FUZZY CONTROL FOR IMPROVED BUILDINGS ENERGY MANAGEMENT SYSTEMS

D. Kolokotsa, G.Stavrakakis , K.Kalaitzakis, D.Tsiavos
Technical University of Crete
Department of Electronics & Computer Eng.Systems Eng. Division
73100 Kounoupidiana Campus, Chania - Crete – Greece
tel:+30 821 37209 fax:+30 821 37202 e-mail:denia@systems.tuc.gr

ABSTRACT: Research on energy efficiency in buildings has proved that the design and even the sophisticated facilities such as Building Energy Management systems (BEMS), aiming to improve the indoor environmental conditions while minimising the energy needs, are not sufficient enough due to users interference. Users are a dynamic part of the building, therefore they should be taken into account in the control strategy. Latest trends in designing Intelligent Building Energy Management Systems (IBEMS) integrate a Man Machine Interface that could store the users preferences and adapt the control strategy accordingly. The objective of the present paper is to present the advantages of the fuzzy control techniques together with a man machine interface based on a smart card terminal in satisfying the users preferences. A fuzzy controller is developed and the minimization of energy consumption is achieved by the use of a suitable cost function for the whole system. The overall control system including the cost function is modeled and tested using MATLAB/SIMULINK.

KEYWORDS: Building Energy Management System, Man Machine Interface, Fuzzy Controller, Cost Function

INTRODUCTION

The Energy crisis in the late 70's combined with the fast development of computers science has led to the development of the Building Energy Management Systems (BEMS). The aims of these systems are to monitor and control the environmental parameters of the buildings and at the same time to minimise the energy consumption and cost. Since then, BEMS have become commercial tools and are implemented in a wide range of applications, especially in large office buildings; thus useful experience is available regarding their benefits and drawbacks.

The objectives of the present paper are to propose the integration of a Man Machine Interface into BEMS that takes into account the users preferences as a dynamic part of the system plus to satisfy the criterion of the energy consumption minimization. The overall control strategy is developed using fuzzy techniques.

CONTROL STRATEGY

The control strategy has the following objectives:

(i) To satisfy the users preferences that are inserted into the system through a smart card unit and to maintain thermal, visual and indoor air quality comfort based on guidelines of related bibliography [2,3].

(ii) To minimize the building's energy consumption for heating/cooling and lighting.

(iii) To supervise the operation of the system.

The above objectives are achieved by the use of a fuzzy controller at each zone level of the building, supervised by a suitable cost function. The detailed description of the control strategy follows.

THE FUZZY CONTROLLER

The aim of the controller is to maintain users comfort over the zone level. Comfort always reflects the subjectivity of the users and is the integration of:

(i) Thermal comfort

(ii) Visual comfort

(iii) Indoor air quality

In this specific application the controlled parameter for thermal comfort, is the Predicted Mean Vote (PMV) introduced by Fanger [1] which depends upon:

(a) The temperature

(b) The relative humidity

(c) The mean radiant temperature

(d) The air velocity

(e) The activity level

(f) The clothing parameter (clo).

The first four parameters are directly measured while the next two are estimated on the basis of the building type and activities.

The PMV index varies in the range of –3 to +3, while the span of thermal satisfaction lies between –0.5 to +0.5 with the Percentage of People Dissatisfied (PPD) index, introduced also by Fanger [1], to be less than 5%.

The controlled parameter selected for estimating visual comfort is the illuminance level, measured in lux [4].

The indoor air quality is mainly influenced by the concentration of pollutants in the controlled space. CO_2 concentration (measured in ppm) is selected for this application, as it represents the presence of users as well as various sources of pollutants in the building.

A fuzzy controller approach [5] has been selected for the control of the above parameters for the following reasons:

i. The limits of comfort and discomfort are fuzzy and subjective.

ii. Oscillations and overshootings have to be avoided in order to minimise discomfort and energy waste.

The fuzzy controller for each of the controlled parameters (PMV, Illuminance levels, and CO_2 concentration) takes the following inputs:

- The error between the desired and the current value of the parameter at time nT.
- The error at time (n-1)T.

The outputs of the controller are:

(i) Increase / decrease of heating / cooling.

(ii) Increase / decrease of window opening or ventilator.

(iii) Increase / decrease of shading adjusting the daylight contribution.

(iv) Increase / decrease of electric lighting.

Thus the fuzzy controller has six inputs, four outputs and 27 rules.

The membership functions used for this application for each controlled parameter are of triangular and trapezoidal type [6].

Three membership functions were selected per input for each of the controlled parameters around the regions zero (Ze), negative (Neg) and positive (Pos).

