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THE EFFECT OF OBJECT POSITIONS ON VENTILATION PERFORMANCE

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ABSTRACT

The effect of the change in object positions (i.e. office furniture) on the air quality in a room was studied using zonal purging flow rates. In relation to the zonal purging flow rate in a room, the transfer probability from the inlet to a certain zone can provide information on the amount of fresh air from the inlet to the zone. In this study, the probability obtained from Markov chain theory was used to analyze the ventilation performance. Also, the mean ventilation effectiveness obtained from the transfer probability was compared with the traditional mean ventilation effectiveness for the room. The velocity fields in a two-dimensional parametric room (6m x 2.7m) were derived from CFD simulation under isothermal conditions. The velocity fields were used to calculate the interconnecting flow rate between zones, and to obtain the velocity data for the whole room and the occupied zone. Several different arrangements of objects (representing room furniture) were used to find the optimum location of the objects.

It was found that the mean ventilation effectiveness using the zonal purging flow rate concept is in agreement with the traditional mean ventilation effectiveness. Findings from this paper show that the object positions can play a key role in influencing ventilation performance, either in a positive or in a negative way. Depending on the location of object and airflow pattern, the presence of an object may produce two opposite effects either a hindering of the airflow in a room or an improvement in the air distribution. Also, an increase in the object lengths and a decrease in the free volume of the room do not always mean that the ventilation effectiveness decreases. The zone where the maximum velocity in the occupied zone occurs was the optimum location of an object in the room investigated.

KEYWORDS

Object positions, Mean ventilation effectiveness, Mixing ventilation, CFD, Zonal purging flow rate, Transfer probability from inlet, Free volume

INTRODUCTION

Even though a good ventilation performance may be predicted at the design stage, the furniture arrangement by the occupants can influence the environment in the room. However, owing to the arbitrary alteration of furniture (i.e. desks), the indoor airflow pattern can change and affect the ventilation condition predicted at the design stage.

Regarding the effect of an object in a room on ventilation performance, Sandberg and Claesson (1998) have found that the object is a factor to consider in the design of ventilation systems. Nielsen et al. (1998) investigated the changes in the air movement in a furnished room compared to an empty room, and also studied the change of velocity in the occupied zone due to the increase of furniture volumes. Although considerable research on the effect of obstructions has been done, no major study on the effect of changes in object locations has been carried out.

This paper focuses on the effect of changes in object location and volume on the ventilation performance. Using the zonal purging flow rate (U_p) as defined by Peng and Davidson (1997), the mean ventilation effectiveness, $<\varepsilon>_{pr}$, is obtained and compared with the traditional mean ventilation effectiveness, $<\varepsilon>_c$. The result obtained for $<\varepsilon>_c$ from the ratio of the exhaust concentration to the room mean concentration is very dependent upon the location of the emission source and the number of the emission sources. Thereby, there is some uncertainty in analyzing the ventilation performance when certain parameters inside the room (e.g. room furniture) are changed. In this paper, the mean ventilation effectiveness modified by the zonal purging flow rate (U_p) is introduced and used for investigating the influence of the change in object locations on the ventilation performance.

DEFINITIONS

Transfer Probability from Inlet (P_{sp}) and Zonal Mean Ventilation Effectiveness (ε_{cp})

The transfer probability, P_{sp} , can be obtained using Markov-chain model, which has been applied by Peng (1997). P_{sp} depends only on the air distribution and zone volume, and represents the fraction of fresh air from the inlet reaching a local zone. Zonal ventilation effectiveness, ε_{cp}, can be obtained from the ratio of the concentration in the exhaust, C_e, to the mean concentration in a certain zone, $<C_p>$. As a spatial average, the zonal mean concentration can be obtained from the ratio between the sum of a local contaminant concentration (C_{cp}) multiplied by a local volume (V_{cp}) in the zone and the zone volume (V_p).

$$\varepsilon_{cp} = \frac{C_e}{<C_p>} = \frac{C_e}{\sum C_{cp} V_{cp} / V_p} \qquad (1)$$

Under condition of complete mixing from mass balance, the two indices, P_{sp} and ε_{cp}, can simply provide information on the amount of fresh air supplied to a zone and a contaminant removal from the zone.

