Management of energy flows for optimizing energy efficiency in dwelling

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Outline

- Context
- Energy management system in dwelling – optimization problem
- Application of public building – Platform PREDIS
- Perspectives

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- **Context**
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  - **Perspectives**

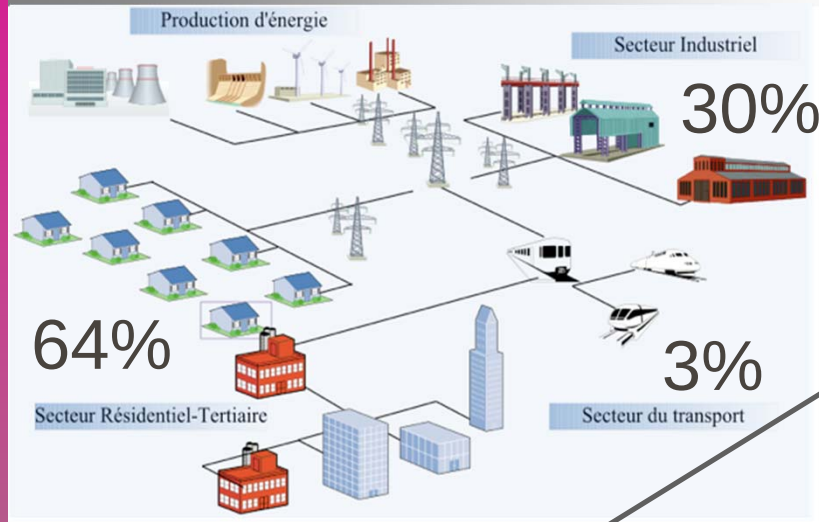
Global climate and energy issues

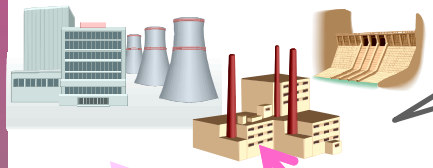
- Increase in anthropogenic greenhouse gas (CO_2, CH_4)
- Increase in global energy consumption (+100% entre 1970 et 2000)
- Decrease the available amount of fossil fuel
- Rising cost of fossil fuels

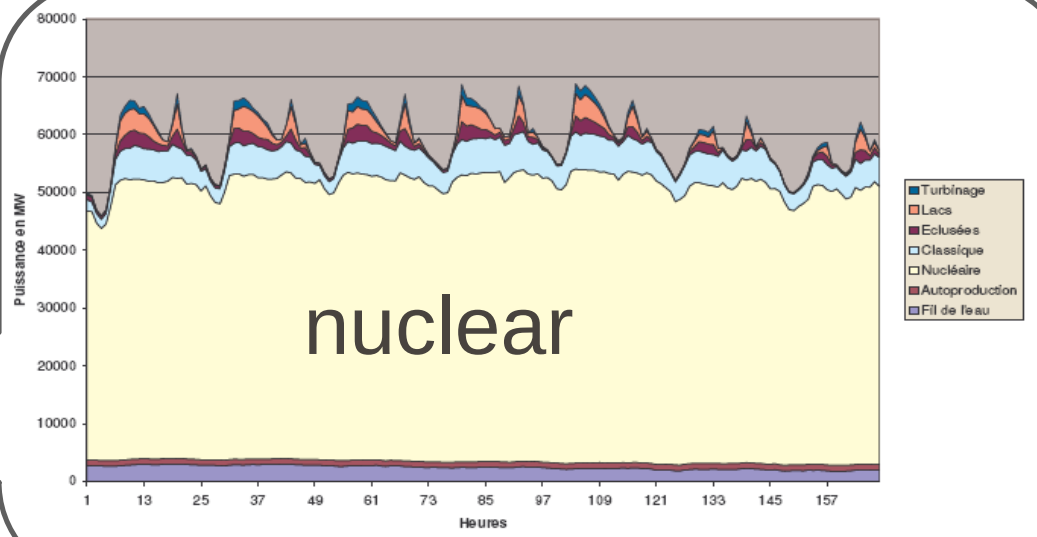
⇨ Targets for the EU in 2020 :

- ≥20% énergies renouvelables
- −20% greenhouse gas emissions
- +20% energy efficiency

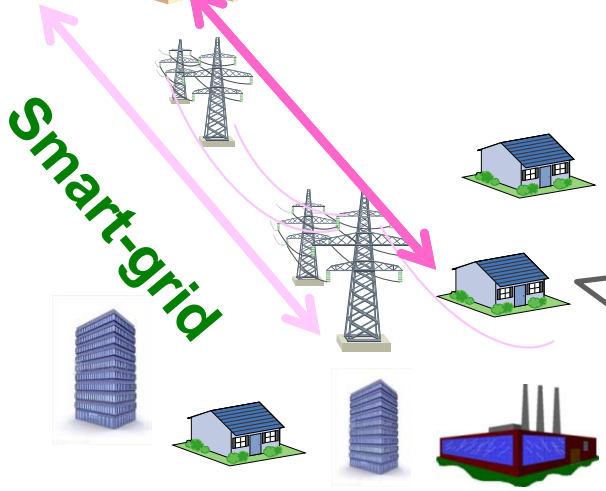
Energy context

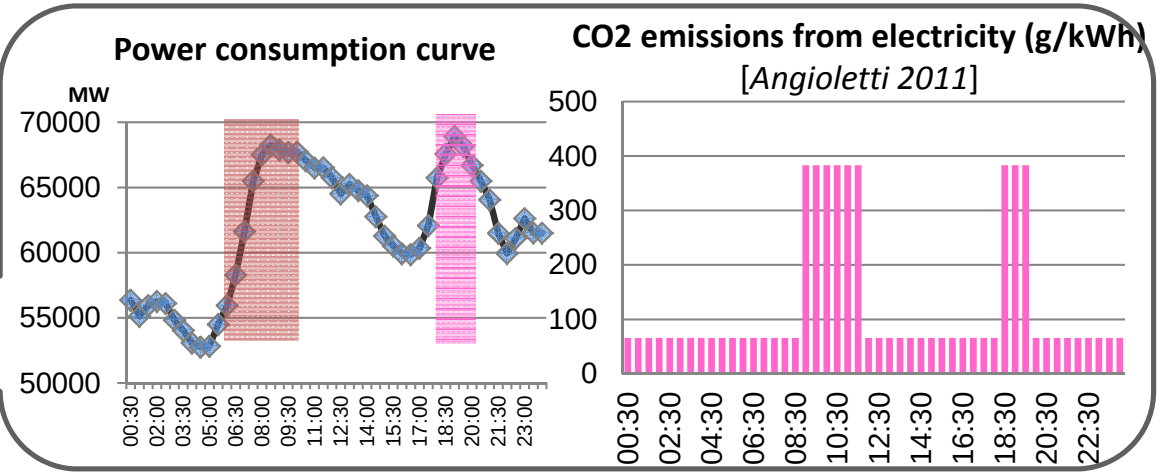




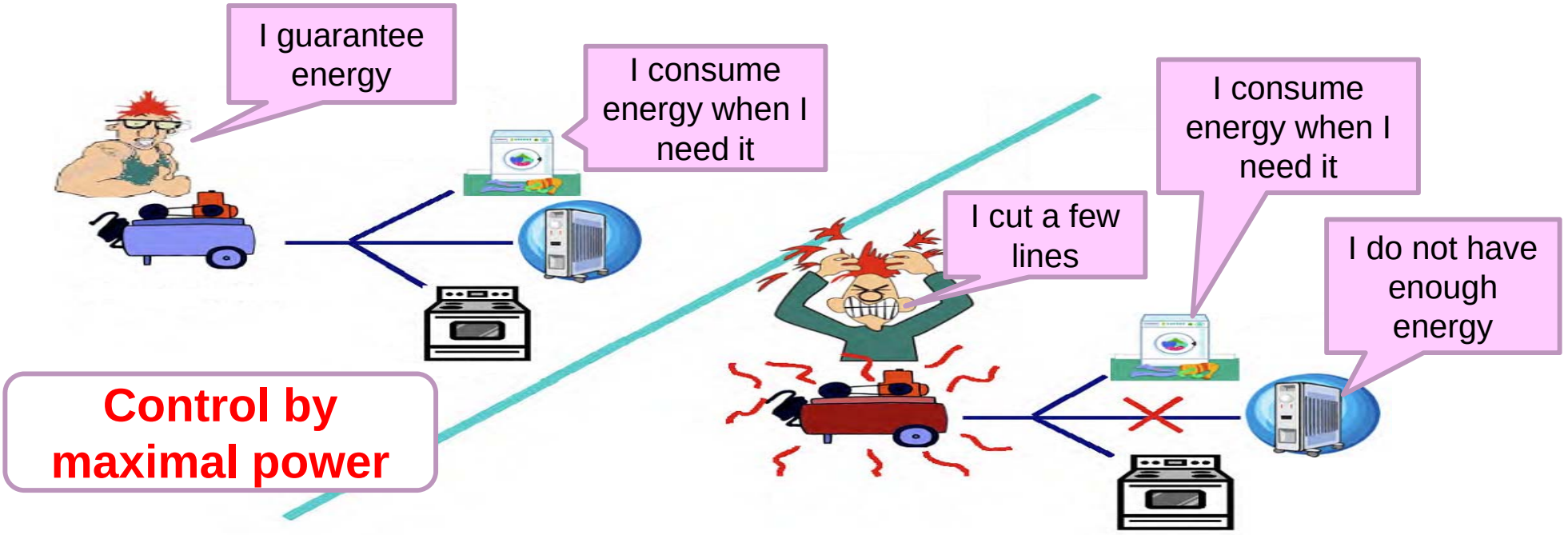


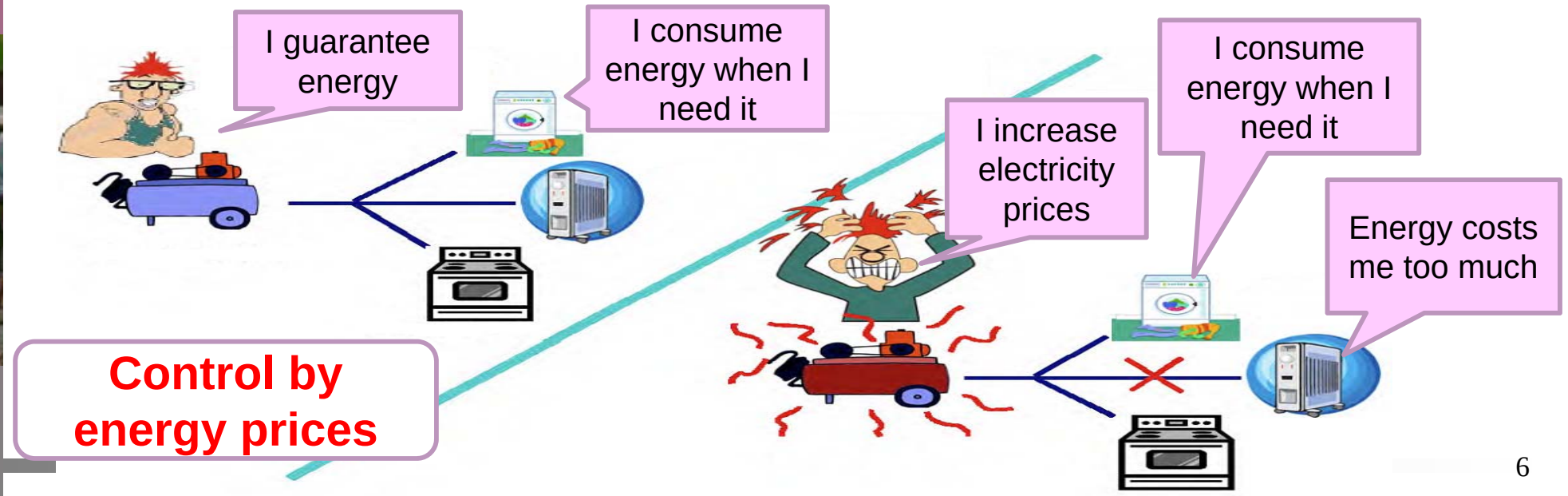
Production pendant une semaine d'automne 2003 – Source RTE





From smart-grid to smart-home



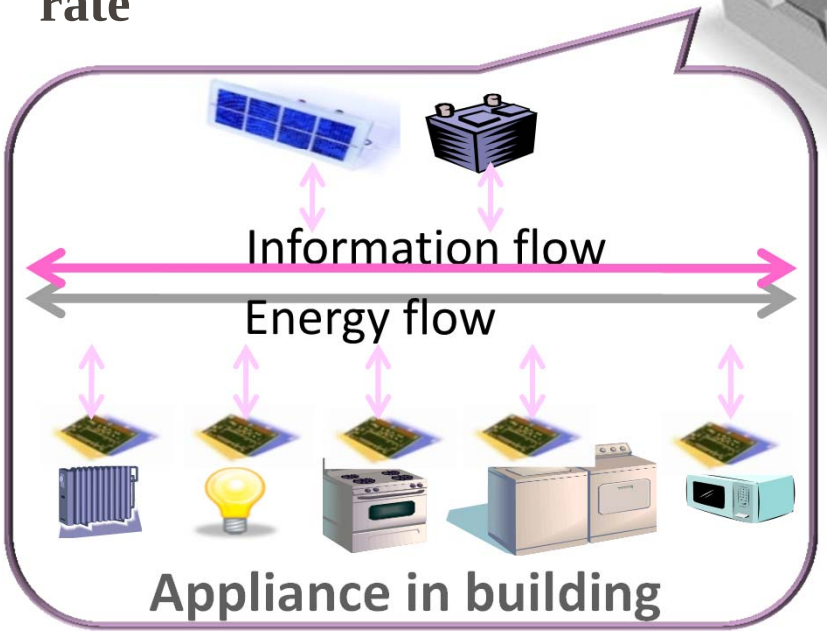


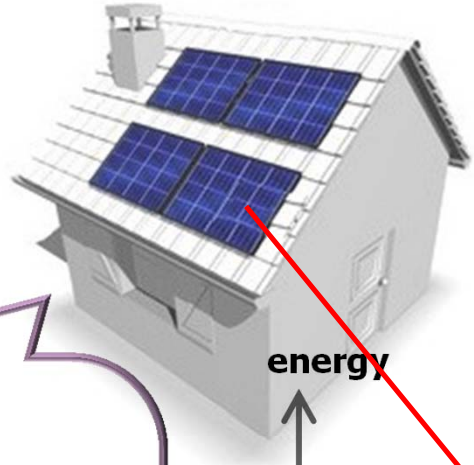
Motivations: Smart-home

Question for building energy management

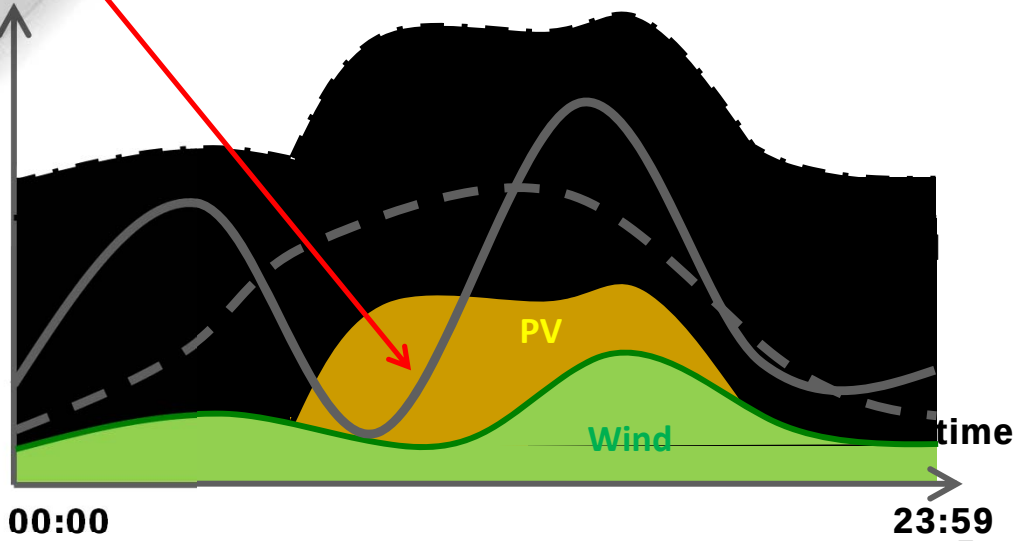
Improve the consumption and local energy production

Maximize occupant comfort, taking into account resource constraints and energy rate





