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VENTILATION EFFECTIVENESS IN A PARTITIONED OFFICE WITH DISPLACEMENT VENTILATION

Jiang, Z.
Centre for Building studies
Concordia University
Montreal, Quebec, Canada

Haghighat, F.
Centre for Building studies
Concordia University
Montreal, Quebec, Canada

ABSTRACT

Unlike conventional ventilation systems, the displacement ventilation system supplies air in the low region of a room while the exhaust opening is usually placed near ceiling. When partitions are used in the occupied zone, the diffusion of supply air may be obstructed. Thus, the existence of the partition may present more significant effects on the air diffusion and retard the contaminant removal more seriously in displacement ventilation systems.

This study concerns the effects of office partition layout on air diffusion and indoor contaminant control in a large partitioned office equipped by a displacement ventilation system. The investigation is conducted by computer simulation for three-dimensional turbulent flow with k-ϵ two-equation model of turbulence. The average contaminant concentrations and age of air in each chamber are taken as indicator in evaluation of the air exchange efficiency and ventilation effectiveness under five different partition layouts.

It is found that the displacement ventilation system provides fresher air to all chambers than a conventional ventilation system, and that a proper arrangement of office partition can reduce the overall concentration level by about 37 percent. With partition being place in the office, the advantage of displacement ventilation, may not be very pronounced.

INTRODUCTION

Indoor contaminants are the major cause of poor indoor air quality [1]. The recent trends of the extensive use of electronic office equipments and the efficient use of office space would inevitably increase the potential danger of high level of indoor contaminant in the working space. Dividing an office into a number of individual workstations is a common practice for efficient use of the office space, which, can provide privacy, but, on the other hand, may cause contaminant retardance in the occupied zone. The degree at which the contaminant removal is affected depends on the partition layout, the position of the contaminant source and the type of ventilation systems, etc.

During the past twenty years, displacement ventilation has been used widely in Scandinavian countries in industrial buildings where special indoor contaminant control is needed. Recently, its application has been extended to office buildings. Displacement ventilation systems supply air at the floor level and exhaust it near the ceiling. This creates inlet condition for the occupied zone and removes the indoor contaminant more efficiently. During summer cooling, the displacement ventilation system increases the temperature stratification in a room, and thus, increases the temperature difference between supply inlet and exhaust so that the cooling efficiency can be increased.

The performance of displacement ventilation system has been examined in previous studies, for example, Chen et al [2], Koganei et al. [3], Stymne et al. [4] and Jiang et al. [5]. However, the influence of partitions on the room air diffusion and contaminate removal with displacement ventilation has not been well understood.

The concentration of indoor contaminant varies rapidly from place to place, and it is usually higher in the occupied zone. The use of partitions can increase the non-uniformity of the contaminant distribution. If the performance of a ventilation system meets the needs of an office without partition, it does not mean that it can also satisfy the demand of the same office after being partitioned. Even changing the arrangement of the partitions can result in the remarkable difference in indoor contaminant level. Now, the question is: how partition layout will affect the contaminant removal in an office ventilated by a displacement ventilation system, and how much?

With ceiling mounted four-way diffusers, the influence of partition layout in an office on contaminant control in an office has been assessed by numerical simulation [6,7]. The office was divided into six individual workstations. Four different layout designs were compared. With a fixed partition arrangement, a contaminant source was placed at different position to clarify the role of indoor air diffusion in contaminant control. However, the influence of partition layout could be different when different ventilation systems are used.

OBJECTIVE OF PRESENT STUDY

The objective of the present study is to evaluate the influence of partition layout on the indoor contaminant level and the air freshness in an office ventilated by displacement ventilation system.
Five partition layout designs for the office are investigated and compared in terms of the overall contaminant level in the entire office, the average concentration and the age of air [8] in each chamber.

The methodology adopted in the study is computer simulation. The discrete conservation equations are solved by the SIMPLE iteration procedure [9], and the turbulence flow is described through k-ε two-equation model of turbulence [10].

CASE DESCRIPTION

The configuration and dimension of the office being studied is demonstrated in Figure 1. The displacement diffuser, located in the back wall, is 1.1 m in height and 0.8 m in width. With an effective area ratio of 0.8, the effective flow area of the diffuser is 0.71 m^2. The supply air velocity at the diffuser is 0.28 m/s, providing 3 ach for the office. The exhaust opening is located near the ceiling on the front wall opposite to the diffuser, having an area of 0.8x0.3 m^2.

The office is divided into four or six chambers by partitions with 0.05 m thick and 1.5 m high. Since the diffuser is installed in the occupied zone, the existence of partition may block the supply airflow. Therefore the possible partition layouts should at least not create a direct obstacle to the supply air. Figure 2 presents five possible arrangements that are expected not to block the supply air. The chamber numbering is indicated in Figure 2 as well. Case 4 is designed by removing the four partitions in west-eastern direction, while a 90 degree rotation of the partitions in Case 4 makes Case 5.

There is a contaminant source in Chamber 1 with an emission rate normalized to be unity. The isothermal situation is considered.

RESULTS AND DISCUSSIONS

To make the analysis simple, we will put Cases 1, 2 and 3 in one group to be compared, and then discuss the other group consisting Cases 3, 4 and 5.

Figure 3 shows the overall concentration in the entire office and the average concentration in each chamber of the office with five different partition layouts. The contaminant concentrations in the office without partition are also indicated.

Case 1 shows an apparently higher overall concentration than other cases. The contaminant concentration in Chamber 1 (the source chamber) is as high as 16.5 and in Chamber 2 is also quite high (7.50), while the concentration in the opposite chambers are significantly lower. The reason for that may be found by examining its airflow pattern. Figure 4 shows the velocity vectors in a horizontal section and two vertical sections. Since the layout of the partition and supply device are symmetric about the central plane of the room from west to east, the airflow is symmetrical too (see Figure 4a). Thus, the air velocity across the symmetric plane is theoretically equal to zero, and so is the mixing of air between the northern and the southern parts of the room. As a result, Chambers 3 and 4 can remain less contaminated. Chamber 2 is located in the down stream of the contaminant source, therefore is directly invaded by contaminant convection. Figure 4a shows that the air can hardly enter the area containing the contaminant source, resulting in a "dead zone" around the source. The contaminant in Chamber 1 is removed mainly by the back flow from the ceiling as shown in Figures 4b and 4c, which elevates the concentration in the chamber.

In order to provide some overall view about the contaminant dispersion, the contaminant distributions in corresponding sections are presented in Figure 5.

Case 2 has the lowest overall concentration among the five. The ventilation air from the diffuser flows directly into the source chamber and dilutes the contaminant in this chamber more effectively than in Case 1 (see Figure 6a). Figure 6b demonstrates how the contaminant in the Chamber 1 is removed and shows the reason that makes the concentration in Chamber 3 higher than in Chamber 2. It is observed that there is a air recirculation in Chamber 3, which may bring the contaminant from the area near the exhaust opening back to the chamber and causes a higher concentration there. Figures 6c and 6d show the contaminant distributions in the region near the source.

From the view point of overall contaminant removal, Case 3 lies between Cases 1 and 2. However, the average concentration in the source chamber is the highest among the cases. It may be so explained that the displacement diffuser is located in a channel formed by the four partitions in the west-eastern direction, therefore, it is not easy for the ventilation air to be mixed with the contaminant in Chamber 1, as seen in Figures 7a and 7c. The air recirculation in Chamber 1, seen in Figure 7b, may also be a cause of the contaminant accumulation in the chamber (see Figure 7d). The overall concentration, which is lower than that in Case 1, indicates that the partition layout in Case 3 prevents the contaminant dispersion into other chambers more effectively than the layout in Case 1 does.

