THE IMPACT OF AIR POLLUTION FROM USED VENTILATION FILTERS ON HUMAN COMFORT AND HEALTH

G Clausen*, O Alm and PO Fanger

International Centre for Indoor Environment and Energy, Technical University of Denmark

ABSTRACT
The comfort and health of 30 women was studied during 4 hours' exposure in an experimental room with either a used or a new filter present in the ventilation system. All other environmental parameters were kept constant. The presence of the used filter in the ventilation system had a significant adverse impact on several perceptions and symptoms, both immediately upon entering the office and throughout the exposure period. None of the perceptions or symptoms were better when the used filter was in the system.

INDEX WORDS
Perceived air quality, SBS symptoms, HVAC, Laboratory and field experiments, Cleaning and maintenance

INTRODUCTION
Numerous field studies have documented that HVAC systems can act as sources of pollution and deteriorate the perceived air quality indoors (Fanger et al., 1988; Thorstensen et al., 1990; Pejtersen et al., 1991). Of the various components in a HVAC system, dirty filters have been identified as a main source of pollution (Pejtersen et al., 1989). Studies have shown that the sensory pollution load from a new filter is negligible after an initial off-gassing period of a few days (Bluyssen, 1993; Pejtersen, 1996; Gholami et al., 1997). The accumulated dust therefore constitutes the pollution source. The purpose of the present study was to assess the impact that this accumulated dust may have on both immediate perceptions of air quality and symptoms developing after longer exposure.

METHODS
The experiment was carried out in an office with a floor area of 36 m^2 and a volume of 108 m^3. Three years prior to this study, the office was renovated with a new low-polluting polyolefine floor covering, and the walls were painted with low-emitting paint. The office and the experimental set-up is shown in Figure 1.

The office was divided into two areas by a 2-metre high partition. The height ensured that it was impossible to see what was behind the partition but the air from one side could still mix with the air from the other side. Six workstations were placed in the larger area. Behind the partition, outdoor air was provided to the room by an axial fan in the window. The air left the room again through an opening under the door. Oil-filled electric heaters (2000W) and ultrasound humidifiers kept the air temperature and the relative humidity constant. When cooling was required an air-conditioning unit was activated. Table fans ensured full mixing in the entire space. A ventilation system recirculating the office air was placed behind the partition. The system consisted of a unit for 0.3·0.6 m bag filters, fans and silencer. The ventilation system was placed with the inlet opposite the outdoor air supply inlet.

