The influence of typical ways of operating an air-handling unit on the sensory pollution load from used bag filters

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ABSTRACT
An experiment was performed to determine whether the sensory pollution emitted from a bag filter that had been used for 3 months in a suburban area in Denmark was influenced by different ways of operating the air-handling unit (AHU). Samples of the used filter were pre-conditioned to simulate three operating conditions: (1) switched off overnight; (2) airflow reduced to 10% overnight; and (3) continuous 100% operation. Outside air passed through the samples and the acceptability of the air after the filter was assessed by a panel of subjects. The results indicate that turning off the AHU or reducing the airflow outside working hours would significantly increase the sensory pollution emitted by a used bag filter immediately after the AHU is turned on, in comparison with continuous airflow through the AHU ($P < 0.05$). After outside air had been passed through the filter for 2 h, no significant differences were found.

INDEX TERMS
Air filter; Perceived air quality; Ventilation system; Air pollution

INTRODUCTION
Used bag filters may pollute the supply air from the HVAC system considerably (Clausen *et al.*, 2002a). This sensory pollution increases in strength during the first 3 months of operation before it stabilizes at a level of about 2.5 decipol (Teijonsalo *et al.*, 1993). A field intervention in a central-London office showed that replacing well-used supply-air pre-filters with new ones caused several significant improvements such as: humidity seemed lower, eyes ached less, head felt clearer; subjects felt better, less tired and more positive and they found it easier to concentrate (Wyon *et al.*, 2000). A field intervention in a call-centre in Denmark showed that changing from used to new supply air filters at low outdoor air supply rate significantly alleviated many Sick Building Syndrome (SBS) symptoms (Wargocki *et al.*, 2002). This indicates that sensory offending chemicals are associated with the particles captured by the filter (Weschsler, 2002).

To reduce energy consumption, it is normal to turn off or reduce the ventilation air volume delivered by the air-handling units (AHUs) outside regular working hours. The unanswered question is: will this lead to an accumulation of chemicals in the air enveloping the filter, causing an increase in the sensory pollution emitted from the bag filter after the AHU is switched back on for normal operation?

Cox and Bluyssen (2000) compared the pollution load from filters with continuous and intermittent airflow without finding any significant difference, but they did not look at the development of the pollution load over time during the first period after the ventilation had been switched on.

An experiment was performed to determine whether the sensory pollution emitted from a bag filter that had been used for 3 months in a typical suburban area in Denmark was

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influenced by different ways of operating the AHU. Samples of used filter were pre-conditioned to simulate three operating conditions: (1) switched off overnight; (2) airflow reduced to 10% overnight; and (3) continuous 100% operation.

METHODS

The measurements took place in Chamber one at the International Centre for Indoor Environment and Energy at DTU in Denmark. The room was supplied with outside air corresponding to 60 air changes per hour. The temperature in the room was kept constant at 24.5°C throughout the experiment. The relative humidity was kept above 40%.

Five identical test rigs were constructed for the experiment (Picture 1). Each consisted of 1 m of 100 mm diameter inlet duct before the sample. After the sample a flexible Teflon coated plastic duct was connected to a fan. After the fan a plastic valve for adjusting the airflow and 1 m of glass tube led up to the assessment point. The filter samples have an area of 79 cm^2. The airflow rate out of the glass tubes was adjusted to 1 l/s. The air velocity through the sample was 12.7 cm/s, which is approximately the same as through a filter in a normally designed AHU with 2.5 m/s face velocity.

Picture 1 One of the test rigs constructed for the experiment.

All the parts except the fans were thoroughly cleaned with a strong detergent and afterwards rinsed first in fresh tap water and then with distilled water. Initial assessments of the empty test rigs showed that the perceived air quality at the assessment point was the same for all the test rigs.

Samples from one used filter were put in three of the test rigs. The filter was a EU7 filter that had been used in an office building 30 km north of Copenhagen near the east coast of Zeeland. The filter had been used from 31 January 2003 to 6 May 2003 with continuous airflow of 3500 m^3/h throughout this period. This yielded an air velocity of 13.7 cm/s through the filter material and a total air volume of about 8 million m^3.

As references for evaluation of the results, a sample from a new unused EU7 filter was put in one test rig and the last test rig was left empty meaning that the air did not pass through a filter before being assessed. In addition, an odour reference generated by releasing a known concentration of acetone was used.

An untrained panel made the assessments. The assessment order was randomized and the assessment subjects were told to wait 1 min between each assessment. People connected to the International Centre for Indoor Environment and Energy, mostly students, did the assessments. This was a blind test for the subjects and the construction of the test rigs ensured that the samples are completely hidden from the subjects who assessed.

The assessment votes were marked on the DTU split scale of air quality acceptability. The votes have been assigned values between –1 (clearly unacceptable) and +1 (clearly acceptable) for statistical analysis and calculation of decipol values.

