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Ventilation Effectiveness in a Partitioned Office with Displacement Ventilation Determined by Computer Simulation

Key Words
Displacement ventilation
Displacement diffuser
Contaminant removal
Contaminant dispersal
Partition placement

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 the 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 important effects on air diffusion, retarding the removal of a contaminant. The present study considers the effects of office partition layout on air diffusion and indoor contaminant control in a large partitioned office equipped with a displacement ventilation system. The investigation was conducted by computer simulation for three-dimensional turbulent flow with a k-ε two-equation model of turbulene. The average contaminant concentrations and age of air in each chamber were indicators in the evaluation of the air exchange efficiency and ventilation effectiveness under five different partition layouts. The displacement ventilation system provides fresher air to all chambers than a conventional ventilation system, and a proper arrangement of office partition can reduce the overall level by about 37%. With partitions in the office, the advantage of displacement ventilation may not be pronounced.

Introduction

Indoor contaminants are the major cause of poor indoor air quality [1]. The extensive use of electronic office equipment and the efficient use of office space increase the chance of accumulating high levels of indoor contaminant in the working space. Dividing an office into a number of individual chambers is a common practice for efficient use of the office space, which can provide privacy but may also cause contaminant retardance in the occupied zone. The degree to which the contaminant removal is affected depends e.g. on the partition layout, the position of the contaminant source and the type of ventilation systems.

Displacement ventilation has been used widely in Scandinavian countries in industrial buildings over the past 20 years where special indoor contaminant control is needed. Recently, this application has been extended to office buildings. Displacement ventilation systems supply air at the floor level and exhaust it near the ceiling. This

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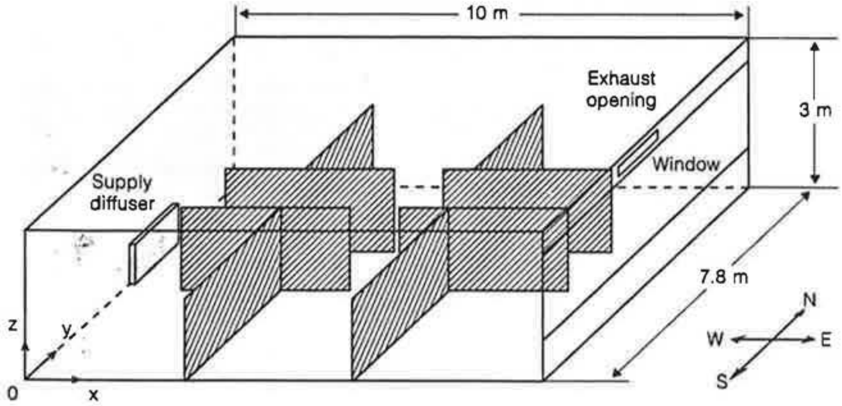


Fig. 1. Partitioned office equipped with displacement ventilation system.

creates an inlet condition for the occupied zone and removes the indoor contaminant 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 systems has been examined in previous studies [2–5]. However, the influence of partitions on the room air diffusion and contaminant removal with displacement ventilation is not 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 a remarkable difference in indoor contaminant level.

With ceiling-mounted four-way diffusers, the influence of partition layout in an office on contaminant control has been assessed by numerical simulation [6, 7]. The office was divided into six individual chambers. Five different layout designs were compared. With a fixed partition arrangement, a contaminant source was placed at different positions 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 the Present Study

The objective of the present study is to evaluate the influence of partition layout on the indoor contaminant level (a hypothetical contaminant, hereafter described as 'contaminant') and the air freshness in an office ventilated by a displacement ventilation system.

