MODELS FOR OPTIMAL CONTROL OF THE AIR-CONDITIONING VARIABLES FROM VENTILATED ROOMS

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Abstract: In this paper are analyzed two models for the optimal control of the air-conditioning variables from a passive ventilated room. Then are discussed the results obtained by simulation in a particularly case of the temperature control. Finally, some hypothesis regarding the optimization models described in this paper are emitted.©

Keywords: passive ventilation, optimal control, fuzzy control, simulation.

1. INTRODUCTION

The optimal control of the air-conditioning variables are realized, as a rule, by means of a numerical system-computer or microprocessor (fig.1), by controlling the usual heating system and the rooms lighting system (the position of the blinds, so, the shaded surface of the windows). This control is applied in reduced situations, for instance, in the rooms which can manage the passive solar captions, the natural ventilation, the heating and the lighting (intelligent rooms (Bagot, 1993; Meyer, 1992) to exist both comfort conditions and a good natural lighting along entire year with reduced power consumption.

2. OPTIMIZATION MODELS

The model that must to be optimized, adequate to the control structure illustrated in fig.1, is given by an discrete equations system of n degree, like (Popescu, 2002).

$$\theta_i(kT_e) = \frac{B}{A}Q_i(kT_e) + \frac{C}{A}Q_s(kT_e) + \frac{D}{A}\theta_e(kT_e) + \frac{E}{A}w(kT_e) \quad (1)$$

where: $\theta_i(kT_e)$ is the internal temperature at the discrete time moment kT_e (with T_e the sampling period), expressed in ^0C; $Q_i(kT_e)$ is the quantity of heating (proceeded from the usual heating system) or the quantity of cold from the room; $Q_s(kT_e)$ is the solar energy transferred in the room through windows; $\theta_e(kT_e)$ is the external temperature; $w(kT_e)$ is the process disturbance (because of the working errors); A, B, C.. are the polynomials under discrete Laplace transformation

$$A=1+a_1z^{-1}+a_2z^{-2}+...,$$

$$B=b_0+b_1z^{-1}+b_2z^{-2}+..., \qquad C=c_0...etc,$$

Depending on the delay operator z^{-1} (on same variable x)

$$z^{-1}x(kT_e)=x[(k-1)T_e]. \quad (2)$$

A recurrent estimator for the last weather data (Cadiergues, 1993; Pitard, 1989) is used for finding the current values of the polynomials coefficients that appear in equation.

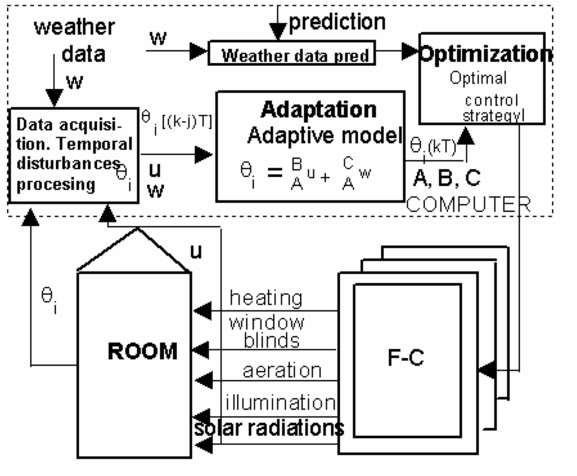


Fig. 1. The block structural schema used for controlling the air-conditioning variables with fuzzy controllers (F-C).

The control structure is based on the previous knowledge and experience. Its rules are expressed as: IF _ THEN_. For instance, IF the cooling and the heating of the weather are forecasted for the same day, THEN nothing happens. The second optimized model, corresponding to the structure of the adaptive systems with self-regulation (fig. 2), is represented by the following state equations:

$$\dot{\mathbf{x}} = \mathbf{Ax}+\mathbf{Bu}+\mathbf{Ew}, \quad \mathbf{y}=\mathbf{Cx}+\mathbf{Du}, \tag{3}$$

where: **x** of (2x1) dimension, is the vector of the state variables, included the measurable values of the temperatures θ_i and θ_z (with θ_z, the temperature value on the internal surface of the room wall); **u** of (2x1) dimension , is the control vector (it control the heating quantity and the position of the blinds for the room shading); **w** of (2x1) dimension, is the disturbance vector (of the weather data); **y** of (1x1) dimension, is the output variables vector (of the room internal temperature θ_i).

