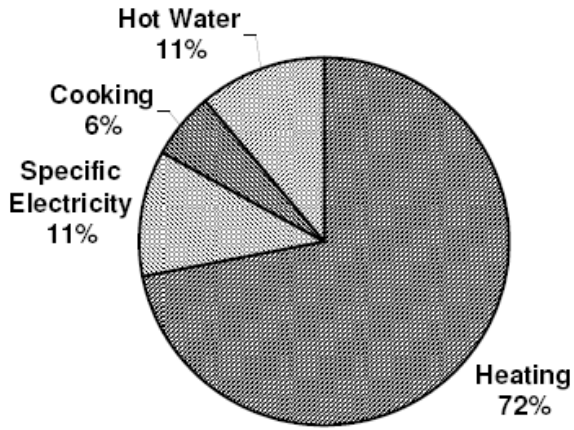
There is not a single definition of an acceptable & smart behavior

Energetic Performance of Buildings

- A building is MIMO system interacting with its environment:
  - ***≠ inputs, ≠ outputs***
  - ***perturbations***



- Energy is segmented in terms of nature and end-uses:



Energetic Performance of Buildings

- An indicator is needed that:
  - *Can be computed*
  - *Allows comparisons between buildings*
  - *Takes into account the intrinsic segmentation of energy end-uses*
  - *Accounts for buildings specificities (materials, location, …)*

Specific documentation of CSTB allows computing an indicator expressed in:

$kWh.m^{-2}.yr^{-1}$

- **Average french consumption = 229 $kW.m^{-2}.yr^{-1}$!**

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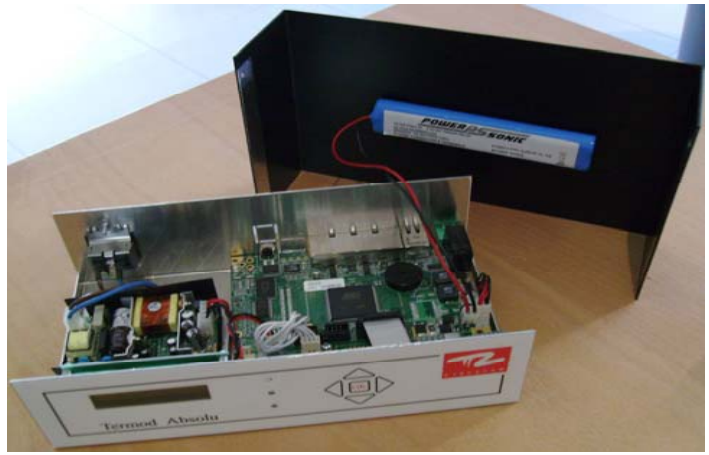
A Prototype for Monitoring and Control

- Prototype was developed and tested with 2 industrial partners
- Constraints:
  - ***Implementation easy, low cost***
  - ***Avoids pulling or drilling cables, few sensors***
  - ***Various configurations***
  - ***Compute the indicator***
  - ***Communicate (WiFi, e.g) with a server ⇆ diagnosis, control***
  - ***In-situ control***



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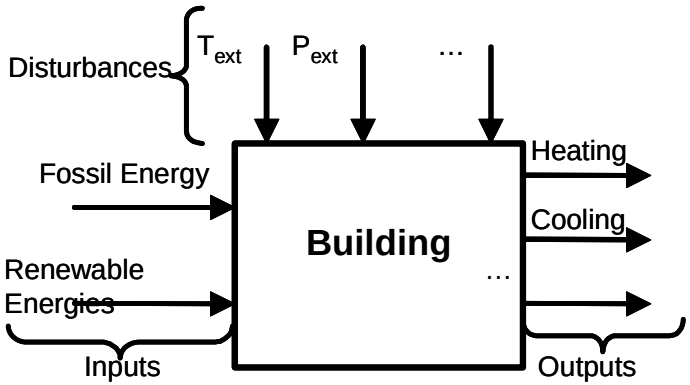
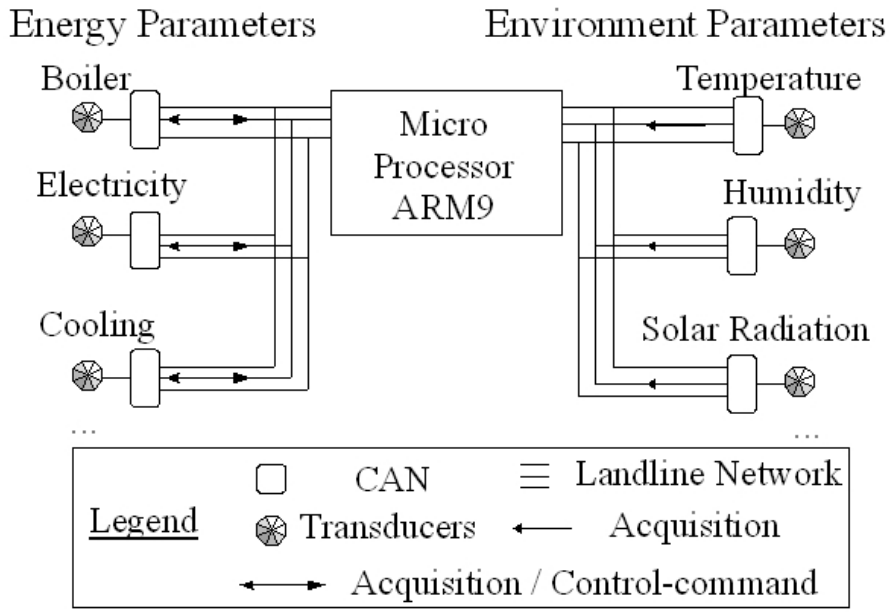
Instrumentation and Data Sets

