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ASSESSMENT OF THE EFFECT OF AIR FILTRATION AND VENTILATION ON REDUCTION OF EXPOSURE TO SUBMICROMETER PARTICLES INDOORS.

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ABSTRACT

The provision of a healthy and satisfactorily clean indoor environment requires that consideration be given to a range of issues, such as the type of indoor environment, indoor and outdoor sources, indoor activity and others. The selection of relevant measures to achieve the required indoor air quality (IAQ) depends on knowledge and understanding of the mechanisms and parameters affecting the concentration levels indoors.

The focus of this work was on assessment of the effect of air filtration and ventilation as the most commonly used remedial actions to reduce exposure to airborne pollutants indoors. A simple one zone mathematical model, developed and validated earlier, was applied to evaluate the effect of various parameters, such as filtration efficiency, filter location, mixing factor, deposition velocity and others, on particle concentrations indoors. The evolution in concentration was conducted for several scenarios assuming different outdoor and indoor air conditions. Indoor concentration has been predicted for a hypothetical building representative of an office type environment, located near a busy road in an urban environment. The model could be applied to any type of building and requires only a limited set of input parameters.

It could be concluded that indoor air is governed by outdoor air, with air filtration and ventilation as the most dominant removal mechanisms. The effect of particle losses due to coagulation and surface deposition for the presented conditions was less significant. The filtering of the supply air is most efficient in comparison with the filter located at other locations. The effect of room volume was insignificant.

KEYWORDS: air cleaning, filtration, modelling, particulate matter, ventilation

INTRODUCTION

The control of contaminants indoors is achieved by one of the following methods: source control, dilution control, or removal control. Although source control is preferred, this option is not always available. Thus, ventilation and air filtration are the main remedial actions applied to reduce exposure to airborne contaminant indoors in general, and submicrometer particles in particular. The very small particles come from a multiplicity of sources, including indoor and outdoor combustion sources and their impact on health has been considered as potentially very significant as they can penetrate deep into the human respiratory tract [1; 2].

There are also other mechanisms affecting particle concentration indoors, but their effect is either negligible or less important than the effect of ventilation and filtration, and they will not be considered here. In particular, gravitation deposition and resuspension of fine particles could be considered insignificant [3]. Also, for the type of indoor environments and particle concentration conditions encountered, coagulation is less significant than ventilation and air filtration [4; 5].

Assessing human exposures necessitates extensive indoor monitoring, which can be expensive and time consuming. Mathematical models could be used to assess the exposure and are useful for implementing control strategies. The models could vary from very simple to very complex. The selection of a model for IAQ assessment depends on the concrete application and the accuracy required. The complex models require a large set of input parameters, which are often not available or carry a high degree of uncertainty. The other issue to be considered is the model validation, which is more difficult for complex programs. While sophisticated models could potentially provide more accurate answers to specific questions, the use of simple models for a general assessment of IAQ and associated parameters under commonly occurring conditions affecting indoor environment, such as in this study, is desirable for various types of applications.

The objective of this paper was to investigate the effects of air ventilation and filtration on submicrometer particles indoors. The problem was studied using a simple mathematical model simulating the time evolution of particle concentration indoors. The evaluation of the effects was conducted for a hypothetical building representing an office type of indoor environment. Simulations were conducted for several indoor/outdoor air scenarios for static and dynamic conditions. The input parameters were related to ventilation (air flowrates, air mixing), filtration (filtration efficiency and filter location in the mechanical system), particle losses due to deposition and coagulation, and effective volume of the space. Variation of the parameters over a range of values relevant to real world data provided quantitative and qualitative assessment of the effects various mechanisms exhibit on IAQ.

METHODOLOGY

Model

A one-zone mathematical model predicting the evolution in total particle concentration indoors was used for the simulations. The model is based on the number balance equation and assumes that changes in particle concentration due to chemical reaction and particle dynamics are negligible and that the pollutants are perfectly mixed [6-8]. These assumptions are valid for most of the work related to non-industrial environments.

The relevant variables affecting the particle concentration indoors are the outdoor and indoor air concentration, air flowrates, the filtration effect of an HVAC system, particle losses due to surface deposition and coagulation, indoor sources, aerosol mixing and the effective volume of the enclosure. The details of the model are presented elsewhere [9].

The model has been validated in laboratory and field studies showing very good agreement between measured and predicted data [10, 11].

Simulation of the effects of ventilation and filtration

The effect of ventilation and air filtration on the evolution of submicrometer particle concentration indoors was investigated theoretically by simulation techniques, applying the model in a range of test conditions. The simulations were conducted for a hypothetical building with an HVAC system representing a general office type indoor environment. The input parameters used were based on previously conducted studies in real buildings [12]. The values of parameters, such as ventilation rate, filter efficiency etc. varied within a range likely to be encountered in real world conditions.

