APPLICATION OF AN ANTICIPATIVE ENERGY MANAGEMENT SYSTEM TO AN OFFICE PLATFORM

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ABSTRACT

This paper depicts a formulation of the global home electricity management problem, which consists in adjusting the electric energy consumption to the cost and availability variations of the power supply. A proposed global multi-layer solving approach includes first the computation of consumption/production coordination plans and then the dynamic matching to the actual consumption/production data. This paper focuses on the anticipative problem. It aims at computing the optimal set-points for the Home Ventilation and Air Conditioning (HVAC) system of a platform over a given planning horizon (typically 24h) according to inhabitant request and weather forecasts. These plans are computed using service models that include behavioral model of the thermal zone with its HVAC system, comfort and cost models. The computation of the optimal plans has been formulated as a Mixed Integer Linear Programming problem. An application to a low consumption building, named PREDIS/MHI, is presented.

INTRODUCTION

A home automation system basically consists of household appliances linked via a communication network allowing interactions for control purposes Palensky and Posta (1997). Thanks to this network, a load management mechanism can be carried out: this is a functionality of the so-called smart home. Load management allows inhabitants, in this paper, to adjust power consumption according to expected comfort and energy price variation. For instance, during the consumption peak periods when power plants rejecting higher quantities of CO_2 are used and when energy price is high, it could be possible to decide to delay some consumption activities by reducing some heater set points. Load management is all the more interesting that the availability and price of the energy vary. It is very complex to manage by users in a dynamic pricing context.

A building energy management system consists in two aspects: the load management and the local energy production management. Zhou and M.Krarti (2005) have proposed optimal control strategies for Home Ventilation and Air Conditioning (HVAC) systems taking into account the natural thermal storage capacity of buildings that shift the HVAC consumption from peak period to off-peak period. Zhou and M.Krarti (2005) has shown that this control strategy can save up to 10% of the electricity cost of a building.

The control temperature in buildings and more generally HVAC is widely studied in automatic control. Nowadays, a lot of studies promote the Model Predictive Control (MPC) for HVAC systems Freire et al. (2008). MPC consists in tracking a reference trajectory. This trajectory is the predicted thermal information for example. The predictive approach proposed in this paper could provide such trajectories for the MPC strategies. However, these approaches do not take into account the energy resource constraints, which generally depend on the autonomy needs of off-grid systems Muselli et al. (2000) or on the total power production limits of the suppliers in grid connected systems.

The household global load management problem is a larger problem than HVAC control. It can be formulated as an assignment problem in which energy is a resource shared by appliances, and tasks are energy consumption of appliances. A discrete optimization method of shortest path is proposed in Ha et al. (2006) to deal with the prediction of optimal indoor temperature.

The generic Home Energy Management Problem (HESP) as a scheduling problem is proposed in (Oliveira et al., 2011). The available electric power at each time is a cumulative resource shared by the appliances. The tasks are the activities requested by the inhabitant that consume the supplied power in given time windows. A mathematical formulation of this problem is proposed that can be written as a Mixed Integer Linear Program (MILP). A lot of data are assumed in this formulation such as weather forecasts and inhabitants' requests. An optimal energy planning is proposed over a given planning horizon, typically one day.

The case study in this paper is a thermal zone of the platform PREDIS/MHI (Monitoring Habitat Intelligent), with its HVAC system. This HVAC system consists of two components: a Controlled Mechanical Ventilation (CMV) with a static heat exchanger to renew fresh air, and a boiler to heat the room. The CMV can be used in three distinct operational modes in order to take advantage of the potential energy savings: free cooling, recycling and heat exchange. The indoor air quality and the inside temperature is controlled by changing the operational mode, changing the air flow rate of the CMV or changing the set point temperature of the heating system. It would be easy to overlook a major area of energy wastage that one component might impact on another. For example, it would be wasteful to increase heating inside a building instead of reducing the air flow rate of the ventilation while the

occupancy is low. It is therefore useful to make these components to work together efficiently.
In this optimization problem, the decision variables are the consumed energy of the boiler, the air flow rate and the choice of operational mode of the CMV at each period. The set of constraints of the problem contains the thermal behavior models of the classroom. The impacts of heat generated internally by lighting, equipment and people on the inside temperature are also taken into account by the thermal model. This optimization problem is a multi-criteria problem. The best compromise is sought between cost and comfort, that consist of both the thermal comfort and the indoor air quality i.e. CO2 concentration.
The characteristics of the thermal zone and its HVAC system of the studied platform is described in section 2. The behavioral models of these elements is presented in section 3. The HESP, defined as an MILP, of this case study is depicted in section 4. Section 5 is devoted to experimental results.

