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Fuzzy-PID control for multisource energy management in buildings

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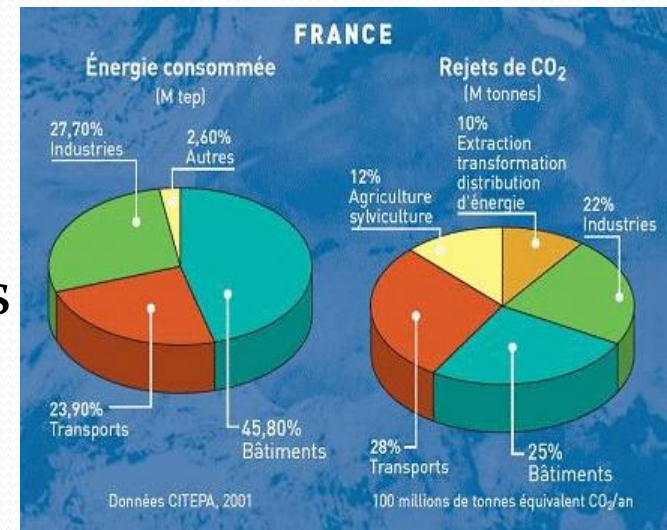
Thursday, December 11th 2008, Session 4
Eco-Conception 2 : ECO-SOLUTIONS

Summary

- Introduction
- Prototype building modelling
- Control strategies
- Control based on PID controller
- Control based on Fuzzy-PID controller
- Optimization results
- Conclusion

Introduction

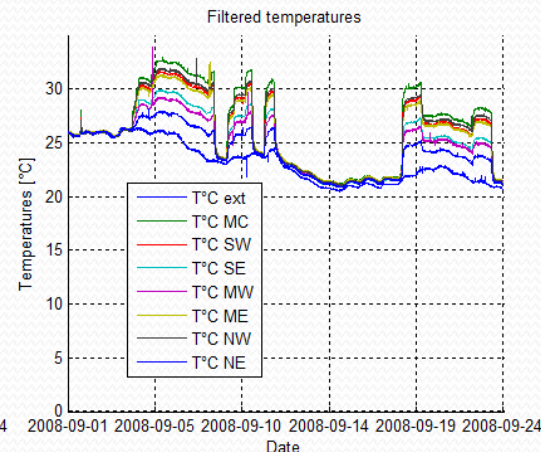
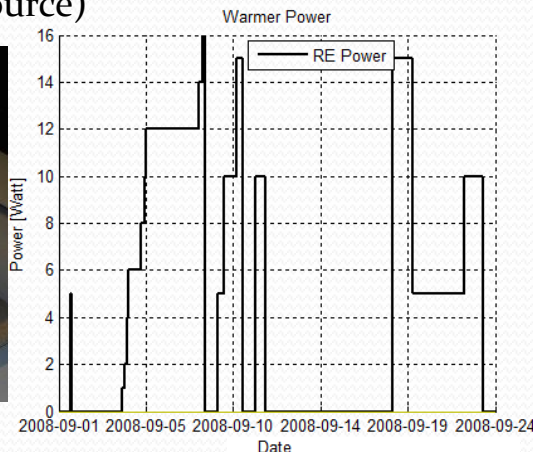
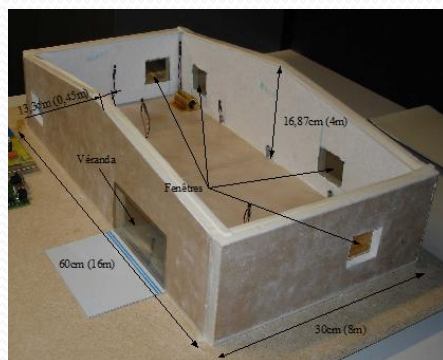
- Building and energy
 - 46% of total energy consumption in France
 - 25% of greenhouse gases emissions
 - Need to save fossil energy
 - ➔ Development of more efficient control strategies



Introduction
Modelling
Control
strategies
PID
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Fuzzy-PID
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Prototype building modelling

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



Prototype building modelling

- Modelling and Identification
 - Choice of an overall equation structure
 - Identification problem formalization (prediction-error minimization)
 - Curve-fitting between experimental and modeled data
 - ➔ Coherent results : mean of all curve-fitting is about 90%

$$T_i(k+1) = \alpha_i T_i(k) + \beta_{1i} u_1^{\rho_{1i}}(k) + \beta_{2i} u_2^{\rho_{2i}}(k) + \gamma_i T_{out}(k)$$

