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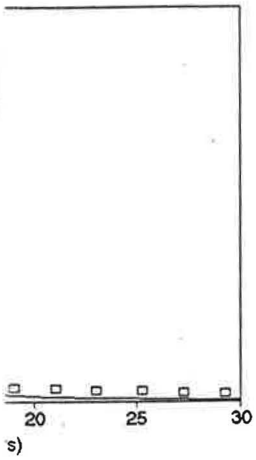

Ethylbenzene

DEVELOPMENT OF A THREE-DIMENSIONAL NUMERICAL MODEL TO INVESTIGATE THE AIR FLOW AND AGE DISTRIBUTION IN A MULTI-ZONE ENCLOSURE

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The airflow pattern and air age distribution in a ventilated two-zone enclosure are investigated by numerical simulation. A three-dimensional turbulent flow is considered. The two zones are connected through a door opening. The air supply opening is located on an end-wall near the ceiling of one zone, while the exhaust opening is on the ceiling of the other zone. The airflow and air age distribution under five door locations are compared for a ventilation rate of 2.5 ACH. The average ages in both zones are presented as a function of door position. It is found that the average air age in the upstream zone is less affected by the door position than that in the downstream zone, and that the door position near the side-walls is expected to give better air circulation.

INTRODUCTION

Knowledge of ventilation effectiveness and airflow patterns is important in the development of control strategies for indoor air quality in an energy-efficient manner. Traditionally, the ventilation systems have been designed based on the assumption that the supply air and the pollutant are well mixed throughout the ventilated space. Similarly, current theoretical models and computer simulation programs are based on the same assumption [1]. Recent investigations have brought the validity of this assumption under question and have shown that large errors could be expected in their performance when perfect mixing assumptions are made [2].

The term "age of air" has been used to describe the transport properties of ventilation systems that do not produce perfect mixing. A number of concepts has been developed [3]. Sandberg and Sjoberg [4] and Skaret [5] introduced the concept of "age of air" to determine average ventilation system performance. The age distribution provides useful information to evaluate the uniformity of the air freshness within an enclosure.

The prediction of pollutant migration in a ventilated space is not an easy task. In a single enclosure, the flow pattern depends on building geometry, source characteristics, position and dimension of air supply and return, air flow rate, etc. When the enclosure is divided by a partition with a door opening in it, the door position is an additional parameter influencing the pollutant migration pattern.

This paper studies the influence of door location on the airflow pattern and the air age distribution in a ventilated two-zone enclosure. The purpose of this study is to examine: (1) the air age distribution in a ventilated enclosure with the door located in the middle of the partition, and (2) the effects of door opening position on the ventilation effectiveness, and the variation of the average age for the two zones.

ANALYSIS

A two-zone enclosure with a supply at the middle of the end-wall in zone A, and a return on the ceiling of zone B, as shown in Figure 1, was employed for numerical simulation. The two zones are connected by a door opening on the partition. The dimensions of the door, the supply and return, listed in Table 1, remain fixed throughout this study. In Table 1, h, b, and l represent the height, width, and the length respectively.

TABLE 1 The Dimensions of the Opening

	door	supply	return
h/H	0.75	0.083	0.056 (1/L)
b/W	0.17	0.083	0.083

The door is placed at five positions, as listed in Table 2, while the partition remains at the middle of the enclosure. The air velocity at the supply opening is 1.0m/s, which provides a ventilation rate of 2.5 ACH.

TABLE 2 Door Opening Position

CASE	1	2	3	4	5
y_D/W	0.17	0.33	0.50	0.66	0.83

With the Bossineqe assumption, the governing equation for the three-dimensional isothermal flow and concentration field can be written in the following conservation form.

$$\frac{\partial \rho\phi}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i \phi) = \frac{\partial}{\partial x_i}\left(\Gamma_{\phi,eff} \frac{\partial \phi}{\partial x_i} \right) + S_\phi \qquad (1)$$

where ϕ indicates each of dependent variables, such as velocity components in three directions, contaminant concentration, and the turbulent properties, k and ε. The computation of k and ε is required due to the k-ε two-equation model of turbulence adopted in this study.

The ceiling, floor, and walls are considered to be well insulated, therefore, an isothermal airflow would be assumed. Besides, the thickness of the partition is considered to be negligibly small in comparison with the length of the enclosure.

The air age (mean value) at a point is defined as the time τ that has elapsed (on average) since the air entered the enclosure. The local mean age of air is computed by the following form [4]:

$$\tau_p = \frac{1}{c_0} \int_0 c$$

where c_0 is the initial

$c_p(\tau)$ is the local conce

own conservation equatic

The average age of

$$\tau = \frac{1}{V_i} \int_{v_i} \tau_p d$$

where V_i represents the v

The computation w system, and the numeric Refs. [6,7].

