Air quality by VAV HVAC system before and after cleaning. Case study.

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SUMMARY

Since the study by P.O Fanger (1988) [1] we know that the Heating Ventilating and Air Conditioning (HVAC) system could be responsible for a large amount of indoor air pollution and Sick Build Syndrome (SBS). The pollution could become from filters, cooling coils and dust accumulated on duct surfaces in systems with poor maintenance.
While the importance of maintenance of air handling units and replacement of air filters is well recognized in Portugal, the cleanliness of ducts is sometimes forgotten. Research is needed on standard methods to measure the surface pollution and criteria to appreciate the cleanliness of duct surface, as well as the requirement for duct disinfection after an adequate mechanical cleaning.
In this paper the results of a study undertaken in a 9 year old office building in Lisbon area with a VAV system are presented, including the methods used to measure the air quality and the surface pollution. The results show that mechanical cleaning contributes to a large reduction in dust concentration in surfaces and in the air supplied to spaces. The concentration of bacteria and moulds in surfaces and in the air was quite low and therefore in this building chemical disinfection is not required.
A continuous audit of the system is recommended (with visual inspection for instance and some measurements) to choose between cleaning some components or the complete system and some suggestions about the criteria to be adopted before cleaning ducts are also offered.

INTRODUCTION

To promote good indoor air quality in buildings we need to supply an adequate air flow rate to dilute and remove pollutants and the supplied air should also be fresh and clean.
In the study of Fanger [1] in 1988 it was shown that HVAC systems could be responsible for 42% of the pollution sensed by occupants. The pollution of HVAC systems has many sources, namely air filters, heating and cooling coils, humidifiers, water condensation pans and ventilations ducts.
The contamination of inert HVAC components (ex. components made of steel, copper, aluminum, etc) could be associated with the transport of contaminants germinated in air handling units, high humidity levels on surfaces, oil residues on surfaces, accumulated dust on ducts which in the presence of water allow the germination of microorganisms.
To reduce the risk of HVAC contamination is proposed [2] an annual audit of HVAC system, periodic replacement of air filters, cleaning of humidifiers, heat exchangers, water condensation pan, etc. Regarding duct it is recommended the cleaning when necessary, without defining the criteria to decide when it will be necessary. Duct cleaning was first

introduced to reduce the fire hazard or the blockage of duct by the dust which reduces the air flow. Nowadays, the impact on the air quality supplied to the building, is also a concern (figure 1).
Regarding the impact of duct pollution in Indoor Air Quality (IAQ) currently there isn't information available that could allow the definition of safe limits for dust or microorganism accumulation in duct surfaces indicating good/bad air quality supplied to spaces. Some previous work suggests that duct cleaning has a minor effect in IAQ [3, 4].
In this study we were interested in showing, using quantitative measurements, the impact of HVAC and especially duct cleaning in the air quality supplied to the building and in the pollution of the duct surfaces.

Dirty duct Clean duct

Figure 1. Ducts

CRITERIA TO EVALUATE DUCT CLEANLINESS

The simplest method to appreciate duct cleaning is the visual inspection, which allows the identification of a large number of anomalies. For instance, dust concentration of 5 to 10 g/m^2 are thick and easily seen [3]. When dust concentration is lower than 0.1 g/m^2, a cleaned duct is observed.
Quantitative methods could be used to appreciate more objectively the dust level inside ducts, namely: the vacuum test method, the gravimetric tape or the optical method [3,4]. To measure microorganism levels contact plates are used [5,6].
To measure dust accumulation, Holopainen [5] showed that the most precise method is the Vacuum test. The tape test method could be used for lower concentrations (lower than 3 g/m^2).
As already referred, a correlation between surface dust concentration and it's impact on indoor air quality, it has not yet been defined. For that reason, quantitative methods have been adopted essentially to determine adequate duct cleaning.
The NADCA association [7] refers that ducts are clean when the measured surface dust concentration (obtained with the vacuum test method with air flow rate of 15 l/min and with the cassette (filter holder) sliding over a structure not touching the surface of the duct) is lower than 0.075 g/m^2.
The APIRAC association [8] considers that acceptable cleanliness of ducts is achieved when the obtained concentration of surface dust is smaller than 1 g/m^2. APIRAC's method uses a collection airflow of 25 l/min and the cassette contact directly with the surface of the duct.
FISIAQ considers two cleanliness classes [9] in new air conditioning ducts: for the P1 class the limit for the concentration of surface dust is 1.0 g/m^2 and for the P2 class the limit is 2.5 g/m^2, if we consider existing ducts limits are 2.0 g/m^2 and 5.0 g/m^2 for the classes P1 and P2 respectively. For P1 category oil residues must be lower than 50 mg/m^2.