The time evolution in particle concentration could be calculated for both number and mass. In the presented study the mass concentration was recalculated from particle number concentration and size distribution, assuming particle sphericity and known particle density. Application of the reverse procedure, ie. determination of the evolution in particle number concentration from known evolution in particle mass is more difficult for the submicrometer particles. This is related to the fact, that the mass of submicrometer particles is very low. To provide a relatively accurate link between particle number and mass concentration would require high resolution in particle mass classification according to particle size.

RESULTS AND DISCUSSION

The effect of ventilation

Two cases will be described here:

Case 1.

The evolution in particle concentration for an indoor environment ventilated by an air handling system (AHS) with constant supply (Q_{SA}) and variable outdoor (Q_{OA}) and return air (Q_{RA}) flowrates. The effect was studied for four cases: (a) $C_{OA} \geq C_{O}$; (b) $C_{OA} \approx C_{O}$ (high concentration); (c) $C_{OA} \approx C_{O}$ (low concentration); and (d) $C_{OA} \leq C_{O}$, where C_{OA} and C_{O} are outdoor and initial indoor particle concentrations, respectively.

From analysing the trends in particle concentrations indoors for the investigated cases presented in Figure 1, conclusions can be drawn as to the best strategies to minimise the concentration. The strategy recommended to minimise the risk associated with outdoor pollutants for Case 1 would be to reduce the amount of outdoor air delivered indoors. To be efficient the process requires continuous monitoring of the pollutant concentration outdoors and a relatively fast response in changing the operational parameters of the ventilation system.

Similarly, the recommended strategy for a constant air volume (CAV) system under the test conditions as in Case 2 and 3 would be to reduce the amount of outdoor air (OA) in supply air (SA). For Case 4, the most effective and rapid method to reduce particle concentrations indoors would be to operate the AHS at the full OA mode with minimum amount of return air (RA). When the pollutant levels indoors are comparable to the level outdoors, the HVAC could be returned to its usual operational mode.

Case 2

The evolution in particle concentration for an indoor environment ventilated by an AHS under variable SA flowrates. Simulations were conducted for the same C_{OA} and C_{O} conditions as discussed in Case 1.