Mean Ventilation Effectiveness, $<\varepsilon>_c$ and $<\varepsilon>_{pr}$

The mean ventilation effectiveness, $<\varepsilon>$, is defined as the ratio of the average purging flow rate, $<U>$ to the ventilation supply flow rate, (AIVC, TN34, 1991),

$$<\varepsilon> = \frac{<U>}{Q} \times 100 \qquad (2)$$

Conventionally, the mean ventilation effectiveness, $<\varepsilon>_c$, has been defined as the ratio between the outlet concentration, C_e, and the room mean concentration, $<C_r>$ or the mean concentration in the occupant zone, $<C_{op}>$.

$$<\varepsilon>_c = \frac{C_e}{<C_r>} \quad \text{or} \quad <\varepsilon>_c = \frac{C_e}{<C_{op}>} \tag{3}$$

The zonal purging flow rate(or regional purging flow rate), U_p, calculated by Markov chain model, is defined as a measure of how much fresh air is supplied to a certain zone (Peng & Davidson1997). The zonal purging flow rate is obtained by multiplying the transfer probability from inlet to a certain zone (P_{sp}) with the supply flow rate (Q) : $U_p = P_{sp}Q$. If the average purging flow rate, $<U>$, is expressed as the spatial mean purging flow rate, the equation for $<\varepsilon>_{pr}$ can be expressed by the transfer probability (P_{sp}) from the inlet to a certain zone p in the room:

$$<U> = \frac{1}{V_r}\int_v U_p dv = \frac{\sum_{p=1}^{n} P_{sp} Q V_p}{V_r}, \text{ thus, } <\varepsilon>_{pr} = \frac{\sum_{p=1}^{n} P_{sp} V_p}{V_r} \times 100 \tag{4}$$

CFD SIMULATION

Under isothermal conditions, a two dimensional parametric room (6.0m x 2.7m) with mixing ventilation was simulated by the CFD code, VORTEX2D (Awbi,1996). Figure 1 shows a schematic of the room geometry. The supply device was centrally positioned at the ceiling, which had a baffle plate to produce two jets along the ceiling as shown in Figure 1. The supply velocity in each direction was 1.2m/s. Two outlets were placed on both end walls at 0.1m height above the floor. The room was divided into 10 zones with the equal volumes (1.8 m^2) except the two zone near the outlets (0.9 m^2). The size of the relevant object used was 1m x 0.8m. The location of object was restricted within the occupied zone from zone[2] to zone[6].

Several different arrangements of the object (representing room furniture) was investigated: (I) One object is placed (e.g.B2- the object in zone2); (II) Two objects are placed (e.g. B26 - the objects in zone2 and zone6); (III) Three objects are placed (e.g. B345 - the objects in zones 3, 4 and 5); (IV) Four objects are placed (e.g. B2345 - the objects in zones 2,3,4 and 5). Also, the room configuration is designed in a symmetric way and object arrangement that lies one upon another is avoided (e.g. case B5, it is the same as the case B2 and is thus excluded from the investigation). In each of the cases; B2, B23, B234 and B2345, the volume ratio between the object volume and the room volume was 4.9%, 9.9%, 14.8% and 19.8% respectively.

For evaluating the indices, i.e. $<\varepsilon>_c$ and ε_{cp}, the emission source was placed in the middle of the object length at a height of 1.2m above the floor. The number of emission sources used was the same as the number of objects, however, the amount of source emissions was the same as that for the empty room, i.e. 10ml/s. For the case of an empty room, the emission source is located in the centre of the room.

