Design and benefits of re-circulating particle filtration units

Michal Spilak*, Lars Gunnarsen and Marie Frederiksen

Danish Building Research nstitute, Dr. Neergaards Vej, 15, DK- 2970 Hoersholm, Denmark

Corresponding email: mis@sbi.dk

SUMMARY
Indoor climate has a great impact on people’s health, comfort and productivity, as they spend most of their time indoors. Several factors such as inadequate ventilation or excessive pollutants generated by building materials, dampness, molds and house dust mites may result in elevated concentrations of pollutants that adversely affect human health. This may lead to increased prevalence of annoyance and symptoms related to poor indoor air quality. In the present paper, re-circulating a particle filtration unit was designed and tested in order to evaluate particle removal. Outdoor air, candles and cigarette smoke were used as pollution sources. Re-circulating airflow rates from 0 L/s to 110 L/s were tested. The results showed similar behavior for all particle types. Steep decays and low concentration levels were obtained, except for the 0 L/s. It was concluded that the use of particle filtration units will have a significant impact on air quality in future interventions.

IMPLICATIONS
Exposure to particulate matter is associated with increased risk of cardiovascular diseases and respiratory problems. The indoor environment is often the most important scenario for exposure to air pollution. The exposure can be reduced by using of PFUs, by limiting the penetration of outdoor pollution and indoor particle sources as well as the decomposition of dust on heated surfaces.

KEYWORDS
Occupant's health, ultrafine particles, $PM_{2.5}$, indoor air pollution

INTRODUCTION
Earlier studies have documented that indoor particles in houses, which is where people spend most of their time, have a negative impact on their health (Bräuner et al. 2008; Berglund et al. 1991; Bluyssen et al. 1996; Mitchell et al. 2007; Wargocki et al. 2002; Sundell, 1994; Skov and Valbjørn, 1987; Schneider et al. 2003). Exposure to this particulate matter is associated with the risk of cardiovascular and respiratory problems and the reduction of concentration levels has therefore a significant impact on health risks.

One of the requirements for the Particle Filtration Units (PFU) was that noise from the units should cause the occupants only minimal annoyance. The fan placed inside a PFU must permit adjustment of the airflow rate from 70m^3/h to 200m^3/h. It is required to reach high filtration efficiency of PM2.5 and ultrafine particles (UFP). A novel design should also include the aesthetic part of design as well as making every unit portable. It is also a requirement that the UFP should be easy to move and operate. Furthermore, the second part of the experiment should appear the same, with the same air movement and noise.

METHODS

Every PFU consisted of a box measuring 1.2x0.45x0.43 m and equipped with a fan capable of controlling the airflow within the range of $70m^3/h$ to $300m^3/h$, a duct silencer and an exhaust diffuser with the option of changing the direction of outgoing air. A labyrinth path for inlet air reduced the noise generated by the fan motor. The dimensions of the exhaust were designed to create enough air movement to circulate the air in the room. A sound-absorbing layer (40 mm thick) was placed inside every filtration box to prevent noise generated by the fan motor, which might disturb occupants during their stay or sleep. A HEPA filter of class H11 (EN 1822) with a total surface area of $3.35m^2$ and an air velocity rate through the filter opening of up to 1.18 m/s, was used in order to achieve high filtrations effectiveness of $PM_{2.5}$ and UFP. Low nominal power supply allowed the unit to be used in households with continuous operation. It was also required that the PFU should be easy to move in order to run the second intervention arrangement.

