Building Simulation 2009
University of Strathclyde, Glasgow
27th - 30th July

CONTROL STRATEGIES FOR MANAGING ENERGY IN A BUILDING MOCK-UP

Julien Eynard, Benjamin Paris, Stéphane Grieu, Thierry Talbert & Frédérik Thiéry
ELIAUS Laboratory, University of Perpignan, Perpignan, France

Tuesday 29th July 2009, 09:20 am

COC1: Simulation Assisted Control and Control Strategy Development

ELIAUS

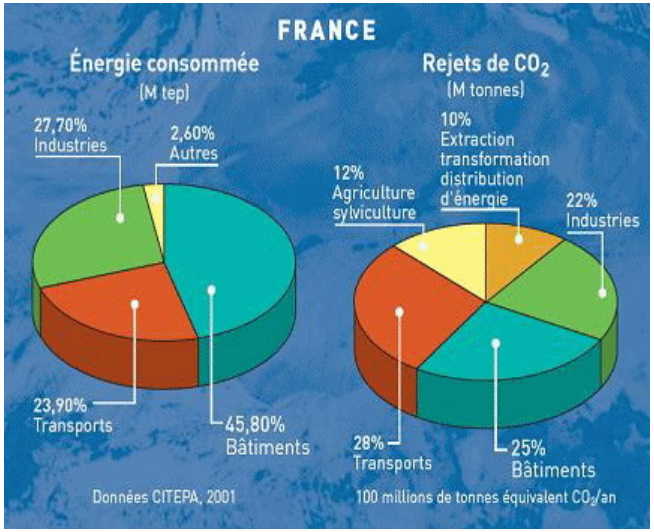
UPVD
Université de Perpignan Via Domitia

Summary

- Introduction
- Simulation of a building mock-up
- Control strategies
- PID control
- MPC-PID control
- Fuzzy-PID control
- Results
- Conclusion and perspectives

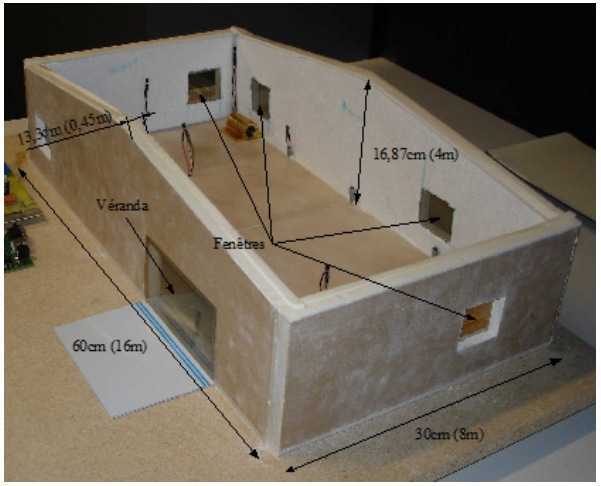
Introduction

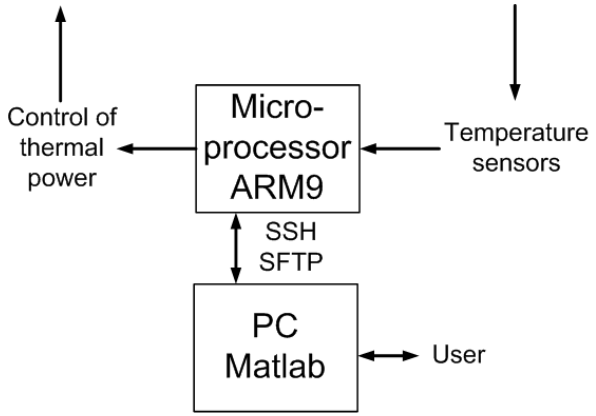
- Building and energy
  - 46% of total energy consumption in France
  - 25% of greenhouse gases emissions
  - Need to save fossil energies
    - ➔ Development of more efficient control strategies