2 Case study : Platform PREDIS/MHI

PREDIS is a center of innovation and training on distributed energy. It is more precisely a demonstration tool on the intelligent management of energy representing a physical network of energy closer to real networks, connecting different modes of decentralized energy production to different uses through an expert supervision system. Platform MHI, installed in PREDIS, is representative of a tertiary low energy building. This platform is highly instrumented and all energy flows are measured using different sensor technologies. This platform allows to study many aspects of a smart home: model building and study the existing modeling tools in analyzing the reasons for differences between study models and reality, understand the problems of measurement (temperature, power,energy, heat flux, lighting, CO_2 concentration, presence, occupancy and activity, ...) and interoperability issues, understanding the distribution of energy consumption, diagnosing appliance uses, setting up energy management strategies, knowing the different home automation technologies, understanding the role of buildings in the issues of smart grid,. . .

2.1 Thermal zone study

The studied thermal zone is a classroom illustrated in figure 1. This thermal zone is surrounded by 5 other adjacent thermal zones: offices, space, EP research, corridor and shed.

2.2 Controlled Mechanical Ventilation (CMV)

Indoor air quality (IAQ) is important since up to 90% of a typical people's time is spent indoors, and poor IAQ has been linked to respiratory illness, allergies, asthma, and sick building syndrome. For this platform, IAQ can be regulated by the CMV system that mixes fresh outdoor air with return air for the air supplied to the indoor space. This CMV may provide heat through air/water exchanger thanks to a fuel boiler. For ensuring that air is changed effectively, this studied ventilation system has three distinct operational modes:

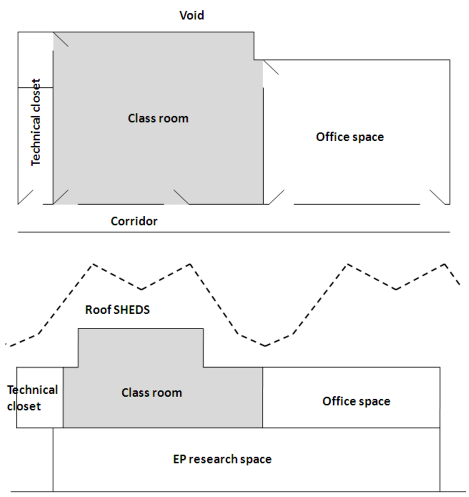

Figure 1: Plan of PREDIS - MHI

- *Recycling mode.* Over winter, when nobody is inside the room, recycling mode is used. In this case, the room is isolated from outside to maintain the heat. Saving is on heating costs. The indoor air is also circulated with slow air flow to be filtered. The heat exchange efficiency is assumed to be equal 1.
- *Heat exchange mode.* Heat exchange mode can provide ventilation in buildings while taking advantage of the potential energy savings associated with the recovery of heat in exhaust air. Thus, the flow of air entering and leaving the system will "cross", without being mixed in the heat exchange unit of the CMV.
- *Free cooling mode.* The free cooling function is used in the summer, during the early morning and evening, cool dry air is drawn in, filtered and circulated into the room with the maximal air flow. In this case, the heat efficiency equals 0.

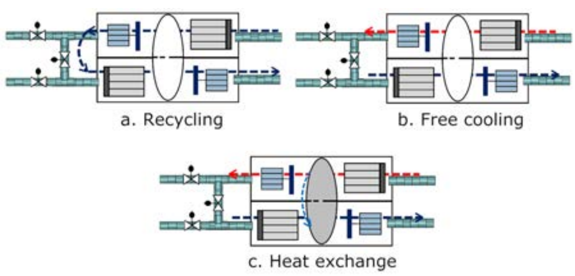

Figure 2: Operational modes of CMV

To avoid a too high CO_2 level, it is necessary to properly ventilate our building with outside air. Ventilating permanently avoid any risk but it would go against an effective management of the energy. Reduction in energy consumption for heating and cooling buildings should therefore not be achieved at the expense of IAQ but with the use of innovative energy management system.

3 Problem modeling

3.1 Characterization of the power supply

Two parameters characterize a power supply i, they are input data of the optimization problem:

- $P(i, t)$ available power at time *t*
- $p(i, t)$ price of the electrical resource at time *t*

A power supply i stands for the available power over the planning horizon and the associated cost at each time for a given production means. Several production means can be involved at home. Allocation of available energy to end-user services is the only addressed problem. Management of the total amount of energy is not addressed.