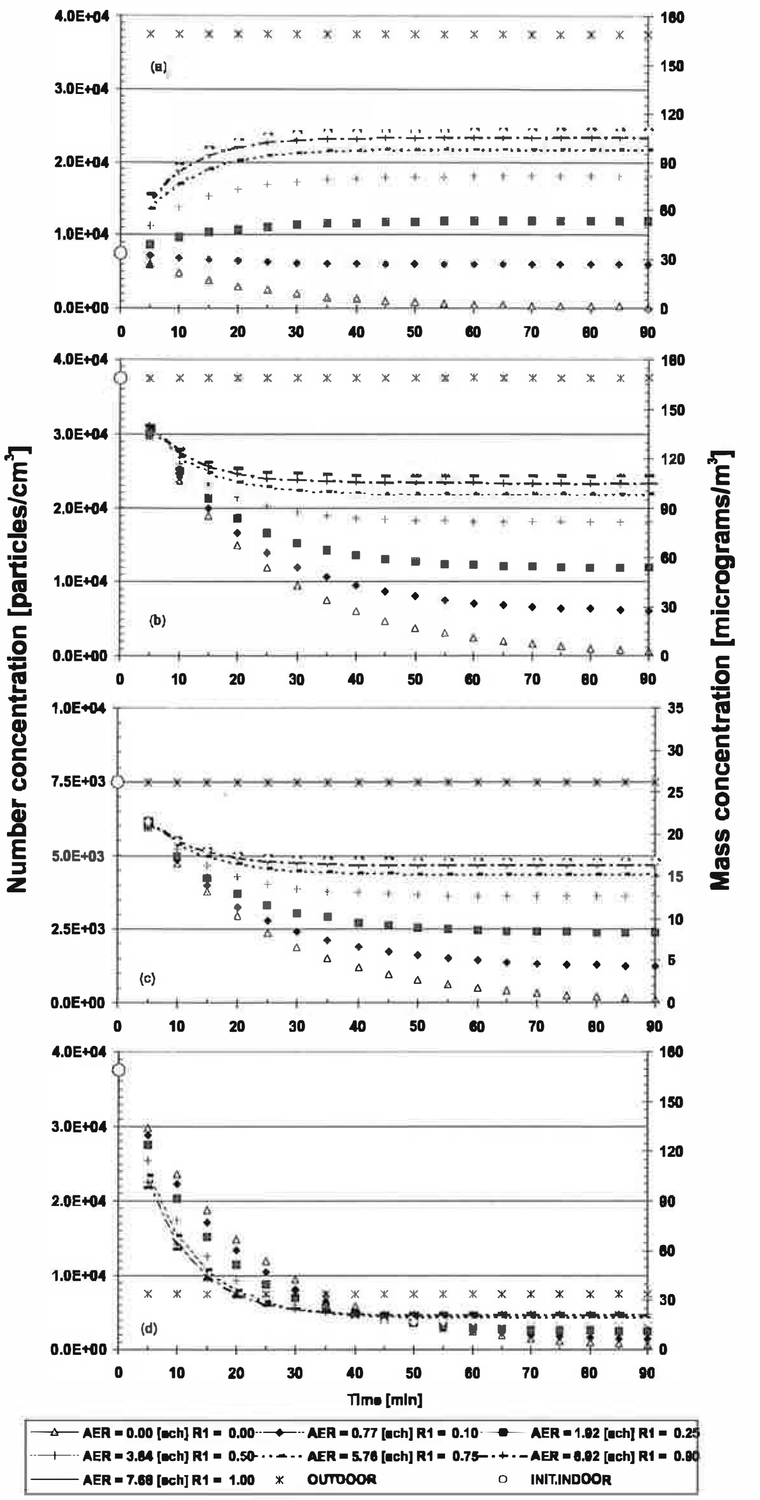

Figure 1. The time evolution of particle concentration simulated for a CAV system: (a) $C_{OA} \geq C_o$; (b) $C_{OA} \approx C_o$ (high concentration); (c) $C_{OA} \approx C_o$ (low concentration); and (d) $C_{OA} \leq C_o$ ($R1 = Q_{OA}/Q_{SA}$).

The conclusion from these simulations was that, for the AHS operated at variable SA flowrate, with the Q_{OA} set as a constant fraction of the Q_{RA}, an increase in Q_{RA} (and thus also Q_{SA}) will decrease the pollutant concentration levels indoors. With an increase in Q_{RA} the response time is reduced and the reduction rate increased, ie. the concentration indoors will decrease quicker and more rapidly. A reduction strategy for this operational mode of an AHS would require increasing the amount of RA recirculated indoors.

The effect of filtration

The effect of filtration on indoor concentration was simulated for a dynamic situation; ie. changing condition outdoors (Figure 2).

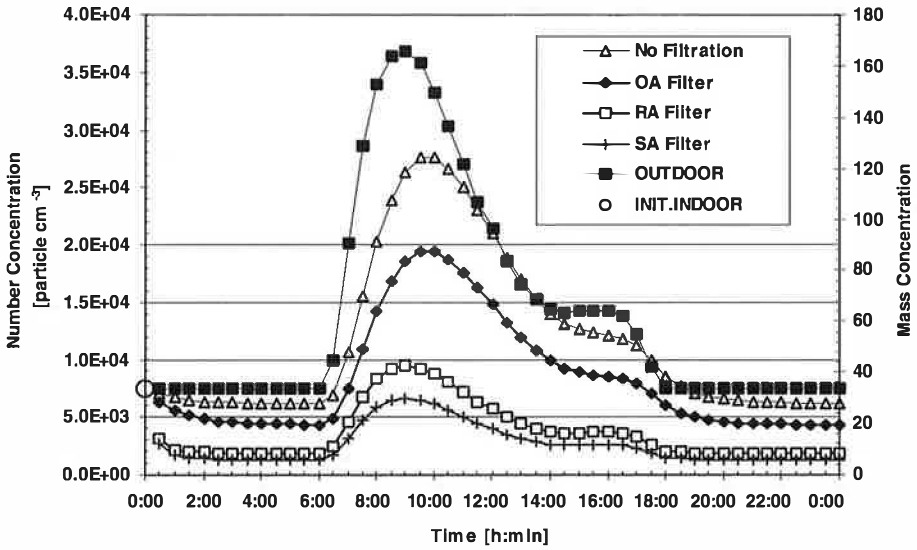

Figure 2. The effect of filtration on particle concentration indoors.

The effect of filter location in an AHS

From Figure 2 it could be concluded that the location of a filter in a building ventilation system is an important parameter in terms of particle concentration reduction strategies. For a system operating under the described conditions, the most efficient reduction was achieved with a filter located at the SA airstream. A slightly smaller reduction effect was shown when a return air filter was applied.

The effect of SA filter efficiency

In this case the simulation demonstrated that the application of an SA filter with efficiency between 15% to 90% reduced particle concentration indoors up to 80 times. The effect of SA filtration is significant with a significant reduction (factor of three) in indoor concentration even for an SA filter of a relatively low efficiency of $\varepsilon_{SA} = 15\%$.

CONCLUSIONS

Although in terms of quantitative assessment the presented results are specific for the conditions considered, the qualitative conclusions made in the study are applicable in general for most real world situations. Assessment of the effect of air filtration, ventilation and other discussed factors on IAQ for specific conditions could be calculated using user defined input parameters.

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