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AN EXPERT SYSTEM FOR THE DESIGN OF VENTILATION SYSTEMS

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ABSTRACT

This paper describes a prototype of expert system for the design of ventilation systems, which applies the fuzzy theory to control the carbon dioxide concentration in relatively small buildings and dwellings. This prototype is formulated as a nonlinear constrained optimization problem, coded by PROLOG and FORTRAN77 and operated in a micro-computer, and has a subprogram for ventilation calculation besides ordinary components of expert system. The consultations in the case of two rooms with a central ventilation system gives the optimum parameters to maintain the indoor air quality within a specified range, after several iterations. Data acquisition and presentation, linking subprogram, and further development are also discussed.

INTRODUCTION

Most of the codes for the ventilation calculation in buildings are difficult for users to utilize on the design stage(1). This research has the final objective to develop the expert system to which Artificial Intelligence (AI) is applied, to help the designers to plan the building ventilation.

Existing systems for ventilation planning may be divided into two types. One is the modular structured program which has many modules of ventilation calculation, e.g. data input/output, calculation of ventilation rate, etc. and the administration part to operate all modules. This system can use the existing program as a library. COMIS(2,3) is one of the cases. The other is a program that has the function which can present the expertise, which is one of the functions of expert system. Some prototypes have been developed in the area of moisture problem(4,5) and the control of energy flow in buildings(6,7).

The system to aid the ventilation planning should be not only able to calculate the ventilation rate but also user-friendly for non-specialist users. Some requisites can be specified as follows, considering so-called conventional programs.
1)Data input: Interactive data input, CAD-input with graphics, and default values are easy for users to use.
2)Ventilation calculation: The algorithm of ventilation calculation has to be efficient.
3)Result output: The explanation function of the result, its limitation, and the technical terms makes the system user-friendly.

4)Recalculation: The user needs several recalculations with partly different input data in the planning process.
5)System modification: For expanding and/or embedding the system, the transportability between different systems is needed.
6)Availability of expertise: Expertise is useful to solve the problem in practical means, but the subjective and ambiguous knowledges should be stated clearly.
7)Data base: The default values and the expertise may be stored in the data base with a certain structure.

DESIGN OF VENTILATION SYSTEMS

The procedure of conventional method to design ventilation systems is generally as follows. At first production rates of contaminants generated in each room are estimated, and ventilation requirements are determined according to their purposes of rooms. Then the rough structure of the ventilation system, such as kind of fans, ductworks and so on, is decided. The next stage is to design it in detail for ductworks, e.g. using the equal friction method, the static regain method and so on. In practice the trial and error method is used in design stage.

The design method described above is enough, as far as mutual ventilation among rooms are ignored, and climate conditions, e.g. wind direction, wind speed and outdoor temperature, are steady. But for the case of the residences with several rooms where mutual ventilations can not be ignored, the ventilation models with higher accuracy should be used. Namely the design should be formulated as the optimization problem to minimize the initial costs and running costs and to realize high indoor air quality. In this paper the optimization problem is to obtain appropriate fan size and resistances of each duct to maintain the prescribed carbon dioxide concentration in rooms, a objective function, at a certain level.

In general basic equations of ventilation model dealed with natural and mechanical ventilation in a multi-room are given as follows:

$$F(p,q,\zeta,f_i)=0 \tag{1}$$

$$G(q)=0 \tag{2}$$

$$H(q,C)=0 \tag{3}$$

where p is the static pressure in rooms, q is the ventilation rates, ζ is the total resistance coefficient, f_i is the kind of fans and C is the carbon dioxide concentration. A constraint is stated as an equation $V<Vmax$, where V is the air velocity in ducts and Vmax is the limitation air of velocity. If it is possible to ignore mutual and natural ventilation in buildings, values of q are given from equation (3) and then an appropriate fan is easily determined from ventilation rate q with equation (1). As this equation set generally has a greater number of unknowns than the number of equations, so that it is impossible to find unique solutions. Therefore the trial and error procedure should be adopted to find optimum solutions of resistance coefficients and fan f_i by evaluating carbon dioxide concentration, using ventilation simulations. This paper describes an expert system to support the above

procedure in stead of the conventional method, with using AI(artificial intelligence) method.

PROTOTYPE EXPERT SYSTEM FOR VENTILATION DESIGN

Basic Characteristics

There are many types of the expert system such as intelligent finding solution type, trial and error type and optimization type, and the suitable knowledge presentation for each type has been proposed(8). The present basic structure is expected to be developed to the complex trial and error type, which infers and modifies the parameters with using knowledge base in the practical stage and contains the intelligent finding solution type which makes the calculation model and simulates the ventilation.

Before making the full system which is time consuming to be completed, a small prototype which has basic functions is developed, because we can investigate the problems for further developing.