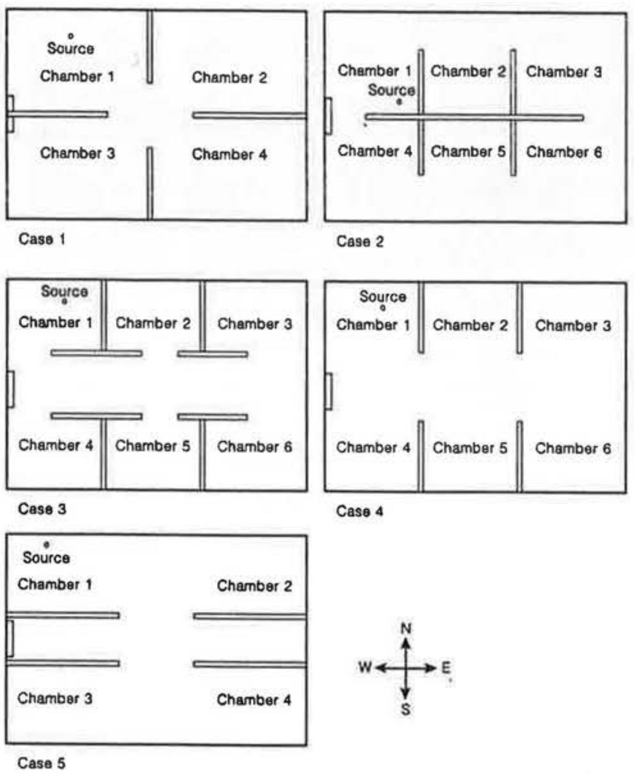
Five-partition layout designs for the office are investigated and compared in terms of the overall contaminant level in the entire office, the average concentration and the age of air [8] in each chamber.

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 modeled through a k-ε two-equation model of turbulence [10].

Case Description

The configuration and dimension of the office being studied are 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 the diffuser, having an area of 0.8×0.3 m^2.

The office is divided into four or six chambers by partitions 0.05 m thick and 1.5 m high. Since the diffuser is installed in the occupied zone, the existence of a 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 would not be expected to block the supply air. 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.



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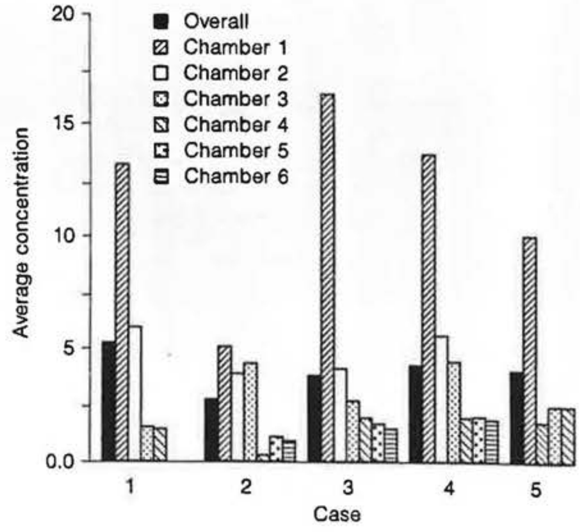

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Fig. 2. Five layouts for partitions.

Fig. 3. Overall concentration in the office and average concentration in each chamber. Without partition: overall concentration = 3.8, average concentration in the occupied zone = 4.0.

According to the simulation, there is a contaminant source in chamber 1 with an emission rate normalized to be unity, and isothermal conditions apply.

Results and Discussions

For the analysis, cases 1, 2 and 3 will be considered in one group. The second group consists of 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 concentrations in the opposite chambers are 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 also symmetric (fig. 4a). Thus, the air velocity across the symmetric plane is theoretically equal to zero, as 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 than the other chambers. Chamber 2 is located in the downstream of the contaminant source, therefore it is directly invaded by contaminant convection. Figure 4a shows that the ventilated air hardly enters the area containing the contaminant source, resulting in a 'dead zone' around the source. The contaminant in chamber 1 is removed mainly by the backflow from the ceiling, as shown in figure 4b and c, 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 (fig. 6a). Figure 6b demonstrates how the contaminant in chamber 1 is removed and shows the reason that makes the concentra-

