COMBINED CONTROL OF NATURAL AND FORCED VENTILATION USING INTELLIGENT CONTROL ALGORITHMS

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ABSTRACT

Results are presented from a study of the performance of fuzzy, rule-based algorithms for the control of indoor air quality through combined control of natural and forced ventilation strategies, whilst simultaneously meeting thermal and visual comfort requirements as part of a global control strategy aimed at optimising the indoor environment with minimum energy consumption. Control algorithms incorporating artificial intelligence techniques offer the possibility of meeting the required levels of indoor air quality through selective exploitation of the potential for natural ventilation and the use of mechanical ventilation. The control algorithms, under development as part of the activities of the BUILTECH research project funded in part by DG XII of the European Commission within the framework of the JOULE III Programme, are founded on the knowledge base of the building physics and support the control of the ventilation, heating, cooling and lighting systems of the building. The CO_2 level has been adopted as the controlled parameter for indoor air quality and is incorporated within the control rules of a fuzzy rule base. The conflicts which arise between the indoor air quality control strategy using natural ventilation and the control of thermal and visual comfort are addressed. The thermal and visual comfort parameters that have been adopted as high level performance variables are controlled through intelligent compensation and adjustment of, amongst other factors, the indoor air velocity and solar control devices, with significant effect on the natural ventilation control strategy.

INTRODUCTION

Energy conscious design and energy management in buildings are important as a means of contributing to security and diversity of energy supplies and also as a means of combating the environmental impact of excess energy consumption on both a global and local scale. Energy consumption in buildings cannot be considered without also accounting for the well being and comfort of the occupants, and experience has shown that building occupants are often not satisfied with the strictly controlled conditions in well sealed buildings and factors such as indoor air quality and the sick building syndrome must be taken into account and lead to a requirement for utilising the available environmental energy sources to a maximum whilst optimising energy consumption. The use of environmental energy sources is one of the major elements of energy conscious design in buildings, and with it come parallel implications for indoor air quality, thermal comfort and visual comfort.

Intelligent control techniques using fuzzy logic controllers offer the possibility of meeting the required indoor comfort conditions by selectively controlling the building plant and the opening of fenestration. The challenge is to meet thermal comfort, visual comfort and indoor air quality requirements simultaneously, whilst minimising energy consumption. It has been demonstrated that it is possible to control natural ventilation using fuzzy logic controllers in order to utilise most effectively the available potential [1],[2], but due to its inconsistent nature natural ventilation alone cannot always guarantee, depending on prevailing climatic conditions and building occupancy, the desired indoor air quality levels.

METHODS

The objective of the simulations carried out in this study was to investigate the performance of combining forced and natural ventilation strategies to improve the indoor air quality levels, particularly under situations where these cannot necessarily be guaranteed through natural ventilation alone.

Whilst the overall objective of the development of the controller is to construct a global controller for thermal and visual comfort and indoor air quality control which can be adapted through a learning mechanism, the study of the performance of the controller with respect to indoor air quality has been implemented through consideration of the following: forced ventilation alone; natural ventilation with fuzzy control; combined natural and forced ventilation with fuzzy control; and global thermal comfort, visual comfort and indoor air quality control with fuzzy logic.

A simple single building zone has been adopted for the simulations. The zone, which has dimensions 5m × 3m × 3m, has a single opening in the south wall, the dimensions of the opening being 1m × 1m. The window is considered to be shaded externally with adjustable venetian blinds and the window opening is adjustable to a maximum of 25% of its area.

The zone is considered to be occupied on a daily basis, with variably one to two occupants and for one hour at midday the zone is considered unoccupied.

The maximum forced ventilation rate is 5 l/s, considered for an office space with a maximum occupancy of two persons.

The fuzzy control of natural ventilation with combined thermal and visual comfort has been presented in [3], and the combined fuzzy control of natural and forced ventilation constitutes a simple modification of the controller outputs to include forced ventilation and reconstruction of the rule based presented therein.

RESULTS

Simulations have been carried out for two ten day periods in the winter and summer seasons using climatic data for Athens.

