

Thermal Comfort Control based on Fuzzy Decision-making

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Abstract

The paper describes a fuzzy decision-making approach to controlling thermal comfort in the occupied zones of an air-conditioned building. The control objective is defined in terms of fuzzy goals and fuzzy cost functions and a fuzzy decision-maker is used to find the most appropriate control action. Simulation results are presented that demonstrate the performance of the comfort control scheme when it is used in different types of buildings. The results show that computing resources need not be wasted on calculating precise values for the control signal, when the control objective is poorly defined.

Keywords: air-conditioning, thermal, comfort, fuzzy, predictive, control

1 Introduction

The thermal comfort of the occupants of a building depends on many factors including metabolic rates, clothing, air temperature, mean radiant temperature, and air velocity and humidity [9]. In most buildings, however, only temperature and humidity can be controlled [6]. Indeed, in many European buildings, over a wide range of humidity, only zone temperature is controlled [4]. In such cases, the control objective is then to maintain the zone temperature within a pre-defined range.

Although thermal comfort can have a significant effect on the productivity of the occupants of a modern, energy efficient building, the economic cost

of low productivity is difficult to quantify precisely [1]. The control objectives are therefore poorly defined. The comfort control problem is further complicated by the uncertain and non-linear behaviour of the air-conditioning system (the associated thermo-fluid processes are spatially distributed and complex, there is frequently a lack of design data, and it is difficult to obtain representative training data on-line). The disturbances acting on the zone (the solar gains, the internal gains and the conduction gains) are also another major source of uncertainty since none of them can be estimated accurately from the available measurements.

Fortunately, the control performance needed to maintain acceptable thermal comfort is normally less demanding than that required in process control applications and fuzzy control of the air temperature is an attractive option. The main drawback of previously proposed control schemes, which are based on direct fuzzy control using fixed expert rules [2], is the time and effort required to acquire a correct, complete and consistent set of rules. The main drawback of schemes based on adaptive fuzzy model-based control [7] is that most of the proposed algorithms calculate overly precise values of the control signal and are computationally demanding [8]. A fuzzy decision making approach to thermal comfort control is proposed in this paper.

2 Fuzzy Model-Based Temperature Control

The proposed scheme for controlling thermal comfort in an air-conditioned building is based on a combination of fuzzy modelling and predictive control techniques. A block diagram of the scheme

is shown in Figure 1. The controller consists of three parts: (i) a fuzzy model of the process, (ii) two fuzzy cost functions to be optimised, $J_C(U)$ and $J_E(U)$, and (iii) a fuzzy decision-making scheme that determines the optimum value of the control signal U_{OPT} , which minimises the combined cost function $J(U) = J_C(U) \text{ AND } J_E(U)$.

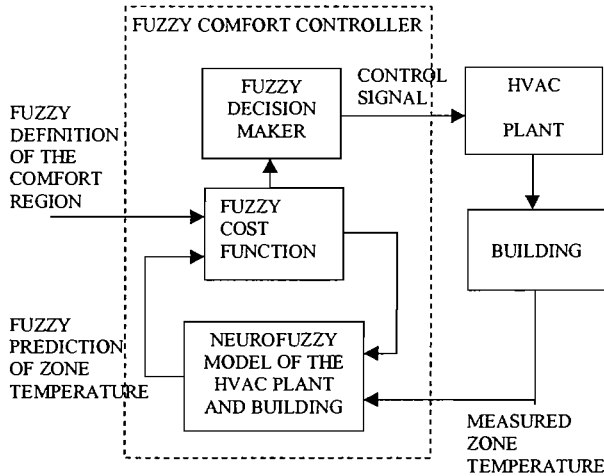


Figure 1: Fuzzy model-based zone temperature control

3 The Fuzzy Model

A fuzzy relational model with five inputs and one output is used in the control scheme. The structure of this non-linear first-order plus time delay auto-regressive model is given by:

$$\hat{T}_z(n+1) = T_z(n) \circ U(n - T_D) \circ Q_s(n) \circ T_a(n) \circ p(n) \circ R$$

where $\hat{T}_z(n+1)$ and $T_z(n)$ are the predicted and the current values of the zone temperature, respectively, $U(n - T_D)$ is the delayed control signal (in this case, the set point value for the pressure-independent VAV terminal boxes supplying cold air to the zone), $Q_s(n)$ is an estimate of the current solar gains, $T_a(n)$ is the current ambient temperature, $p(n)$ is the Boolean output of a presence sensor that indicates whether the zone is currently occupied, \circ is the fuzzy composition operator (here, sum-product is used), T_D is the dead time on the control action expressed as an integer number of sampling intervals, and R is the fuzzy relational array.

The fuzzy model is generated using a fuzzy identification scheme [5] and training data obtained from a simple linear model of the building and plant whose parameters are based on available design information.

4 The Fuzzy Cost Functions

There are two fuzzy cost functions: one for thermal comfort, and the other for the energy consumption. A fuzzy measure of thermal comfort $J_C(U)$ is found by matching the fuzzy prediction of the zone temperature, for each fuzzy value of the control signal, to the zone temperature set point. A fuzzy proximity measure is used to indicate the closeness of the two fuzzy values. The fuzzy measure of the energy consumption $J_E(U)$ is derived directly from the fuzzy value of the control signal.

5 The Fuzzy Goals

The fuzzy comfort goal, G_C , has a trapezoidal membership function centred around 0°C to reflect the acceptable comfort band around the set-point temperature. The fuzzy energy goal, G_E , has a triangular membership function, centred around an energy consumption of 0%.