A listing of airflows in test rigs throughout the experiment is shown in Table 1. Assessments were made three times on 11 June: After 0.5 h (between 9.30 and 10 a.m.), after 2 h (between 11.00 and 11.30 a.m.) and after 6 h.

Table 1 Airflows in test rigs throughout the experiment with simulated day and night operation

Test rig	Simulates	Preconditioning (100 h)	Night (16 h)	Day (8 h)
1 Used-off	Switched off overnight	Full	Off	Full
2 New	Reference—new filter	Full	Off	Full
3 Used-10%	Airflow reduced to 10% overnight	Full	10% of full	Full
4 None	Reference—no filter	Full	Off	Full
5 Used-full	Continuous 100% operation	Full	Full	Full

The samples were assessed at the beginning and at the end of the preconditioning phase. This confirmed that all three samples from the used bag filter had approximately the same sensory source strength.

RESULTS

The assessment scores were analysed statistically with SPSS release 11.00. The distribution of the assessments scores was tested for normality with the Shapiro–Wilks test and a general skewness test and this showed that all the relevant data could be treated as normally distributed.

Figures 1 and 2 show the means of the assessments scores with their 95% confidence interval after 30 min and after 2 h. The confidence interval for the three used filter samples (denoted Used-off, Used-10% and Used-full) overlap, meaning that there is no significant difference in the assessments score values between these samples.

The perceived air pollution from the used filter samples were calculated from the difference between perceived air quality of exhaust air from the used filter samples and perceived air quality of exhaust air from the reference without filter (Figure 3). The sample that had not been ventilated during the night improved most from 0.5 to 2 h after the fan was switched on.

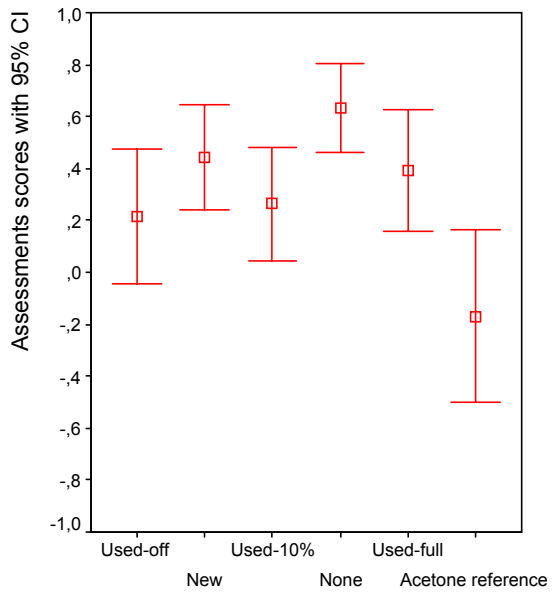

Figure 1 Assessments scores with 95% confidence interval after a night and after 30 min with full airflow through the samples; 14 subjects assessed the samples

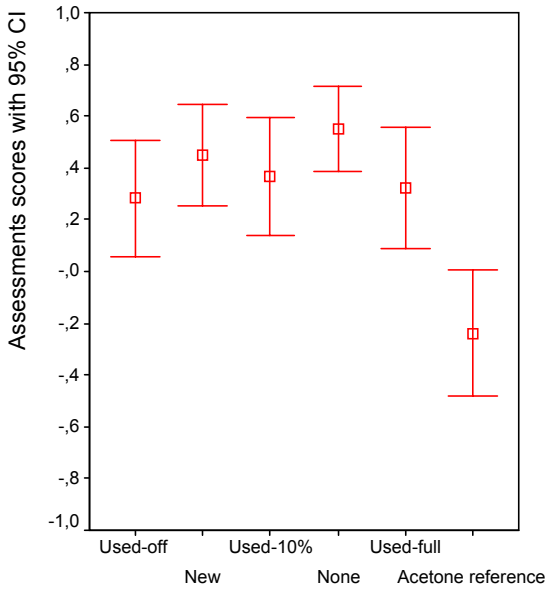

Figure 2 Assessments scores after a night and after 2 h with full airflow through the samples; 17 subjects assessed the samples