Five membership functions are used per output (Zero, Small Positive, Small Negative, Positive, Negative).

The membership functions of the PMV error at time nT (pmve0) and the error at time (n-1)T (pmve-1) are illustrated in Fig. 2.1.2.a. and 2.1.2.b. The membership functions for heating / cooling are illustrated in Fig.2.1.2.c.

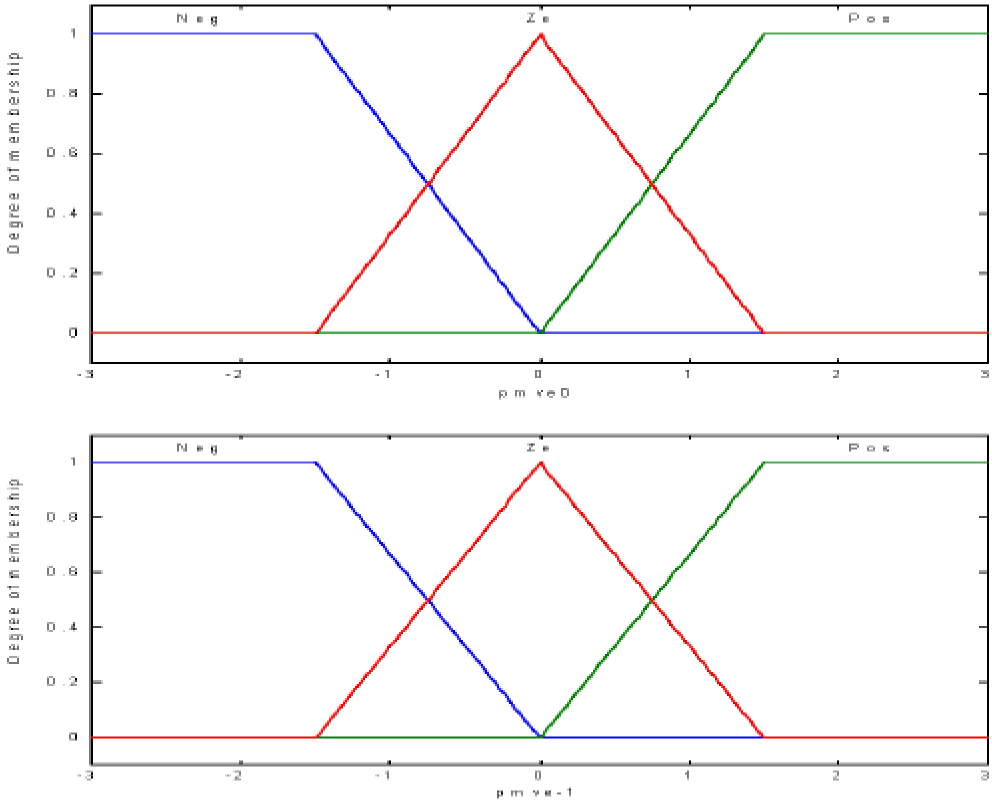

Figure 2.1.2.a., b Membership functions for the‘pmve0’ and ‘pmve-1’ inputs

The membership functions of the CO_2 concentration error at time nT and (n-1)T, as well as the membership functions for the illuminance levels are of the same type with those of PMV. The membership functions of the outputs of the PI controller are of the same type with those for heating/cooling and are illustrated in Fig.2.1.2.c.

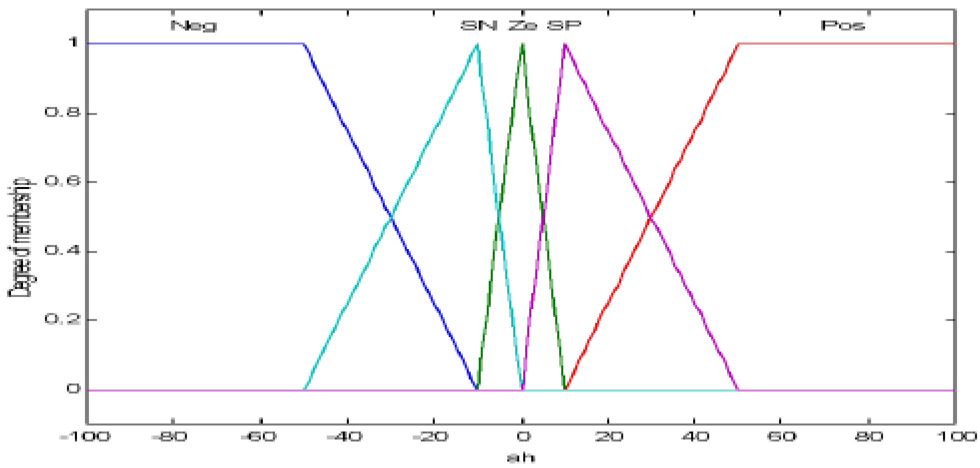

Figure 2.1.2.c. Membership functions for heating/cooling outputs of the fuzzy controller

The controller has been modeled using the MATLAB/SIMULINK Software. The model of the building has been developed by the University of Athens in the framework of the Joule III Research Programme JOE3 – CT 97 0044.

