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A study of the characteristics of dust associated microorganism deposit in HVAC system

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ABSTRACT

Recently, the interaction between particles retained on HVAC and indoor air quality has gained more attention due to their possible relationship to irritation, health outcomes, and odors. The purpose of this study was to offer some reference data, contributing to a insights into particle and bioaerosols deposited in real HVAC systems. The HVAC system sanitary condition in a high-rise building in Xi'an, China was investigated. The deposition dust was quantified and the accumulated microorganisms (including bacteria and fungi) were identified by morphology method in different parts of central air-conditioning system. Results revealed that the average size of the particles of dust fell into the range of 6–20μm, with the exception of the fresh air section. Secondly, the loading rates for the return air duct may quickly than the supply air duct for the buildings with a lot of indoor sources. We should give more attention to return air duct when arrange HVAC systems cleaning schedules. Thirdly, the index of microorganisms was more sensitive than deposition dust because the microorganism concentration already had exceed the threshold, while the deposition dust were still under the limiting value. Lastly, in the process of controlling microorganisms, it is more effective to perishing the bacteria due to always higher concentration than fungi in the same parts.

KEYWORDS

IAQ;
Central air-conditioning;
Dust;
Particle;
Bioaerosols;
Indoor air.

INTRODUTION

A large portion of the population spends 90% of their time indoors, and indoor pollutant concentrations are frequently higher than outdoor contaminant levels[1]. As a result, indoor air quality (IAQ) in civil architecture environments has been the object of intense concern for many years[2-3]. Much research indicates that IAQ has a strong relationship to the inadequacy of the ventilation and air-conditioning system of the building[4–5]. One important reason is particles in indoor environments may deposit on the surfaces of heating, ventilation and air conditioning (HVAC) systems. Such deposits can lead to indoor air quality problems and performance of HVAC systems degradation. For instance, as air flows through ducts, deposition to duct surfaces may alter airborne particle size distributions and therefore affect exposures of building occupants[6-9]. Fouled heat exchangers have diminished heat transfer performance, increased pressure drop, and can cause contamination of working fluids[10]. Furthermore, filters, coils, and ducts can also act as reservoirs from which biological contaminants can resuspend into the air stream, causing indoor bioaerosol problems[11]. Therefore, from an environment perspective, particles deposit on the surfaces of HVAC systems may cause many respiratory symptoms such as cough, shortness of breath, wheezing and asthma attacks, as well as chronic obstructive pulmonary disease, cardiovascular diseases and lung cancer[12].

Despite these efforts, little has been reported on the characteristics of dust inside a real central air-conditioning system. Hence, this work focuses on physical and biological behavior of dust inside a typical central air-conditioning system. The purpose of this study was to offer some reference data, contributing to a insights into particle and bioaerosols deposited in real HVAC systems. These new information would be useful for improving our ability to predict particle and bioaerosols loading rates in HVAC systems, estimate HVAC systems cleaning schedules and improve indoor air quality.

EXPERIMENTAL METHODOLOGY

There is a wide range of bioaerosols that have been identified in indoor environments. However, for deposition on HVAC systems we are largely interested in two types of organisms: fungi and bacteria. There are other biological agents present in indoor air that also present health concerns, such as viruses, dust mites, algae, and pollen. These particles are either relatively rare (viruses), large and not particularly biological active in HVAC systems (dust mites, pollen).

Therefore, the items measured include the particle size of HVAC dust and the concentrations of microorganisms (fungi and bacteria). Before analyzing the results, it is important to describe the experimental methodology.

The sampling site

The sample was obtained from the dust in the ventilation and air-conditioning system in a high-rise building in Xi'an, China, located in the northwest of China, in the cold region. Outdoor particulate pollution is serious, the average concentrations of PM10 in Xi'an and Xiaozhai (Xiaozhai is a nearest air quality monitoring station from the building) reached 0.129 and 0.118 mg/m^3, respectively. The building is located downtown with heavy automotive traffic. It is an office building. It was completed in 1994, with 31 floors and an area of 40,000 m^2. And the covered area of per capita is about 10 m^2.