A prototype to be developed is expected to have the basic functions, such as:
1) The system is written as a stand alone program and can be executed at a 16-bit personal computer. The commercial developing tool is not used;
2) Data input is interactive at present, though the window and the mouse make the input much easier;
3) The knowledge is presented with production rule and/or frame, and should be easy to understand and edit;
4) The inference engine is written in Prolog or LISP, and has a forward chaining, fuzzy chaining or frame system;
5) The part of ventilation calculation is written in FORTRAN or C, and the calculation result is linked as a file;

Architecture of the Prototype

The prototype consists of user interface, inference engine, knowledge base, ventilation calculation, and the data base as shown in Figure 1.

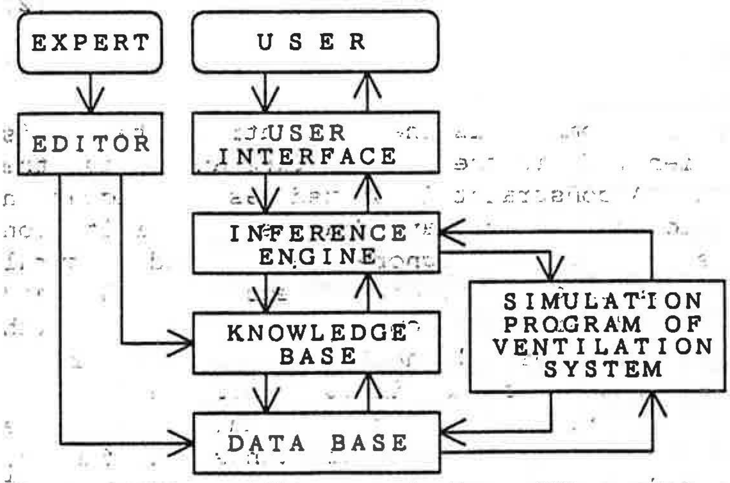

FIGURE 1. The Structure of the Prototype

Knowledge base represents the expertise and data base which consists of the fixed data such as weather data, regulation, etc. All parts are written in Prolog except the ventilation calculation part written in FORTRAN77. As Prolog used here can not be linked with FORTRAN, the files are administrated by the batch file.

Knowledge Base

A method to select an appropriate fan and the rules in knowledge base to infer the optimum resistance coefficient of ducts to optimize the objective function, the prescribed carbon dioxide concentration in rooms, is described.

Appropriate fan is determined by a forward chaining system using production rules considering the average carbon dioxide concentration. Resistance coefficients of each duct are estimated by a fuzzy chaining system to maintain carbon dioxide concentration in each rooms. Control variables are inferred by using fuzzy control rules shown in Figure 2

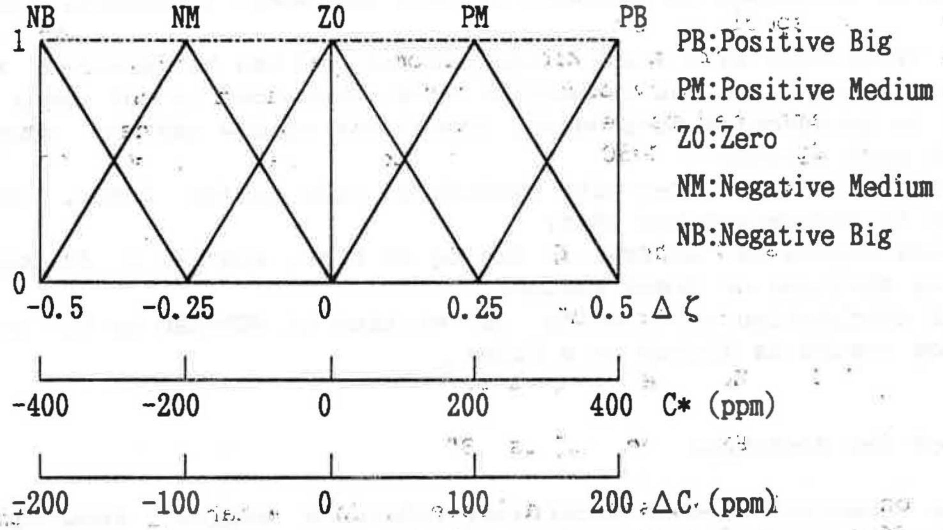

FIGURE 2. Five Triangular Fuzzy Numbers

TABLE 1. Fuzzy Control Rules

Δζ		ΔC				
		NB	NM	ZO	PM	PB
C*	NB	NB	NB	NM	ZO	ZO
	NM	NB	NM	NM	ZO	ZO
	ZO	NM	NM	ZO	PM	PM
	PM	ZO	ZO	PM	PM	PB
	PB	ZO	ZO	PM	PB	PB

C* : the difference between Copt(prescribed value) and C

ΔC : the difference between the previous value of C and the present one

Δζ : the modified parameter

and Table 1. In this table and figure C^* is the difference between the prescribed value Copt and the calculated value C, and ΔC is the difference between the previous value and the present one of carbon dioxide concentration in rooms. If modified parameters are obtained by a fuzzy chaining, new resistance coefficient is given by:

$$\zeta' = (1 - a*\Delta\zeta)*\zeta \qquad (4)$$

where a is the accelerated coefficient, $\Delta\zeta$ is the modified parameter. The triangular fuzzy numbers are used as a membership function to determine modified parameters using fuzzy control rules.

