Impact of ventilation strategies on particle deposition in a test chamber

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ABSTRACT
A cubic experimental chamber with 2.5m of sides was designed to measure the impact of the ventilation on particle concentration. Particles of 0.3 - 15µm diameter were used. Two ventilation parameters were studied: the ventilation rate (0.5 and 1.0 ach) and the inlet and outlet locations (inlet in the bottom part and outlet in the top part of the room; inlet in the top part and outlet in the bottom part of the room; and inlet and outlet both in the top part of the room).

Results show that the ventilation acts differently according to the particle size. For small particles (particle diameter lower than 5µm), deposition depends both on the airflow path within the room and on the strength of the ventilation. The effect of the inlet and outlet locations is less notable for coarse particles.

This 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 has to be taken into account for models of indoor particle pollution.

INDEX TERMS
Air quality, Particle matter, Deposition, Ventilation strategy, Buildings physics.

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 can have a greater effect on personal exposure.

Particle deposition to 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 particle deposition process were reported by Hinds (1982), Wallace (1996) and recently by Lai (2002a). 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), air flow conditions (Nomura et al., 1997; Jamriska et al., 2000; Lai et al., 2002b), 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 effects of ventilation strategies and the effects of air change rate on the size-resolved particle deposition rate.

METHODS

Indoor particle pollution modeling

To evaluate the evolution of the particle concentration within a room, under isothermal conditions, the mass balance of the pollutant is written as a function of the incoming polluted air, the particle deposition on the walls and the mass of pollutant leaving the zone. Considering that the room is a well-mixed ventilated zone and that there is no pollutant source in the room, the time-dependent particle concentration is given by:

$$\frac{dC_i(t)}{dt} = \lambda_v C_0(t) - \lambda_v C_i(t) - \lambda_{de} C_i(t) \quad (1)$$

where t is the time (h), $C_i(t)$ is the indoor particle concentration (number of particles.m^{-3}) at time t, λ_v is the air change rate (h^{-1}), $C_0(t)$ is the outdoor concentration at time t, and λ_{de} is the particle deposition loss rate coefficient (h^{-1}).

In the case of low outdoor particle concentration (in comparison to indoor level) or ventilation system equipped with a particle high efficiency filter, the particle infiltration from outdoor can be neglected and a direct analytical solution to Equation 1 is given by:

$$C_i(t) = C_i(0)\exp(-\lambda_g \times t) \quad (2)$$

where $C_i(0)$ is the initial indoor concentration and $\lambda_g = \lambda_v + \lambda_{de}$ represents the overall loss rate (h^{-1}).

Experiments

Particle concentration measurements were performed in a cubic test-room with 2.5m sides, covered with wood panels. The layout of the room is shown in Figure 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. High efficiency filters were used to prevent incoming particles from outdoor (filter 1) and to avoid particle releases outside of the test-room (filter 2). Locations of the inlet and the outlet are presented in Table 1. Measurements were made under isothermal condition (20°C ± 2°C) and constant relative humidity (50% ± 10%). Two dust monitors (optical particle counter) continuously measured the particle concentration in the range 0.3 - 15μm. The first one was located at the inlet to control the particle concentration of the incoming air, the second one was placed at the center of the room.

Table 1. Inlet and outlet locations.

	Configuration 1 "Bottom – Top"	Configuration 2 "Top - Bottom"	Configuration 3 "Top - Top"
Inlet Position (m)	X= 0 Y= 0.306 Z = 1.25	X= 0 Y= 2.194 Z = 1.25	X= 0 Y= 2.194 Z = 1.25
Outlet Position (m)	X= 2.5 Y= 2.194 Z = 1.25	X= 2.5 Y= 0.306 Z = 1.25	X= 2.5 Y= 2.194 Z = 1.25

