Comparison of dust from HVAC filters, indoor surfaces, and indoor air

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SUMMARY
HVAC filters are long-term, passive samplers and may offer new perspectives for exploring the indoor environment. This paper focuses on microbiological contaminants and heavy metals and compares concentrations of these contaminants in filter dust to those from air and settled dust samples in eight residential buildings. We used the standard spread plate method for culturable fungi and bacteria and atomic absorption spectroscopy for measuring selected heavy metal (Pb, Cd and As) concentrations. HVAC filter microbial concentrations appear to be consistent with the levels found in other locations, especially for spores and fungi. Metal concentrations found at different locations also seem to be comparable, but the correlation is not as clear as it is for the microorganisms. We conclude that HVAC filters hold promise as a sampling mechanism, but a larger database and exploration of other critical factors is needed before definitive associations can be made.

KEYWORDS
Indoor dust, HVAC filtration, Heavy metals, Bacteria, Fungi

INTRODUCTION
HVAC filters are an untapped resource for studying particles in indoor environments. Approximately 60% of the buildings in the United States have a central forced air conditioning system that uses filters (US Bureau of Census, 2005). These filters essentially serve as long-term, passive samplers that can be collected with minimal effort and analyzed for a broad range of indoor contaminants. In this paper, we focus on fungi, bacteria, and heavy metals. The presence of microorganisms indoors has been related to several health and discomfort outcomes including infectious diseases, respiratory diseases, odors, and dissatisfaction (e.g., Gyntelberg et al., 1994). Exposure to toxic heavy metals can also cause damage to nerves, the liver and bones (e.g., Moore, 1990). Moreover, some metals have been classified as possible human carcinogens and some are linked to reproductive problems and birth defects. This paper compares concentrations of the contaminants in filters to those from air samples and settled dust.

Researchers use several different approaches to assess indoor exposure to microbial bioaerosols and heavy metals. Several studies report concentrations of microorganisms in indoor air that range from 10^2 - 10^4 CFU m^{-3} for both bacteria and fungi (Bouillard et al., 2005; Ross et al., 2000; Sessa et al., 2002). However, reported values are often difficult to compare because they vary substantially depending on several factors, including sampling technique and location. Typical floor dust concentrations for bacteria and fungi range from 10^5 to 10^7 CFU g^{-1} dust (e.g., Bouillard et al.; Nilsson et al., 2004). After isolating and identifying bacterial strains from air and settled dust samples, Bouillard et al. (2005) concluded that the latter was a better environmental support for bacterial survival and could be considered as a reservoir for microbial contamination of air. Numerous researchers have also measured heavy metal concentrations in dust samples (e.g., Adgate et al., 1998; Oliver et al., 1999). Concentrations are generally in the μg g^{-1} range, except for Pb and Zn which are generally in the mg g^{-1} range. Many of these studies were short term in nature and therefore provide a snapshot of contaminant concentrations. A potential resource that has received less attention is HVAC filters that may provide an integrated measure of indoor contaminant concentrations.

While both microbial populations and metals found in air and settled dust have been studied, their presence in HVAC dust and their relationship to these other measurements remains unclear. Microorganisms are non-conservative contaminants whose populations can increase or diminish over time depending on environmental conditions, whereas heavy metals are generally conservative contaminants that remain unchanged for long periods of time (Fubini, 1997). The objective of this study is to determine biological and heavy metal concentrations found in HVAC filter dust and compare them with those found in dust collected from other locations as well as with air samples. A goal of this study is to investigate the use of HVAC filters as a tool for characterizing occupant exposure.

METHODS

A sample of convenience of eight residential buildings located in Austin, Texas was selected for this investigation. The homes range in building age, number of occupants, presence of likely indoor sources of microbiological and heavy metal contaminants, and filter efficiencies. All of the buildings had air central air conditioning that recirculates all air, as is typical of residences in the Southern U.S.

