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Time-resolved Aerosol and Fluorescent Bioaerosol Concentrations in an Air-Conditioned and Mechanically Ventilated Office in Singapore

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SUMMARY

Using an ultraviolet-light induced fluorescence (UV-LIF) technique, we measured number concentrations of total aerosol particulate matter (tPM) and fluorescent biological aerosol particles (bioPM) (1.0-3.0 μm and 3.0-5.0 μm diameter) in an office and outdoors, sampling with 1-min resolution. The air-conditioning and mechanical ventilation (ACMV) system equipped with high-grade filters was effective in controlling both tPM and bioPM indoors. As expected, removal efficiencies were found to be size dependent. One human subject walking on the carpet was found to be a strong contributor to bioPM, resulting in 2-3 times higher concentration than that outdoors. Compared to the times when the room is vacant, the biological proportion of total airborne particles increased by an order of magnitude during the light walking period. Consequently, indoor-to-outdoor ratios depend on the ACMV operating conditions and on human activities. This pilot study provides preliminary data concerning the bioPM levels in an indoor environment equipped with an ACMV system. Ongoing investigations using this approach promise to improve our understanding of the processes that influence indoor bioaerosol levels and the effectiveness of control alternatives.

INTRODUCTION

Conventional indoor bioaerosol studies have relied heavily on culture-based sampling, with well-documented limitations. Alternatively, filter-based or impinger-based sampling can be used, in combination with DNA-based quantification methods. However, neither approach is well suited for studying short-term dynamic processes that might influence the concentrations and fates of bioaerosols indoors. New developments in biosensing technology utilize ultraviolet-light induced fluorescence (UV-LIF) measurement techniques for real-time detection of biological aerosol particles. This approach provides opportunities in various applications, such as in laboratory studies (Agranovski et al., 2003) and in semiurban outdoor areas. Nevertheless, few studies have used UV-LIF measurement to investigate bioaerosols in indoor environments. One example, reported by Bhangar et al. (2014), characterized fluorescent biological aerosol particle levels and occupant emissions in a mechanical ventilated classroom in the United States. To date, there are no studies utilizing UV-LIF to investigate indoor bioaerosols in tropical regions. Among other considerations, the indoor environment in tropical climates is regularly served by air conditioning and mechanical ventilation (ACMV) systems with a high propensity for condensed water, which might influence indoor levels of biological aerosol particles.

The specific aim of this preliminary investigation is to characterize the impact of an ACMV system and human occupancy on biological aerosol particles in a meeting room in an urban environment in Singapore. We report on the acquisition and analysis of simultaneously measured indoor and outdoor particle number concentrations (PNC) for total aerosol particulate matter (tPM) and for fluorescent biological aerosol particles (bioPM). Information on ACMV operation status and human activities was also obtained, all with 1-min time resolution.

METHODS

A meeting room with carpeted flooring and a central air conditioning and mechanical ventilation (ACMV) system in a university building in western Singapore was selected as the study site. The room volume was 150 m^3 based on physical dimensions. It shared ACMV ducts with nearby offices and labs. The ACMV system was a central forced-air system with integration of outdoor air intake and indoor air recirculation. The ACMV system operated from 8:00 to 22:00 every day. The room air-exchange rate (AER) was 2.6±0.3 (mean±sd) per hour when the mechanical ventilation system was on. The supply air to the room, which comprised about 90% recirculated air and 10% outdoor air (according to ACMV design), was filtered with MERV 13 filters that were replaced every 3-6 months. When the mechanical ventilation system was off, the infiltration and leakage caused the room AER to be 0.7±0.03 per hour. The AER was evaluated through sulphur hexafluoride (SF_6) tracer decay tests. The mean value and standard deviation of AER was determined from analysing three SF_6 decay tests (5 hours of data for each test when the ACMV system was on, 12 hours of data for each test when the ACMV system was off).

Observational monitoring was conducted for 6 days (1-6 Jan 2015, labelled D1-D6). The room was unoccupied during the monitoring period except 13:00 to 16:00 on D3-D6. One human subject performed light walking during the occupied period. Biotrak (Model 9510-BD; TSI, Inc.) was used to measure time-resolved number concentrations of tPM and bioPM in two particle-size ranges (1.0-3.0 μm and 3.0-5.0 μm). The device was configured to sample air during 40 s out of every 1 min. The sampling flow rate was 28 L/min. We took measurements indoors and outdoors by using tubing and an auto-switch device. The frequency of switching between indoor and outdoor samples was once per four minutes. The indoor sampling inlet (S1) was placed at the center of the study room, at a height of 1.2 m. Outdoor air (S2) was sampled via an inlet protruding from a window to the building corridor.