In the United Kingdom [9] the maximum limit allowed is de 1.0 g/m^2 in supply ducts and 6 g/m^2 in exhaust ducts, measured according NADCA method.
A technical note from Chow et al [10] recommends cleaning when surface dust measured with the NADCA method detects concentrations higher than 6 g/m^2 in exhaust ducts and higher than 1 g/m^2 for supply air duct or exhaust ducts on a system with air recirculation
There are no reference limits for microbiological contamination. Luoma et al reports [4] presents some results with mean concentrations of fungi ranging from 0.05 to 11 cfu/cm^2 and bacterial concentrations ranging from 0.03 to 13 cfu/cm^2.
A Norwegian expert group [3] presents three risk classes for surface microbiological contamination. For fungi, concentrations lower than 1000 cfu/g of dust presents a low risk, for concentrations smaller than 3000 cfu/g of dust present medium risk and, finally, the risk will be high for concentrations higher than 3000 cfu/g. For bacteria, low risk is defined for a concentration lower than 6000 cfu/g, medium risk for concentrations lower than 10000 cfu/g and high risk will be for concentrations higher than 10000 cfu/g .
Regarding recommendations for surface cleanness, we have rules for surfaces in contact with cold stored foodstuffs [11], which states that the microbiologic contamination should be lower than 1 cfu/cm^2 to be in the excellent class, a microbiological contamination lower than 10 cfu/cm^2 to be in the good class. Clean Rooms for pharmaceutical industry have four classes: A - 0.04 cfu/cm^2, B - 0.2 cfu/cm^2, C - 1.0 cfu/cm^2, D - 2.0 cfu/cm^2 [11].

DESCRIPTION OF THE HVAC SYSTEM

This study was conducted in a 9 years old office building in Lisbon area, with a VAV ventilation system. The study was carried out on the east side of the building with the air handling unit is placed at the roof, figure 2. This system is 100% outdoor air (without recirculation). The air handling unit has a nominal capacity of 45 690 m^3/h and is connected to a duct 1.5 m × 0.9 m. In this air handling unit a two step filtration scheme is applied, with filters of class G3 and F9 [12].
The system is made with galvanized steel ducts. At the exit of air handling unit and in the vertical shaft the duct has rectangular cross section. For air distribution in every floor one main duct spiral oval is used, (figure 3). The connection of VAV box to the oval duct is made with oval or round ducts. The connection of air supply diffusers to the VAV box is made with flexible ducts. Inside the VAV box a sound insulation material is used.

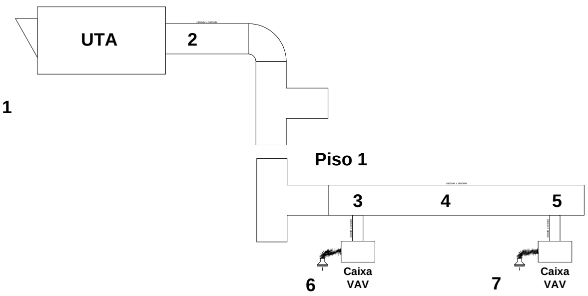

Figure 2. Schema of supply air duct and measurement location

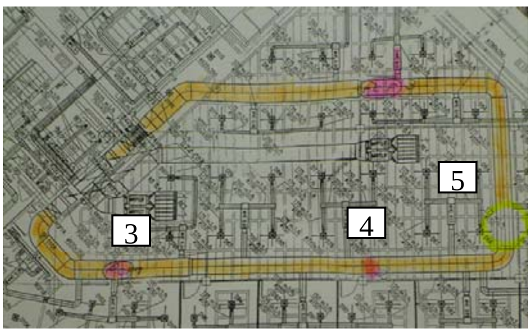

Figure 3. Supply air duct and measurement location

METHODS

To appreciate the effect of 9 years of HVAC system use on the quality of supplied air to the rooms, and to test the effect of HVAC cleaning without disinfection, concentrations of bacteria, fungi and particulate matter (dust) were determined in air and inner surfaces of air ducts, before and after cleaning.