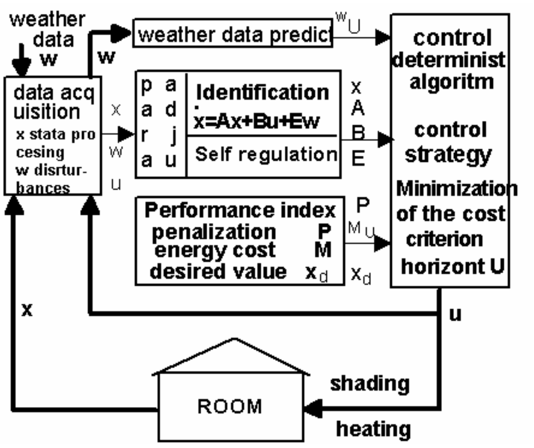


Fig. 2. The block structural schema used for controlling the air-conditioning variables in ventilated rooms.

The identification method used for determining the coefficients matrix **A**(2x2), the control matrix **B**(2x2), the transition matrix **C**(2x1) and the output matrix **D**(2x1), is described by *Bacot* (Bacot, 1985).

The control structure uses a mathematical optimized algorithm that searches the control variables in the set [t, t+N], with N search horizons minifying a criterion as

$$J=\int\left[\frac{1}{2}\left(x(t)-x_d\right)M\left(x(t)-x_d\right)^T+C^T u(t)\right]dt,$$

where: $\mathbf{x_d}$ is the desired temperature vector at a time moment inside of the room and **M** is the cost price matrix (of the energy consumption), symmetrical and semi positive defined, of 2x2 dimension.

The algorithm requires the future evolution knowledge of the energy consumption **M**, of the desired inside temperature included in the vector $\mathbf{x_d}$, and of a state **x**. The future states are anticipated using the prediction in the model case (range forecast). Knowing the initial conditions vector $\mathbf{x}_0$, the algorithm developed in (Bacot, 1985), calculates the optimal strategy of control, that is

$$\underbrace{\min}_{u\in U} J(\mathbf{x}_0;\, t_0,\, \mathbf{u}(t)), \tag{4}$$

respecting the imposed restrictions (the minimum of heating quantity given by the room usual heating system and the maximum of sun energy capture).

3. RESULTS

The results obtained in the particularly case (one input, more outputs) of the automatically control of the temperature in a room (fig.1), with a usual heating system (radiator with maximum dissipate power of 4 kW) are illustrated as follows. It is imposed to correlate the crisp control u with the input variable θ_i (the room temperature) by a controller. It is considered that the optimal temperature inside a room (it characterized the comfort feeling), is 21 ^{0}C, when the membership degree of the crisp control is equal with 1. The following five linguistic terms are accepted to describe the temperature inside a room: TFJ- very low temperature, TJ – low temperature, TM- medium (optimal) temperature, TI – high temperature, TFI- very high temperature defined by the membership function fa, having the graphical representation illustrated in fig.3.a. The following five linguistic terms are accepted to describe the dissipated power inside a room: QZ- zero dissipated power, QR - reduced dissipated power, QMd- medium (optimal) dissipated power, QM–big dissipated power, QFM- very big dissipated power defined by the membership function having the graphical representation illustrated in fig.3.b.