For the same partition layout as in Case 3, the overall contaminant level and the average concentrations in Chambers 1-6 with a ceiling-mounted diffuser are also computed and presented in Table 1. These figures are all higher in displacement ventilation. It may indicate that displacement ventilation is not suitable for partitioned offices.

When removing the four partitions in the west-eastern direction, we found that the average contaminant concentration in the source chamber descends from 20.5 to 17.15 in the expense of the overall concentration increase from 4.81 to 5.50. The reason is that the contaminant emitted from the source is less confined to Chamber 1, and the air can move more freely. The contaminant dispersion in the room is consequently enhanced.

To compare with Case 3, Figure 8 shows the velocity and concentration distributions for Case 4.

In Case 5, the two pairs of parallel partitions in Case 4 are turned from the west-east to the north-south. The overall concentration in this case is found to be close to the same as in Case 4, but the average concentration in Chamber 1 is reduced from 17.15 to 12.7. However, this figure may not mean an improvement of the contaminant removal from Chamber 1, because in Case 5, the volume of Chamber 1 with which the average carried out is larger. It makes the average value smaller. The average concentration in Chamber 2, the direct downstream of the contaminant source is surprisingly lower than those in Chambers 3 and 4 that seem to be well separated from the contaminant source in Chamber 1. Although there is no partition between Chambers 1 and 2, the convection between the two chambers may be quite weak. Figure 9 shows the flow patterns in Case 5. The form of air circulation (see Figure 9b) may prevent, to a certain extent, the contaminant in Chamber 1 transporting to Chamber 2 through convection, and therefore can reduce the concentration level in Chamber 2.

The overall concentration in the entire office and average concentration in the occupied zone (under 1.9m) of the office without partition is 3.86 and 4.0, respectively, lower than most cases except Case 2. It means that with the existence of partitions, the movement of supply air may be retarded in the region near supply opening. Hence overall contaminant and the contaminant level in the occupied zone can become higher than the case without partition. The advantage of displacement ventilation is diminished unless the partitions are properly arranged.

The average age of air in each chamber for the five cases are presented in Figure 10. The layout of Case 5 gives the worst air freshness in the chambers, as seen in Figure 10, since the ventilation air, being guided by the partitions, may not be easy to enter the chambers. Case 2 seems to be the best. It is noted that, for all cases except Case 2, Chamber 1, although located closer to the supply diffuser, has the highest average age of air among the chambers, and the age of air in the chamber near the eastern wall is relatively low. It implies that the supply air does not enter Chamber 1 directly from the diffuser. Instead, it circles around the office before entering Chamber 1.

CONCLUSIONS

The effects of different partition layouts on the ventilation effectiveness and air exchange efficiency in a large office are investigated by computer simulation. The ventilation air is supplied into the office by a displacement diffuser located in the back wall, and is evacuated from the office through an exhaust opening near ceiling on the front wall. The indoor air quality is assessed by (1) the overall concentration in the office and (2) the average contaminant concentration and (3) the average age of air in each chamber. After evaluating five different partition arrangements, the following conclusions may be obtained:

- The air freshness is not directly related to the number of partition used in the office but to the arrangement of the partitions.
- The average age of air in the chamber closest to the diffuser may be higher than that in the chamber far apart from the diffuser.
- In order to remove the contaminant from its source chamber, the source chamber should be exposed directly to the supply air (Case 3 for example).
- Using more partition may diminish the dispersion of contaminant over the entire region of the office, but the average concentration in the source chamber may become higher (compare Cases 1 and 3, or Cases 3 and 4).
- With tendency of air movement from floor to ceiling, contaminant source near the floor is the upstream of air movement. Therefore in general, the occupied zone in the displacement ventilation is cleaner than that in conventional ventilation while the overall

concentration may be higher. With the existence of partitions, the movement of supply air could be retarded in the region near supply opening. Hence contaminant level in the occupied zone could become high. The advantage of displacement ventilation is diminished unless the partitions are very carefully arranged.

The mode of contaminant dispersion can be different when considering buoyancy flow. However, the present study demonstrates that, by means of computer simulation, we are able to assess a number of possible partition arrangements and to determine which one is most suitable to their particular requirements.

ACKNOWLEDGEMENT

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Table 1 Contaminant concentrations in displacement and mixing ventilation

	Overall	No. 1	No.2	No.3	No.4	No.5	No.6
displacement	4.81	20.50	5.21	3.46	2.45	2.16	2.0
ceil. diffuser	1.90	10.99	0.42	0.29	0.24	0.13	0.14

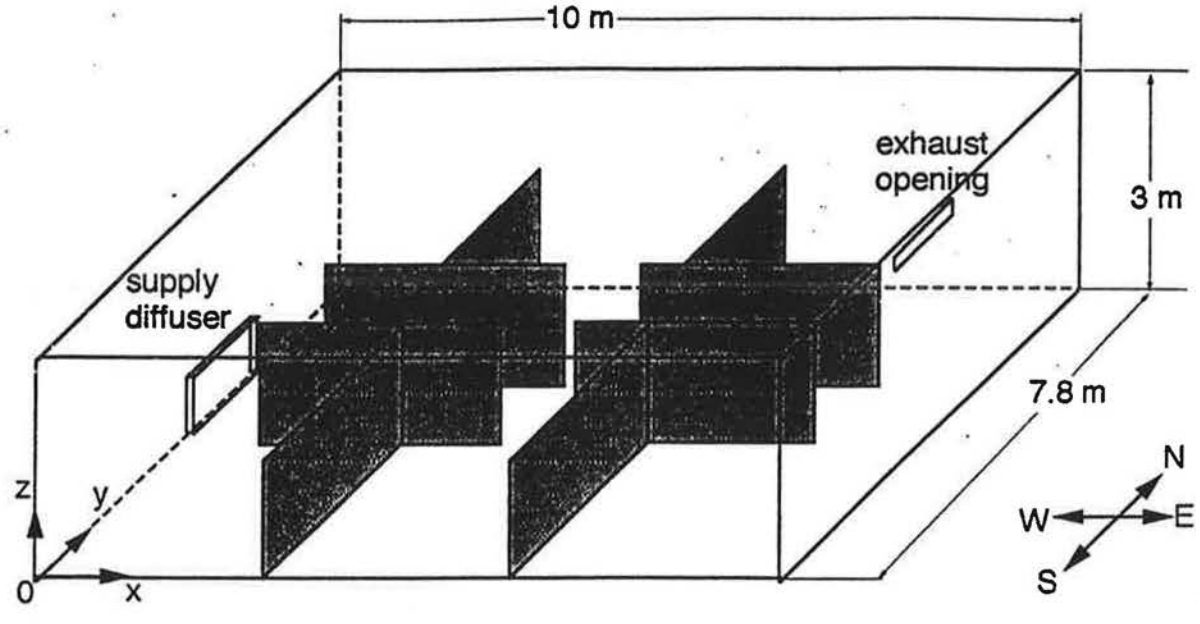
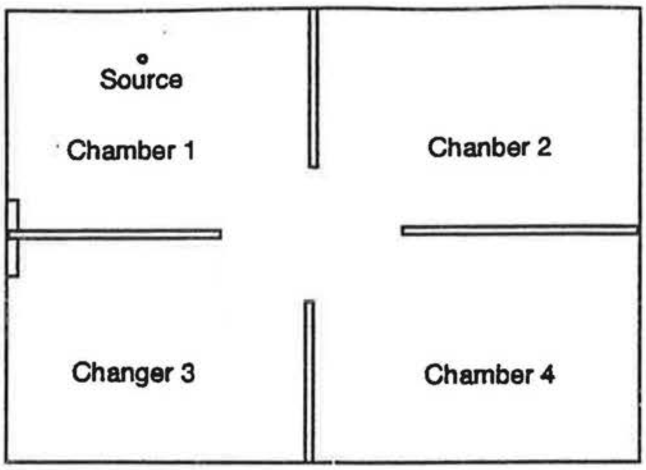
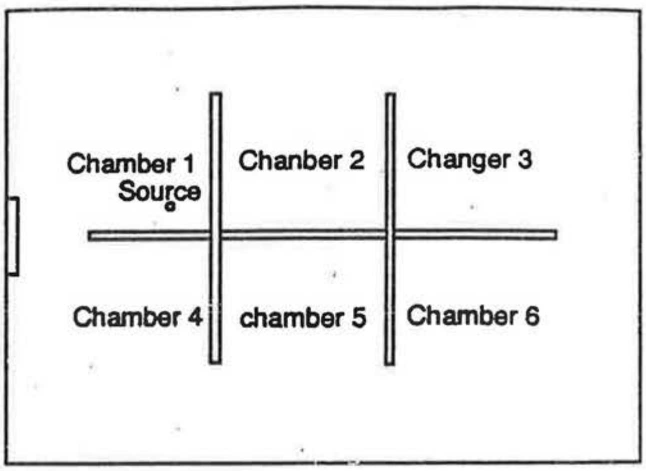


