UDC 624

INFLUENCE OF OUTDOOR PARTICULATE POLLUTION AND METEOROLOGICAL PARAMETERS ON INDOOR FINE PARTICLES LEVELS IN TWO DIFFERENT VENTILATION SYSTEMS

Rahmeh M. a,b*, Limam K.a, Michea B.b
Iurchenko Iev.L. c, Koval O.O. c
aLaboratory of engineering sciences for environment (LaSIE), University of La Rochelle, France
bVENTILAIRSEC, Saint-Herblain, France
cAcademy of Civil Engineering and Architecture", 49600 Dnipropetrovsk (Ukraine)

Introduction. The ambient air pollution is reaching dangerous level for people's health in many cities. The world health organization "WHO" estimates more than two million death per year from breathing in tiny particles present in indoor and outdoor air ("WHO | Tackling the Global Clean Air Challenge" 2013).

The serious consequences of short and long-term exposure to high levels of fine particles PM2.5, the particles with an aerodynamic diameter smaller than 2.5 μm, were shown in numerous studies. This PM fraction may cause pulmonary and cardiovascular disease, adverse changes in cardiac autonomic function, vasculature alterations, modulated host defenses and immunity, lung cancer and hypoxemia (Pope and Dockery 2006). Thus, it's responsible for a decrease in life expectancy with a higher early mortality.

The indoor particulate air pollution consists of particles emitted and formed inside plus the outdoor particles that have infiltrated into the building, principally via the ventilation system. In this study, we focus on examining the difference of the influence of outdoor sources on the measured indoor concentration of particles with diameters range between 0.3 and 3.0 μm in two different ventilation systems: The multi supply-only ventilation (M-SOV) and the extract-only ventilation (EOV) systems.

Methods.

Experimental site

The experiment is carried out in an airtight two-story house located in the rural aera. There is no indoor production of contaminants due to the non-occupancy of the house. As for the exterior pollution, it was mainly caused by the nearby construction sites and the slight rural circulation.

The measurements of particles were performed in the 2nd floor bedroom. This room has a window facing the one and only car pathway.

Studied ventilation systems

In this study, two ventilation systems are tested:

1) The Multi Supply-Only Ventilation (M-SOV). It works by mechanically introducing fresh, filtered and preheated air into the living-room and bedrooms. As for the evacuation, steal air goes out through natural vents installed in the utility rooms (kitchen, bathroom and toilets). We have fixed the insufflation flow rate during the tests with a global mean value

around a 104 m3/h. The insufflation rate in the studied bedroom is about a 25 m3/h. The machine used for M-SOV is the VMI® produced by Ventilairsec, France. The efficiency of the embedded filter (reference TITAPAK SA-HPE F7) is shown in table 1 (CETIAT 2009).

Table 1

Filtration efficiency of the VMI®

	0.3-0.5 μm	0.5-0.7 μm	0.7-1.0 μm	1.0-2.0 μm	2.0-3.0 μm	3.0-5.0 μm	5.0-10 μm
Eff (%)	82.1 ± 0.2	89.9 ± 0.3	93.3 ± 0.4	95.3 ± 0.2	96.7 ± 0.2	98.4 ± 0.1	99.3 ± 0.2

2) The Humidity-Controlled Extract-Only Ventilation (HC-EOV). This system is commonly used in the low-energy French homes and known as VMC hygro B. The fresh air enters naturally through hygro-regulated air inlet fixed on the windows of living-room and bedrooms while the polluted air is extracted in the utility rooms via hygro-regulated mechanical extractors. Thus, the air flow rates vary in function of humidity level inside the dwelling.

Instrumentation

The number concentration of particles is monitored using 4 optical particles counters produced by GRIMM aerosol technik GmbH&Co.KG, Ainring, Germany: model 1.108 (reproducibility: ±3% across the entire measuring range).

Two OPCs are installed in the attic as shown in figure 1 in order to calculate the filtration efficiency of the VMI®. The 3rd is positioned at the middle of the bedroom at a high of 1.10 m and the 4th one is posed outside the room near the air inlet to measure the indoor and outdoor particles concentrations respectively (figure 2).