3.2 Room envelope modeling

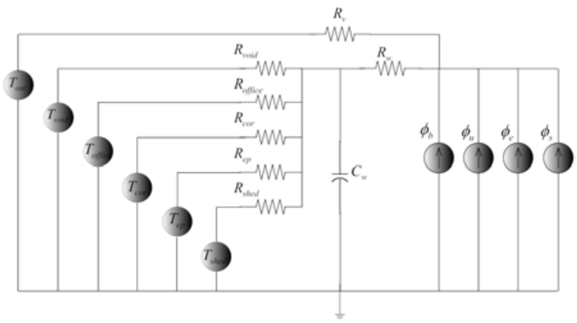

Figure 3: 1st order circuit model of PREDIS with ventilation

For a thermal phenomena, heat conduction is the dominant mechanism that determines the temperature. There exists a well-known duality (Krum, 2000) between heat transfer and electrical phenomena. Any heat flow can be described as a ”current”, and the passing of this heat flow through a thermal ”resistance” leads to a temperature difference equivalent to a ”voltage”. This is really Ohm’s law for thermal phenomena. Thermal resistances are enough for describing steady-state behavior, but dynamic behavior is important, and this requires thermal ”capacitances” as well. Thermal capacitances imply that even if the power flow changes instantaneously, there is a delay before the temperature changes and reaches steady state. The thermal resistances and capacitances together lead to exponential rise and fall times characterized by thermal RC time constants similar to the electrical RC constants.

The best reduced order model structure, that represents the thermal behavior of the class room, is proposed in (Sarabi et al., 2013) in using an iterative nonlinear optimization approach that leads to parameter estimation . The equivalent RC Circuit is shown in Figure 3 where R_{space}, R_{ep}, $R_{offices}$, R_{shed} and R_{cor} are thermal resistances of each wall between thermal zone and adjacent zones, R_w is equivalent thermal resistance of the walls , C_w is equivalent thermal capacitance of the walls. The identified values of these parameters are given in table 1. T_{in} is the temperature of thermal zone, T_w is equivalent temperature of the walls and T_{space}, T_{ep}, $T_{offices}$, T_{shed} and T_{cor} are average temperatures of 5 adjacent zones.

Table 1: Identified parameters of the classroom envelope

R_w	R_{space}	R_{shed}	R_{ep}
5.35e-4	0.0109	0.0064	0.002
$R_{offices}$	R_{cor}	C_w	
9.64e-5	0.0124	4.73e+6	

$$
\begin{aligned}
&\frac{dT_w(t)}{dt} = AT_w(t) + BU(t)\\
&T_{in}(t) = C.T_w(t) + DU(t)\\
&U = \left[\begin{array}{cccccc} T_{space} & \phi_h & \phi_u & \phi_e & \phi_s & T_{ep} \end{array}\right.\\
&\qquad\qquad \left.\begin{array}{cccc} T_{shed} & T_{offices} & T_{cor} & T_{out} \end{array}\right]^T\\
&A = \frac{1}{C_w}\left(\frac{R_v}{R_w(R_w+R_v)} - \frac{1}{R_w} - \frac{1}{R_{space}} - \frac{1}{R_{ep}} - \right.\\
&\qquad \left. - \frac{1}{R_{shed}} - \frac{1}{R_{offices}} - \frac{1}{R_{cor}}\right)\\
&B = \frac{1}{C_w}\left[\begin{array}{cccc} \frac{1}{R_{space}} & \frac{R_v}{R_w+R_v} & \frac{R_v}{R_w+R_v} & \frac{R_v}{R_w+R_v} \end{array}\right.\\
&\left.\begin{array}{cccccc} \frac{R_v}{R_w+R_v} & \frac{1}{R_{ep}} & \frac{1}{R_{shed}} & \frac{1}{R_{offices}} & \frac{1}{R_{cor}} & -\frac{1}{R_w+R_v} \end{array}\right]\\
&C = \frac{R_v}{R_w+R_v}\\
&D = \frac{R_w R_v}{R_w+R_v}\left[\begin{array}{cccccccccc} 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & \frac{1}{R_v} \end{array}\right]
\end{aligned} \tag{1}
$$