Increase in renewable energy part



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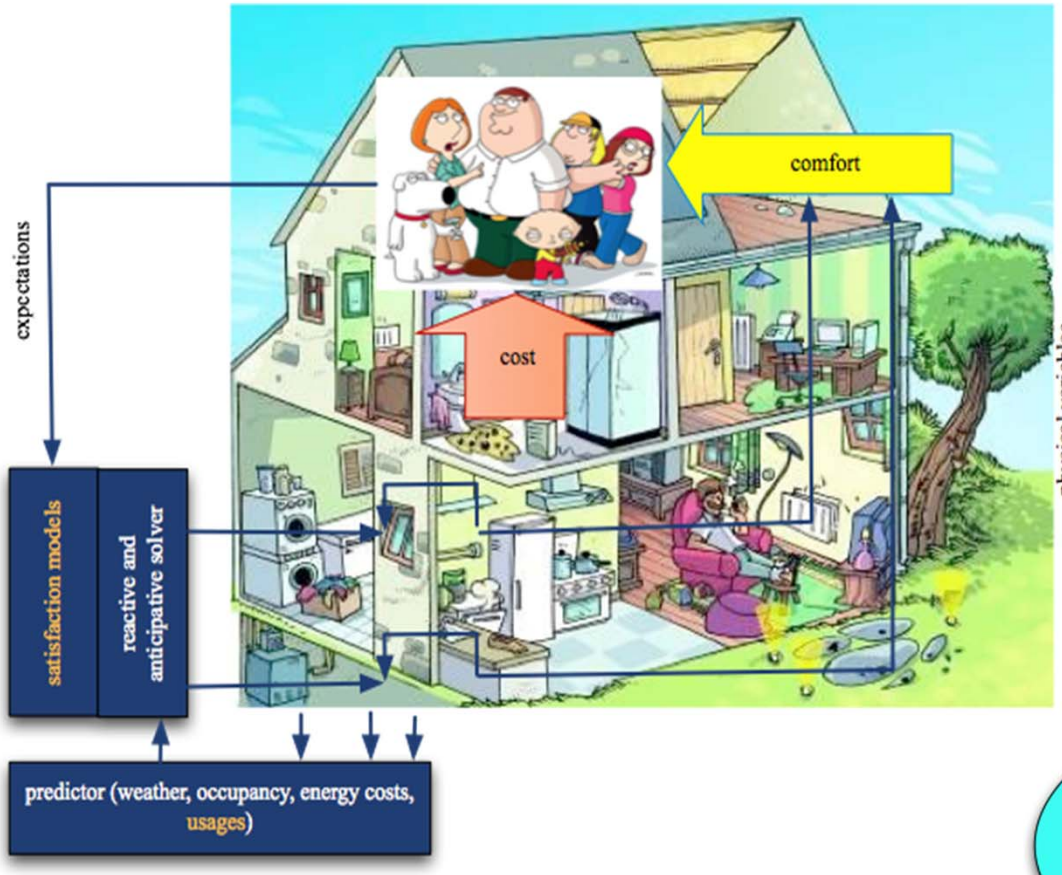
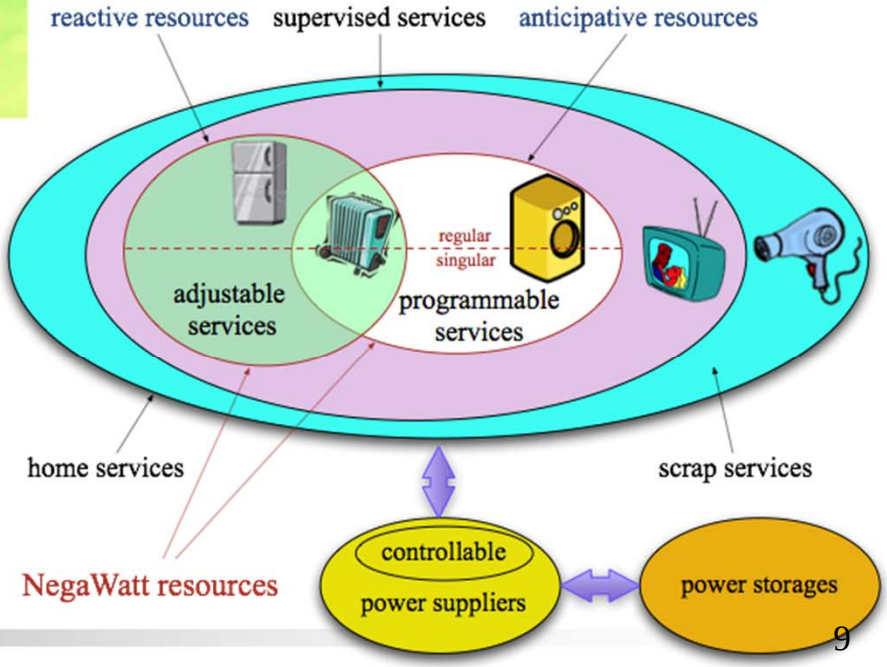
Building Energy Management:? Principle