The followings particle's ranges were captured: 0.3-0.4, 0.4-0.5, 0.5-0.65, 0.65-0.8, 0.8-1.0, 1.0-1.6, 1.6-2.0 and 2.0-3.0 μm. As well as the particles number concentration of particles with a diameter greater than 3.0 μm.

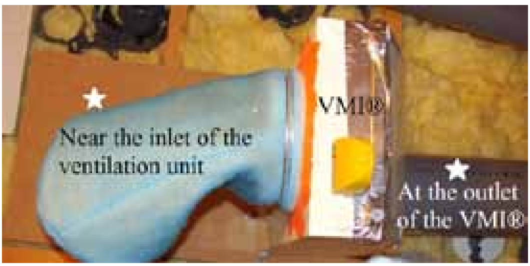

Figure 1. Sampling points for filtration efficiency measurements

Figure 2. Sampling points for indoor/outdoor particles measurements

The interior temperature and relative humidity were measured using TINYTAG ultra 2. As for the meteorological parameters (air temperature, relative humidity, barometric pressure as well as wind speed and direction) were recorded using a Vaisala WXT520 station. Additionally, ventilation air velocities were acquired via TSI 8475 and 8455 transducers.

Results and analysis

The measurements were carried out in weekday. The test duration is 24 hours for each system. The average exterior temperature, relative humidity and wind speed were 9°C, 75% and 2 m/s during HC-EOV test respectively. While during the M-SOV test they were 14°C, 46% and 3 m/s respectively. The meteorological parameters mean value and range during the sampling periods are presented in table 2.

Table 2

Meteorological parameters during sampling periods

	Text (°C)			HRext (%)			Tint (°C)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
HC-EOV	3	9	12	52	75	90	16	16	17
M-SOV	11	14	18	50	76	89	18	19	21

	HRint (%)			Vvent (m/s)		
	Min	Mean	Max	Min	Mean	Max
HC-EOV	59	62	67	0	2	6
M-SOV	51	56	60	0	3	8

Filtration efficiency

The figure 3 shows the mean filter's efficiency calculated during two different tests for all particles size intervals. As we can see, the in-situ measured efficiencies are lower than those declared by the manufacturer (table 1). This can be due to the difference between the measurement protocol and the particles type used in this study and those used in the technical center (CETIAT). There, they used latex aerosol (solid particles), an electrostatically neutralized particles for this matter. Also, the difference can be due to the position of the sampling point which is neat the outlet of the VMI®. Therefore, further measurements will be conducted to calculate the filtration efficiency of the machine.

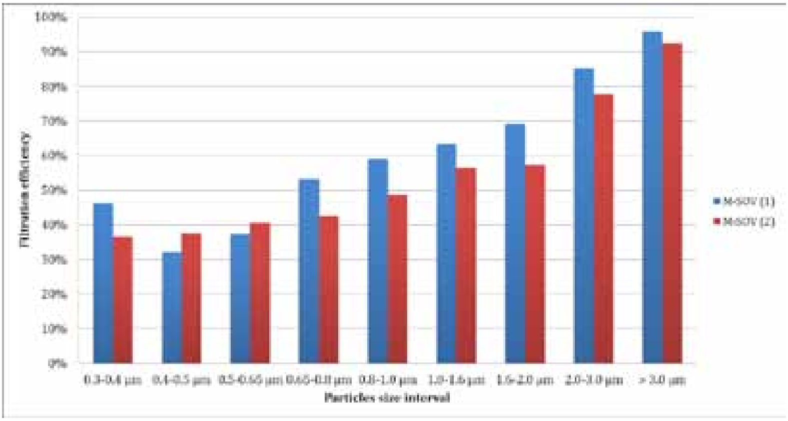

Figure 3. Filtration efficiency of VMI® measured in-situ

Correlation between indoor particulate pollution and outdoor PM concentration and meteorological parameters

The Pearson correlation analysis was used in order to investigate the relationship between outdoor particles concentration and air flow driving forces, like the inside-outside room pressure and temperature differences and the wind speed, with the indoor particulate pollution. As well as, we investigate the relationship with the interior and exterior relative humidity because the variation of RH may induce a variation in size distributions of particles (Xiaohong Yao et al. 2007).

