DYNAMICS OF AIR POLLUTION CONTROL FOR AN OBSTRUCTED ENCLOSURE

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ABSTRACT

A dynamic model for prediction of pollution in an obstructed enclosure has been developed. The mathematical model is based on coupled lumped parameter modeling of total volume of enclosure. The state space representation is established to compute time response of pollution in the system. The computed results have been verified by comparing with results of an established model based on computational fluid dynamics. The effects of incoming pollution from outside, produced indoor pollution from sources, and percentage of recirculated air have been investigated. The developed model considers maximum allowable indoor pollution and determines the required incoming flow rate in terms of percentage of recirculated air. As results of these analysis a design guidelines for determination of optimum flow rate and settlement time versus percentage of recirculated air are presented.

1. INTRODUCTION

An accurate determination of the indoor air pollution and the ventilation systems is often expected when designing a building. Therefore, a knowledge of the amount of pollution at all times and the required fresh air supply has been of practical importance as well as of the theoretical interest. The problem of dynamic response of the indoor pollution has been studied by several investigators. In most analyses distribution characteristics of air ventilation system and air quality control have been considered on the basis of computational fluid dynamics (CFD).

The other alternative approach is the lumped parameter method, also called the macroscopic model. In this technique, the whole enclosed medium can be divided into a number of sub-volumes. The time variation of continuation in sub-volumes can be formulated based upon continuity principles. The approach, due to ease of analysis, is very versatile in prediction of pollution concentration in different regions and its dispersion.

Attention has been confined in subsequent publications to obtain numerical solutions for prediction of pollution in an obstructed enclosure. For extensive literature review see references (1), (2), (3). In these analyses, the time variation of indoor pollution has been predicted using models based on computational fluid dynamics. Although these models are expected to provide accurate solutions, they require excessive computational time, and in most cases they are limited to simple cases.

$$q\, C_2 = V_3\, \dot{C}_3 + q\, C_3 - S_3 \tag{1.c}$$

$$q\, C_3 = V_4\, \dot{C}_4 + q\, C_4 - S_4 \tag{1.d}$$

$$q\, C_4 = V_5\, \dot{C}_5 + q\, C_5 - S_5 \tag{1.e}$$

$$q\, C_5 = V_6\, \dot{C}_6 + q\, C_6 - S_6 \tag{1.f}$$

Where q is the steady state flow rate, P is the percentage of recirculation, and S_i is the generated polutant in the i^{th} control volume. Also, the state space model will be given by the following equation.

$$\{\dot{C}\} = [\,A\,]\,\{C\} + [\,G\,]\,\{S\} + [\,B\,]\,C_{in} \tag{2}$$

where

$$\{\dot{C}\} = \frac{d}{d\,t}\,\{C\} \tag{3}$$

{C} is the concentration vector representing pollutant concentration at all control volumes. [A] is the state matrix, [B] is the input matrix [G] is the source matrix, {S} is the pollution generated for each control volume, C_{in} is the input pollution of the fresh air. The amount of contaminated concentration as a function of time are determined by solving eqn.(2) using Matlab programming.

3. VALIDITY OF THE SIMULATED MODEL

The lumped parameter model is compared with available data for the similar geometry of the system. In this case for a specific flow rate of 0.004 m^3/s time variation of concentrated pollutant at each control volume were determined and are presented in Fig.(2). For comparison, recirculation source, and incoming pollutant are not considered. A 100% initial condition for pollutant concentration at each control volume is assumed. The mean computed concentration from this case is compared with those determined using computational fluid dynamics (2). The comparison indicates that for the first fifteen minutes excellent agreement is achieved. However, for a longer period the results diverge from each other. This comparison is presented in Fig.(3) It is believed that due to very low incoming flow rate (natural ventilation) the computational model provides better accuracy because of the distribution of pollutant concentration within each control volume. Nevertheless, authors trust that at high flow rates (forced ventilation)

Among the investigators who have contributed to this area, Yamamoto et al., (4) have presented a direct solution to a multizone indoor contaminant distribution model. They provided an analytical tool to evaluate problems of indoor air quality and analyzed pollutant migration in the building.

This paper presents mathematical formulation of a lumped parameter model for obstructed enclosure. The validity of the presented model is examined and excellent agreement is established by comparing the obtained results with the available data based on computational fluid dynamics. Also, the effect of percentage of recirculated air on time response of pollution concentration at different regions for given flow rate has been studied. In addition, the design chart relating the minimum required flow rate and the settlement time for maximum allowable pollution concentration versus the amount of recirculated air for various height of obstacle have been determined.

2. STATE-SPACE SIMULATION

The physical system being considered is an enclosure with a partition. A portion of the exhausted air is being recirculated and added to the supplied fresh air. The system includes a pollution source at certain regions. Figure (1) depicts the schematic drawing of the model and the sub-volumes considered for the analysis. Average concentration for the i^{th} control volume is presented by C_i and V_i respectively. The govrning equations, conservation of mass, for control volumes are given in eqn.(1).