Simulation of a building mock-up

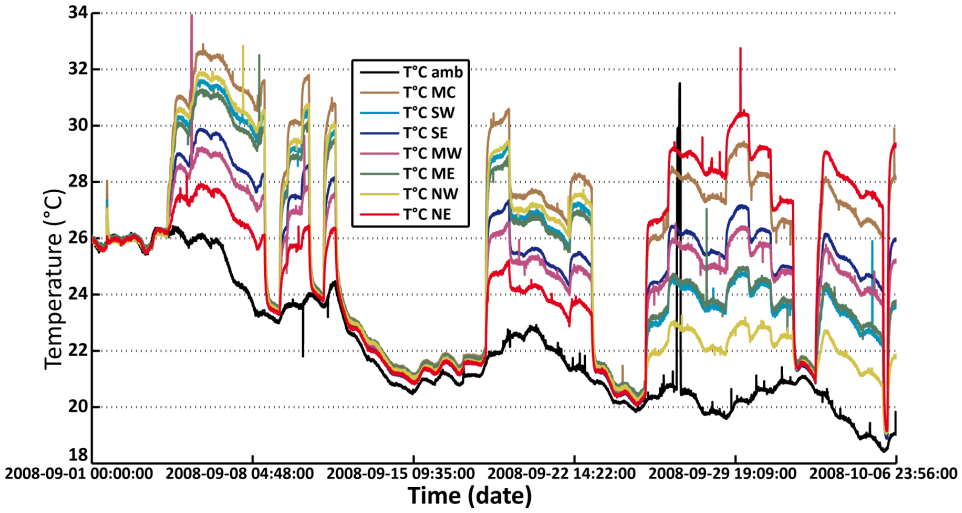
- Fabrication of a building prototype
  - Scale: 1/24 (120 m^2)
  - Material: Plasterboard, tile floor, polystyrene and polyane
  - Complete, versatile and easy to install instrumentation
- Development of a monitoring system (ARM9, data acquisition and control)
  - 8 sensors for temperature acquisition
  - 2 energy sources available for heating :
    - Renewable (Main source)
    - Fossil (Extra source)





Simulation of a building mock-up

- Modelling
  - Experimental acquisitions
  - Choice of an overall equation structure
  - Formalization of the identification problem (prediction-error minimization)

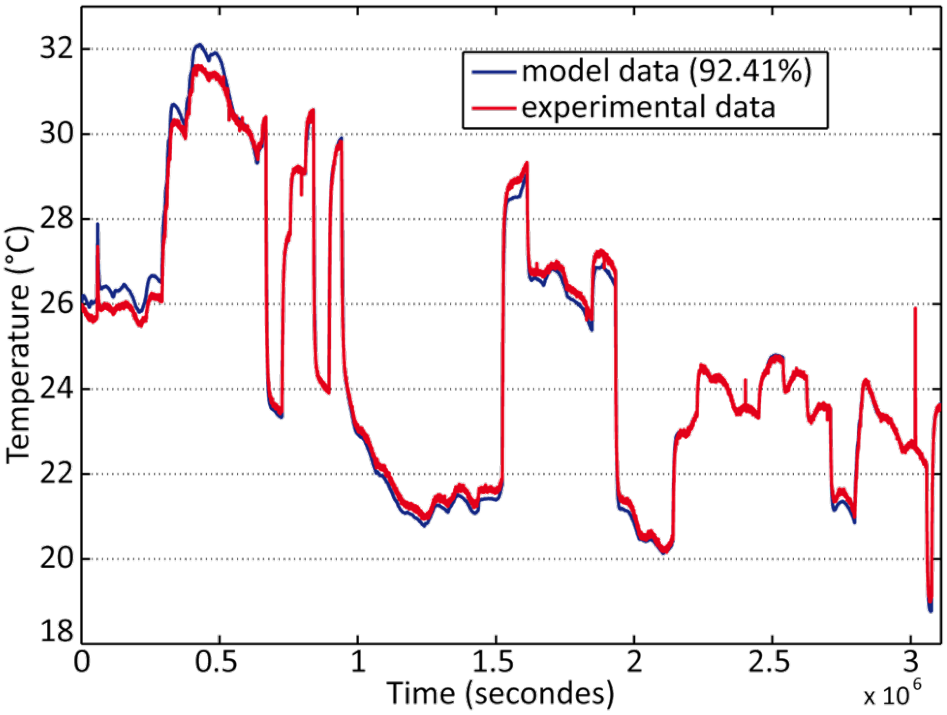


$$T_i(k+1)=\alpha_i.T_i(k)+\beta_{i1}.u_1^{\rho_{i1}}(k)+\beta_{i2}.u_2^{\rho_{i2}}(k)+\gamma_i.T_{out}(k)$$

$$\min_{\alpha,\beta_1,\beta_2,\rho_1,\rho_2,\gamma}\left[J=\sum_{k=1}^{N}\left(T_{mes}(k)-T_{mod}(k)\right)^2\right]$$

Simulation of a building mock-up

- Results of Identification
  - Curve-fitting between experimental and modeled data
  - ➔ Coherent results : mean of all curve-fitting is more than 90%