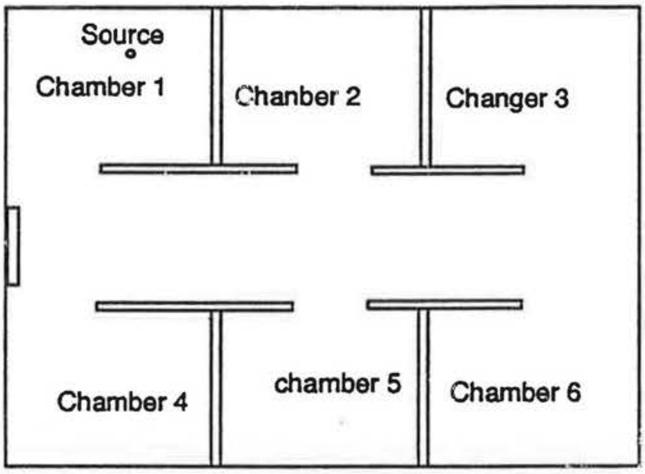
Figure 1 Partitioned office equipped with displacement ventilation system



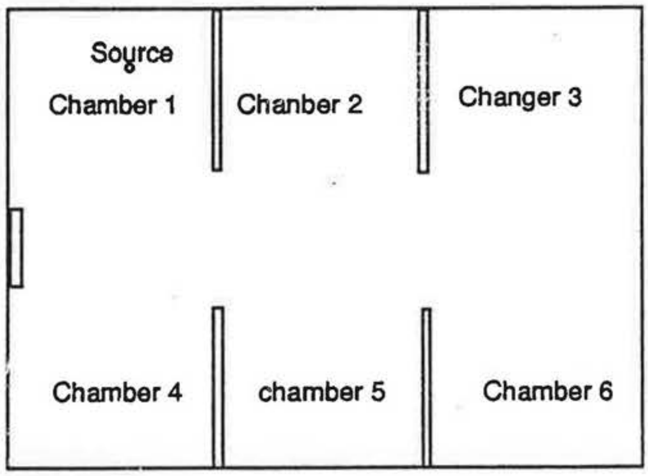
Case 1



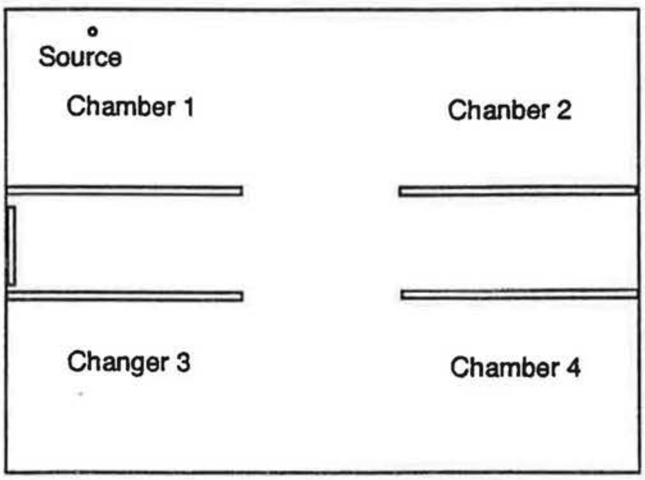
Case 2



Case 3

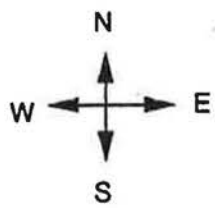


Case 4



Case 5

Figure 2 Five layout for partitions