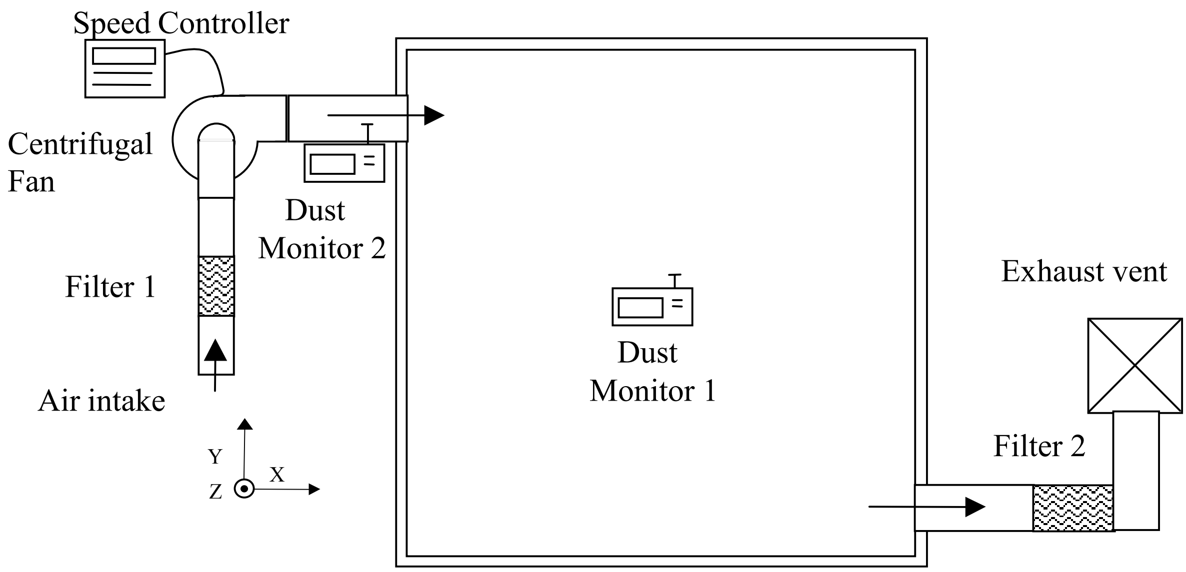

Figure 1. Schematic diagram of the experimental system (median vertical plan).

The experimental procedure was the following: the ventilation system was set to a predetermined airflow rate, the dust monitors were switched on and the particle powder was injected in the room after reaching steady particle concentration profiles (background noises). Figure 2 presents typical evolutions of the particle concentration during the tests. The particle concentration was measured every minute during two hours. Values during the first 15min correspond to the background particle concentration. Particles were instantaneously injected at time t = 15min. Linear decreases (in log scale) corresponding to particle concentration exponential decays were then measured. The overall loss rate λ_g of Equation 2 was determined by linear regression of the decrease part of the curves. The correlation coefficient r^2 was usually higher than 0.95. All experiments were reproduced five times.

Note that preliminary tests have been carried out to assess the particle concentration within the room. Comparison of the concentration levels measured by the dust monitor 2 at the outlet, in the jet (at the center of the room) and in one bottom corner with those measured by the dust monitor 1 (located at the center of the room) shows that the overall relative error is lower than 9%. This implies that the room can be considered as a well-mixed zone that the 1-zone model (Equation 1) can be used to determine the overall loss rate coefficient.