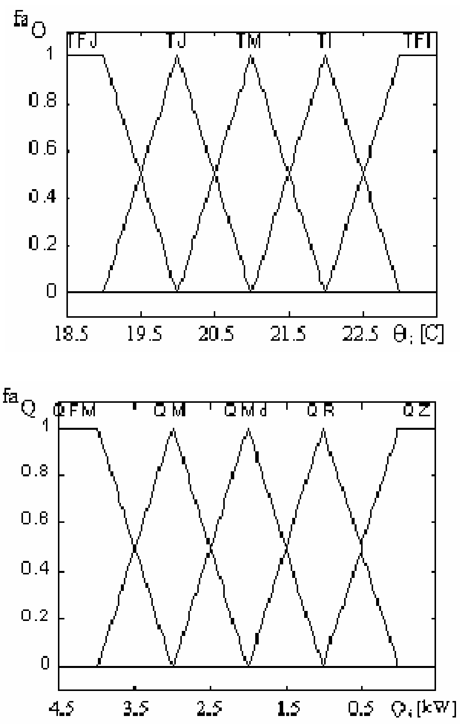


Fig. 3. Graphical representation of the membership function adjacent at the terms: a) temperature; b) dissipated power.

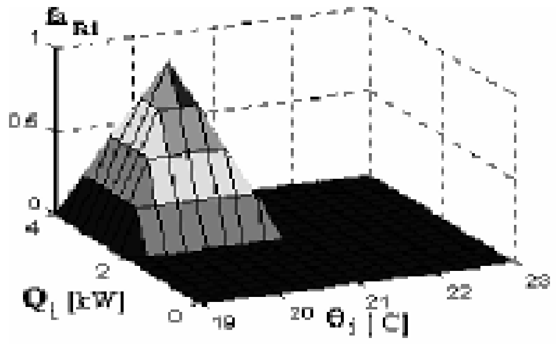
Accepting that the base set has discrete values (from $0,5\ ^0C$ to $0,5\ ^0C$), then the notion of thermal comfort (optimal O) and radiator dissipated power (Q) will be graphical represented (Popescu, 2002). The base rule (R) that determines the control can be defined considering the temperature θ_i, as follows:

R_1: *IF* (θ_i=TFJ) *THEN* (u=QFM),
R_2: *IF* (θ_i=TJ) *THEN* (u=QM),
R_3: *IF* (θ_i=TM) *THEN* (u=QMd),
R_4: *IF* (θ_i=TI) *THEN* (u=QR),
R_5: *IF* (θ_i=TFI) *THEN* (u=QZ),

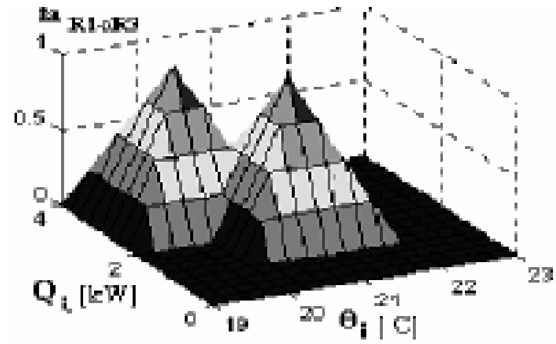
that corresponds to some rules as: ...*IF* inside the room is comfortable *THEN* the dissipated power is 2 kW, *IF* inside the room is very cool *THEN* the dissipated power is 4 kW,... Considering as reference value for the temperature inside the room $20.25\ ^0C$, then will be activated the rules R_1 and R_3.

Their evaluation is realized with the product MIN-MAX, with a view to enunciate the consequent conclusion (the control).

The correlation antecedent-consequent for each rule and the set of rules are usually illustrated by inference tables (matrix) that can be graphical represented (fig. 4.a).



a)



b)

Fig. 4. The control matrix surfaces for the rules: a) R_1; b) R_1 and R_3.

The graphical representation of the decision matrix corresponding to the rules R_1 and R_3 are illustrated in fig. 4.b. Because for any value of the input variable the controller will realize a single value of the control, for the fuzzy product must be applied the defuzzyfication.