Sample collection

Floor dust, high surface dust and HVAC filter dust samples were collected 2-3 times over a six-month period from the residences described above. A composite sample of living room and main bedroom floor dust was acquired from each building using a Dynamite Plus, Dirt Devil vacuum equipped with an Indoor Biotechnologies Duststream Collector. To avoid areas heavily soiled with outdoor particles, care was taken to ensure that the sampling area did not include surfaces near doors. A high surface sample was collected using the same vacuum technique from the top surfaces of door frames, shelves, tables and counters. Two HVAC filters were collected from the sites approximately three months apart, while the settled dust samples were collected approximately four weeks apart from each other. On a subset of five buildings, floor and high surface dust samples were collected three times. All the samples were stored in a 4º C environmental chamber until the analyses were performed.

In the same five buildings where three dust and high surface samples were collected, air samples were also collected. The sample height ranged from approximately 1 m to 1.5 m above the floor level. An impinger (SKC Biosampler®) was connected to a vacuum pump that operated at a constant volumetric flow rate of 12.5 L min^{-1} for a period of 4 hours. The microorganisms were captured in a phosphate buffer solution (PBS) consisting of 8 g/L NaCl, 0.2 g/L KCl, 1.44 g/L Na_2HPO_4, and 0.24 g/L KH_2PO_4 and stored at 4°C.

Sample analysis

The enumeration of culturable microorganisms (both bacteria and fungi) present in the bioaerosol samples, settled dust, and HVAC dust samples were completed using the standard spread plate method 9215C (APHA, 1998). The enumeration of the culturable microorganisms from the settled dust and the HVAC dust samples were similar. In both cases, the microorganisms present in the dust were transferred into the PBS solution by sonication and vortexing for 10 minutes each. For bacterial enumeration, samples were plated on R_2A agar containing 0.04% cycloheximide. For fungal counts, the aliquot was plated on Sabouraud dextrose agar (SDA) plates containing 0.01% chloramphenicol. Bacterial plates were incubated for 3-7 days at 30°C, while the fungal plates were incubated for 7-14 days at room temperature (approximately 23°C). After incubation, the number of bacterial and fungal colonies formed was counted and the results were used to estimate the airborne concentration of the viable microorganisms in CFU m^{-3} or the concentration in the dust CFU g^{-1} dust. Triplicates of each dilution were plated and the average number of colonies formed was reported. The ability of the microorganisms to form spores was also evaluated by pasteurizing an aliquot of the samples for 15 minutes at 75ºC and then plating the samples as described above. Any colonies that formed likely originated from spores and represent an estimate of the spore-forming fraction of the population. To evaluate the effect of sample storage, a subset of three HVAC filter samples were analyzed a second time after several weeks of storage at 4°C. After storage, analysis of the samples yielded an average count of 70% of the original (before storage) counts for total bacteria, 74% for bacterial spores, 47% for fungi and 75% for fungal spores.

Heavy metal concentrations in the HVAC filter, floor, and high surface dust were determined via atomic absorption spectroscopy. Dust samples were digested according to microwave-assisted digestion method 3030K (APHA, 1998) and subsequently analyzed for the selected heavy metals (Pb, As, Cd) according to method 3111B (APHA, 1998). To verify and improve the accuracy of the measurements, field blanks, reagent blanks and periodic calibration checks were also analyzed.

RESULTS AND DISCUSSION

Microbial analysis

Concentrations of culturable bacteria and fungi from each of the four sampling locations are reported in Figure 1. Multiple samples at the same site were given equal weighting, so there are 21 samples (three at each of five sites and two at the remaining three sites) of floor and high surface dust, 14 HVAC samples (two filters from each of six sites and one each from the remaining two sites), and five air samples (one each at five sites) shown in the figure. Total concentrations derive from the counts of all the microorganisms able to form colonies on the specific agar plate. Spores are the fraction of the total that is able to survive the pasteurization treatment and generate colonies. The lowest end of the box represents the 25^{th} percentile, the top represents the 75^{th} percentile, and the horizontal bar inside the box indicates the median. Single points outside the box are the outliers.