RESULTS

In this study, the the time needed to replac

$$\tau_n = \frac{\text{the v}}{\text{the vol}}$$

The average air ag locations are presented i much smaller than that in air age is decreased whe y/W=0.17 northward to y/W largest value when the do The average air age de central position towards

Figure 3 illustra horizontal sections for The air age in zone A is or the vertical section the air circulation in t that in the north part. I smaller than that in the located on the ceiling, other areas. It is noted air age in zone B is quit

Figure 4 demonstra vertical section y/W=0.1 the upstream zone, zone A Ref. [7]. As a result, the each other. The local ag downstream zone, zone B, is lower than that for t 1, the vertical section enters zone B without tra

At the horizontal

$$\tau_p = \frac{1}{c_0} \int_0 c_p(\tau)\, d\tau, \qquad (2)$$

where c_0 is the initial contaminant concentration of the enclosure, and $c_p(\tau)$ is the local concentration at time τ, which is determined by its own conservation equation.

The average age of each zone is calculated as

$$\tau = \frac{1}{V_i} \int_{V_i} \tau_p\, dV, \qquad (3)$$

where V_i represents the volume of the zone.

The computation was carried out in a 20×14×14 uniform mesh system, and the numerical procedure is similar to that described in Refs. [6,7].

RESULTS

In this study, the air age is normalized by a reference time τ_n, the time needed to replace the air in the enclosure;

$$\tau_n = \frac{\text{the volume of the enclosure}}{\text{the volume flow rate of supply air}}.$$

The average air ages of the two zones for five different door locations are presented in Figure 2. The average air age in zone A is much smaller than that in zone B for all cases. In zone A, the average air age is decreased when the door opening is moved from the position y/W=0.17 northward to y/W=0.833. In zone B, the average air age has its largest value when the door is located in the middle of the partition. The average air age decreases as the door opening moves from the central position towards the walls.

Figure 3 illustrates, the age distributions in vertical and horizontal sections for case 3 (door at the middle of the partition). The air age in zone A is decreased when the horizontal level rises up or the vertical section moves from south to north. This indicates that the air circulation in the south part of the zone is not as good as that in the north part. In zone B, the local age in the lower region is smaller than that in the higher region, since the exhaust opening is located on the ceiling, where the air age is always higher than in other areas. It is noted that in the region near the southern wall, the air age in zone B is quite uniform.

Figure 4 demonstrates flow patterns and age distributions at the vertical section y/W=0.13, for cases 1, 3 and 5. The flow patterns in the upstream zone, zone A, strongly resemble each other, as observed in Ref. [7]. As a result, the age distributions in this zone are similar to each other. The local age is increased from ceiling to floor. In the downstream zone, zone B, the average air age in this section for case 1 is lower than that for the other two cases. The reason is that in case 1, the vertical section crosses the door opening, and the fresh air enters zone B without traveling a long way in zone B.

At the horizontal section near the floor, z/H=0.04, as shown in

Figure 5, there is an increase in the local age from the partition to the western wall in zone A for all cases. The average age of zone A in this section rises when the door opening is moved from north to south. This is due to the fact that the exhaust opening is located near the northern wall, and the air in zone A is sucked into the exhaust with less resistance when the door opening is close to the exhaust (case 5). In zone B, the local age increases from the partition to the eastern wall for case 1. In the other two cases, the age in the central areas are higher than in the periphery, since the air movement is in a rotational form.

CONCLUSION

The airflow pattern and the air age distribution in a ventilated partitioned enclosure are predicted by numerical simulation. Effects of door opening positions on the air movement are also investigated. The following conclusions are drawn from this investigation:

- The average air age in the upstream zone is much lower than the age in the downstream zone (their ratio is about 0.6);
- The average air age in Zone A is decreased with the door opening moving from the southern wall towards the northern wall;
- The central position of the door opening results in the highest average age in the downstream zone. When the door opening is moved to either side, the average age in this zone is decreased.

For such an arrangement of supply and exhaust openings as described above, the best location for a door opening in the partition seems to be near the southern wall.

REFERENCES

[1]. Haghighat F (1989) Air infiltration and indoor air quality models - a review, International Journal of Ambient Energy 10:1-8.

[2]. Haghighat F, Fazio P, Rao J (1990) A procedure for measurement of ventilation effectiveness in residential building, Building and Environment.

[3]. Liddament M W (1987) A review and bibliography of ventilation effectiveness - a definitions, measurement, design and calculation, AIVC, AIC-TN-21.

[4]. Sandberg M, Sjoberg M (1983) The use of moments for assessing air quality, Building and Environment, 18:181-197.

