Removal of ultrafine particles by ventilation air filters

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SUMMARY
The purpose of the investigation is to clarify how the filtration efficiency for ultrafine particles (UFPs) varies depending on the aerosol size distribution upstream of the filter. Filter classes F5-F7 (according to the European standard EN779) and combinations of these filter classes are studied.

The fractional filtration efficiency for particles ranging from 5 nm to 100 nm was estimated based on previous publications. The downstream concentration and size distribution was calculated for each of four outdoor aerosols representing both urban and rural conditions. When interpreting data expressed as the total number concentration (d_p>5 nm), the studied F7-filter (corresponding roughly to MERV 13 according to the applicable US-standard) showed filtration efficiencies between 65% and 83%. The results also indicate that measurements with an instrument providing the number concentration of particles larger than 20 nm will underestimate the total UFP-filtration efficiency by about 10%-units, estimated as an average value for all of the studied filter classes.

KEYWORDS
Air filters, ultrafine particles, size-distribution, filtration efficiency, particle mass

INTRODUCTION
Investigations from the fields of medicine and environmental medicine have indicated a possible association between human health and ultrafine particles (Nemmar et al. 2002). Only few of the published studies have considered the exposure indoors. However, considering that people in the western world spend in average over 85% of their time at work, home, school etc, a reasonable assumption is that a substantial reduction of the indoor concentration of UFPs would reduce the potential health hazard to the population.

Previous studies have shown clear differences between indoor and outdoor concentrations of UFPs, and also large differences between the concentrations in various urban and rural locations (Matson 2004; Morawska et al. 2003). Both indoor activities and the use of air filtration substantially influence the indoor exposure to UFPs (Wallace and Howard-Reed 2002).

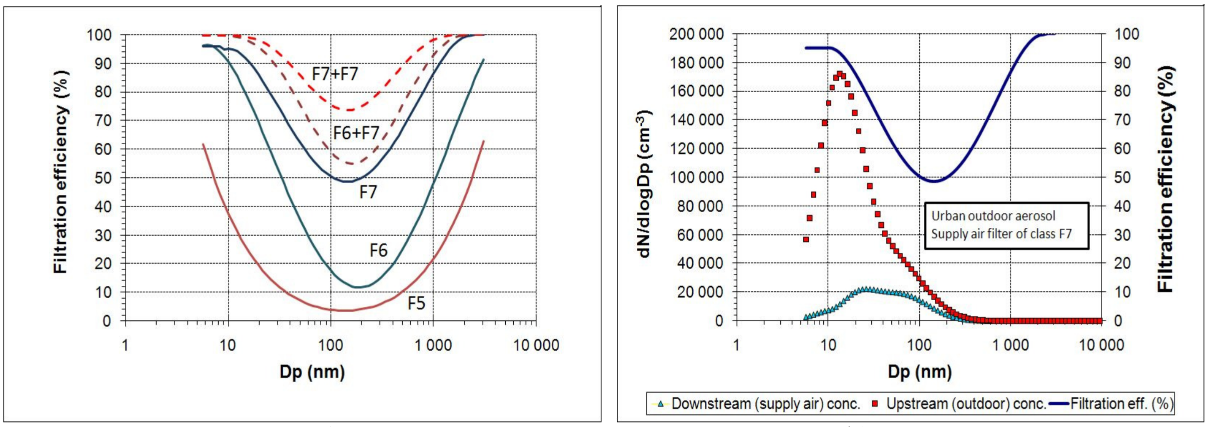
Measurements and preliminary modelling (Matson and Ekberg, 2005) have indicated that supply air filters of classes F7-F8 may result in about 70% reduction of the indoor concentration of UFPs supplied to the building from outdoors. The filtration efficiency for commonly used filters increases with decreasing particle size in the ultrafine size range (Hinds, 1982, Hanley et al., 1994). However, neither the European, nor the US standards comprise evaluation of filter performance for UFPs. There is comparatively little data on filter performance regarding UFPs.

