Verification Of Cleanliness Of HVAC-Systems

by Pertti Pasanen

University of Kuopio, Department of Environmental Sciences, Kuopio, Finland

ABSTRACT

Inner surfaces of the supply air delivery system are part of the indoor surfaces. This and technical performance make it important that cleaning of a HVAC system should be included in a proper maintenance program. Research work and cleaning actions have been done in many countries, however, the methods to verify the cleanliness varies and they seem to measure unequally the cleanliness. Filter sampling method is the most used method for determination of dust and debris amount on the surface. However, the dust loosening techniques differ in the methods and the results from different studies are not well comparable to each other. Dust tape and gel tape methods are applied more recently and they seems to be suitable quick tests for surfaces which are not heavily contaminated with dust layer like surfaces in recently built systems. Oil residues are also a group of contaminants that decreases indoor air quality of ventilated spaces and a method to verify this contamination is also discussed in this paper.

INTRODUCTION

In recent years, poor indoor air quality has more frequently been claimed to cause health problems for building occupants. Performance of ventilation systems turn usually as a topic of conversations when indoor air quality is discussed, although in most of the cases causality between the well-being and performance of ventilation system could not be verified. However, in some epidemiological studies, the prevalence of symptoms has been higher in buildings with mechanical ventilation systems than that in buildings with natural ventilation (Finnegan et al. 1984, Skov and Valbjorn 1987, Robertson 1988). The more technical the ventilation system is the more symptoms seems to occur. The proper performance of the more technical systems with cooling devices and humidifiers demands more care and skills from the maintenance personnel. Dust, micro-organisms, construction residues, and other contaminants may change the clean air delivery into a source of fungal spores (Morey and Williams 1991), odors (Fanger et al. 1988, Pejtersen et al. 1989), or volatile organic compounds (Molhave and Thorsen 1991, Sundell et al. 1993). Among health and hygienic problems the dirty ventilation system may lead to increased energy consumption, increased cleaning costs, elevated risk of corrosion and cause a clog and malfunction of fire damper (Loyd 1992).

Public discussion of the hygiene of HVAC systems has led to demand of regular cleaning of HVAC systems in office buildings. Because of the costs, the owner or landlord of the building usually has opposite opinion of the need of cleaning action. To solve this controversy opinion, a proper and valid methods are needed to measure quantitatively the cleanliness of the surfaces in HVAC system. Definition of the cleanliness may include several parameters such as the amount of deposited dust, counts of fungal spores or bacteria, and also amount of the oil residues from manufacture of the components. The methods to quantify these parameters are discussed in this paper.

DEPOSITED DUST IN HVAC SYSTEMS

The dust and debris in HVAC system may be deposited from various sources depending on the life cycle of the system. Dirt from building construction time including the intrinsic debris from manufacture and transportation of the components is the main origin in a recently built system. In older systems the deposited dust comes more important and deposition rate is strongly affected by efficiency of supply air filters and local air pollution around the building environment.

The mass of deposited dust and debris is generally more important than the number of particles in determining the cleanliness of air ducts. Deposition of particles on the inner surfaces of the HVAC system is affected by several mechanisms whose importance depends on the size of particle, dimensions of the systems and air flow characteristics within the HVAC system. Brownian and turbulent diffusion and gravitational settling are the main mechanisms for particle deposition in straight air ducts, while inertial impaction is important in bends. Brownian diffusion is a strong deposition mechanism in the wall adjacent to the duct wall for submicron-sized particles (Wallin 1994). At air flow velocities less than 6 m/s, gravitational settling is an important mechanism for larger particles (D_p >2 μm) which produces a particle layer on the bottom of the duct. At greater velocities, turbulent diffusion (lower micron sizes) increases and the deposition site is less dependent on the orientation of the duct surface. Inertial impaction causes larger particles to set le on the surfaces in bends of the duct.

Evaluation methods

Dust accumulation has been studied in air ducts of public buildings in the Nordic countries (Nielsen et al. 1990, Laatikainen et al. 1991, Fransson et al. 1995, Fransson 1996, Lahtivuori 1996), Canada (Auger 1994) and Japan (Ito et al. 1996). Different methods have been developed for determining the amount of accumulated dust on duct surfaces. Dust levels obtained in different studies are presented in Table 1.