Winter Period Simulations

For the winter period and using the fixed forced ventilation rate, the CO_2 levels remain significantly high during the occupied period (Figure 1). On the other hand, all of the fuzzy logic controllers maintain the CO_2 levels at levels only slightly higher than the desired levels of 800ppm, however the energy consumption levels for the fuzzy logic natural ventilation controller and the fuzzy logic combined natural ventilation and forced ventilation controller are slightly higher than those for forced ventilation only (Figure 2). This is however, only to be expected given that the indoor air quality levels attained by the fuzzy logic controllers are significantly better than those for the forced ventilation alone.

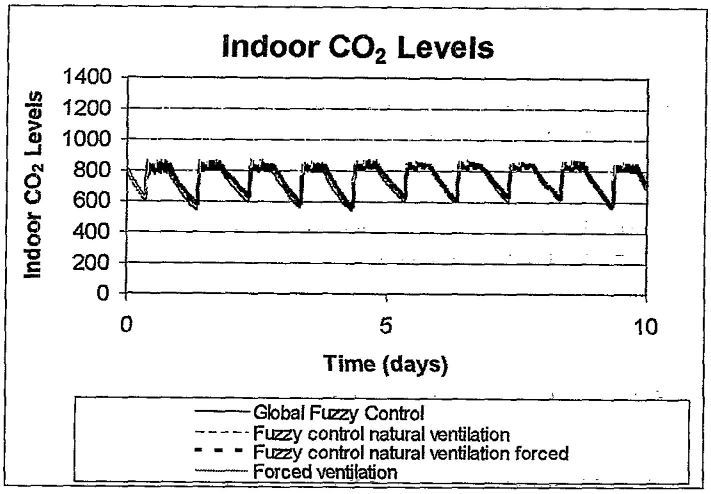

Figure 1. Simulated indoor CO_2 levels with set-point 21°C and forced ventilation rate 5 l/s

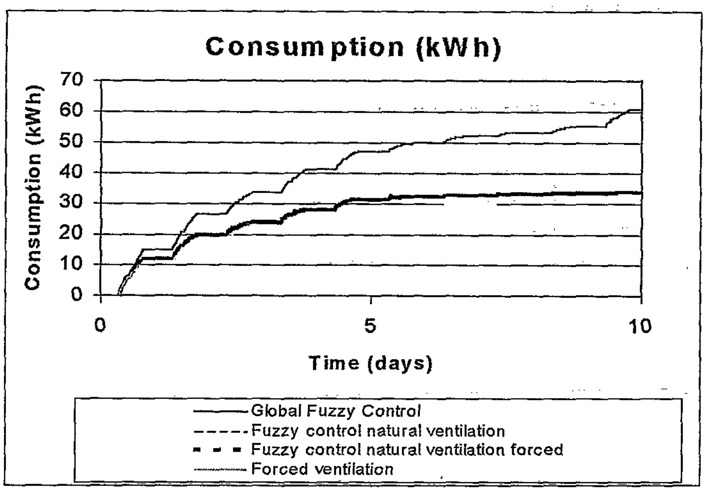

Figure 2. Cumulative consumption levels with set-point 21°C and forced ventilation rate 5 l/s

The indoor air temperature and hence the thermal comfort indicator, the PMV index, is much higher for the global fuzzy controller as compared to the other controllers (Figure 3).

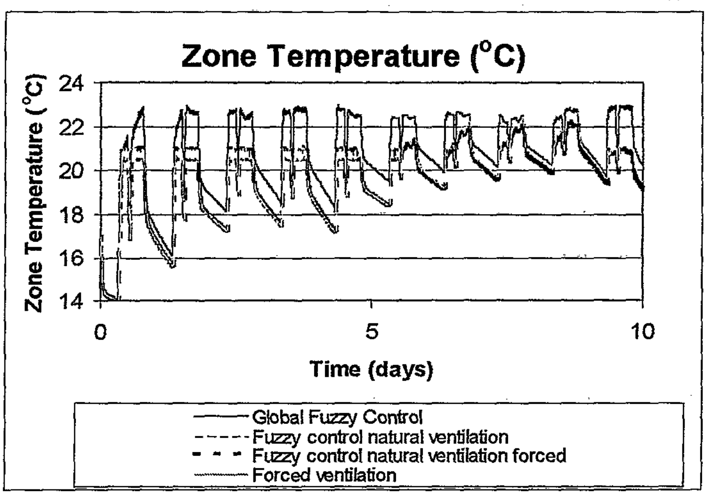

Figure 3. Simulated indoor temperature with set-point 21°C and forced ventilation rate 5 l/s