The sampling air conditioning system

The fan coil unit (FCU) is installed above the 3rd floor of the building, while the air handling unit (AHU) system is installed below the 3rd floor of the building. Air filter (Mid) is installed in the HVAC system. Duct in the building is made of galvanized steel. The hydraulic equivalent diameter is about 700mm. The design wind speed in sampling duct is 6 m/s. Brazed aluminum plate-fin heat exchanger is used in the HVAC system. Fin spacing is 4.2mm. The design wind speed in brazed aluminum plate-fin heat exchanger is 3.5 m/s.

The sampling method

The methods of dust and microorganism sampling are presented in the standard. It can give you information about how to sampling and counting. In order to compare the characteristics of dust from an air-conditioning system, the central air-conditioning system has been divided into seven typical segments. It include the fresh air segment, return air segment, mixing box segment, filter segment, cooling and fan segment, and air supply duct. Side-by-side random samples were collected from each segment. Each sampling area was 10 cm^2. Ten sampling points were selected in each segment for every experiment.

Particle size test

The dust was conserved in a jar that was sterilized by the drying method. The analysis of the particle size was conducted with a laser diffraction particle size analyzer (Beckman LS230), with a measuring range of 0.375–2,000 μm. Two kind of method including dry and wet can be used. In order to avoid some particles dissolve, dry method was carried in the experimental.

Microorganism preparation

Biological sampling can assist in determining if microorganisms are present in a particular environment, and if the amount is unusual. It can also aid in locating the source of the mold reservoir and facilitate remediation. Although the sample collection techniques used for microbes and other particles possess some similarities, there are considerable differences in the analyzing methods used. Microbial analyses are mainly based on cultivation of microbes before calculating, whereas particles are analyzed by gravimetrical techniques.

The fungi and bacteria were incubated according to China Standard[13]. Sabouraud's Agar (SDA) and Nutrient Agar Medium (NAM) were used for fungi and bacteria incubation, respectively. Fungi were incubated for 168 hours at 28°C, and bacteria was incubated for 48 hours at 37°C. The microbial experiments were strictly controlled under sterile operational procedures. Glass utensils were sterilized at 121°C for 30 minutes before use. The larger equipment was disinfected with 75% ethanol. Every sample was duplicated and the vacant one was utilized in the experiment. The dust sample was dissolved in 100 ml of Tween 80 by hand-shaking, and then 1 ml of solution was incubated on a culture dish. The analysis was performed three times for each dilution and the average number of colonies formed was recorded.

RESULTS AND DISCUSSION

The particle size of the dust

HVAC dust is a potential resource that may enhance our understanding of indoor occupant exposure. It can be collected with minimal effort and analyzed for a broad range of contam-inants.Figure 1 shows the percentage of cumulative volume and the size of the particle. Results revealed that the average size of the particles of dust fell into the range of 6–20μm, with the exception of the fresh air section.

Particle loading rate

Three sets of the same experiments were conducted, respectively. They have been named experiment-1, experiment-2 and experiment-3. TABLE 1 shows the concentration of dust in fresh air segment, return air segment, mixed air segment and air supply duct(It is difficult to obtain the per unit area concentration of dust in heat exchangers and filters). According to the air conditioning system running time and concentration of dust, loading rate can be calculated(TABLE 3). The loading rates ranged from 0.73 to 1.19 g/(m^2·month) for the supply duct, ranged from 1.54 to 2.89 g/(m^2 • month) for the return duct loading rates in three experiments. The literature presented the overall