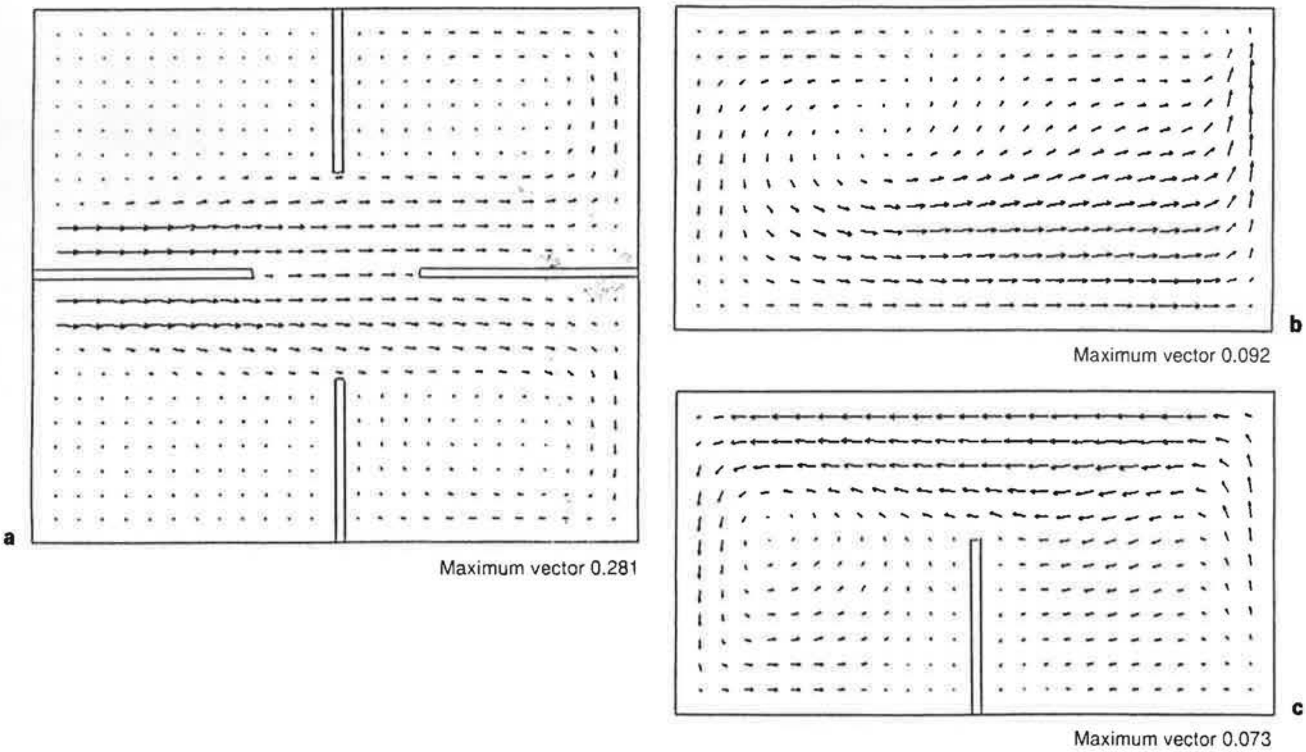

Fig. 4. Velocity distribution in case 1. **a** Horizontal section z/H = 0.27. **b** Vertical section y/W = 0.63. **c** Vertical section y/W = 0.88.

