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EFFECT OF OUTDOOR AND RECIRCULATED AIR SUPPLY ON INDOOR PARTICULATE CONCENTRATION

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A theoretical model for predicting the time dependence of indoor particulate concentration is developed in which all sources and sinks are considered. The model is based on variable ventilation conditions: full outdoor, recirculated air or a combination. An experimental set-up was used to validate the proposed model. It has been concluded that when the outdoor concentration is high and in the absence of indoor source, large fraction of recirculation air would keep indoor concentration at low level. In the presence of potential indoor source full outdoor air is required to maintain clean indoor environment. Flexible ventilation strategies have to be followed to maintain minimum particulate pollution levels.

INTRODUCTION

For health and safety consideration, indoor air is required to be strictly fit for consumption. Health effects related to indoor air quality have been reviewed by many workers (1).

Most indoor air pollution problems can be lessened or solved by increased air mixing, ventilation, eliminating indoor sources or by cleaning recirculated air. On the other hand, many energy conservation strategies involve reducing building air exchange rates. The later, however, can cause an increase in pollutant levels if there is an indoor pollution source.

Currently, efforts concentrate on reducing infiltration caused by air leaks through the building envelope (2,3,4). In 1946 ASHRAE set an air exchange rate of 1.7 $m^3.hr^{-1}$ (10 $ft^3.min^{-1}$). In 1973 ASHRAE then reduced the recommended value to 0.85 $m^3.hr^{-1}$ (5 $ft^3.min^{-1}$). At these low levels it was found that air quality can be adversely affected by accumulation of chemical and physical contaminants.

In residences built during the last 30 years, 100% of the air is recirculated; outdoor makeup air is all infiltration. Air filters are used to reduce dust resuspension.

In commercial buildings, recirculated air accounts for 80 to 100% of ventilation depending on design (5) and operation (6,7). It is very difficult to achieve energy savings in such systems without major changes in the air flow patterns.

The present paper investigates theoretically and experimentally the effect of outdoor air supply and recirculation rates on the indoor air quality. Particulate matter is the only pollutant considered in this work, where the outdoor concentration and indoor source strength are of varying nature.

Model Description

Figure 1 is a schematic illustration for a model test room showing sources and sinks of particulate matter. It represents the generalized ventilation case in which the supplied air may be totally outdoor, recirculated or mixture of both.

Under the conditions illustrated in Fig.1, the steady state conservation of mass equation for particles can be written as:

$$(1-F)\,QECo + FQEC_i + CoQ_\ell + \dot{m} = FQC_i + Q_\ell C_i + V_s A\, C_i \qquad (1)$$

where

F = fraction of recirculated air
Q = volume flow rate in the air handling system ($m^3 s^{-1}$)
Co = average outdoor particulate concentration ($\mu g\ m^{-3}$).
C_i = average indoor particulate concentration ($\mu g\ m^{-3}$).

$\dot{m}$ = dust generation from room floor ($\mu g\ s^{-1}$).
Q_ℓ = volume flow rate of air leaking from the room ($m^3\ s^{-1}$).
V_s = deposition velocity of dust particles ($m\ s^{-1}$).
A = dust deposition area inside the room (m^2).
V = indoor volume (m^3).
E = filter penetration.

The following assumptions are used in the model:

1- The room pressure is higher than that of the outside environment (pressurized ventilation), so, only air leakage from outside is considered.
2- Both Q and F are fixed during the test period.
3- concentration of indoor dust is considered to be fully mixed, and
4- outside concentration C_o is considered constant.

The time dependent indoor particle concentration is then obtained from:

$$C_i(t) = \frac{[(1-F)EQC_o + \dot{m}]}{[(1-E)FQ + Q_\ell + V_s A]}\left[1 - e^{-\frac{1}{v}[(1-E)FQ + Q_\ell + V_s A]t}\right] + C_1\, e^{-\frac{1}{v}[(1-E)FQ + Q_\ell + V_s A]t} \qquad (2)$$

Where C_1 is the average indoor particulate concentration at time zero ($\mu g\ m^{-3}$).

Equation 2 may also be used to predict the indoor particulate concentration $C_i(t)$ for some special ventilation conditions.

Experimental Test Rig and Procedure

A model of a typical room at King Saud University was built and equipped with a fan for air feeding, two fibrous filter holders one inside and one outside the room carrying millipore filters of 18 mm diameter, two gates for regulating the air flow rates, two sampling systems, and a micromanometer. The recirculated and outdoor air paths were provided with pitot-static tube for the determination of the flow velocities and hence the volumetric flow rate.

A large rotary fan was used to disperse evenly a fine dust and kept running during the test period. The test dust was analyzed for size distribution and the mass median diameter (MMD) was determined (15 µm). The indoor filters were changed every two minutes while the outdoor ones were kept for the whole test period.