When investigating the efficiency of air filtration, the result may vary depending on the method used for measurement. New instruments, that can measure the total number concentration of particles larger than a certain size, have become rather common. One example is the P-Trak, which is widely used to count particles larger than 20 nm.

The objective of the paper is to clarify how the filtration efficiency varies depending on the aerosol size distribution upstream of the air filter. Filters of classes F5-F7 (according to the European standard EN779) and combinations of these filter classes are considered in the investigation.

METHODS

The fractional filtration efficiency for particles ranging from 5 nm to 100 nm was estimated based on previous publications (Hanley et al. 1994; Fisk et al. 2002), see Figure 1a. The downstream concentration and size distribution was calculated for each of four outdoor particle size distributions, of which one is shown in Figure 1b. The characteristics of all four outdoor size distributions are indicated in Table 1.



a) b)

Figure 1. a) Filtration efficiency for the studied fine filters. b) The F7-filtration efficiency plotted together with one of the model outdoor aerosol size-distributions and the calculated downstream aerosol size distribution.

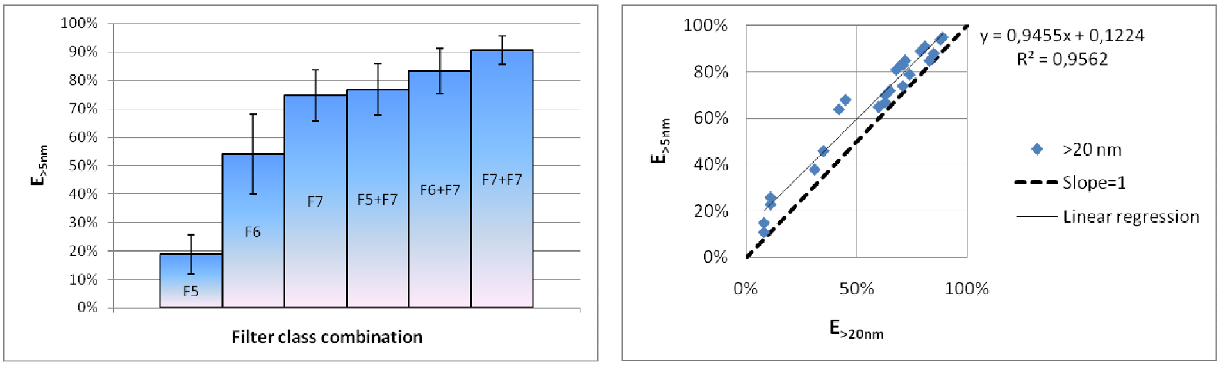
Table 1. Particle size-distributions used (N=total number conc., σ=standard deviation, D_p=count mean diameter. Each distribution has three modes, indicated by the indices 1-3.

Aerosol type	N_1	σ_1	D_{p1}	N_2	σ_2	D_{p2}	N_3	σ_3	D_{p3}
Rural *	$6.65 \cdot 10^3$	1.7	15	147	3.6	54	$1.99 \cdot 10^3$	1.8	84
Urban A *	$9.93 \cdot 10^4$	1.8	13	$1.1 \cdot 10^3$	4.6	14	$3.64 \cdot 10^4$	2.2	50
Urban B – Spring **	$10.2 \cdot 10^3$	2.0	16	$12.4 \cdot 10^3$	1.9	50	$5.70 \cdot 10^3$	1.9	126
Urban C – Winter **	$6.30 \cdot 10^3$	2.0	19	$11.5 \cdot 10^3$	1.8	53	$9.40 \cdot 10^3$	1.9	117

* From Jaenicke (1993)
** From Wu et al. (2008)