without partition

Overall concentration: 3.8
average concentration in occupied zone: 4.0

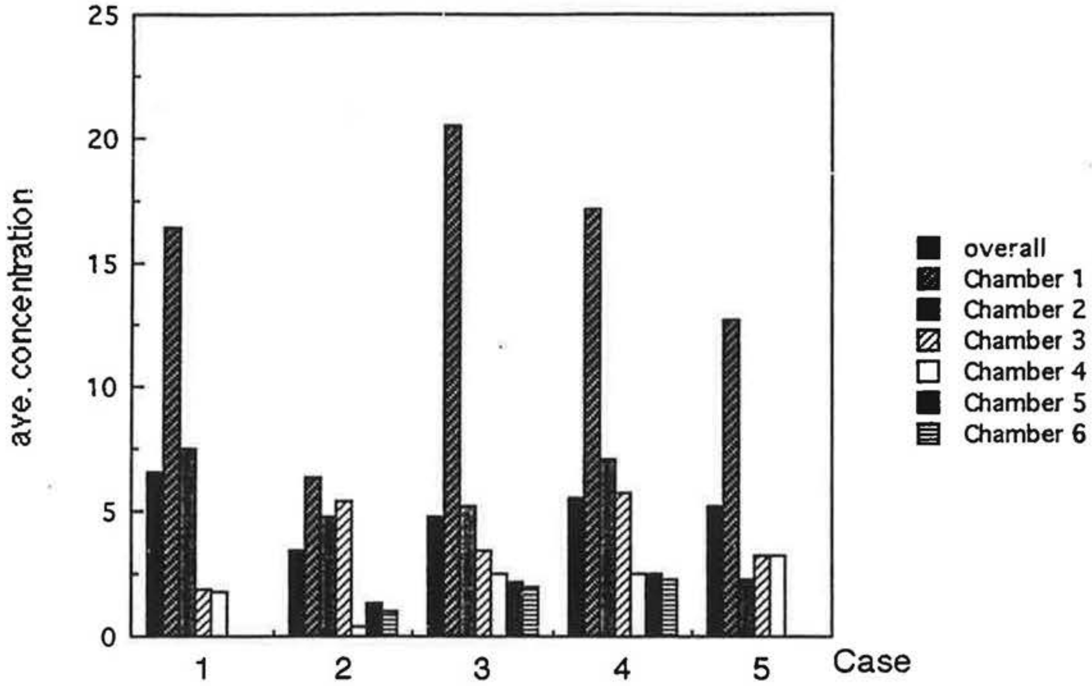
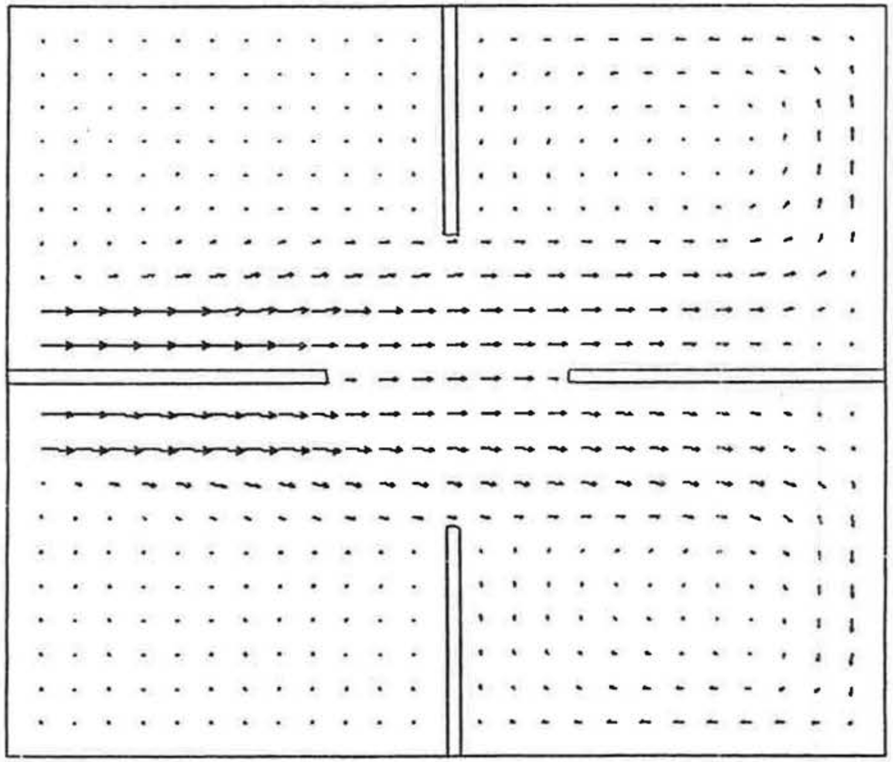
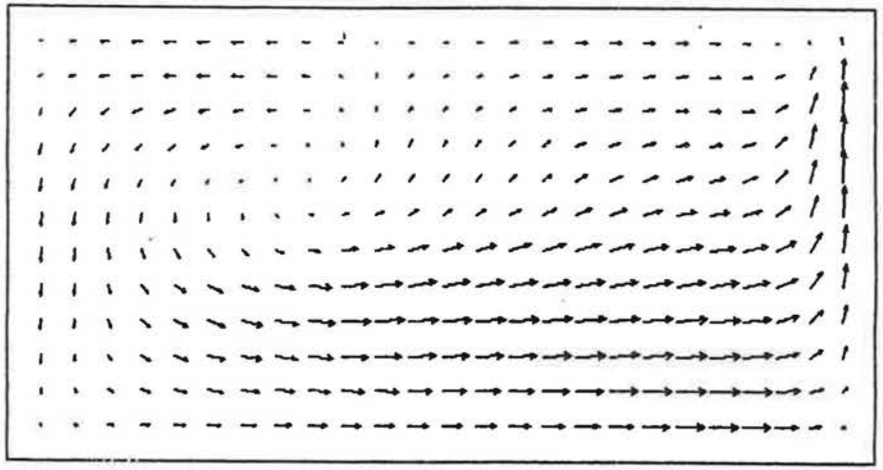


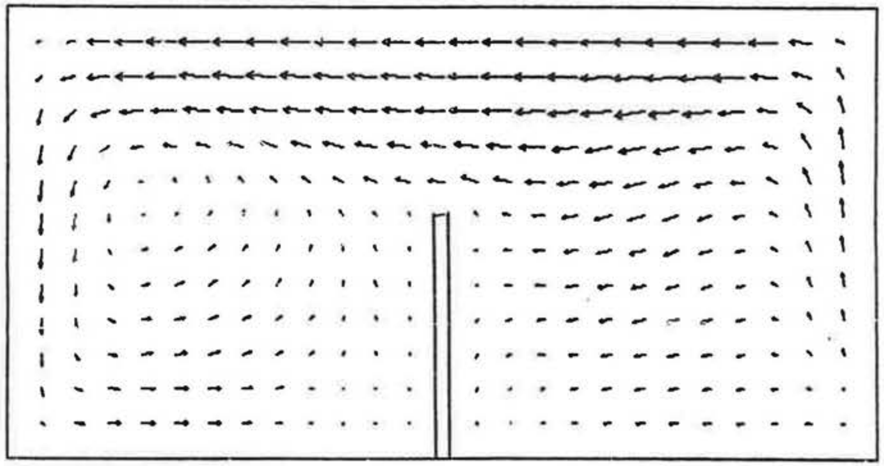
Figure 3 Overall concentration in the office and average concentration in each chamber