3.3 CMV modeling

The heat recovery unit, illustrated in figure 5, allows fresh air to be pre-heated by exhausting air with a global efficiency ς. Assuming fresh and exhausting air flows are the same ($Q_f = Q_e = Q_{air}$ with Q_{air} the air flow through exchanger), this global instantaneous efficiency ς defined as (2) with T_{ei}, T_{fi}, T_{eo} and T_{fo}, respectively the fresh air and exhausting air inlet temperature, and the fresh air and exhausting air outlet temperature. Q_f and Q_e, respectively the air flow of fresh air and exhaust air through exchanger. The corresponding heat loss $\Delta\phi$ is (28)

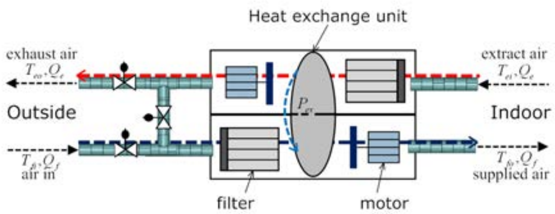

Figure 5: Structure of the ventilation device

$$\varsigma = \frac{T_{fi} - T_{fo}}{T_{fi} - T_{ei}} \tag{2}$$

$$
\begin{aligned}
\Delta\phi &= (1-\varsigma)\rho_{air}c_{air}Q_{air}(T_{fi} - T_{ei})\\
&= (1-\varsigma)\rho_{air}c_{air}Q_{air}(T_{in} - T_{out})
\end{aligned} \tag{3}
$$

These losses are characterized in a thermal envelope by a conductivity G_v for the inflated air flux between T_{in} and T_{out}:

$$G_v = (1-\varsigma)\rho_{air}c_{air}Q_{air} \tag{4}$$

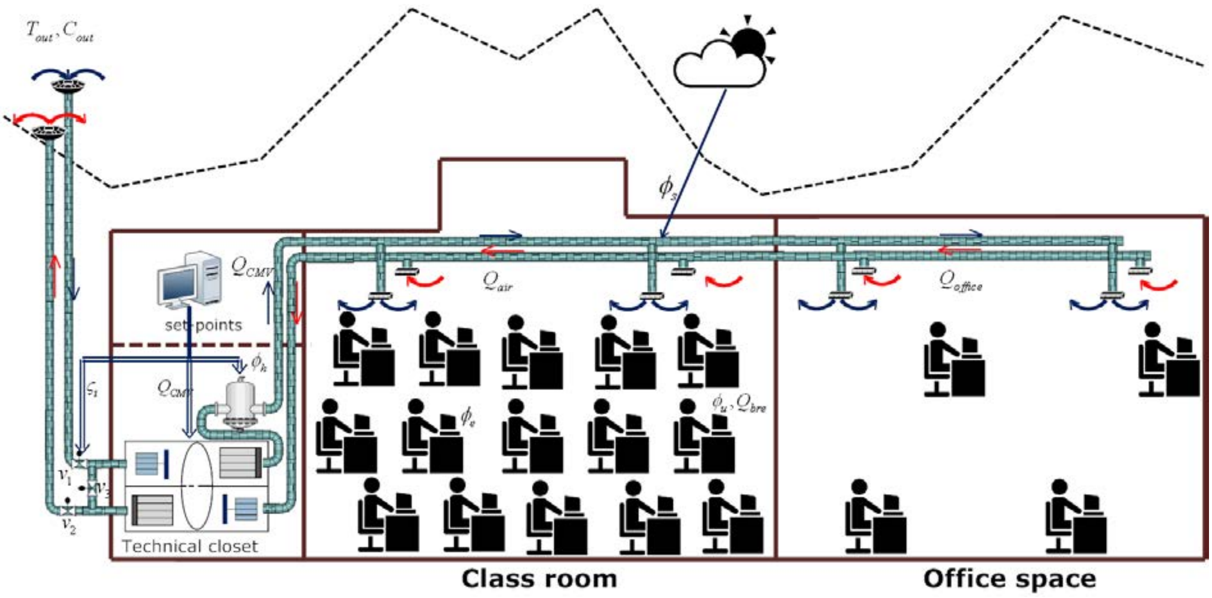

Figure 4: CMV system for thermal zone

Therefore, the resistance modeling the exchanges with outdoor, which depends on the operational mode, is given by:

- Recycling mode:

$$R_v = \infty \tag{5}$$

- Heat exchange mode:

$$R_v = \frac{1}{(1-\varsigma)\rho_{air}c_{air}Q_{air}} \tag{6}$$

- Free cooling mode:

$$R_v = \frac{1}{\rho_{air}c_{air}Q_{air}} \tag{7}$$

3.4 Indoor air quality modeling

The model represents the CO_2 rate in an occupied room exchanging air with outdoor is given by:

$$\begin{aligned}\frac{dC_{in}(t)}{dt} &= \frac{Q_{air}(t)+n.Q_{bre}(t)}{V}C_{out} \\ &- \frac{Q_{air}(t)+n.Q_{bre}(t)}{V}C_{in}(t)\end{aligned} \tag{8}$$

with:

- C_{in} the inside CO_2 rate of the platform (ppm)
- C_{out} the inside CO_2 rate (ppm), C_{out} = 392ppm.
- Q_{air} the exchanged air flow with outside (m^3/h)
- Q_{bre} the respiratory flow of each person inside the room (m^3/h)
- n the number of person inside the room.
- V the volume of the room (m^3)

The exchanged air flow with outside in this model depends on the chosen mode of the CMV.

4 HESP for PREDIS/MHI

In this paper, a MILP formulation of the optimization problem is proposed. Let $H = \{0, 1, \ldots, T-1\}$ be the planning horizon consisting of T time periods with a length T_e. At every planning period k, the amount of energy allocated to the CMV system has to be decided in order to maximize the cost of energy consumption and the user dissatisfaction. The decision variables are *the consumed energy of the boiler*, *the air flow rate* and *the choice of operational mode of the CMV* at each period k. Energy costs and resource availability are assumed to be constant over a length T_e of a planning period. In this case, in the approach developed in this paper, T_e is a data item given by the variation of the resource.

4.1 Power supply model

Based on the problem description of a power supply i, the following constraint can be written:

$$E(i,k) \leq P(i,k).T_e, \forall k \in \{0, ..., T-1\} \tag{9}$$

where $P(i,k)$ stands for the maximum available power, and $E(i,k)$ the energy supplied during the time window $]kT_e, (k+1)T_e]$. This constraint aims at converting available power into a maximum amount of energy per planning period.

4.2 Ventilation unit

To get a MILP representation, the operation of the ventilation is divided in 4 operational modes: recycling, low heat exchange, high heat exchange and free cooling. An air flow rate of the CMV (Q_{CMV}) corresponding is assigned to each mode as in table 2. The air flow rate of the classroom can be deduced in (10). The consumption of the ventilation can be calculated in function of the air flow through the speed of air pumps in (11) (H-A. Dang and Wurtz, 2010). The resistance modeling the exchanges with outdoor of each mode is given by equation (5,6,7). The characterization of each operational mode of the ventilation is thus summarized in table 2.

$$Q_{class} = 0.61 Q_{CMV} \quad (10)$$

$$P_{CMV} = 8.64 \times 10^{-5} (\frac{Q_{CMV}}{0.56} - 500)^2 + 65 \quad (11)$$

Table 2: Characterization of each operational mode of the CMV

i	**mode**	$Q_{CMV}(i)$ (m^3/h)	$R_v(i)$ (K/W)	$P_{CMV}(i)$ (W)
0	Recycling	100	∞	135
1	Low heat exchange	200	0.0297	155
2	High heat exchange	500	0.0119	175
3	Free cooling	1100	0.0054	500

The choice of operational mode of the ventilation at each period can be formulated using binary variables denoted $\zeta(i,k)$. Each period, an optimal operational mode for the ventilation is chosen, it yields:

$$\sum_{i=0}^{4} \zeta(i,k) = 1, \forall k \quad (12)$$

4.3 Heating unit

The equation (1) can be integrated on the discretized planning period $[kT_e, (k+1)T_e[$. In automatic control theory, one of the most commonly used formulations for integration of such an equation is based on the following hypothesis: the uncontrolled variables are assumed to be constant throughout the planning period. It yields:

$$\begin{aligned} T_w(k+1) &= F(i).T_w(k) + G_o(i)T_{out}(k) + \\ &+ G_\phi(i)\left[\phi_h(k) + \phi_u(k) + \phi_e(k) + \phi_s(k)\right] \\ &+ G_a(i) \\ T_{in}(k) &= H_w(i)T_w(k) + H_o(i)T_{out}(k) \\ &+ H_\phi(i)\left[\phi_h(k) + \phi_u(k) + \phi_e(k) + \phi_s(k)\right] \end{aligned} \quad (13)$$