The PFU was tested in a ventilated, full-scale room with a total volume of 32 m^3 (Ekberg and Nielsen, 1995). The walls and the ceiling of the chamber consisted of glass panels mounted in aluminum frames. The floor was made of high-pressure laminated fiberboard. Low concentration of polluting gases, vapors and particles in the supply air was ensured by means of a HEPA filter placed in the main supply duct. The conditioned and cleaned supply air entered the laboratory through a displacement ventilation system. To achieve a good mixing of indoor air with particles generated by artificial pollution sources, a portable fan was added. Through the whole measurement, the chamber was kept at constant over-pressure (11±1 Pa), temperature (21±1.0°C) and relative humidity (45±5 %). The room was equipped with a Philips Nanotracer to measure the concentration of ultrafine particles (particles/cm^3) in the range of 10-300 nm. The particle measurement device was placed in the center of the room at a height of 1 m above the floor. Situated inside the tested room, the PFU was set to provide four levels of flow rate (110 L/s, 50 L/s, 20 L/s, and 0 L/s). In order to identify the actual ventilation rate generated by the main ventilation system, the tracer gas method was used (with N_2O). From the obtained results, the main ventilation supply was calculated to be 8.2 L/s by the method described by Heidt and Werner (1986).

Three different sources of polluted air were tested: outdoor air and air polluted by burning candles and cigarette smoke. Outdoor air was blown into the hall where the test room was situated. The heating system heated the air to room temperature. By opening the door to the test room, polluted air was mixed with clean air inside the room. In the candle-experiment, six candles were burned for approximately 20 minutes to reach similar concentration levels. Cigarette smoke pollution was generated by lightning and burning one cigarette in the test room before every measurement started.

RESULTS

Figure 1 shows the characteristics of concentration decay when outdoor air was used as a source. The highest particle reduction occurred in the case of maximum flow rate. As the re-circulating flow decreased, a longer period was necessary to reach low levels of air pollution. When candles and cigarette smoke were used (see Figure 2 and Figure 3), conditions showed characteristics similar to the previous case. Again, the concentration decayed more rapidly by increasing the PFU flow rates.

