The verifying concept for the cleanliness of HVAC systems

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ABSTRACT

The visual evaluation method has been created for a primary method to verify cleanliness of HVAC system. The results of two simple measuring methods for thickness of dust and debris were compared to accumulation values measured by vacuum sampling method. The thickness of dust layer and the dust accumulation results correlated when the dust was homogeneous but the correlation was poor if the quality of the dust varied. Both the field and laboratory studies showed that a commercial contact method gave lower microbial counts than the swab method with cultivation. However, the contact method is useful method for the microbial control because it is very simple and easy to use. Two tape sampling methods to quantify mineral fibre counts on HVAC surfaces were tested. The gelatine tape is suitable for quantitative analyses with light microscope and the carbon tape is suitable for use with the scanning electron microscope.

INDEX TERMS

Ventilation system; Kitchen exhaust; Surfaces; Cleanliness; Measurement technique

INTRODUCTION

HVAC systems should be cleaned at regular intervals, especially if the systems contain combustible material such as grease or organic dust of clothes. For example, the British guideline (HVCA, 1998) prescribes that the cleaning intervals of the kitchen extracts should be 3–12 months depending on usage level (2–16 h/day) of the kitchen and in Finland the cleaning interval is stated to be 1 year for these kinds of accumulations.

The national orders and guidelines for duct cleaning differ from each other. For example, the interval of the control and cleaning, the control methods and trigger values to clean are different. For example, in Sweden, cleaning is required when the amount of accumulated dust exceeds 1 g/m^2 (The Swedish National Board of Housing, Building and Planning, 1992). In Britain, the trigger value for cleaning is 1 g/m^2 (60 µm) for supply ducts and 6 g/m^2 (180 µm) for extract ducts (HVCA, 1998). In the USA, the national association have set a value of 0.1 g/m² for evaluation of the cleaning work (NADCA, 1992) and thus these are not comparable to one another. The measuring methods are based on vacuum sampling in all the mentioned guidelines, but the method is applied in a different manner, which makes the comparison of the results difficult (Fitzner *et al.*, 2000).

Aims of this study were to develop a verifying concept for the HVAC systems. The selected evaluation, sampling and measuring methods will be applied to a robot with a video camera. The final product will contain the measuring equipments for evaluation of cleanliness to reach all sections of the HVAC systems via a few cleaning hatches.

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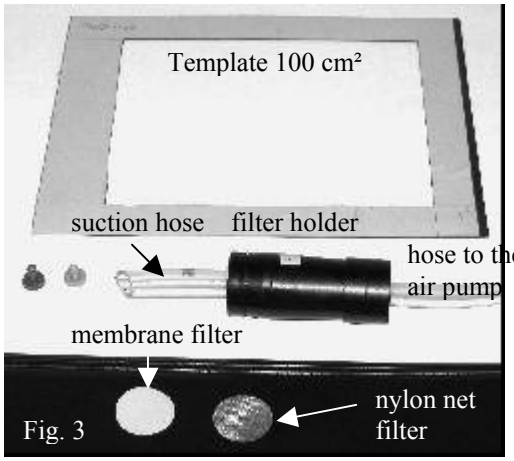
DESCRIPTION OF THE METHODS

The Visual Evaluation Method for Cleanliness of HVAC ducts

The visual evaluation method with a visual scale has been designed for use as a primary method to evaluate the cleanliness of HVAC system (Holopainen *et al.*, 2002b). The visual evaluation is aided by a robot with a video camera, which allows the evaluation of the cleanliness of the whole ductwork. The scale consists of six photographs, which display six dust accumulation levels from cleaned duct to over 10 g/m^2. The amount of dust was measured with the vacuum test method with a template of 100 cm^2 (Pasanen *et al.*, 1992).

The Measurement Methods for Dust Contaminations on HVAC Ducts

A simple measuring method for thickness of dust and other dirt layers was developed. In the comb method, the measuring comb (Figure 1) is set down to the surface so that the comb's outermost longest teeth are in close contact with the surface. When measuring, the comb is pressed or drawn a short distance on the contaminated surface, the shorter measuring teeth in the middle of the comb touch the contamination, if the dust layer reaches to the teeth. The comb method was tested in a laboratory against the Finnish vacuum test method (FiSIAQ, 2001).



Figures 1–3 Measurement of the thickness of the contamination layer (µm) with the comb method (Figure 1); with the deposit thickness test (DTT) device (Figure 2) and measurement of the dust accumulation (g/m²) with the vacuum test method (Figure 3).

The British guideline for good practice of the cleanliness of ventilation systems (HVCA, 1998) recommends the deposit thickness test (DTT) (Figure 2) with a device based on the electromagnetic induction. The procedure is started with an initial measuring series of 20 readings in a template on dusty surface after which the surface is carefully cleaned. In the second phase, the template is set precisely at the same place and the second set of the readings is taken. The difference of the averages before and after the cleaning is considered as the thickness value. The device is easy to calibrate with a film of known thickness. The sensor of the DTT is designed for plane surfaces.