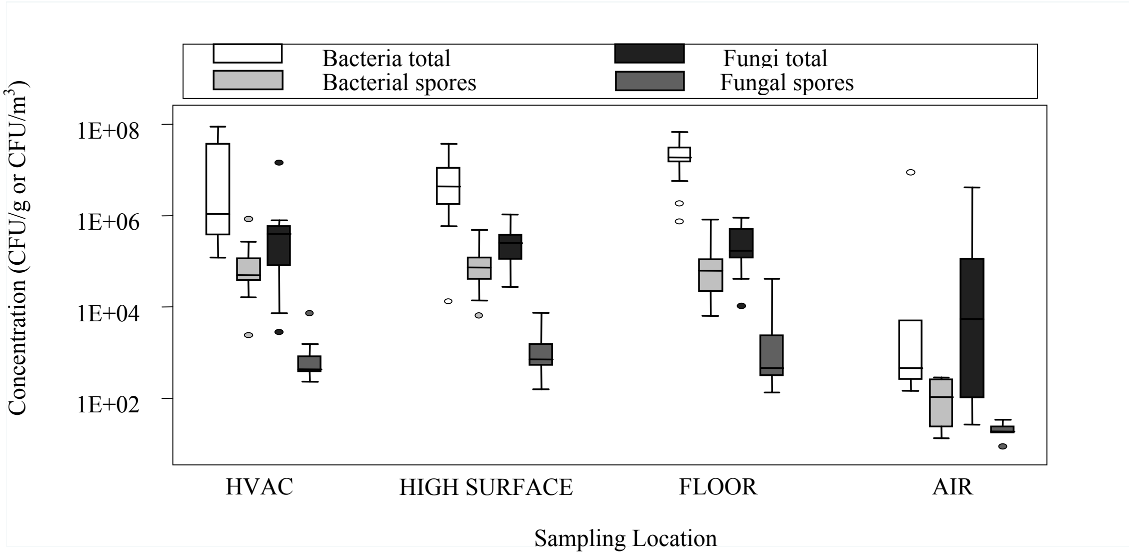

Figure 1. Culturable microbial concentrations by sampling location. Air samples have dimensions of CFU/m^3 and all others have dimensions of CFU/g.

Despite a wide range of microbial concentration data from the different sites and dust sampling locations, there are several patterns evident in the results: for all sampling locations, viable bacterial concentrations are higher than the viable fungal concentrations and spore concentrations are generally two orders of magnitude lower than the total concentrations. Total bacteria concentrations range from 10^4 to 10^7 CFU/g, with greater concentrations found on the floor, followed by high surfaces, and HVAC filter samples. In addition, total bacteria concentrations in the floor samples have a smaller range than the other two dust sampling locations. Fungal dust concentrations ranged from 10^3 to 10^6 CFU/g. Bacteria and fungal spore concentrations are more consistent across the sampling locations than the total microbial concentrations. Specifically, the distributions of bacteria spore concentrations are very similar, while a slightly larger variability can be found in the fungal spore distributions in the floor samples. Bacterial spore concentrations typically fluctuated in the 10^4 - 10^5 CFU/g range, while fungal spore concentrations tended to vary from 10^2 to 10^4 CFU/g. Different trends were observed for the air samples. For example, there are much higher fungal concentrations relative to the bacterial concentrations and greater variability. However, there were only five airborne bioaerosol samples and therefore these results should be interpreted with caution.