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

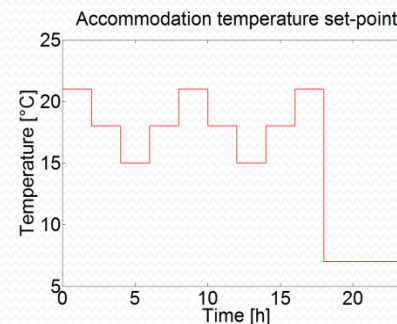
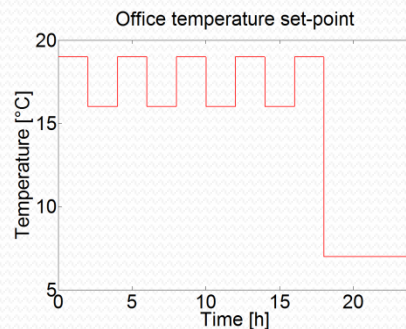
$$s.a. \begin{cases} 7 \text{ indoor thermal equations} \\ -1 < \alpha < 1 \\ -10 < \beta_1 < 10 \\ -10 < \beta_2 < 10 \\ 0 < \rho_1 < 1 \\ 0 < \rho_2 < 1 \\ -10 < \gamma < 10 \end{cases}$$

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

Modeled variables	Curve-fitting [%]
T°C South East	92.22
T°C South West	91.52
T°C North East	88.80
T°C North West	91.45
T°C middle East	90.69
T°C middle West	86.59
T°C middle ceiling	91.15

Control strategies

- Control scenarios specifications
 - Based on occupancy scenarios and temperature set-point (THCE 2005 rules)
 - **Office:** medium time occupancy and medium temperature levels
 - **Accommodation:** long time occupancy and high temperature levels
 - 8 days of temperature set-point « packed in tight » on 24 hours to have a ratio between transitory phase and stationary phase representative of a real building



Control strategies

- Constraints and criteria specification
 - Heating power constraints
 - Temperature set-point constraints
 - Temperature set-point criterion
 - Fossil consumption criterion
 - Global performance criterion
 - Objectives
 - Maximize the performance criterion
 - Respect the constraints

$$\begin{cases} u_{RE} < U_{\max_RE} & s.a. & U_{\max_RE} = 80 W \\ u_{FE} < U_{\max_FE} & s.a. & U_{\max_FE} = 34 W \\ U_{\max} = U_{\max_RE} + U_{\max_FE} = 114 W \end{cases}$$

$$C_{1:10} : |T_{sp}(j) - T_{mean}(j)| < 0.1^\circ C$$

$$j \in \{1h; 3h; \dots; 17h; 21h\}$$

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

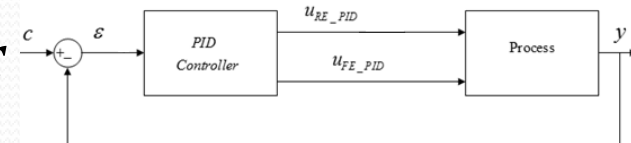
$$\%_{FE} = 100 \times \frac{E_{FE}}{E_{Tot}}$$

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

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PID controller

- PID is the classical controller
- Heating power repartition
- Optimal PID controller
 - Optimization of PID gains
 - Maximization of performance criterion
 - Constraints respect
 - Building model
 - PID equations
 - Power constraints
 - Set-point constraints



$$u_{RE_PID} = u_{sat_PID}$$

$$u_{FE_PID} = 0$$

if $u_{RE_PID} > U_{max_RE}$ then

$$u_{RE_PID} = U_{max_RE}$$

$$u_{FE_PID} = u_{sat_PID} - U_{max_RE}$$

if $u_{FE_PID} > U_{max_FE}$ then $u_{FE_PID} = U_{max_FE}$

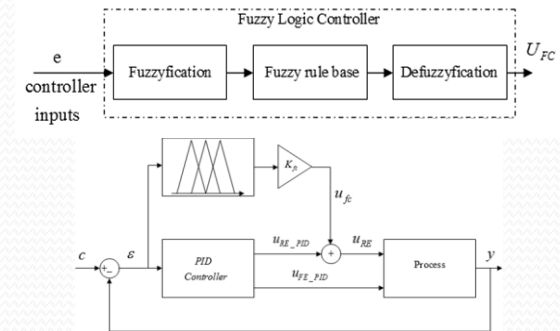
end

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

$$s.a. \begin{cases} 7 \text{ indoor thermal equations} \\ \text{PID controller} \\ 1000 < K_p < 0 \\ 1 < K_i < 0 \\ 1 < K_d < 0 \\ 10 \text{ set - point constraints } C_{110} \end{cases}$$