The results presented in table 3 shows a significant positive correlation between outdoor and indoor concentrations of 1.0 µm particles or smaller. The correlation is higher in the case of HC-EOV system. As for the super-particles (diameter larger than 1.0µm), the small Pearson coefficients may be explained by the fact that the larger outdoor particles possessed lower penetration efficiency (Tippayawong et al. 2009). The pressure difference influences positively on the indoor sub-particles (diameter smaller than 1.0µm) in HC-EOV case while it influences negatively in M-SOV case. In fact, the ΔP is negative in extraction mode, so when it increases it will help introducing outdoor pollution via infiltrations whereas the pressurization induced by the insufflation mode will prevent it. The temperature difference and relative humidity appeared to have more influence with sub-particles in HC-EOV mode than the M-SOV mode when the opposite is noticed with the super-particles. The indoor PM is more sensible to wind speed variation in extraction mode. The negative correlation with sub-particles is may be because the higher the wind speed is, the lower the fine particles concentration in the atmosphere.

Table 3

Pearson correlation coefficient: indoor particles concentration

	Cout (P/l)	ΔPin-out (Pa)	Δtin-out (°C)
0.3-0.4 μm	0.747	0.555	0.841
0.4-0.5 μm	0.724	0.559	0.842
0.5-0.65 μm	0.710	0.580	0.844
0.65-0.8 μm	0.709	0.591	0.829
0.8-1.0 μm	0.602	0.563	0.742
1.0-1.6 μm	0.062	0.042	-0.064
1.6-2.0 μm	0.504	-0.257	-0.489
2.0-3.0 μm	0.065	-0.350	-0.562
> 3.0 μm	-0.291	0.075	-0.350
0.3-0.4 μm	0.725	-0.431	0.108
0.4-0.5 μm	0.582	-0.621	0.079
0.5-0.65 μm	0.413	-0.643	-0.236
0.65-0.8 μm	0.364	-0.412	-0.407
0.8-1.0 μm	0.176	-0.240	-0.536
1.0-1.6 μm	-0.069	-0.057	-0.649
1.6-2.0 μm	-0.117	0.148	-0.610
2.0-3.0 μm	-0.512	0.095	-0.692
> 3.0 μm	-0.285	-0.234	-0.421

$p<0.05$ $p<0.01$ $p<0.0001$

	RHin (%)	RHin (%)	Ws (m/s)
0.3-0.4 μm	-0.554	0.434	-0.579
0.4-0.5 μm	-0.556	0.435	-0.585
0.5-0.65 μm	-0.590	0.403	-0.597
0.65-0.8 μm	-0.624	0.357	-0.584
0.8-1.0 μm	-0.652	0.244	-0.487
1.0-1.6 μm	-0.276	-0.284	0.250
1.6-2.0 μm	0.121	-0.404	0.486
2.0-3.0 μm	0.221	-0.403	0.644
> 3.0 μm	-0.125	-0.480	0.362
0.3-0.4 μm	-0.270	0.439	-0.160
0.4-0.5 μm	-0.235	0.182	-0.393
0.5-0.65 μm	0.121	-0.017	-0.085
0.65-0.8 μm	0.384	-0.166	0.204
0.8-1.0 μm	0.569	-0.352	0.346
1.0-1.6 μm	0.693	-0.522	0.509
1.6-2.0 μm	0.684	-0.574	0.483
2.0-3.0 μm	0.748	-0.771	0.457
> 3.0 μm	0.352	-0.386	0.154

A simple linear regression analysis is used to evaluate the effect of outdoor particles concentration on the one indoor. We took the latter (Cin) as dependent variable and the Cout as explanatory variable. The model equation is written as follow:

$$C_{in} = \alpha + \beta C_{out} + \varepsilon$$

C_{in} and C_{out} are the indoor and outdoor concentrations respectively, α is a constant, β is the regression coefficient, it's also called "effects" and ε is the error term with zero mean value. The coefficient of determination, called also goodness of fit R^2 is used as indicator of the percentage variation in the indoor measured particles concentration which can be attributed to infiltration from outdoors (Colome et al. 1992).

