THE EFFECT OF DUCT CLEANING ON INDOOR AIR QUALITY IN OFFICE BUILDINGS

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ABSTRACT
The effect of duct cleaning on supply air quality, duct cleanliness, air exchange and working environment was studied in 15 non-problem office buildings. Mass and number concentrations of particles, concentrations of microbes, volatile organic compounds and CO_2 were measured in outdoor, supply and indoor air. Samples of accumulated dust were taken from the inner duct surfaces and supply and exhaust air flows were measured. An Indoor Climate Questionnaire was delivered to over 900 employees before and after the duct cleaning. Duct cleaning had no measurable effect on supply air quality. The results showed that the average amount of dust on the inner duct surfaces decreased from 8.4±9.1 to 1.9±2.1 g/m^2. The employees perceived the working environment better after the cleaning than before it.

INDEX TERMS
Cleaning, Ventilation system, Office building, Supply air, Working environment

INTRODUCTION
Most office buildings in Finland have balanced supply and exhaust ventilation system and the material used for ventilation ducts is sheet metal. According to national recommendations, inspection and cleaning of the ventilation system in office buildings is recommended every fifth year (FiSIAQ 2001). Although inspection and cleaning originally concerned the exhaust ducts for fire safety reasons, in recent years cleaning of supply air ducts have became more frequent as the awareness of the connection between ventilation system maintenance and indoor air quality (IAQ) has increased. The most common cleaning technique of air ducts in Finland consists of mechanical loosening the dust with rotating brushes and suction of removed particles from the ductwork to a filtration unit with sufficient air velocity. However, the effects of mechanical duct cleaning on ventilation system hygiene and IAQ are not well known. The aim of this study was to investigate the effect of mechanical duct cleaning on ventilation system hygiene and IAQ in office buildings. The results of the seven first measured offices were presented in Indoor Air ´99 (Luoma et al. 1999) and Healthy Buildings 2000 (Ikäheimo et al. 2000) conferences.

METHODS
Case study buildings
Field measurements were carried out at 15 non-problem office buildings during years 1997-2000. Eight of these buildings located in the central part of Finland and the rest in the southern part of Finland. All study buildings were provided with a mechanical supply and

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exhaust ventilation system and none of these buildings used recirculated air. The efficiency of the supply air filters varied from EU4 to EU8.

Ventilation systems of the 15 office buildings were cleaned for the first time and the reason for the duct cleaning was the national recommendation to inspect and clean the ventilation system at regular intervals. The cleaning included both supply and exhaust ventilation systems. The section of ductwork to be cleaned was first under pressured and then cleaned with rotating brushes. The terminal devices were removed and washed. In most of the buildings, new supply air filters were installed and air flows were balanced after the cleaning.

Study design and field measurements

In each building, two to five rooms were selected to represent IAQ of the whole building. Field measurements were performed few days prior to duct cleaning and at least one month after the cleaning. Air quality parameters were measured in supply, indoor and outdoor air. The average time period between the IAQ measurements before and after the cleaning was 5.4 months. Thus, the measurements were carried out at different seasons.

Particle mass concentrations were measured gravimetrically by collecting samples on 37 mm diameter polycarbonate filters (0.8 µm pore size) using open face filter cassettes. Sampling time was 5-6 hours and flow rate was 20±5 L/min. The filters were stabilized 24 hours in a constant humidity room before the weighing (precision 1 µg). Laboratory and field blanks were used for quality control of sampling. Particle number concentrations of supply air were measured with a portable optical particle counter (Climet-500) in size ranges 0.3-0.5, 0.5-1.0, 1.0-5.0, 5.0-10 and 10-25 µm. Ten successive 1 min samples were collected at the supply air terminal devices in each location. Airborne bioaerosol samples were collected with N6- or 6-stage Andersen samplers for 5 to 10 min using 28.3 L/min flow rate. Fungi were collected to malt extract agar (M2) and dichloran glycerol agar (DG18) and tryptone glucose yeast agar (THG) was used for bacteria. Agar plates were incubated for 7 days for fungi and 5 to14 days for bacteria at 25°C and colony forming units (cfu) were determined. Volatile organic compounds were collected on Tenax absorption tubes using 0.1 L/min flow rate and 60-90 min sampling time. Samples were analyzed with thermodesorption gas chromatograph, equipped with mass selective detector. The TVOC concentration was determined as toluene equivalents from range C_6-C_{16}. CO_2 concentrations were determined with IR-analyzer (Vaisala, Finland) by using 5 min sampling time.