RESULTS

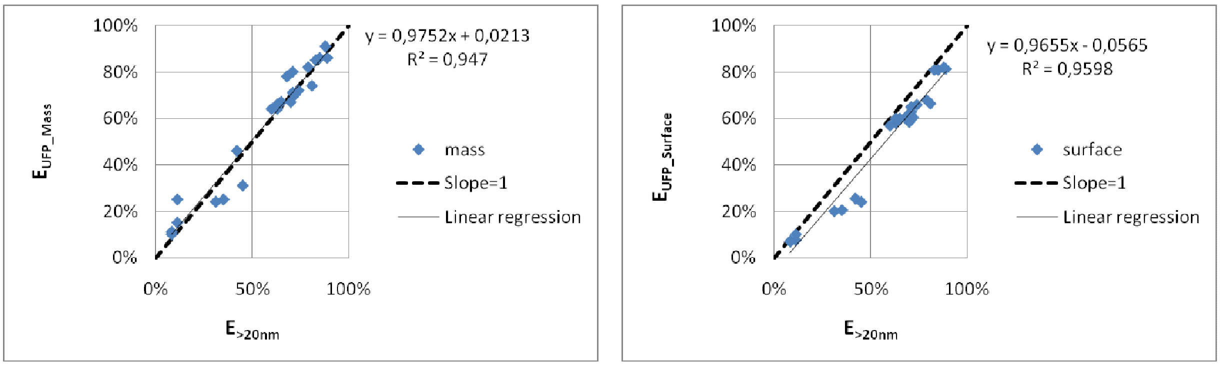
When interpreting data expressed as the total number concentration (d_p>5 nm), the studied F7-filter (corresponding roughly to MERV 13 according to the applicable US-standard) showed filtration efficiencies between 65% and 83%. The corresponding data for all filter classes and combinations of filter classes is shown in Figure 2a. As illustrated by Figure 2b, the results also indicate that measurements with an instrument providing the number concentration of particles larger than 20 nm will underestimate the total UFP-filtration efficiency by about 10%-units, estimated as an average value for all of the studied filter classes.



a) b)

Figure 2. Calculated filtration efficiency based on the total particle number >5 nm. a) plotted for each filter class studied; b) plotted for all filter classes against the corresponding efficiency based on particle number >20 nm.

The filtration efficiencies were also calculated based on the mass and surface of the studied aerosols (assuming spherical particles). As indicated in Figure 3a, the efficiency values obtained for the number concentration of particles larger than 20 nm ($E_{>20nm}$) were close to the efficiency values calculated based on the total mass of particles larger than 5 nm ($E_{UFP\text{-}Mass}$). The filtration efficiency based on the surface of particles larger than 5 nm varied only slightly with the outdoor aerosol size distribution.



a) b)

Figure 3. Calculated filtration efficiencies for all of the filters and filter combinations shown in Figure 2. a) Efficiency based on particle mass (>5nm) plotted against the efficiency based on particle number (>20nm). b) Efficiency based on particle surface (>5 nm) plotted against the efficiency based on particle number (>20nm).

DISCUSSION

Neither the European, nor the US air filter standards comprise determination of the fractional filtration efficiency in the ultrafine particle size-range. This can be considered as a major lack since such small particles are pointed out as being of particular importance for human health. Filters of class F7 seem to capture at least 65 % of the total number of particles larger than 5 nm. Two F7 filters installed in series will improve the efficiency to about 85-95 %, which possibly would be a performance similar to that of one single F9 filter. However, the present study did not comprise investigation of filter classes higher than F7. The project will be carried on with both modelling and measurements on F8 and F9 filters.

The results show that the measured performance of air filters may vary strongly with the upstream particle size distribution, depending on the method used for the concentration measurements. The analysis also indicates that it would be possible to make a fair translation between various filtration efficiency measures, e.g. based on the number of particles larger than 5 nm or 20 nm, or based on the total particle surface or total particle mass. This enables various efficiency measures, such as $E_{>5nm}$, $E_{UFP\text{-}Mass}$ and $E_{UFP\text{-}surface}$(>5nm) to be fairly estimated from measurements of the total number concentration of particles larger than 20 nm, which is a widely used technique nowadays.

CONCLUSIONS

The UFP filtration efficiency for common ventilation air filters vares strongly with particle size distribution. This must be acknowledged especially if measurements are based on cumulative concentration measurements of particles larger than a certain size, e.g. 20 nm. By installation of filters of class F7 it should be possible to remove about 75% of the total number of UFPs. Lower filter classes provide substantially less protection from this potentially hazardous type of air pollution.

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