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Effect of ventilation strategies on particle decay rates indoors: An experimental and modelling study

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Abstract

A cubic experimental chamber of 2.5 m × 2.5 m × 2.5 m was designed to study the impact of ventilation strategies on the indoor particle concentration. Particles of 0.3–15 μm aerodynamic diameter were used. The combined effects of the ventilation rate (0.5 and 1.0 ach) and the inlet and outlet locations (six different strategies) were tested. Results show that the ventilation acts differently according to the particle size. For small particles (particle diameter lower than 5 μm in diameter), deposition is increased by a factor 2 when the airflow was changed from the Top–Top to the Bottom–Top inlet/outlet configuration. Increasing the ventilation rate from 0.5 to 1.0 h^{-1} does not modify deposition for the Top–Top configuration but decreases it by 2.8 for the Bottom–Top. The effect of the inlet and outlet locations is less notable for coarse particles. This experimental study reveals that the ventilation strategy has to be well adapted to the particle size in order to improve its effectiveness. We show that the locations of the inlet and the outlet can be a very important parameter and have to be taken into account to predict particle indoor air quality. In addition, a numerical model of particle dispersion was developed. The program calculates instantaneous distributions of air velocity, using the large eddy simulation (LES) method. Trajectories of particles are obtained by implementing a Lagrangian particle model into the LES program. We simulated the experimental conditions in the three-dimensional numerical model and results show that ventilation strategy influences particle deposition in the room. A comparison of numerical and experimental results is given for 5 and 10μm particles. Particle behaviour is well predicted and this model seems to be adapted to predict indoor particle air quality in buildings. More experimental results are needed for a better validation of the numerical model, essentially for small particles.

Keywords: Air quality; Particle matter; Large eddy simulation; Lagrangian model; Building physics

1. Introduction

Indoor air pollution has become a major subject over the past few decades. In the urban environment, outdoor air which is heavily polluted by industrial activities and vehicle emissions, penetrates inside building, and influences the indoor air quality. In addition, indoor particle sources, such as tobacco smoke and cooking vapours can have a greater effect on personal exposure (Abt et al., 2000).

Particle deposition on surfaces and adapted ventilation strategy can substantially reduce indoor particle concentrations, resulting in improving the indoor air quality. To predict particle pollution in buildings, size-resolved deposition rate can be used. Reviews of experimental studies on the particle deposition process

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were reported by Hinds (1982), Wallace (1996) and recently by Lai (2002). Generally, these studies give large variability in deposition rate for each particle size. Size of the experimental room (Nazaroff et al., 1993), roughness of surfaces (Abadie et al., 2001), airflow rates (Roed and Goddard, 1990; Fogh et al., 1997; Nomura et al., 1997; Jamriska et al., 2000), inlet/outlet locations (Mundt, 2001; Zhao et al., 2004), furnished or unfurnished room (Thatcher et al., 2002), are parameters that influence the indoor particle deposition rate.

In the present study, measurements of the particle concentration evolution in a mechanically ventilated room have been carried out to investigate the combined effects of ventilation strategies and air change rate on the size-resolved particle deposition rate.

A numerical model, using large eddy simulation (LES) and Lagrangian particle model was developed. Particle deposition rates are obtained by calculating a large number of particle trajectories. Numerical results show that particle deposition velocity is influenced by the ventilation strategy.

2. Experiments

2.1. Experimental methodology

Particle concentration measurements were performed in a cubic test-room with 2.5 m sides, covered with wood panels. The layout of the room is shown in Fig. 1. The test-room is equipped with a mechanical ventilation system. The airflow was adjusted via an electronic fan speed controller: two airflow rates, corresponding to 0.5 and 1.0 air change per hour (ach), were calibrated using the tracer decay method with sulphur hexafluoride (SF6). These air-exchange rates were chosen according to AIVC 44 (1994) that reports that in European buildings exchange rates range from 0.2 to 1.0 h^{-1}, with a mean value of 0.4 h^{-1}. The uncertainty of the calculated air change rates was $\pm 0.05\,h^{-1}$. High-efficiency filters were used to prevent incoming particles from outdoor (filter 1) and to avoid particle

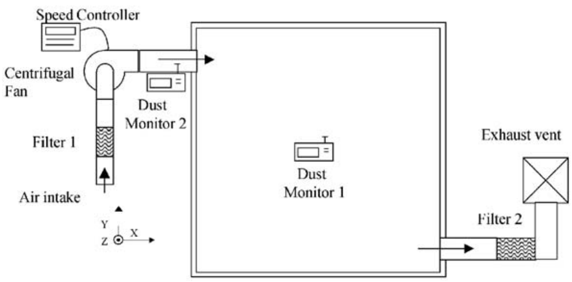

Fig. 1. Schematic diagram of the experimental system (cross-section).

Table 1
Inlet and outlet centre locations (vertical axis: Y)

Configuration	"Bottom–Top"	"Top–bottom"	"Top–Top"
Inlet location (m)	$X = 0$	$X = 0$	$X = 0$
	$Y = 0.3$	$Y = 2.2$	$Y = 2.2$
	$Z = 1.25$	$Z = 1.25$	$Z = 1.25$
Outlet location (m)	$X = 2.5$	$X = 2.5$	$X = 2.5$
	$Y = 2.2$	$Y = 0.3$	$Y = 2.2$
	$Z = 1.25$	$Z = 1.25$	$Z = 1.25$

releases outside of the test-room (filter 2). The ventilation air enters the room through the inlet section (0.07 m × 0.07 m) and exhausts through the outlet section (0.07 m × 0.07 m). Locations of the inlet and the outlet are presented in Table 1. The two ventilation rates give Reynolds numbers based on the air velocity at inlet and inlet height from 2000 to 4000. All measurements were performed under isothermal condition (20 °C ± 2 °C) and constant relative humidity (50% ± 10%). Two dust monitors (optical particle counter, GRIMM 1.108) continuously measured the particle concentration in the range 0.3–25 μm. In the present study, we focused our analysis on particles lower than 15 μm in diameter because they represent the majority of indoor particle pollutant and a potential danger for human health. The first counter was located at the geometrical centre of the room; the second one was placed at the inlet to control the particle concentration of the incoming air.

The experimental procedure was the following: the ventilation system was set to a predetermined airflow rate, the dust monitors were switched on. The particle concentration was measured every minute during 2 h. Fig. 2 presents typical evolutions of the particle concentration during the tests. Values during the first 15 min correspond to the background particle concentration. Polydispersed polyamide powders (0.3–15 μm; spherical shape; obtained by direct polymerization) were instantaneously injected at time $t = 15$ min by the use of a compressed air device (as suggested by Hinds, 1982) at different locations within the whole volume. The ventilation airflow is enough to obtain concentration homogeneity as already reported by Thatcher et al. (2002). Maximum particle concentration was 10^7 particles dm^{-3}. At this level, coagulation is insignificant compared to the deposition process (Hinds, 1982).

Based on this particle concentration, the time required to reach the Boltzmann equilibrium is 5–6 min (Reist, 1993).

Note that preliminary tests have been carried out to assess the particle concentration homogeneity within the room for each configuration. Comparison of the