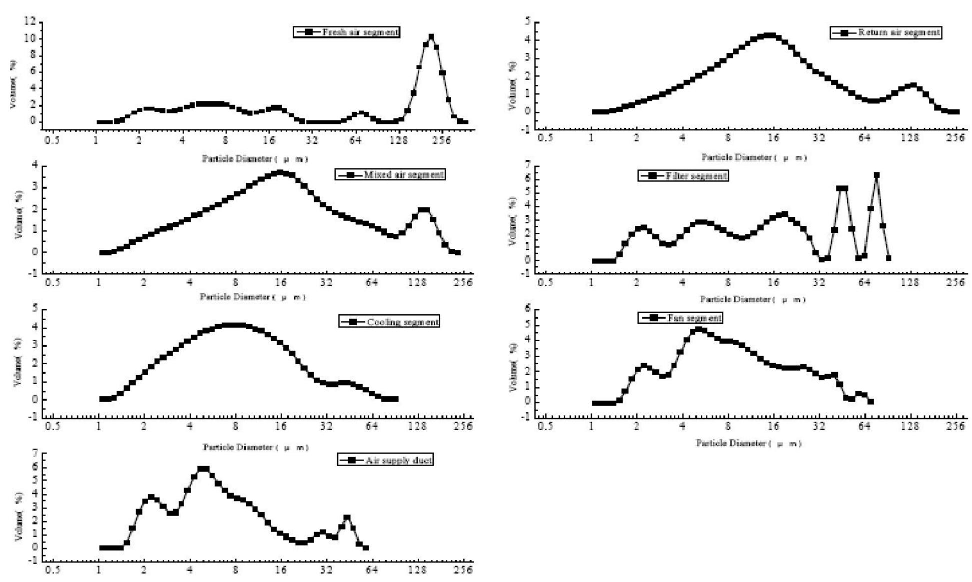


Figure 1 : The percentage of cumulative volume and the size of the particles in Experiment

medians loading rates 1.00 g/(m^2 • month) for the supply duct and 0.262 g/(m^2·month) for the return duct[14]. It is clear that loading rates for the supply duct in this study is consistent with the literature. However, it is distinct difference for loading rates for return duct between them. This discrepancy is mainly likely caused by the fact that there was really quite a difference for indoor sources between them (loading rates are dependent on outdoor particle distributions, indoor sources, HVAC operation strategy, filtration, and so on[14]). The building investigated has terrible floor and walls, which may produce a lot of particles in indoors, expressly for large particle. The particles can suspend into the return air stream and deposit in return air duct. More to the point, for all except the smallest particles considered, deposition increases with increasing particle size. It is also the reason for particle size deposit in return air segment is greater than particle size deposit in air supply duct (Figure 1).

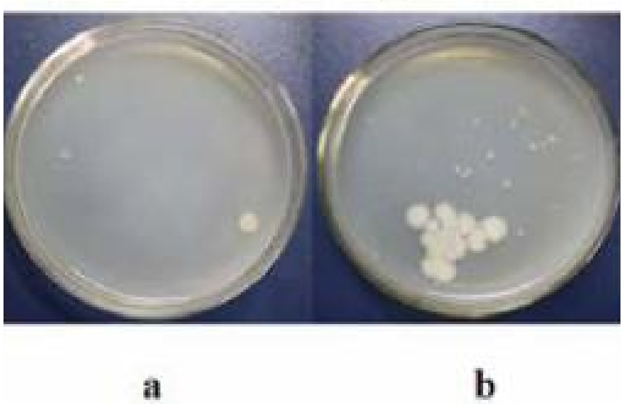
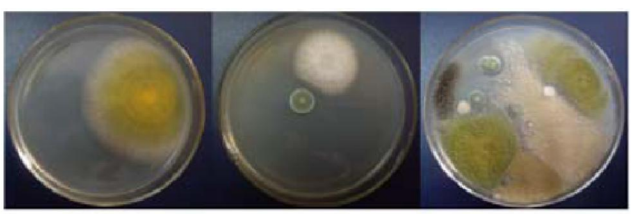


Figure 2 : Bacteria colonies photos



a b c

Figure 3 : Fungi colonies photos

Through the above analysis we can conclude that the loading rates for the return air duct may quickly than the supply air duct for the buildings with have a lot of indoor sources. We should give more attention to return air duct when arrange HVAC systems cleaning schedules.

The concentrations of microorganisms

The pictures of bacterial and fungal colonies were shown in Figures 2 and 3 respectively. As the individuals of fungal colonies in the Petri dish were large and prone to overlapping, the masking effect was more significant than it was for bacteria. The b in Figure 2 and the c in Figure 3 display the masking effect. Therefore, in order to get more accurate results, the colonies were counted daily, and the maximum number was regarded as the number of fungal and bacterial colonies.

Fungi can be identified according to its microscope colonial morphology. The detective fungi contained Penicillium, Aspergillus, Cladosporium, Alternaria, Mucor, and Trichoderma.