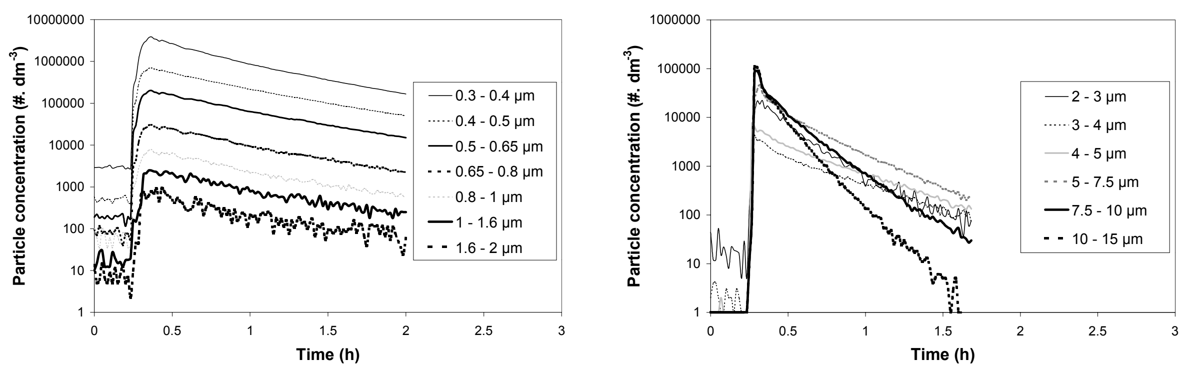

Figure 2. Particle concentrations for selected particles size range during an experiment.

RESULTS

Figure 3 presents the overall particle loss rate coefficient λ_g as a function of particle size for the three tested configurations i.e. "Bottom - Top", "Top - Bottom" and "Top - Top" configurations. Graphics on the left side correspond to an airflow set to 0.5 ach, those on the right side correspond to 1.0 ach. Error bars include deviations from the five runs mean value and equipment systematic errors. Figure 4 sums up all the results for two ventilation rates, error bars were not included in order to improve the readability of the graphics.