THE ROLE OF THE COST FUNCTION

The aim of the developed system, as mentioned before, is to achieve minimisation of the energy consumption while maintaining comfort. This is achieved introducing a suitable cost function of the form:

$$\text{Cost } F = w_1 *f_1 + w_2 *f_2 + w_3 *f_3 + w_4 *f_4 + w_5 *f_5 \quad \text{(eq. 2.2.1.)}$$

where f_1, f_2, f_3, f_4, f_5 are the normalised parameters for:

(a) PMV

(b) [CO2]

(c) Daylight contribution

(d) Energy consumption for heating/cooling

(e) Energy consumption for electric lighting

respectively, and w_1, w_2 , w_3 , w_4 , w_5 are the weights of each parameter.

The weights of the parameters are initially estimated using the Principal Component Analysis method (PCA)[7]. During real time operation the weights are tuned according to the users preferences, with the parameters characterized by the strongest variation to have the highest weights.

The acceptable limits for the comfort parameters are:

$-0.5 \leq \text{PMV} \leq 0.5$ [1]

600 ppm ≤ [CO2] ≤ 800 ppm [1,2]

300 lux ≤ Illuminance ≤ 1000 lux [1,2]

Having determined the acceptable limits of the parameters f_1, f_2, and f_3, random generators are used to generate values within the acceptable limits. The objective is the determination of the optimum limits of the cost function as a whole. The weights are estimated using PCA and the resulting values are:

$w_1 = 0.4462$ $w_2 = 0.4432$ $w_3 = 0.4541$

$w_4 = 0.4396$ $w_5 = 0.4527$

The optimum cost function lies between 0 and 2 as shown in Fig.2.2.a. The optimum energy use per day is modelled using MATLAB / SIMULINK. For heating / cooling an optimum energy consumption of 200 kWh/m^2 per year is considered, while for electric lighting the level is 100 kWh/m^2 per year (Fig. 2.2.b, 2.2.c.).

The daily energy consumption computed by the model is divided by the optimum energy consumption per day to provide the parameters f_4 and f_5. The simulation results for the cost function for three winter days are presented in section 3.