* Contact author email: gc@mek.dtu.dk

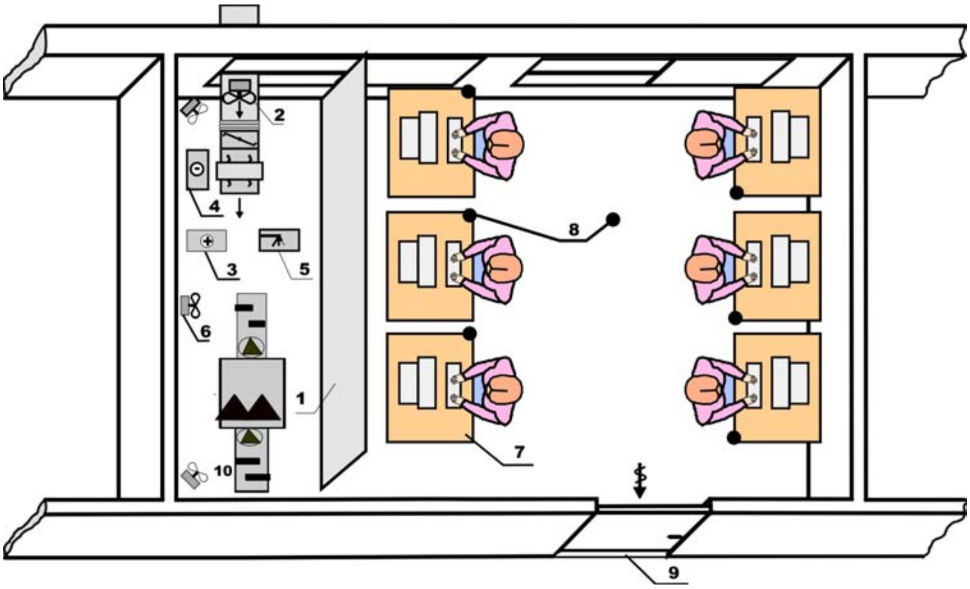

Figure 1. Plan of the experimental office. 1: partition, 2: outdoor supply fan with damper and silencer, 3: electric oil-based heater, 4: air-conditioning unit, 5: electric humidifier, 6: mixing fan, 7: workstation, 8: measuring points for air temperature, relative humidity and concentration of tracer gas , CO_2, utrafine particles and ozone, 9: ventilation exhaust, 10: recirculating ventilation system with a filter.

Thirty female subjects aged 20 –30 (average ± std= 23.4 ± 2.6) years participated in the experiment. No subjects suffering from respiratory diseases were included. To check their olfactory sense, all the subjects passed a ranking test, in which four samples of 1-butanol (10, 80, 320, and 1280 ppm) had to be ranked according to strength (ISO 8587; 1988). None of the participants dropped out during the experiment.

The experiment was carried out with two bag filters: a new filter and a used filter, both EU7 fibre glass filters, with a size of 0.3m·0.6 m. The filter had six bags and the total surface area of the filter was 2 m^2. The new filter used in this experiment had been ventilated in a ventilation system for 3 days at 500 l/s before use. As the new filter was used only for one or two experimental sessions, a total of four new filters were used in this experiment. The used filter had been used for one year in a Copenhagen suburban area and was changed one month prior to the start of this experiment. The flow through it had been at 500 L/s during 12 hours per day, giving an approximate total of $7.8 \cdot 10^6$ m^3 filtrated air. The used filter was, before the start of the experiment and between experimental days, placed in a ventilation system and ventilated with 70 L/s outdoor air.

The filter was placed in the office system three hours prior to the start of the experiment and was returned to the normal ventilation system after the end of each experimental day. The flow through the filter was kept constant at 105 L/s throughout the experiment. During the experiment, the office was ventilated with a constant outdoor air supply rate of 48 l/s corresponding to 8 L/s·person or $1.6h^{-1}$ or 1.33 $L/s \cdot m^2$. This meets the design criteria for Category B landscaped offices (CEN, 1998). The subjects were asked to stay thermally neutral during the experiment by adjusting their clothing.

The experiment was carried out on every workday in three subsequent weeks in the period 21 May to 11 June 2001. The subjects were divided into five groups, each with 6 women. Each group came on the same workday for three weeks, and each subject participated in three different sessions, first a training session and then one session for each condition. Each condition was repeated five times, every second day with the new filter and every other second day with the used filter. Each experimental session lasted from 18^{00} to 22^{30}. Questionnaires were filled out 1, 56, and 175 minutes after entering the office. After 240 minutes the subjects left the office and re-entered 3 minutes later to assess the air quality. (The results of these assessments are not included in the present paper.)

RESULTS

The distributions of the data obtained from the questionnaires were tested for normality with Shapiro-Wilk's W test. If they were normally distributed, they were tested by means of analysis of variance, ANOVA, or by t-test for independent samples. Data without normal distributions were tested with Kruskal-Wallis one-way analysis of variance or Friedman two-way analysis of variance.

In Table 1 is shown the results of measurements characterizing the indoor environment

Table 1. Levels of indoor environment parameters in the office (average ± std.).

	With used filter	**With new filter**
Air temperature, (°C)	22.5 to 24.2 (23.5 ± 0.3)	22.4 to 24.2 (23.5 ± 0.3)
Operative temperature (°C)	23.8 to 24.6 (24.2 ± 0.2)	23.8 to 24.6 (24.2 ± 0.2)
Relative humidity, (%)	34 to 45 (40 ± 2.5)	37 to 45 (40 ± 1.5)
Sound pressure level (dB(A))	45	46
Air velocity (m/s)	< 0.15	< 0.15
Outdoor air supply (l/s)	46	49
CO_2 , inside (ppm)	920 ± 219	1000 ± 100
Ozone, indoors (ppb)	0.8 to 14.6 (7.3 ± 3)	5 to 12.6 (9.1 ± 1.7)
Ultra-fine particles, inside (counts/cm3)	1280 to 4200 (2323 ± 1073)	809 to 3010 (1855 ± 628)
Lighting level (lux)	355	450

The quality of the outside air was evaluated as good and varied only little between experimental days. On average, acceptability of the outside air corresponded to approximately 1% dissatisfied.