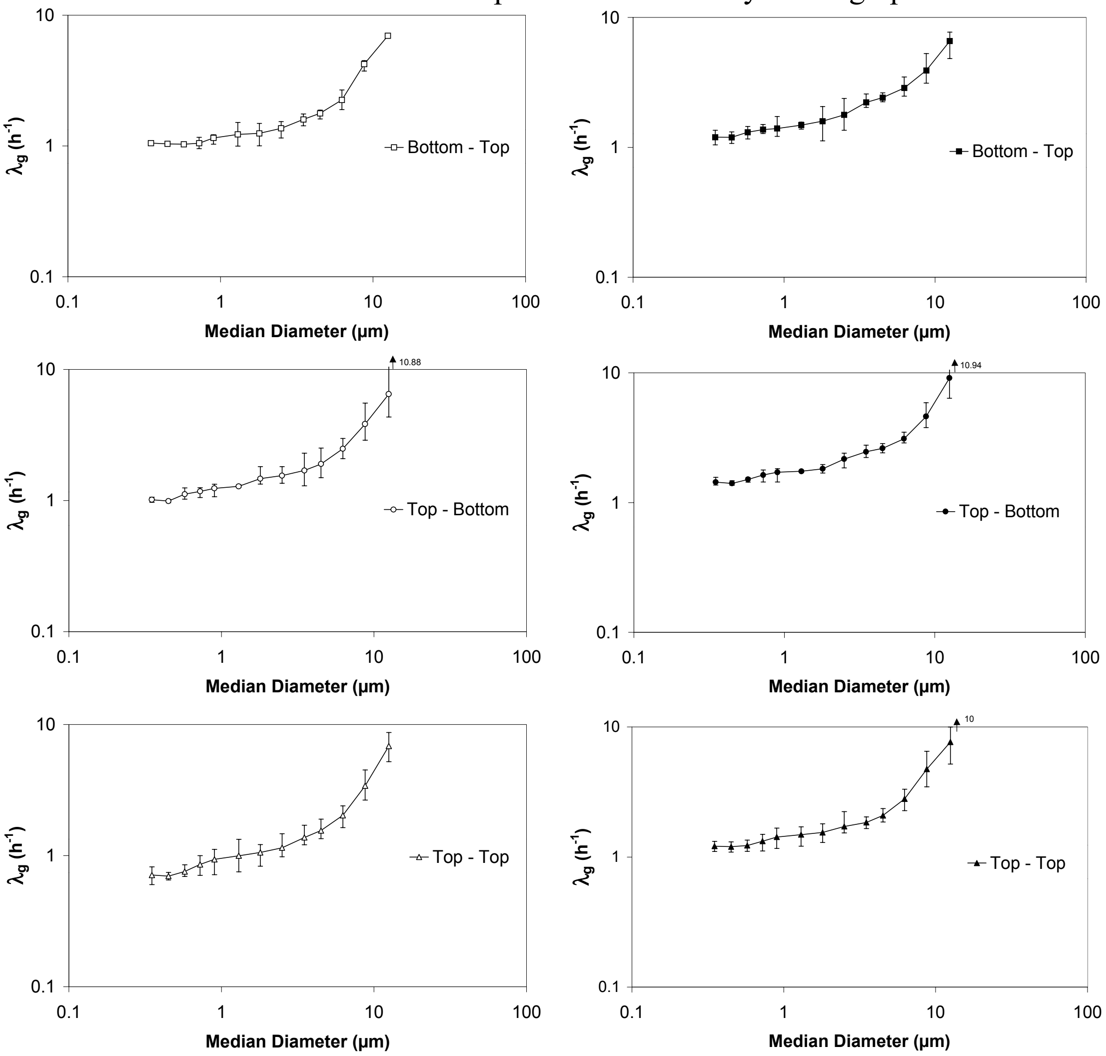

Figure 3. Overall loss rate coefficient λ_g according to particle size, inlet/outlet location and ventilation rate (left side : 0.5 ach, right side : 1.0 ach).

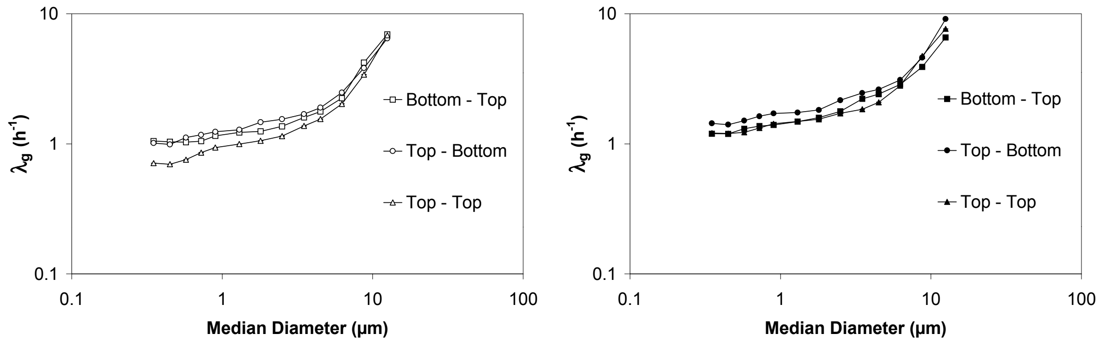

Figure 4. Influence of the inlet/outlet locations on the overall loss rate coefficient for two ventilation rates (left side : 0.5 ach, right side : 1.0 ach).

DISCUSSION

For the two studied ventilation rates (Figure 4), the ventilation strategy "Top - Bottom" gives the highest overall loss rates. The lowest values are given by the "Top - Top" configuration, excepted for particles greater than 8.75µm (note that for this particle size, errors are too high to compare the results). Values obtained for the "Bottom - Top" configuration are closed to those for the "Top - Bottom" configuration with a ventilation rate λ_v set to 0.5 ach, and closed to those for the "Top - Top" configuration for $\lambda_v = 1.0$ ach.

In order to compare the different ventilation strategies tested in this study, we defined a coefficient, P_{eff} given by Equation 3, which gives the relative improvement of a given configuration in comparison with the "Top - Top" configuration.

$$P_{eff} = \frac{\left(\lambda_{g,\lambda_v,conf.} - \lambda_{g,\lambda_v,top-top}\right)}{\lambda_{g,\lambda_v,top-top}} \tag{3}$$

where $\lambda_{g,\lambda v,conf.}$ is the overall loss rate (h^{-1}) depending on the ventilation rate and the ventilation strategy and $\lambda_{g,\lambda v,top-top}$ is the overall loss rate for the "Top - Top" configuration.