To compare the performance of the different controllers the set-point for the controllers has been set to 23°C, upon which the thermal comfort indicator becomes qualitatively similar, the energy consumption difference is reduced significantly but the air quality levels, as expected, remain poor. Furthermore, by increasing the forced ventilation rate the air quality levels using forced ventilation only are improved to a standard similar to that of the fuzzy controllers and the energy consumption is found to approach that of the global controller, but without visual comfort control. In comparison to the continuous forced ventilation strategy, the indoor air quality fuzzy logic controllers with constant room temperature set point and without visual comfort control demonstrate the capacity to control indoor air quality sufficiently but indicate slightly increased energy consumption (Figure 4).

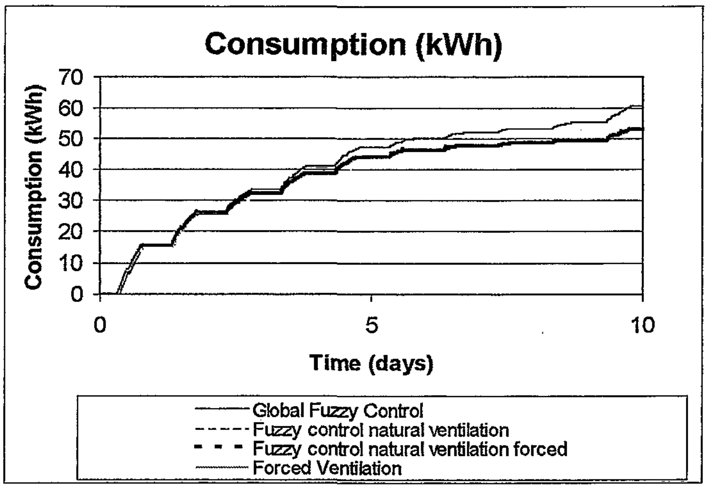

Figure 4. Cumulative consumption levels with set-point 23°C and forced ventilation rate 10 l/s

Summer Period Simulations

Simulations have also been carried out for a ten day period during the summer. The initial set point selected was 26°C for the summer period, however in order to compare the performance of the controllers qualitatively with respect to thermal comfort, this was increased to 27°C.

As with the simulations for the winter period the forced ventilation rate has been increased for the case of constant forced ventilation in order to obtain qualitatively similar indoor air quality levels. With forced ventilation the indoor air quality is guaranteed with the CO_2 levels being maintained constantly at or below a level of approximately 800ppm. For the prevailing climatic conditions and the occupancy pattern, none of the fuzzy logic controllers are capable of maintaining the CO_2 levels at the desired levels (Figure 5). However, the use of combined natural and forced ventilation fuzzy control presents improved performance over the natural ventilation fuzzy logic controller alone. Whilst the energy consumption over the simulated period using the global controller incorporating the combined control of natural and forced ventilation is reduced only slightly (Figure 6), the thermal comfort is significantly improved (Figure 7). For the second part of the simulation period, where the thermal comfort conditions are directly comparable, the global fuzzy controller presents reduced consumption for the summer conditions.