Figure 2 illustrates bacteria and fungi mean culturable concentrations from the eight sites investigated. For each location, the left bar represents the bacteria data while the right bar summarizes the fungal data. The entire bar represents the mean total culturable concentration, while the bottom section of the bar represents the fraction that is able to form spores and survive the pasteurization treatment. Five sites out of the total eight have the highest concentration of total bacteria in the floor samples and only two (Sites 2 and 3) have variability greater than two orders of magnitude. Also, for five sites the same sampling location has both the greatest total and spore bacteria concentration. In four sites, the same sampling location has both the greatest total bacteria and fungi concentration. From Figures 1 and 2 it is clear that both bacteria and fungi are able to populate and survive in the dust present indoors, even if they do not have the ability to form spores. Important for this work, microorganisms appear to readily colonize the dust on HVAC filters, with concentrations similar to what was found in the dust that settles inside the residences.

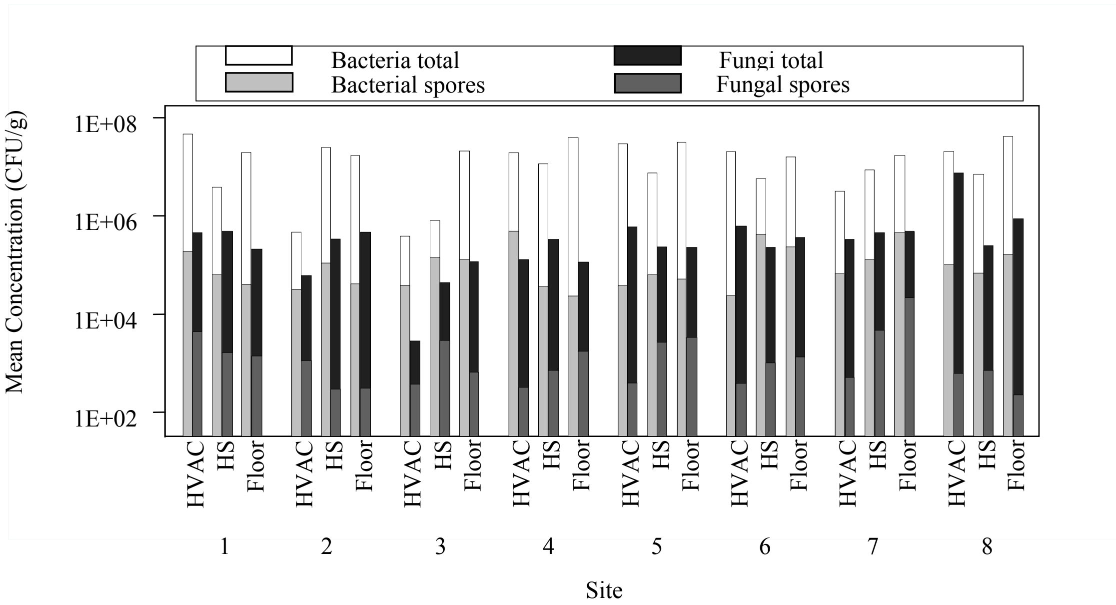

Figure 2. Mean culturable microbial concentrations by location within building.

Table 1 presents the ratio of the median microbial concentrations at each location with respect to the median concentration observed in the high surface samples. Total median bacteria concentrations in the floor samples are higher than that observed in the high surface and HVAC filter samples. An opposite trend is observed for the median total fungi concentration, which is higher on the HVAC filters than on the high surface samples; the floor samples have the lowest relative fungi concentrations. The bacterial and fungal spore data demonstrates similar trends, with both HVAC filter and floor median concentrations lower than high surfaces levels. Nevertheless, it appears that the HVAC filter dust samples provide comparable information about indoor microbial contamination as other indoor dust samples, suggesting that these filters may be a promising location for collecting samples for indoor assessments.