Table 2 presents the P_{eff} values for the "Top - Bottom" and "Bottom - Top" configurations. As noted before, the “Top – Bottom” configuration is more efficient to remove particles from the room (29% compared to 23% for 0.5 ach and 19% compared to 1% for 1.0 ach). The difference between the two configurations is found greater for the high airflow rate (6% for 0.5 ach compared to 18% for 1.0 ach) but efficiency is greater for the low airflow rate. Finally, fine particles (lower than 5µm in diameter) are more sensitive to the ventilation strategy than coarse particles.

Table 2. Comparison of the ventilation strategies compared to the "Top - Top" configuration.

Median Particle diameter (µm)	*0.35*	*0.45*	*0.575*	*0.725*	*0.9*	*1.3*	*1.8*	*2.5*	*3.5*	*4.5*	*6.25*	*8.75*	*12.5*	**Average efficiency**
0.5 ach Top - Bottom	43%	42%	48%	37%	32%	29%	39%	35%	23%	22%	23%	13%	-5%	**29%**
0.5 ach Bottom - Top	48%	49%	36%	23%	23%	23%	18%	19%	16%	14%	11%	24%	2%	**23%**
1 ach Top - Bottom	19%	17%	23%	23%	20%	17%	18%	26%	34%	26%	11%	-3%	19%	**19%**
1 ach Bottom - Top	-1%	-1%	7%	3%	-2%	0%	3%	4%	20%	16%	2%	-18%	-14%	**1%**

To investigate further the influence of the ventilation on the particle concentration, we present results of the particle deposition velocity V_{de} that is linked to the particle deposition loss rate λ_{de} (Equation 4) and is currently used to evaluate the strength of the particle deposition on walls.

$$V_{de} = \frac{\left(\lambda_g - \lambda_v\right)}{3600} \times \frac{V}{S} \tag{4}$$

where V_{de} is the particle deposition velocity ($m.s^{-1}$), λ_g represents the overall loss rate (h^{-1}),λ_v is the air change rate (h^{-1}), V is the volume of the room (m^3) and S is the total area of the room (m^2).

As illustrated in Figure 5 there is no notable difference between the "Top - Top" or the "Top - Bottom" configurations for the two airflow rates. But, for the "Bottom - Top" configuration, higher airflow rate leads to lower deposition. This is due to the fact that the airflow isolates the floor from the core of the room and delayed the particles to deposit onto this surface which is the preponderant particle deposition surface in rooms. As a result, increasing the air movement within the room does not necessary increase the particle deposition and the path followed by the air has to be taken into account in real room.

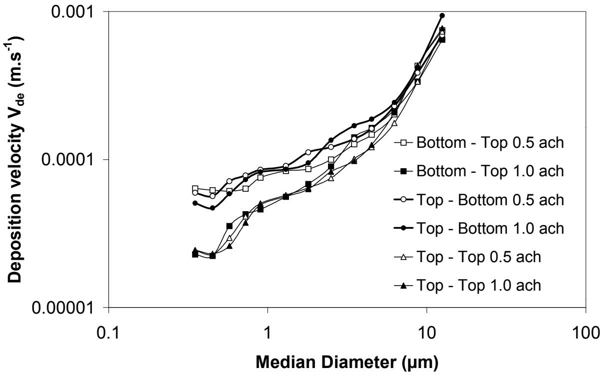

Figure 5. Particle deposition velocity as a function of particle size.

CONCLUSION

By measuring the particle concentration evolution in a mechanically ventilated room, the present study brought new experimental data that were needed to improve our knowledge of the influence of the ventilation on the particle pollution.

As shown by previous studies, particles removal from indoor air depends on the airflow rate but we demonstrate that it depends on the airflow path within the room as well. We found that the influence of the inlet/outlet locations is stronger for fine particles (lower than 5µm in diameter) than for coarse particles and that an increase of the airflow turbulence does not necessary lead to higher deposition.

The choice of a ventilation strategy, i.e. the airflow rate as well as the inlet/outlet locations, has to be carefully taken in order to limit the particle pollution in rooms.

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