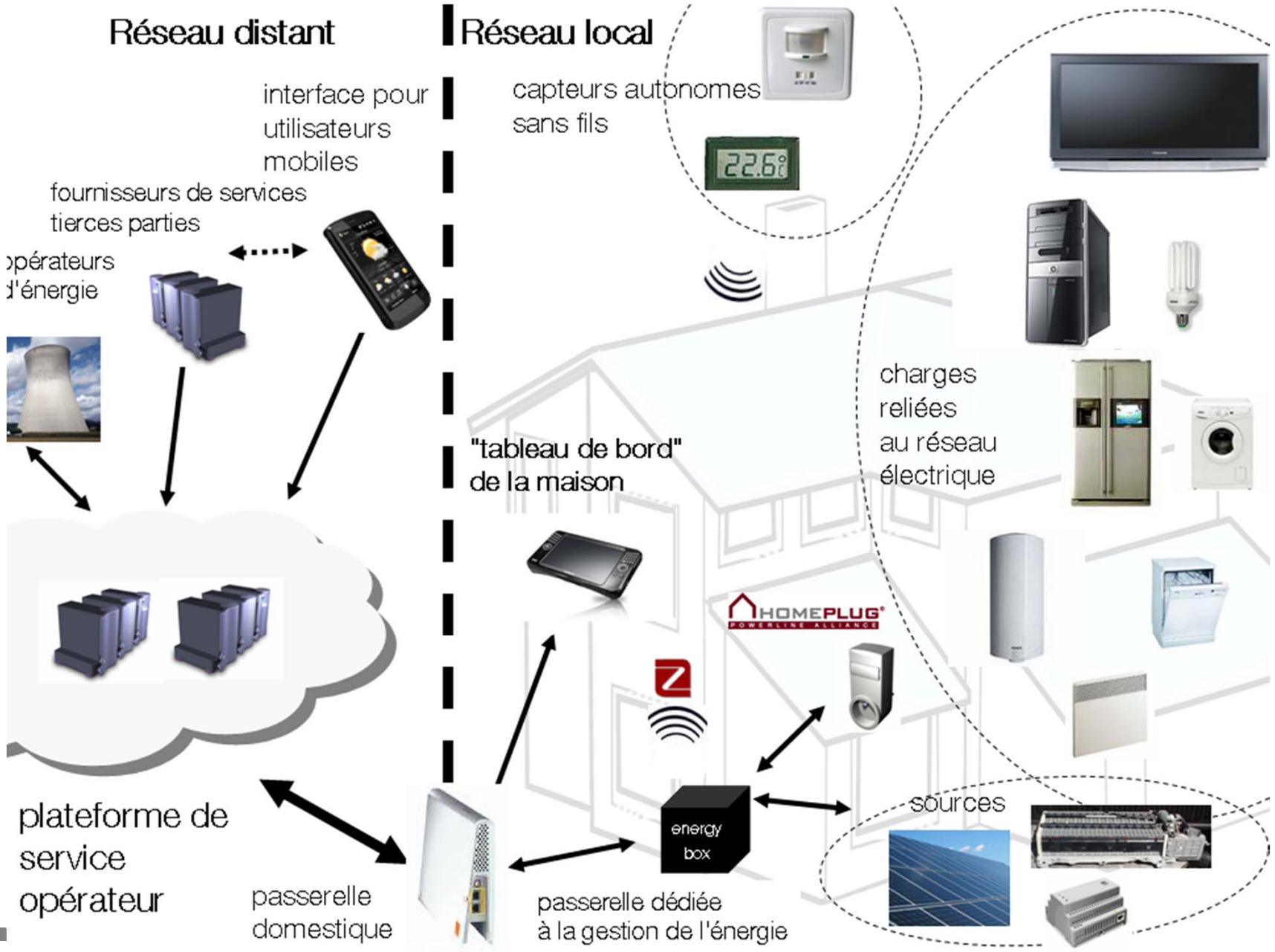


maximizing
energy efficiency

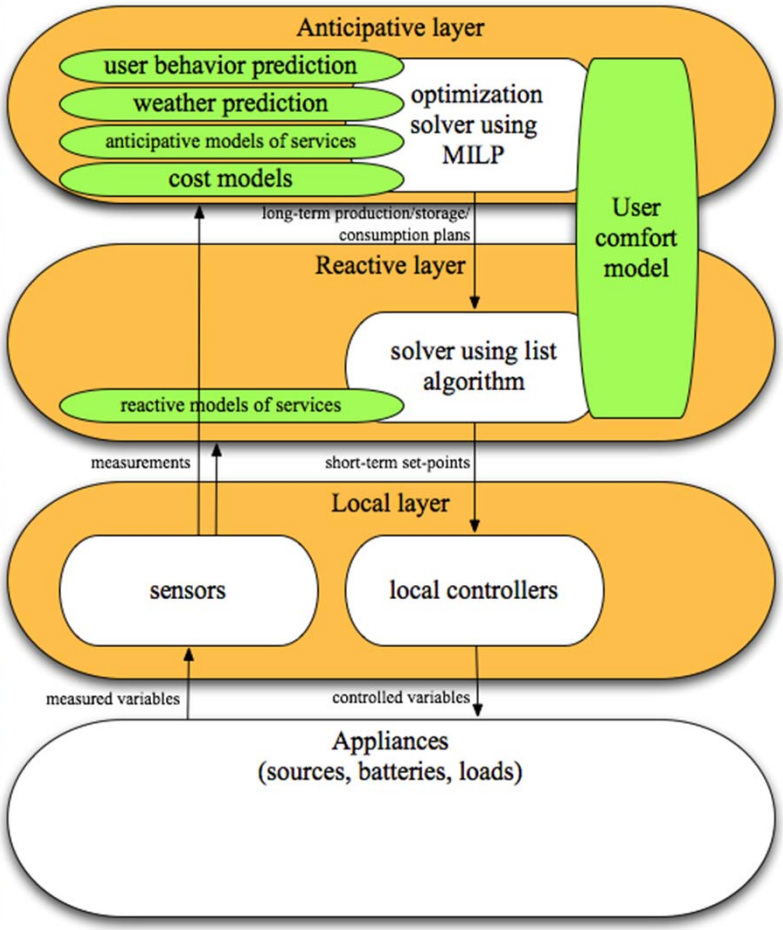


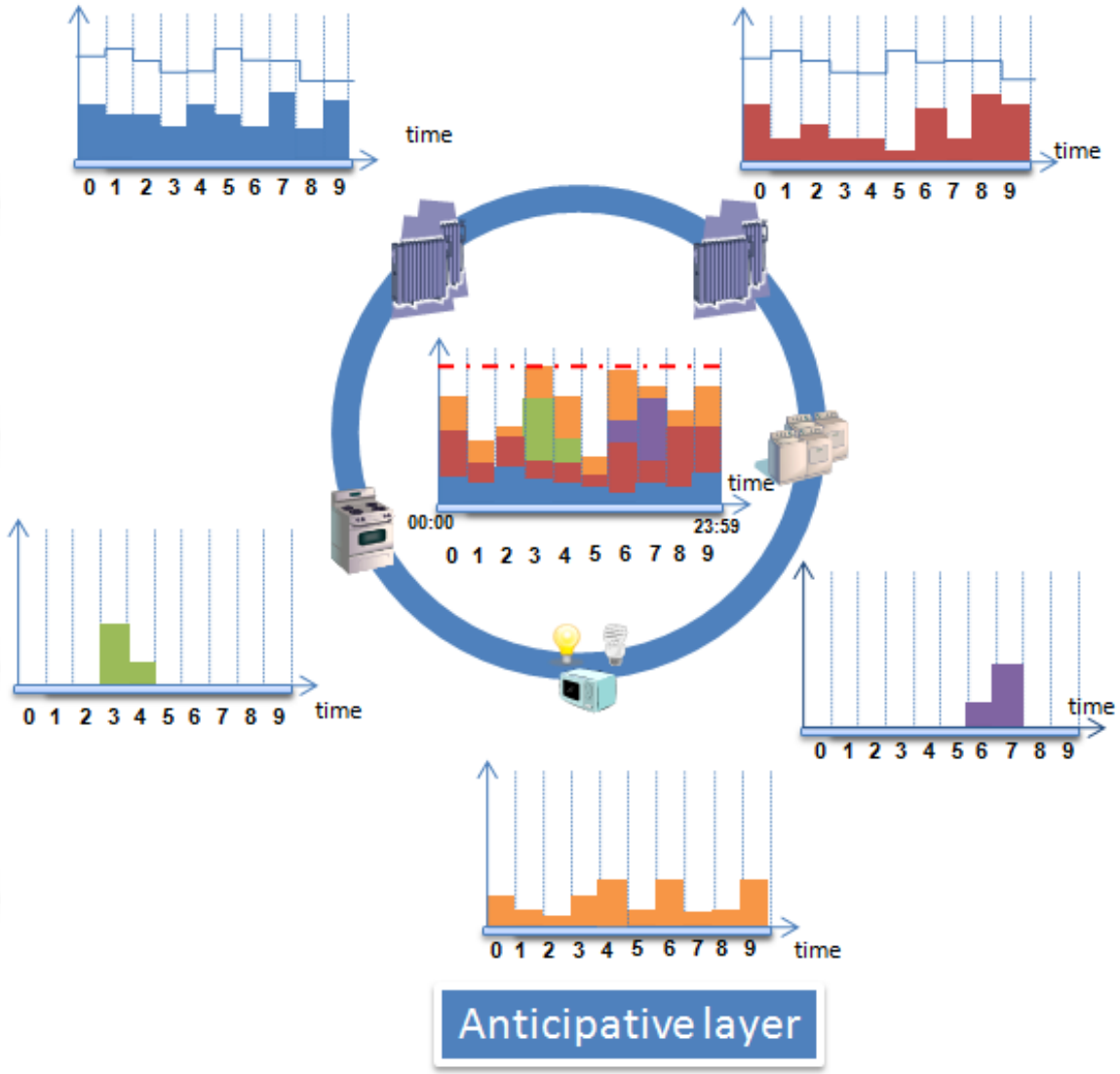
energy → **service** → comfort

Energy Management Platform

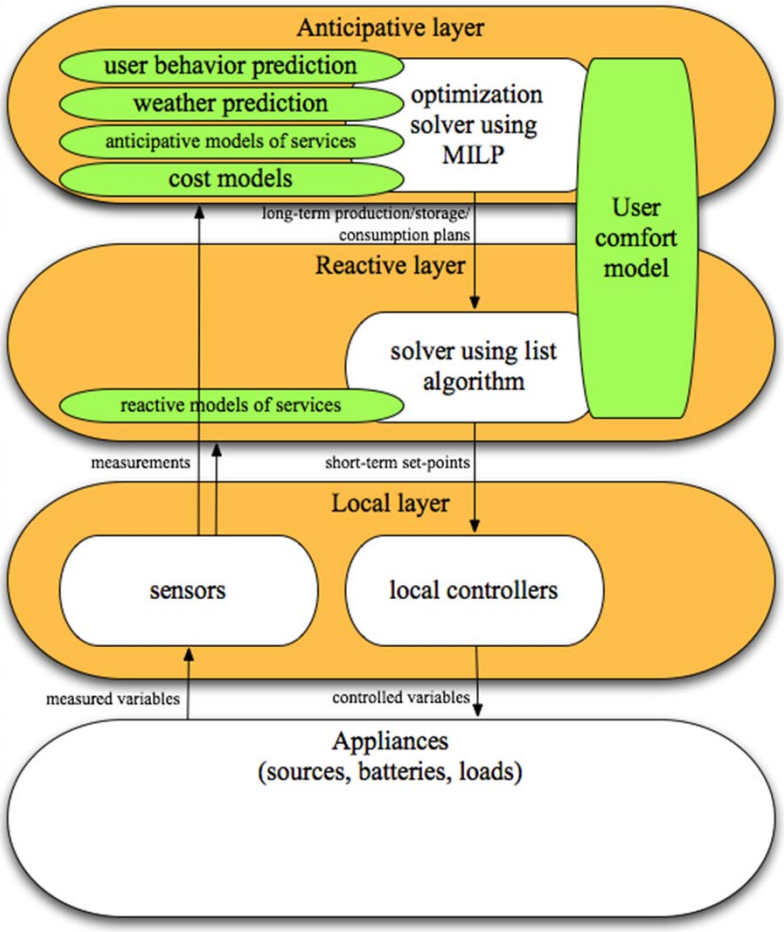


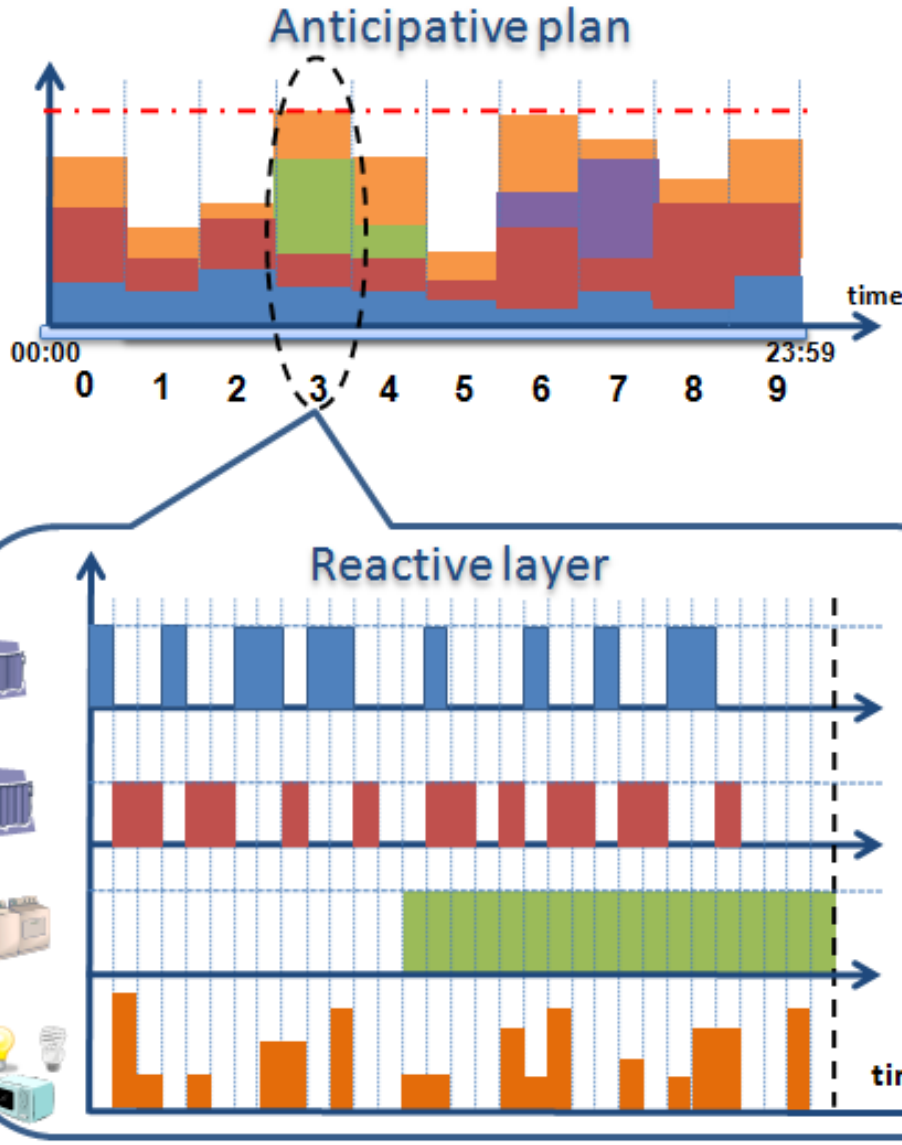
Three-layer architecture



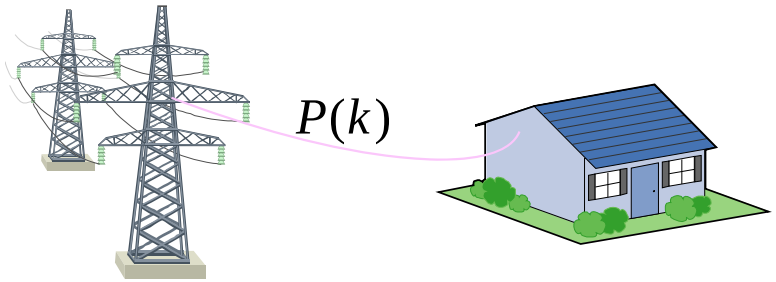


Mécanisme de pilotage de multicouche





Energy supply



Subscription contract

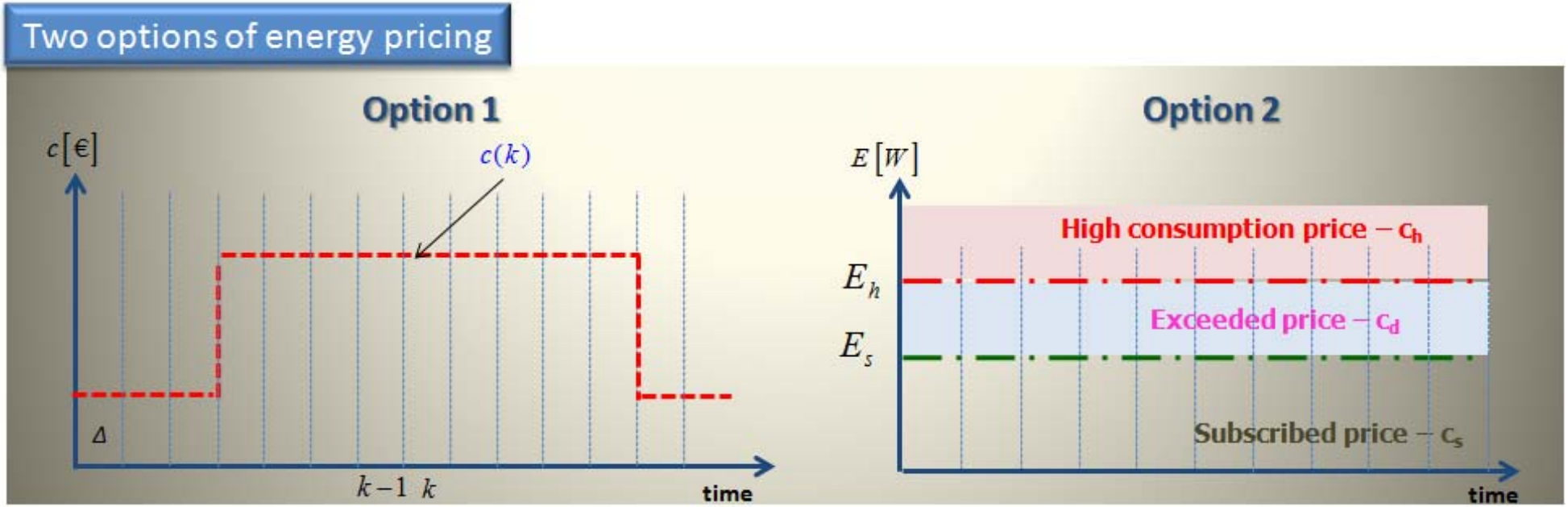
$$E(k) \le P(k)\Delta$$

Energy pricing - option 1

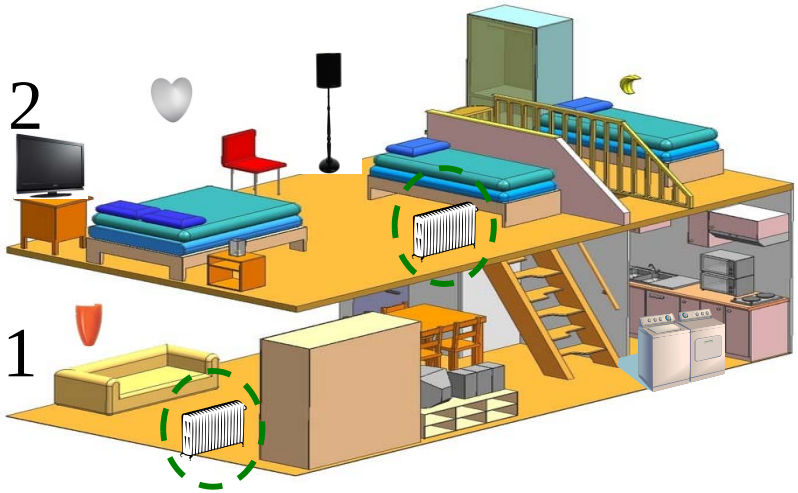
$$C(k) = c(k)E(k)$$

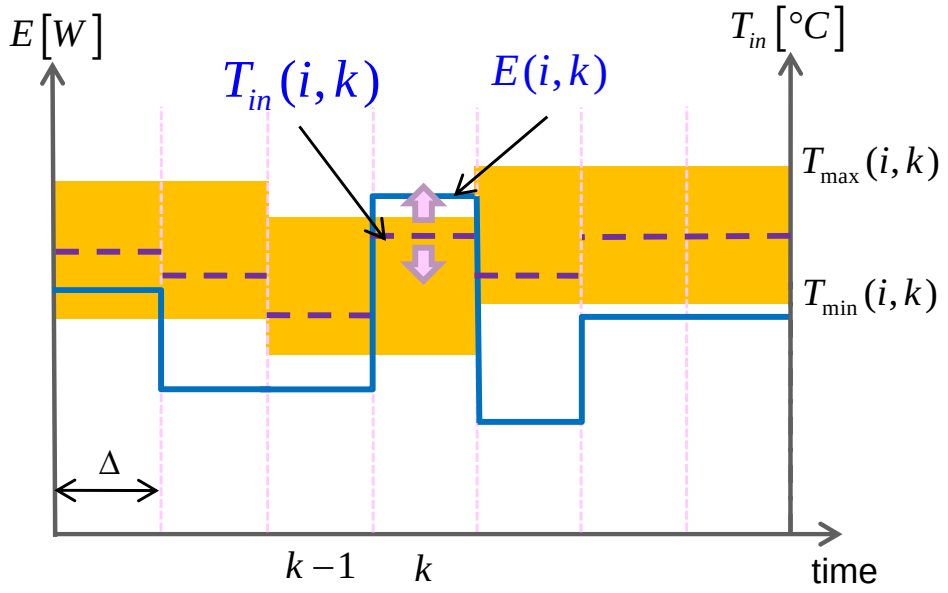
Energy pricing - option 2

$$C(k) = c_s \min\left[E(k), E_s(k)\right] + c_d \max\left\{0, \min\left[E_s(k), E(k) - E_s(k)\right]\right\}$$
$$+ c_h \max\left[0, E(k) - E_h(k)\right]$$



Permanent service





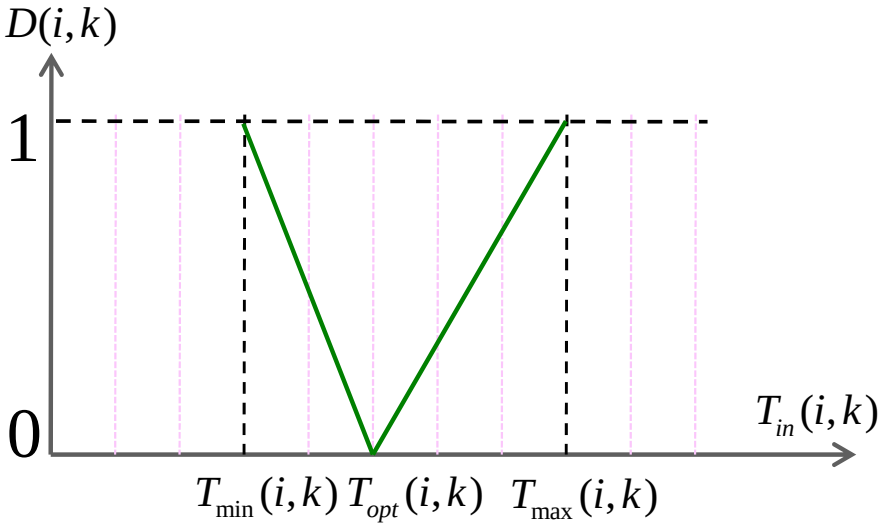
Thermal model

$$T_{in}(i,k+1) - e^{-\frac{\Delta}{\tau(i)}} T(i,k) - G(i,k)(1-e^{-\frac{T_e}{\tau(i)}}) E(i,k)$$

$$-(1-e^{-\frac{T_e}{\tau(i)}}).T_{ext}(i,k) - \Phi_s(i,k)(1-e^{-\frac{T_e}{\tau(i)}}) = 0$$

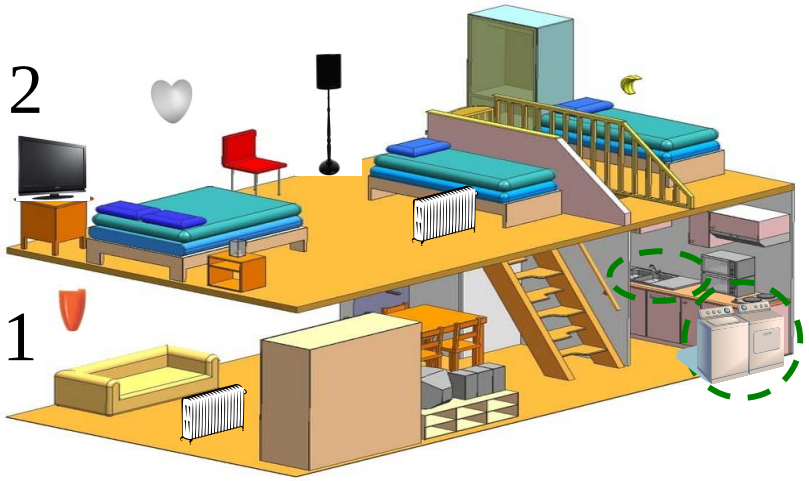
Discomfort criteria

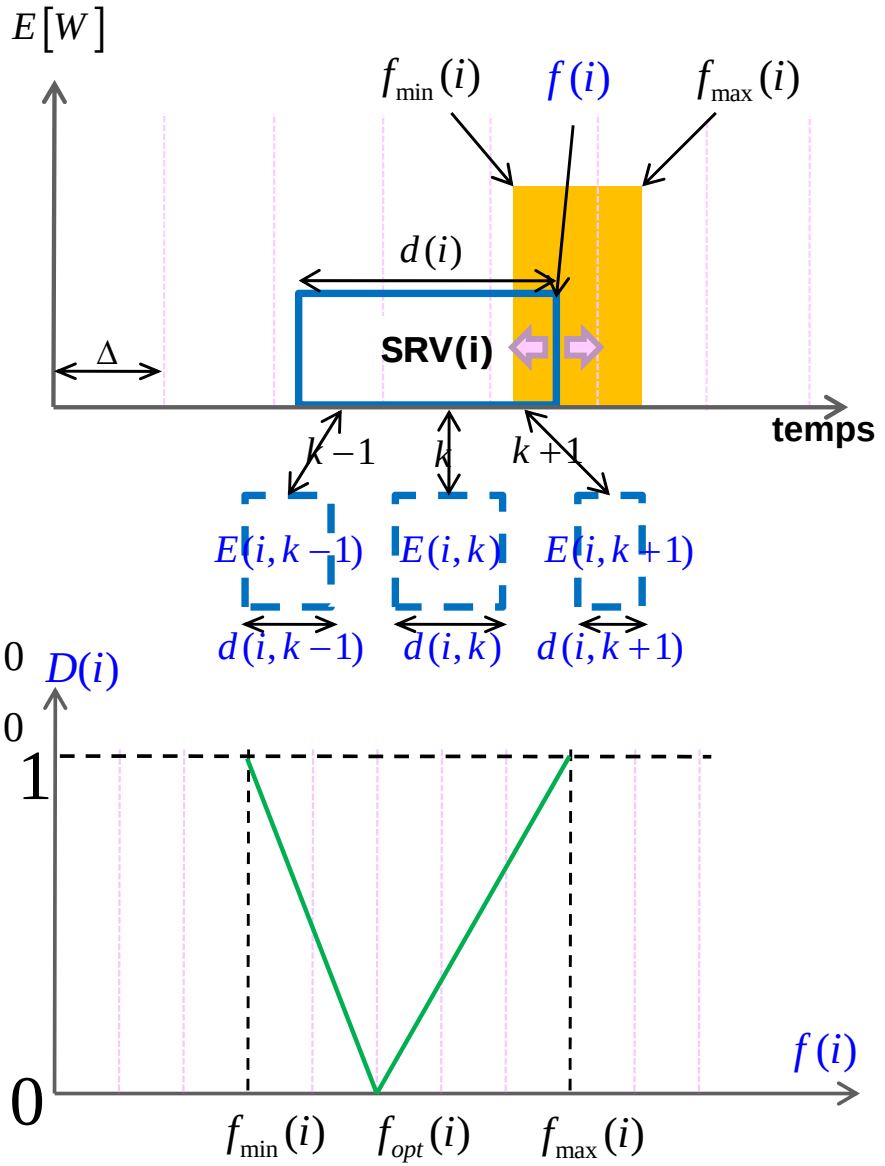
$$D(i,k) = \begin{cases} \dfrac{T_{\text{opt}}(i,k) - T_{\text{in}}(i,k)}{T_{\text{opt}}(i,k) - T_{\text{min}}(i,k)} & \text{si} \quad T_{\text{in}}(i,k) \le T_{\text{opt}}(i,k) \\ \dfrac{T_{\text{in}}(i,k) - T_{\text{opt}}(i,k)}{T_{\text{max}}(i,k) - T_{\text{opt}}(i,k)} & \text{si} \quad T_{\text{in}}(i,k) > T_{\text{opt}}(i,k) \end{cases}$$



Piecewise linear function of thermal dissatisfaction (ISO7730)

Temporary service





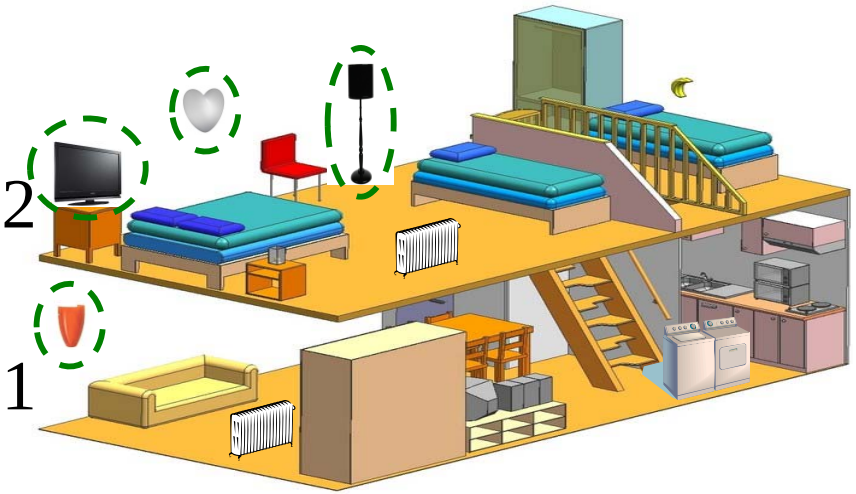
Behaviour model

$$E(i,k)=\begin{cases}\left\{\text{Min}\left[f(i),(k+1)\Delta\right]-\text{Max}\left[f(i)-d(i),k\Delta\right]\right\}P(i) & \text{si} \quad E(i,k)>0\\ 0 & \text{si} \quad E(i,k)\le 0\end{cases}$$

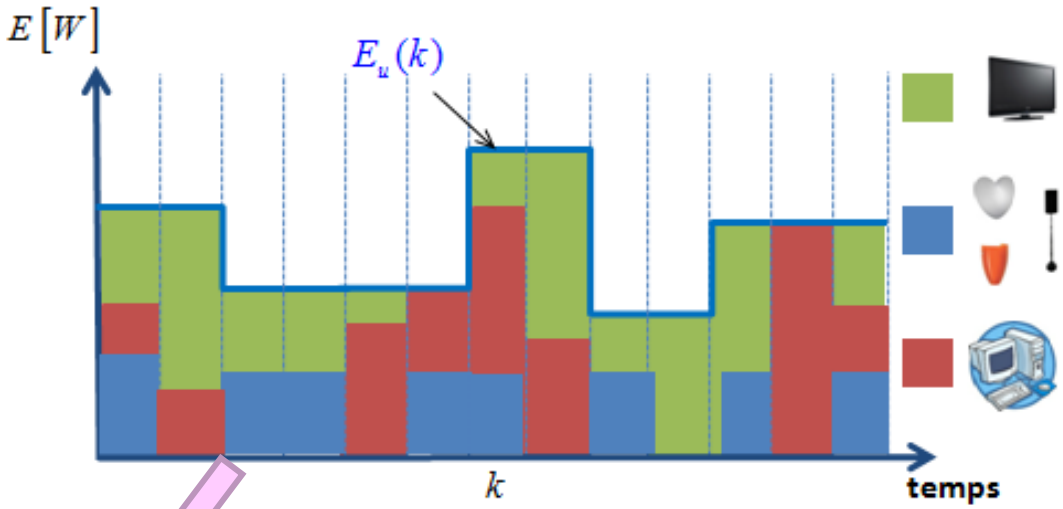
Discomfort criteria

$$D(i)=\begin{cases}\dfrac{f_{opt}(i)-f(i)}{f_{opt}(i)-f_{min}(i)} & \text{si} \quad f(i)\le f_{opt}(i)\\ \dfrac{f(i)-f_{opt}(i)}{f_{max}(i)-f_{opt}(i)} & \text{si} \quad f(i)> f_{opt}(i)\end{cases}$$