The DTT device and the Finnish filter sampling methods were compared in the laboratory. The theoretical detection limit for the DTT-device was also calculated based on the standard deviation of the zero-samples. The zero-samples were sampled from the clean galvanized sheet metal similar to that used for the manufacture of air ducts. The sampling was repeated two times at exactly the same position of the template. The standard deviation of the remainder of the repeated 20 samples was calculated and the detection limit (6× standard deviation) was determined. Test was repeated seven times and total number of the sampling points was 140.

The Finnish classification of indoor climate, construction and building materials (FiSIAQ, 2001) recommends the vacuum test method (Pasanen *et al.*, 1992) as the measurement technique for the cleanliness on the HVAC ducts. The sampling device of the vacuum test method (Figure 3) consists of a pre-weighted membrane and nylon net filters inside of the filter holder and a suction hose (PVC), and an air pump and template of 100 cm^2. The air flow of the pump is 10 dm^3/min. Before and after the sampling, the filters, filter holders and the suction hoses are stored in a desiccator for a minimum of 3 days. After this, they are weighed together. In the round ducts, the samples are collected from one of the lower quarters of the duct, which is rejected to the lowest and broadest lines of the duct. All the samples are taken carefully from the duct surface by moving the suction hose crosswise over the area rejected by the template.

The Measurement Methods for Grease Contaminations on Kitchen Exhausts

The results obtained with the comb method, the DTT device described in previous paragraphs and the modified Finnish vacuum test method were compared in the field study. The modified vacuum test sampling was made in two phases. In the first phase, the unfastened deposition was sampled as described in the previous paragraph. In the second phase, the fastened deposition was first loosened with a metal splint and after scraping the deposition was sampled as previously described. In both phases, the sample weights were obtained from the difference of the total weight of the filter holder, membrane filter and the suction hose before and after sampling.

The Measurement Methods for Microbial Contamination on HVAC ducts

The microbe concentrations measured with the contact method (Salo *et al.*, 2000) and the swapping method (Meklin *et al.*, 1996) were compared in the laboratory and on the field. In the laboratory studies, the metal sheets were contaminated with dust, which was collected from the HVAC filters and contaminated with *Aspergillus versicolor* spores. The contaminated dust was spread onto the metal sheets by an aerosol generator (Weyel *et al.*, 1984). In the field study, 21 sampling points were selected from the ductwork. TPC and Y&F plates were used for sampling the total cultivable microbial count (bacteria, yeasts and fungi) and yeasts and fungi, respectively. In the laboratory, the 2% malt extract agar (M2) and trypton–yeast–glucose (TYG) agar were used for growth medium of the swab samples. In the field study, the Hagem and dichloran-glycerol (DG18) agars were used instead of M2 for fungi and yeasts and TYG-agar plates were used for bacteria. In both laboratory and field studies, the samples with contact and swab methods were sampled simultaneously.

The Measurement Methods for Fibres on HVAC ducts

Two tape sampling methods for the measurement of mineral fibre contamination on ventilation ductworks were studied. The samples were collected on gelatine (Schneider *et al.*, 1990) and carbon tapes from the duct surfaces. The samples on gelatine tape were analysed with light microscopy (magnification 200×, number of analysed areas was 200, total area 1.14 cm^2 and detection limit 1 fibre/cm^2). These measurements were qualified with a scanning electron microscope (SEM). The carbon tape samples were sampled from another building's surfaces and the samples were analysed with SEM.

RESULTS AND DISCUSSION

The Visual Evaluation Method

The visual inspection scale was developed to support the subjective evaluation of inspectors, constructors and building owners. The results of the study (Holopainen *et al.*, 2002a) showed that the experienced visual inspectors could even estimate the amount of dust in relatively

clean air ducts. However, dust adhered more firmly on older duct surfaces than on newly installed ones and this makes the evaluation process more difficult. It may be recommended that the inspector wipe the surface with a finger or a comb to help the evaluation process.

The Measurement Methods for Dust Contamination

The laboratory studies showed that thickness of dust layer (μm) measured with the comb technique did not correlate with the amount of dust (g/m²) measured with the Finnish vacuum test method. It was concluded that high variation of the density of accumulated dust was the main reason for the lack of correlation. Additionally, when the accumulated dust was fresh, the density of dust was lower than when it was accumulated earlier. However, the dust accumulation results measured with the comb and vacuum test methods correlated (R^2 = 0.5–0.9 and $P_{T\text{-test}}$=5 × 10^{-4}–5 × 10^{-9}), when the dust layer was homogeneous.

The average of the determined detection limit for the DTT device was 38 μm and detection limit varied between 14 and 63 μm. The detection limit using this method is as high as the British guideline for the dust accumulation in supply air ducts, which is 60 μm. In two laboratory studies, the amounts of the dust accumulation were 1.6 and 0.8 g/m^2. The mean thickness of the dust layers measured with the DTT device was 10.7 and 10.4 μm. In both laboratory studies, the thickness of dust layer was below the detection limit of the DTT device and so a comparison of the methods is difficult. The results showed that the measured dust accumulations are below of the detection limit of the DTT device. The DTT device is therefore an unreliable method for estimating the typical dust accumulation in supply air ducts.