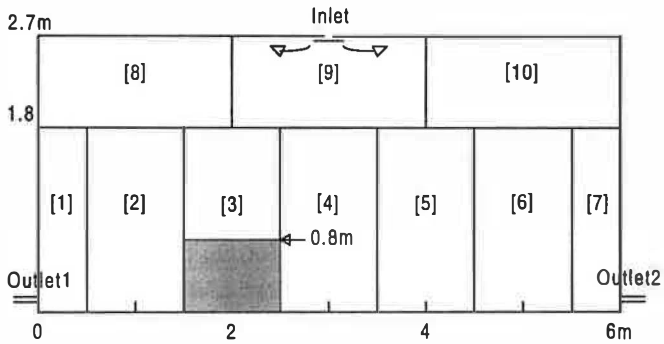

Figure 1: The room configurations and the imaginary zones when an object is placed at zone [3], i.e. B3

RESULTS AND DISCUSSION

Comparison between Mean Ventilation Effectiveness, $<\varepsilon>_{pr}$ and $<\varepsilon>_c$

Figures 2, 3 show different profiles of mean ventilation effectiveness, $<\varepsilon>_{pr}$ and $<\varepsilon>_c$, and the mean velocities in the whole room and in the occupied zone respectively. The trend of mean velocity at two cases is similar to the mean ventilation effectiveness.

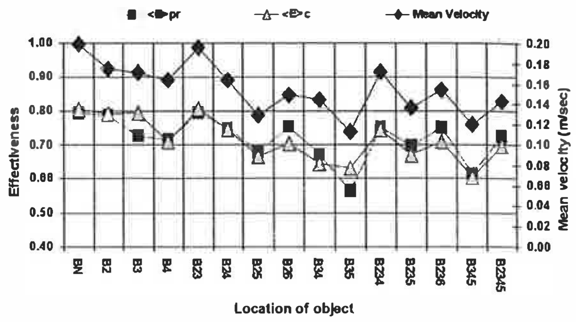

Figure 2: Variation of mean ventilation effectiveness and mean velocity in the room

As shown in Figure 2, the agreement between $<\varepsilon>_{pr}$ and $<\varepsilon>_c$ is generally good in spite of two distinctive definitions mentioned above. However, for the occupied zone in Figure 3, although the trend of $<\varepsilon>_{pr}$ and $<\varepsilon>_c$ is similar, the values are different. This discrepancy can be explained by the different methods used for calculating the two mean ventilation effectiveness.

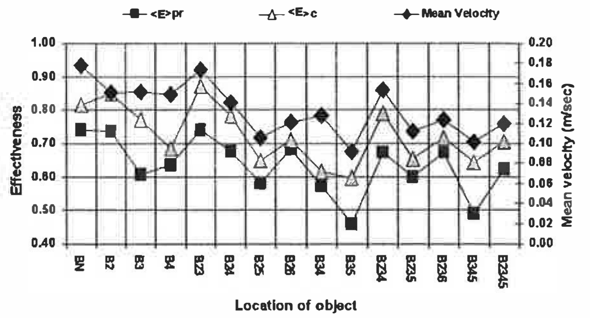

Figure 3: Variation of mean ventilation effectiveness and mean velocity in the occupied zone

$<\varepsilon>_{pr}$ is obtained from the probability distribution function (i.e. Markov Chain Theory) but $<\varepsilon>_c$ is calculated by the sampling distribution function. Therefore, in order to apply the transfer probability in $<\varepsilon>_{pr}$, the interconnecting flow rates between zones should be normalized with respect to the ventilation supply flow rate (Peng & Davidson 1998). Unlike $<\varepsilon>_{pr}$, the method of calculating $<\varepsilon>_c$ is based on the mean value for the occupied zone. In other words, the mean $<C_{op}>$ used for obtaining $<\varepsilon>_c$ is derived from the spatial average of the sum of the dimensionless concentrations in the occupied zone. As shown in Table 1 for the zonal ventilation effectiveness (ε_{cp}), the high and the low values indicate low and high concentration respectively in the zone. In the occupied zone, the difference between the zones with sources and zones without sources is substantial. The emission sources were located at a height of 40 cm above the object and the same number of sources as objects was used. The value obtained is thus dependent upon the location and the number of emission sources. The ventilation effectiveness $<\varepsilon>_c$ was found to be very sensitive to the object location in the occupied zone. In view of characterizing the air flow pattern and the contaminant dilution, the mean ventilation effectiveness $<\varepsilon>_{pr}$ and $<\varepsilon>_c$ can thus complement each other for examining ventilation performance.