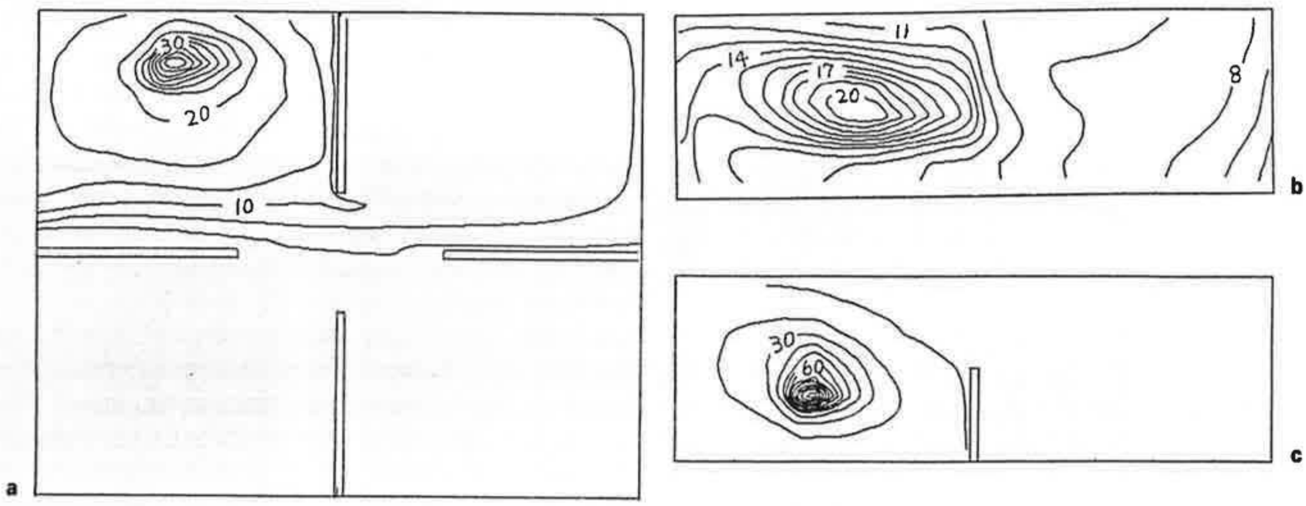

Fig. 5a–c. Contaminant distribution in case 1 (sections as in fig. 4).