Energy balance and objective function



Unsupervised services



Energy balance

$$E(k) = \sum_{i \in SRV_s} E(i,k) + E_u(k), \forall k$$

Objective function

$$J = \sum_{k=0}^{T-1} C(k)E(k) + \frac{\beta}{\sum_{i \in SRV_p} \alpha(i) + \sum_{i \in SRVT} \alpha(i)} \left[\sum_{i \in SRV_P} \sum_{i=0}^{T-1} \alpha(i)D(i,k) + \sum_{i \in SRV_T} \alpha(i)D(i) \right]$$

energy cost

discomfort

Classification of uncertainties

Parametric uncertaintis : uncertainties modeled as intervals

$$\tilde{T}_{ext}(i,k) \in \left[T_{ext}(i,k) - \hat{T}_{ext}, T_{ext}(i,k) + \hat{T}_{ext}(i,k) \right] [°C]$$

$$\tilde{\Phi}_s(i,k) \in \left[\Phi_s(i,k) - \hat{\Phi}_s(i,k), \Phi_s(i,k) + \hat{\Phi}_s(i,k) \right] [W]$$

$$\tilde{G}(i,k) \in \left[G(i,k) - \hat{G}(i,k), G(i,k) + \hat{G}(i,k) \right]$$

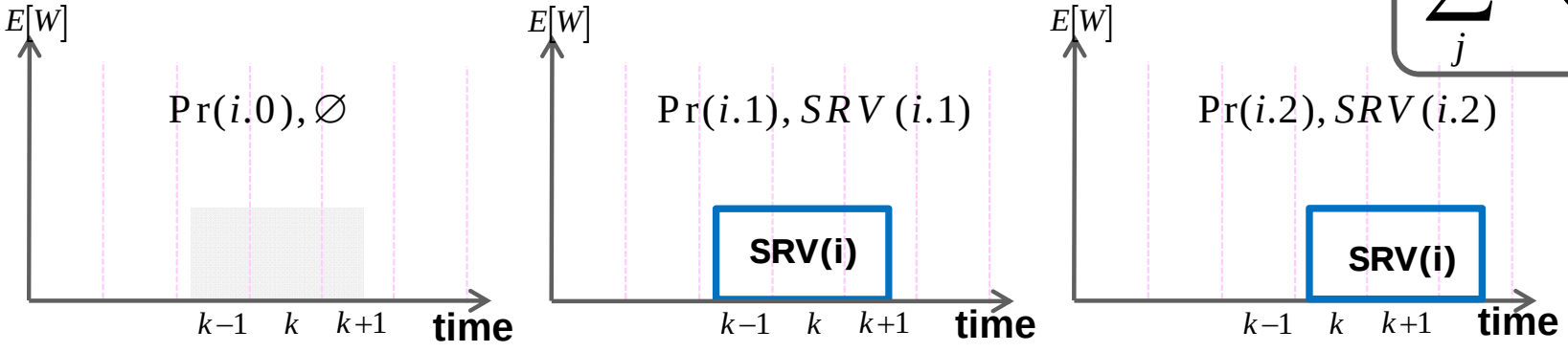
$$\tilde{d}(i) \in \left[d(i) - \hat{d}(i), d(i) + \hat{d}(i) \right] [s]$$

$$\tilde{P}(i) \in \left[P(i) - \hat{P}(i), P(i) + \hat{P}(i) \right] [W]$$

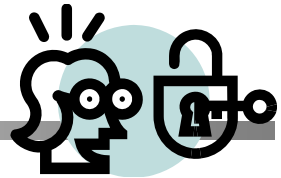
$$\tilde{E}_u(k) \in \left[E_u - \hat{E}_u(k), E_u + \hat{E}_u(k) \right] [W]$$

Uncertainty of occurrence : The uncertainties concern the starting of the non-programmable temporary services

$$\sum_j \Pr(i.j) = 1, \forall i$$



Taking into account uncertaities in optimization problem



Resolution approach

Parametric uncertainties

Difficulties

Capacity to guarantee the performance of the optimized plans towards the uncertainties?

Robust approachs

- Multiparametric programming
- Robust formulation of Bertsimas and Sim
- Scenario robust approach

Uncertainties of occurrence

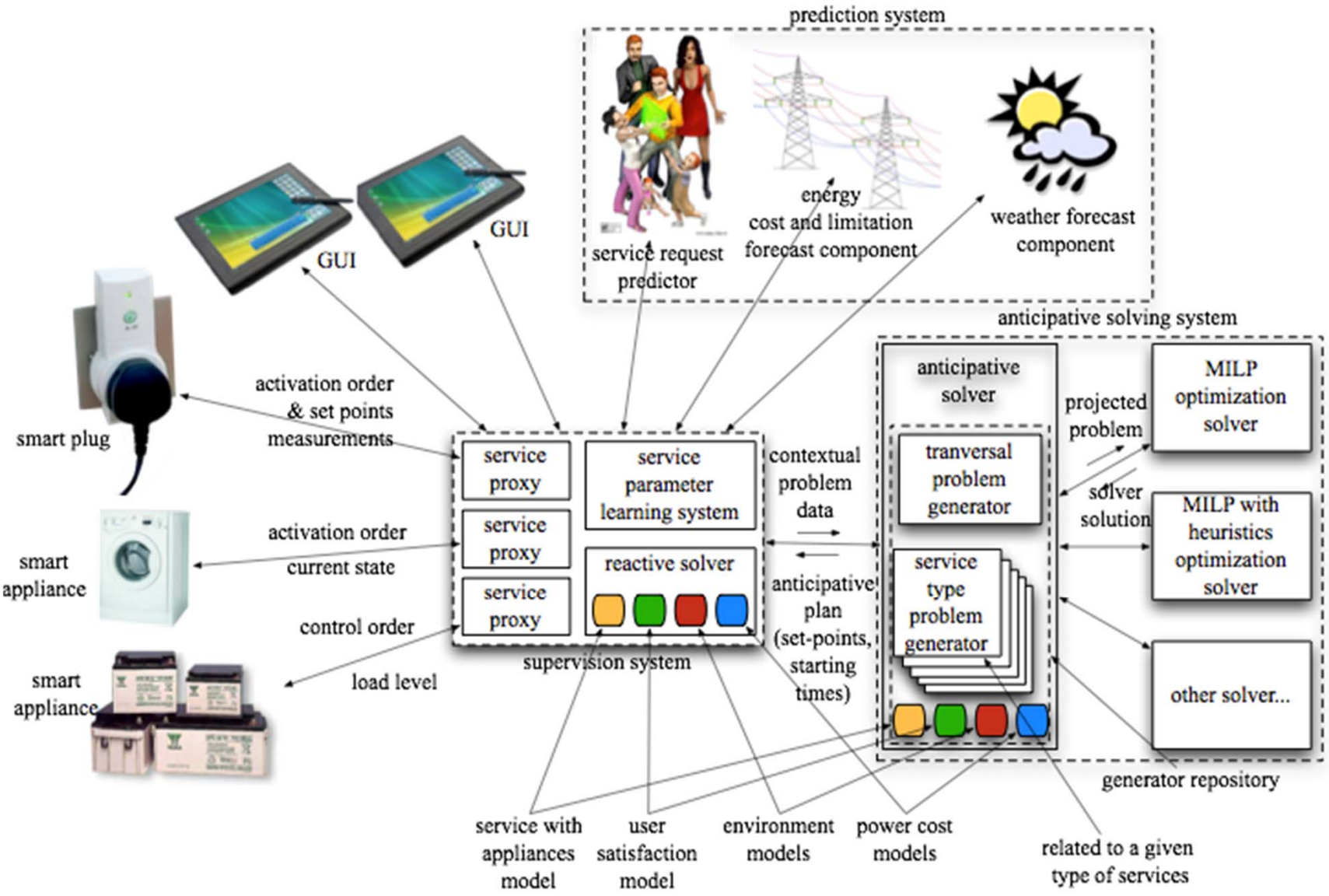
Difficulties

How much energy is it necessary to reserve for this type of service?

Stochastic approach

- Stochastic programming

Building Energy Management: G-homeTech



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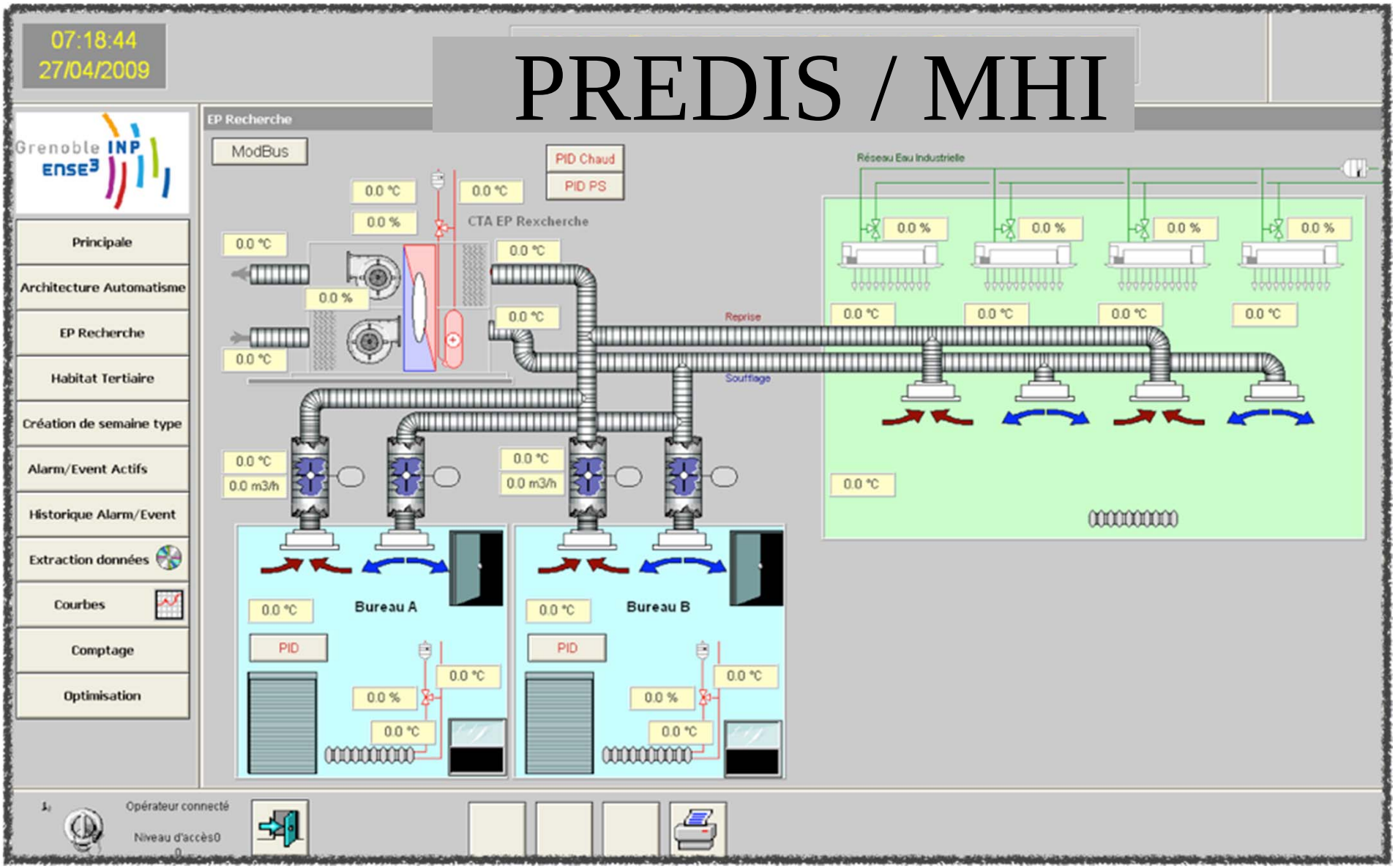
Platform PREDIS – ANR Project RéactivHome