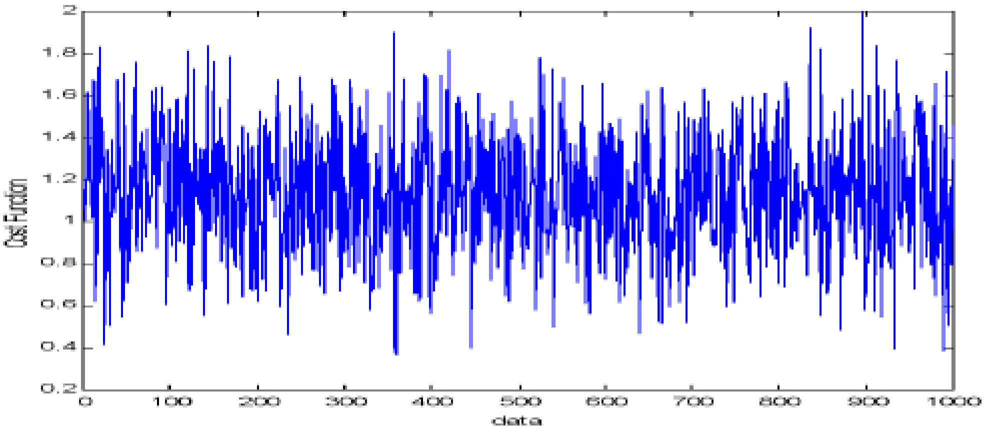

Figure 2.2.a. Optimum values of the cost function

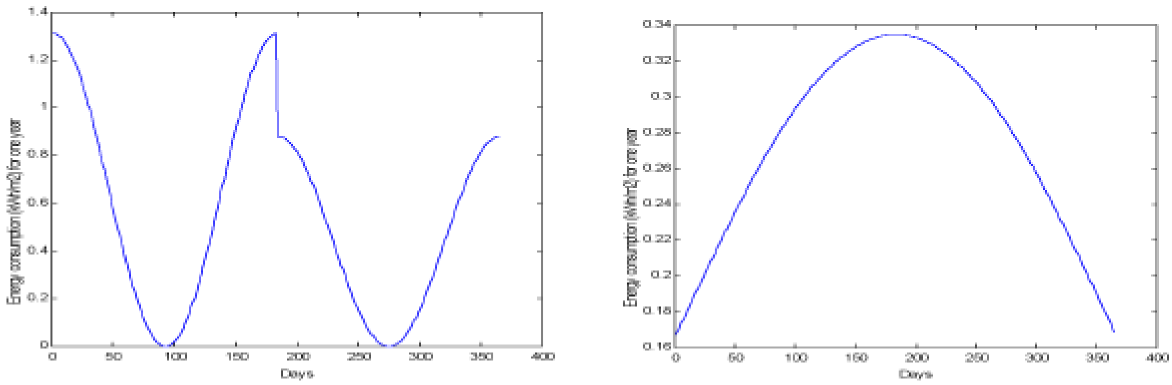

Figure 2.2.b,c. Energy consumption in kWh/m^2 for heating/cooling and electric lighting per day over one year period

SIMULATION RESULTS

The described fuzzy controller is tested using MATLAB / SIMULINK. The response of the controlled parameters are shown in Fig. 3.1. for three typical winter days. The set point in Fig. 3.1. is PMV = 0, [CO_2] = 800 ppm and illuminance = 500 lux.

The users preferences are modelled using random generators providing various set points for the PMV, [CO_2] and illuminance levels within the acceptable limits. The PMV set point is changing once every 3 hours while the [CO_2] once every 7 hours, considering that if the pollutants concentration is kept within the acceptable limits, people are satisfied.

The simulation results for an one day period are illustrated in Fig. 3.2. The PMV is approaching the set point smoothly and without any overshootings or oscillations.