[5]. Skaret E (1984) A survey of concepts of ventilation effectiveness, SINTEF, report STFIS A4057.

[6]. Haghighat F, Jiang J, Wang J C Y (1989) Natural convection and air flow pattern in a partitioned room with turbulent flow, ASHRAE Transactions, 95: Pt. 2.

[7]. Haghighat F, Wang J C Y, Jiang Z (1990) Three-dimensional analysis of airflow pattern and contaminant dispersion in a ventilated two-zone enclosure, ASHRAE Transactions, 96: Pt. 1.

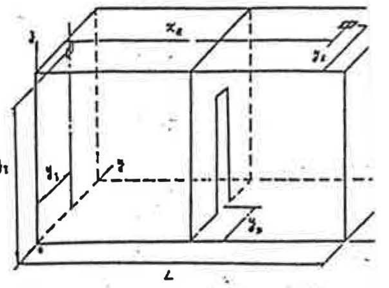
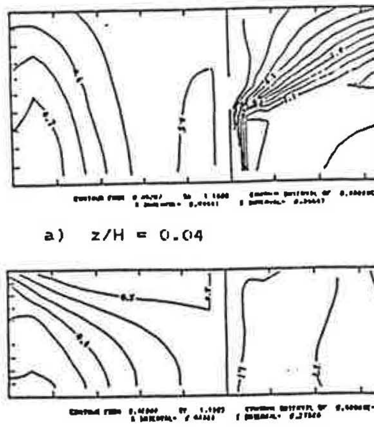


Fig. 1 Configuration of the two-zone

$Y_I/W = 0.50$ $z_I/H = 0.88$

$Y_E/W = 0.88$ $x_E/L = 0.75$

LxWxH = 10Mx4Mx3M



a) z/H = 0.04

c) y/W = 0.13

Fig.3 Age contours

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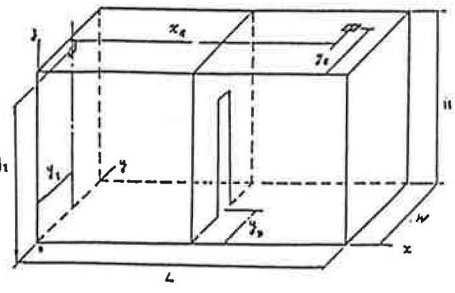

