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

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ABSTRACT

In this study, the effect of duct cleaning on the indoor air quality and on the ventilation system hygiene in non-problem office buildings was investigated. Six office buildings were selected from local duct cleaning companies' contracts. A questionary was distributed among the occupants prior to and after the duct cleaning. Also several air quality parameters were measured in outdoor air, indoor air, and supply air and ventilation system hygiene measurements were performed prior to and after duct cleaning. Based on the results, the effect of duct cleaning on indoor air quality and ventilation system hygiene was estimated. The indoor air quality and the amount of complaints and symptoms were about the same before and after the duct cleaning, however, dust concentrations on the inner duct surfaces decreased in almost every building.

BACKGROUND

Most office buildings in Finland have balanced supply and exhaust ventilation system and the material used for ventilation ducts is sheet metal. According to regulations, inspection and cleaning of the ventilation systems in office buildings is recommended every tenth year. Although inspection and cleaning originally concerned the exhaust ducts, in recent years cleaning of supply air ducts have increased 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 filtration unit with sufficient air velocity. However, the effects of mechanical duct cleaning on ventilation system hygiene and IAQ are not well known [1]. The aim of this study was to investigate the effect of mechanical duct cleaning on ventilation system hygiene and IAQ in office buildings.

METHODS

Case study buildings

Field measurements were carried out at six non-problem office buildings. Two of them located in Southern Finland (Buildings A and B) and the rest in Central Finland (Table 1). The study buildings were equipped with balanced ventilation systems and recirculated air was used in none of them. Smoking was prohibited in each building. In every building, the main reason for having the ductwork cleaned was to obey the recommendation of regular inspection and cleaning of ventilation systems. Noteworthy, in every building, this was the first time the ductwork was cleaned.

During the study periods, indoor temperature was 23 ±2.1 °C, and the relative humidity was 29 ±16 %RH. Windows were kept closed during the measurements. Other building details are shown in Table 1.

Table 1. Study buildings.

Building	Completed[1]	Number of floors[2]	Supply air filtration[3]	Air exchange rate (1/hr)[4]	Number of rooms studied	Number of employees[5]
A	1982	8	EU8	3.3	2	216
B	1897/1986	4	EU6	1.4	2	90
C	1970/1990	2	EU6	2.0	5	25
D	1980	2	EU6	1.3	5	25
E	1978	5	EU4	4.0	3	30
F	1982	4	EU6	8.0	3	20

1) When the building was completed and/or when a major renovation was completed.
2) Number of floors above ground level.
3) Supply air filtration class before the duct cleaning.
4) Based on measurements in 2-5 rooms. Calculation based on measured exhaust air flows.
5) Number of employees who received the questionnaire.

Study design and sampling methods

In every study building representative rooms (2-5 rooms/building) were selected for IAQ measurements. Field measurements and a questionnaire [2] were conducted a few days before the duct cleaning started. About a month after the duct cleaning was completed, the same field experiments were repeated. The time between the repeated measurements varied between 1.5-7 months depending on the duration of the duct cleaning work.

The measured air quality (AQ) parameters included particle mass concentration, concentration of fungal spores and bacteria, total volatile organic compounds (TVOC) and CO_2 concentration. The AQ parameters were measured both in the air of the selected rooms and in the supply air at the vicinity of the supply air terminal device. The samples were collected in outdoor air under a rainshield at the building roof-top. Sampling was conducted during normal business hours.

Particulate mass concentrations were determined gravimetrically by collecting particles on 37 mm dia, 0.8 µm pore polycarbonate filters using open face filter cassettes at a flow rate of 20 ±5 L/min and an average sampling period of 5.2 ±0.7 hr. Two filter blanks were used. Filters were equilibrated for 24 hr in a constant humidity room (51 ±9.8 % RH, 21 ±1.5 °C) prior to weighing to a precision of 1 µg. Bioaerosol samples were collected in a N6- or six-stage Andersen sampler for 5 or 10 min with flow rate of 28.3 L/min. Fungi were collected on malt extract agar and bacteria were collected on tryptone glucose yeast agar. Both agars were incubated for 7 days at 25 °C. Number concentrations were determined. CO_2 concentrations were determined by using ~5 min sampling time with IR-analyser (Vaisala, Finland). TVOC were collected on Tenax TA, during 60-90 min sampling time with a flow rate of 0.1 L/min. TVOC were quantified in toluene equivalent with gas chromatography equipped with thermal desorption injector. Components in the boiling point range from 60 to 300°C were detected (C_6-C_{16}).