The **filter sampling method** is based on weighing of dust vacuumed on a filter from a known area. The filter may be weighed alone without filter holding cassette or the cassette and filter can be weighed together. In the latter method, the dust fastened on the walls of the cassette is easily counted to the sample. In Figure 1 this method is used as a reference. In some studies the dust is loosened from the surface by scraping with a metal blade (Nielsen et al. 1990) which may take also some metallic zinc particles from rough surfaces (Franson et. al. 1995). Although soft plastic scapers are not so effective to loose the tightly fastened dust they are recommended because they leave the metal surface untouched (Pasanen 1998). The dust can also be loosened by suction which takes effectively the loose particles to the sample (NADCA, 1992), thus, the result describes more the amount of potential particles that can be driven to air stream than the total dust deposition if the dust is tightly fastened on the surface.

Sampling site and size of the area is selected and determined variously in different studies. The standard method by NADCA determines a constant 100 cm^2 area with a specimen and the thickness of the specimen determines the suction distance from the surface. In most studies the sample is collected from the bottom of the duct which is well argued especially in rectangular ducts because most of the accumulation occurs to the bottom surface of the duct. In circular air ducts, the definition of the bottom is not so clear, and therefore, the diameter of the duct affects the broadness of the accumulation area. In Finnish studies (Pasanen et al. 1992, Lahtivuori 1996, Pasanen 1998), the sample area is determined so that a quarter sector from lowest to widest line of the duct is chosen as the boundary lines of the sample area. This means that different sizes of specimen are needed for different duct diameters.

A sticky tape is also used to collect deposited dust particles from the surface (Fransson et al. 1995). The tape is weighed before and after collection of the dust and the difference of the mass is used in calculation of the dust density on the surface. The shape and dimensions of the tape restricts the sampling area constant. The method is rapid if the balance is used in the field. According to preliminary studies with different tapes the moisture and hygroscopicity of the tape material affects the reliability of the method. The collection capacity of tape on surfaces with dusty surfaces rejects also the usefulness of the method. Tests on the surface with recently deposited dust revealed that the recovery is good from surfaces with dust accumulation level less than 5 g/m^2 (Figure 1).

Cloth wiping method is also used to collect dust from a certain area and the recovery the method is good (Ito et al. 1996).

A gel tape method (Schneider et al. 1996) is developed for verification of the cleanliness of indoor surfaces. The sample is collected on a transparent tape which contains gelatin gel as a glue. The transparency of the tape is measured with a special analyser, BM Dust Detector, before and after the sampling. The analyser gives a percentage value (%) which is related to the density of dust particles on the gel surface. The method is well described and verified in article by Schneider et al. (1996).

Comparison of the methods

According to the preliminary comparison of dust accumulation methods (Fransson et al. 1995), Table 1, the dust loosening and collection efficiency of the methods varied in a wide range. The collection recoveries (efficiencies) have been determined only for cloth wiping and NADCA standard methods. For the cloth wiping method, average recoveries of dust varied from 87% to 95% (Ito et al. 1996). The recoveries of the NADCA method tested using t pical surfaces present on HVAC systems was 70% on galvanised sheet metal, 40% on duct liner, and 16% on fibre board surfaces (Anon 1995). These recoveries are based on a few laboratory studies.

The performance of dust collection of gel tape, dust tape and filter methods were compared at laboratory in dust density range of 0.3-15 g/m^2. The test surfaces were prepared in controlled conditions. The dust particles collected from supply air filters were aerosolised and spread to the sheet metal surfaces in a exposure chamber. The sample sites were randomised. The study showed that the methods based on weighing of the sample gave equal results in the range 0.3-4 g/m^2. Above the range the dust tape did not have capacity enough the take all the dust from the surface. The result of the gel tape method showed that the method gives quite linear relationships between the dust density if the dust density do not exceed 4 g/m^2. The results are shown in the Figure 1.

Table 1. Summary of studies dealing with dust accumulation in air supply ducts.