TABLE 2 reports the concentrations of microorganisms. We can see from TABLE 2 that the bacteria concentrations in all the sampling sites ranged from 60,000 to 220,000 CFU/g in three experiments, while the fungi concentrations in all the sampling sites ranged from 60,000 to 180,000 CFU/g in three experiments. The mean concentration of fungi in return air segment and air supply duct for two HVAC systems were given in literature[15], the current study is lower than the mean value reported in the literature.

From TABLE 2 we also can see that the culturable bacterial concentrations were consistently greater than the fungal concentrations for the sites inves-tigated. The same conclusion was reported in the literature[16]. The highest concentration of microorganisms was found in cooling segment. Similar results were reported in the literature[17]. It was most probably due to coil run for

TABLE 1 : The particle loading rate

		Fresh air segment	Return air segment	Mixed air segment	Air supply duct
Experiment-1	Dust (g • m^{-2})	31.98	14.01	14.06	4.38
	loading rate(g/m^2 • month)	5.33	2.335	2.343	0.73
Experiment-2	Dust (g • m^{-2})	28.45	10.76	12.51	7.21
	loading rate(g/m^2 • month)	4.06	1.54	1.79	1.03
Experiment-3	Dust (g • m^{-2})	33.55	17.31	15.22	7.15
	loading rate(g/m^2 • month)	5.59	2.89	2.54	1.19
References[14]	loading rate(g/m^2 • month)	——	0.262	——	1.00

very long periods of time, as well as coil with inadequate drainage or sufficient surface roughness or deposited hygroscopic material that they retain moisture for long periods of time (Moisture is a limiting factor for bacterial and fungal growth).

Microbial contam-inants captured on HVAC filters in nine buildings[16] and this building investigated were presented in Figure 4. From Figure 4 we can see that the mean concen-tration across the sites from site 1 to site 9 for bacterial and fungi was 1.4×10^7 and 1.1×10^6 CFU/g, respectively. Although the culturable bacterial and fungal concentrations observed in the current study are slightly lower than the mean values reported in the literature, which are similar to the values of site 9 reported in the literature. One important reason may be that site 9 was the one light public building, whose operational mode of HVAC system is similar with the building in this study (others reported in literature are residential buildings). Many studies have suggested that microbial contamination of HVAC filters occurs because filters collect sufficient organic material and nutrients to support microbial growth[18-19]. Kemp[20] also observed enhanced fungal growth when additional nutrients were delivered to HVAC filters. Therefore it is essential to clean the filter more frequently.

TABLE 3 shows the concentrations of dust and microbial in the fresh air segment, return air segment, mixed segment and the air supply duct. The per unit

TABLE 2 : The mean concentration of Microorganisms in dust (CFU / g)

Sampling sites	bacteria	Fungi
Fresh air segment	$(61700)^1$ $(71500)^2$ $(82300)^3$	$(61600)^1$ $(66500)^2$ $(77500)^3$
Return air segment	$(91700)^1$ $(87500)^2$ $(81200)^3$	$(78300)^1$ $(71500)^2$ $(76400)^3$ $(306000)^{\text{literature[15]}}$ $(622000)^{\text{literature[15]}}$
Mixed air segment	$(86700)^1$ $(79600)^2$ $(84400)^3$	$(65000)^1$ $(77300)^2$ $(78600)^3$
Filter segment	$(105000)^1$ $(92400)^2$ $(116500)^3$	$(80000)^1$ $(89500)^2$ $(105000)^3$
Cooling segment	$(205000)^1$ $(197500)^2$ $(213500)^3$	$(135000)^1$ $(165500)^2$ $(178600)^3$
Fan segment	$(156700)^1$ $(165200)^2$ $(174600)^3$	$(91666)^1$ $(124000)^2$ $(132500)^3$
Air supply duct	$(186700)^1$ $(165300)^2$ $(185300)^3$	$(100000)^1$ $(135000)^2$ $(143100)^3$ $(287000)^{\text{literature[15]}}$ $(3160000)^{\text{literature[15]}}$

area concentration of micro-organisms in the fresh air segment, return air segment, mixed segment and the wall of the air supply duct can be calculated with the data from TABLES 2 and 3. The results are shown in TABLE 3. The inner surface hygiene requirements in HVAC were presented in TABLE 4[13]. Contrast TABLE 3 and TABLE 4, the following conclusions can be obtained. The highest concentration of micro-organisms existed in the fresh air segment, was approximately 2 times the China standard. And the mean concentration of fungi in this study was between the two results were given by literature[15].