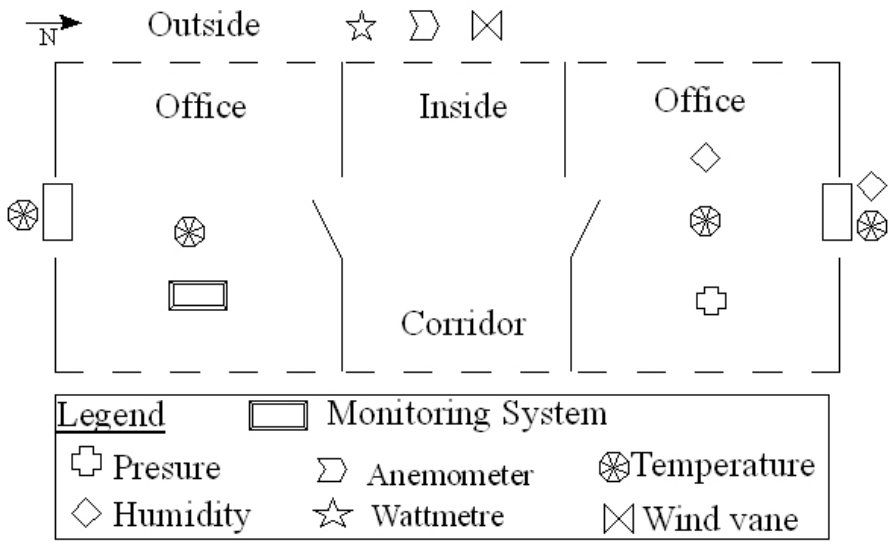




The way the architecture is developed, the kind and number of implemented sensors should be consistent with the interaction between the considered building and its environment

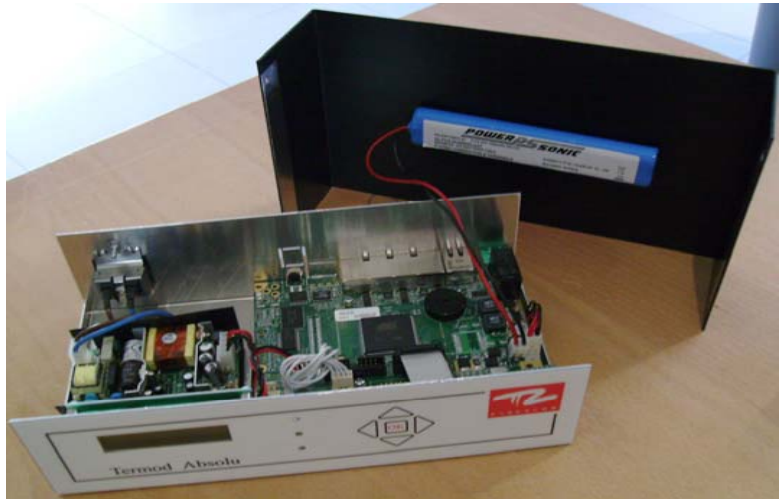
Instrumentation and Data Sets

- Focus on:
  - ***In- and Outdoor Temp.***
  - ***Wind & Solar Radiations (Renewable energies …)***
  - ***Indoor Moisture (comfort parameter: explains user's behaviour)***
  - ***Pressure***
- Location and number of sensors depends on the objectives and on the building



Hardware

- ARM9 processor:
  - *Low level of energy consumption.*
  - *Implementation of control algorithms is possible (High memory level)*
  - *Computation power*
  - *Can handle various signals*
  - *Connectivity*