Effect of Object Volume and Location on Ventilation Performance

Nielsen et al. (1998) found that the maximum velocity in the occupied zone (v_m) can be reduced by increasing the object volume in the room. As shown in Figure 4, all cases are classified into three regions according to the location of v_m. The v_m in the empty room (BN) occurs in the zone[2] and zone[6], and is higher than that in furnished room cases. For Region (b) where v_m occurs in zone[2], there is a good correlation between the maximum velocity and the increased object volumes. However, the regions (a) and (c) have no such a correlation.

The influence of increased object volume on the ventilation performance is also analyzed by the mean ventilation effectiveness, $\langle \varepsilon \rangle_{pr}$, and the results can be seen in Figure 5 and Table 1. In order to investigate the effect of the reduction of free volume, four cases with free volumes of 95%, 90%, 85%, and 80% are defined on the basis of the empty room. The results show that $\langle \varepsilon \rangle_{pr}$ is not proportional to the increase in object volume for all four cases. It is found that an increase in the length of an object and a decrease in the free volume of the room do not always mean a decrease in the ventilation effectiveness.

Table 1 shows the results of $\langle \varepsilon \rangle_{pr}$ and v_m for the cases of separated and attached objects (i.e. B24 and B234; B25, B235 and B2345; B26 and B236; B35 and B345). There is a slight decrease in $\langle \varepsilon \rangle_{pr}$ and v_m when the object volumes increase except the cases B35 and B345. Therefore, the object volume can be regarded as a minor parameter when studying its effect on the ventilation performance. Rather, the change in object location has more significant effect on ventilation performance.

As shown in Figure 5 and Table 1, the change in object location influences the airflow pattern and the ventilation effectiveness, $\langle \varepsilon \rangle_{pr}$. When the object is located in zone[2] (B2), $\langle \varepsilon \rangle_{pr}$ is similar to that of an empty room (BN) and it is the highest in Case [II]. In cases of B3 and B4, the results of $\langle \varepsilon \rangle_{pr}$ for the whole room are different from those of $\langle \varepsilon \rangle_{pr}$ for the occupied zone. In other words, more fresh air is supplied to the occupied zone in case B4 than in case B3. Also, the ventilation effectiveness of the upper zone (above the occupied zone) in case B3 is higher because the

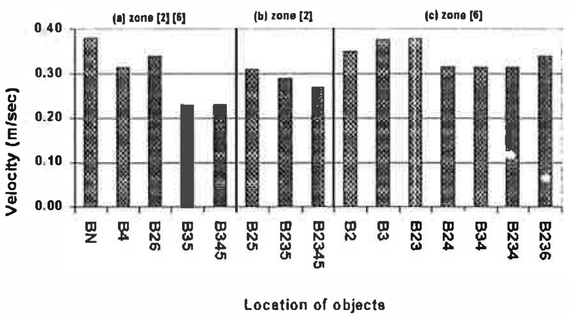

Figure 4: Maximum velocity in the occupied zone according to object location; (a) - v_m occurs at zone [2] and [6], (b) - v_m occurs at zone [2], (c) - v_m occurs at zone[6]

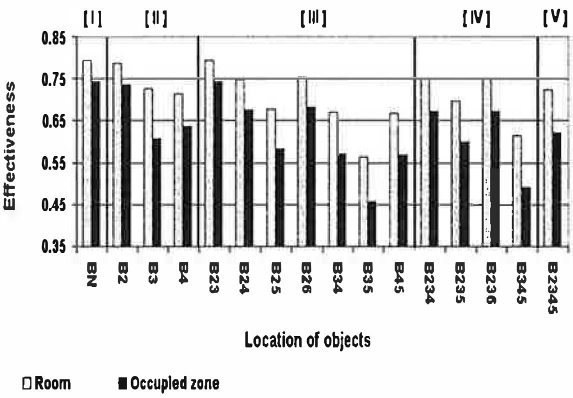

Figure 5: The mean ventilation effectiveness, $\langle \varepsilon \rangle_{pr}$ for different cases; (I) Empty room, (II) One object, (III) Two objects, (IV) Three objects, (V) Four objects

