How the filtration of the incoming air decreases the particle concentration within a school equipped with a balanced ventilation system

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ABSTRACT

To study the impact of the filtration efficiency level on the particle concentration in a rural school equipped with a balanced ventilation system with heat recovery, measurements of indoor and outdoor particle concentrations have been carried out by using three different efficiency filters. The tested filters are respectively classed G4, F7 and F9 according to NF EN 779 (2012). Air has been sampled alternatively and continuously inside the fresh air duct at the inlet of the air handling unit, inside the delivered air duct at the outlet of the air handling unit and inside the exhaust air duct. These samples have been analyzed by an optical particle counter for particle concentration measurements in the 0.3 – 10 µm particle size range. Particle concentration values have been used for the filtration efficiency calculation as well as for the calculation of the I/O ratio of the indoors to the outdoors particle concentration. The results show that the efficiency of the G4 filters on the finest particles being in size lower than 1 µm is very low and close to zero. But with the use of the F7 filters and even more with the F9 filters the filtration efficiency is much better, respectively 47 to 55 % with the F7 filters and 82 to 87 % with the F9 filters at 0.4 µm (depending on the day of measurements). When the school is unoccupied, the I/O ratio decreases as the filtration efficiency increases. When the school is occupied, the I/O ratio is the same as when the school is unoccupied considering particles smaller than 0.5 µm. But for larger particles, the I/O ratio is higher and increases when the particle size considered increases and when the filter class decreases. The I/O ratio exceeds 1 depending on the class of the filter and the particle size considered.
In summary, the ventilation system used in the studied school is able to protect people as the I/O ratio is lower than 1 for the most harmful (diameter < 1 µm) and most abundant (99 % in number) particles recorded outdoors when fine filters (F7 or even better F9) are installed within the air handling unit.

KEYWORDS

Ventilation, Air filtration, school, particle concentration, IAQ

1 INTRODUCTION

The European Commission claims that buildings consumed 41 % of the final energy in Europe in 2010 (European Commission, 2013). Moreover, the average energy consumption of the building sector (220 kWh/m^2 in 2009) has increased by around 1 % per year since 1990, with residential buildings (around 200 kWh/m^2 on average) representing a 0.6 % per year increase compared to 1.5 % per year for non-residential buildings (around 200 kWh/m^2 on average). As a consequence of the energy and environmental issues, it is necessary to reduce the energy consumption of buildings. So, the air tightness of building envelopes is being improved and the air change rate due to infiltration is decreasing. It is then even more

important than in the past that the buildings are equipped with well designed and working ventilation systems in order that the air renewal within buildings is ensured.
Balanced ventilation with heat recovery is one of the systems whose use is supposed to allow the buildings to reduce their energy consumption. These systems include air filters used to protect the heat exchanger (both on the fresh air and exhaust air sides) and to enhance the quality of supplied air.
In schools, it has been shown by various studies (Turunen et al. (2014), Mendel et al. (2013), Wargocki and Wyon (2013), Bako-Biro et al. (2012), De Gids (2007)) that the children are very sensitive to the amount of fresh air provided to them as there is a negative impact on their absenteeism, performances, well-being and perception of air quality when the air flow rate decreases. But the fresh air provided to the school by the mechanical systems comes from outdoors and it may be polluted by a mixture of various pollutants amongst them particles. Then the filtration of the incoming air can help to reduce the amount of pollutants injected into the schools and to enhance the indoor air quality. But how efficient the filters have to be in order to contribute to good indoor air quality?
The objective of our study was to determine the influence of the filtration efficiency of the particulate filters used for the filtration of the air provided to a nursery school by a balanced ventilation system with heat recovery on the particle concentrations within the school. There is according to our knowledge no data available in the literature on this topic.

2 METHOD AND MEASUREMENTS

Measurements with three different filtration levels were performed in a recent nursery school equipped with a balanced ventilation system with heat recovery. The school is located in a rural environment in France. Four identical filters have been installed in parallel within the air handling unit. The three types of filters are respectively classed G4, F7 and F9 according to NF EN 779 (2012).

2.1 The school and its ventilation system

2.1.1 The school

The nursery school is located in a rural environment (a town of 1200 inhabitants) at about 50 km from Lyon in France, away from busy roads and without specific outdoor pollution sources (see Figure 1). The school has been built in 2010 and about 100 children attend it in 4 different classrooms (see Figure 2) from Monday to Friday except on Wednesday afternoon. There are also corridors, a sports room, a sleeping room, toilets (with its own mechanical ventilation system) and offices for the teachers.