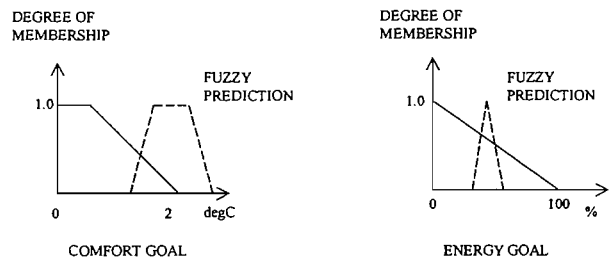


Figure 2 Fuzzy goals for comfort and energy

The relative importance of maintaining thermal comfort and of saving energy is determined by the widths of the fuzzy goal functions. If, after exhaustively searching through all fuzzy values of U , the controller can find no value of the control signal which, to some extent, satisfies both goals simultaneously, the goals are automatically relaxed by lengthening the bases of the membership functions until they are achievable.

6 The Fuzzy Decision-Maker

The fuzzy cost functions are compared to their respective fuzzy goals to determine the extent to which the goals are satisfied [3]. The degree of similarity between the fuzzy cost function and fuzzy goal is taken as the ratio of the common area between the two membership functions to the total area underneath the membership function of the fuzzy cost function. The two area ratios produced by a particular value of control action are multiplied (ANDed) to produce a discrete membership function for the fuzzy control signal U_{OPT} that is optimal in terms of both thermal comfort and energy consumption. The fuzzy optimal control signal is then transferred to a conditional defuzzification scheme.

7 Conditional Defuzzification

The fuzzy control signal generated by the fuzzy decision-making process is compared to the current value of optimal control action to see whether the set point of the flow actuator should be changed. If the possibility of the new fuzzy optimal control signal given the current value of the control signal is greater than some pre-defined threshold, the set point remains unchanged. Otherwise U_{OPT} is defuzzified and sent to the flow actuator. The choice of the threshold determines the level of actuator activity.

8 Application to Different Types of Buildings

The simulation results presented in Figures 3 and 4 demonstrate the performance of the comfort control scheme when used to control the zone in two different modes. The first mode (see Figure 3) is one in which the thermal comfort of the occupants of the zone is a priority, such as would be the case if the zone was being used as a conference room of a modern office building.

The occupancy period is from 07.30 until 18.30. The comfort region is the shaded area between 23°C and 25°C . The threshold for conditional defuzzification is set at 0.8. Compared to conventional PI control using a constant set point of

24°C , the energy consumption is reduced by 6% and the control activity by 74%.

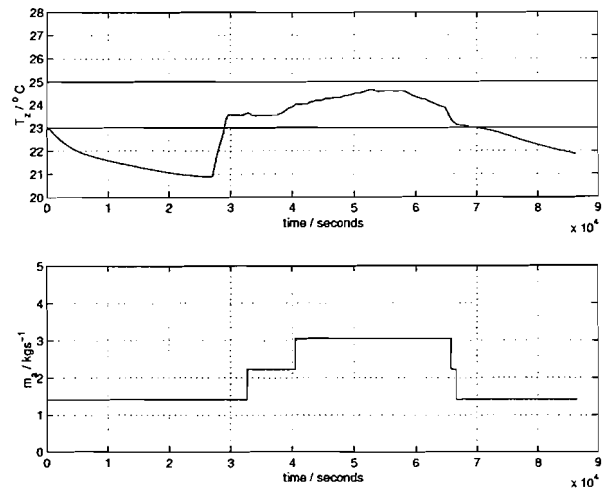


Figure 3 Temperature control in a zone where the thermal comfort of the occupants is important

In the second mode (see Figure 4), the cost of energy is the major concern. This scenario could occur if the zone were employed as a school classroom, for example, where thermal comfort is not necessarily a great priority, but where conserving energy certainly might be.

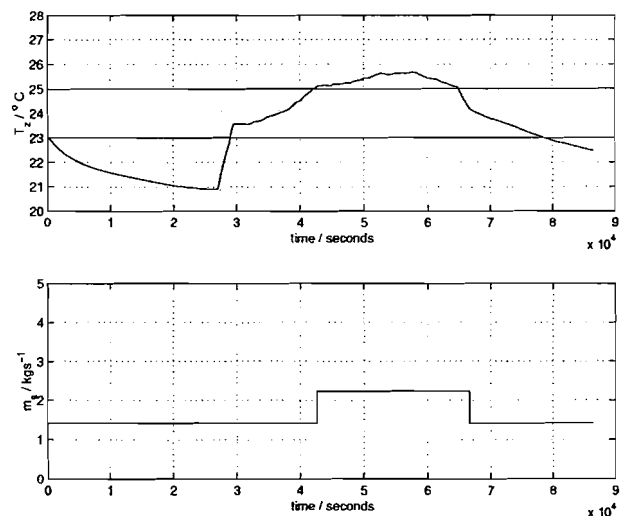


Figure 4 Temperature control in a zone where energy savings are important

Compared to conventional PI control using a constant set point of 24°C , the energy consumption is reduced by 22% and the control activity by 83%.

In both cases, the set point of the controller is set to the *neutral temperature* of the zone, which is defined as the temperature at which people are neither too hot nor too cold. A neutral temperature of $24^{\circ}C$ is assumed here.

9 Conclusions

The fuzzy model-based controller can maintain the zone temperature within the comfort region with a minimum of control activity. Precise optimisation is unnecessary when the control objective is poorly defined.

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