Study on particles' mass balance as a function of the ventilation rate in a test cell

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ABSTRACT

The indoor air quality is a very important issue and it generally depends on the airtightness of the shell, the ventilation rates, the deposition and the resuspension rates of the particles and the internal sources as well.
The whole experimental procedure took place in a PASSYS test cell, which is located at the University Campus of Athens. At the internal door of the test cell, a blower door system was mounted, in order to control the pressure difference between the internal and external environment as well as the equivalent airflow through the internal of the test cell.
The aim of this study is the investigation of the balance of the particles' concentration in two cases; firstly, by keeping the pressure difference between the external and the internal environment near to zero and then by changing the pressure difference as follows: 0.1–4 Pa, 4.1-8Pa, 8.1-12Pa. The calculations of the deposition velocities have been performed for the following ranges of aerodynamic diameter: values less than 1μm, 1-2.5 μm, 2.5-5 μm, 5-10 μm.
In order to measure the infiltration rates the tracer gas decay method has been used with INNOVA 1312 tool. The particles' concentration has been measured through the HANDHELD 3016 IAQ as well. The deposition velocities range from 0.027m/h for values of particles less than 1μm to 0.670m/h for particles of 5-10 μm, in case of zero pressure difference. The deposition velocities have also been calculated for the cases that the pressure difference varies in a specific range.

1. INTRODUCTION

The indoor air quality is very important issue, as people spend a lot of time indoors. In order to define the indoor air quality, it is necessary to study all the procedures that take place indoors as well as the source and the fate of particles, [1], [2].
The indoor concentration can be calculated as:

$$C_{in} = \frac{L_{fi} A_{fi} R + \lambda_v PVC_0 + G}{\left(A_d u_d + \lambda_v V\right)} \quad (1)$$

where C_{in} is the indoors concentration of particles (mg*m^{-3}), L_{fi} is the mass loading of particles (mg*m^{-2}), A_{fi} is the surface area of floors(m^2), R the resuspension rate of particles from floors (h^{-1}), λ_v is the air exchange rate, C_0 is the outdoor concentration (mg*m^{-3}), P is the penetration factor of particles in the building, V is the volume of the building (m^3), G is the generation rate of particle indoors (mg*h^{-1}), A_d is the total surface area for deposition (m^2) and u_d is the deposition velocity (m*h^{-1}). The equation does not take into account the effects of evaporation, condensation and coagulation.
In the first part of the experimental procedure, the deposition velocities are defined in steady state conditions, while in the second part they are defined in different pressure differences between inside and outside the test cell.

In the first part of the experimental procedure, an indirect method is performed, in order to evaluate the deposition velocities for all size ranges of particles. More specifically, an artificial increase of the particles' concentration is noticed into the building, after an excessive number of cigarettes smoked. The building is remained empty and there are not internal sources of particles.
Based on equation 1, the elements $L_f A_f R$, G can be considered negligible. Also the term of infiltration $\lambda_v PVC_0$ can be ignored, while the exfiltration is much higher because of the higher indoor concentrations.
The variation of particles' concentration is exclusively due to exfiltration phenomenon as well as to deposition. Equation 1 is converted to $A_d u_d C_{in} = -\lambda_v V C_{in}$ (2) so the variation rate of concentration can be calculated by the equation (3)

$$V \frac{dC_{in}}{dt} = -(\lambda_v V C_{in} + A_d u_d C_{in}) \quad (3)$$

and finally the deposition rate is given from equation (4).

$$\Rightarrow \lambda_d = \frac{1}{t} \ln \frac{C_i}{C} - \lambda_v \quad (4)$$

The deposition velocity is defined from the deposition rate from the equation $u_d = \frac{\lambda_d V}{A_d}$ (5).
As it can be seen from the equation above, it is necessary to measure the particles concentration inside the building as well as the infiltration rate at regular steps. Also, these parameters must be measured for each particle size (<1μm, 1.0-2.5 μm, 2.5-5.0 μm, 5.0-10.0 μm), while they vary according the particle size. Regarding the infiltration rate λ_v, it is defined by the tracer gas method, which is based on the decay of an ejected gas concentration (N_2O) and it is evaluated from the equation below.

$$\lambda_v = \frac{1}{(t - t_0)} \ln\left(\frac{K}{K_0}\right) \quad (6)$$

K, K_0 are the final and the initial concentrations of the gas N_2O (at the moment t and t_o) [7]. Small time steps are selected, in order to minimize the weather effect.
Also, it is noticed that the meteorological conditions are considered steady during the experiments. The ambient temperature, the wind speed velocity and direction, the relative humidity, the indoor temperature as well as the pressure difference between inside and outside are measured enduringly in order to verify the steadiness of meteorological conditions.
In the second part of the experimental procedure, the variation of the particles concentration can be calculated from the equation:

$$\frac{dC}{dt} = -\lambda_v C_{in} - \lambda_{dr} C_{in} + \frac{\lambda_{fan}}{V} C_0 + \lambda_v C_0 \quad (7)$$

where $\lambda_v C_{in}$ is the exfiltration term, $\lambda_{dr} C_{in}$ is the deposition-resuspension term, $\frac{\lambda_{fan}}{V} C_0$ represents the concentration of income particles through the fan, λ_{fan} is the airflow through the fan as it is recorded in the DM4 manometer and finally $\lambda_v C_0$ is the infiltration term. The deposition – resuspension term is finally given by the equation:

$$\lambda_{dr} = \frac{\lambda_{fan} C_0}{VC_{in}} - \frac{1}{C_{in}}\frac{dC}{dt} - \lambda_v + \frac{\lambda_v C_0}{C_{in}} \quad (8)$$

2. EXPERIMENTAL PROCEDURE

2.1. The test cell description

The experimental procedure took place in a test cell, which is situated in the University Campus of Athens. The test cell is constituted from an auxiliary space and a main space where the experiment was performed. The volume of the main room is about $38m^3$ (5.00m x 2.76m x 2.75m) and the total internal surfaces area is about $70m^2$. The test cell is well insulated and the conditions inside are controlled.