Study platform



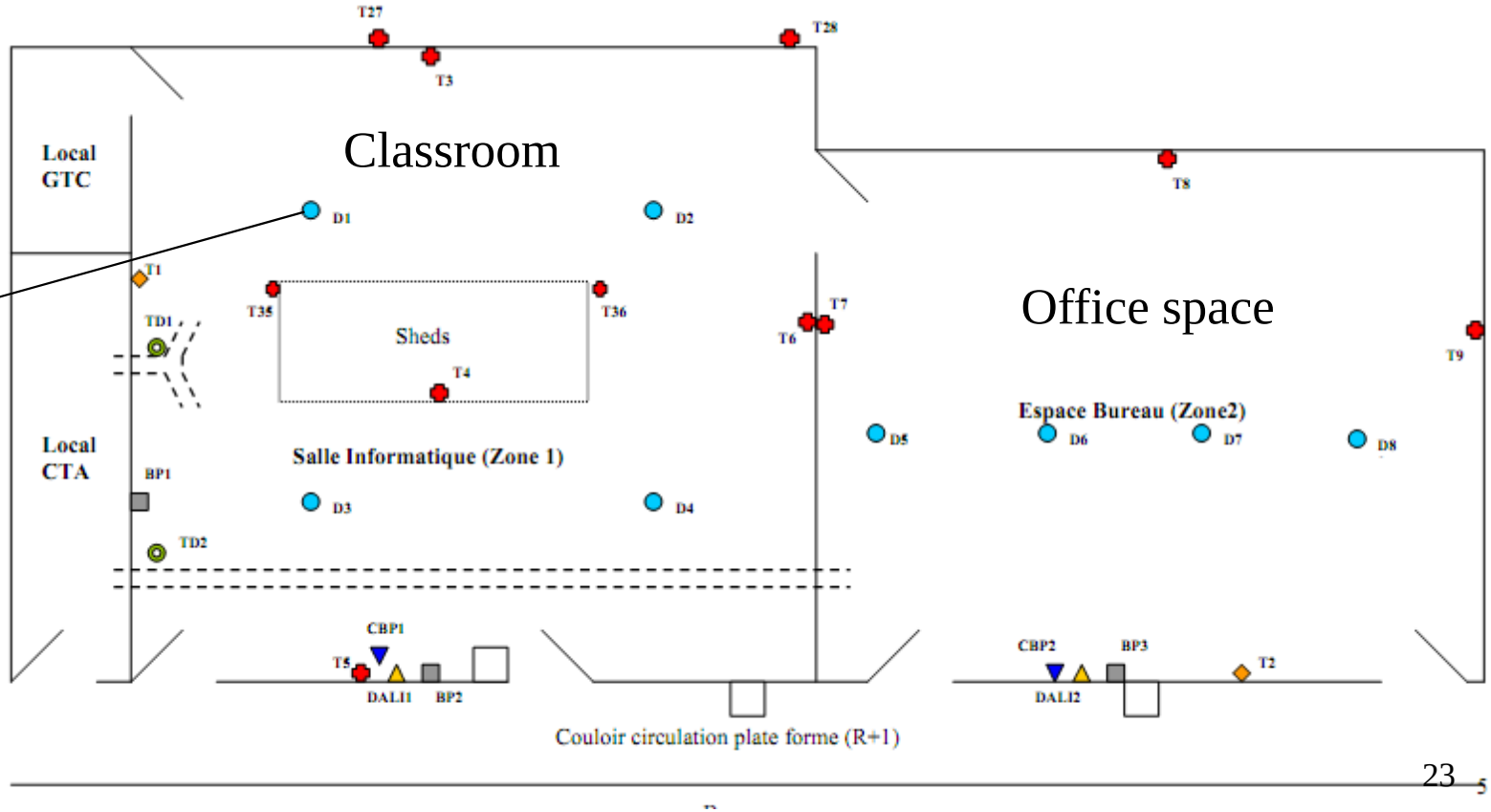
Sensors and actuator

Wattmeters

Temperature and humidity sensor

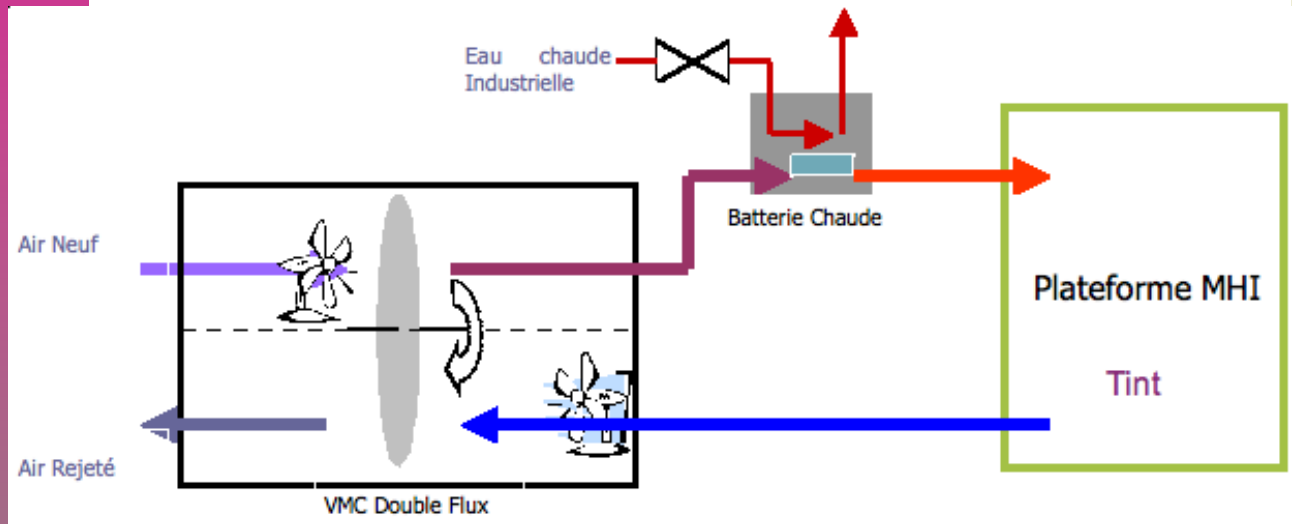
Controllable plugs

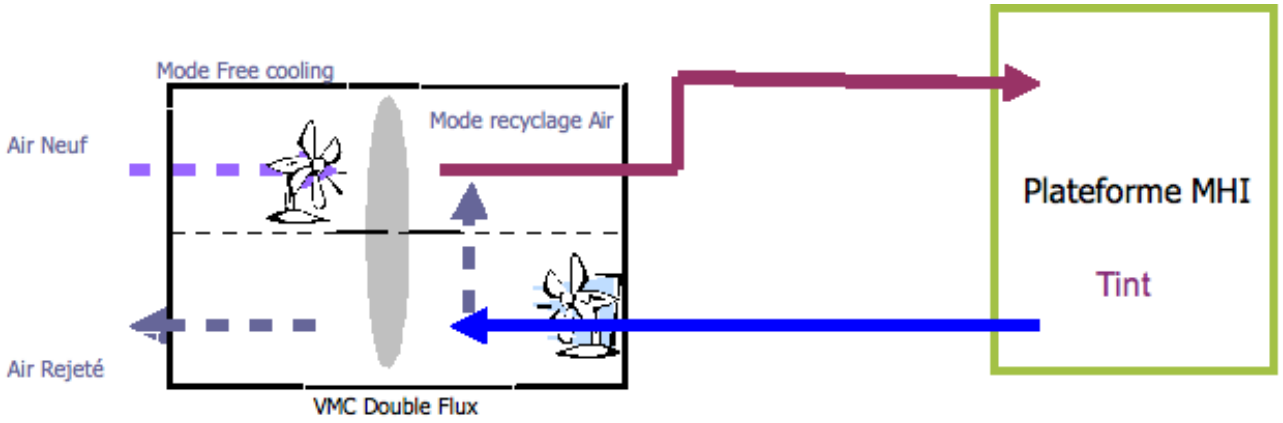
Luminosity Regulation DALILON



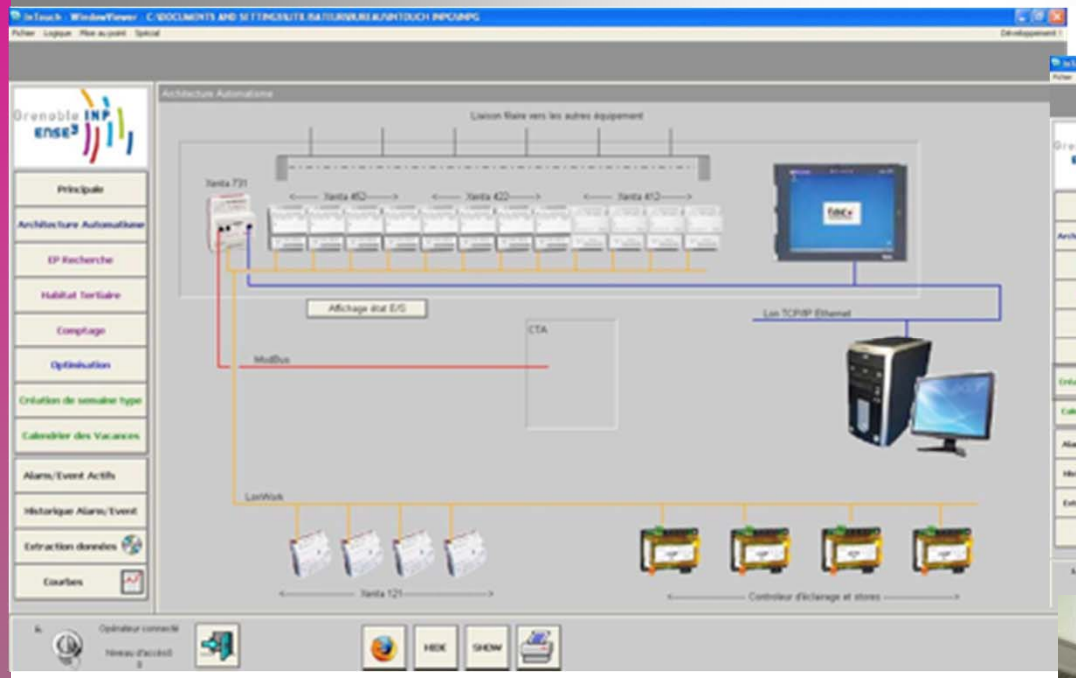
HVAC system

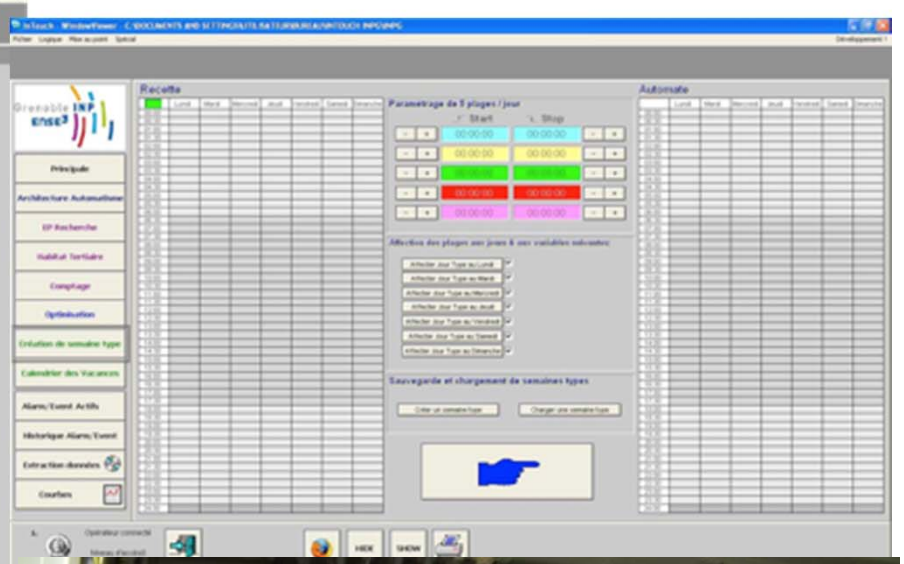
System HVAC (Heating, Ventilation and Air Conditioning)

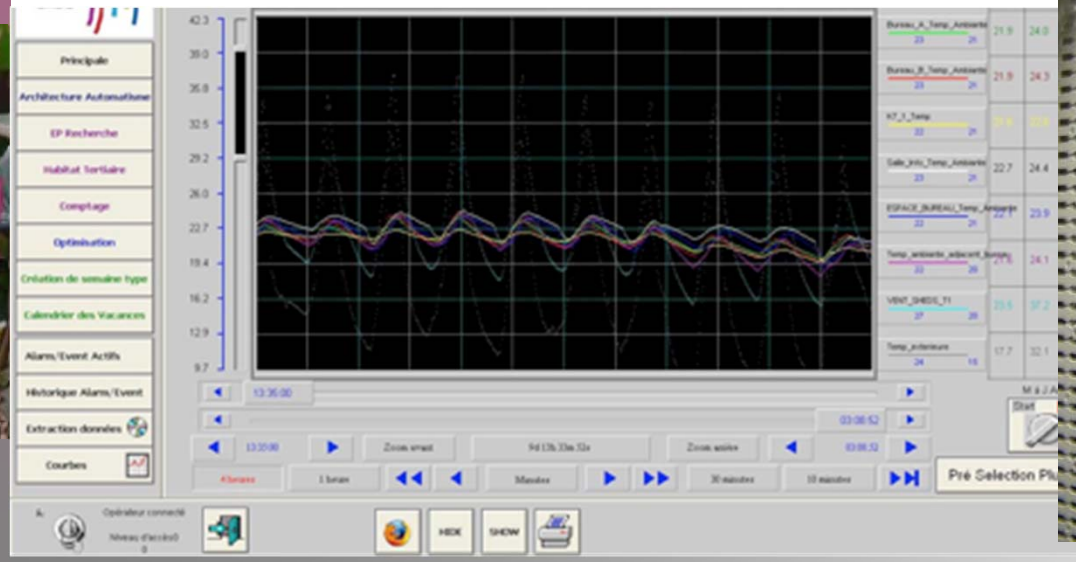




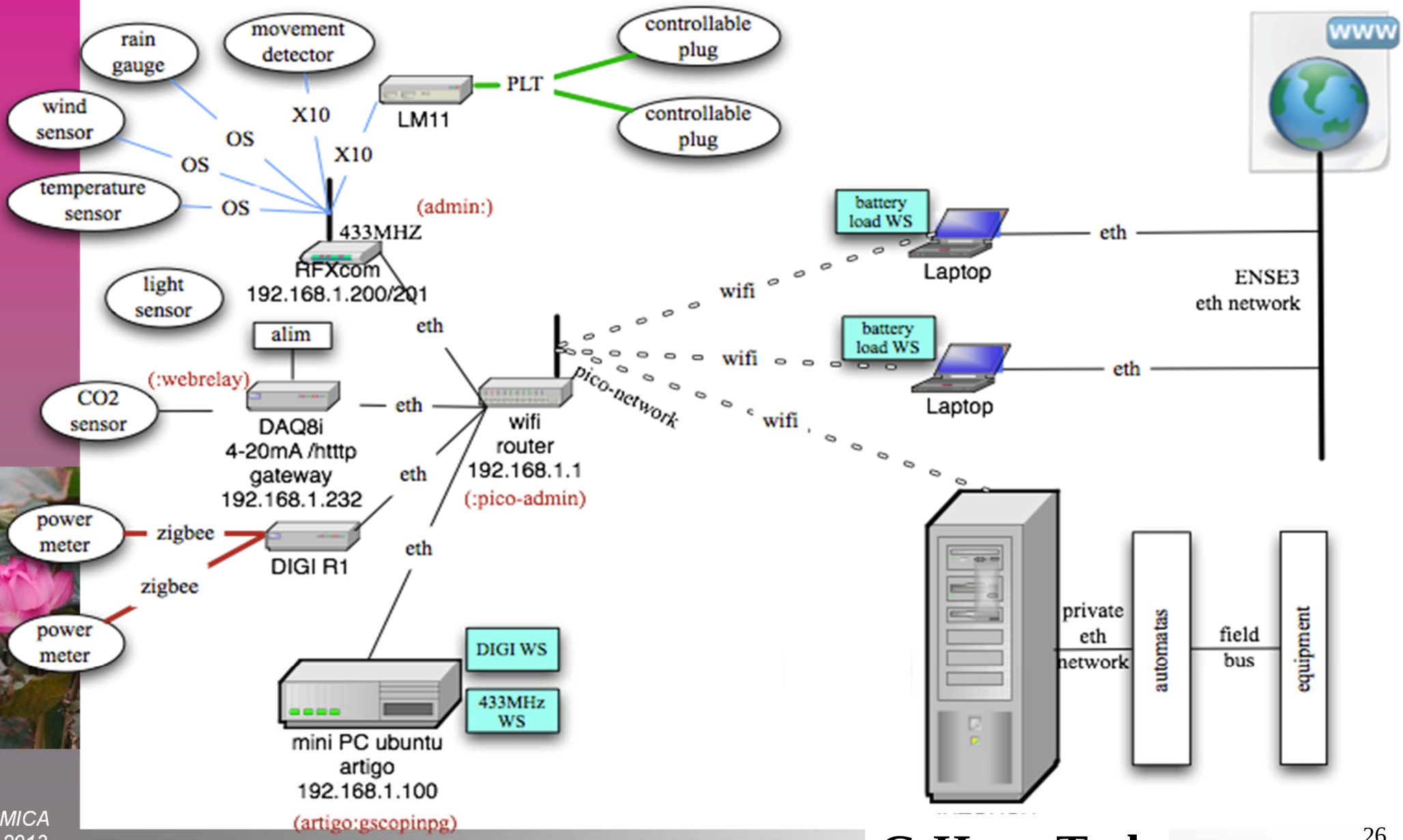
Plateform PREDIS: monitoring



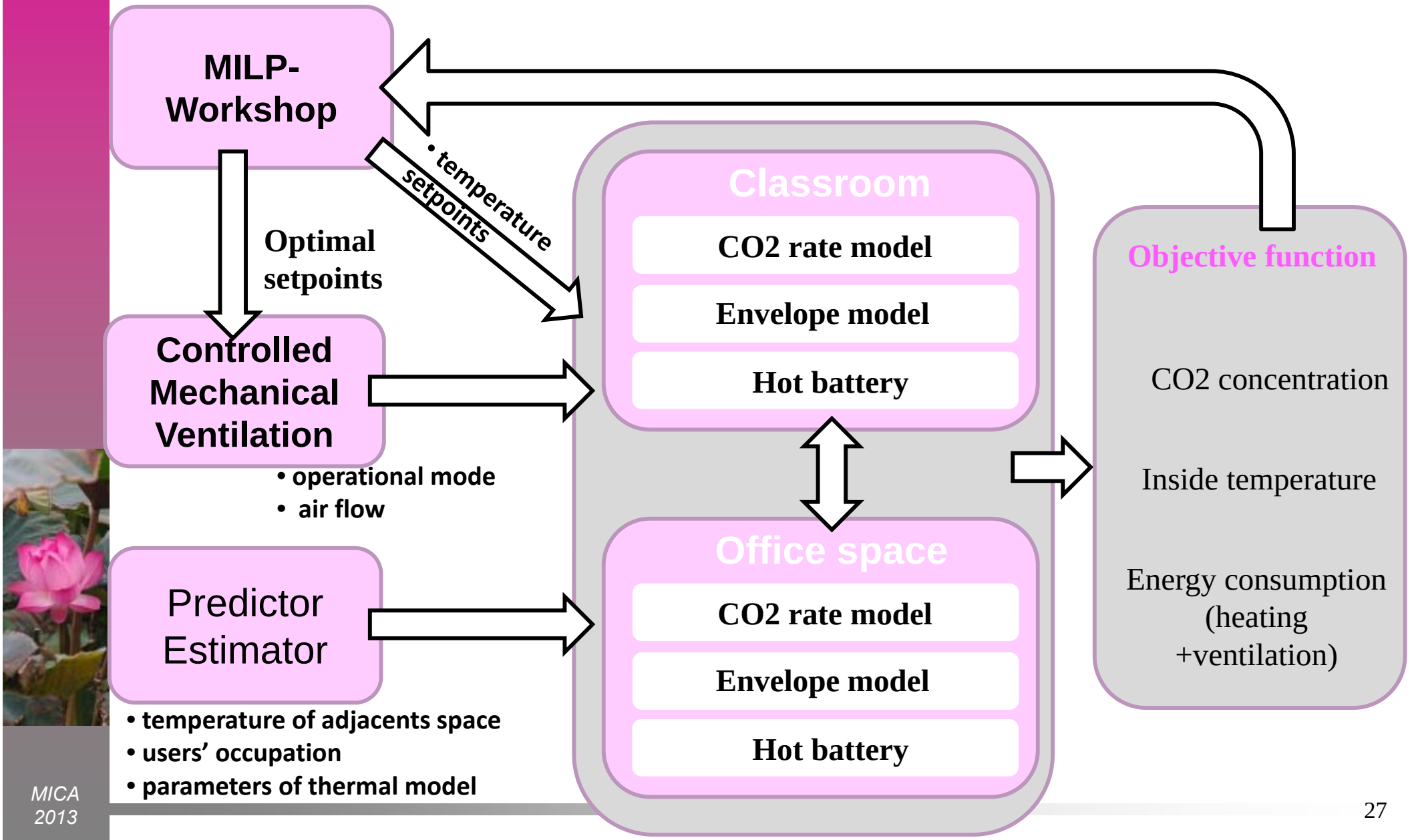




Energy Management System

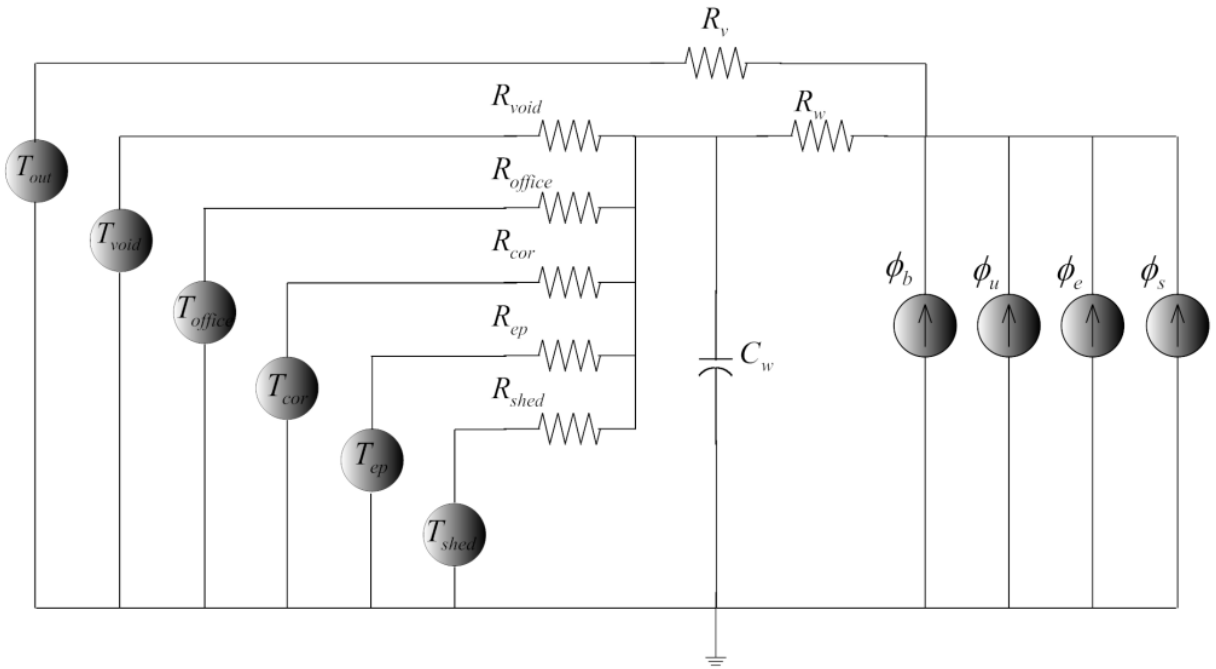


Energy management : principle



Thermal model

Classroom



$$\frac{dT_w(t)}{dt} = AT_w(t) + BU(t)$$

$$T_{in}(t) = C.T_w(t) + DU(t)$$

$$U = \begin{bmatrix} T_{void} & \phi_h & \phi_u & \phi_e & \phi_s & T_{ep} & T_{shed} & T_{office} & T_{cor} & T_{out} \end{bmatrix}^T$$

$$A = \frac{1}{C_m}\left(\frac{R_v}{R_w(R_w+R_v)} - \frac{1}{R_w} - \frac{1}{R_{void}} - \frac{1}{R_{ep}} - \frac{1}{R_{shed}} - \frac{1}{R_{office}} - \frac{1}{R_{cor}}\right)$$

$$B = \frac{1}{C_m}\begin{bmatrix} \frac{1}{R_{void}} & \frac{R_v}{R_w+R_v} & \frac{R_v}{R_w+R_v} & \frac{R_v}{R_w+R_v} & \frac{R_v}{R_w+R_v} & \frac{1}{R_{ep}} & \frac{1}{R_{shed}} & \frac{1}{R_{office}} & \frac{1}{R_{cor}} & -\frac{1}{R_w+R_v} \end{bmatrix}$$