Table 1. Ratio of median microbial concentrations with respect to high surfaces

	Total Bacteria	Bacterial Spores	Total Fungi	Fungal Spores
HVAC	0.25	0.90	1.59	0.91
Floor	4.34	0.85	0.68	0.66

Heavy metals

Figure 3 presents the concentrations of Pb, Cd and As at the different sampling locations considered during this investigation. Of the three metals, Pb was present in the highest concentrations at all three locations with a total median concentration of 30.9 μg/g and values as high as 315.2 μg/g. This is consistent with previous studies as Pb has been reported to be abundant in indoor dust (e.g., Oliver et al., 1999). Cd and As have comparable profiles with much lower median concentrations of 1.6 and 1.3 μg/g, respectively. However, As has greater variability than Cd with values up to 75.2 μg/g. The metals concentrations found in the high surface samples are greater than those present in the other two locations for all three metals, while HVAC and floor data have similar levels.

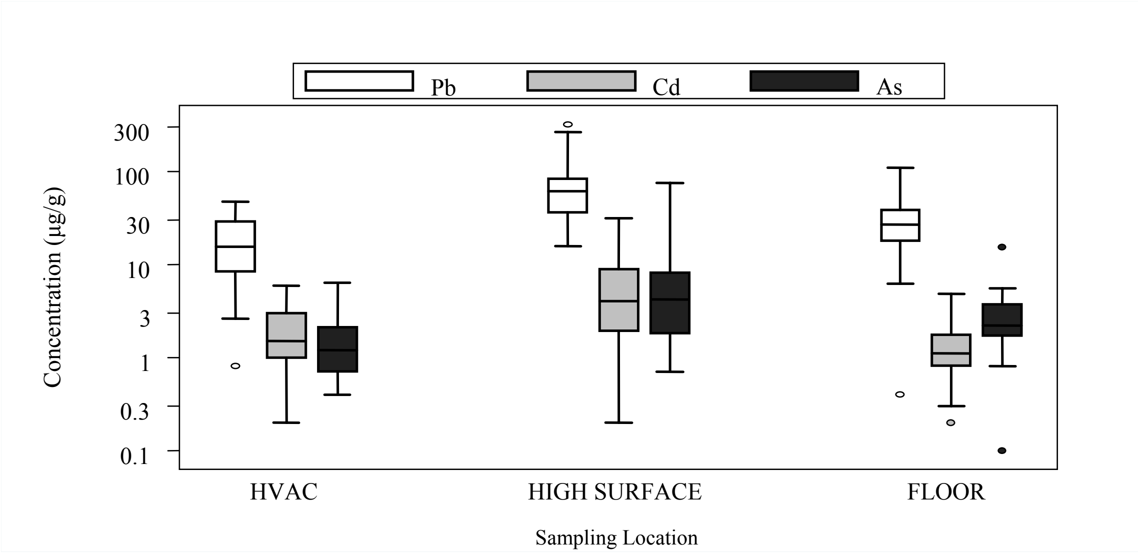

Figure 3. Heavy metal concentrations by sampling location.

Figure 4 presents mean heavy metal concentrations from the eight sites investigated. For Pb, the high surface mean concentrations were the greatest in all the eight sites investigated, while in six of the sites HVAC samples have the lowest mean Pb concentration. Cd and As have mean concentrations ranging from a fraction to a few µg/g, except for site five where the mean Cd concentration in the high surface samples reaches a mean value of 16.6 µg/g. However, there is a significant variability in the trends and it is not yet possible to identify a clear pattern. Dissimilarities detected in the samples from different sites may be due to the presence of specific sources, such as paint for Pb, or cigarette smoking for Cd. Variations observed between different dust samples may be due to particle size differences related to varying filter efficiencies and deposition locations. Therefore, the use of HVAC filters as sampling location for heavy metal requires further investigation.

Table 2 shows the ratio of the median heavy metal concentrations at each location with respect to the median concentration observed in the high surfaces samples. As mentioned above, concentrations detected in the high surface samples are greater than those found in the other two locations and therefore all the ratios are lower than 1. For Pb and As, HVAC filter samples are lower than floor samples, while for Cd, we observe the opposite situation. From these data it seems that floor dust tends to be more contaminated with Pb suggesting that leaded fuel or previous use of exterior lead paint may be possible sources. Such lead may be attached to very large particles which are less likely to be found on high surfaces or in the HVAC filter. Cd may be derived from cigarette smoke as well as from other sources, while As contamination might be associated with remodeling and wood treatment. HVAC filters seem to present heavy metal concentrations similar to those found in floor samples and with further investigation, could be utilized as a tool to rapidly evaluate possible metal contamination.