For the calculus of the crisp control u^* (the defuzzyfication of the fuzzy information), corresponding to the temperature of $20.25\ ^0C$, it is used the centroid method. For the membership functions of singleton type, this method is given by the relation

$$u^*(Q_i^*)=\frac{\sum_{k=1}^{17} f_a\left(\theta_{ik}, Q_{ik}\right) Q_{ik}}{\sum_{k=1}^{17} f_a\left(\theta_{ik}, Q_{ik}\right)}=2.71[\text{kW}], \quad (5)$$

where, with fa(θ_{ik},Q_{ik}) are noted the degrees of accomplishment the activated rules conclusions R_k and with Q_{ik} the singleton abscises used to characterized the linguistic terms of the output linguistic variables.

In fig.5. is illustrated the control obtained at the activation of the rules R_1 and R_3.

The fuzzy control simulation realized in MATLAB (fig. 6) is illustrated in fig. 7 (the curve 2), comparative to the control given by a conventional P controller. The same problem (Popescu, 2002) can be solved considering the control error (in normal values) in antecedent and the crisp control u in consequent.

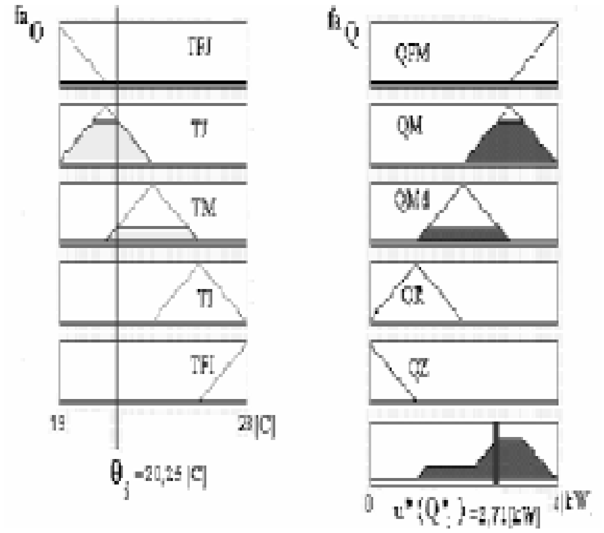


Fig. 5. The graphical presentation of the membership functions corresponding to the activation rules R_1 and R_3.

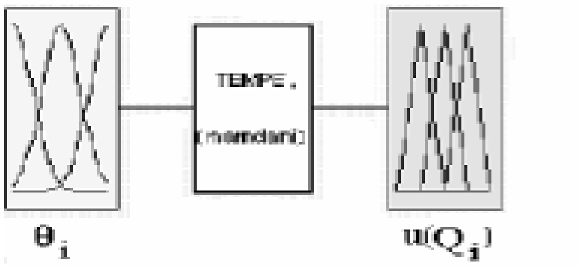


Fig. 6. The structural block schema of fuzzy controller simulation.

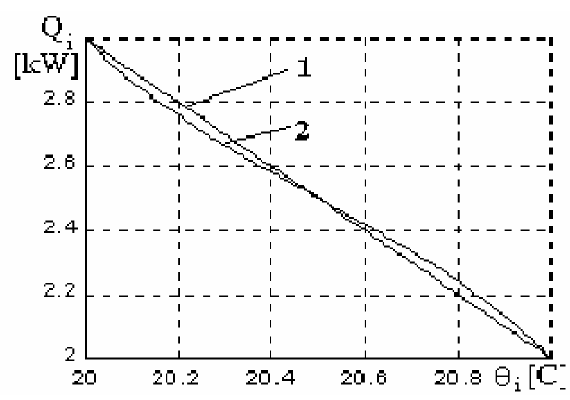


Fig. 7. The temperature control: with P controller (the curve 1); with fuzzy controller (the curve 2).

4. COMPARISONS

It is necessary a comparison of the results obtained using those two optimal control structures described and illustrated in fig.1 and fig.2. The most indicated way is their implementation and study on a model similarly with the real one (numerical simulation). However, in the case of using first method (fig.1), is obvious that because of nonusing of an optimization mathematical algorithm, the calculus period of the control variables is much longer (because of the defuzzyfication method), (Preitl and Precup, 1997).
On the other hand, there are big chances to obtained unreal solutions because of the system discontinuity and non linearity. Although many simulation programs are available, no one doesn't match to the automatic control study of the room air-conditioning variables. Thus, to control the temperature inside the room it is proposed a structural block simulation schema (fig. 8), that has 5 simulation modules.

