Ultrafine and fine particles, VOC and odour emissions from dusty air filters

Marko Hyttinen[a,*], Pasi Yli-Pirilä[a], Marko Björkroth[b], Pertti Pasanen[a], Taisto Raunemaa[a], Pentti Kalliokoski[a]

[a]*Department of Environmental Sciences, University of Kuopio, POB 1627, FIN-70211 Kuopio, Finland;* [b]*Helsinki University of Technology, Helsinki, Finland*

ABSTRACT

Fine particles (4–700 nm), odour and VOC emissions before and after the used supply air filters were studied in a ventilation unit. The pre-filter (G3) did not collect fine particles at the test conditions, but acted as a source of particles 50–300 nm in size. The F7 fine filter, located after the pre-filter, collected quite effectively even the finest particles. Sensory evaluation showed that intensity of odour was highest after the F7 fine filter. VOC analyses did not clearly reveal which compounds caused the odour released from the filters.

The study showed that the presence of fine particles did not contribute significantly to the odour perception in the supply air. Congruent to the previous findings, odour emission seems to be related to compounds that originate from coarse particles.

INDEX TERMS

Fine particles; VOC; Odour, Filter; Supply air

INTRODUCTION

Supply air has been shown to be one of the main causes of air stuffiness in offices (Fanger *et al*. ,1988). In ventilation systems, supply air filters have usually been the main odor source (Pejtersen *et al*. 1989). Odor of supply air is assumed to at least partly be due to emissions of volatile organic compounds from the dust particles. Even though the TVOC concentrations have more frequently been slightly higher downstream of the filter, no clear changes in the chemical composition of volatile organic compounds (VOCs) content have been found with the conventional sampling technique on Tenax (and SIII) adsorbent.

The aim of this study was to investigate the contribution of fine particles to the odour emissions from used supply air filters.

METHODS

Filters

For the study, supply air filters were collected from air handling units 1 and 2, which were located in urban office buildings in the metropolitan area of Helsinki. The air handling unit 1 was equipped with a two-stage filtration: G3 pre-filter and F7 fine filter. The unit 2 had only F7 fine filter. Filters were used in both units 6 months.

Odour, VOC and particle concentrations were compared to over the filters. All the experiments were made in test ventilation system. Only VOC results of the other F7 filter (taken from unit 2) are presented. Air flow in the test unit was adjusted to 0.5 m^3/s and face

* Corresponding author. E-mail: marko.hyttinen@uku.fi

velocity 1.5 m/s. Also a new F7 filter was employed in the tests. Relative humidity of supply air was controlled by a humidifier and a Vaisala temperature and humidity probe.

Particles

Particle size distributions were analysed by TSI (Thermo Systems Inc.) L-SMPS (Long-Scanning Mobility Particle Sizer) system consisting of a DMA3071 differential mobility analyser (size range 15–740 nm) and CPC 3022A condensation particle counter. The N-SMPS (N = nano) equipped with a DMA 3085 (size range 4–150 nm) and CPC 3025A were also in use. Particle concentrations were measured in the middle of a duct about 0.3 m upstream (outdoor air) and downstream of the filters. Both analysers were applied at the same sampling point simultaneously. Sampling location was changed by using a four-way ball valve. A 1-min stabilization and three consecutive 2-min analysing periods were used for a typical data collection cycle. Results were presented as average values.

VOCs

VOCs were collected on Tenax GR adsorbent simultaneously upstream and downstream of the filters and from the duct at distance of 20 m from the filters. The samples were analysed with an automated thermal desorption coldtrap injector (Perkin Elmer ATD 400) connected to a gas chromatograph (HP 6980) equipped with a mass selective detector (MSD 5973).

Sensory Panel

Trained sensory panel (Bluyssen and Walpot, 1993; Fanger, 1998) consisted of 20–30-year old students. Number of panelists were 12–14.

RESULTS

Particles

Used G3 pre-filter collected a small fraction of ultrafine particles (size range of 4–50 nm), but worked as a source of particles ranging in size from 50 to 300 nm (Figure 1). Penetration of particles through a F7 filter in ambient particle concentration was highest in the size range 50–100 nm. Comparison of collection efficiency of the ‘new’ and ‘used’ F7 filter was also made (Figure 2). In the size range between 4 and 50 nm, used filter was more efficient, meanwhile in size range between 100 and 700 nm new filter collected particles more efficiently. There was no observation of noteworthy particle shedding from the filters when air handling system was shut down and turned on again.