Fig. 1 Configuration of the two-zone enclosure

$Y_I/W = 0.50$ $z_I/H = 0.80$

$Y_E/W = 0.88$ $x_E/L = 0.75$

LxWxH = 10Mx4Mx3M

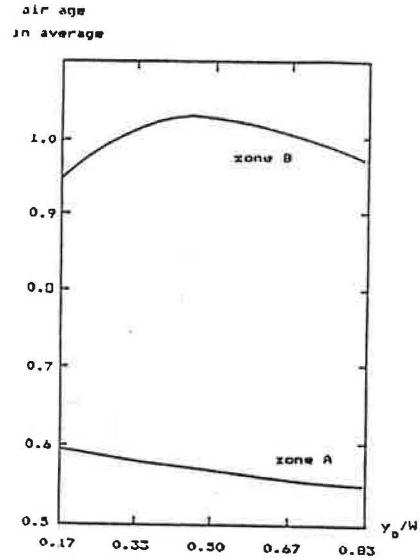

Fig. 2 Variation of average air with door position

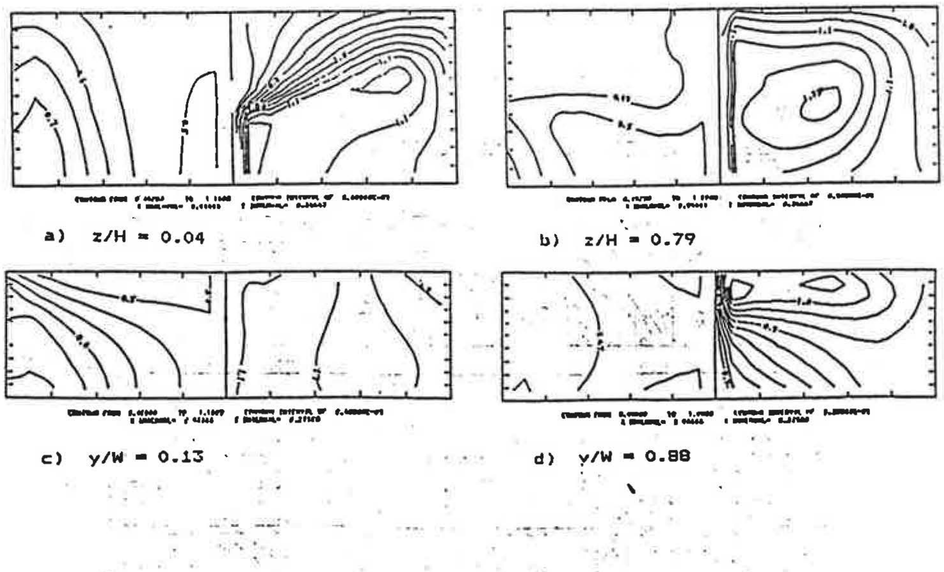

Fig.3 Age contours for the case with $y_D/W = 0.5$

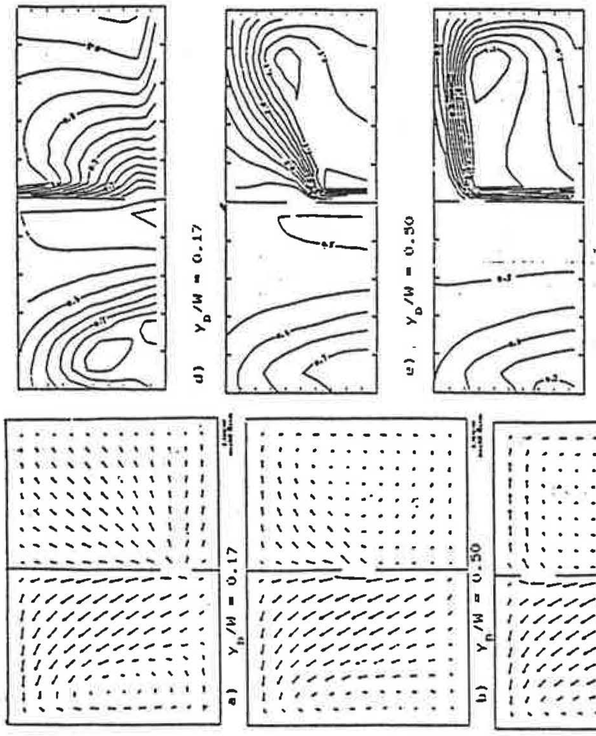

Fig. 5 Airflow patterns and age distributions at z/H = 0.04

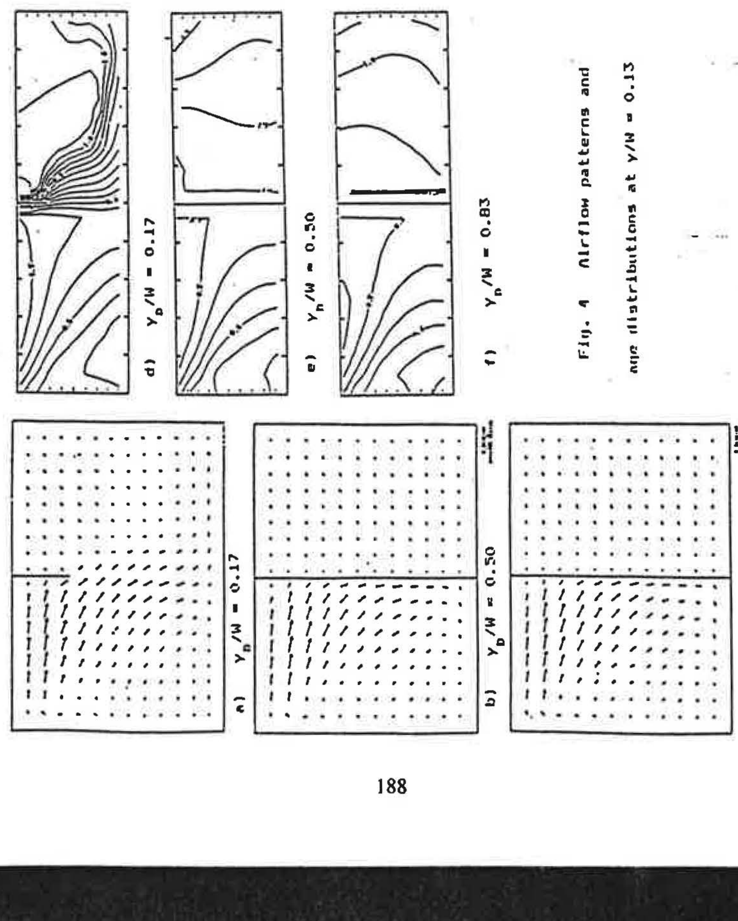

Fig. 4 Airflow patterns and age distributions at y/W = 0.13

A MATHEMATICAL MODEL TO PRED
IN OPERATING THEATRES.

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Acceptable exposure to indoor
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INTRODUCTION

Ventilation strategies are of
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Recently we performed a workp
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and predict nitrous oxide leve