Dust samples from the duct surfaces were collected from the inner duct surfaces using a vacuum pump and a pre-weighted filter cassette. Mixed cellulose ester filters (37 mm, pore size 0.8 μm) were used and weighed together with filter cassettes with a balance to a precision of 100 μg. For standardisation of the sampling area to ducts with various diameters, the dust samples in spherical ducts were collected from an area which was rejected with a specimen between the bottom line and the line on the widest level of the duct [3]. The length of the sampling area depended upon the limited space or on the amount of dust. The sampling areas varied from 100 to 320 cm^2. Adjacent areas were used for collecting samples prior to and after duct cleaning. In addition, inner surfaces of ventilation ducts were examined with naked eye. After sampling, the filter cassettes were first weighed and then for determination of concentrations of viable fungal spores and bacteria the dust sample was suspended in dilution water and cultivated on agar plates. Surface density of fungal spores and bacteria (cfu/cm^2) were calculated.

Supply and exhaust air flow rates were determined in the terminal devices with velocity measurements or with pressure difference measurements. The measurements were done before and after the cleaning action.

Duct cleaning in study buildings was performed by four different duct cleaning companies, but all of them used a similar technique. The technique included following steps: (1) to underpressure the ducts, (2) to use rotating nylon brushes to loosen and disperse the debris, and (3) to remove the dirt to a collection point with a sufficient velocity of air. Fans, heat exchangers, and terminal devices were vacuum cleaned and washed with water and detergent, if possible. After duct cleaning, measurement and adjustment of air flow rates was done at all study buildings except for Buildings A and F.

Questionnaire

A standard indoor climate questionnaire [2] was delivered to occupants a few days prior to the duct cleaning and at least a month after the duct cleaning was finished. The questionnaire asked about the employees' background factors, work environment, work conditions, and present symptoms. The questionnaire was delivered into the occupants' mail boxes and they were asked to return it to a certain maintenance person by internal mail.

RESULTS

Indoor air quality

Levels of particulate mass, TVOC and CO_2 (shown in Table 2) were low or comparable to concentrations reported in other studies [4].

Particulate mass and CO_2 concentrations were similar before and after the cleaning (Table 2). In two buildings (Buildings A and D), TVOC concentration was higher after than before the duct cleaning. At Building A, this was probably due to the beginning of using recirculation after the duct cleaning. Recirculated air may have distributed VOC emissions from other parts of the building, e.g., by wet floor cleaning, to the studied rooms. In rest of the buildings, the TVOC concentrations were lower after duct cleaning than before duct cleaning.

Table 2. Indoor air quality measured before and after duct cleaning. Results are averaged over rooms studied in each building (see Table 1 for details).

Building	Mass conc. ($\mu g/m^3$)		TVOC conc. ($\mu g/m^3$)		CO_2 conc. (ppm)	
	Before	After	Before	After	Before	After
A	8.0	7.7	105	265	505	510
B	10.9	10.7	115	70	515	500
C	NA	NA	48	18	NA	450
D	NA	NA	39	64	480	490
E	24.0	20.3	67	59	490	440
F	9.2	2.7	87	25	590	563
Indoors,	n=18		n=30		n=34	
average ± SD	13 ±8.3		74 ±67		499 ±74	
range	1.7 - 31		15 - 290		350-690	
Outdoors	n=10		n=12		n=11	
average± SD	66 ±89		38 ±31		357 ±29	
range	3 - 298		4 - 100		330-410	

NA Not available.

Fungal spore concentrations outdoors averaged 112 ±147 cfu/m^3 (<3-525 cfu/m^3, n=12), and concentrations in supply air were always lower (average 31 ±60 cfu/m^3, <3-337 cfu/m^3, n=40). The highest supply air concentration (122 cfu/m^3) was obtained at Building C where open windows influenced on the result during a warm summer day. *Cladosporium* sp, a common outdoor air fungus, was dominantly present in the samples.

Duct hygiene

Visual inspection of the ducts showed no signs of water or microbial contamination and the effect of duct cleaning could be clearly seen; amount of deposited dust was visibly low after the cleaning. The amount of dust averaged 6.5 ±10.8 g/m^2 (0.7-47 g/m^2, n=17) before the duct cleaning and the level decreased to 2.1 ±2.7 g/m^2 (0.2-8.8 g/m^2, n=17) due to duct cleaning. On the contrary, surface dust concentration at Buildings C and D increased (Table 3) but visually the ducts seemed to have been cleaned. Pieces of concrete were found in the samples taken after cleaning, which were probably dispersed from other locations by the rotating brushes and the air velocity has not been sufficient to remove these dense particles. The lowest levels of deposited dust after the duct cleaning were 0.2-0.5 g/m^2.

At two sampling points (Building B) the visual inspection showed that the inner duct surfaces were untouched after duct cleaning. The results (Table 3) confirmed the finding. Interviewing the duct cleaning company revealed that the cleaning had been done at selected portions of the ductwork. The contract with the building owner and the cleaning company stated that cleaning will be done at locations where it is necessary.