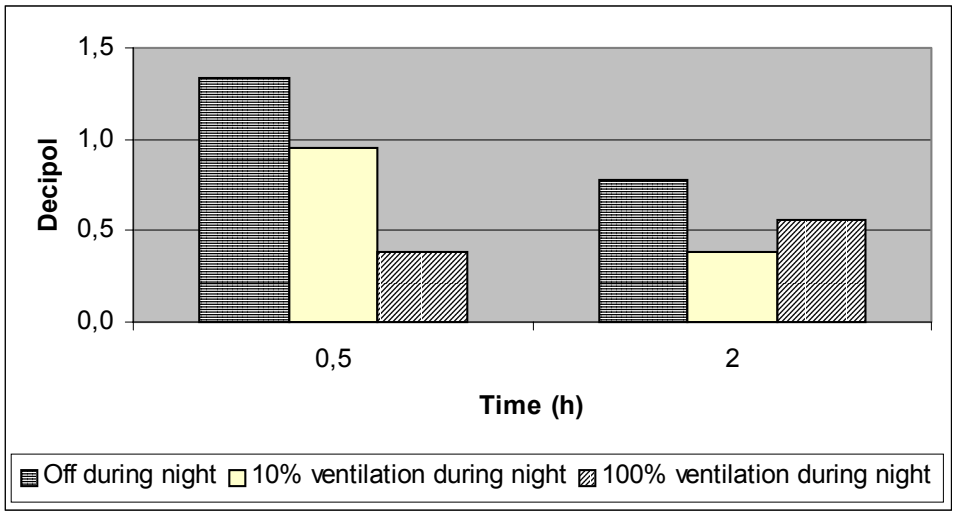

Figure 3 Development of perceived air pollution after a night.

If the vast majority of the subjects assess the difference between two samples in the same direction, there might be a significant difference between the samples even if the mean differences are small. Such a comparison is often called a repeated-measures comparison and was examined by using Student's Paired-Samples *t*-Test procedure. Here the two cases with reduced or no airflow were compared with the sample with continuous airflow. The results are shown in Table 2. There was a significant difference between the 'Used-10%' sample and 'Used-full' sample after 0.5 h of ventilation (pair 2, $P < 0.021$, 2-tailed).

Table 2 Paired differences achieved with a paired samples *t*-test

		Paired Differences of acceptability				
				95% Confidence Interval of the Difference		
		Mean	Std. Deviation	Lower	Upper	Sig. (2-tailed)
Pair 1	Used-off 1/2h - Used-full 1/2h	-,1779	,32048	-,3629	,0072	,058
Pair 2	Used-10% 1/2h - Used-full 1/2h	-,1279	,18297	-,2335	-,0222	,021
Pair 3	Used-off 2h - Used-full 2h	-,0418	,50600	-,3019	,2184	,738
Pair 4	Used-10% 2h - Used-full 2h	,0441	,47603	-,2006	,2889	,707
Pair 5	Used-off 1/2h - Used-off 2h	,0442	,52493	-,2894	,3777	,776

There are no significant differences after 2 h (pairs 3 and 4), and there was no significant improvement in the 'Used-off ' sample between 0.5 and 2 h of ventilation (pair 5), but in this case only the12 subjects who took part in both assessments were used in the statistical analysis, i.e. considerably fewer subjects.

DISCUSSION

The acceptability of the'Used-10%' sample (airflow reduced to 10% overnight) was significantly lower than that of the 'Used-full' sample (continuous 100% operation) after 0.5 h of full ventilation (Table 2, pair 2, $P < 0.021$, 2-tailed). After 2 h there were no significant differences between the samples (Table 2, pairs 3 and 4). This shows that different ways of operating an AHU resulted in a real difference in the pollution load from a used bag filter immediately after the AHU was turned on, but this difference is greatly reduced after ventilation has continued for some time. This indicates that there is a continuous emission of odorous products on particulate matter associated with the filter surfaces and that these products accumulate during periods with no or reduced airflow through the filter.

Since it is statistically proven that the 'Used-10%' sample smelled worse than 'Used-full' sample after 0.5 h it should be valid to assume that even the 'Used-off' sample will smell worse than the 'Used-full' sample which means that the results can be analysed for 1-tail significance. Such an assumption leads to a significant difference between the Used-off and the Used-full sample ($P < 0.029$, 1-tailed).

The increased pollution load caused by this bag filter used during the months of February, March and April is about 0.6 decipol or about 8 olf/m^2 filter. This is less than expected from other experiments (Teijonsalo *et al.*, 1993; Clausen *et al.*, 2002b). This indicates that the pollution load from a used filter can be strongly influenced by the amount and the composition of the particulate matter associated with the filter surfaces, as one would expect. This again is affected by parameters such as: when it has been used (time of year), placement of the air intake, where the building is situated together with the total filtered air volume.

Similar assessments were made after a simulated weekend with 11 subjects who assessed the samples. No significant differences were found in this experiment. This may be explained by the relatively small size of panel used.

CONCLUSIONS AND IMPLICATIONS

Turning the AHU off or reducing the airflow outside working hours would increase the sensory pollution emitted by a used bag filter immediately after the AHU is turned on compared with continuous airflow through the AHU ($P < 0.05$). The consequence is that the

IAQ deteriorates or more outside air is required. After outside air had been passed through the filter for 2 h, no significant difference between operating conditions was found in terms of the sensory pollution emitted from the filter.

Based on these findings an AHU with used bag filters should be switched on several hours before the workers enter the office to minimize the sensory pollution emitted from the bag filter. A more energy-efficient strategy would be to modify the AHU with an additional timer-controlled damper to permit outside air to be passed through the bag filter and rejected for 2 or more hours, bypassing the building to avoid the energy cost of conditioning this cleansing air and distributing it in the building.

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