Figure 1 : Outside of the school


Figure 2 : Inside of a classroom

2.1.2 The ventilation system

The school is mechanically ventilated (100 % fresh air) with a balanced ventilation system with heat recovery for the mechanical driving of both the incoming and the exhaust air. The balanced ventilation system uses an air handling unit (see Figure 3) which in its normal use is equipped with F7 class filters (NF EN 779 (2012)) for the filtration of the incoming air while G4 class filters are used for the filtration of the exhaust air. On both sides, 4 filters are used in parallel.

The regulation of the ventilation system ensures that it is well balanced, that means the incoming air flow equals the exhaust air flow. The air flow varies between 500 and 2700 m^3/h as it is modulated and depends on the number of children present within the classrooms.
The fresh air is diffused within the classrooms and the corridor via ceiling diffusers and is extracted via ceiling grilles.

Figure 3 : The air handling unit of the ventilation system

2.1.3 The filters

For the needs of our study it has been decided to use pleated G4 filters (Figure 4a), mini-pleated F7 filters (Figure 4b) and mini-pleated F9 filters (Figure 4c).

Figure 4a : The G4 filter

Figure 4b : The F7 filter

Figure 4c : The F9 filter

2.2 Measurements

During the measurements (3 consecutive days per week for 3 consecutive weeks in September and October 2014), the air flows have been set and periodically controlled (measurements of the air velocity on straight area of the ducts) to values always between 2400 and 2600 m³/h (air exchange rate: 1.3 to 1.4 vol/h). The regulation of the ventilation system has allowed to balance the incoming and the exhaust air flows.

Air has been sampled alternatively and continuously inside the fresh air duct at the inlet of the air handling unit (which is supposed to be representative of the outdoor air), at the outlet of the air handling unit inside the delivered air duct and inside the exhaust air duct (which is supposed to be representative of the indoor air). These samples have been analyzed by an optical particle counter for particle concentration measurements in the 0.3 – 10 µm particle size range. Particle concentration values have been used for the in-situ filtration efficiency (E) calculation (comparison of the particles concentrations measured in the fresh air duct and in the delivered air duct) as function of particle size as well as for the calculation of the I/O ratio of the indoors to the outdoors particle concentration (comparison of the particles concentrations measured in the fresh air duct and in the exhaust air duct).

For each testing condition corresponding to one type of filters being studied (see 2.1.3.), 1 day measurements has been carried out per week (one day different every week) which means that 3 days measurements have been carried out per type of filters. The filters are installed at the end of the afternoon the day prior to the measurements.

Also, the performances (pressure drop and efficiency by particle size on DEHS particles) of the filters have been measured in laboratory prior being installed in-situ. The test air flow rate in laboratory is 650 m³/h which corresponds approximately to the value met in-situ taking into account 2400 to 2600 m³/h for 4 filters used in parallel.

Finally, during the measurements the doors and the windows of the school have been kept closed.

3 RESULTS AND DISCUSSION

3.1 Filters efficiency

The filter efficiency has been measured both in laboratory and in-situ. Both types of values can be compared because the air flow rate per filter is the same in laboratory and in-situ.
Each day of measurements, the efficiency has been calculated 10 to 15 times because the particles concentration has been alternatively and successively measured at the three measuring points. So for the in-situ values (see Figure 5) the curve represents an average taking into account about 35 to 40 results.

The results show that the in-situ filtration efficiency of the air handling unit is very close to that of the filters measured in laboratory (see Figure 5) which means that the filters are installed within the air handling unit with no significant leaks.

Not surprisingly the efficiency of the G4 filters on the finest particles being in size lower than 1 µm is very low and close to zero.
But with the use of the F7 filters and even more with the F9 filters the filtration efficiency is much better, respectively 52 % with the F7 filters and 82 % with the F9 filters at 0.4 µm.