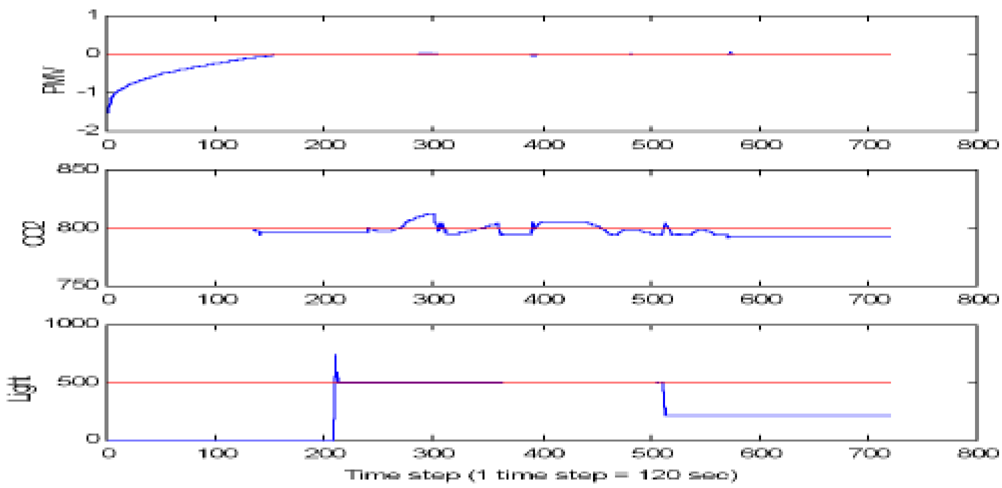

Fig. 3.1. Fuzzy controller response for fixed set points

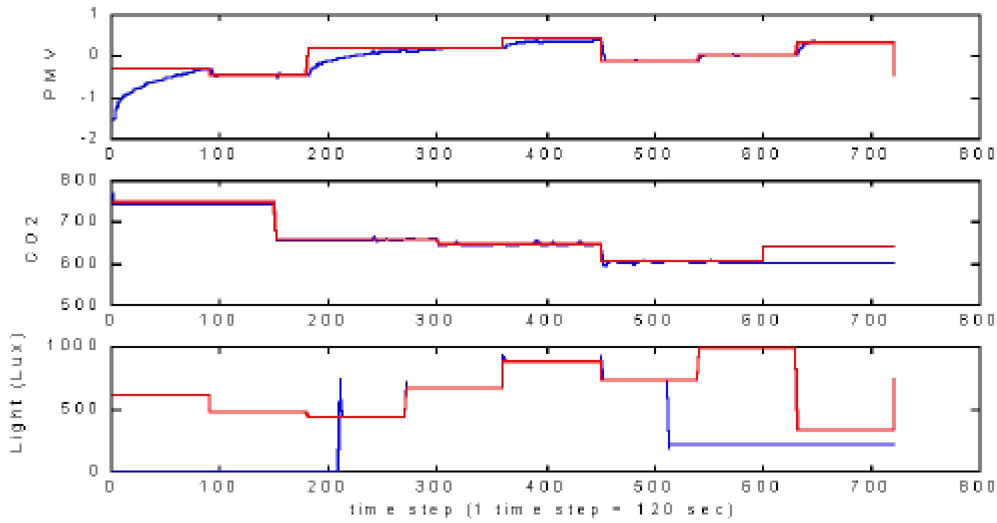

Figure 3.2. Fuzzy controller response for users preferences

The [CO_2] concentration follows the desired set point accurately. As it can be observed after the time step 600, the set point is higher than the [CO_2] concentration in the space, but due to the absence of occupants the CO_2 level cannot be increased.

As far as the lighting levels are concerned, the controlled parameter follows the desired values, quite satisfactory. The overshooting observed at time step 200 is due to the immediate increase of lighting levels because of the daylight contribution. During the night, the desired lighting levels cannot be reached due to low level of electric lighting used by the model.

The simulation results for the cost function for three winter days is depicted in Fig.3.3. The cost function is kept within the acceptable limits. This may not be always true when the system is in actual operation. For that reason, after the installation of the system and during the on line operation, the cost function is estimated every 1/4 hour. When the cost function is out of the acceptable limits, the responsible parameter is punished by reducing the weight of the rules responsible for its control.

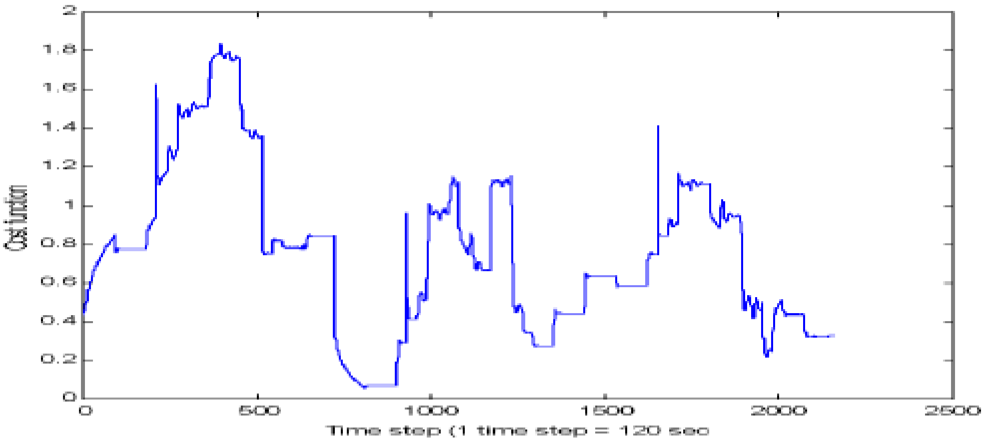

Fig. 3.3.Cost function for three days simulation of the fuzzy controller

CONCLUSIONS

The described BEMS integrates the users preferences and ensures energy saving by the use of a suitable cost function. The energy consumption per m^2 for both heating/cooling and lighting is below the levels recommended by the bibliography. The users preferences are satisfied without oscillations and overshootings by the use of the fuzzy controller. The performance of the system in real time operation will contribute to the improvement of the overall system performance.

ACKNOWLEDGEMENTS

The research work is performed in the framework of the BUILTECH JOULE Research Programme (JOE3 - CT –970044) in part funded by the European Commission DG-XII.

REFERENCES

Fanger P.O. (1970), Thermal Comfort Analysis and Applications in Environmental Engineering, Mc Graw Hill, New York.
Francis Allard, Natural Ventilation in Buildings, James & James, ISBN 1 873936729.
M. Santamouris, et al, Passive Cooling in Buildings, James & James.
N. Baker et al, Daylight in Architecture, A European Reference Handbook, James & James, ISBN 1873936214.
D. Misir et al, Design and Analysis of fuzzy PID controller, Fuzzy Sets and Systems 79 (1996) pp297-314.
R.C. Berkan, S.L. Trubach, Fuzzy systems design principles, IEEE PRESS.
K.I. Diamantaras, S.Y. Kung, Principal Components Neural Networks, John Wiley and Sons Inc.