To obtain the worst possible scenario, we studied the first floor of the building, because it's bigger the distance to the air treatment unit and dirtiest ducts are expected.
Figure 2 and 3 represent the measuring points for air determinations (1 to 7) and inner duct surface determinations (2,3,4 and 5). The selection was made in order to obtain information about the effect of HVAC components in the quality of supplied air and also to study correlations between surface and air pollution.
To obtain an estimation of airflow, we measured air velocity profile at the same points where the air contamination was assessed.

Surface Contamination

To collect surface samples for microbiological or dust analysis, the HVAC system was turned off and holes were opened in ducts at selected locations to give assess to inside of ducts. The measurements were done on inner surfaces near the holes.
Sampling of viable microbiological samples on the surfaces was performed using bioMerieux contact plates filled with the appropriate culture media, Count-Tact (ref. 43 501) to collect bacteria and Count-Tact Sobouraud Glucose Chloranfenicol with neutralizer (CTSCD, ref. 43 580) to collect fungi. At least two samples at each measuring point were taken.
The collection of surface particulate matter (accumulated dust) was done according with the APIRAC procedure [8], using the vacuum test method. It was used the ROBImech equipment, with a flow rate of 25 l/min. Filters were weighted before and after collection, at the laboratory.
The amount of dust inside ducts is not homogeneous, presenting higher concentrations near the joints of the steel duct. The methods for measuring the accumulated dust do not specify the sampling places. Therefore, to correct this possible source of error, we performed collections in both "clean" and "dirty" points.

Air Contamination

The collection of total particulate matter in the air was performed using pumps calibrated for a 2 l/min flow rate and membrane filters previously weighted. The collection time was approximately 12 hours.
Sampling of viable microorganisms inside the ducts was performed using impact samplers. Andersen-N6 impactor, calibrated to 25.32 l/min, was used inside the ducts and a MAS 100 impactor (Merck) calibrated to 100 l/min used to collect microorganisms at the terminal devices in unoccupied spaces because human beings are important sources of bacterial contamination.
To culture fungi Malt Extract Agar with chloranfenicol was used and Trypticase Soy Agar was used for bacterial counts. Plates were incubated at 27ºC and 37 ºC for fungi and bacteria respectively.
Inside the ducts the air velocity was measured using an Airflow thermo-anemometer model TA 5.

RESULTS AND DISCUSSION

The measurements before system cleaning were carried out on the 18th and 19 th of March 2005 (figure 4 and 5 – Before Clean). The measurements after cleaning were performed on the 5 th and 6 th of May, 2005 (figure 4 and 5 – After Clean).
In figure 4 the results of measurements in air are presented, namely: bacteria, fungi and total particulate matter. In figure 5 the results of measurements in duct surfaces before and after

cleaning are shown. The results of bacteria and fungi are the average of two measurements, while the particles are the average of 12 h measurement.