a) Horizontal section z/H=0.27 Maximum Vector 0.281

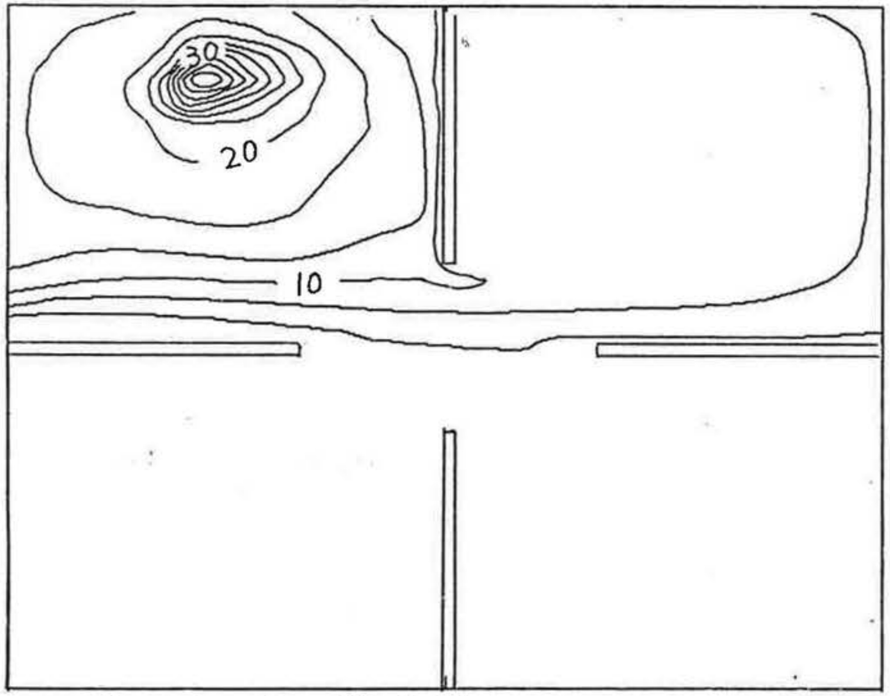


b) Vertical section y/W=0.63 Maximum Vector 0.092

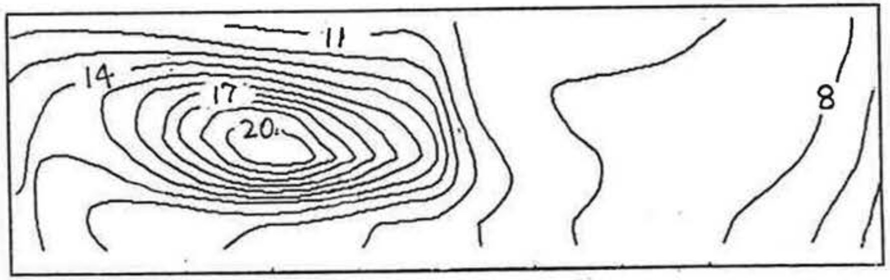


c) Vertical section y/W=0.88 Maximum Vector 0.073

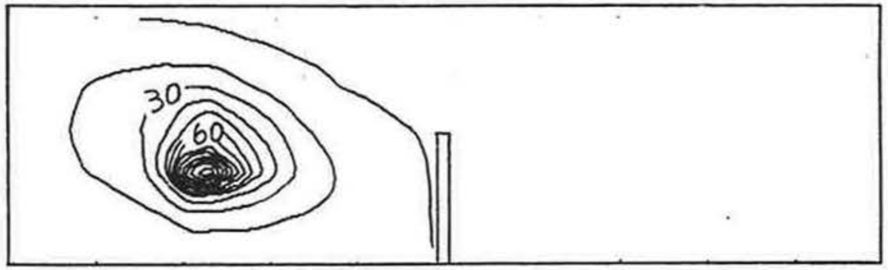
Figure 4 Velocity distribution in Case 1



a) Horizontal section z/H=0.27

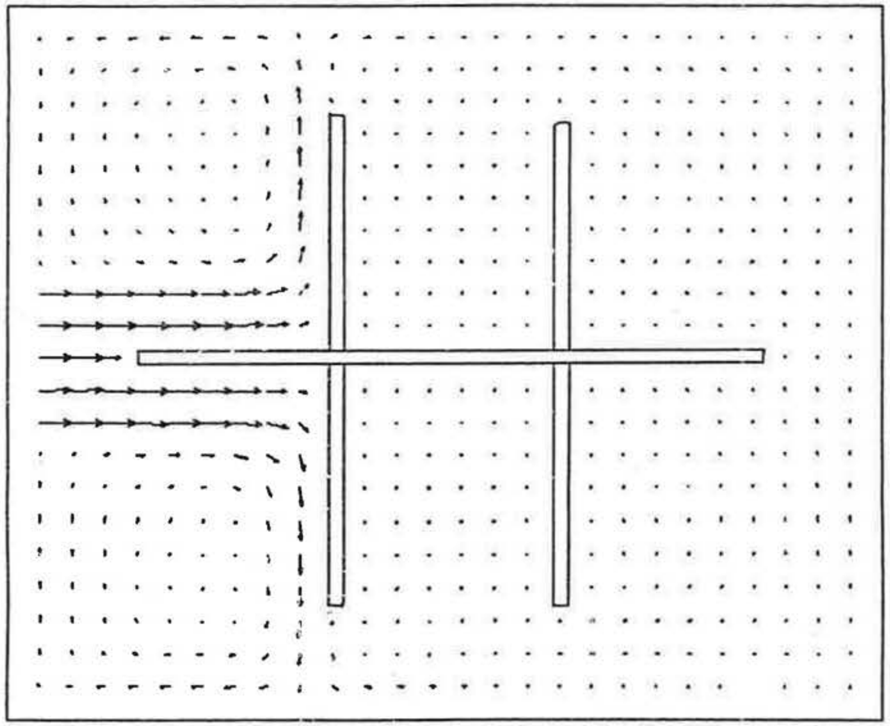


b) Vertical section y/W=0.63

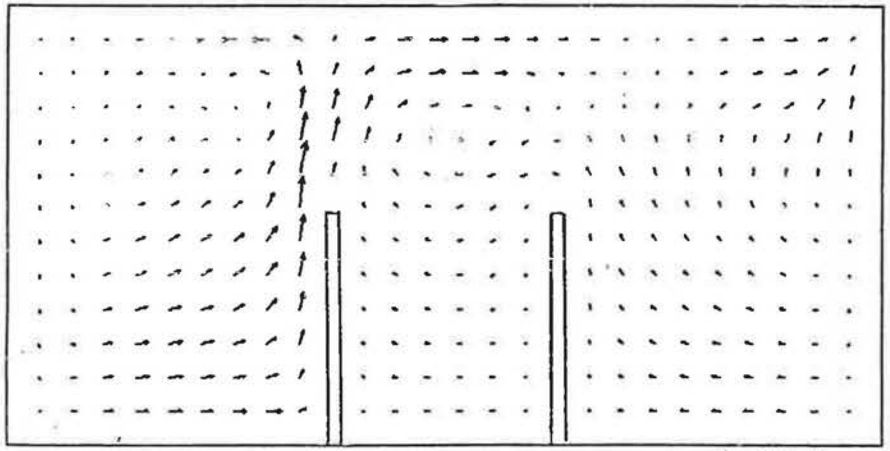


c) Vertical section y/W=0.88

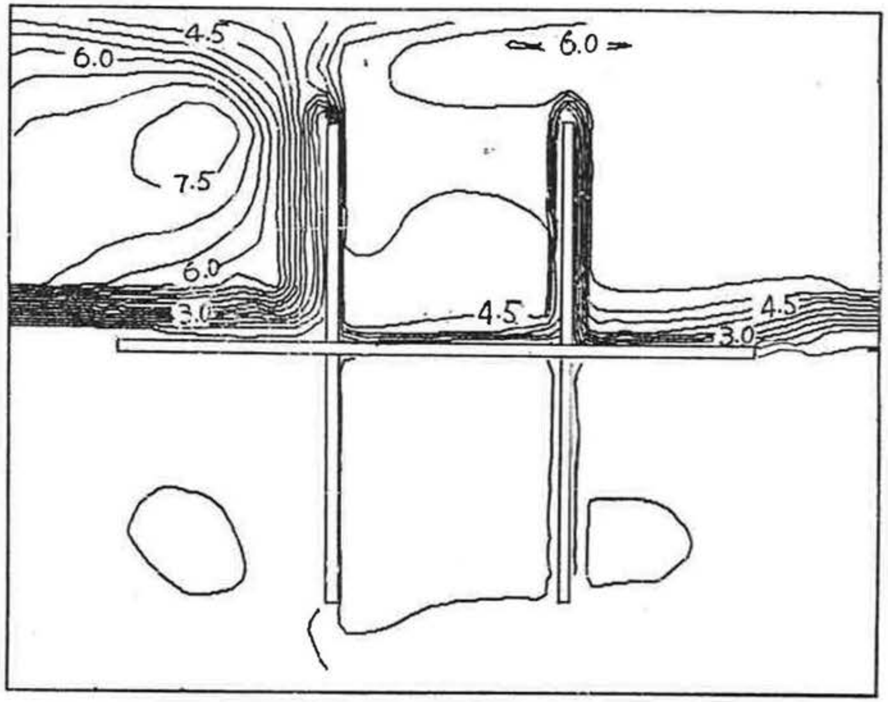
Figure 5 Contaminant distribution in Case 1