Results and Discussion

The general equation (2) has been used to predict the variation of indoor particulate concentration $C_i(t)$ with time for two conditions:

a) The indoor particulate concentration is initially very low (75 $\mu g.m^{-3}$), the outdoor concentration is kept constant at a level of 500 $\mu g.m^{-3}$ with particles having a mass median diameter of 8 µm, and no particulate source exists inside the room, i.e. m = 0

b) as (a) but with a particulate source inside the room with variable strength m, ($\mu g.s^{-1}$).

For both cases, the air exchange process has been represented in the model through the variation of the outdoor and recirculated air percentages, (1-F) and F respectively.

Figure 3 shows the variation of $C_i(t)/C_i(0)$ with time for different recirculated air percents. The figure shows that except for F = 100%, the indoor concentration initially increases at a high rate, then the rate gradually decreases until a nearly constant indoor concentration is achieved. The indoor concentration level is greatly affected by the recirculated air percent, for example, when F = 0 (all outdoor air with no circulation), the indoor concentration reaches a steady state level of 10 times the initial value after one hour of ventilation. When F = 25% $C_i(t)/Co$ = 7.5, while for F = 75% a value of 4 is obtained and for F = 75% the indoor concentration is only doubled. For air recirculation (F = 100%) the indoor concentration decreases and completely vanishes after about 40 minutes. This is because of the continuous filtration of the recirculated air as it passes through the filter with an efficiency E (Fig.1). These results show that for outdoor environment with high particulate concentration, large fraction of indoor air is better be recirculated with only small fraction of outdoor air admitted to maintain the required amount of oxygen inside the building. It has to be emphasized that the present results and arguments are valid only for particulates (the only pollutant considered in this work); for gases the argument would be quite different. The effect of mean particle size on the indoor concentration has also been examined. Only the inhalable particulate size range was selected for this purpose, such a range is considered hazardous to human health. Figure 4 shows the effect of particle mean diameter on the change of $C_i(t)$ with time with 50% air recirculation and without indoor particulate source, the particulates are carried only with the outdoor air where Co = 500 $\mu g\ m^{-3}$. It is noted from Fig. 4 that larger particles have lower concentration, this is due to their higher settling velocity which is responsible for their faster losses from the indoor atmosphere than smaller particles.

When an indoor particulate source exists, the recirculation and outdoor air fractions must be adjusted based on the strength of such a source and the outdoor dust concentration. Figure 5 shows a case with the following conditions:

initial indoor concentration 75 μgm^{-3}, outdoor concentration 500 μgm^{-3}. indoor particulate source of strength 190 $\mu g.s^{-1}$ and recirculation air percent from 0 to 100%. It is noted from the figure that minimum indoor concentration would be achieved in such a case by admitting 100% outdoor air (F=0%) and by continuous exhaust of the indoor air to the environment after filtering it. The concentration levels represented by the different curves in Fig.5 would, however be lower if the actual Co is less than 500 $\mu g.m^{-3}$ which is considered to be relatively high in normal environments. Figure 6 shows the effect of indoor source strength with F = 0% and all other conditions are similar to those considered in Fig.5. The effect of source strength on $C_i(t)$ is very sensible.

To validate the theoretical model presented in this paper, some experiments were conducted on the model test room described earlier. The experiments were arranged to cover all conditions presented in the model, but due to time limitation the conditions in which the indoor particulate source exists are not presented here. However, validation of the first part would prove the reliability of the model in general.

Figures 7 - 9 show the comparison between theoretical and experimental results with recirculation air fraction of 0, 65 and 85%. Figure 7 shows that good agreement is obtained when F=0 i.e. air is totally from outdoor. As the recirculated air fraction increases the agreement becomes poorer. The reason for this may be that both recirculated and outdoor air portions do not mix properly at the sampling location as assumed in the model. furthermore the calculations are based on single particle diameter value (MMD = 15 μm) while the real dust contains a mixture of large and small particles.

In general it may be noted from Figs. 7 - 9 that the model presented here can be used satisfactorily to estimate the indoor particulate concentration at different ventilation conditions.

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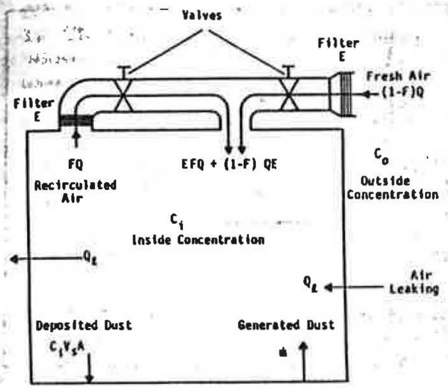

Fig.1. The main sources and sinks for dust in the test room.