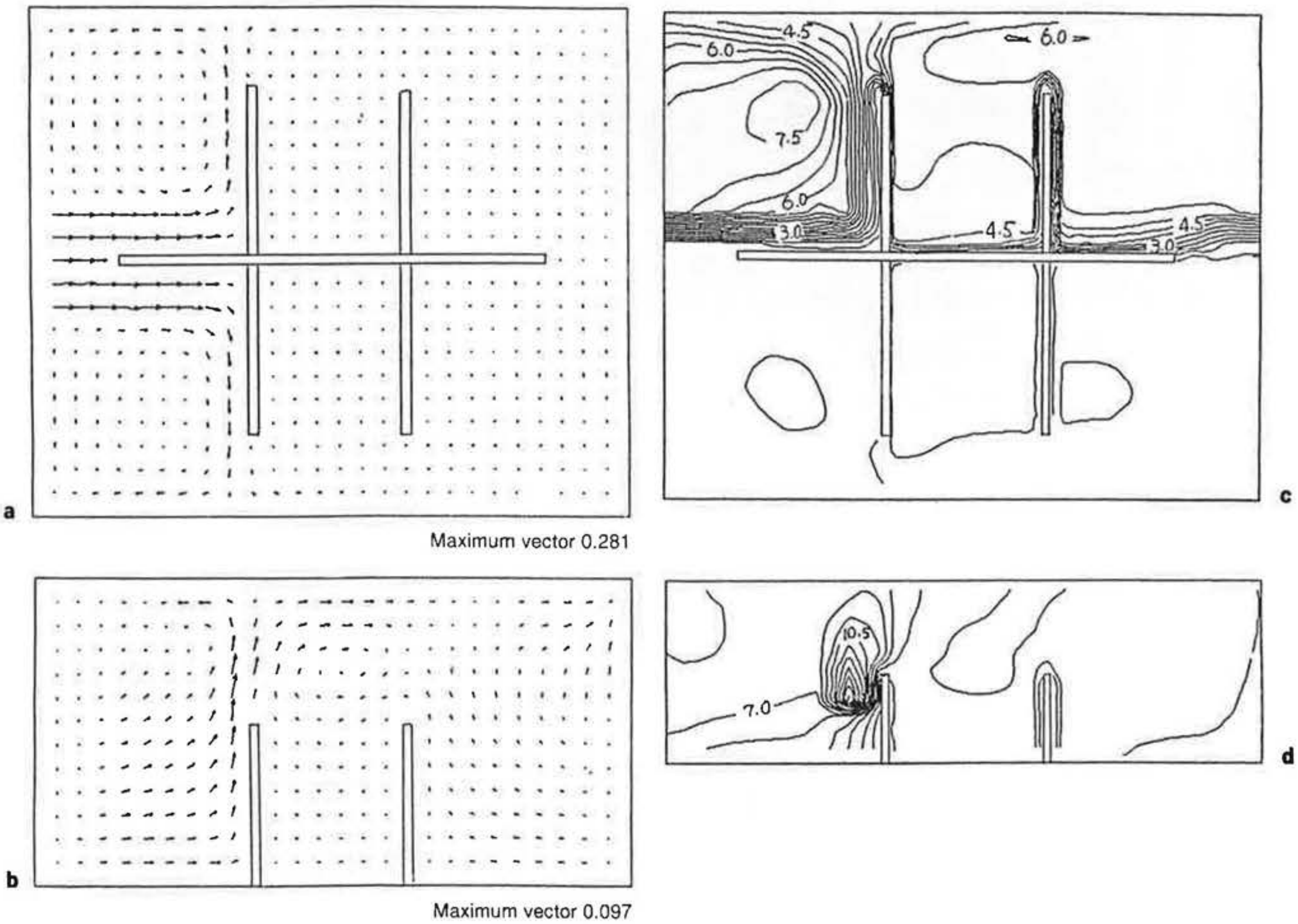

Fig. 6. Distributions of velocity and contaminant in case 2. **a** Velocity vectors at horizontal section z/H = 0.27. **b** Velocity vectors at vertical section y/W = 0.63. **c** Concentration distribution at horizontal section z/H = 0.27. **d** Concentration distribution at vertical section y/W = 0.63.

tion in chamber 3 higher than in chamber 2. It is observed that there is an air recirculation in chamber 3, which may bring the contaminant from the area near the exhaust opening back to the chamber and cause a higher concentration there. Figure 6c and d show the contaminant distributions in the region near the source.

For overall contaminant removal, case 3 lies between cases 1 and 2. However, the average concentration in the source chamber is the highest of all cases. 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 figure 7a and c. The air recirculation in chamber 1, seen in figure 7b, may also be a cause of the contaminant accumulation in the chamber (fig. 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 results in case 1.

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 values are all higher with displacement ventilation, which may indicate that displacement ventilation is not suitable for partitioned offices.

When removing the four partitions in the west-eastern direction, the average contaminant concentration in the