Type of building	n	Age (years)	Surface density of dust mean	Surface density of dust range	Annual deposition rate	Sampling method	Relative efficiency of the method [a]	Reference
			g/m²	g/m²	g/m²a		%	
school, office	13	3-29	6.8	1.1-50.9	0.7	filter, metal blade	100 [b]	Nielsen et al. 1990
school, office	6	5-11	18.2	3.6-140	2.3	filter, plastic blade	not tested	Laatikainen et al. 1991
dwelling	33	0-45	0.2	≤2.7	≤0.1	NADCA method	<1 [c]	Auger 1994
office	14	3-34	13.2	1.2-158	1.0	filter, plastic blade	not tested	Pasanen 1994
dwelling	24	2-16	n.a. [d]	0.2-3.9	n.a.	duct cleaning	not tested	Kalliokoski et al. 1995
not reported	4	19-37	2.6	1.9-3	0.2-0.3	tape	38	Fransson et al. 1995
school, office	21	5-26	12.2	0.9-94	1.1	filter, plastic blade	not tested	Lahtivuori 1996
not reported	4	22-32	7.5	n.a.	n.a.	cloth wiping	48	Ito et al. 1996

[a] Fransson et al 1995
[b] Reference method, value 100%
[c] Relative effectiveness was very low
[d] The surface density is calculated on the basis of the whole duct area
n.a. Not available

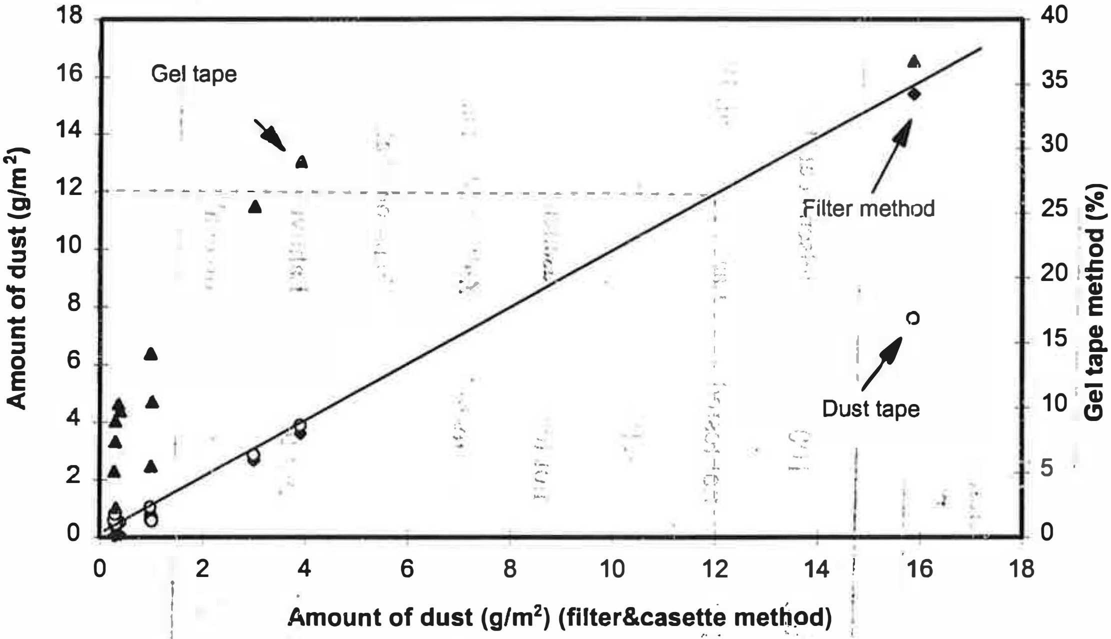

Figure 1. Dust densities measured with different weighing methods. Gel tape method gives the results as percentage relative to dust coverage of the surface. The filter method in which filter and cassette are weighed together is used as a reference method.

MICROBIAL CONTAMINATION

Micro-organisms are ubiquitous and will grow wherever environmental circumstances are suitable. HVAC systems with relatively high air humidity, accumulated moisture, adequate substrates, such as dust or decayed insulation with organic debris, and suitable temperature provide a favourable environment for microbial growth. Case reports and studies have shown that microbial contamination by fungi and bacteria is common in water reservoirs, e.g., cooling towers, humidifiers (e.g. Ager and Tickner 1983), drain pans, traps and sumps (Morey and Williams 1991, Iida et al. 1996), cooling coils (e.g. Byrd 1996), heat exchangers, and thermal or acoustic insulation (e.g. Bernstein et al. 1983, Morey and Williams 1991, Morey 1992, Foarde et al. 1996).