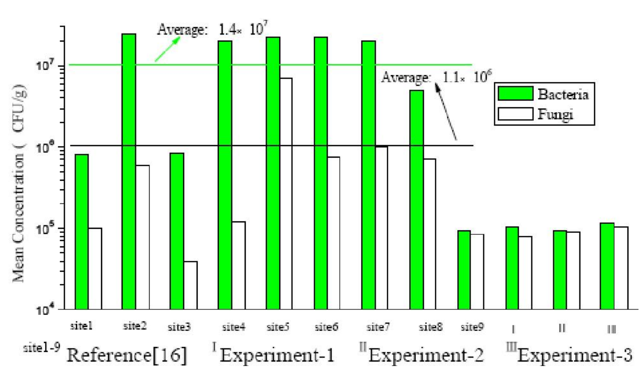


Figure 4 : Mean microbial concentration in HVAC filter dust

It also can be seen from the TABLE 3 that the concentration of microbial exceeded the China standard more easily than the dust and the concentration of bacteria exceeded the China standard more easily than the fungi. Therefore disinfection measures should be paid more attention in air conditioning system operation management. And it is more effective to perishing the bacteria due to always higher concentration than fungi in the same parts. At the same time cleaning frequency for fresh air segment should be increased.

DISCUSSION OF THE POTENTIAL BIASE

Every species is going to grow/die at a different rate under given environmental and nutrient conditions.

TABLE 3 : The concentration of dust and microbial in the inner surface of HVAC

	Fresh air segment	Return air segment	Mixed air segment	Air supply duct
Dust (g • m^{-2})	31.98/28.45/33.55	14.01/13.76/17.31 (2.06)(2.26)	14.06/12.51/15.22	4.38/7.21/7.15 (5.57)(13.29)
Greater than standard	Yes/ Yes/ Yes	No/ No/ No (No)(No)	No/ No/No	No/ No/ No (No)(No)
Bacteria (CFU • cm^{-2})	197/203/276	128/126/141	122/100/128	82/119/132
Greater than standard	Yes/ Yes/ Yes	Yes/ Yes/ Yes	Yes/ Yes/ Yes	No/ Yes/ Yes
Fungi (CFU • cm^{-2})	197/189/260	110/98/132 (63)(346)	91/97/120	44/97/102 (65)(4194)
Greater than standard	Yes/ Yes/ Yes	Yes/ No/ Yes (No)(Yes)	No/ No/ Yes	No/ No/ Yes (No)(Yes)

TABLE 4 : The inner surface hygiene requirements in HVAC[13]

Item	Limit value
Dust	≤20(g • m^{-2})
Bacteria	≤100(CFU • cm^{-2})
Fungi	≤100(CFU • cm^{-2})

Some species will dominate the microbial community after a very short period. The use of culture analysis to detect bacterial and fungi in dust exclusion of some types of bacterial and fungi. Spores may be unable to grow in culture because they are nonviable, or they are viable but injured, or because the nutrients or temperature conditions are not appropriate. These phenomena can be influenced by sample storage, transport, and age factors. In order to reduce the test biases caused by above phenomenon, on-site culturing method is adopted in this experiment. It reduced the time of preservation and transportation. Despite this caveat, this experiment provides data of deposition on a real central air-conditioning system, which is an important first step.

CONCLUSION

The experimental results presented here show that there is a clear potential for common indoor bioaerosols to deposit and be viable on HVAC system. Surface dust sampling methods are necessary for the quantitative evaluation of the need to clean HVAC system and to control the quality of cleaning work.

Based on the experimental results and analysis, the following conclusions may be drawn from this work:

1) The loading rates for the return air duct may quickly than the supply air duct for the buildings with a lot of indoor sources. We should give more attention to return air duct when arrange HVAC systems cleaning schedules.
2) The concentration of microbial exceeded the China standard more easily than the dust. Therefore disinfection measures should be paid more attention in air conditioning system operation and management.
3) Because fresh air segment is often easier to accumulate dust, inspecting and cleaning frequency for it should be increased.
4) In the process of controlling microorganisms, it is more effective to perishing the bacteria due to always higher concentration than fungi in the same parts.

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