Picture 1. The test cell building (southwest elevation).

Picture 2. The interior of the test cell building.

2.2. Experimental Instrumentation

The particles' concentration is measured by HANDHELD 3016 IAQ. This instrument can measure particles 'size of 0.3, 0.5, 1, 2.5, 5 και 10μm with airflow 0.1cfm. At the same time, temperature and relative humidity sensors are connected with the instrument in order to register the indoor parameters. The software Lighthouse Data Transfer stores all the data.

A multi gas analyzer (Innova 1312), which makes use of the photoacoustic infrared spectroscopy technique, was used in order to evaluate the infiltration rate of the building λ_v, by using the decay method. The tracer gas used in this experiment is N_2O.

Indoor temperature and relative humidity were measured by temperature and relative humidity sensors (EBRO data loggers).

A basic blower door system including a calibrated fan, a door panel system and a device to measure fan flow and building pressure was used in order to vary the

pressure difference between the interior and the exterior of the building and define the airflow inside the building at the same time.
The pressure difference as well as the airflow inside the building was measured by DM4 dual digital manometer.

2.3. Results of the experimental procedure

2.3.1. Calculation of the deposition velocities under steady state conditions

The deposition velocities of all particles' ranges are calculated by the indirect method, which is described above. According to this method, an artificial increasing of particles concentration was realized after a successive number of smoking cigarettes [3], [4]. During the experiment, the entrance door of the test cell remained closed. The experimental procedure took place at noontime, at summer period in order to keep the weather conditions constant. The experimental procedure was repeated five times [5], [6].
The particles' concentration with diameter <1.0 μm, 1.0-2.5 μm, 2.5-5.0 μm, 5.0-10.0 μm was recorded with time step 5 minutes for eight hours. The infiltration rate was determined by the tracer gas method and the average infiltration rate value was calculated about 0.2ACH.
The average deposition velocities for all particle ranges are presented in Table 1 and in Figure 1.

Table 1: Average deposition velocities u_d (m/h) for all particle ranges.

Deposition velocity of particles (m^3/h)				
Particles size/ Date	**<1.0 μm**	**1.0-2.5 μm**	**2.5-5.0 μm**	**5.0-10.0 μm**
17-9-07	0.016	0.061	0.108	0.604
5-10-07	0.023	0.121	0.169	0.665
18-10-07	0.040	0.142	0.198	0.730
19-10-07 (a)	0.034	0.121	0.202	0.733
19-10-07 (b)	0.022	0.107	0.179	0.620

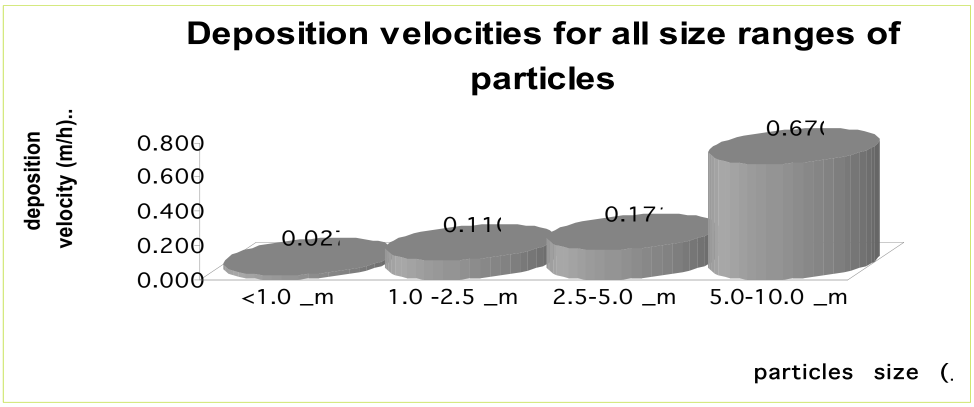

Figure 1: Deposition velocities for all size ranges of particles

2.3.2. Calculation of the deposition velocities under specific pressure differences

In the second part of the experimental procedure, the particle mass balance was investigated as a function of the pressure difference between indoors and outdoors.
A blower door system is mounted on the entrance of the test cell, in order to study the particles' concentration balance under specific pressure differences (0.1-4Pa, 4.1-8Pa, 8.1-12Pa). The pressure differences as well as the airflows inside the test cell were recorded with DM4 dual digital micromanometer.

The experimental procedure was repeated five times. The duration of each measurement balanced from two to three hours.
The infiltration rate is calculated again and its average value is equal to 0.27ACH.

Table 2: Average deposition velocities ud (m/h) for all particle ranges, under specific pressure differences

Average value of λdr				
Particles size/pressure difference	<1.0 μm	1.0-2.5 μm	2.5-5.0 μm	5.0-10.0 μm
0.1-4Pa	1.12	2.37	2.97	6.86
4.1-8Pa	2.93	4.58	5.40	9.64
8.1-12Pa	3.75	5.95	6.92	10.68

3. CONCLUSIONS

The particle mass balance was investigated in steady state conditions where the pressure difference between indoors and outdoors was assumed near to zero and under specific pressure differences.
In both cases, the concentration reduction rate of particles is higher depending on the size of particles. The deposition velocity is increased when the aerodynamic diameter of particles is increased. It is noticeable that under specific pressure differences the deposition-resuspension factor is increased as the aerodynamic diameter is increased. Finally, the deposition-resuspension factor is increased as the pressure difference between outdoors and indoors is increased.

4. REFERENCES

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