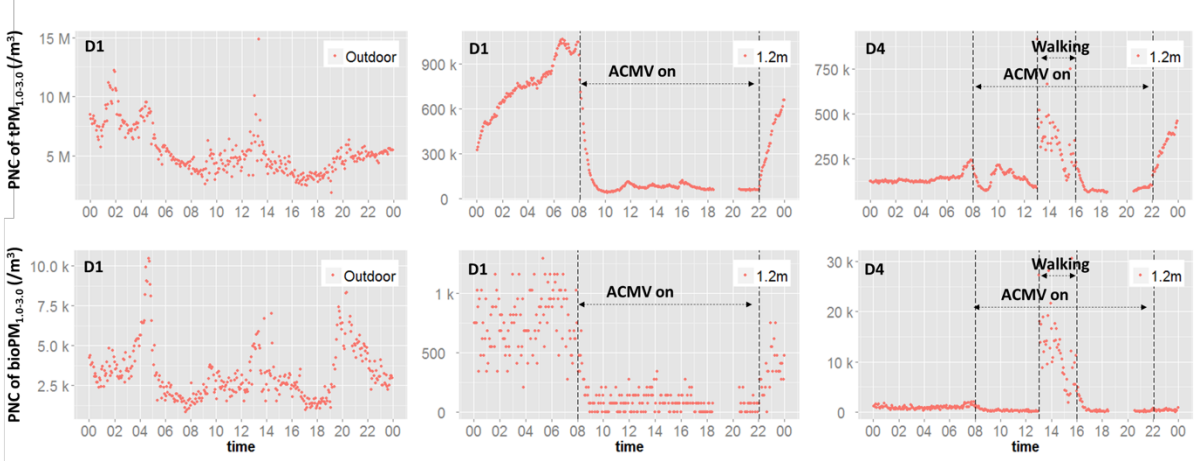
Calibration testing of aerosol losses in the tubing and auto-switch device was conducted before the monitoring period. For this purpose, the sampling inlets were collocated for 5 hours in an outdoor environment at a height of 1.2 m. We added a third sampling inlet (S3), which didn't connect with any tubing or switch device. Sample S3 was designated as the reference case. The objective was to adjust data from S1 and S2 to match as closely as possible the response of the S3, so as to offset the aerosol losses during transport from the point of sampling and the point of measurement. The calibration factors specific to S1 and S2 are 0.95±0.07 and 0.94±0.07 for $tPM_{1.0\text{-}3.0}$, 0.54±0.09 and 0.53±0.10 for $tPM_{3.0\text{-}5.0}$, 0.80±0.15 and 0.79±0.11 for $bioPM_{1.0\text{-}3.0}$, 0.52±0.12 and 0.52±0.09 for $bioPM_{3.0\text{-}5.0}$.

RESULTS AND DISCUSSION

Figure 1 illustrates the time series plots of the $tPM_{1.0\text{-}3.0}$ and $bioPM_{1.0\text{-}3.0}$ concentrations measured indoors and outdoors. Comparing outdoor tPM with outdoor bioPM (Figure 1a),

the concentration profile for bioPM didn't always follow the broad trends of the tPM, implying that their sources were time dependent and the composition of tPM was changing at different times of the day. The biological proportion of total airborne particles (BPTP) of outdoor particles in the 1.0-3.0 µm and 3.0-5.0 µm diameter range were 0.14±0.12% (mean±sd) and 0.82±0.68%, respectively, during the monitoring period.

The ACMV system served as an important indoor/outdoor air exchange pathway. The ACMV system equipped with high-grade filters effectively reduced the indoor aerosol concentrations. As shown in the concentrations plots for indoor environment (Figures 1b and 1c), the concentrations for both tPM and bioPM dropped significantly as soon as the ACMV system was turned on at 8:00, indicating the effectiveness of this removal mechanism.