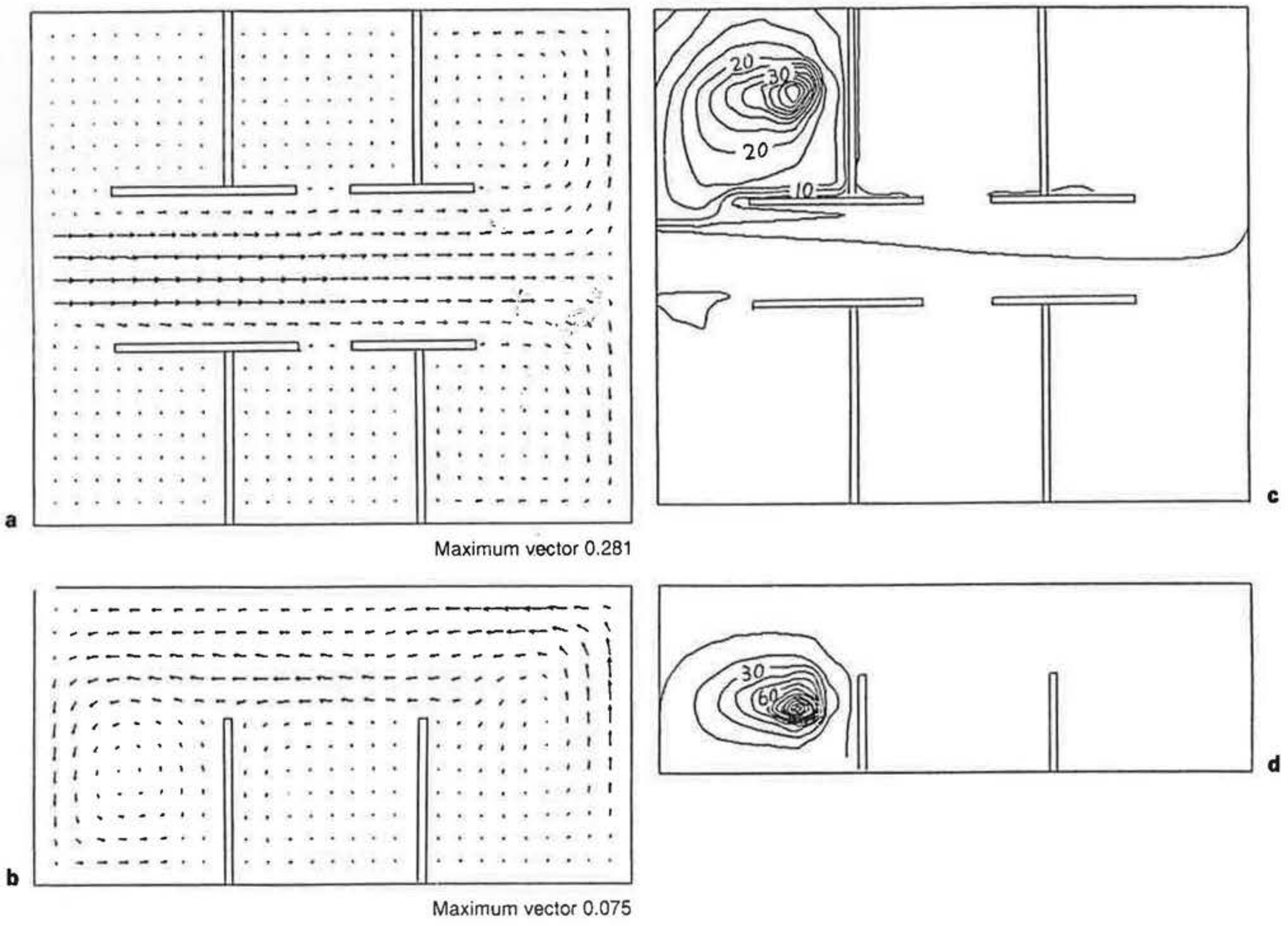

Fig. 7. Distributions of velocity and contaminant in case 3. **a** Velocity vectors at horizontal section z/H = 0.27. **b** Velocity vectors at vertical section y/W = 0.82. **c** Concentration distribution at horizontal section z/H = 0.27. **d** Concentration distribution at vertical section y/W = 0.82.

source chamber descends from 20.5 to 17.15, whilst the overall concentration increases from 4.81 to 5.50. This occurs because the contaminant emitted from the source is less confined to chamber 1, and the air can move more freely, so the contaminant dispersion in the room is 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 direction. The overall concentration in this case is found to be close to that in case 4, but the average concentration in chamber 1 is reduced from 17.15 to 12.7. However, this latter value may not follow from an improvement of the contaminant removal from chamber 1, because in case 5, the volume of chamber 1 with which the average is determined is larger. It makes the average value smaller. The average concentration in chamber 2, directly 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 (fig. 9b) may reduce the transport of the contaminant in chamber 1 to chamber 2 through convection and therefore reduce the level in chamber 2.