The perceptions and symptoms reported by the subjects are shown in Table 2.

The presence of the used filter in the ventilation system had a significant adverse impact on several perceptions and symptoms. Immediately upon entering the office the acceptability of the air quality was lower, the odour intensity was higher, there was greater irritation in the nose, the perceived dryness was higher, the perceived freshness of the air was lower, the acceptability of the overall environmental conditions was lower, the perceived intensity of headache was higher, the ability to think clearly was lower and the perceived intensity of dizziness was higher.

Table 2. Perceptions and symptoms

	NEW FILTER			*USED FILTER*			*DIFFERENCE P-LEVEL*		
	1 min	*57 min*	*175 min*	*1 min*	*57 min*	*175 min*	*1 min*	*57 min*	*175 min*
Acceptability, air[1]	0.3	0.4	0.5	0	0.3	0.4	0.0003	0.03	
Odour intensity[2]	1.2	0.5	0.5	2	0.7	0.6	0.00003		
Eye irritation[3]	0.4	0.8	1.0	0.6	1.0	1.0			
Nose irritation[3]	0.6	0.5	0.6	1.1	0.6	0.7	0.006		
Throat irritation[3]	0.4	0.5	0.5	0.6	0.5	0.6			
Perceived humidity[4]	44	41	43	36	39	41	0.017		
Perceived freshness[4]	36	43	40	24	33	44	0.0002	0.006	
Perceived brightness[4]	45	48	47	47	47	47			
Perceived noise[4]	60	63	66	65	66	66			
Acceptability, noise[1]	0	0.1	0.1	0	0.1	0.1			
Acceptability, environment[1]	0.3	0.2	0.3	0	0.1	0.1	0.0005	(0.06)	0.017
Nose dryness[4]	62	63	66	67	70	66			
Throat dryness[4]	42	40	48	40	44	46			
Eye dryness[4]	36	47	49	41	55	51			
Intensity of headache[4]	9	15	18	21	20	24	0.05		
Easiness of thinking[4]	80	74	63	68	65	65	0.01		
Dizziness[4]	6	7	6	10	11	14	0.05		
Tiredness[4]	34	38	48	39	39	46			
Ability to concentrate[4]	73	71	58	70	61	58			
Sleepiness[4]	30	34	47	31	33	38			

[1]Acceptability scale (continuous from "-1: Clearly acceptable" to "1:Clearly unacceptable"), [2]Intensity scale (continuous from "0: No odour" to "5: Overwhelming odour"), [3]Irritation scale (continuous from "0: No irritation" to "5:Overwhelming irritation"), [4]Visual-analogue scale with labelled endpoints (left end-point = 0, and right end-point = 100)

After approximately 1 hour in the office, the presence of the filter still had an impact on the perceived air quality, on the perceived freshness of the air, and on the overall environmental conditions. Furthermore, the ability to concentrate was significantly lower.

After almost 3 hours in the office the acceptability of the overall environmental conditions was still found to be significantly lower with the used filter in the system. None of the data showed any improvements in the perceptions or symptoms when the used filter was in the system.

From the initial assessments of acceptability, the pollution load from the used filter and the office was estimated to be approximately 0.72 olf/m^{2}floor and approximately 0.13 olf/m^{2}floor with the new filter in the system.

DISCUSSION
The present study demonstrates that a used filter in an HVAC system can have a negative effect on both the immediate perception of the indoor air quality and on perceptions and health-related symptoms reported after longer exposures.

It is not clear which agents in the accumulated dust is responsible for these effects. Metabolites from microbial activity in the dust and on the filter surface have long been the prime suspect in the search for an explanation. But recent research has disproved this (Alm 2001). Alternatively the cause may be the formation of odorous and irritating compounds from reactions between organic matter in the dust and O_3 or other chemicals in the air. We know that in a loaded filter like the one used in the present study the surface area of the dust may be several hundred square meters. This surface provides ample opportunity for sorption by chemicals in the air. Changes in environmental conditions may subsequently cause the sorbed chemicals to be re-emitted to the ventilation air.