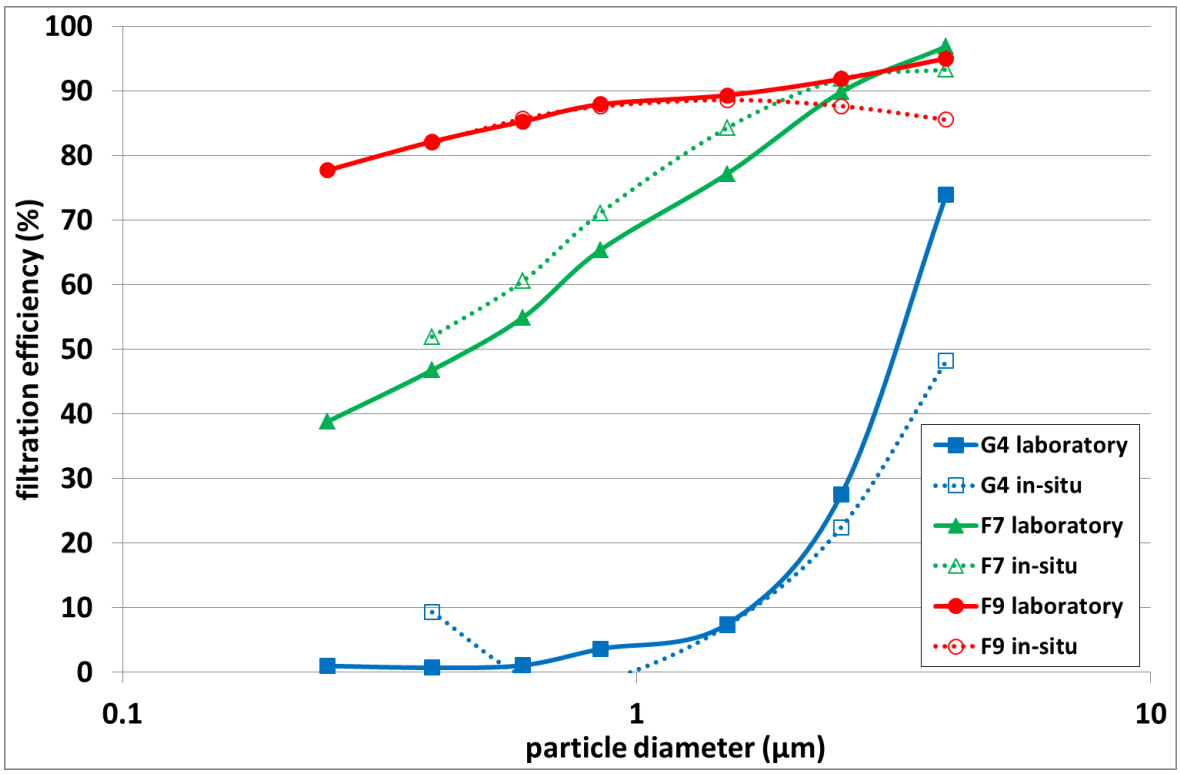

Figure 5 : Filter efficiency determined both in laboratory and in-situ

3.2 Indoor/outdoor particle concentration ratio

The indoor particle concentration depends on many parameters amongst them the outdoor particle concentration. For this reason the influence of the type of filters on the indoor particle concentration is expressed on the indoor/outdoor particle concentration ratio.
Figure 6 gives an example of typical indoor/outdoor particle concentration ratio as function of time, particle size and children attendance during a full school day.

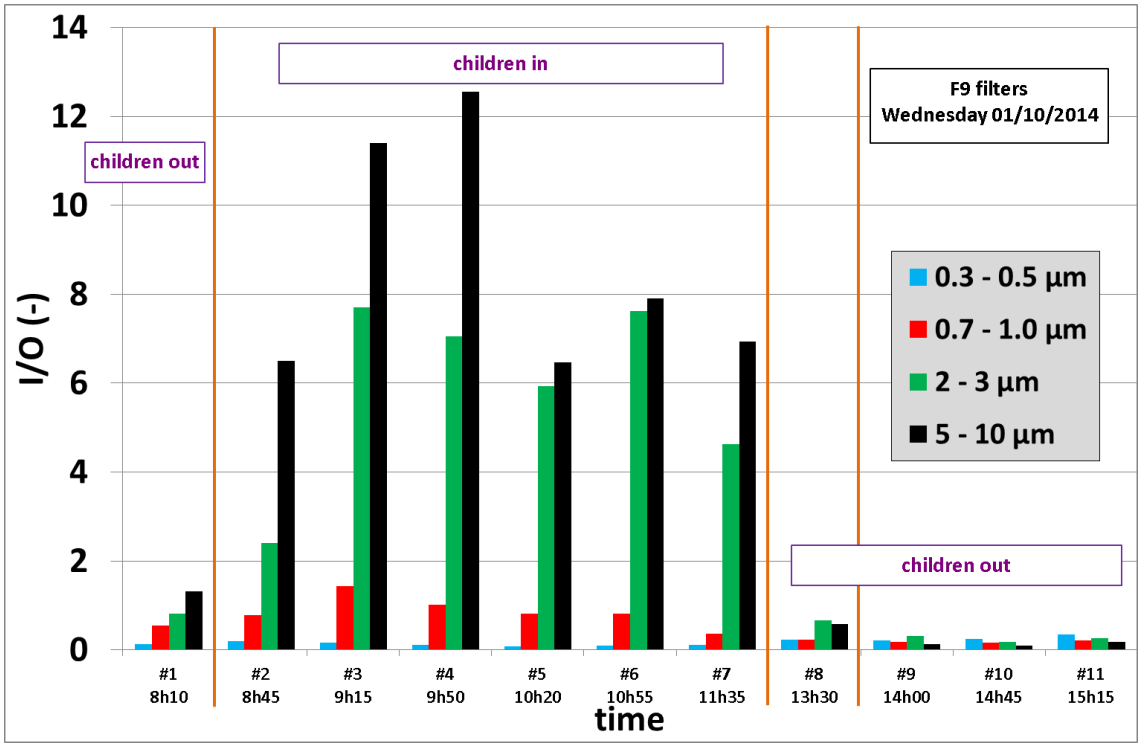

Figure 6 : Indoor/outdoor particle concentration ratio as function of time, particle size and children attendance