The results of the analysis are shown in table 4 for the HC-EOV system and in table 5 for the M-SOV system. The p-value proves that we can reject the null hypothesis (H0: β=0) for most particles sizes with a risk lower than 0.01%. The values on bold characters, suggest that the H0 can't be rejected, thus in this case there's no influence of outdoor particulate pollution on indoor levels.

The correlation coefficient R^2 values indicate that 55.9, 52.4, 50.5, 50.2 and 36.2% of the variation in the indoor fine particles levels (between 0.3 and 1.0 μm) can be due to that outdoors in HC-EOV mode. As for the M-SOV, the outdoor concentration accounted for 52.6 and 33.9% of the variation in 0.3-0.4μm and 0.4-0.5μm indoor particles concentrations respectively. We noticed a weak correlation (R^2<0.01) between outdoor and indoor super-particles in both cases except for 1.6-2.0μm range in HC-EOV system and for 2.0-3.0μm range for M-SOV, where R^2 is about 26%.

Table 4

Regression correlation parameters: HC-EOV

HC-EOV	**0.3-0.4**	**0.4-0.5**	**0.5-0.65**	**0.65-0.8**	**0.8-1.0**
R²	0.559	0.524	0.505	0.502	0.362
t	13.734	12.807	12.320	12.263	9.196
Pr > |t|	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
α	6728.028	1983.525	600.487	158.132	78.381
β	0.133	0.121	0.140	0.171	0.156

HC-EOV	**0.8-1.0**	**1.0-1.6**	**1.6-2.0**	**2.0-3.0**	**> 3.0**
R²	0.362	0.004	0.254	0.004	0.085
t	9.196	0.761	7.114	0.799	-3.709
Pr > |t|	<0.0001	0.448	<0.0001	0.425	0.000
α	78.381	66.447	13.766	22.723	5.803
β	0.156	0.014	0.138	0.010	-0.030

Table 5

Regression correlation parameters: M-SOV

M-SOV	0.3-0.4	0.4-0.5	0.5-0.65	0.65-0.8	0.8-1.0
R^2	0.526	0.339	0.171	0.132	0.031
t	12.851	8.737	5.539	4.768	2.183
Pr > |t|	<0.0001	<0.0001	<0.0001	<0.0001	0.031
α	4588.800	1087.889	687.656	374.492	264.901
β	0.123	0.102	0.103	0.105	0.043

M-SOV	0.8-1.0	1.0-1.6	1.6-2.0	2.0-3.0	> 3.0
R^2	0.031	0.005	0.014	0.262	0.081
t	2.183	-0.845	-1.438	-7.274	-3.633
Pr > |t|	0.031	0.400	0.153	<0.0001	0.000
α	264.901	167.735	52.733	54.119	7.545
β	0.043	-0.011	-0.022	-0.052	-0.035

Indoor/outdoor particles concentration ratio

The hourly average ratios between indoor and outdoor particles number concentration were calculated for each system and presented in figure 4 and figure 5. In all cases, I/O ratio is found to be well below a value of 1. However, the HC-EOV presents higher ratios than the M-SOV system for almost all of the particle size ranges. This difference can be due to a higher ventilation rate provided by the M-SOV system in the bedrooms. Previous study using a tracer gas allowed us to evaluate it: we found a 0.24 h-1 in the case of HC-EOV while we found a ventilation rate of 0.66 h-1 in the case of M-SOV. In fact, a lower air exchange rate means a low dilution rate and accumulation of indoor particles (Zhu et al. 2005; Weschler and Shields 2003). As it shown in figures, the I/O ratio increases with decreasing particle size which can be explained by the low penetration efficiency of larger outdoor particles and gravitational sedimentation of larger indoor particles (Tippayawong et al. 2009).