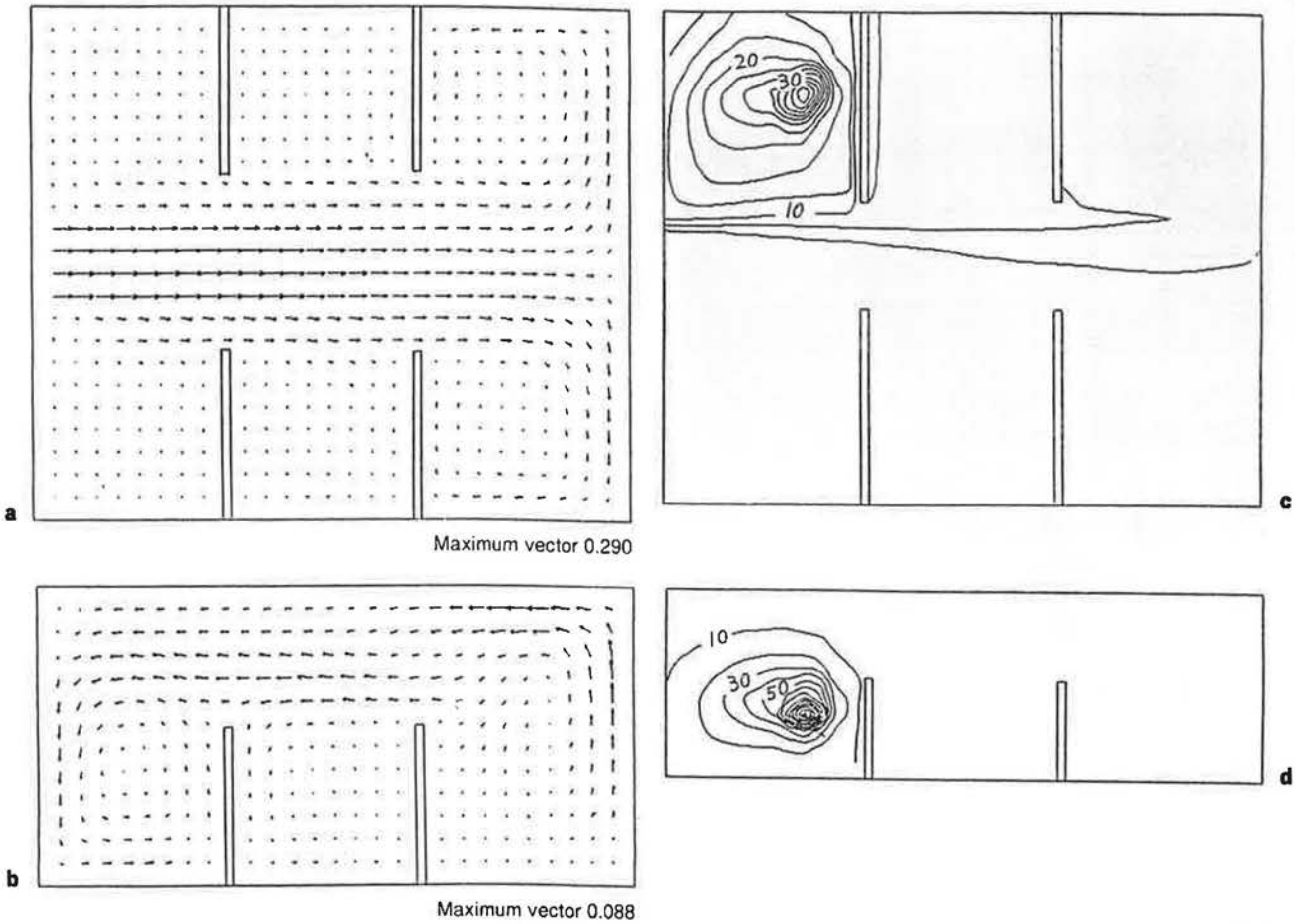

Fig. 8. Distributions of velocity and contaminant in case 4. **a** Velocity vectors at horizontal section z/H = 0.27. **b** Velocity vectors at vertical section y/W = 0.82. **c** Concentration distribution at horizontal section z/H = 0.27. **d** Concentration distribution at vertical section y/W = 0.82.

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

The local mean age of air is defined as the time t that has elapsed since the molecules entered the room. The age of air presented in this paper is normalized by a reference time, the time needed to replace the air in the room. The

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
Ceiling diffuser	1.90	10.99	0.42	0.29	0.24	0.13	0.14