The influence of relative humidity (RH) on the particle concentration after the filters was examined. When relative humidity of air was increased (before moistening RH 19±1% and temperature 23±1°C, during moistening RH 46±3% and temperature 19±1°C), the efficiency of G3 pre-filter in the particle size range from 50 to 700 nm was decreased. In case of F7 filter, increase of humidity increased also the filtration efficiency of particles in the size range from 50 to 700 nm by 20%. The humidity did not affect the efficiency in the size range from 4 to 50 nm. The experiment was repeated with another F7 filter and results were similar.

The highest measured particle concentration in ambient air was in the size range of 9–12 nm, after the pre-filter the highest concentration obtained was in the 14–20 nm range, and after the fine filter, in the 40–50 nm range. In Figure 3, the particle size distributions before and after the G3 and F7 filters as detected by L-SMPS equipment are presented.

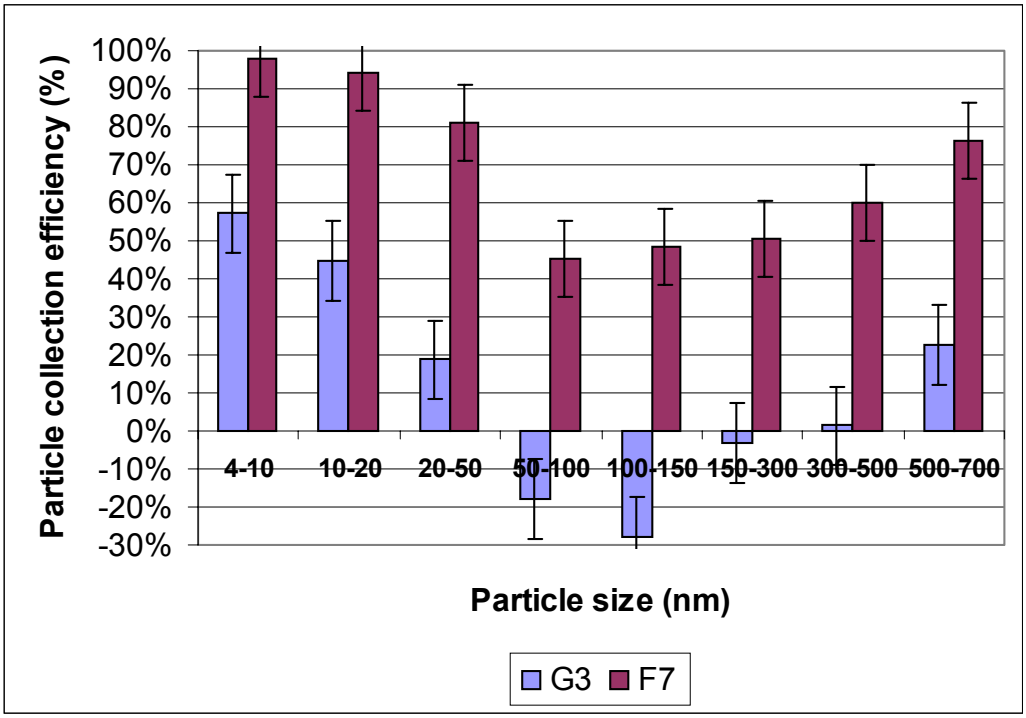

Figure 1 Particle collection efficiency of G3 and F7 filters (4–700 nm) in ambient particle concentration. Particles from 4 to 100 nm are measured by N-SMPS and particles from 100 to 700 nm by L-SMPS equipment. Time of measurement 19.2.2002; 10:00–11:00.