with

$$\begin{aligned} F &= \sum_i \zeta(i).e^{-\frac{T_e}{\tau(i)}} \\ G_o &= \sum_i \zeta(i)\frac{R_{eq}(i)}{R_w + R_v(i)}\left[1 - e^{-\frac{T_e}{\tau(i)}}\right] \\ G_\phi &= \sum_i \zeta(i)\frac{R_v(i)R_{eq}(i)}{R_w + R_v(i)}\left[1 - e^{-\frac{T_e}{\tau(i)}}\right] \\ G_a &= \sum_i \zeta(i)R_{eq}(i)\left[1 - e^{-\frac{T_e}{\tau(i)}}\right]\left(\frac{T_{space}}{R_{space}} + \frac{T_{shed}}{R_{shed}}\right. \\ &\left. + \frac{T_{ep}}{R_{ep}} + \frac{T_{offices}}{R_{offices}} + \frac{T_{cor}}{R_{cor}}\right) \\ R_{eq}(i) &= \frac{1}{\frac{1}{R_w + R_v(i)} + \frac{1}{R_{space}} + \frac{1}{R_{shed}} + \frac{1}{R_{ep}} + \frac{1}{R_{offices}} + \frac{1}{R_{cor}}} \\ \tau(i) &= R_{eq}(i)C_w \end{aligned} \quad (14)$$

$T_{out}(k)$, $T_{space}(k)$, $T_{ep}(k)$, $T_{offices}(k)$, $T_{shed}(k)$, $T_{cor}(k)$, $\phi_s(k)$ are given or estimated data from weather forecast. They corresponds to the data of the optimization problem. $T_{in}(k), \phi_h(k)$ are the decision variables.

4.4 Evolution of inside CO2 concentration

The evolution of inside CO_2 rate is represented in the equation 8. Using a zero-order hold, the discrete time model is given by:

$$C_{in}(k+1) = \sum_i F(i,k)\zeta(i,k)C_{in}(k) + \sum_i G(i,k)\zeta(i,k) \quad (15)$$

with:

$$\begin{aligned} F(i,k) &= e^{-\frac{Q_{air}(i,k) + n.Q_{bre}(k)}{V}T_e} \\ G(i,k) &= \left[1 - F(i,k)\right]\frac{n.C_{\mathrm{bre}}.Q_{bre}(k) + C_{out}Q_{air}(i,k)}{Q_{air}(i,k) + Q_{bre}(k)} \end{aligned} \quad (16)$$

$T_{in}(k), \phi_h(k)$, $Q_{air}(i,k)$ are the decision variables. In this model, the product $\zeta(i,k)C_{in}(k)$ has to be linearized.

4.5 Energy balance

A constraint modeling the production/consumption balance must also be added. This constraint can be written:

$$E(k) = \phi_h(i,k) + P_{CMV}(k).T_e, \forall k \in \{0, \ldots, T-1\} \quad (17)$$

4.6 Objective function

The energy management problem can take into account the occupant comfort as an optimization criterion as well as energy cost. In this multi-criteria problem, the best compromise is sought between comfort and cost. The user's comfort is defined by a satisfaction indicator quantified by the difference between a preferred value defined by the user and the optimized value.

4.6.1 Economic criterion

The optimization problem consists in minimizing the cost of energy consumption. The objective function to be minimized can be written as:

$$c = \sum_{k=0}^{T-1} p(k).E(k) \quad (18)$$

The objective function and the cost parameters can be adjusted to every pricing policy. Power supply services can be seen as different resources associated with a vector of supplies rather than a matrix. Indeed every end-user service needs a given quantity of the energy resource provided by the supplier.

4.6.2 Comfort satisfaction

Thermal satisfaction. The occupant's thermal satisfaction can be quantified by the difference between an expected preferred value and the optimized value of inside temperature. Let's define $T_{opt}(i,k)$ as the preferred temperature at each planning period. According to the comfort standard 7730, AFNOR (2006) proposes typical models for thermal comfort that depend on type (office, room, etc.) and quality (humidity and air velocity) of the environment. These models are based on an aggregated criterion known as the predictive mean vote (PMV) modeling the deviation from a neutral environment. In this case, for a given type and quality of the environment, a discomfort index $D_{thermal}(i,k)$ can be computed for the thermal zone i at each planning period k from the following equation:

$$D_{thermal}(i,k) = \begin{cases} \frac{T_{opt}(i,k)-T_{in}(i,k)}{T_{opt}(i,k)-T_{min}(i,k)} & \text{if} \quad T_{in}(i,k) \leq T_{opt}(i,k) \\ \frac{T_{in}(i,k)-T_{opt}(i,k)}{T_{max}(i,k)-T_{opt}(i,k)} & \text{if} \quad T_{in}(i,k) > T_{opt}(i,k) \end{cases} \quad (19)$$

where $T_{opt}(i,k)$ stands for the requested temperature, and $T_{min}(i,k)$ and $T_{max}(i,k)$ stand, respectively, for the minimum and maximum acceptable temperatures.