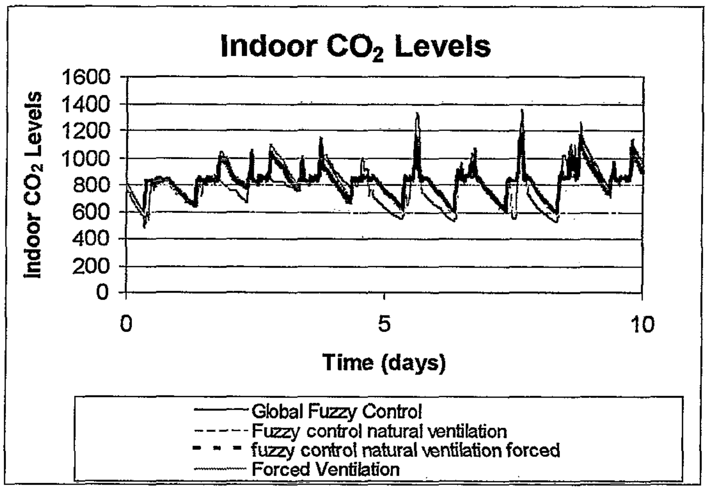

Figure 5. Simulated indoor CO_2 levels with set-point 27°C and forced ventilation rate 10 l/s

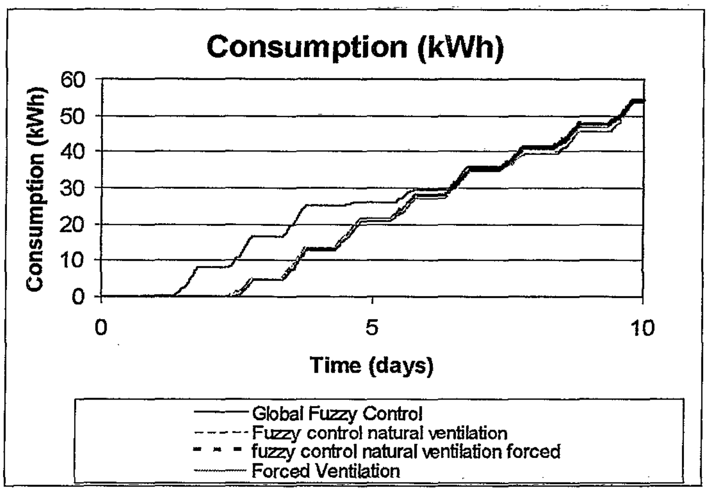

Figure 6. Cumulative consumption levels with set-point 27°C and forced ventilation rate 10 l/s

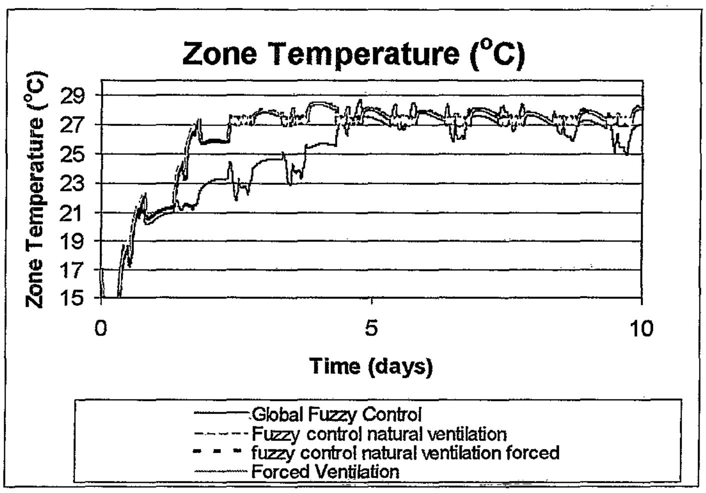

Figure 7. Simulated indoor temperature with set-point 27°C and forced ventilation rate 10 l/s

DISCUSSION

The simulations demonstrate that the combined fuzzy logic control of natural and forced ventilation demonstrates improved performance over the use of fuzzy controlled natural ventilation alone. The selection of an appropriate rule base, or indeed an adaptive system, is necessary to improve the performance of the controller.

Given the multi-criteria optimisation process involved it is difficult to assess quantitatively the reduction in energy consumption and the improvement in indoor environment that may be attained using fuzzy logic controllers of this type. It is therefore necessary to consider the development of a performance assessment method indicating the deviation of the controlled parameters from the desired values and taking into account the energy consumption in order to obtain a single quantitative value for indoor environmental performance which will allow evaluation and classification of controller performance.

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