The Measurement Methods for Contaminations of Kitchen Exhaust Ducts

The Finnish vacuum test method (Pasanen *et al.*, 1992), where the plastic suction hose is used, was not effective enough for cleanliness evaluation of kitchen exhaust ducts (Table 1). The sampling efficiency of the method was low (mean 24% and range 13–31%). With the vacuum test method, where the fastened deposition was first loosened with a metal splint from the surface, the duct looked clean after the sampling. The vacuum test with scraping gave reliable and exact value for dirtiness, but it is a laborious and painstakingly slow method.

The comb method is an easier and a faster method than the vacuum method with scraping. In the field tests, the comb and the scraping methods gave the same kinds of results (N = 10; R^2 = 0.84; $P_{T\text{-test}}$ = 4 × 10^{-5}). However, it was noticed in this study that the properties of contaminant layer has an effect on the measurement results.

The DTT device is also easy to use and by this method results can be obtained fast. The DTT method is not as fast and easy as the comb method, because the test surface should be cleaned before the reference measurement. In the field tests, the DTT and the scraping methods gave similar results (N = 7; R^2 = 0.91; $P_{T\text{-test}}$ = 8 × 10^{-2}). The detection limit (58 μm) of the DTT method is also not a problem, because in the British guideline the contamination layer for exhaust duct is 180 μm (HVCA, 1998). The DTT method can be used only for flat surfaces and thus it is not useful for measurements on round spiral seam ducts.

Table 1 The dirtiness of the kitchen exhaust ducts measured with three measuring methods

Sampling method	Vacuum test method with scraping			
Sampling point	Dirtiness (g/m²) before cleaning	Dirtiness (g/m²) after cleaning	Effectiveness of the cleaning (%)	
1	142	75	47 %	
2	Not measured	225	Not measured	
3	Not measured	224	Not measured	
4	34	15	54 %	
5	Not measured	29	Not measured	
6	105	16	85 %	
7	73	16	78 %	
8	Not measured	24	Not measured	
Average	88	78	66 %	
Sampling method	Comb method			DTT-device*
Sampling point	Dirtiness (µm) before cleaning	Dirtiness (µm) after cleaning	Effectiveness of the cleaning (%)	Dirtiness (µm) after cleaning
1	175-400 (mean=288)	125-250 (mean=188)	35 %	148
2	Not measured	125-175 (mean=150)	Not measured	421
3	Not measured	Not measured	Not measured	Not measured
4	75-125 (mean=100)	75-125 (mean=100)	0 %	117
5	Not measured	50-125 (mean=88)	Not measured	-3
6	125-175 (mean=150)	50-75 (mean=63)	58 %	64
7	125	50-100 (mean=75)	40 %	23
8	Not measured	50-150 (mean=100)	Not measured	43
Average	125	85	33 %	116

*The deposit thickness test (DTT) device based to the electromagnetic induction (HVCA, 1998).

The Measurement Methods for Microbial Contamination on HVAC ducts

The laboratory and field studies showed that the microbial concentrations measured with the contact method were lower than those with the swab method. The ratios of the mean concentrations measured with contact and swab methods were 52% (total fungi), 53% (yeast) and 22% (yeast + bacteria). In the laboratory study, the contact method gave 35% of *Aspergillus versicolor*, 51% of total fungi and 27% of yeast concentrations compared to the swab method. The detection limits of the contact method (sampling area 9.6 cm^2) were 1 CFU/cm^2—5.2–10.4 CFU/cm^2. The swab method has no upper detection limit because the sample can be diluted. However, the low upper detection limit of the contact method is not a problem for the measurement of the microbial contamination level on HVAC ductworks, because the typical microbial levels in the HVAC ducts are low in properly maintained systems (Laatikainen *et al.*, 1991).

The Measurement Methods for Fibres on HVAC ducts

The fibres sampled by the gelatine tape could not be analysed with SEM because the gelatine partly evaporated during the SEM analysis. However, the gelatine tape is suitable for light microscopic analyses and it allows counting the fibres on the surface. The mean fibre concentration of the studied HVAC system was 112 fibres/cm² (variation 11–1490 fibres/cm²). The measured fibre concentrations were considerably higher than typical fibre concentration on the other surfaces in the buildings (Schneider *et al.*, 1990). The carbon tape was suitable for SEM analyses and the method allowed the analysis of the chemical composition of fibres.

IMPLICATIONS

Based on this study, a remote-controlled video camera robot for the inspection and cleaning of HVAC ducts has been developed. The visual evaluation with the video camera is a primary method and visualization can be aided with the comb method. If the cleanliness cannot not be evaluated clearly enough with the visual inspection, the contamination level can be measured

with the vacuum test method or with the DTT device. The microbial contamination will be measured with the contact method and the fibre contamination with the tape sampling method.

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