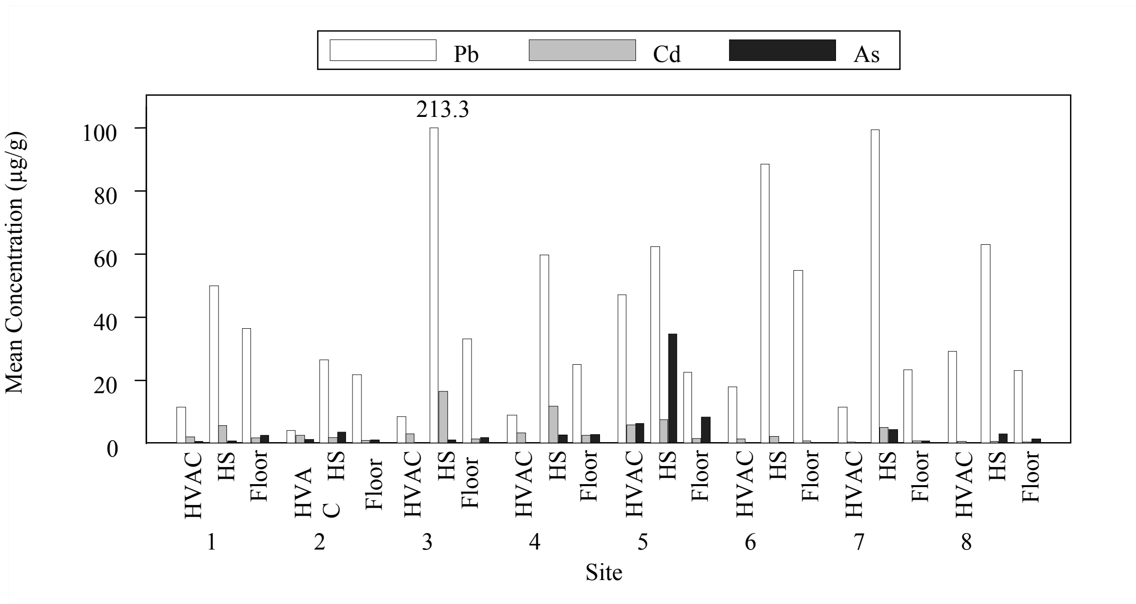

Figure 4. Mean metal concentrations by locations within building.

Table 2. Ratio of median heavy metal concentrations with respect to high surfaces.

	Pb	Cd	As
HVAC	0.19	0.38	0.11
Floor	0.44	0.27	0.38

CONCLUSIONS

We have measured and compared biological and metal concentrations in HVAC, settled dust and air samples. The culturable microbial concentrations seem to follow similar patterns with total bacteria and fungi concentrations in the range of 10^6 - 10^7 and 10^3 - 10^5 CFU/g, respectively. Spore concentrations are typically a small fraction of the total viable concentrations. HVAC filter concentrations seem to be consistent with the levels found in other locations, especially for bacterial and fungal spores as well as culturable fungi. Heavy metal concentrations found in different locations also seem to be comparable, especially for HVAC and floor samples, but the correlation is not as clear as it is for the microorganisms. High surface samples typically have the greatest concentrations of heavy metals out of the three sampling locations. We conclude that HVAC filters hold promise as a sampling mechanism, although a more extensive investigation including an evaluation of filter efficiency, filter runtime, and potentially other contaminants is warranted. The work lays the foundation for developing more extensive sampling campaigns to investigate HVAC filter dust as an integrated measure of exposure to other pollutants that have the tendency to accumulate on particles.

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