Fungal growth on new and used insulation and duct materials has been tested in the laboratory (Table 2). According to these tests, high RH (97%) alone does not usually support the growth of *Penicillium chrysogenum*, a common fungus found in air conditioning systems (Foarde et al. 1996b). When materials were wetted, slight fungal growth appeared in some materials within six weeks, indicating that new and clean insulation material may also contain sufficient nutrients for fungal growth. However, the composition of resins and other agents prevented fungal growth on some MMVF materials (Chang et al. 1996, Foarde et al. 1996a-b). Furthermore, no growth occurred on unused materials at lower RHs (Foarde et al. 1996b).

Contamination of materials with debris or dust offers nutrients for fungi and may permit growth at lower humidities (Table 2). On porous materials, soiling levels of 5-10 g/m^2 hastened fungal growth at 97% (Chang et al. 1996) but not on galvanised steel surfaces.

However, much higher soiling (90-180 g/m^2) on the galvanised steel surface supported fungal growth at 90-97% RH (Chang et al. 1996). With high soiling levels (100-200 g/m^2) on unused insulation materials, significant microbial growth was detected at an RH range of 90-94% within a week, and at 85% RH after five weeks. In addition, accumulated dust and debris on used insulation, fibreglass duct board, and fibreglass duct liner supported fungal growth at 97% RH. A decrease in temperature decreased the growth rate. However, in six weeks the amplification of spores may achieve the same level at 23 and 12°C (Foarde et al. 1996b). The researchers concluded that conditions favourable to fungal growth in HVAC systems are common, and that moisture control is the most important preventive action (Chang et al. 1996, Foarde et al. 1996a-b).

Amount of microbial contamination is usually determined with **cultivation methods** which also enables the identification of the genera of micro-organisms. The determination of the fungal spore and bacteria counts can be done from the dust sample collected as described previously. The only restriction is that the mass of sample must be high enough, at least 100 mg, for reliable determination. In the method the sample is mixed and shaken up in a known volume of dilution water from which it is plated on suitable nutrient agar for bacteria and fungi. **Direct counting** of spores or microbial cells with aid of microscopy is usually impossible because of the high density of dust particle with various light reflectance properties in the samples. Cultivation method is also used for water samples from humidifiers or other water reservoirs. The insulation and other soft material samples are able to treat as dust samples.

The surface sample can be collected also by **swiping method,** in which a known area is swiped crosswise with a cotton wool stick wetted in sterile dilution water. The sample is cultivated as the dust sample. Both the methods gives results in colony forming units per square meter (CFU/m^2) if the dust sample is collected from a known area. Whatever the method is used for microbial analysis, attention should be paid for prevention of contamination of the samples during sampling and during treatment of the sampling instruments. Especially bacteria may be originated from the person who takes the samples.

Table 2. Fungal growth on HVAC materials at various contamination levels at various relative humidities of air.

Material	Type of contamination	T °C	Relative humidity of air (%): 75 80 85 90 95 100
unused GF insulation/ duct board	Clean	21	
unused GF insulation/ duct board	5-10 g/m² soiling	21	
unused GF insulation/ duct board	100-200 g/m² soiling	21	
used GF insulation	contaminated in field conditions for 5-10 years, relatively clean	21	
Galvanised steel	no soiling	21	
Galvanised steel	7 g/m² soiling	21	
Galvanised steel	90-180 g/m² soiling	21	
used GF filter	used for 4 months at 40% and 80 % of RH	Amb	
used GF filter	used for 12 months	Amb	
used GF filter	used for 12 months, no air flow in test conditions	21	upstream side only; growth on both sides
(used) GF filter	one year recirculation filter relatively clean	21	
(used) GF filter	artificial nutrients with water spray	21	
used GF filter	used 6 months no air flow in test conditions	20	
		5	
		20	

Manifestation of the fungal growth

Amb = ambient temperature w = week or weeks

References: Pasanen et al. 1991c, Kemp et al. 1995a-b, Chang et al. 1996, Foarde et al. 1996b.

OIL RESIDUES

The HVAC-components are most often made of galvanised sheet metal, which needs corrosion protection to avoid hydroxylation of the zinc surfaces during storage and transport from steel mill. These viscous fluids form a sticky layer on the surface decreasing cleanliness and hygiene of manufactured components. Further, lubrication is needed to decrease friction between machine tool and the sheet metal during manufacture of some components with sharp bends or bows. A part of the lubricant remains as a thin layer on the interior surface of the product where it increases dust accumulation on the surface and serves as a potential growth media for microbes (Wallin 1994, Fransson 1996). Evaporation of hydrocarbons from oil residue decreases the perceived quality of the air passed through the ventilation system (Pasanen et al. 1995, Björkroth et al. 1996).