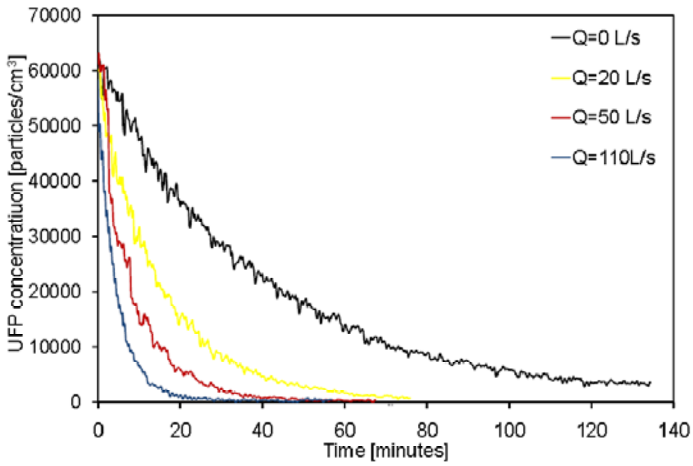

Figure 1. Concentration decay of outdoor air as a pollution source

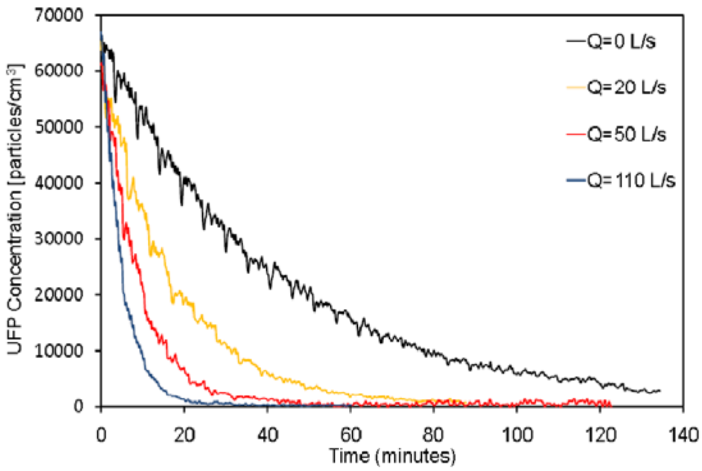

Figure 2. Concentration decay of candles as a pollution source

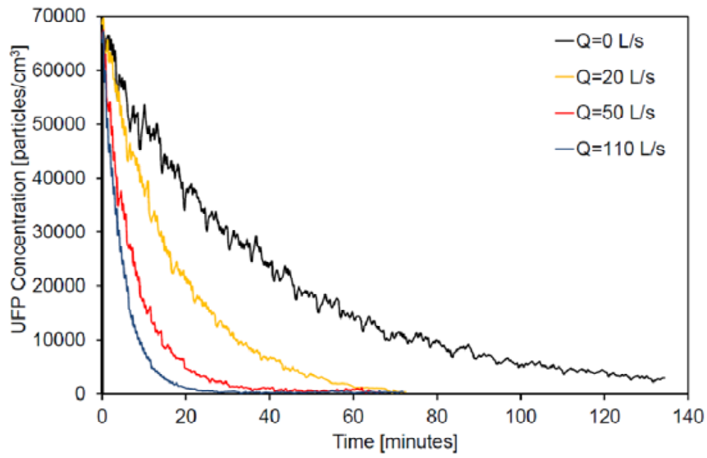

Figure 3. Concentration decay of cigarette smoke as a pollution source

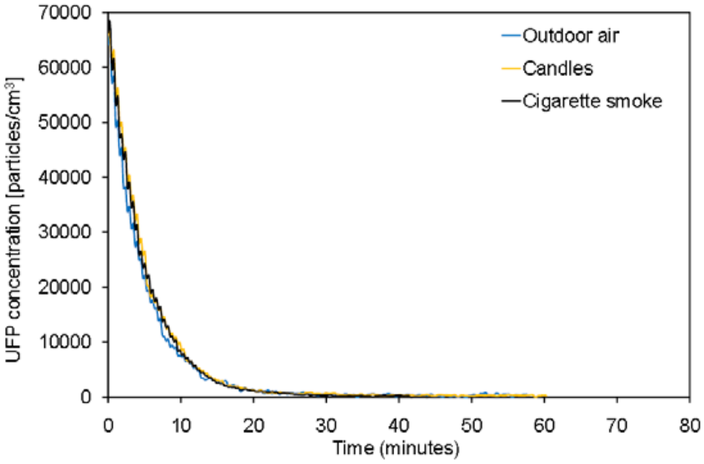

Figure 4. Concentration decay of outdoor air, candles and cigarette smoke as pollution sources with a PFU re-circulating airflow rate of 110 L/s.

Comparing different sources with the PFU setting of 110 L/s (see Figure 4) showed that the PFU removed UFPs with the same effectiveness for all tested pollution sources. Similar decay continuance occurred when 50 L/s and 20 L/s were set. Particles were removed and steady-state concentrations did not exceed 500 particles/cm^3. A different situation occurred in the case when only the main ventilation system was operating (see Figure 5). None of the three cases (outdoor air, candles and cigarette smoke) achieved a concentration close to zero level.

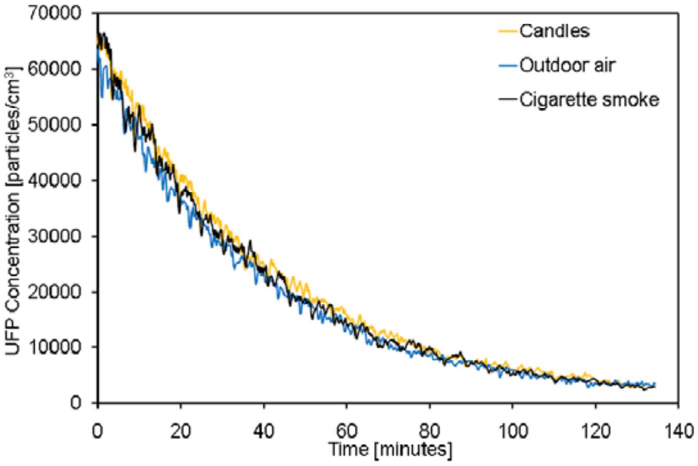

Figure 5. Concentration decay of outdoor air, candles and cigarette smoke as pollution sources with a PFU re-circulating airflow rate of 0 L/s.