(a) Outdoor concentrations on day D1

(b) Indoor concentrations on day D1

(c) Indoor concentrations on day D4

Figure 1. Time series data for the number concentrations of total particles (tPM, top 3 frames) and biological aerosol particles (bioPM, bottom 3 frames) in the diameter range 1.0-3.0 µm measured (a) outdoors on day D1, (b) indoors on day D1, and (c) indoors on day D4.

The presence of a human occupant is an important factor for both indoor tPM and bioPM. Figure 1(c) shows a significantly higher indoor concentration occurring at 13:00-16:00 on D4, which coincides with a designated light walking period. The probable causes of the observed peaks are resuspension of tPM and bioPM from the carpet and shedding from the clothing, hair or skin of the occupant. The indoor/outdoor (I/O) ratios for bioPM (2.1 for 1.0-3.0 µm particles, 3.3 for 3.0-5.0 µm particles) were significantly higher than the values for tPM (0.10 for 1.0-3.0 µm particles, 0.33 for 3.0-5.0 µm particles) (Table 1), which indicates that walking on the carpet makes a stronger contribution to bioPM than to tPM. The time-averaged BPTP indoors was 1.9% and 5.6% for the particles in the size range 1.0-3.0 µm and 3.0-5.0 µm, respectively, higher than the BPTP estimated for unoccupied periods by one order of magnitude. This result further substantiates the important role of human activities contributing to bioaerosols indoors.

Overall, across the 6 monitoring days, the time-averaged outdoor concentration of total airborne particles in the 1.0-3.0 µm (and 3.0-5.0 µm) diameter range was 4000k/m^3 (150k /m^3); the value for biological aerosol particles was 3.2k/m^3 (1.1k/m^3) (Table 1). The indoor concentrations were less than a quarter of the outdoor concentrations when the room was vacant. During occupied times, the average indoor-outdoor (I/O) ratios for bioPM were higher than the value for tPM by a factor of 20 for 1.0-3.0 µm particles and by a factor of 10

for 3.0-5.0 μm particles. These higher ratios indicate that the particles resuspended from carpet and/or shed from occupants were strong determinants of indoor bioPM levels.

Table 1 Time-averaged and size-resolved particle number concentrations (PNC) of total airborne particles (tPM, 1000 particles per m^3), biological aerosol particles (bioPM, particles per m^3), and indoor-to-outdoor concentration ratios (I/O).

Condition	**ACMV on, unoccupied**				**ACMV on, occupied**			
Particle size	**1.0-3.0 μm**		**3.0-5.0 μm**		**1.0-3.0 μm**		**3.0-5.0 μm**	
	tPM (×1000)	bioPM	tPM (×1000)	bioPM	tPM (×1000)	bioPM	tPM (×1000)	bioPM
Indoor								
PNC	106	241	3	79	228	6490	44	2989
I/O	0.03	0.08	0.02	0.10	0.10	2.1	0.33	3.3
t(h)	75	75	75	75	9	9	9	9
Outdoor								
PNC	3420	2829	145	811	2364	3130	134	901
t(h)	75	75	75	75	9	9	9	9

CONCLUSIONS

Real-time data from monitoring tPM and bioPM provides interesting and potentially important insights linking indoor environments with building operation. The number concentrations of tPM and bioPM of the particles in size range 1.0-3.0 μm and 3.0-5.0 μm in an unoccupied meeting room were lower than the outdoor levels by one to two orders of magnitude. It is also worth noting that the I/O ratios in the unoccupied room diminished significantly when the ACMV system was operating. The reduction can be attributed to particle removal provided by the high grade filters and, probably, reduced outdoor particle infiltration owing to slight pressurization of the indoor environment. Activity of human occupants was an important source for tPM and bioPM. Light walking resulted in a 2-3 times higher indoor bioPM concentration than measured outdoors. Data indicate that the biological proportion of total airborne particles was one order-of-magnitude higher during light walking, compared to times when the room was vacant. Further investigations with real-time UV-LIF instruments have the potential to inform deeper understanding of indoor bioaerosol dynamics.

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REFERENCES

Agranovski V, Ristovski Z, Hargreaves M, et al. (2003). Real-time measurement of bacterial aerosols with the UVAPS: Performance evaluation. *J Aerosol Science*, **34**, 301-317.

Bhangar S, Huffman J A, Nazaroff W W (2014). Size-resolved fluorescent biological aerosol particle concentrations and occupant emissions in a university classroom. *Indoor Air*, **24**, 604-617.