CO2 satisfaction. As such, inside air quality depends on the CO_2 concentration from this preferred value. Just as for thermal satisfaction, a CO_2 dissatisfaction criterion for a zone i is defined as follows:

$$D_{CO_2}(i,k) = \begin{cases} \frac{C_{opt}(i,k)-C_{in}(i,k)}{C_{opt}(i,k)-C_{min}(i,k)} & \text{if} \quad C_{in}(i,k) \leq C_{opt}(i,k) \\ \frac{C_{in}(i,k)-C_{opt}(i,k)}{C_{max}(i,k)-C_{opt}(i,k)} & \text{if} \quad C_{in}(i,k) > C_{opt}(i,k) \end{cases} \quad (20)$$

4.6.3 Optimization criteria

Depending on the occupant requests, a compromise between cost and comfort has to be formulated. This is generally the case when energy cost is variable as the higher cost corresponds to peak consumption periods. In this paper focused on problem modeling, a very simple aggregation approach has been implemented. The corresponding objective function to be minimized is depicted by the following equation:

$$\begin{aligned} J = \quad & c + \frac{\beta}{\alpha_t + \alpha_{CO_2}} \Big(\alpha_t \sum_{k=0}^{T-1} D_t(i,k) + \\ & + \alpha_{CO_2} \sum_{k=0}^{T-1} D_{CO_2}(i,k) \Big) \end{aligned} \quad (21)$$

Parameters α_t and α_{CO_2} depict the priority between thermal and CO_2 criteria, while parameter β depicts the relative importance granted by the user to cost criteria and discomfort criteria. The parameter β makes it possible to distinguish thrifty from comfort addict occupants.

The optimization problem HESP of this case study is defined by equations 9 to 21. Linearizion using integer variables of these inequalities is not addressed in this paper.

5 Experimental results

Let's consider an example of one day. The French energy pricing is used that has a low cost 0.0567€ in slack periods $k = \{0,1,2,3,4,5,22,23\}$ and a cost greater by 0.0916€ in the peak periods $k \in \{6 \leq k \leq 21\}$. The maximum power supply is 7000W. The prediction of occupation of the classroom is given in figure 6. The required minimum and maximum allowed temperatures equal respectively 22°C, 20°C and 24°C. The inside CO_2 concentration is limited to 1200 ppm. The outdoor temperature forecast and the predicted occupancy of the classroom is given, respectively, by figures 6a,b. The volume of this classroom is $V = 270m^3$. The generated power of each person inside this classroom is estimated at 80W. The generated power of appliances (lights, laptops,...) per person inside this classroom is estimated by 5W. The efficiency of the CMV is estimated, from measure, by 0.5.

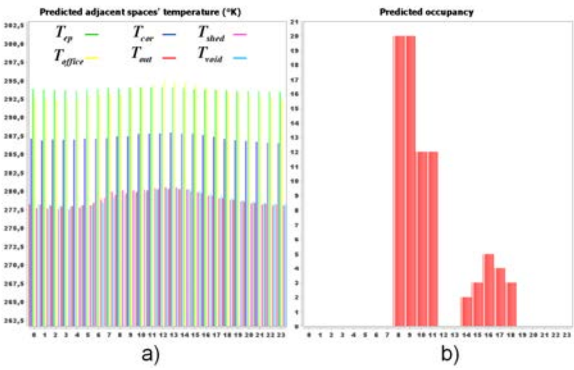

Figure 6: Prediction of occupancy and adjacent spaces' temperature

Optimization problem is solved by using IBM ILOG CPLEX Optimizer 12.3 within few seconds. The anticipated operational modes of the CMV and estimated CO_2 concentration inside the studied zone are illustrated, respectively, in figures 7a and b. Figure 7,a shows that the CMV is anticipated to work in recycling mode to isolate the thermal zone from outside for maintaining the heat during the night and during the early morning. We can observed in figure 7,b that the free cooling mode is planned to be executed between 8am and 10am for ensuring the CO_2 concentration criteria because of high occupancy. The high heat exchange will be used during day to heat the room when it is occupied.