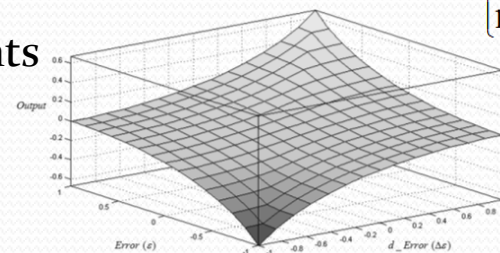
Fuzzy-PID controller

- Fuzzy logic control
- Fuzzy-PID structure
- Optimal fuzzy-PID controller
 - Optimization of the fuzzy-PID gains
 - Maximization of the performance criterion
 - Constraints respect
 - Building model
 - Fuzzy-PID equations
 - Power constraints
 - Set-point constraints



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

$$s.a. \begin{cases} 7 \text{ indoor thermal equations} \\ \text{Fuzzy-PID controller} \\ 1000 < K < 0 \\ 1 < K_i < 0 \\ 1 < K_d < 0 \\ 1 < K_{fc} < 2000 \\ 10 \text{ set-point constraints } C_{1-10} \end{cases}$$

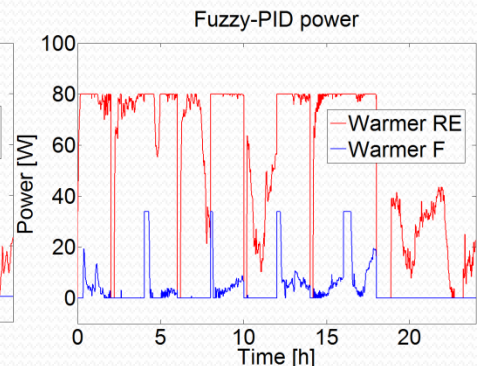
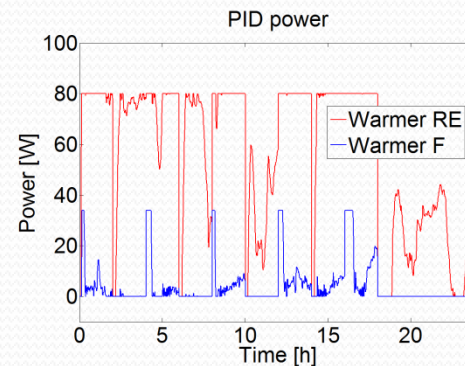
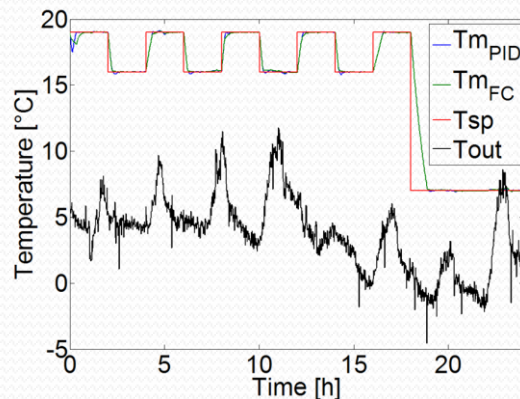


Optimization results

- Fuzzy-PID: identical set-point tracking but 7% of fossil energy saving

PID			Fuzzy-PID			
Kp	Ki	Kd	Kp	Ki	Kd	Kfc
Gains for office temperature set-point						
51.3	0.391	1.00	52.8	0.223	1.00	761
Gains for accommodation temperature set-point						
80.0	0.993	0.596	52.3	0.378	1.00	60.8

	RE [Wh.m ⁻²]	FE [Wh.m ⁻²]	%FE	Ic [%]	Ip [%]
Office temperature set-point					
PID	7500	533	6.64	71.9	65.3
FC-PID	7555	494	6.14	72.0	65.8
Accommodation temperature set-point					
PID	7431	882	10.6	69.8	59.2
FC-PID	7496	819	9.9	69.5	59.7



Conclusion

- Fabrication of a building prototype and a monitoring system
- Creation of a thermal model of the building
- Definition of criteria for the control strategy
- Performance comparison between two kind of controllers (PID et fuzzy-PID)
- Results : 7% of fossil energy saving with a fuzzy-PID

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