We notice in both cases an increase in I/O ratio between 12:30 and 14:30. It can't be referred to indoor sources like cooking because the home was not occupied, but it can be explained by the increase of outdoor temperature. The Pearson correlation analysis was used again to investigate the relationship of the indoor/outdoor ratio with outdoor concentration and meteorological parameters. The results presented in table 6 shows a significant negative correlation between the I/O ration and ΔT (°C) for all particles size and for the both systems. Hence, any decreasing in temperature difference induces an increase in I/O ratio. The figure 6 illustrates decreasing in ΔT between 12:30 and 14:30.

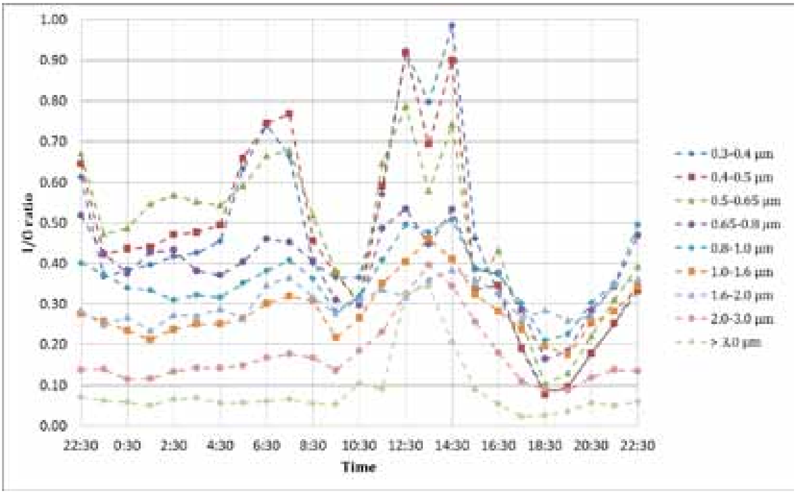

Figure 4. Hourly average of indoor/outdoor particles concentration ratio: HC-EOV

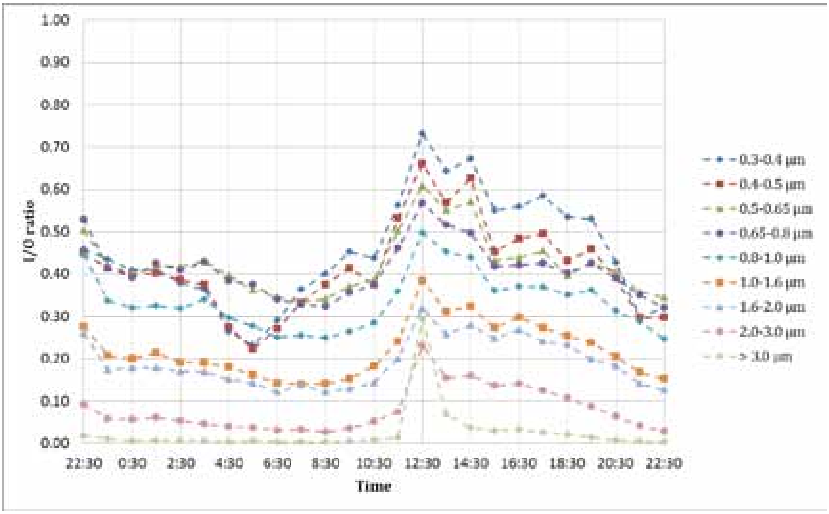

Figure 5. Hourly average of indoor/outdoor particles concentration ratio: M-SOV

Table 6

Pearson correlation coefficient: indoor/outdoor particles concentration ratio

HC-EOV	Cout (P/l)	ΔPin-out (Pa)	Δtin-out (°C)	RHin (%)	RHin (%)	Ws (m/s)
0.3-0.4 μm	-0,536	-0,223	-0,536	0,130	-0,469	0,542
0.4-0.5 μm	-0,562	-0,269	-0,502	0,233	-0,343	0,596
0.5-0.65 μm	-0,614	-0,332	-0,406	0,312	-0,154	0,600
0.65-0.8 μm	-0,492	-0,094	-0,107	0,062	-0,057	0,306
0.8-1.0 μm	-0,484	0,099	-0,052	-0,189	-0,236	0,138
1.0-1.6 μm	-0,696	0,095	-0,231	-0,279	-0,530	0,204
1.6-2.0 μm	-0,582	0,230	-0,103	-0,341	-0,263	-0,116
2.0-3.0 μm	-0,661	-0,020	-0,523	-0,212	-0,772	0,315
> 3.0 μm	-0,528	0,072	-0,439	-0,159	-0,597	0,338
M-SOV						
0.3-0.4 μm	-0,835	0,016	-0,752	0,808	-0,872	0,348
0.4-0.5 μm	-0,804	-0,035	-0,735	0,769	-0,804	0,329
0.5-0.65 μm	-0,782	-0,076	-0,699	0,706	-0,731	0,338
0.65-0.8 μm	-0,723	-0,015	-0,612	0,741	-0,649	0,354