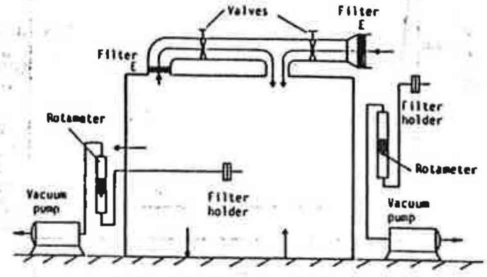

Fig.2. The Experimental Set-up.

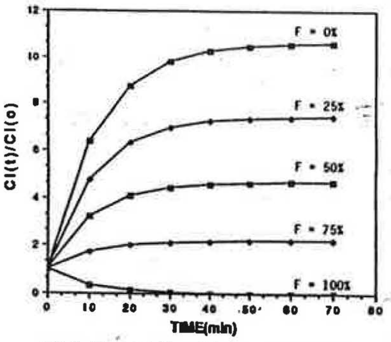

Fig.3 Time variation of indoor concentration ($C_o = 500\ \mu g m^{-3}$, $C_{i(o)} = 75\ \mu g m^{-3}$, $\dot{m} = 0$, $d_p = 8 \mu m$).

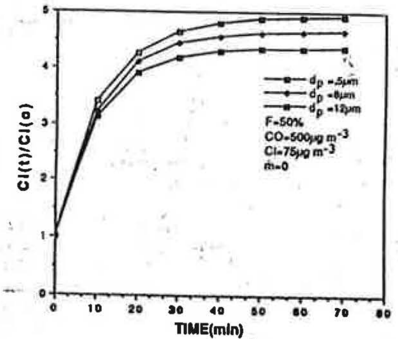

Fig.4. Time variation of indoor concentration.

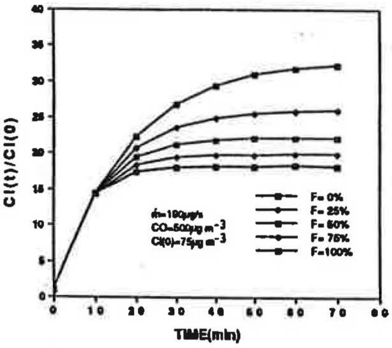

Fig.5. Time variation of indoor concentration.

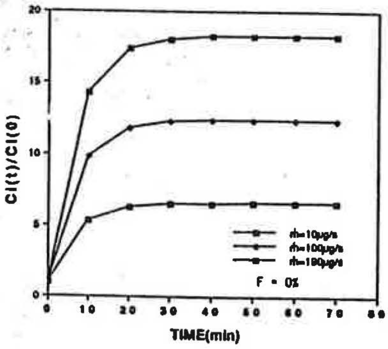

Fig.6. Time variation of indoor concentration.

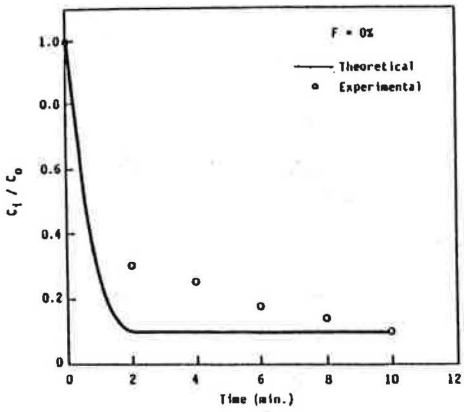

Fig.7. Comparison between theoretical and experimental variation of indoor concentration.

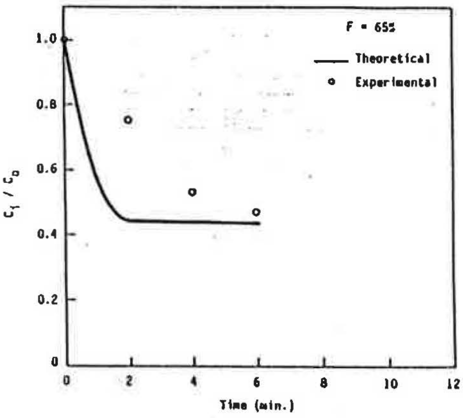

Fig.8. Comparison between theoretical and experimental variation of indoor concentration.

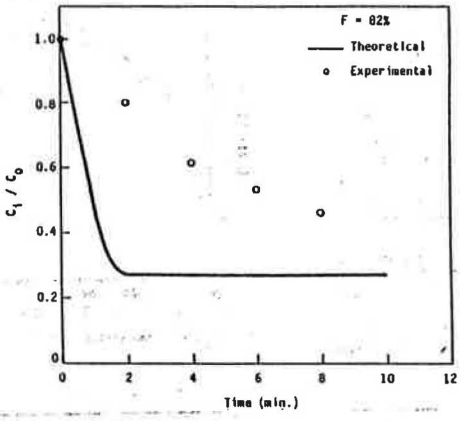

Fig.9. Comparison between theoretical and experimental variation of indoor concentration.