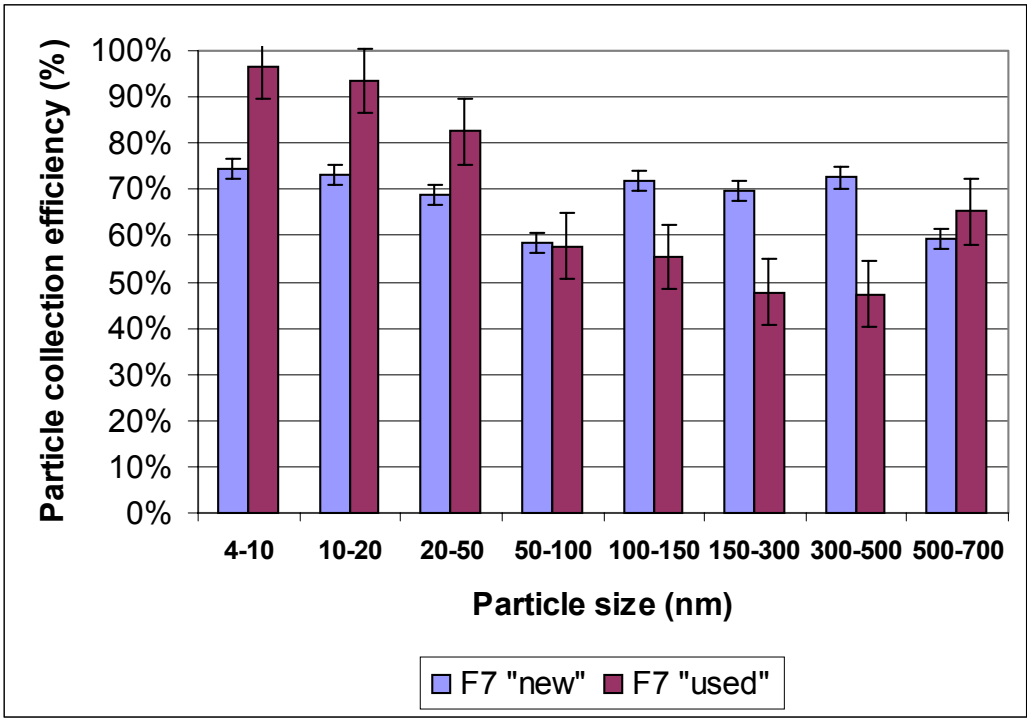

Figure 2 Particle collection efficiency of clean and dirty F7 filter (4–700 nm) in ambient particle concentration. Particles from 4–100 nm are measured by N-SMPS and particles from 100 to 700 nm by L-SMPS equipment. Time of measurement 19.2.2002; 14:10–15:20.

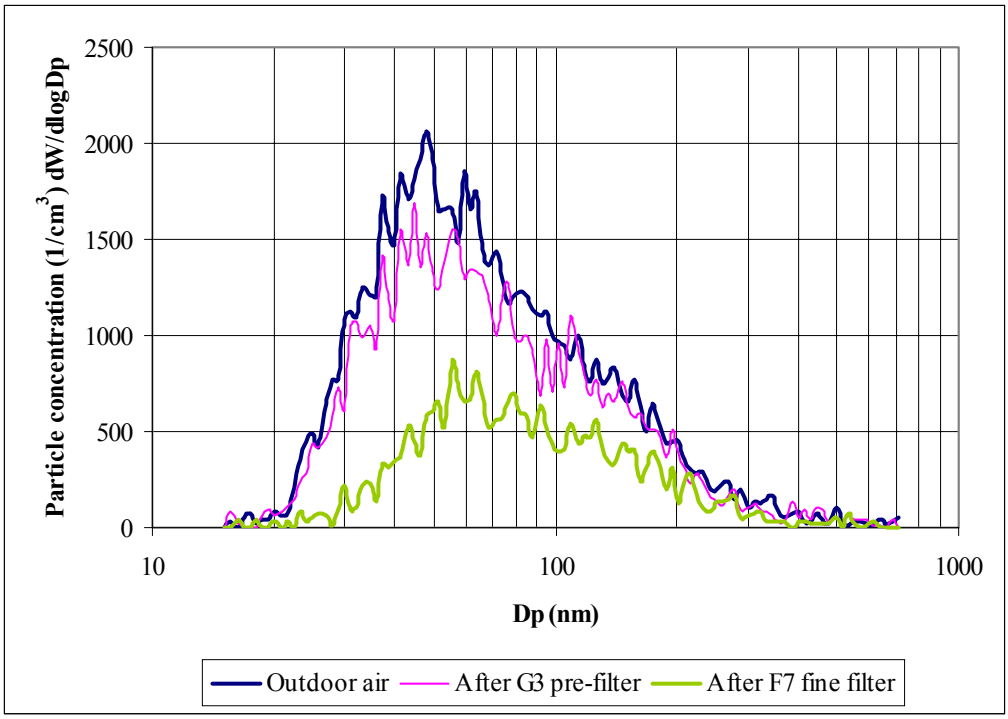

Figure 3 Particle size distributions upstream and downstream the G3 pre- and F7 fine filters obtained by L-SMPS equipment. Time of measurement 19.2.2002; 9:30–9:50.