0.8-1.0 μm	-0,727	0,056	-0,616	0,675	-0,739	0,333
1.0-1.6 μm	-0,758	0,103	-0,680	0,736	-0,848	0,371
1.6-2.0 μm	-0,681	0,209	-0,609	0,683	-0,794	0,348
2.0-3.0 μm	-0,726	0,107	-0,710	0,751	-0,877	0,370
> 3.0 μm	-0,353	-0,217	-0,440	0,370	-0,413	0,167

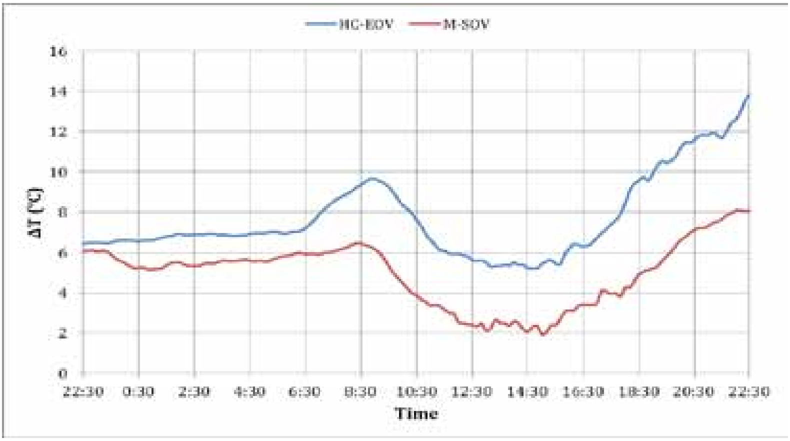

Figure 6. Temperature difference during sampling periods

Conclusion

This study is an experimental evaluation of the influence of the outdoor fine particles concentration, indoor-outdoor temperature and pressure differences, interior and exterior relative humidity and wind speed on the indoor levels of particles pollution with two different ventilation systems. An experimental investigation was carried out in a residential house situated in a rural area. The results show that the correlation between indoor and outdoor particles concentration is strongly dependent on the particles size range. The variation in submicrometer indoor particles concentrations is highly attributed (36-57%) to the variation of those outdoor in case of extraction-only ventilation. Whereas there's a weak correlation between indoor and outdoor particles in case of supply-only ventilation except for 0.3-0.5 μm size range (34-53%). In the other side, the average input/output particles concentrations ratio is lower than 1 in both studied cases and for all size ranges because there's no indoor pollutant production. Yet, I/O ratio is higher in HC-EOV the in M-SOV case. In addition there's significant negative correlation between I/O ratio and temperature difference.

Finally, the M-SOV system could limit the entry of outdoor airborne particles inside the house thanks to the air filtration, the pressurization effect and the high air exchange rate.

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