Samples of accumulated dust were taken from the inner duct surfaces using a vacuum pump and pre-weighted filter cassettes (37 mm mixed cellulose ester filter, pore size 0.8µm). Filters were weighted together with cassettes (precision 100 µg). For consistency of the sampling area in ducts with various diameter, dust samples in spiral ducts were collected from an area which was rejected with a specimen between the bottom line and the line on the widest level of duct (Pasanen et al. 1992). Sampling areas used were 100-200 cm^2. The cleanliness of the ducts was inspected also visually before the cleaning and afterwards. In seven buildings, the bioaerosol content of the accumulated dust was detected from the collected dust suspending the weighted dust to dilution water and cultivating on agar plates. In eight buildings, samples for microbial analysis were collected from the inner duct surfaces by sterile swab and cultivated. Agars, incubation time and temperature were similar to air samples of microbes.

Supply and exhaust air flow rates were measured with velocity or pressure difference measurements from the terminal devices in each study rooms. Ventilation rates were determined using the measured exhaust air flow rates and volumes of the room. Temperature and relative humidity were measured from outdoor and indoor air. Temperature of outdoor air ranged from –14 °C to 30 °C before and from –16 °C to 26 °C after the cleaning. The ranges of relative humidity were 18-85% and 25-90 %, correspondingly.

Indoor Climate Questionnaire
A self administrated Indoor Climate Questionnaire (MM-Questionnaire) was delivered to 931 employees few days before the duct cleaning and at least one month after the cleaning process. Employees' background factors, working conditions and workplace related symptoms were asked in the questionnaire. The recall period for the questionnaire was three months before the cleaning and one month after the cleaning.

RESULTS

Thermal environment, ventilation and supply air quality
Means, standard deviations and numbers of observations of thermal environment, ventilation, supply air quality and duct hygiene parameters are listed in Table 1. No statistical analysis is performed for the results of measurements or questionnaire data.

The measured mean indoor air temperatures were, in general, quite high with an average of 22.7°C before cleaning and 22.6°C after cleaning. Indoor air RH was at normal level. The mean air flows per person exceeded 20 L/s per person before and after cleaning. The mean ventilation rate at studied offices was 1.7±0.9 1/h before and 2.3±2.1 1/h after the cleaning.

Mean airborne dust concentration in supply air was below 7 μg/m^3 before and after cleaning and it was lower than concentrations in indoor air (12.0±6.2 μg/m^3 before cleaning, 11.8±6.0 μg/m^3 after cleaning) and outdoor air (18.9±14.2 μg/m^3 before cleaning, 29.8±30.4 μg/m^3 after cleaning). Particle mass concentration in supply air was about 34% of that in the outdoor air before cleaning and about 23% after the cleaning. Number concentration of particles <1μm increased with 88% from levels observed before cleaning. Also, the outdoor air concentration of particles <1μm increased with 144% from levels before cleaning. The average TVOC concentration in supply air before duct cleaning was 71±75 μg/m^3, which was lower than concentrations in indoor air (117±105 μg/m^3) and outdoor air (100±124 μg/m^3). After the cleaning, TVOC concentrations in outdoor air (52±50 μg/m^3) and supply air (52±61μg/m^3) were similar but indoor air concentration was higher (74±71μg/m^3). Average indoor air CO_2 concentrations were higher than corresponding outdoor air concentrations, which were below 350 ppm. Concentrations of viable fungal spores and bacteria in supply air were low in general and average fungal spores and bacteria concentrations measured before and after cleaning were below 60 cfu/m^3. Fungal spores and bacteria concentrations outdoors ranged between 140-320 cfu/m^3.

Duct hygiene
Surface dust levels of supply air ducts ranged from 0.7 to 47.0 g/m^2 before cleaning and from <0.1 to 8.8 g/m^2 after cleaning. Duct cleaning decreased the average surface dust load from 8.4±9.1 to 1.9±2.1 g/m^2 (Table 1). Thus, the reduction of dust load was 77%. At four buildings, the average dust load was after cleaning higher than presented limit value (2.0 g/m^2) for accumulated dust in office building ventilation systems (FiSIAQ 2001). The average microbe concentrations on the inner duct surfaces were lower after the cleaning than before the cleaning. Fungal concentration on M2 agar decreased about 70% and on DG18 agar about 90%.

Table 1. Statistics of thermal environment and ventilation parameters, supply air concentrations, and duct hygiene parameters measured before and after duct cleaning in 15 non-problem office buildings.

Measured parameter	*Unit*	*Before duct cleaning*			*After duct cleaning*		
		Mean	*Stdev*	*n*	*Mean*	*Stdev*	*n*
Air temperature[1]	°C	22.7	1.7	45	22.6	1.3	44
Relative humidity[1]	%	31	15	45	26	14	44
Air flow	L/s person	22.9	13.8	40	27.1	13.2	40
Ventilation rate	1/h	1.7	0.9	40	2.3	1.2	41
Airborne dust	$\mu g/m^3$	6.4	5.7	34	6.8	4.6	30
Dust particles:	1/L						
0.3-0.5 µm		69,800	78,900	14	133,000	146,700	14
0.5-1.0 µm		6,000	6,700	14	9,200	10,000	14
1.0-5.0 µm		500	700	14	700	800	14
5.0-10 µm		41	47	14	70	97	14
10-25 µm		12	17	14	12	18	14
Airborne microbes:	cfu/m^3						
M2		36	61	45	20	23	45
DG18		22	55	44	17	26	43
THG		21	30	44	57	105	44
TVOC	$\mu g/m^3$	71	75	45	52	61	43
CO_2[1]	ppm	504	84	45	475	71	44
Surface dust[2]	g/m^2	8.4	9.1	61	1.9	2.1	51
Microbe load on duct surface:	cfu/cm^2						
M2		7	13	56	2	3	55
DG18		13	58	56	1	2	54
THG		830	3660	52	610	2230	52