Table 1. Particle removal for outdoor air, candles and cigarette smoke as a pollution source

PFU air change rate (h^{-1})	Outdoor air (h^{-1})	Candles (h^{-1})	Cigarette smoke (h^{-1})
12.37	12.06	12.04	12.03
5.63	5.90	5.90	5.78
2.25	3.04	3.04	2.68
0	0.79	0.79	0.76

$$C_i = C_0 \exp^{-(n_{TOT} t_i)} \quad (1)$$

where C_i is the number of particles, i.e. concentration, in elapsed time t_i, C_0 is the initial number of particles, i.e. concentration, n_{TOT} is the total ventilation air change rate (ACR) .

$$n = n_{TOT} - n_{MV} \quad (2)$$

where n is the particle removal and n_{MV} is the main ventilation air supply.

Table 1 shows the particle removals obtained from the measurements. PFU air change rate was a flow set on the filtration units. In the case of 12.37 h^{-1} (110 L/s), results for each pollution sources were lower than the real PFU ventilation rate. However all three values were very similar. The values varied more for 5.63 h^{-1} (50 L/s) and the ventilation rate was lower than the real rate when candles were used as a pollution source. Higher values of removals were calculated for 2.25 h^{-1} (20 L/s), where outdoor air particles were found to be removed the fastest. The biggest differences were observed when the PFU was turned off (0 L/s). Although no air passed the filter, measurements showed little removal.

DISCUSSION

The experimental measurements used in our study were designed to test the behavior of particle removal with the use of PFU. Tests indicated that a higher re-circulating airflow rate led to steeper decay, and less elapsed time was necessary to reach steady-state and thus low levels of concentration. Ventilation rates estimated from decay curves were close to the real ventilation rate set on PFU (see Table 1) and the level of particle removal was high. On the other hand, lower airflow rates differed between calculated ACR and ACR set on the PFU. The lower airflow rate used, the bigger the difference obtained. This was caused by small air movement and thus poor mixing in the laboratory.

Table 1 shows removals for every pollution source when UFP was turned off (0 L/s). The fact that particles tend to stick to a room surface explained the removal even though no air was passed the HEPA filter. For high airflow rates, all particles behaved homogeneously, regardless of pollution source (outdoor air, cigarette smoke or candles).

Results of our test corresponded to the results obtained by Bräuner et al. (2008). According to Bräuner et al., re-circulating units placed in apartments removed particles efficiently. However, a higher airflow rate was used (150L/s).

During the experiment no obstacles were placed inside the test room, such as furniture which in real apartments reduces the ability of the air to mix well.

Based on recirculation particle filters, future interventions will be carried out in the Greater Copenhagen area in 40 dwellings housing elderly people to change the particle concentrations from normal to lower levels. Each dwelling is to be situated close to highly trafficked roads and outdoor air supply should therefore not be provided by mechanical ventilation. During interventions, re-circulating airflow rates should be far higher than the outdoor air supply by infiltration. A four-week period of measurements will be divided into two different intervention arrangements: One using the filter and one without it. This is intended to ensure that the interventions were blinded to the occupants.

To improve the clean air distribution in monitored rooms and thus avoid the irritation caused by draft. It is recommended to make further studies of that the total airflow should be provided by several exhausts or UFPs. This will allow us to use higher airflow rates without jeopardizing occupant comfort.

CONCLUSIONS

Particle removal decreases with a decreasing total airflow rate and thus the use of PFUs had a significant impact on air quality during the intervention study described here. We recommend the use of higher airflow rates in apartments in order to achieve high particle removal effectiveness. Under real-life conditions, proper mixing, acceptable air movement and thus high removal effectiveness could be reduced by obstacles and furniture placed in the apartment. However, it is important not to generate too high a velocity, which might disturb the occupants while they stay or sleep in monitored apartments.

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