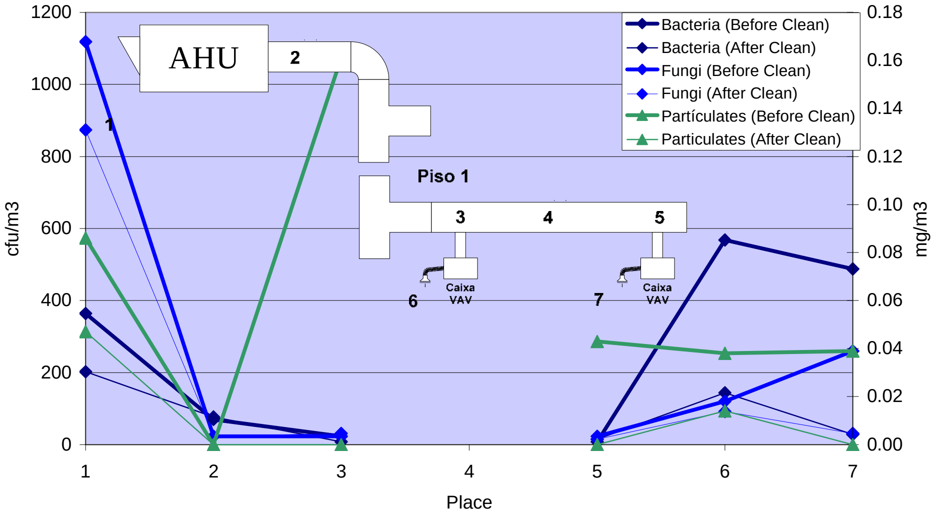

Figure 4. Measurement in air

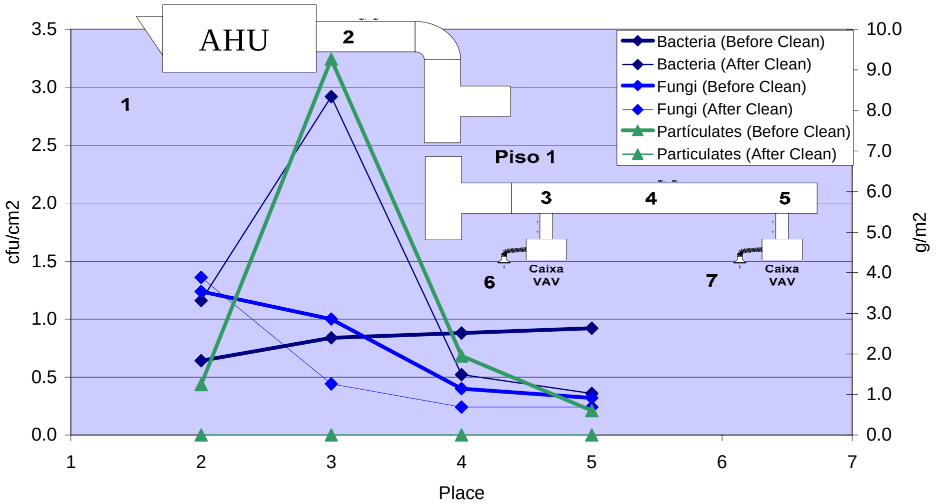

Figure 5. Measurements in duct surface

General appreciation

The duct network of the HVAC system under study was relatively clean, with a surface dust concentration under $2g/m^2$ and a microbial concentration inside the range classified as excellent for surfaces in contact with food, class C for "clean rooms" and close to the lowest levels referred by Luoma et al [4].

In the following paragraphs we present the main conclusions regarding the effect of mechanical duct cleaning in supplied air.

Air handling unit

Comparing the results obtained outdoors (A1 point) with the results obtained beyond the air handling unit (A2 point), it's possible to conclude that filters were effective in the removal of

contaminants, as we can see for the reduction of pollutants (microorganisms and particulate matter).
The results obtained before and after cleaning (points A1 and A2) were not significantly different, despite the cleaning.

Ducts

To appreciate the effect of duct network in the contamination of air, we compare the results obtained beyond the air handling unit (point 2) and 1st floor entrance (point 3) and between point 3 and point 5 the remote point of duct system.
There is no difference between the results obtained for microbiological contamination in point 2 (after passing the air handling unit) and 3 (1st floor entrance), although there is an increase on particulate matter concentrations (from not detected to 0.16 mg/m^3). This increase on particulate matter in air may be associated to the displacement of particles settled at the bottom of the vertical shaft
Analyzing the results obtained in surfaces we verify that bacterial and fungal concentrations are almost constant between samples collected after passing the air handling unit and 1st floor entrance point. However there is a larger dust deposition at the entrance of 1st floor (10 g/m^2) than after passing the air handling unit (1.3 g/m^2). The observed difference may be due to the air flow bend near the collection point, which promotes the settlement of particles, and also to the large particle concentration in air in this zone.
Between the entrance in the 1st floor and the remote point (points 3 and 5) a reduction in particle matter concentration in air is registered (0.16 mg/m^3 to 0.04 mg/m^3), with almost the same concentration of micro-organisms. The reduction of particle concentration in air is associated with the reduction of average air velocity along the duct, which promotes the settlement of heavier particles. Regarding surface concentration, we detect the same changes as in air, *ie*, the micro-organism concentrations are almost constant and there is higher concentration of dust at the beginning of duct (10 g/m^2) than in the most remote point (2.0 g/m^2).
Analysing these results we conclude that there isn't a direct correlation between particle and micro-organism concentration in duct surface, because the micro-organisms remain almost constant in several collection points, while the particle concentration presented a large variation. Regarding particle concentration in air and in surface, there is a direct correlation.
With those results we can see that mechanical cleaning of duct surface is effective to remove particles, since we obtain a substantial reduction in surface particle concentration after mechanical cleaning and we also obtain a large reduction of particle concentration in air. After mechanical cleaning, the surface particle concentration complies with APIRAC criteria (≤1 g/m^2) and also with NADCA criteria (0.075 g/m^2), in spite of the large differences in measurement method of APIRAC and NADCA.
The micro-organism concentrations present slight variation (before and after mechanical cleaning). Because of the low micro-organism concentration (surface concentration of 0.2 and 1.4 cfu/cm^2 and concentration in air of 8 and 70 cfu/m^3) it seems that the impact in air quality is low and therefore chemical disinfection can be avoided.
In this study, we find that the collection point in duct surface could have an impact on the results obtained. Points very close to duct irregularities (the bending zone in spiral duct, joints, etc) could have large differences in dust concentration. The changes in dust deposit, however, didn't correspond to a change in micro-organisms concentration. We also notice that the higher micro-organism concentrations were found near the places of lower particle concentration.