The temperature set-points are presented in the figure 8,a . Out of the occupation periods, the inhabitant discomfort is not taken into account. The heating consumes the maximal power to heat the room between 8am and 10am because of the free cooling mode of the ventilation that is anticipated to ensure inside air quality. The estimated energy cost during this day can be observed in figure 8,b. The total energy cost of this day is 2,411€. Then one can conclude that the HESP leads to an optimal control strategies for the CMV during one day in taking into account both occupant satisfaction and the energy cost.

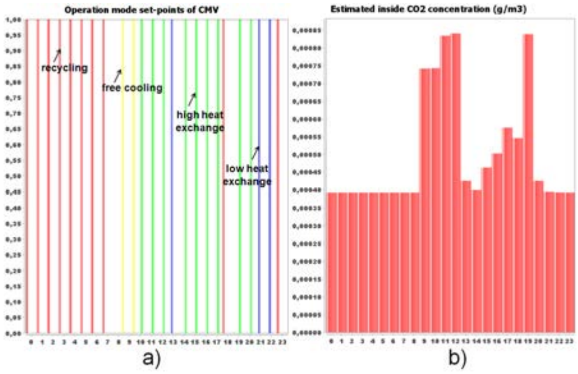

Figure 7: Operational mode setpoints of the CMV

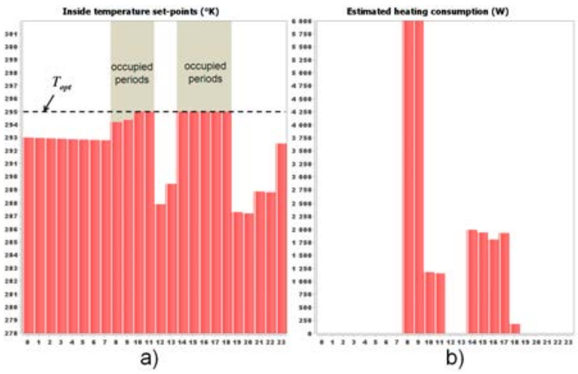

Figure 8: Inside temperatures set-points

CONCLUSION

This paper proposes a formulation of the global home electricity management problem, which consists in adjusting the electric energy consumption/production in housing. The paper focuses on the anticipative layer, which computes optimal schedules to control appliances according to inhabitant requests and weather forecasts. These schedules are computed using service models that include behavioral, comfort and cost models. The discrete time formulation of the energy management problem, that leads to tractable mixed linear programs, has been proposed for the classroom of platform PREDIS/MHI. The optimization problem aims computing the optimal set-points for the HVAC system of the platform over a given planning horizon (typically 24h). Nevertheless, the multi-criteria optimization has to be more precisely studied in order to provide the well adapted strategy to the inhabitant. A cost constraint approach could be interesting.

REFERENCES

AFNOR 2006. Ergonomie des ambiances thermiques. *Norme européenne*.

Freire, R., Oliveira, G., and Mendes, N. 2008. Predictive controllers for thermal comfort optimization and energy savings. *Energy and Buildings*, 40:1353–1365.

H-A. Dang, B. Delinchant, S. G. and Wurtz, F. 2010. Modélisation électrique dune vmc double flux et optimisation de sa commande pour l'éfficacité énergétique. *IBPSA, France*.

Ha, D.-L., Ploix, S., Zamai, E., and Jacomino, M. 2006. A home automation system to improve the household energy control. In *INCOM2006 12th IFAC Symposium on Information Control Problems in Manufacturing*.

Krum, A. 2000. *Thermal management*, chapter The CRC handbook of thermal engineering, pages 2.1–2.92. CRC Press, Boca Raton, FL.

Muselli, M., Notton, G., Poggi, P., and Louche, A. 2000. Pv-hybrid power system sizing incorporating battery storage: an analysis via simulation calculations. *Renewable Energy*, 20:1–7.

Oliveira, G. D., Jacomino, M., Ha, D. L., and Ploix, S. 2011. Optimal power control for smart homes. In *The 18th World Congress of the International Federation of Automatic Control (IFAC), Milano, Italy*.

Palensky, P. and Posta, R. 1997. Demand side management in private home using lonworks. In *Proceedings.1997 IEEE International Workshop on Factory Communication Systems*.

Sarabi, S., Ploix, S., Le, M. H., Dand, H.-A., and Wurtz, F. 2013. Assessing the relevance of reduced order models for building envelope. *Building Simulation Conference 2013*.

Zhou, G. and M.Krarti 2005. Parametric analysis of active and passive building thermal storage utilization. *Journal of Solar Energy Engineering*, 127:37–46.