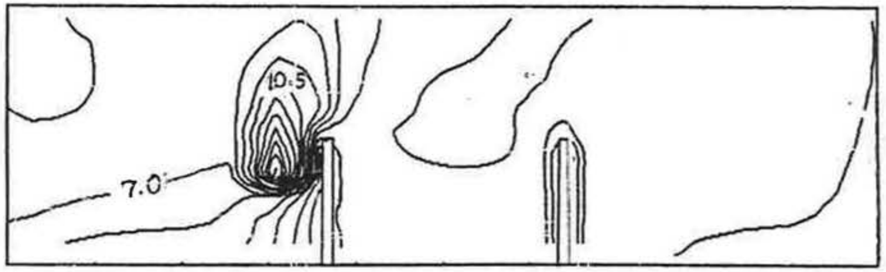
a) Velocity vectors at horizontal section z/H=0.27 Maximum Vector 0.281



b) Velocity vectors at vertical section y/W=0.63 Maximum Vector 0.097

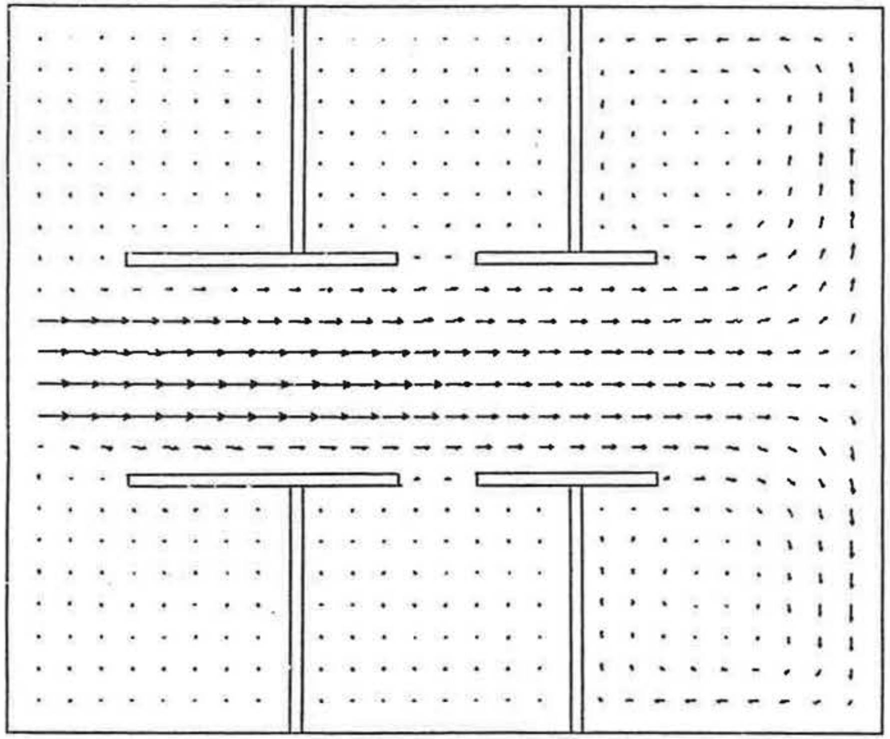


c) Concentration distribution at horizontal section z/H=0.27

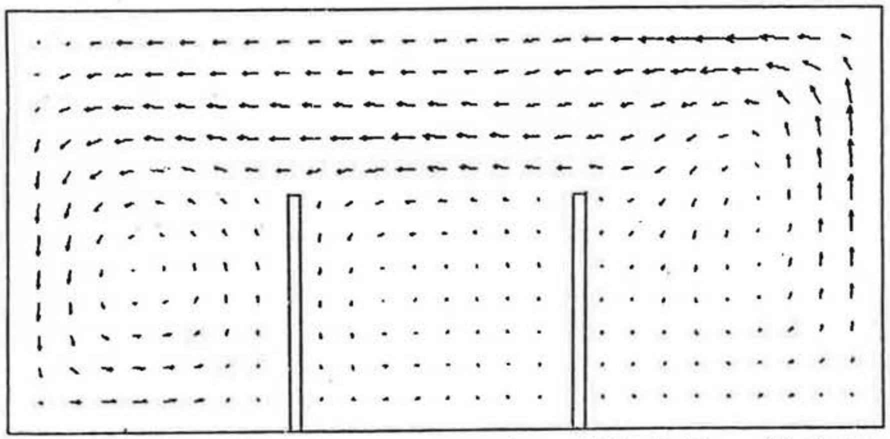


d) Concentration distribution at vertical section y/W=0.63

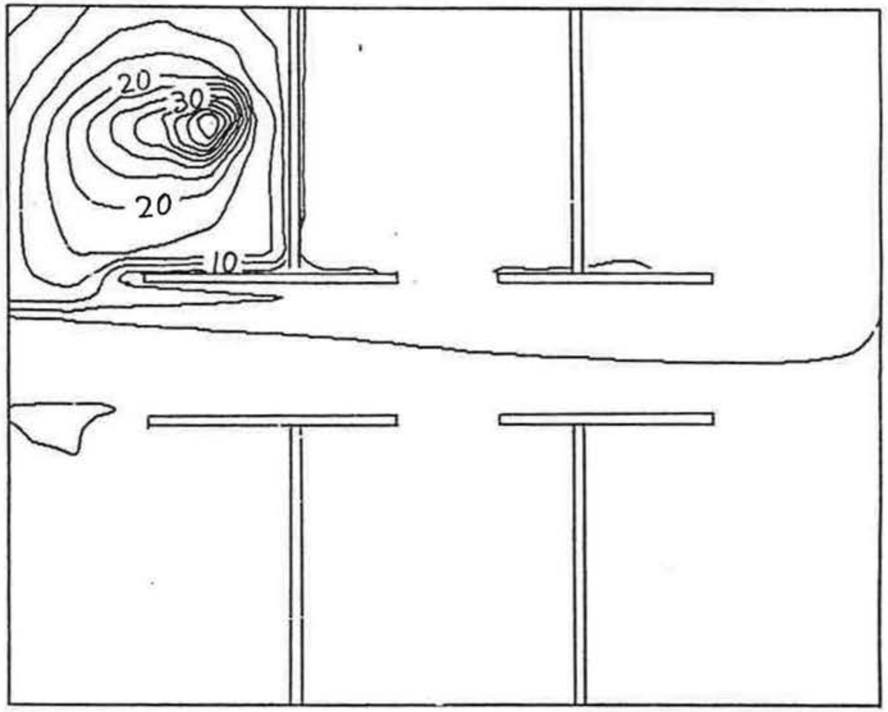
Figure 6 Distributions of velocity and contaminant in Case 2