The concentrations of fungal spores and bacteria on the inner duct surfaces averaged 4.7 ±7.0 cfu/cm^2 (0-18 cfu/cm^2, n=22) and 1.1 ±1.0 cfu/cm^2 (0.2-2.0 cfu/cm^2, n=22) before the cleaning and 2.1 ±4.7 cfu/cm^2 (0.1-18 cfu/cm^2, n=22) and 2.5 ±4.5 cfu/cm^2 (0.1-17 cfu/cm^2, n=22) after the cleaning, respectively. Detailed results are shown in Table 4.

Table 3. Surface dust concentration in ducts before and after duct cleaning.

Building	Surface dust concentration (g/m^2)									
	Site 1		Site 2		Site 3		Site 4		Site 5	
	Before	After	Before	After	Before	After	Before	After	Before	After
A	2.1	0.5	5.6	0.3	7.0	0.3	2.3	0.4	-	-
B	4.6	4.4	8.8	7.2	-		-		-	-
C	4.1	8.8	1.9	0.4	47	0.3	0.7	4.6	-	-
D	2.7	0.5	1.1	0.2	3.5	0.4	1.0	0.4	1.5	4.6
E	8.9	1.3	7.1	1.3	-	-	-		-	-

Table 4. Average (± SD) concentrations of fungi and bacteria in dust collected from ventilation ducts before and after duct cleaning.

Building	Fungal concentration		Bacterial concentration		No. of sampling sites
	Before (cfu/cm^2)	After (cfu/cm^2)	Before (cfu/cm^2)	After (cfu/cm^2)	
A	0.8 ±0.5	0.3 ±0.5	0.3 ±0.0	0.2 ±0.1	8
B	16.5 ±2.1	9.5 ±12.0	1.5 ±0.7	1.2 ±1.1	4
C	0.9 ±1.3	1.5 ±0.9	1.5 ±0.8	0.5 ±0.7	6
D	10.1 ±9.8	0.3 ±0.2	1.5 ±1.7	0.1 ±0.0	10
E	0.3 ±0.3	0.5 ±0.5	0.5 ±0.1	5.4 ±7.4	6
F	2.5 ±2.9	3.5 ±6.2	1.3 ±0.7	6.5 ±5.8	10

Questionnaire

The groups of respondents answering to the questionnaires before and after cleaning were otherwise similar, but the portion of smokers was higher (18%) after cleaning than before cleaning (11%, Table 5). The amount of complaints concerning the work environment was low or normal (<25% being bothered by work environmental factors every week, Table 5) both before and after duct cleaning. The amount of symptoms related to work was low or normal (<18% of respondents suffering often or sometimes, Table 5) and a slight decrease was noticed in the symptom related to nasal problems (irritated, stuffy or runny nose).

DISCUSSION

Mass concentrations of particles, TVOC, fungi, and CO_2 in indoor air were low or normal before and after duct cleaning. Thus, duct cleaning could not have a measurable lowering effect on these concentrations; duct cleaning did not deteriorate the air quality either. The amount of complaints and symptoms reported by the building occupants was low or normal both before and after the duct cleaning, which is supported by prior expectation that these buildings were not so called complaint buildings. Surface concentrations of dust decreased from 6.5 to 2.1 g/m^2 and as low as 0.2-0-5 g/m^2 surface dust concentrations were obtained with careful mechanical cleaning of the duct surfaces. It is important to complement measured surface concentrations with visual inspection of the duct surfaces, since rotating brushes may remove dirt from one place to an other in the duct work. This study showed that duct cleaning in non-problem office buildings did not have a measurable effect on indoor air quality and that the visual inspection and quantitative analysis of dirt in the ductwork are the most important factors with which the effects of duct cleaning can be evaluated. Since this study is on-going,

the data will be complemented with additional 8-10 office buildings, some of which are known to have indoor air quality problems.

Table 5. Work environment questionnaire. Totally 406 questionnaires were delivered in 6 office buildings before and after duct cleaning.

Characteristics of the respondents		Before cleaning	After cleaning
Response rate	%	55	53
Average age	yr.	44	43
Portion of women	%	44	46
Portion of smokers	%	11	18
Respondents suffering from			
Asthmatic problems	%	9	10
Hayfever	%	37	35
Eczema	%	24	20
Bothering environmental factors			
Draught	%	8	3
Room temperature too high	%	7	16
Stuffy "bad" air	%	17	17
Dry air	%	23	16
Dust and dirt	%	19	18
Workplace related symptoms			
Itching, burning or irritation of the eyes	%	12	12
Irritated, stuffy or runny nose	%	18	14
Hoarse, dry throat	%	12	11

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