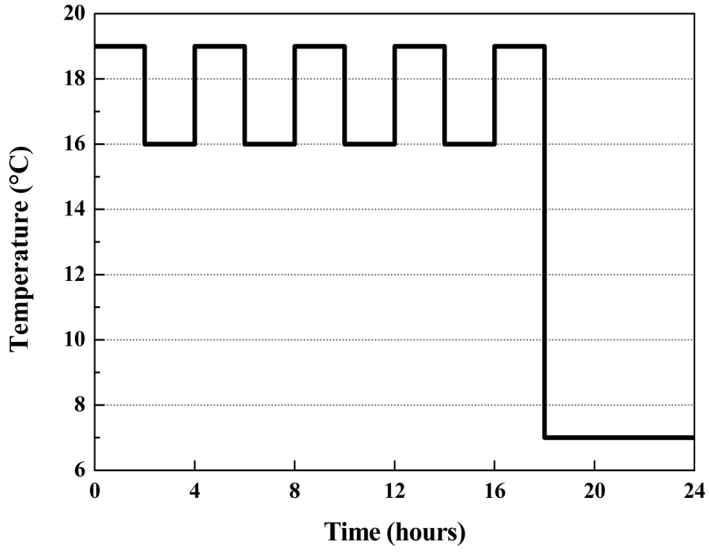


$$fit = 100 \times \left(1 - \frac{\|T_{mod} - T_{mes}\|}{\|T_{mes} - < T_{mes} >\|} \right)$$

Modeled variables	FIT [%]
T_{SE}	93.12
T_{SW}	92.41
T_{NE}	92.76
T_{NW}	92.59
T_{ME}	91.40
T_{MW}	88.07
T_{MC}	92.00

Control strategies

- Control scenario specifications
  - Based on occupancy scenarios and temperature set point (THCE 2005)
- Criteria specifications
  - Temperature set-point
  - Fossil consumption
  - Global performance



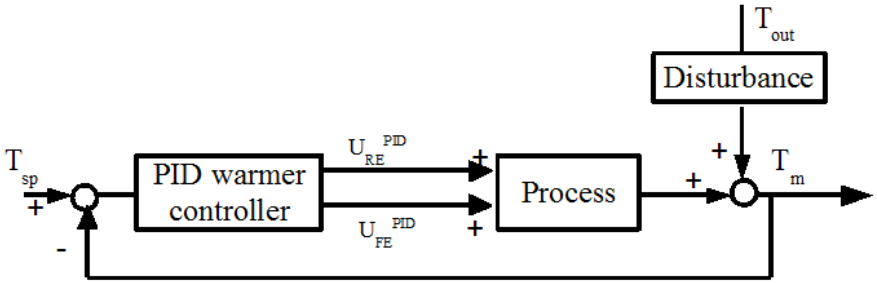
$$I_{C[\%]} = 100 \times \left(1 - \frac{\left\| T_{sp} - T_m \right\|}{\left\| T_{sp} - < T_{sp} > \right\|} \right)$$

$$\%_{FE} = 100 \times \frac{E_{FE}}{E_{\cdot\cdot}}$$

$$I_P = \left(I_C - \%_{FE} \right)$$

PID control

- PID is a classical controller
- Heating power repartition
- Optimal PID
  - Optimization of PID gains (K, K_i, K_d)
  - Maximization of I_P



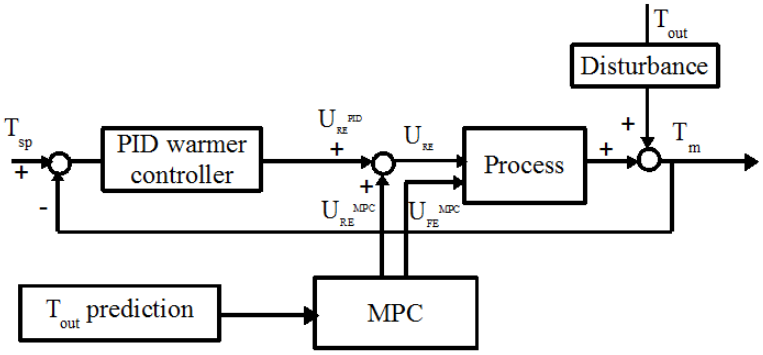
$$\begin{cases} x_i(k) = x_i(k-1) + K_i \cdot \left(T_{sp}(k) - T_m(k)\right) \\ x_d(k) = K_d \cdot x_d(k-1) + \left(T_m(k-1) - T_m(k)\right) \\ u(k) = K_p \cdot \left(c(k) - y(k) + x_i(k) + x_d(k)\right) \\ u\_sat_{PID}(k) = u_{PID}(k) \\ if\ \left(u_{PID}(k) > U_{\max}(k)\right)\ then\ u\_sat_{PID}(k) = U_{\max} \\ if\ \left(u_{PID}(k) < 0\right)\ then\ u\_sat_{PID}(k) = 0 \\ x_i(k) = x_i(k) + \left(T_e / K.T_{aw}\right) \cdot \left(u\_sat_{PID}(k) - u(k)\right) \end{cases}$$

$$\max_{K, K_i, K_d} \left(I_p = I_C - \%_{EF}\right)$$

$$s.a. \begin{cases} \text{thermal equations} \\ \text{PID controller} \end{cases}$$