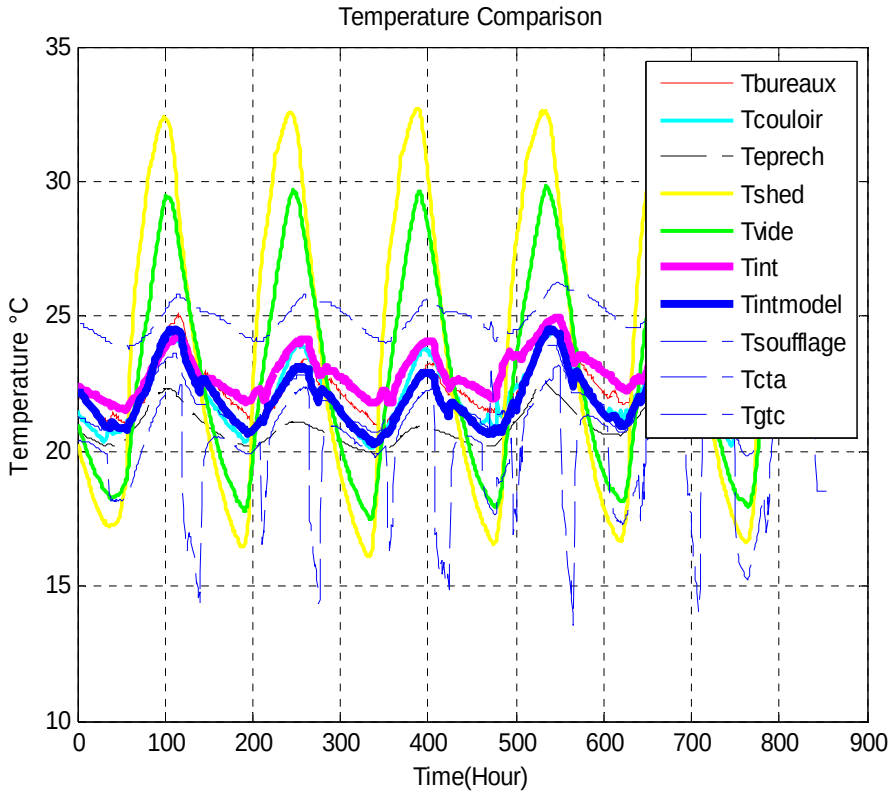
$$C = \frac{R_v}{R_w+R_v}$$

$$D = \frac{R_w R_v}{R_w+R_v}\begin{bmatrix} 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & \frac{1}{R_f} \end{bmatrix}$$

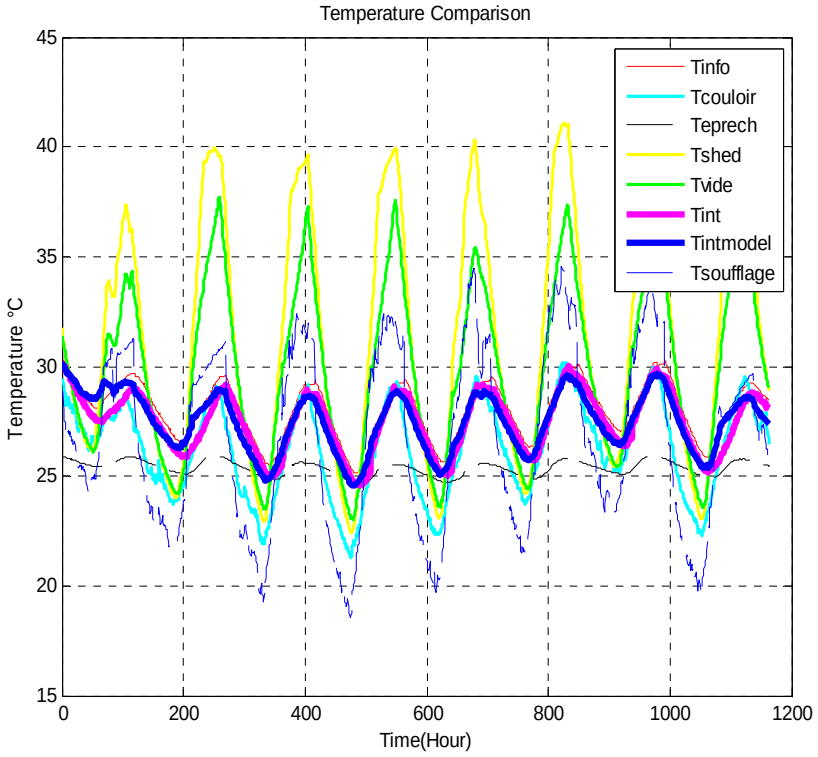
Parameters identification of thermal model

Identification with mesurements (23/02/2012 – 28/02/2012)

Classroom



Office space



	Rm (K/W)	Cm (J/K)	Rvide (K/W)	Reprech (K/W	Rshed (K/W)	Rbur (K/W)	Rcou (K/W)	**ΔTmoy** (° C)
Classroom	**5,3492e-4**	**4,7296e6**	**0,0109**	**0,002**	**0,0064**	**9,6451e-5**	**0,0124**	**0.2651**
Office space	**4,1186e-4**	**4,0728e7**	**0,0115**	**0,0030**	**0,0322**	**9,6442e-5**	**0,013**	**0.1506**

Controlled Mechanical Ventilation (1)

- **Free cooling**

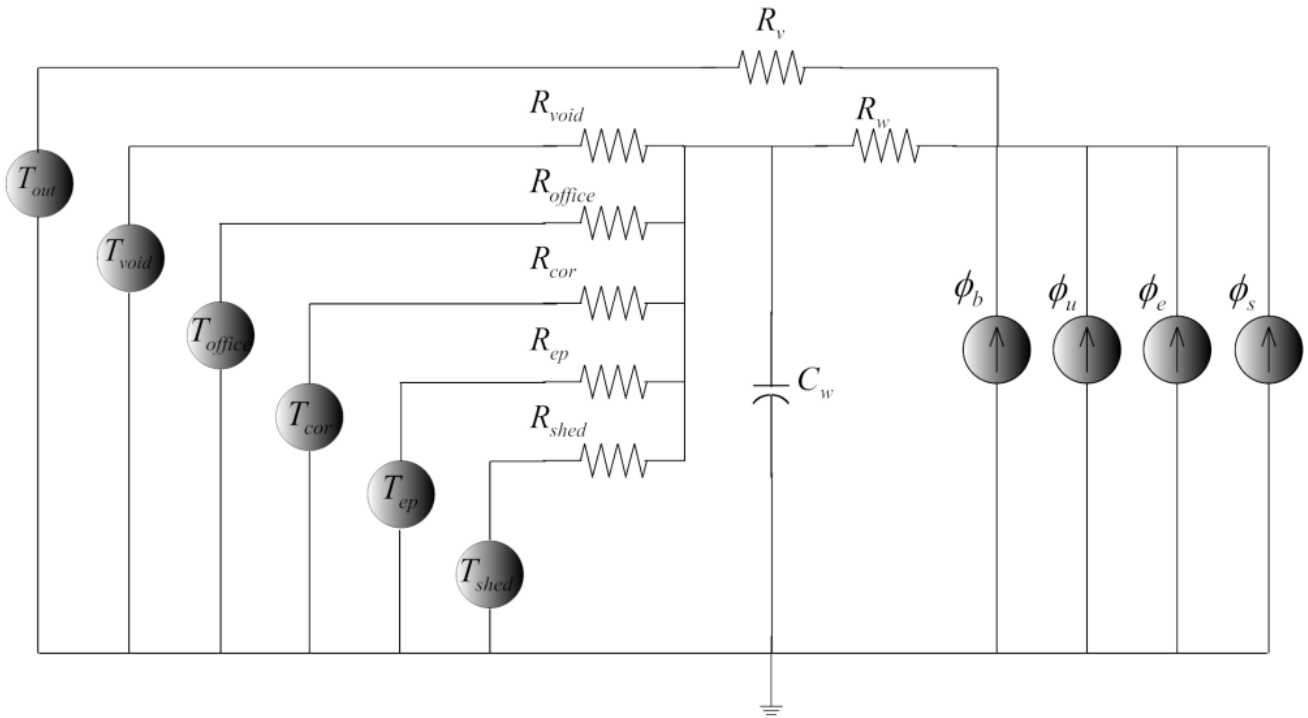
$$R_v = \frac{1}{\rho_{air} C_{air} Q}$$

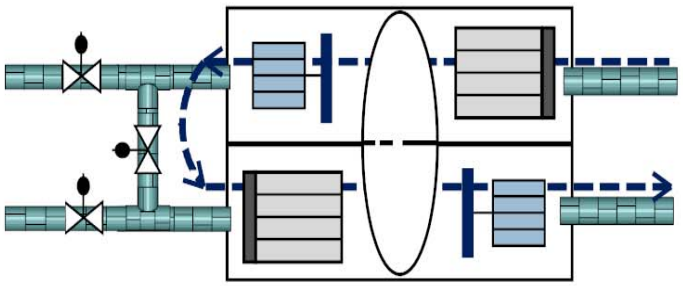
- **Heat exchange**

$$R_v = \frac{1}{(1-\zeta)\rho_{air} C_{air}}$$

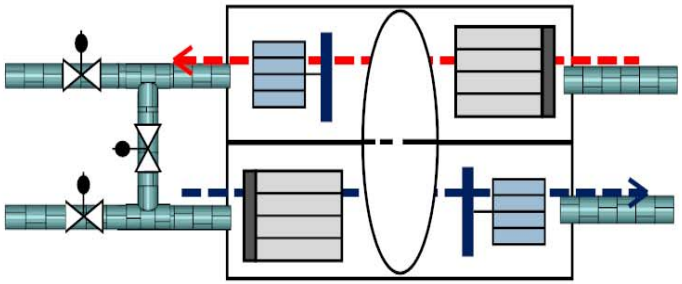
- **Recycling**

$$R_v = \infty$$

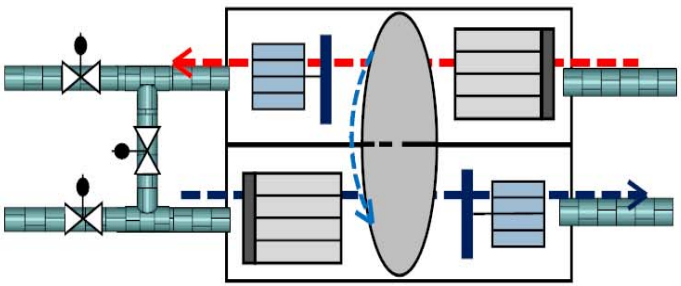




a. Recycling



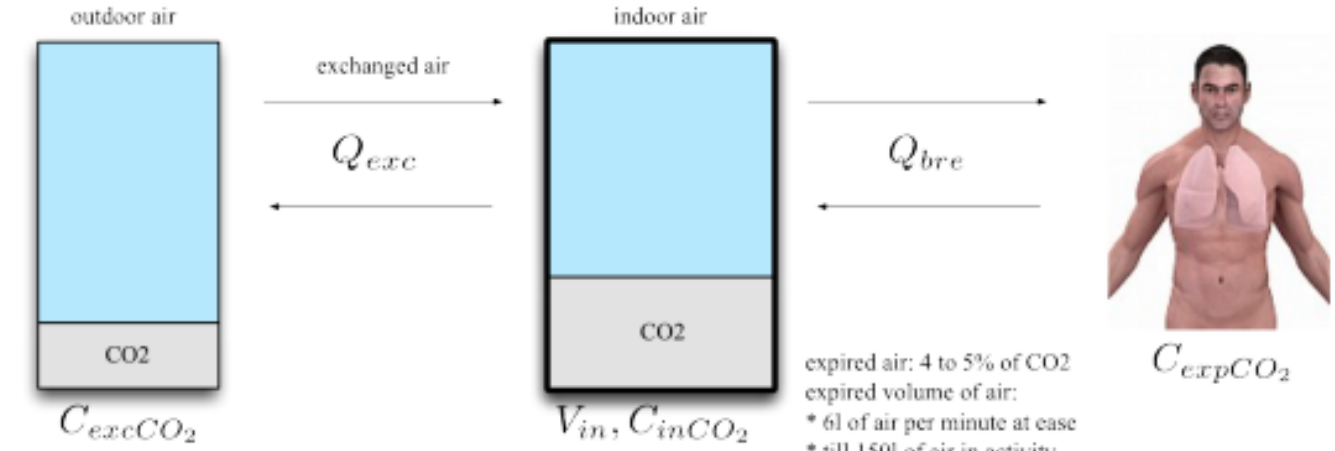
b. Free cooling



c. Heat exchange

CO2 concentration and objective function

CO_2 concentration evolution inside the room



$$\frac{dC_{inCO_2}}{dt} = -\sum_i \frac{\zeta_i Q_{exc,i}(k\Delta) + Q_{bre}(k\Delta)}{V_{in}} C_{inCO_2} + \frac{C_{expCO_2} Q_{bre}(k\Delta)}{V_{in}} + \sum_i \frac{C_{outCO_2} \zeta_i(k) Q_{exc,i}(k\Delta)}{V_{in}}$$

$$\forall k, \quad \sum_i \zeta_i(k) = 1$$

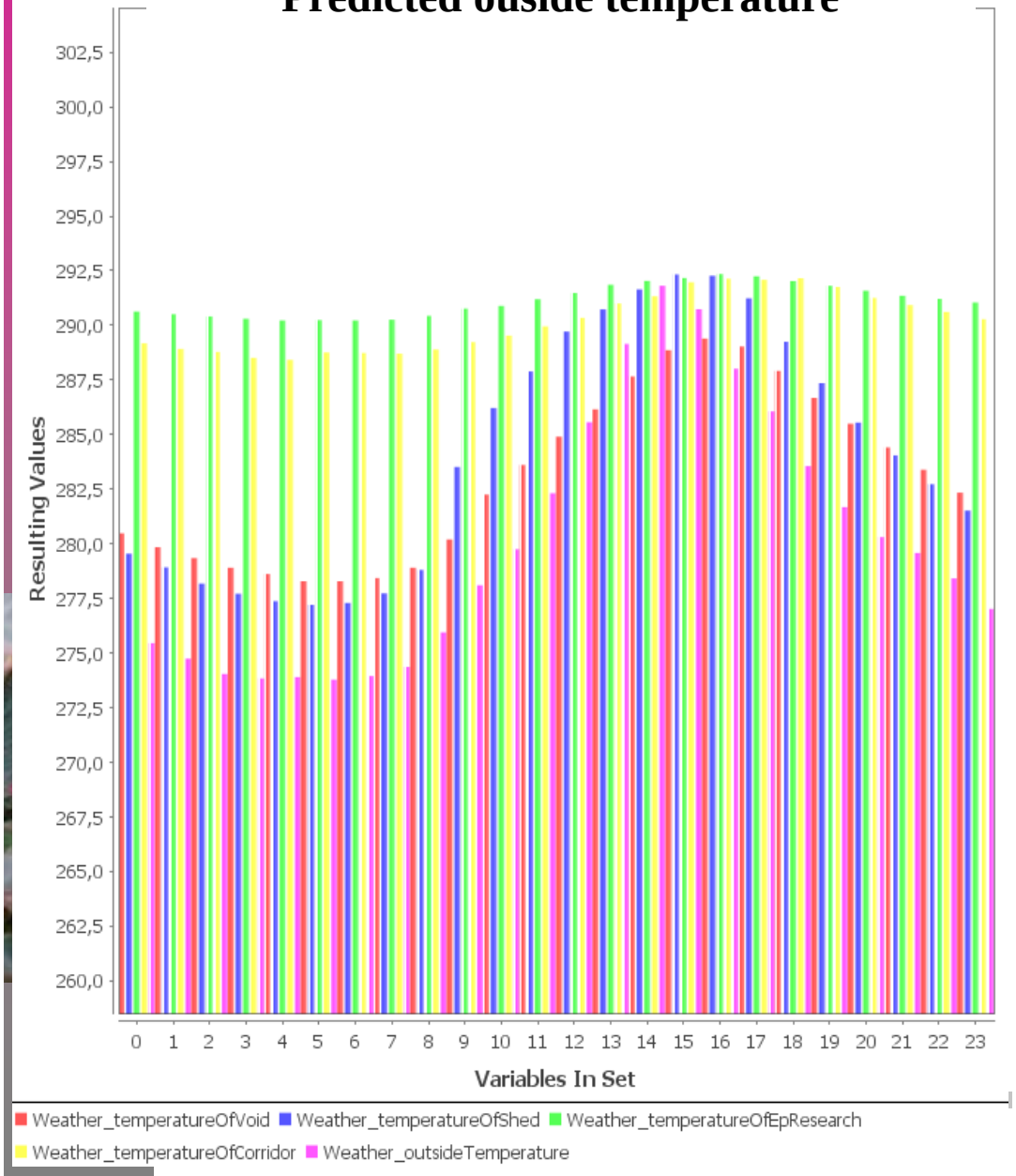
Objective function

$$J = \alpha \sum_{k=0}^{T-1} C(k)E(k) + \beta \sum_{i \in SRV} \sum_{k=0}^{T-1} \alpha(i) D(i,k) + \gamma \sum_{k=0}^{T-1} C_{CO_2}(k)$$