Volatile organic compounds (VOCs)

Concentration of total VOCs in ventilation system was, in all measurements, below 33 µg/m^3. Before (outdoor air) and after the filters VOC concentrations varied and no clear trend was observed between different compound groups (Table 1). However, measurements made in the second day using the F7 filter only showed clear increase in VOC concentrations downstream the filters (Table 2). In particular, concentrations of aromatic hydrocarbons and aldehydes were higher downstream the filters. Total concentration of compounds (conceivably pyrrole, 2-pentanone), which could not reliably identified, were higher downstream the filters. In all measurements, the most distinct was the increase of aliphatic hydrocarbons in the duct at 20 m downstream the filters. When humidity of air was high, there was increase of aldehydes and unrecognized compounds downstream of the filters. In contrast, in some measurements, influence of humidity was opposite. This was proposed to be due to earlier diminishing of the compounds on the particles attached to the filters.

Table 1 Influence of used G3/F7 filters and duct (length 20 m) on the VOC concentrations (µg/m^3). Effect of increased relative humidity on the concentrations is presented in the corresponding adjacent columns (+RH)

Compounds	Outdoor air	Outdoor air + RH	After G3	After G3 + RH	After G3 + F7	Duct (20m)	
						Dry conditions	+ RH
Alcohols	0.0	0.3	0.8	0.2	0.5	0.6	0.1
Alkanes	0.6	0.9	0.6	2.4	0.5	4.5	6.7
Aldehydes	5.2	5.0	3.7	4.0	1.7	3.5	3.7
Aromatic hydrocarbons	10.0	5.1	6.5	7.8	6.9	14.4	9.0
Terpenes	0.0	0.5	0.0	4.0	0.0	0.6	0.6
Carboxylic acids	0.6	0.2	0.0	0.3	0.8	1.0	0.2
Others	8.6	0.0	4.1	0.6	11.4	7.3	0.0
Total	25.0	11.9	15.8	19.3	21.8	32.0	20.4

Table 2 Influence of used F7 filter and duct (length 20 m) on the VOC concentrations (µg/m^3). Effect of increased relative humidity on the concentrations is presented in the corresponding adjacent columns

Compounds	Outdoor air	Outdoor air + RH	After F7	After F7 + RH	Duct (20m), dry conditions
Alcohols	0.4	0.0	0.1	0.0	0.7
Alkanes	2.0	1.1	1.5	3.6	3.6
Aldehydes	3.4	0.0	5.4	6.5	10.6
Aromatic hydrocarbons	2.7	1.7	4.1	2.2	7.8
Terpenes	0.1	0.0	0.0	0.0	0.0
Carboxylic acids	0.0	0.5	0.0	0.0	0.8
Others	3.8	5.6	6.5	9.8	6.1
Total	12.3	9.0	17.6	22.5	29.6

Sensory panel

Intensity of odour was evaluated by trained sensory panellists (Figure 4). Amount of odorous compounds increased considerably after the F7 fine filter. Increase of relative humidity did raise odour intensity significantly after the F7 fine filter, but the effect was only temporary.