VAV box and diffusers

To assess the impact of VAV boxes, flexible duct and diffusers we compared the results of measurement points 3/6 and 5/7.

From the results obtained at these points, we can see a large increase of micro-organisms in air between the main duct of the room and the exit at air diffusers. This indicates that VAV boxes, flexible duct and diffusers have good conditions to the germination of micro-organisms (namely bacteria) that are drawn by air flow. Regarding particle concentration between collection points 3/6 we can see that there is a settlement of particle in these components, which could create media for the development of micro-organisms if the humidity conditions are adequate, because the availability of water is the driving force in the growth of micro-organisms.

In this case study, with mechanical cleaning we detected a large decrease of particles and micro-organisms in the air supplied indoors. If we look at contamination classes of air [13], the air supplied before cleaning would belong to the intermediate contamination class and after cleaning would be classified as very low pollution.

The main focus of contamination of air supplied to the building was the branch VAV box and the flexible ducts, which were very dirty.

CONCLUSION AND RECOMMENDATIONS

In this case study the contamination of one VAV system and its impact on the air quality supplied to the building before and after mechanical cleaning, was analysed.

We found that after 9 years of use the system could be considered clean, even though this was not clean after construction. The concentration of micro-organisms and particles was generally low, and some points presented higher particles concentration but that still didn't compromise the air quality.

The main focus of pollution are the VAV box and/or flexible duct. Before the cleaning an air concentration of bacteria of 500 cfu/m^3 was measured and after cleaning this concentration decreased to 28 and 140 cfu/m^3. In spite of this reduction, after cleaning, these components remained the main source of air pollution.

For the dirt in duct surface we didn't found a correlation between particle concentration and micro-organism, because micro-organisms concentration remains almost constant from dirty collection points to clean collection points. However, we obtained a correlation between particle matter in air and duct surface.

Regarding the criteria for clean ducts, we found that the 1 g/m^2 limit [11] to start cleaning duct system is very stringent, because in this system (which presented higher values in some places) the duct was not source of pollution of air. In absence of other information, we think that it could be reasonable to adopt the class P2 criteria (5 g/m^2) [9] as the limit beyond that which cleaning the ducts is needed. As criteria to asses the cleanliness of the cleaning operation we could use the criteria of 1 g/m^2, or a lower value, for example 0.1 g/m^2, measured with the APIRAC method, because in this building both criteria were satisfied. Regarding the micro-organisms concentration in duct surface, we think that the contamination risk is low for ducts that comply with class D of pharmaceutical industries (2 cfu/cm^2) [11], taking into account the results obtained and the Norwegian recommendations [4]. For concentrations above this limit (2 cfu/cm^2), we think that a study of the impact of surface contamination in the contamination of air supplied to the building should be performed, before cleaning or disinfecting the ducts.

We found that the vacuum test method could be adopted as measurement method for the assessment of duct cleanliness regarding particles and that the mechanical cleaning is effective in the removal of particles and micro-organisms.

With these results we also show that before a complete system cleaning, some measurements should be done to find potential sources of pollution and clean only the contaminated components, cutting maintenance costs.
In the course of this work we also noticed the importance of the dirt left from construction. It is quite important to follow rules to protect HVAC during construction and probably do some cleaning after construction and before turning on the HVAC installation.

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