MPC-PID control

- Model Predictive Control
- Online minimization of a quadratic cost J
- Optimal MPC
  - Optimization of ω
  - Maximization of I_P



$$\min_{\Delta u(k/k),\cdots,\Delta u(k+c-1/k)} J = \sum_{i=0}^{p-1} \left(\left| \left(T_{m(k+i+1/k)} - T_{sp(k+i+1)} \right) \right|^2 + \left| \omega \cdot U_{FE\ (k+i/k)}^{MPC} \right|^2 \right)$$

$$\max_{\omega} \left(I_p = I_C - \%_{FE} \right)$$

$$s.a. \begin{cases} \text{thermal equations} \\ \text{Best PID controller} \\ \text{MPC controller} \end{cases}$$

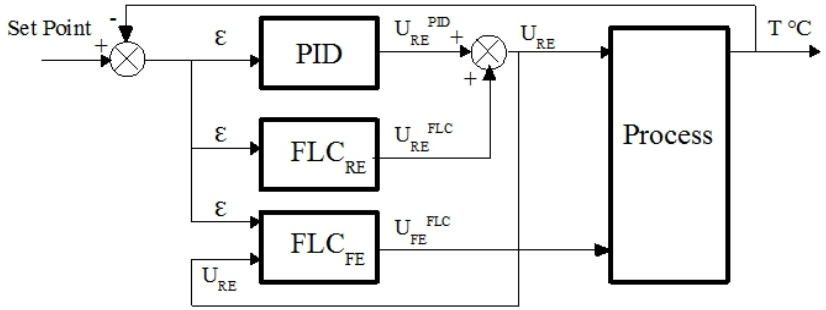
under constrains:

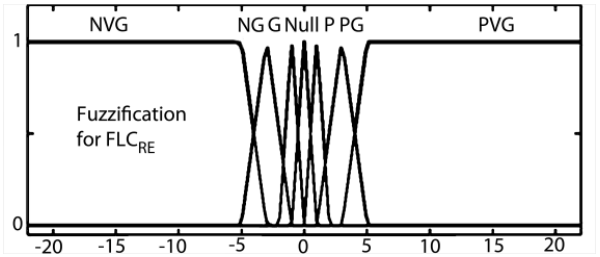
$$\begin{cases} \text{model equations} \\ \text{PID control equations} \\ U_{RE\min} \le U_{RE(k+i/k)} \le U_{RE\max} \\ U_{FE\min} \le U_{FE(k+i/k)} \le U_{FE\max} \\ \Delta u(k+h) = 0, \quad h = \{c, \ldots, p-1\} \end{cases}$$

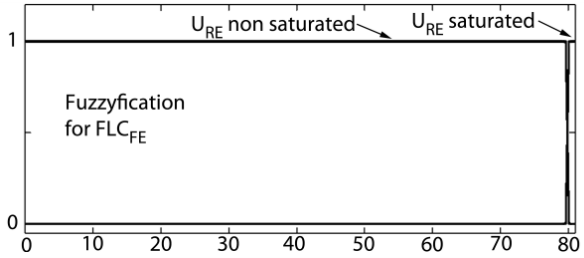
Fuzzy-PID control

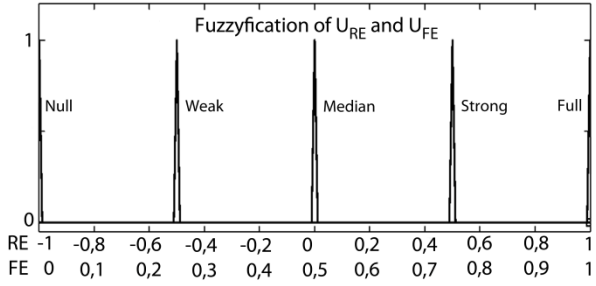
- Fuzzy logic controller
  - Fuzzification
  - Inference
  - Defuzzification
- Optimal Fuzzy-PID
  - Optimization of fuzzy gains (K_{RE}, K_{FE})
  - Maximization of I_P