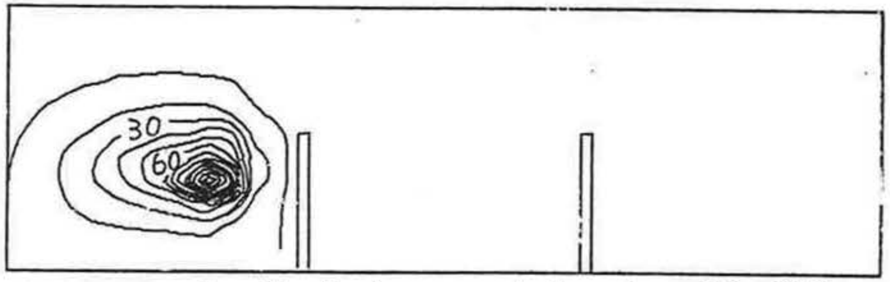
a) Velocity vectors at horizontal section z/H=0.27 Maximum Vector 0.281



b) Velocity vectors at vertical section y/W=0.82 Maximum Vector 0.075

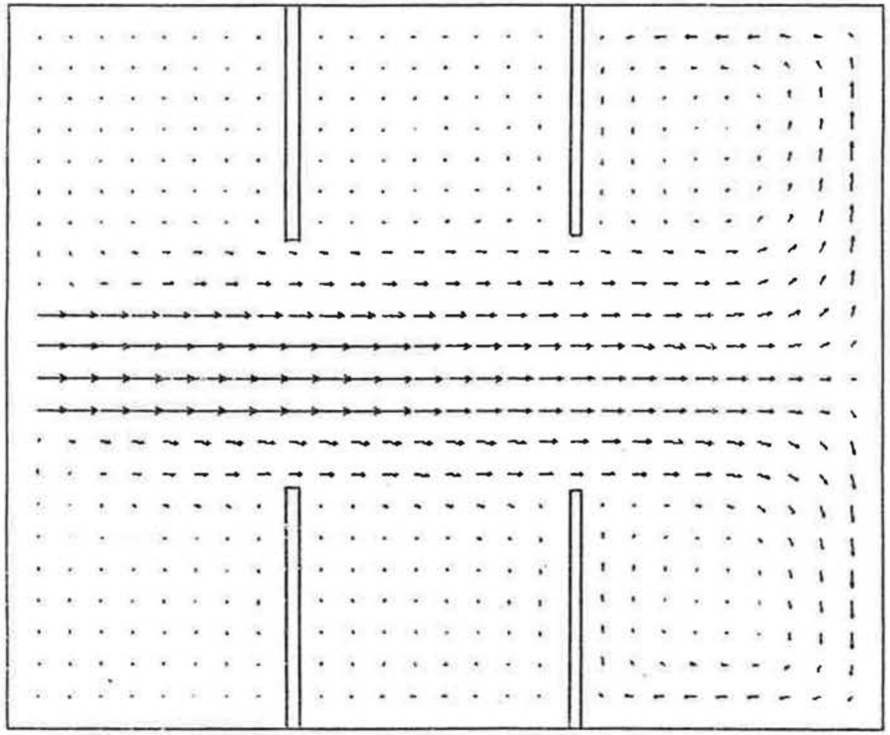


c) Concentration distribution at horizontal section z/H=0.27

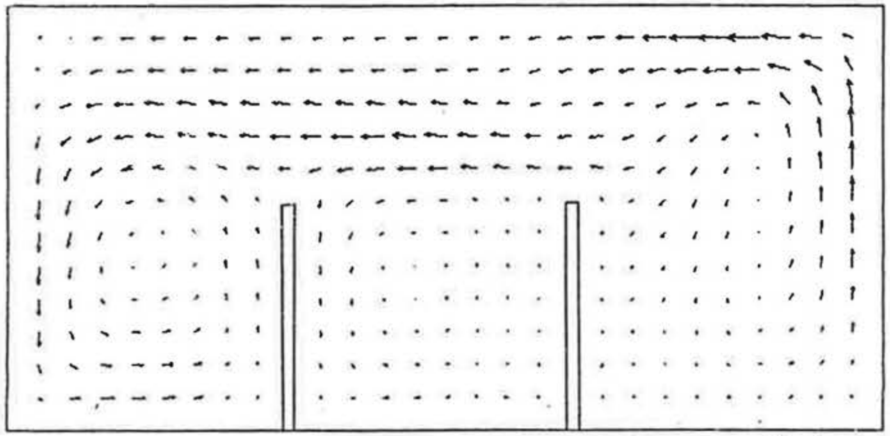


d) Concentration distribution at vertical section y/W=0.82

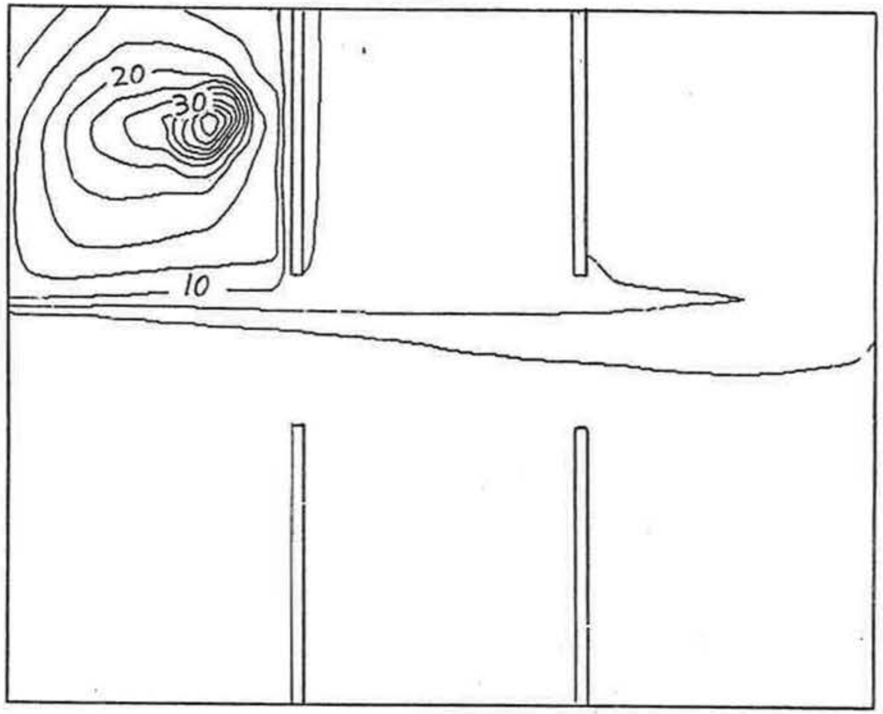
Figure 7 Distributions of velocity and contaminant in Case 3