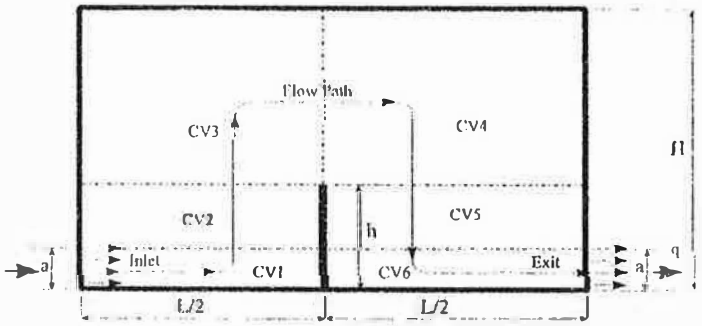

Figure 1. Schematic model for the obstructed enclosure
(H = 2.5 m, L = 4 m, h = 1 m, a = 0.2 m)

$$\frac{1}{100}\,[(100-P)\,C_{in} + PC_6]\;q = V_1\dot{C}_1 + q\,C_1 - S_1 \qquad (1.a)$$

$$q\,C_1 = V_2\,\dot{C}_2 + q\,C_2 - S_2 \qquad (1.b)$$

better agreement can be achieved.

4. EFFECT OF RECIRCULATION ON POLLUTANT DISPERSION

Assuming that the level of pollutant entering the considered enclosure, and indoor sources is zero the dispersion of pollutant at each control volume for a constant 5 air change pr hour (ACH) were determined. A typical dispersion curve for 20% recirculation (P = 20) is illustrated in Fig.(4). The results indicate that concentration at every control volume decays rapidly except in the first control volume for certain time. As it is shown when concentration in this volume reduces to the level of recirculation, the slope of the dispersion will be momentarily reduced by a considerable amount.

5. DESIGN REQUIREMENTS FOR INDOOR AIR QUALITY CONTROL

The required minimum air flow rates for different percentages of recirculation as well as settlement time for maximum allowable concentration are investigated. In the analysis, CO_2 is considered to be the only pollutant substance. The maximum allowable 1000 ppm in the enclosure, as recommended by ASHRAE (5), is assumed. In addition, a concentration of 345 ppm for incoming fresh air was considered. The time response for each control volume for an optimum flow rate at a specific recirculation percentage is computed and is presented in Fig.(5). To provide design guide-lines, variation of optimum flow rate for (99% of allowed pollutant is illustrated in Fig.(6).

6. CONCLUSION

A lumped parameter dynamic model for determination of pollution concentration at different region of an obstructed enclosure is introduced. This model is capable of considering the effect of recirculation, and possible pollutant sources within the enclosure. The computed results compared well with the available results obtained using computational fluid dynamic. The model was used to predict the optimum required flow rate for a set maximum allowable pollutant in the enclosure.

7. REFERENCES

1. Bejan, A.,Lage, J. L., and Anderson, R, 1991, "Efficiency of transient contaminant removal from a slot ventilated enclosure", Int. J. Heat Mass Transfer, Vol. 34 pp 2603-2615.

2. Delfanian, F., 1995, "Infiltration and obstructed ventilation effects on indoor air movement and pollutant removal", Ph. D. Dissertation, North Dakota State University.

3. Rieder, W., and Delfanian, F., 1991, "Simulation of airborne pollutant levels and infiltration flows in an enclosure", J, Solar Energy Engineering, Vol. 113, pp 236-243.

4. Yamamoto, T., Owen, M. K., Ensor, D. S., Sparks, L. E., Damle, A. S., Lawless, P. A., 1989, "Fast direct solution methods for multizone indoor model", Building systems: Room Air and Air Contaminant Distribution, ASHRAE publication.

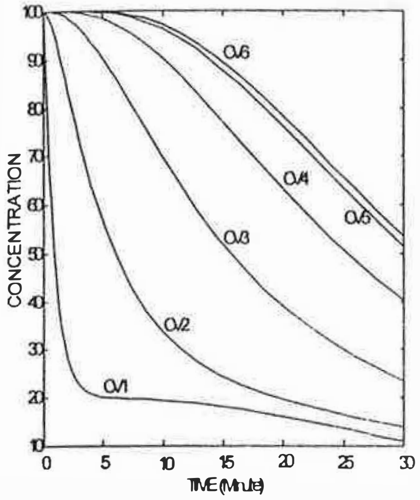

Figure 2. Pollutant concentration for control volumes

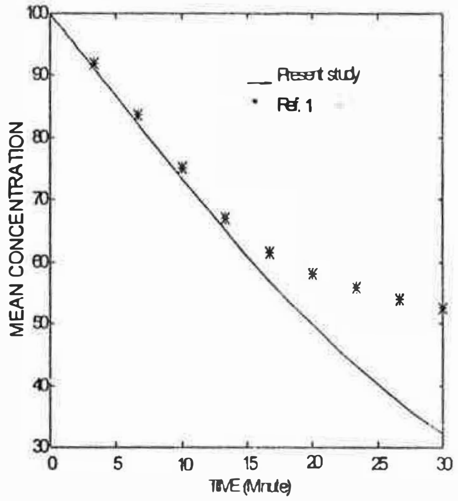

Figure 3. Comparisson of present results with those of Reffrence(2)