[1]Measured from indoor air, [2]Measured from inner duct surface

Questionnaire

The response rate in questionnaire was 63% before and 59% after cleaning. The background factors of the respondents were similar before and after cleaning (Table 2). The number of respondents ever suffered from hayfever or eczema was lower after cleaning. This can be explained by the fact that partly different people answered to the questionnaire before and after cleaning. Prevalence of respondents ever suffered from asthmatic symptoms or eczema was similar compared to other studies (Bluyssen et al. 1996), but the prevalence of hayfever was higher in this study. Complaints concerning draft and too high room temperature were similar before and after cleaning. Instead of this, complaining about stuffy "bad" air, dry air and dust and dirt reduced after cleaning. The highest improvement in these parameters was detected with stuffy air. Prevalence of work related symptoms was also slightly lower after cleaning.

Table 2. Characteristics of respondents, perceived indoor climate and symptoms of 931 employees of 15 office buildings before and after the duct cleaning.

Background factors	*Unit*	*Reference value*[2,3]	*Before duct cleaning*	*After duct cleaning*
Average age	year		44	44
Portion of women	%		56	57
Portion of smokers	%		17	18
Respondents suffered ever from				
Asthmatic symptoms	%	10	10	11
Hayfever	%	25	42	36
Eczema	%	27	29	21
Environmental factors[1]				
Draft	%	4	12	11
Too high room temperature	%	5	9	9
Stuffy ”bad” air	%	10	29	15
Dry air	%	20	23	19
Dust and dirt	%	10	17	14
Workplace related symptoms[1]				
Itching, burning or irritation of the eyes	%	6	15	12
Irritated, stuffy or runny nose	%	9	21	18
Hoarse, dry throat	%	5	13	11

[1]Bothered every week, [2] Andersson 1999, [3]Bluyssen et al. 1996

DISCUSSION

Particle mass, TVOC and CO_2 concentrations of supply air were low and consistent with previous office studies (Bluyssen et al.1996). Also airborne microbe concentrations were low. Number concentration of particles <1µm was higher after cleaning, but this can be explained by the fact that outdoor concentration of particles <1 µm was also higher after the cleaning. Higher concentration after cleaning could be also result of the changing the new supply air filters. New filters are not so efficient than used ones (Ottney 1993). Thus, duct cleaning had no measurable effect on supply air quality. Instead of this, the average amount of dust on the inner surfaces decreased from 8.4±9.1 to 1.9±2.1 g/m^2. Correspondingly, mean microbe load on inner duct surface decreased due to cleaning and this finding was consistent with a previous study (Collet et al. 1999). The improvement of duct cleanliness was also noticed visually.

The average air flows exceeded 20 L/s person before and after cleaning and duct cleaning and rebalancing the ventilation system mainly increased air flows in the investigated rooms. Even though the ventilation rates on average were above 20 L/s person, variation of the air flows were high among the investigated rooms, even inside the same building. Air flows were below 20 L/s person in 50% of the measured rooms before the cleaning. After cleaning and rebalancing the ventilation systems the proportion decreased to 33%.

According to employee’s answers to the questionnaire, nearly all factors concerning the working environment were improved. Also, the prevalence of work related symptoms was slightly reduced after the cleaning. Andersson (1998) has presented the reference values for this questionnaire for non-problem office buildings in the Nordic countries (Table 2). In our study the mean percentage of selected environmental factors and workplace related symptoms were from 2 to 3 times higher than those reference values. The highest difference was detected with stuffy air. A high prevalence of stuffy air complaints before cleaning refers to insufficient ventilation. This contradicts with the measured air flow rates per person which were at levels suggested by Seppänen et al. (1999). One possible explanation could be insufficient air flows in the several rooms not measured in this study.

CONCLUSIONS AND IMPLICATIONS

This study proved that the effects of duct cleaning on IAQ are difficult to measure in non-problem buildings. On the other hand, employees perceived improvement of IAQ and reduced prevalence of work related symptoms. Duct cleaning is important part of ventilation system maintenance, because simultaneously with duct cleaning the possible technical failures can be detected and air flows rebalanced. Thus, if maintenance is neglected, IAQ problems might occur, leading to complaints by personnel and extra costs for building management.

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