Before the children arrive to the school the I/O ratio is generally low, lower than 1. In the example presented in Figure 6, the I/O ratio is higher than 1 for the 5-10 µm particles which can be explained by the presence within the school of teachers. The I/O ratio increases immediately after the children arrive (at 8h30), see #2 to #7 in Figure 6, and this trend is more pronounced when the particle size increases with I/O ratio values which can largely exceed 1 ; the I/O ratio appears not influenced by the presence of the children if we consider the smallest measured particles (0.3 - 0.5 µm).
After the children and the teachers have leaved the school for lunch break (at 12h30), see #8 to #11 in Figure 6, the I/O ratio value returns back to much smaller values which are well below 1 for all the particle sizes considered (children do not go to school on Wednesday afternoon).

The summary of the 9 full school measurement days is reported in Table 1 and the indoor/outdoor particle concentration ratio is expressed as function of time, particle size and children attendance.

When the school is unoccupied, the I/O ratio decreases if the filtration efficiency increases: 0.92 to 0.95 with the G4 filters (the efficiency of these filters is close to zero), 0.41 to 0.52 with the F7 filters and 0.30 to 0.38 with the F9 filters for particles with diameter lower than 3 µm. For larger particles there is no clear relationship (the amount of particles is low both indoors and outdoors) but the I/O ratio is still lower than 1.

When the school is occupied by children and teachers, the I/O ratio is the same as when the school is unoccupied considering particles smaller than 0.5 µm; this is explained by the fact that these small particles mainly come from outdoors and are not generated indoors. But for larger particles, the I/O ratio is higher and increases when the particle size increases and when the filter class decreases. The I/O ratio exceeds 1 (largely in some situations) depending on the class of the filter and the particle size considered.

Table 1: Indoor/outdoor particle concentration ratio with no children within the school (in blue) and with the children at school (in red in brackets)

Filters	G4			F7			F9		
Particle diameter	Day 1	Day 2	Day3	Day 1	Day 2	Day3	Day 1	Day 2	Day3
0.3 - 0.5 (µm)	0.96	0.89	-	0.70	0.34	0.51	0.43	0.33	0.27
	0.93 (0.81)			0.52 (0.58)			0.34 (0.27)		
0.7 - 1.0 (µm)	0.84	1.06	-	0.31	0.48	0.43	0.41	0.32	0.18
	0.95 (1.43)			0.41 (0.79)			0.30 (0.75)		
2 - 3 (µm)	1.29	0.55	-	0.15	0.75	0.51	0.56	0.34	0.25
	0.92 (5.09)			0.47 (2.43)			0.38 (3.15)		
5 - 10 (µm)	0.52	0.41	-	0.15	1.19	0.63	0.73	0.29	0.14
	0.46 (6.86)			0.66 (6.39)			0.39 (5.24)		

4 CONCLUSIONS

In a recent (2010) nursery school located in a rural environment in France and equipped with a balanced ventilation system with heat recovery, the impact of the filtration efficiency level

of the incoming air has been studied on the particle concentration within the school represented by the indoor/outdoor particle concentration ratio (I/O). There are 4 classrooms and an average of 100 children. Doors and windows were closed during the measurements. The air exchange rate was 1.3 to 1.4 vol/h.

When the children and the teachers are present, the I/O ratio value is primarily controlled by the filtration for the smallest particles (diameter < 0.7 µm); the I/O ratio is then close to 1 with G4 filters and decreases as the class of the filters increases. For the biggest particles which are generated indoors there is less influence of the filtration and the I/O ratio may largely exceed 1.
The filtration of the incoming air provided to the studied nursery school can reduce the exposition of the children to fine particles whose sources are outdoors. The influence of the class of the filters on the I/O ratio in a school has not been studied according to our knowledge and only one study carried out in a commercial has been identified (Rendek et al. (2011)) whose conclusions are similar to those of this study.

In order to reduce the amount of the biggest particles within the school, it has been decided to complete our study and to carry out the same kind of measurement with one portable air cleaner in operation within each of the 4 classrooms.

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