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HUMAN EMISSIONS OF SIZE-RESOLVED FLUORESCENT BIOLOGICAL AEROSOL PARTICLES INDOORS

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INTRODUCTION

Humans play a prominent role as a source of biological aerosol particles in densely occupied indoor spaces (Fox et al., 2005; Qian et al., 2012; Scheff et al., 2000). Emission processes include shedding from the respiratory tract; shedding from human skin, hair, and clothing; and resuspension of particles from the floor and other contact surfaces. Human activity levels vary on short time-scales; however, associated bioaerosol emissions have been evaluated only through time-integrated or snapshot measurement techniques. The present study utilizes continuous measurements, collected at high time-resolution over an extended duration using a fluorescence-based technique, to evaluate the influence of sitting and walking on airborne biological particle emissions. The objective of the present study is to characterize humans as sources of coarse (2-15 μm) fluorescent biological aerosol particles (FBAP) indoors. Sampling in a classroom under ordinary use was augmented by measurements during simulated activities in a chamber.

METHODS

Observational monitoring was conducted during approximately four weeklong occupied periods and three unoccupied periods over the course of a year, in a large classroom (volume ~ 650 m^3) with a single-pass mechanical ventilation system, hard tile flooring, and no history of moisture damage. Classroom observations were supplemented with 2-h experiments (or “treatments”) conducted in a carpeted, mechanically ventilated environmental chamber (volume ~ 70 m^3) that simulated an office room. Indoor FBAP levels were measured with 5-min resolution using an ultraviolet aerodynamic particle sizer (UV-APS; TSI, Model 3314). Supplementary particle and copollutant monitors were operated indoors and outdoors. Classroom occupancy levels were recorded through direct observation.

A steady-state approximation of a single-compartment material balance model (Equation 1) was applied to quantify per-person FBAP number emission rates, E_{ij}, for six particle size groups i (created from 28 UV-APS size bins between 2 and 15 μm) during each class session or treatment, j.

$$E_{ij} = N_{\text{net,avg,ij}} \times V \times (k_i + a) \quad (1)$$

In Equation (1), $N_{net,avg,ij}$ is the average increment of FBAP number concentration attributable to occupants; V is the indoor volume; a is the air-exchange rate (5 h^{-1} for the classroom, and 1.6-3 h^{-1} for the chamber); and k_i is the size-specific particle deposition rate coefficient. Values for a and k_i were based on the rate of decay of CO_2 and particles during immediate post-emission periods in the classroom (or chamber), when conditions quickly went from being occupied to unoccupied. For the analysis presented here, classroom deposition loss rates have also been applied to the interpretation of chamber data.

The increment of FBAP number concentration associated with each session was evaluated as the average concentration during the last 15-min of a lecture (classroom), or the last 60-min of a treatment (chamber), minus the appropriate baseline (i.e., the expected contribution from outdoor particles). For the chamber, the baseline was assessed as the 10-min mean concentration before each treatment was initiated, when the room was unoccupied. For the classroom, the baseline was an empirically determined "indoor concentration of outdoor particles," evaluated separately for each weeklong monitoring period based on outdoor FBAP levels before and after the study period, and the indoor/outdoor particle ratio during unoccupied periods.

RESULTS AND DISCUSSION

Figure 1 presents mean coarse (2-15 μm) FBAP emission rates (± standard errors) for varying numbers of occupants seated or walking in the chamber, with the carpeted floor exposed, or covered with plastic sheeting to suppress resuspension.

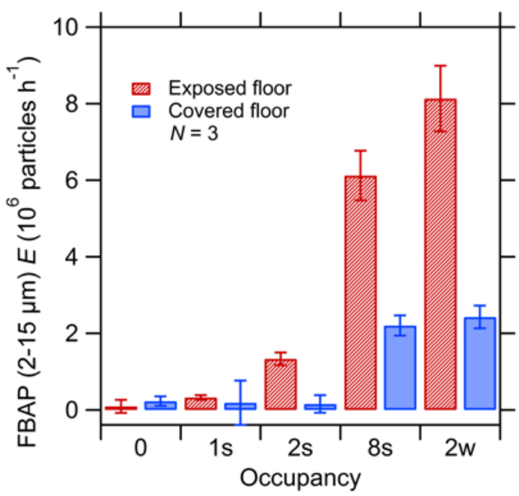

Figure 1. Estimated mean coarse (2-15 μm) FBAP number emission rates from chamber experiments, shown as a function of the number of people (0, 1, 2, or 8) seated (s) or walking (w) in the room, and the floor covering (carpet either exposed or covered with plastic sheeting).

Mean emission rates evaluated on a per-person basis were 0.6, 1, and 4 (× 10^6 h^{-1} $person^{-1}$) for the chamber-seated (N = 9), classroom lectures (N = 49), and chamber-walking (N = 3) conditions, respectively. A comparison of these means suggests that results from the chamber are reasonably representative of the real-life classroom environment sampled.

Size distributions of mean FBAP emission rates are presented in Figure 2. Patterns emerge in comparing the chamber and classroom results. The size distribution for chamber-walking emissions matches the upper 95^{th} percentile of lecture-session emissions. In contrast, both the particle size dependence and the magnitude of chamber-seated emission rates are similar to the lower 5^{th} percentile of lecture session emissions. These comparisons suggest that the spread of emissions observed during lecture classes might be explained by differences in the activity level of occupants (students and professor), who are typically predominantly seated with variations in the level of walking (e.g., by students stepping out for a break, or the professor in the course of lecturing).

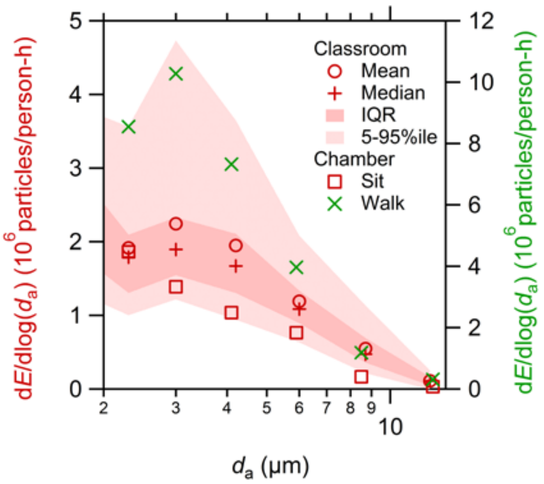

Figure 2. Size distributions of per-person emission rates of coarse FBAP numbers during lecture sessions in the classroom (*N* = 49; left axis), and seated (*N* = 9; left axis) and walking (*N* = 3; right axis) treatments in the chamber. Chamber results are shown for the floor-exposed condition. d_a is the median aerodynamic diameter of each particle size group.

Walking likely increases particle emissions relative to sitting through resuspension (from contact between shoes and flooring) and shedding (from increased vigor of bodily movements). By comparing emissions during the floor exposed vs. floor covered conditions, the floor-resuspension component is estimated to represent, on average, about 70% of walking emissions. Surprisingly, the floor covering reduced average emissions during sitting by about the same fraction, suggesting a significant portion of emissions during sitting occur through contact with the flooring (though this value is uncertain as absolute values were close to or below the limit of quantification for seated, floor-covered treatments). Seated emission rates were about 0.15 as large as walking emission rates under both floor covered and floor exposed conditions.

CONCLUSIONS

Indoor coarse FBAP emission rates from humans depended on their number and activity level. Emissions from walking and sitting were reduced when the floor was covered with clean plastic sheeting that suppressed resuspension from the flooring.

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