The fourth module must contain the room mathematical model and to simulate the dynamic response of the internal temperature θ_i, related to the external temperature θ_e, the heating quantity (the energy) Q_r proceeded from the sun radiation inside the room, the heating quantity proceeded by natural convection (natural ventilation) Q_{cv}, the heating quantity proceeded from the internal heating sources and the heating quantity proceeded from the usual heating system of the room Q_i.

The room model can be expressed by the following state equations:

$$\dot{\mathbf{x}} = \mathbf{Ax}+\mathbf{Bu}, \text{ cu } \mathbf{u} = \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix}, \qquad (6)$$

$$\mathbf{y}=\mathbf{Cx}+\mathbf{Du}, \text{ cu } \mathbf{y}=\theta_i(t),$$

where: u_1 is the control variable of the heating quantity from the room air; u_2 is the control variable of the heating quantity because of the solar radiation on the room walls areas; u_3 is the control variable of the external temperature.

The first module must contain a data basis with informations about weather data (Duță et al., 1982).

The second module, first must change over the heating quantity because of the total solar radiation into heating quantities because of the direct radiations Q_{r_dir} and diffused Q_{r_dif}, on the room area. The heating quantity derived from the total solar radiation on the room area Q_r, is calculated as a sum of the heating quantities derived from the direct and diffused radiation and from the reflected radiation (Duță et al., 1982).

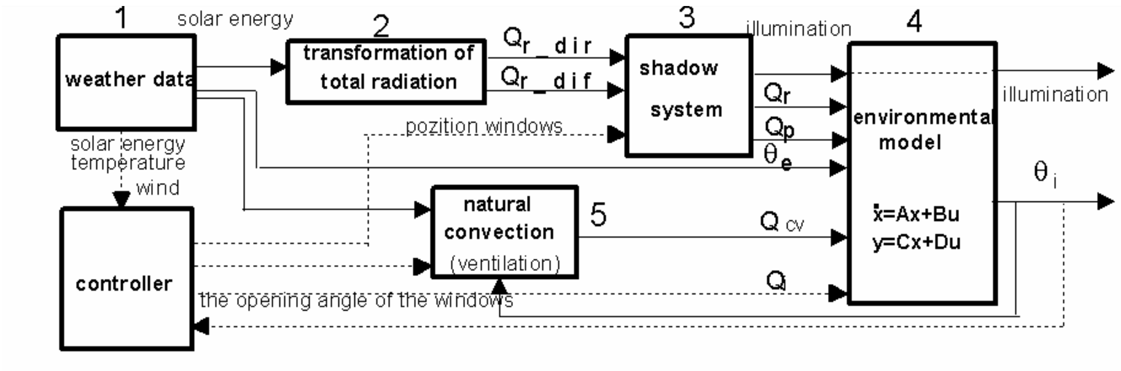


Fig. 8. The proposed simulation block structural schema, in the case of automatic control of the temperature θ_i.

The third module must catch the shadow system effect, calculating the natural illumination and the quantity of heating inside the room because of the solar radiation, depending on the sun position and the Q_p room placement (Popescu, 1998).

The illumination calculus can be realized with the day light factor method (depends on the room dimensions, the thermal properties of the windows and on the materials of the walls on the one hand, and on the other hand of that part of transmitted solar energy called LTA (Lam, 2000).

The fifth module must calculate the heating quantity derived by natural convection - natural ventilation Q_{cv}, depending on the wind speed and the opening angle of the windows.

The heating quantity derived from the room heating system (radiator) Q_i, can be considered as a linear function in respect of the control variable of the system temperature controller (Redares, 1986).

5. CONCLUSIONS

In the optimal control case of the air-conditioning variables from the passive ventilated rooms, besides are economized important electrical energy quantities used to put available the artificial light, the environment quality will be much improved if the natural light cover as big as it is possible area inside the room. Because these cases are some limited situations, it shall must be analyzed the case in which in the room is a climatic system.

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