An Example of Consultation

The model of ventilation calculation and some constants are shown in Figure 3. The model has two rooms and a ventilation system. The fan flow rate and the duct resistance are controlled by the inference in order to set the carbon dioxide concentration of two rooms within the accepted values.

The wind pressure is specified by a certain meteorological condition and the generation rates of carbon dioxide in rooms are fixed. The rules to estimate fan size are written by production rules in first step, and the fuzzy control rules are used to determine duct resistances in next step. For example if C*=300ppm and ΔC=50 ppm, modified parameter $\Delta\zeta$ =0.2699 is given by fuzzy rules as:

if "C* is PM" ***and*** "ΔC is ZO" ***then*** "$\Delta\zeta$ is PM"

if "C* is PM" ***and*** "ΔC is PM" ***then*** "$\Delta\zeta$ is PM"

if "C* is PB" ***and*** "ΔC is ZO" ***then*** "$\Delta\zeta$ is PM"

if "C* is PB" ***and*** "ΔC is PM" ***then*** "$\Delta\zeta$ is PB"

The consultation results are shown in Table 2. In the table ζ_1 is the resistance coefficient of duct I, ζ_2 is that of duct 2. And C_1 is the

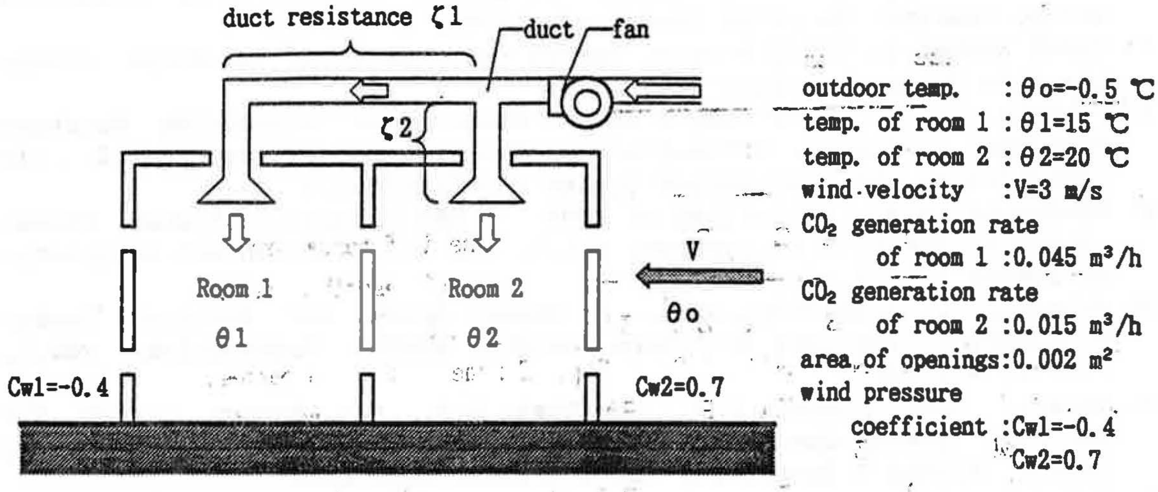

FIGURE 3. The Model of Ventilation

TABLE 2. Consultation Results

No.	Init. ζ_1	Init. ζ_2	ζ'	ζ_1	ζ_2	C_1(ppm)	C_2(ppm)	Iterations
1	2	2	$(1-\Delta\zeta)*\zeta$	3.97	31.96	790.8	755.0	21
2	2	20	$(1-\Delta\zeta)*\zeta$	2.89	29.42	760.4	750.7	6
3	2	2	$(1-2*\Delta\zeta)*\zeta$	3.59	31.98	779.6	756.1	15
4	2	20	$(1-2*\Delta\zeta)*\zeta$	2.99	29.90	763.2	751.8	3

carbon dioxide concentration of room 1, C_2 is that of room 2. The iteration number depends on the initial values of duct resistance coefficient and the correction equation of the coefficient. All the cases can succeed to keep the carbon dioxide concentration in the region of 750-850 ppm.

CONCLUSION

The prototype has shown that the two steps of inference determine the optimum parameters of the ventilation system after several iterations, where the first step gives the fan size and the second step applies the fuzzy theory to estimate the correction of the duct resistance coefficients. Especially the application of fuzzy theory is expected to allow us to control indoor air quality with considering the sense of human-beings, that is sometimes ambiguous. For a further development, the system may need the user interface such as the mouse and the window.

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