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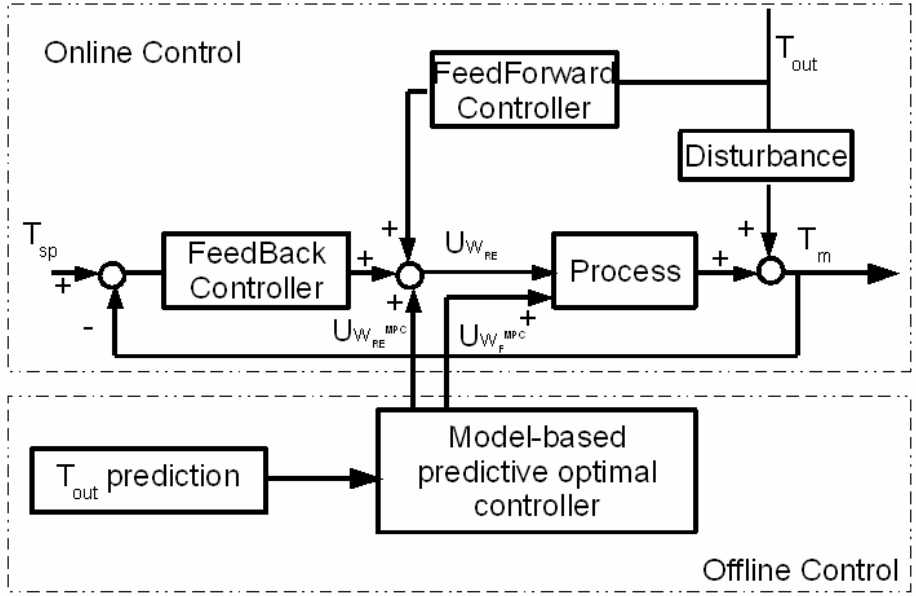
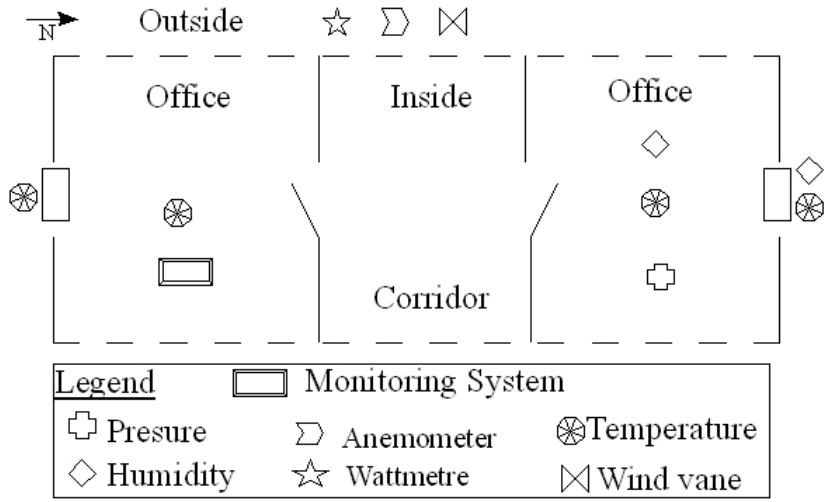
Control and Optimization Algorithms

- Combine on-line control and Optimization
  - ***Ensure satisfaction of daily comfort***
  - ***Maximizes the use of Renewable Energies***
- Exploit as much as possible sensors
  - ***Mix of FB and FF control***
  - ***Use e.g. meteorological predictions***
  - ***Use consumption histograms***



Control and Optimization Algorithms

- Model Description:
  - *University's offices*
  - *10m long, S-N orientation*
  - *Equipped with 2 warmers (RE & FE)*
- Standard Heat propagation Equation
  - *Room = homogenous & isotropic material*
  - *Linear, distributed*
  - *Crank Nicholson discrimination method*



$$\frac{\partial T}{\partial t} = a_x \frac{\partial^2 T}{\partial x^2} + \frac{h}{\rho Cp}\frac{\partial T}{\partial x} + \sum_i \frac{a_{xi}}{\rho_i Cp_i} P_i$$

$$\frac{\partial T}{\partial x} = \frac{h\Delta T}{\rho Cp}$$

Control and Optimization Algorithms

- On-line control loop:
  - ***Control of RE warmer using FB+FF***
  - ***Ensures moving setpoint tracking***
- Off-line MPC:
  - ***Predicts perturbations and setpoints changes***
  - ***Computes extra RE power upon RE warmer saturation (if needed)***
  - ***If RE warmer is saturated, computes optimally FE power***