Table 1: The velocity and the several indices of effectiveness in the occupied zone for different cases

Case	Free Volume	Object Location	Velocity (m/sec) Mean	Velocity (m/sec) Max.	Psp Low	Psp High	Ecp Low	Ecp High	<E>pr	<E>c
[I]	1	BN	0.18	0.38 [2] [6]	0.71	0.76	0.84	0.87	0.74	0.82
[II]	0.95	B2	0.15	0.35 [6]	0.57	0.76	0.32	1.23	0.74	0.85
		B3	0.15	0.38 [6]	0.44	0.75	0.22	1.27	0.61	0.77
		B4	0.15	0.31 [2] [6]	0.36	0.66	0.26	1.99	0.64	0.68
[III]	0.90	B23	0.17	0.38 [6]	0.66	0.74	0.38	1.60	0.74	0.87
		B24	0.14	0.32 [6]	0.62	0.67	0.44	1.90	0.68	0.78
		B25	0.11	0.31 [2]	0.46	0.66	0.39	1.27	0.58	0.65
		B26	0.12	0.34 [2] [6]	0.64	0.68	0.56	0.75	0.68	0.71
		B34	0.13	0.32 [6]	0.37	0.66	0.22	1.46	0.57	0.62
		B35	0.09	0.23 [2][6]	0.40	0.46	0.33	1.09	0.46	0.60
[IV]	0.85	B234	0.15	0.31 [6]	0.62	0.65	0.42	1.92	0.67	0.79
		B235	0.11	0.29 [2]	0.45	0.66	0.46	1.47	0.60	0.65
		B236	0.12	0.34 [6]	0.64	0.66	0.51	0.84	0.67	0.72
		B345	0.10	0.23 [2] [6]	0.37	0.66	0.33	1.10	0.49	0.64
[V]	0.80	B2345	0.12	0.27 [2]	0.48	0.66	0.24	0.82	0.62	0.70

object positioned in zone 3 deflects the main air stream upwards and away from the occupied zone.

When two objects are positioned in different zones (B23), $<\varepsilon>_{pr}$ is equivalent to that for an empty room (BN) and is highest in Case [III]. For the case B23, when the downward air jet attaches to the side walls, the objects in zones 2,3 help guiding the air to the occupied zone.

When the objects are in zone3 and zone5 (i.e.B35), $<\varepsilon>_{pr}$ is the lowest of all other cases, because the objects hinder the main air stream from reaching zones 3,4 and 5 and lead to a deflection of flow upwards in front of objects B3 and B5. The air movement in zones 3, 4 and 5 is stagnant. Through comparison between case B23 and case B35, it is found that, depending on the location of object, the object may play two roles: as a guidance or as a hindrance to air flow. Also, as can be seen in Case [IV], the objects in cases B234 and B345 have respectively guidance and hindrance effect to air flow.

For the case B2, B23 and B234, v_m and $<\varepsilon>_{pr}$ are similar to those for the empty room case (BN) or are respectively higher than the other cases with the same object volume. Therefore, the optimum object position for ventilation performance is thus strongly related to the position where the maximum velocity in the occupied zone occurs. When one puts furniture in an empty room, the region where v_m occurs (e.g. zones 2 and 6) should be considered as positioning the furniture. If the furniture is located in the zone where the velocity is small (e.g. zones 3 and 5), this may create stagnant regions in the room.

CONCLUSIONS

The main findings in this paper are:

1. There is a correlation between the mean ventilation effectiveness, $<\varepsilon>_{pr}$ and $<\varepsilon>_{c}$.
2. An increase in object lengths in a room and a corresponding decrease in free volume of the room do not guarantee that the ventilation effectiveness would decrease.
3. The zone, where the maximum velocity in the occupied zone occurs, can be considered as an optimum object position, i.e. can give good ventilation effectiveness.
4. Depending on the location of object and airflow pattern, the presence of an object may produce two opposite effects either a hindering of the airflow in a room or an improvement in the air distribution.

For future work, experimental measurements and 3D CFD simulations would be required to validate the results obtained from the two- dimensional simulation predicted in this paper.

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