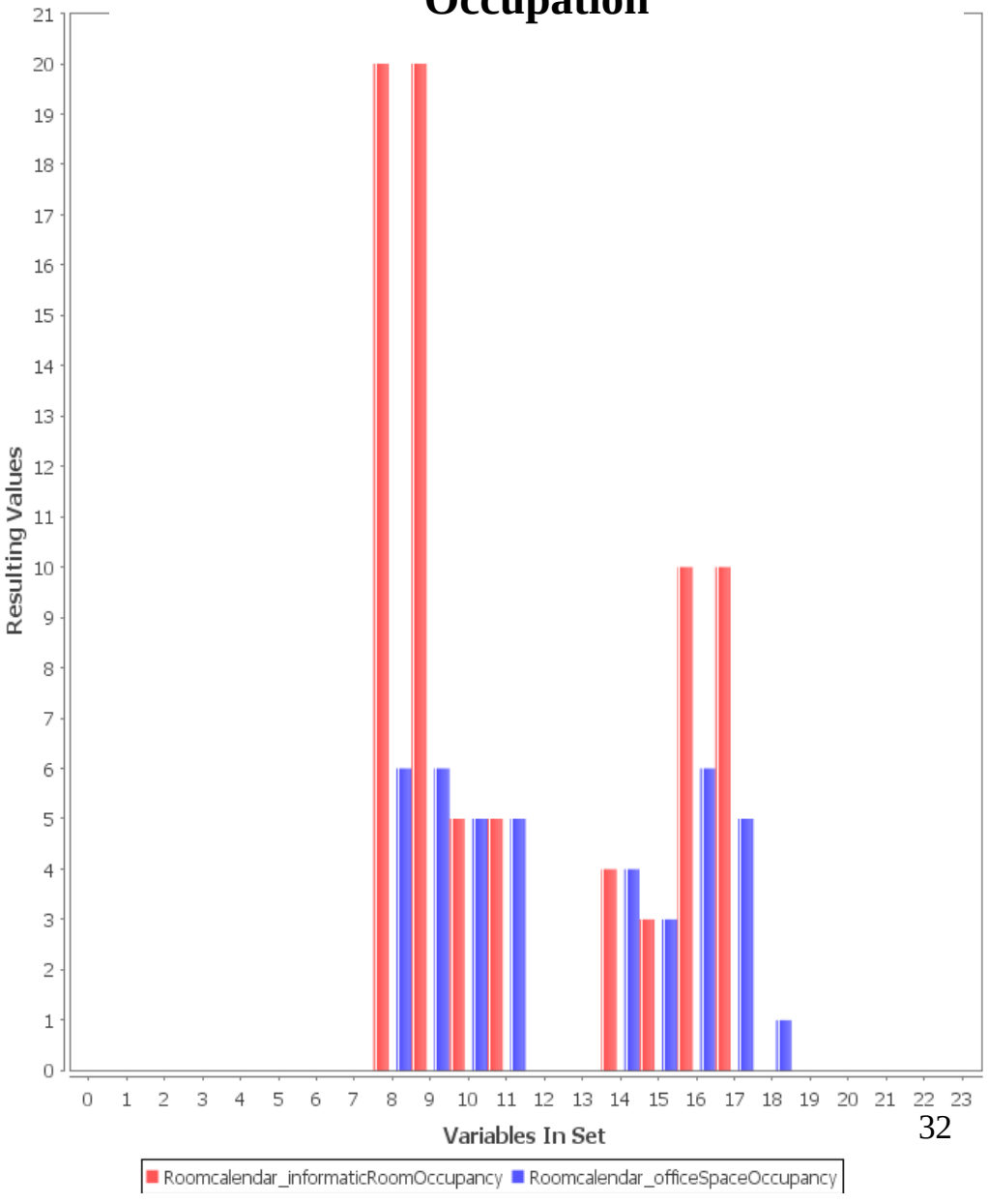
energy cost **thermal satisfaction** **CO_2 concentration**