In recent years, building contractors, and customers have started to demand clean and high quality HVAC components, and therefore, solutions to manufacture oil free HVAC components have been sought. Therefore, air duct manufacturers use mainly sheet metal which is corrosion protected by chromium acid treatment or organic inactivation process of he zinc surface. However, sampling and analysis methods for the oil residues have not been available until recently. The proper and well validated quantification method for oil on a surface is firstly needed by a manufacturer who will develop methods to produce components with low oil residues. Secondly, the validated analysis method is needed by designers and building contractors who will order a clean and odour free HVAC system in order to ensure high IAQ for the building.

Two sampling methods have been applied to collect the oil from the sheet metal surface. In **swiping method** the sample area is swiped crosswise with glass or cotton wool sampler from an area of 100 cm^2 bordered with a specimen. The swiping sampler is prepared by immersing the swap in a test tube containing 2 ml of tetrachloroethylene (TCE) after which the excess solvent is pressed carefully back in the tube. In laboratory, the solvent is evaporated and the sample is dissolved in a know amount of TCE and total amount of oil components are analysed with spectrophotometer.

Filter contact method is based on the pressing an immersed glass fibre filter (Munktell filter MG 160) on the surface with a constant pressure. The filter (5 cm*5 cm) is immersed in tetrachloroethylene (0,036 ml tetrachloroethylene/cm^2), after which it is placed and pressed the surface to be sampled. The filter is pressed with a constant pressure device adjusted to a force of 42 N which gives 17.5 kPa pressure on the 25 cm^2 surface. In irregular surfaces like bends and joints the filter is covered with a cleaned PFTE film and pressed with fingers. After the sampling the filter is closed in a test tube and the analysis is performed similarly to the glass wool and cotton wool samples.

According to preliminary results the oil levels are low on the sheet metal which is protected against corrosion with chromium acid treatment. On the surface where oil mist is used for corrosion protection the oil concentrations on the surface ranged from 500 to 1000 mg/m^2. The two methods have different recoveries; the swiping method took about 60 % of the total oil due to some loss of solvent remaining on sample surface during sampling. The filter contact method with constant pressure device had better recovery and repeatability (91 ± 2%).

Both the methods showed that the oil is unequally distributed on the surface and several samples are needed for reliable measurement (Pasanen et al.1999).

SUMMARY

Dust and debris in HVAC system is considered as an impurity that need to be removed by regular or irregular cleaning action for efficient function of HVAC system. In many cases different opinions exists about the need for cleaning, and therefore, consistent methods to verify dustiness or cleanliness of the system are needed. Filter sampling method is reliable and it is suitable for a wide range of dust levels, however, it is laborious and needs time to stabilise the samples. Dust tape method is not so effective to loose firmly fixed particles from surface and the dust binding capacity of the tape seems to be sufficient on surfaces with dust less than 4 g/m^2. Gel tape method which gives a comparable density of dust as percentage of dust coverage on the surface is rapid, but the repeatability of the method is not as good as with the other methods. It has quite the same range than the dust tape method. Both the methods seem to be useful for quick verification of cleanliness of new installations if the surface does not contain oil residues.

Air duct in normal buildings are not sterile. If unusual high microbial contamination is suspected due excess moisture in the system the swipe sample or dust sample methods for taken cultivation are suitable. A few or single dominating fungal genus with high counts may be an indicator for microbial contamination. The cleaner the surfaces are the slower and lower is the risk to get microbial growth problem in the system.

Oil residues are one group of impurities on new HVAC components that decreases the quality of air passed through the system. Galvanised sheet metal which was covered with corrosion protection oil contains oil up to 1 g/m^2 of oil. While the oil concentrations are low on the sheet metal surface which is treated with oil free corrosion protection. Variation in the oil concentrations is wide on the same sheet metal and also in the manufactured components. This variation should be taken account in sampling design. The filter contact method showed the best recovery and repeatability and the method was good compared to the glass wool and cotton wool swiping methods.

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