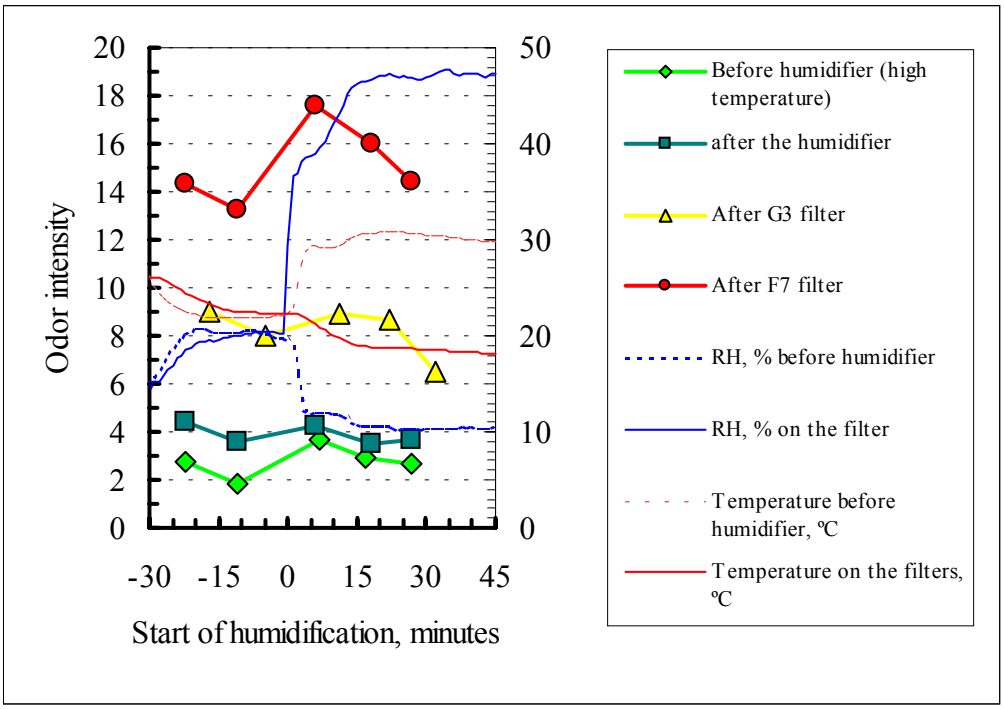

Figure 4 Influence of relative humidity on the odour intensity before and after the G3 and F7 filters.

DISCUSSION

Particle concentration after the G3 pre-filter was at the same level as in ambient outdoor air, occasionally even higher. This was probably due to coincidental release of particles, attached on the filter media. As expected, particle concentration decreased considerably after the F7 fine filter. At the same time, intensity of odour increased notably from the level after the G3 filter. Results indicated that increase of relative humidity did mainly influence the release of odorous compounds from the F7 filter, which was not earlier exposed to the high variation of

weather conditions (unlike the G3 filter). Increase of humidity also improved the filtration efficiency of F7 filter, which supports the hypothesis that water molecules affect the sorption phenomenon of odorous compounds attached to the particles. Particle concentrations were measured only in a single site, and thus no variation of particle distribution in different locations of ventilation system is known. The detected particle collection efficiency was lowest in all filters at the size range between 50 and 300 nm (Figure 1). Minimum filtration efficiency is usually at particle sizes between 100 and 400nm, depending on fibre diameter and air velocity (McDonald and Ouyang, 2001).

Concentration of aliphatic hydrocarbons increased in ventilation system. Results indicated that source of these compounds was not dusty filter, but dirty and oily duct. The amount of VOC compounds in the ventilation system was low and variation before and after the filters was partially inconsistent. Concentration of aromatic hydrocarbons and aldehydes was higher after the (unit 2) F7 filter. Emission of these compounds from the dusty filters has been reported previously (Hyttinen *et al*., 2001). Amount of compounds, which could not reliably identified, did also increase in the ventilation system. Some of these compounds may have influence on the odour perception after the dusty filters. However, total VOC concentrations were in all measurements low, which made the conclusions on their influence to the odours released from the filters problematic.

Results indicated that ultrafine and fine particles are not essential factors in odour emissions released from the filters. It seems that odour emission is related to the compounds that are emitted from coarse particles attached to the filter media. This is supported by a previous study in which coarse particle fractions did cause higher odour emissions than finer ones (Pasanen *et al*., 1995).

REFERENCES

Bluyssen, M. and Walpot, J.I. (1993). Sensory evaluation of perceived air quality, *Proceedings of the 6th International Conference on Indoor Air Quality, Indoor Air'93*, Vol. 1, pp. 65–70.

Fanger, P.O., Lauridsen, J., Bluyssen, P.M. and Calusen, G. (1998). Air pollution sources in office and assembly halls, quantified by the olf unit. *Energy and Buildings* **12**, 7–19.

Hyttinen, M., Pasanen, P. and Kalliokoski, P. (2001), Adsorption and desorption of selected VOCs in dust collected on air filters. *Atmospheric Environment* **35**, 5709–5716.

McDonald, B. and Ouyang, M. (2001). Air cleaning particles. In: Spengler, J.D., Samet, J.M. and McCarthy, J.F. (eds), Indoor Air Quality Handbook, pp. 9.1–9.28. New York: McGraw-Hill.

Pasanen, P.O., Pasanen, A.-L., Kalliokoski, P. and Tuomainen A. (1995). Prefilters and fine filters as a source of contaminants. In: Haghighat, F. (ed.), *Proceedings of Indoor Air Quality,Ventilation and Energy Conservation in Buildings*, Centre for Building Studies, Concordia University, Montreal, Canada, Vol. 2., pp. 957–964.

Pejtersen, J., Bluyssen, P., Kondo, H., Clausen, G. and Fanger, P.O. (1989). Air pollution sources in ventilation systems. In: Kulic, E., Todorovic, B. and Novak, P. (eds), *Proceedings of CLIMA 2000,* Air Conditioning Components and Systems, Yogoslavic Committee of Heating, Refrigerating and Air Conditioning and Union of Mechanical and Electrical Engineers and Technicians of Serbia, Beograd. Vol. 3, pp. 139–144.