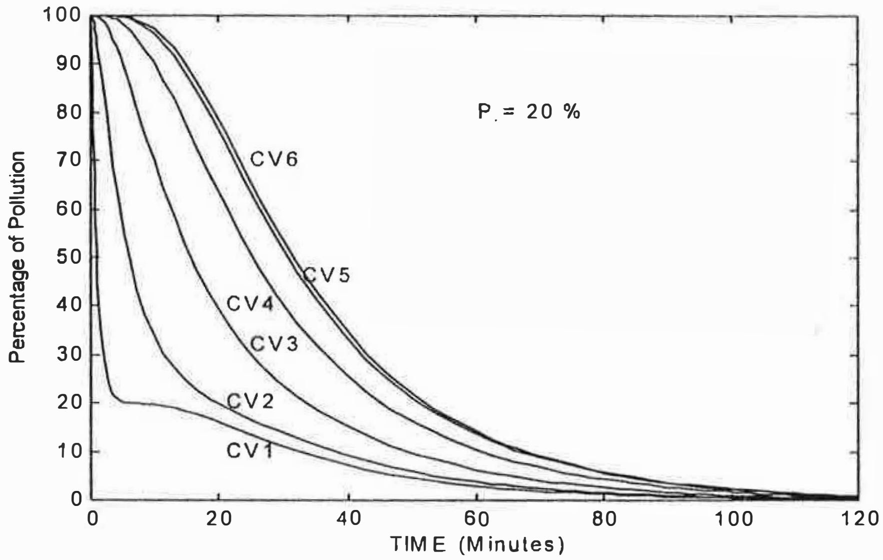

Figure 4. Pollutant disperssion curves for control volumes with 20% air recirculation

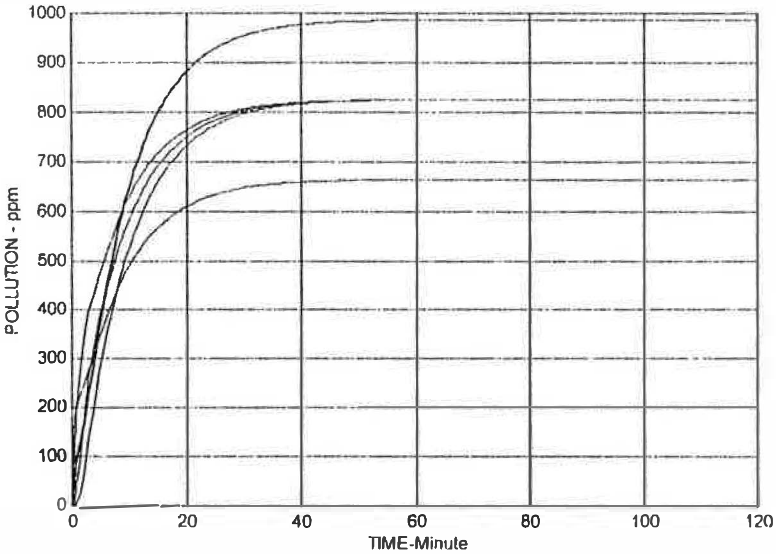

Fig. 5. Time response of pollutant in each control volume for 50% air recirculation

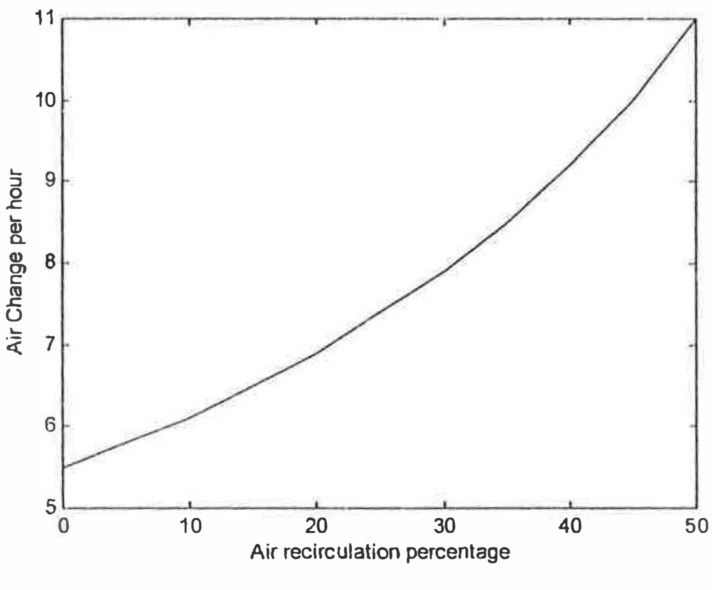

Fig. 6. Optimum required ACH versus the percentage of air recirculation