Optimization input

Predicted ouside temperature

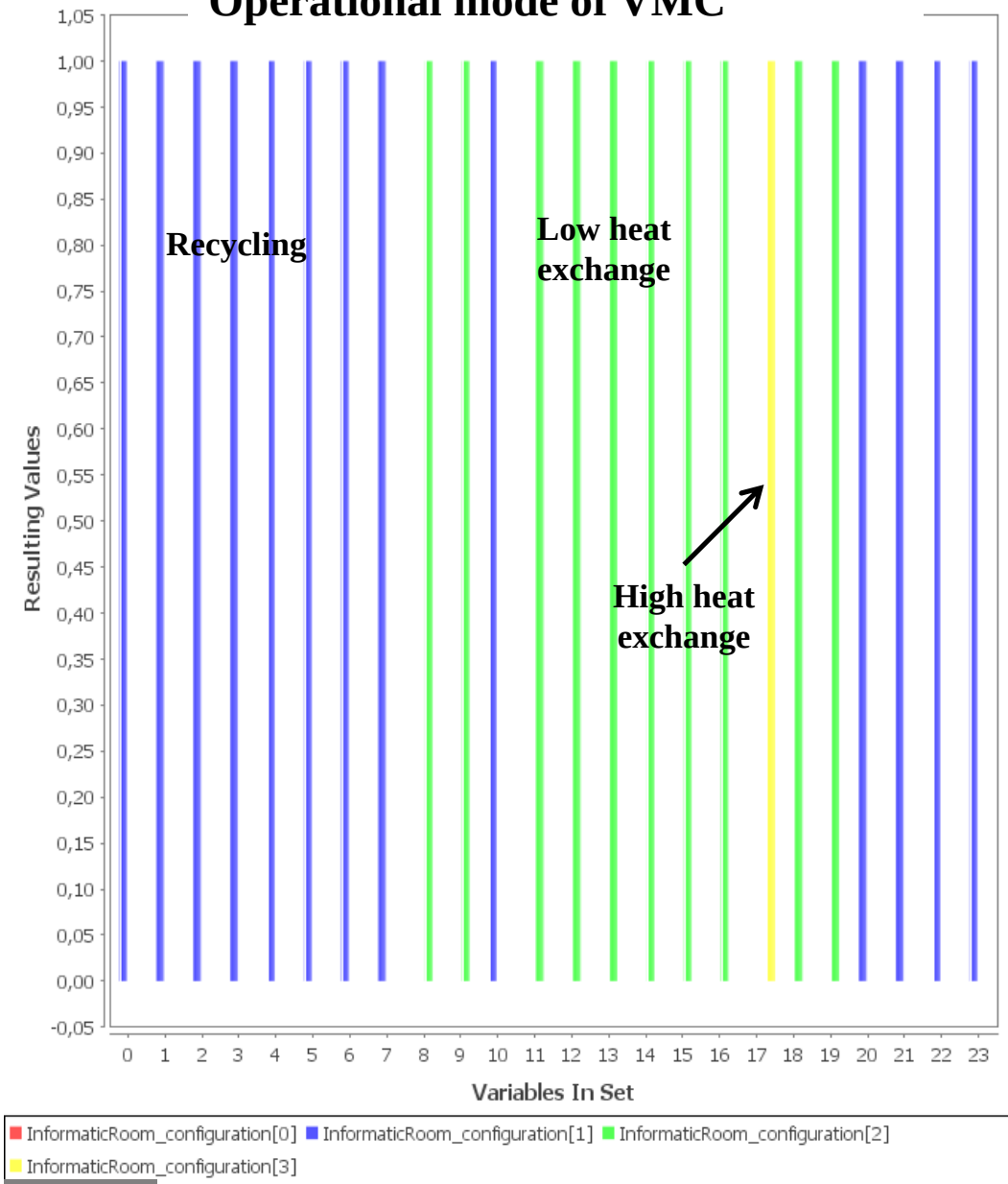


Occupation

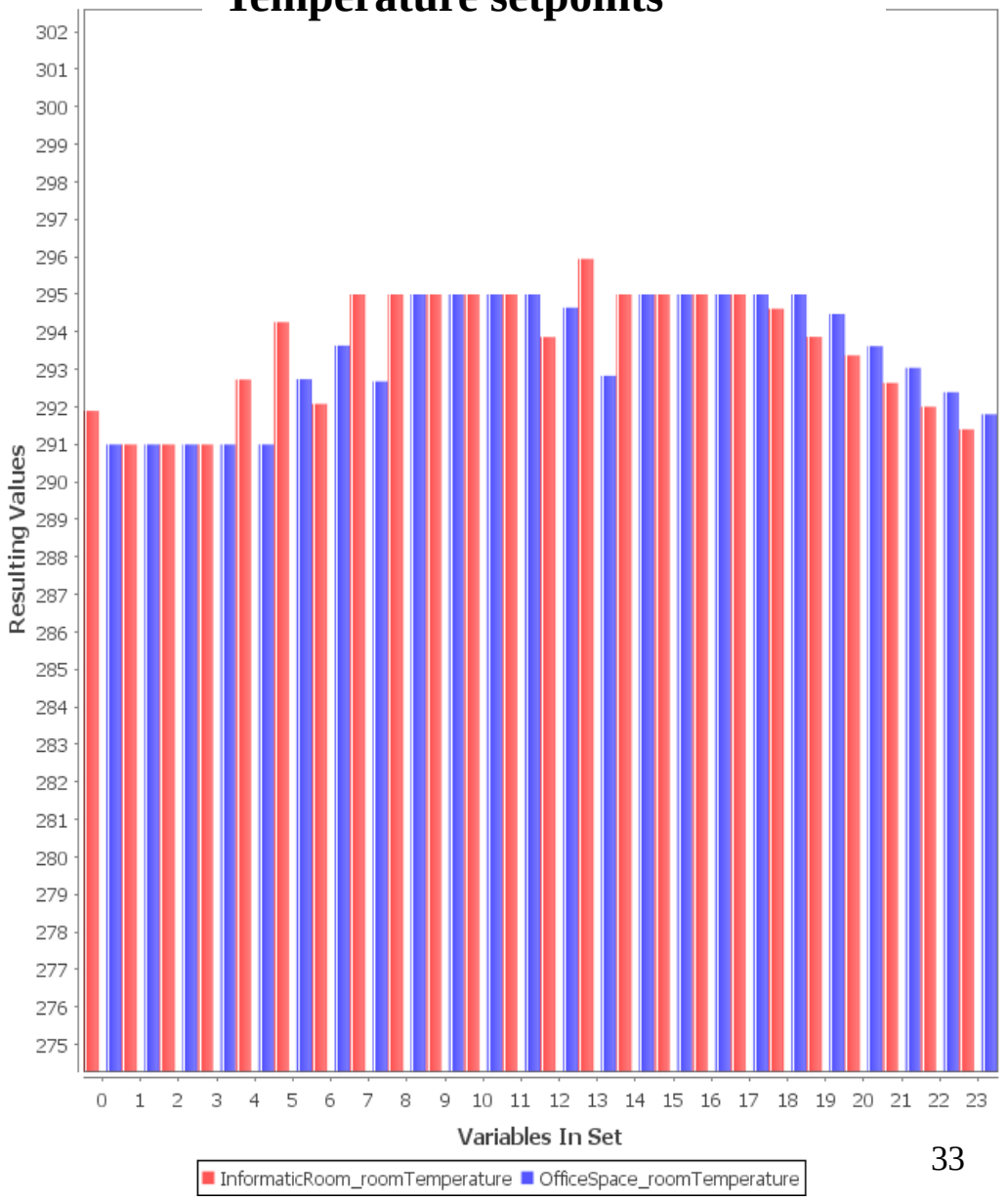


Setpoints given by MILP-Workshop

Operational mode of VMC

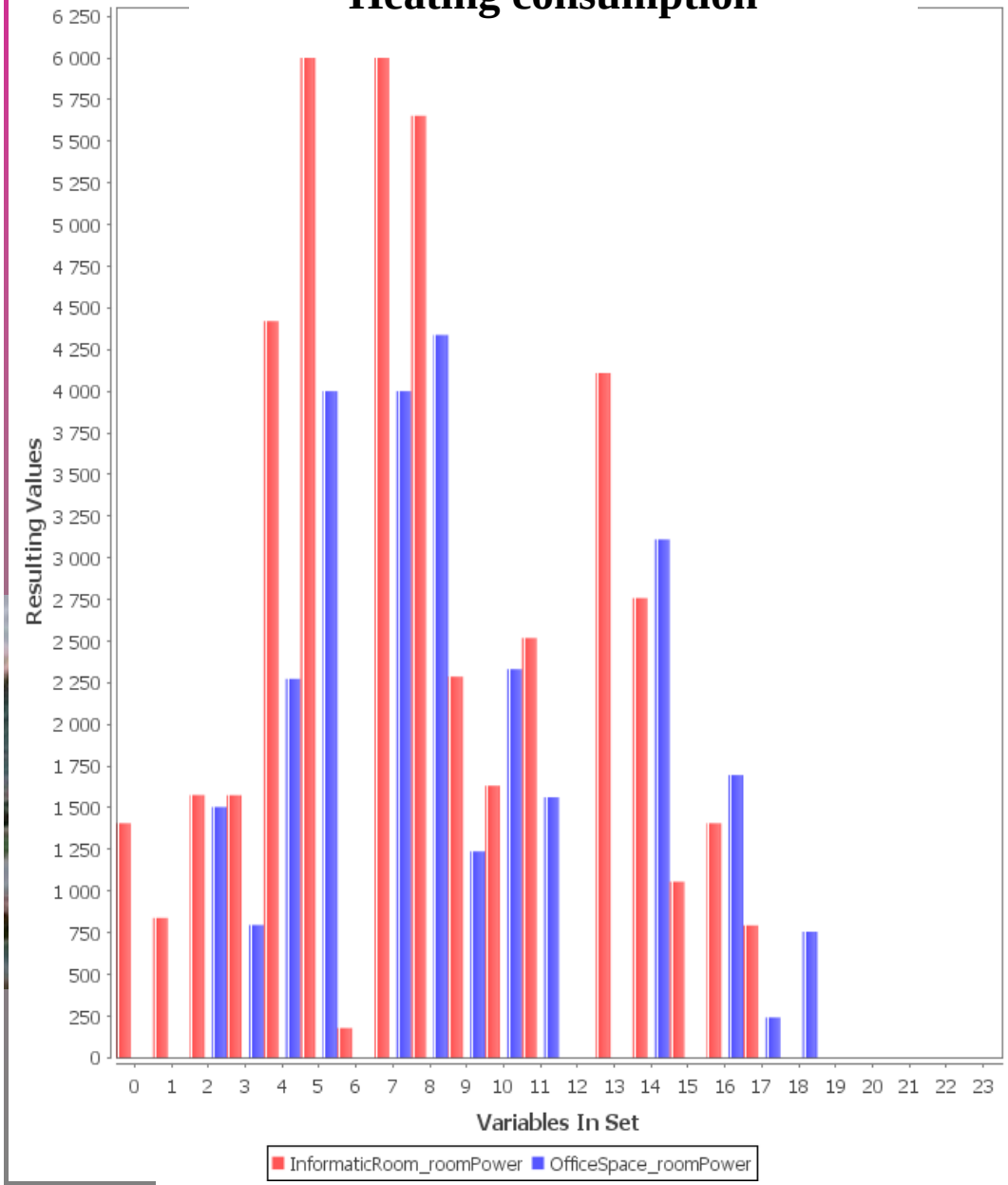


Temperature setpoints

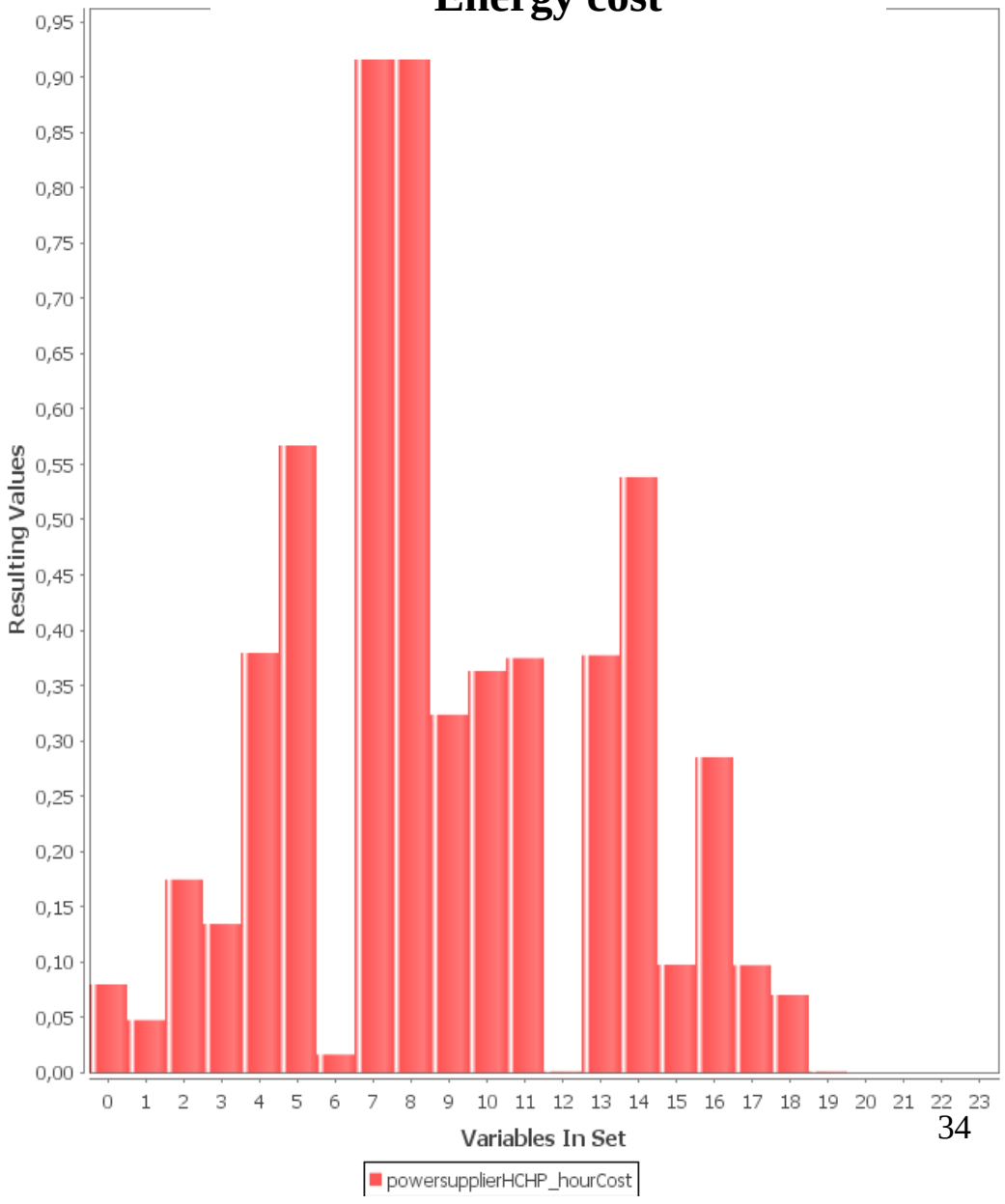


Estimated consumption and energy cost

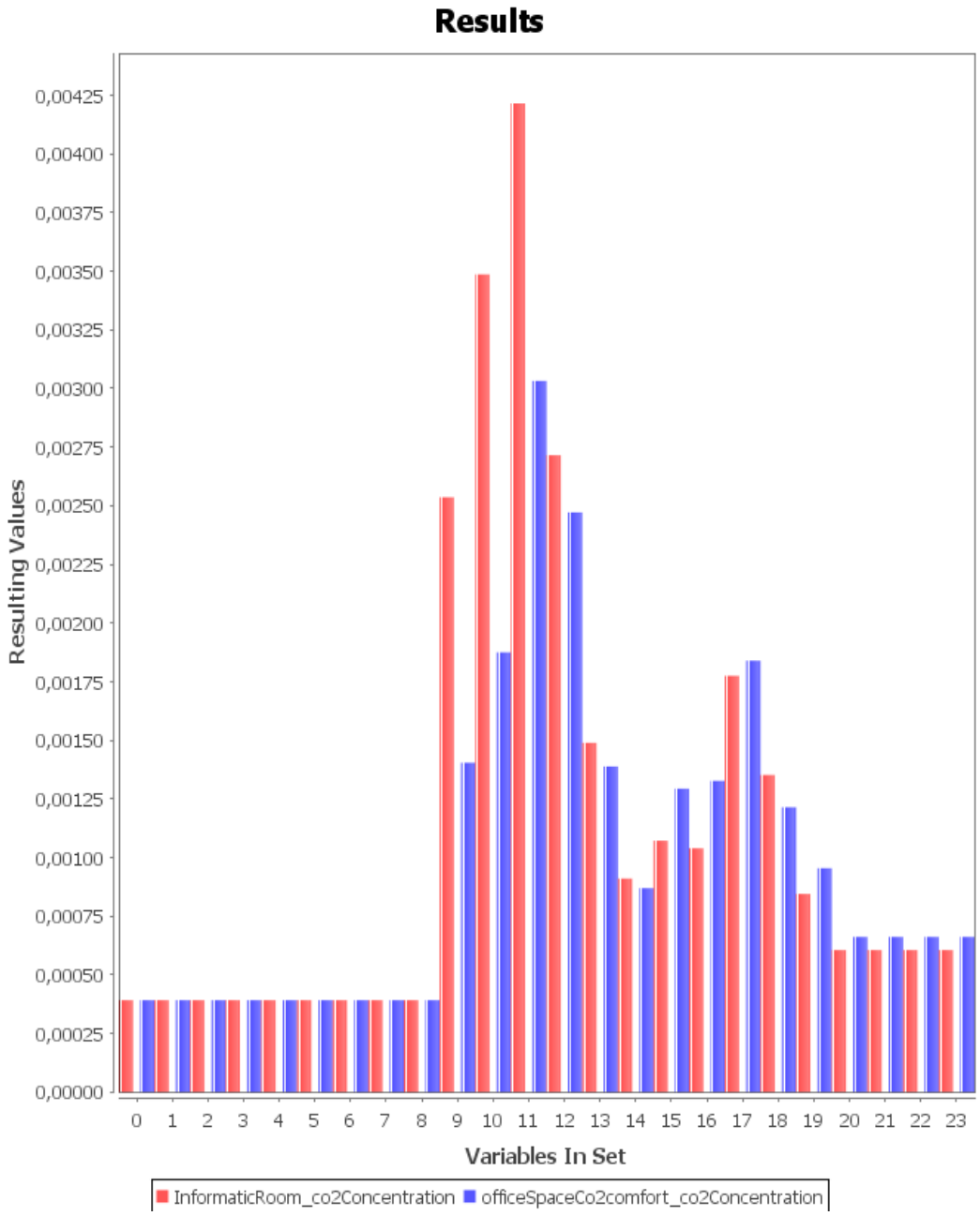
Heating consumption



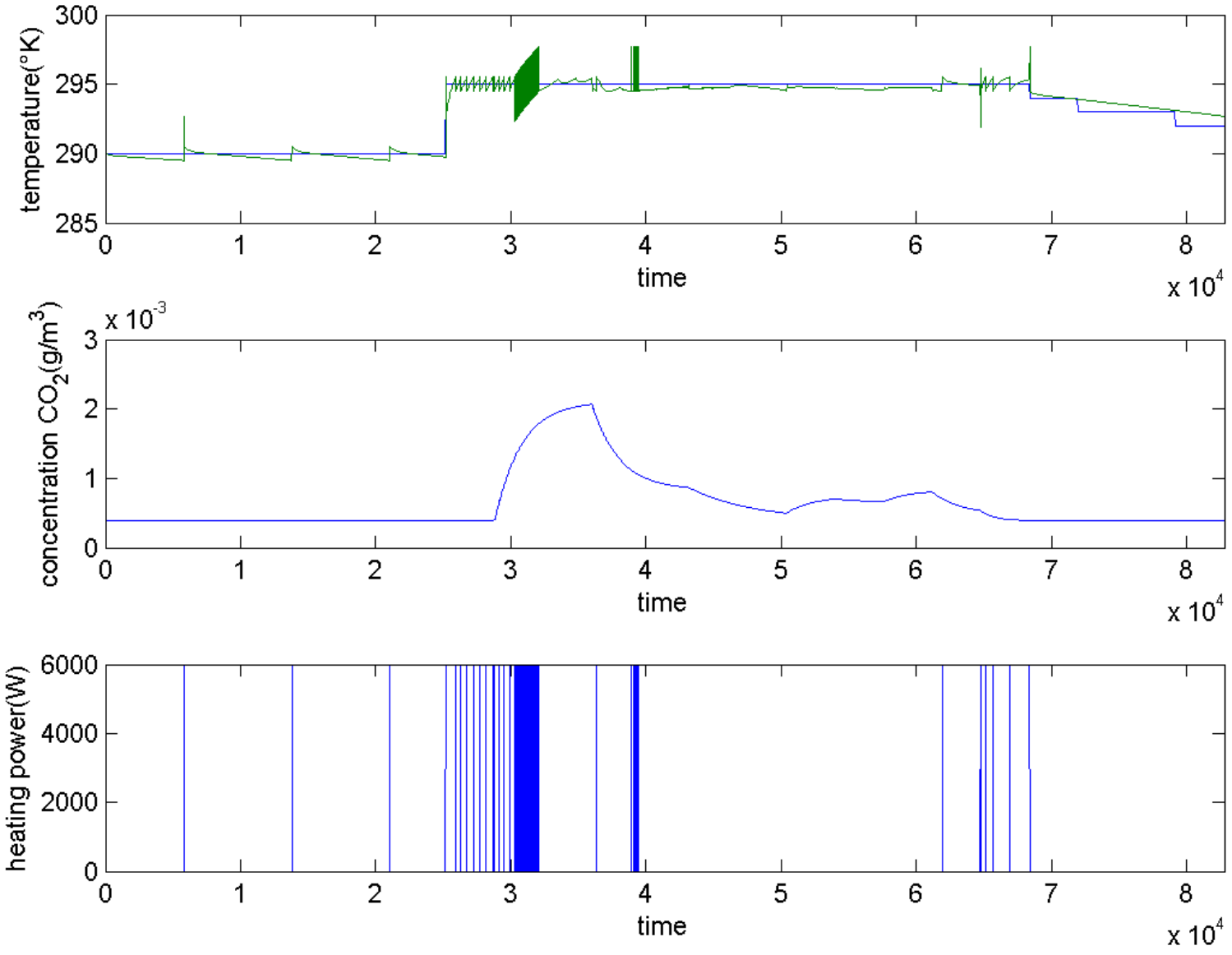
Energy cost



Estimated CO_2 concentration

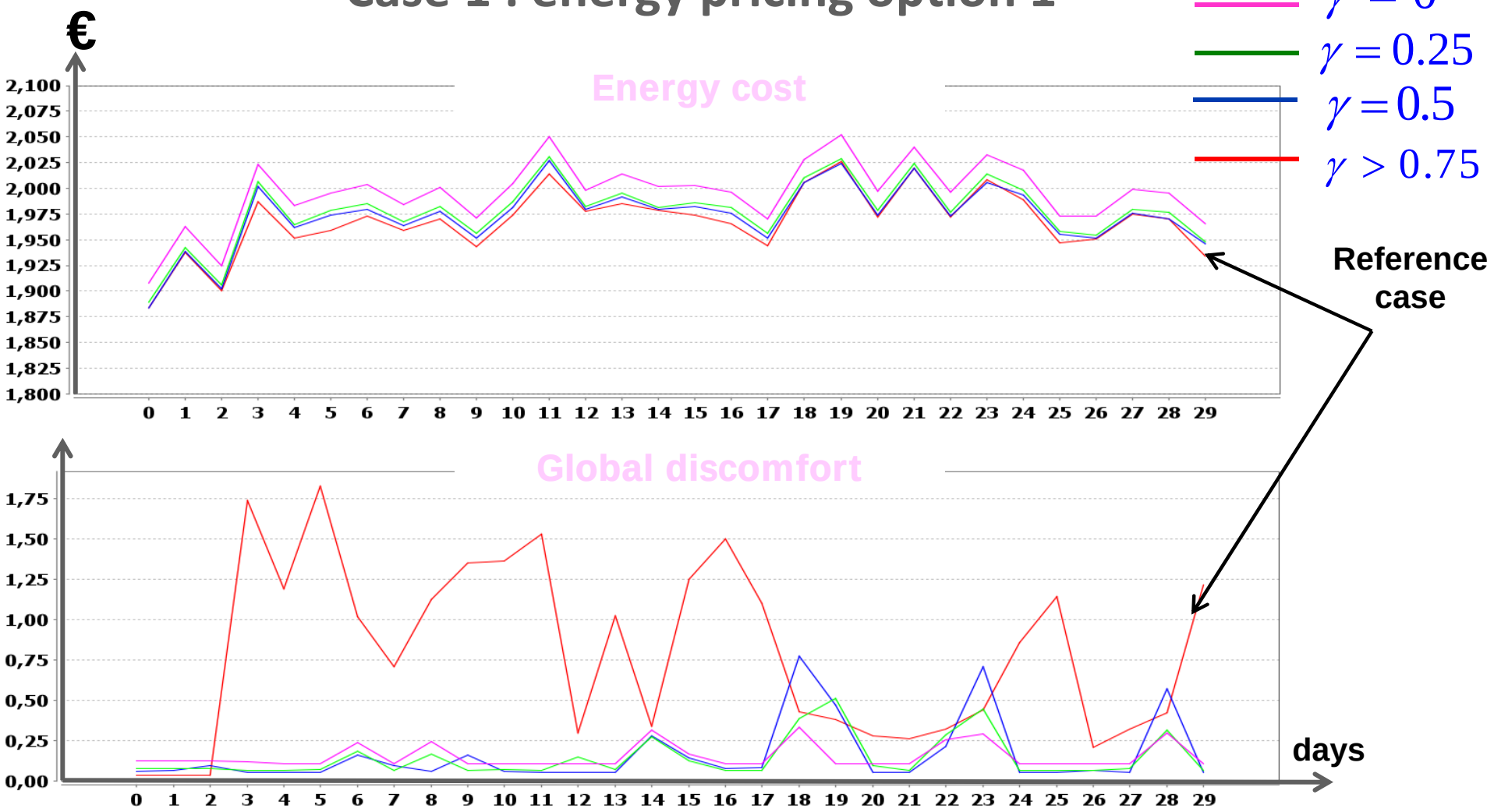


Experimental results (1)



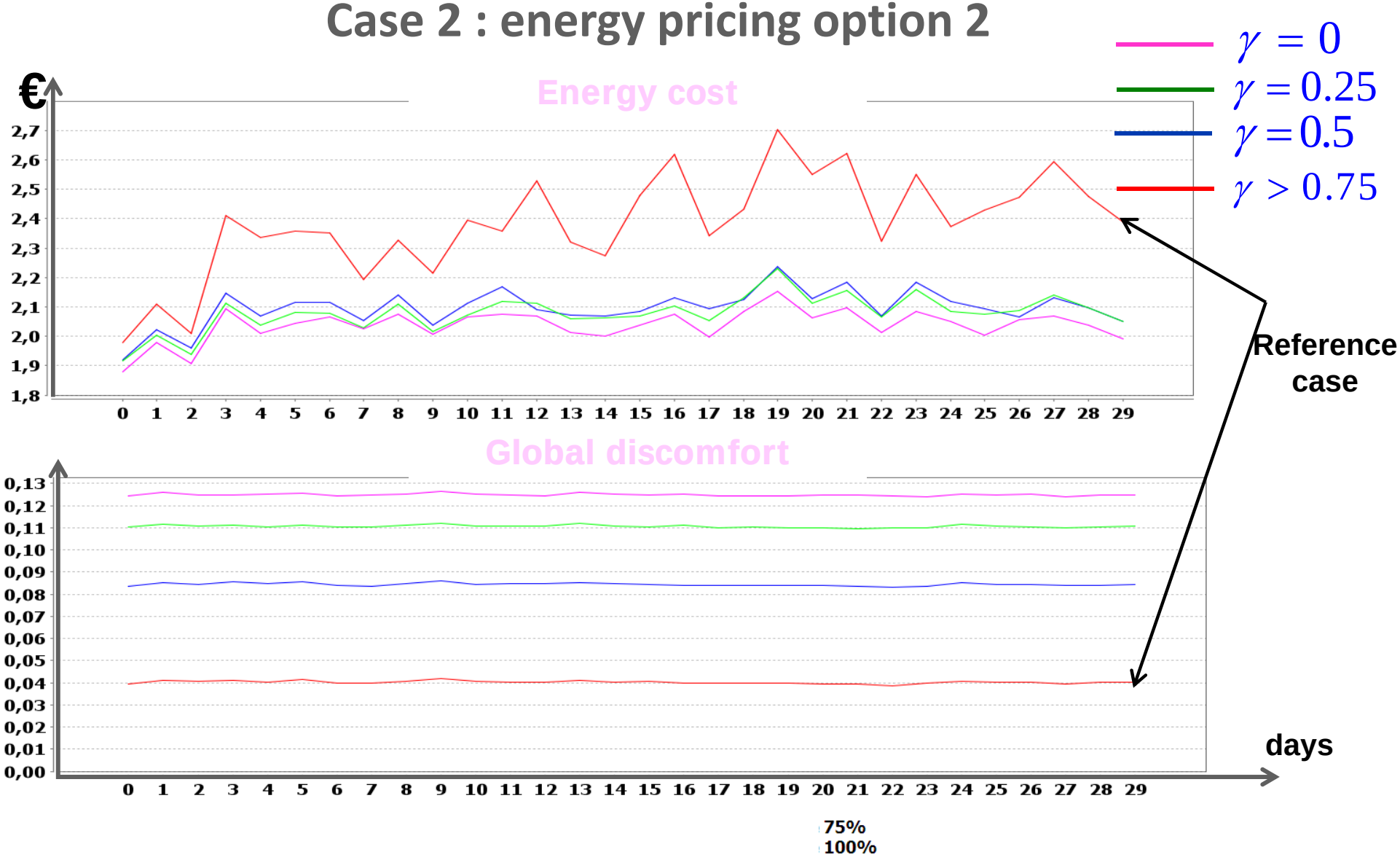
Experimental results (2)

Case 1 : energy pricing option 1



Experimental results (3)

Case 2 : energy pricing option 2



Outline

- Context
- Energy management system in dwelling – optimization problem
- Application of public building – Platform PREDIS
- **Perspectives**

Perspectives

- Experiment over one full year
- Development of a library of relevant models
- Use other solvers suitable for strategy adjustments
- Reuse models for other application: model learning, diagnosis,…