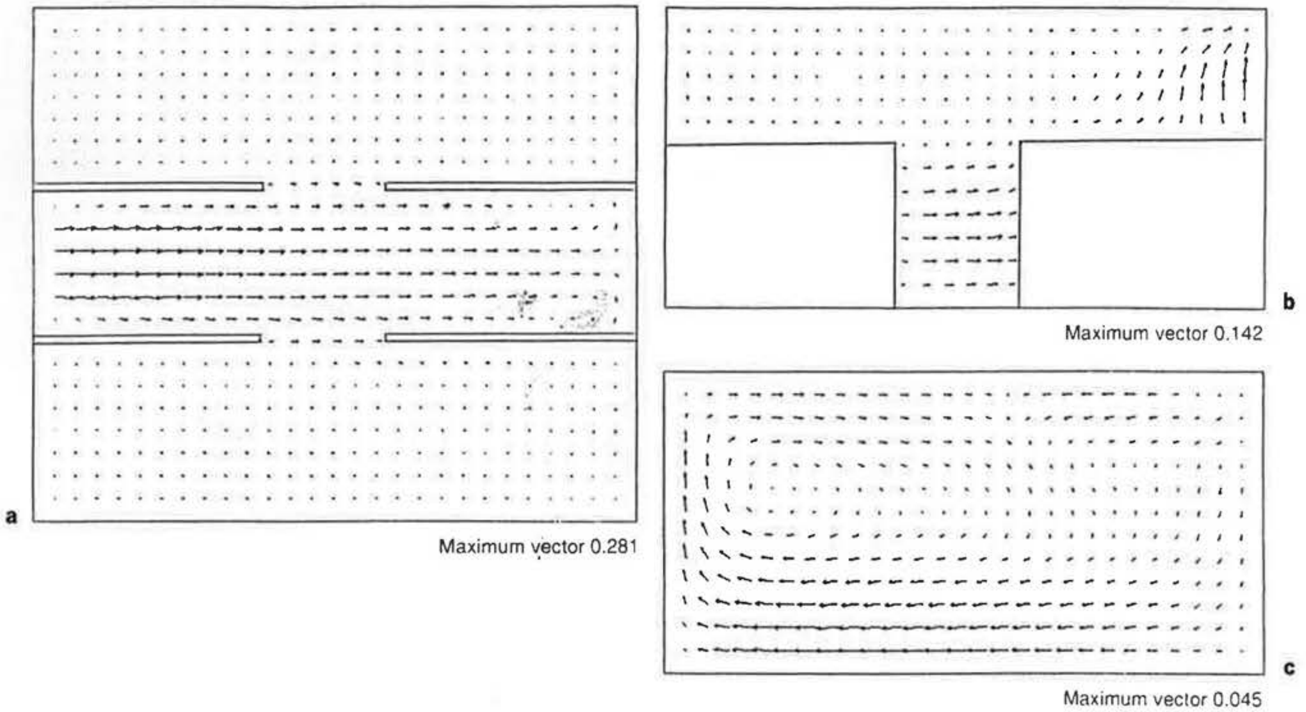

Fig. 9. Velocity distribution in case 5. **a** Horizontal section z/H = 0.27. **b** Vertical section y/W = 0.60. **c** Vertical section y/W = 0.82.

average ages 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 readily enter the chambers. Case 2 provides the best configuration. It should be 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. This implies that the supply air does not enter chamber 1 directly from the diffuser, but, instead, it circles around the office before entering chamber 1.

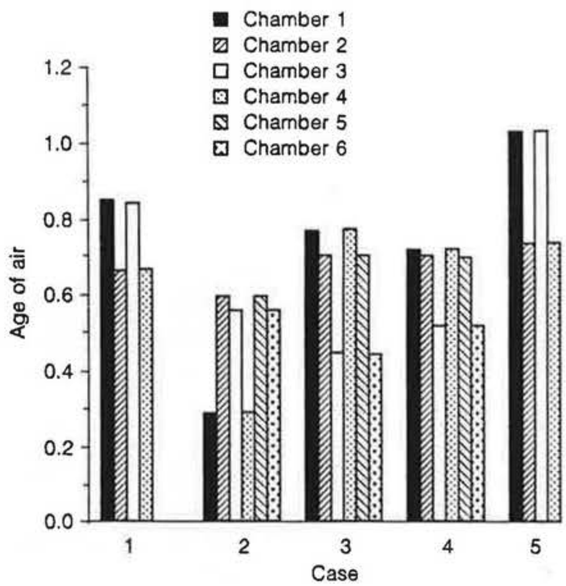

Fig. 10. Average age of air in each chamber.

Conclusions

The computer simulation of five different partition arrangements indicates that when the indoor air quality is assessed by (1) the overall concentration in the office, (2) the average contaminant concentration and (3) the average age of air in each chamber the following conclusions may be obtained: (1) the air freshness is not directly related to the number of partitions used in the office but to the arrangement of the partitions; (2) 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; (3) 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); (4) using more partitions 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); (5) with the tendency of air movement from floor to ceiling, a contaminant source near the floor is in 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 the supply opening. Hence the 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.

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