$$\max_{K_{RE},K_{FE}} \left(I_p = I_C - \%_{EF} \right)$$





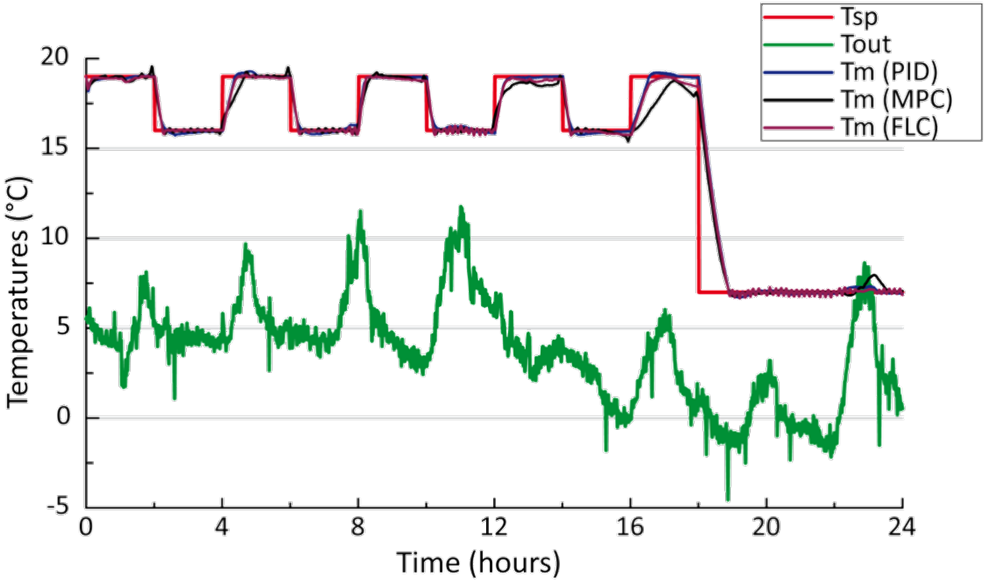


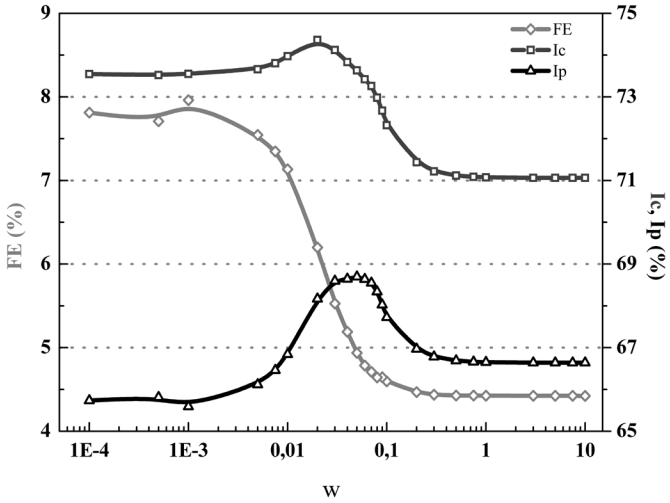


Optimization results

- PID: 521 Wh.m^{-2} of fossil energy
- Fossil energy saving
  - MPC-PID: 140 Wh.m^{-2}
  - Fuzzy-PID: 51 Wh.m^{-2}

	E_{RE} [Wh.m^{-2}]	E_{FE} [Wh.m^{-2}]	$\%_{FE}$ [%]	I_C [%]	I_P [%]
Office temperature set-point					
PID	7494	521	6,5	72,0	65,5
MPC	7339	381	4,9	73,6	68,7
FLC	7731	470	5,7	72,4	66,7





Results and discussion

- PID
  - Very easy development and implementation
  - Good results if optimized
- MPC-PID
  - Hard development (need an linear internal model)
  - Need an on-line optimizer (fast processor)
  - Best results **(27% of fossil energy saving)**
- Fuzzy-PID
  - Not very difficult to develop
  - Easy to implement
  - Interesting results **(10% of fossil energy saving)**

Conclusion and perspectives

- Conclusion
  - Modelling of a building mock-up
  - Definition of criteria for the control strategies
  - Performance comparison of different kind of optimal controllers (PID, MPC-PID, FLC-PID)
  - Results: significant fossil energy saving
- Perspectives
  - Enforce the controllers to the mock-up
  - Extend to a real building on a scale of 1/1

The End

- Thank you for your attention
- Please feel free to ask any questions

CONTROL STRATEGIES FOR MANAGING ENERGY IN A BUILDING MOCK-UP

ELIAUS

UPVD
Université de Perpignan Via Domitia