$$\min_{U_{WF},U_{WRE}^{MPC}} \left(\sum_{k=1}^{Hp} \left(U_{WF}(k)\right)^2 \right)$$

s.t.: Dynamic Model

Input bounds:

$$U_{W_F}^{\min} \le U_{W_F}(t) \le U_{W_F}^{\max}$$

$$U_{W_{RE}}^{\min} \le U_{W_{RE}}(t) \le U_{W_{RE}}^{\max}$$

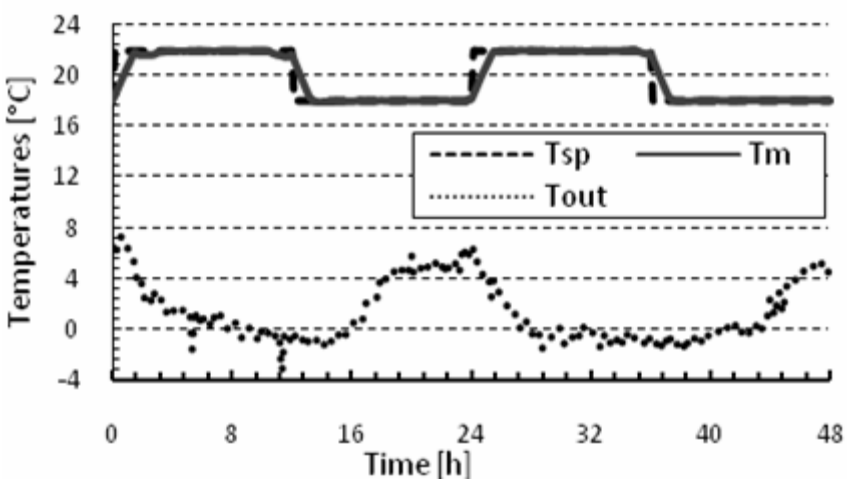
Setpoint tracking:

$$\left| T_m(H_p) - T_{sp}(H_p) \right| = 0$$

$$\left| T_m(H_c) - T_{sp}(H_c) \right| = 0$$

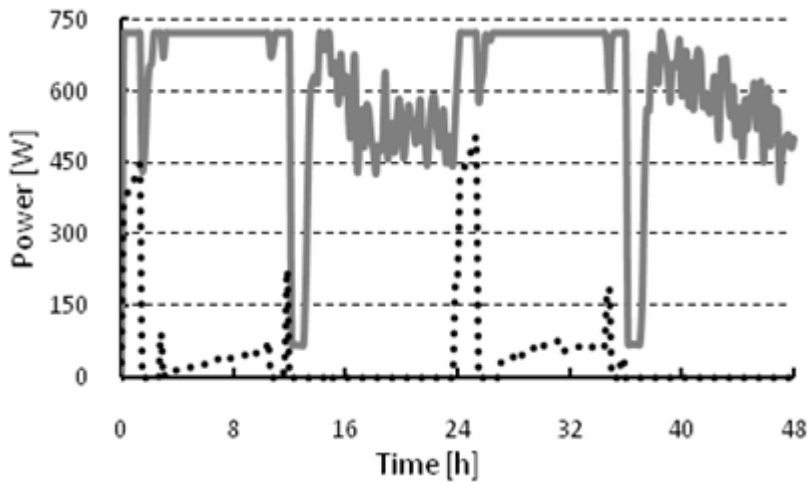
$$\forall t, \quad U_{W_{RE}}(t) = U_{W_{RE}}^{PI+FF}(t) + U_{W_{RE}}^{MPC}(t)$$

Control and Optimization Algorithms



Performance Indicator Values

	Open-loop	FB/FF	FB/FF+MPC
W_{RE}	792	1223.3	1227.6
W_F	792	100.9	93.5



Total energy consumption ↘

Preference is given to RE by MPC

Setpoint tracking = OK

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Conclusions and Perspectives

- A prototype was developed:
  - ***Energetic performance monitoring***
  - ***Cost-effective***
  - ***Easy to handle and implement***
  - ***Allows control and optimization of RE and FE consumption***
  - ***Testing has begun at UPVD, PyresCom & BP Solar HQ***
  - ***Simulation results show large potential for FE consumption ↘***
- Perspectives:
  - ***Develop a more complex model for testing and implementation***
  - ***Implementing FB+FF/MPC on ARM9 architecture***
  - ***In-Situ Applications***

Introduction

- Several limitations:
  - ***Legal documentation ⇆ « jungle »***
  - ***Clear objectives ?***
  - ***Stringent constraint for private buildings ⇆ avoiding drilling or pulling cables …***
  - ***Lack of adapted electronics***
  - ***Lack of adapted control and optimization tools***