The pollution load from office has previously been assessed to be 0.1 olf/m^2floor (Witterseh, 2001). The pollution load from the new filter was therefore only 0.03 olf/m^2floor. In contrast, the pollution load of the used filter was 0.62 olf/m^2floor. This load is one order of magnitude higher than the load recently determined by Clausen et al. 2002 for a similar filter used in a system supplying a typical ventilation rate of 0.7 L/s m^2floor. However, the filter used in the present study was oversized for the space. The nominal airflow, and the airflow at which it was previously used, was 500 L/s, but in the present study the airflow passing the filter was only 105 L/s and the outdoor air supply rate to the office was 48 L/s.

Shortly after entering the office, the intensity of headache and dizziness, and the ability to think clearly were reported to be adversely affected by the presence of the used filter. It is unlikely that breathing air for such a short period that has been polluted from passing through a used filter could give a headache. However, the annoyance experienced through the sensory system may have amplified the intensity of symptoms experienced even before the exposure started.

CONCLUSIONS
A used filter in a HVAC system can have a negative effect on both the immediate perception of the indoor air quality and on perceptions and health-related symptoms reported after longer exposure.

ACKNOWLEDGEMENTS
This work has been supported by the Danish Technical Research Council (STVF) as part of the research programme of the International Centre for Indoor Environment and Energy established at the Technical University of Denmark for the period 1998-2007

REFERENCES
Alm, O., Clausen, G. and Fanger; P.O. 2000. “Exposure-response relationships for emissions from used ventilation filters. Proc of Healthy Buildings 2000.

Alm, O., 2001: Ventilation filters and their impact on human comfort, health and productivity. International Centre for Indoor Environment and Energy, Technical University of Denmark, (Ph.D.-thesis (MEK-I-Ph.D. 01-02))

Bluyssen, P. 1993. “Do filters pollute or clean the air?” Air Infiltration Review, Vol. 14, No 2, March 1993, pp. 9-13

CEN Report 1752. 1998. “Ventilation for buildings – Design criteria for the indoor environment”. Brussels, European Committee for Standardization.
Clausen, G., Alm, O. and Fanger, P.O. 2002. “Sensory source strength of used ventilation filters” Proc. of the 9th International Conference on Indoor Air Quality and Climate - Indoor Air 2002
Fanger, P. O.; Lauridsen, J.; Bluyssen, P.; and Clausen, G. 1988. “Air pollution sources in offices and assembly halls, quantified by the olf unit”. Energy and Buildings, 12, 7-19.
Gholami, S.; Pejtersen, J.; Clausen, G.; and Fanger, P. O. 1997. “Sensory pollution load caused by HVAC components”. Proceedings of IAQ'97 Healthy Buildings, Washington DC, USA, Vol. 1, pp. 545-550
ISO 8587. 1998. “Sensory analysis – Methodology – Ranking test”
Pejtersen, J.; Clausen, G.; Sørensen, J.; Quistgaard, D.; Iwashita, G.; Zhang, Y.; Onishi, T.; and Fanger, P. O. 1991. “Air pollution sources in kindergartens”. Proceedings of Healthy Buildings-IAQ 91, Washington D.C., ASHRAE. pp. 221-224.
Pejtersen, J.; Bluyssen, P.; Kondo, H.; Clausen, G.; and Fanger, P. O. 1989. “Air pollution sources in ventilation systems”. Proceedings of CLIMA 2000, Sarajevo, August 1989, Vol. 3, pp. 139-144
Pejtersen, J. 1996. “Sensory pollution and microbial contamination of ventilation filters”. Indoor Air 6: 239-248.
Thorstensen, E.; Hansen, C.; Pejtersen, J.; Clausen, G.; and Fanger, P. O. 1990. “Air pollution sources and indoor air quality in schools”. Proceedings of Indoor Air ’90, Toronto. Vol. 1, pp. 531-536.
Witterseh, T. 2001. “Environmental perception, SBS symptoms and the performance of office work under combined exposures to temperature, noise and air pollution. Ph.D. Thesis, MEK-Ph.D.01-01.