a) Velocity vectors at horizontal section z/H=0.27 Maximum Vector 0.290



b) Velocity vectors at vertical section y/W=0.82 Maximum Vector 0.088



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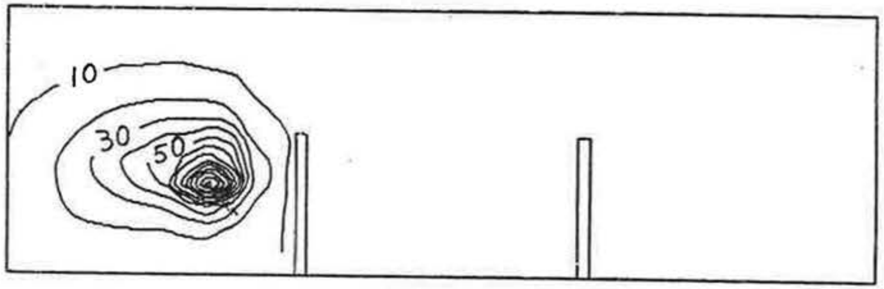
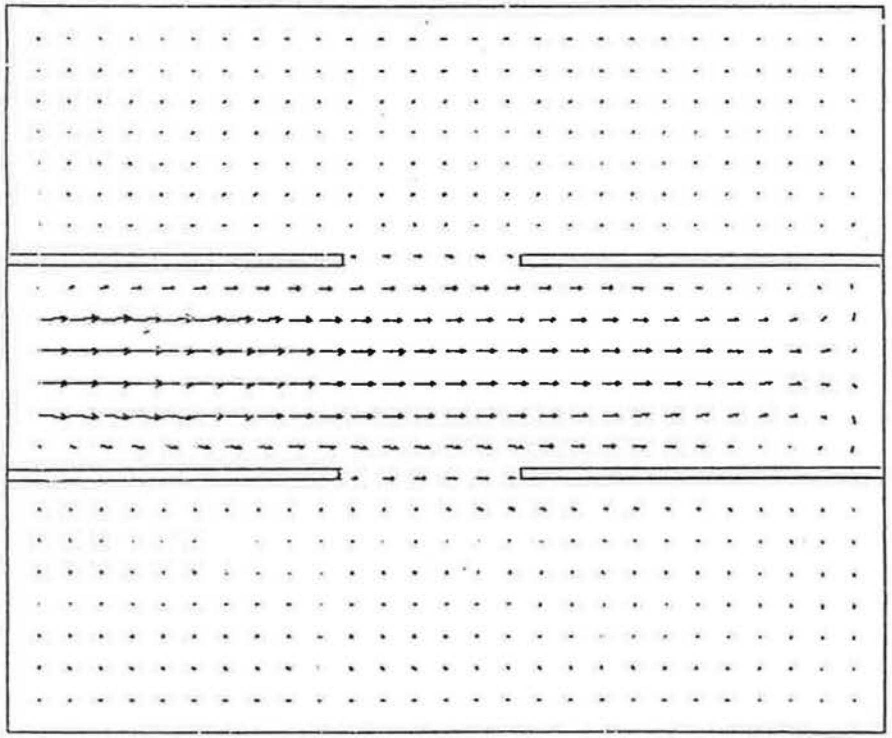


d) Concentration distribution at vertical section y/W=0.82

Figure 8 Distributions of velocity and contaminant in Case 4



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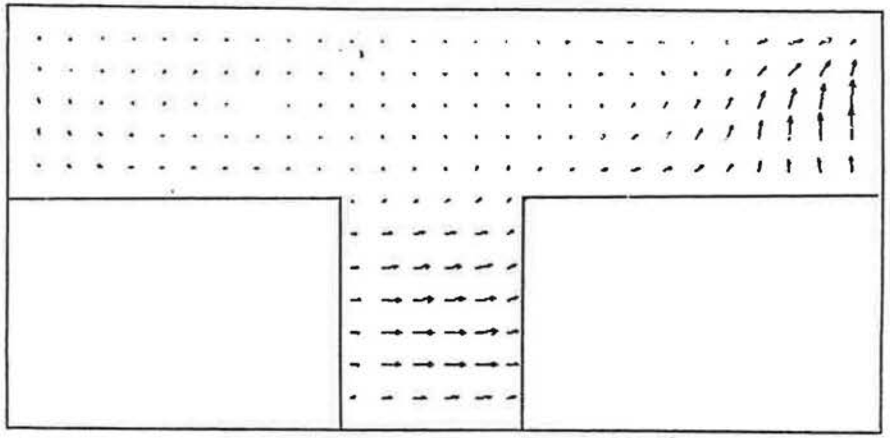
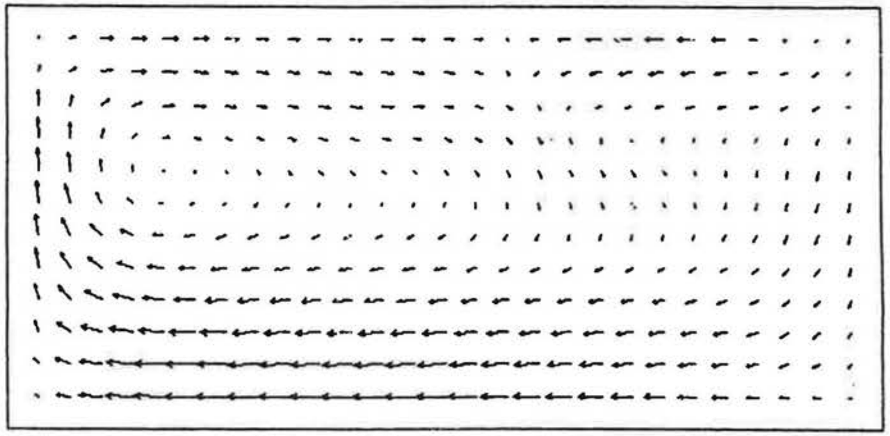


b) Vertical section y/W=0.60 Maximum Vector 0.142



c) Vertical section y/W=0.82 Maximum Vector 0.045

Figure 9 Velocity distribution in Case 5

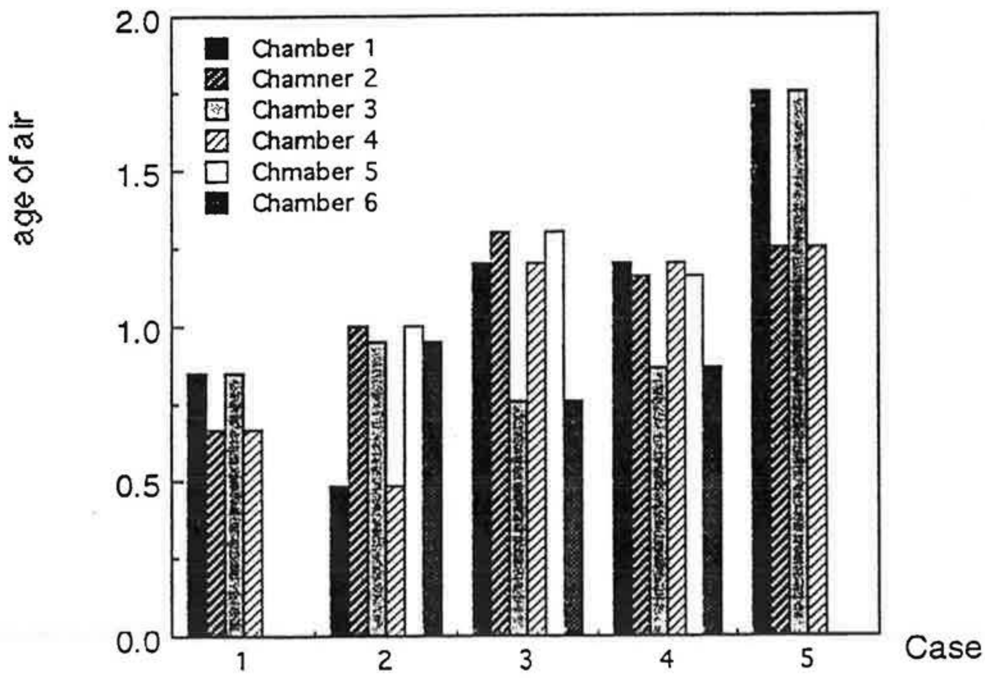


Figure 10 Average age of air in each chamber