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Reduction of Outdoor and Indoor $PM_{2.5}$ Source Contributions via Portable Air Filtration Systems in a Senior Residential Facility in Detroit, Michigan

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Abstract

The Reducing Air Pollution in Detroit Intervention Study (RAPIDS) was designed to evaluate cardiovascular health benefits and personal $PM_{2.5}$ exposure reductions via indoor portable air filtration units among older adults in Detroit, Michigan. This double-blind randomized crossover intervention study has shown that compared to sham, air filtration for 3 days decreased 3-day average brachial systolic blood pressure by 3.2 mmHg. The results showed that HEPA-type and true HEPA air filtration units mitigated median indoor $PM_{2.5}$ concentrations by 58% and 65%, respectively. A source apportionment analysis was recently completed using a positive matrix factorization model on outdoor and indoor $PM_{2.5}$ data collected during the study. The major sources for outdoor $PM_{2.5}$ were secondary aerosols (34%), traffic (29%), iron/steel industries (18%), sewage/municipal incineration (12%), and oil combustion/refinery (7%). The major indoor sources were organic compounds (56%), traffic (17%), secondary aerosols (16%), smoking (9%), and iron/steel industries/urban dust (2%). Infiltration of outdoor $PM_{2.5}$ for sham, HEPA-type and true HEPA air filtration was 69%, 49% and 40%, respectively. The results of this study provide insights into what types of major $PM_{2.5}$ sources this community is exposed to and what type of air quality and systolic blood pressure improvements are possible in a real-world setting through the use of economical portable air filtration units.

Background & Rationale

The World Health Organization attributes more than four million deaths per year to ambient fine particulate matter ($PM_{2.5}$), mainly from heart disease, stroke, COPD, and acute respiratory infections. Given that people spend over 88% of their time indoors, interventions targeted at reducing indoor $PM_{2.5}$ could be a practical way of improving cardiovascular (CV) health (Maestas et al., 2019). The Reducing Air Pollution in Detroit Intervention Study (RAPIDS) was designed to evaluate cardiovascular health benefits and personal $PM_{2.5}$ exposure reductions via indoor portable air filtration units among older adults in Detroit, Michigan. We recently reported that among older adults living in low-income senior housing in Detroit, three-day use of HEPA filtration units reduced personal-level $PM_{2.5}$ exposures by 42% (15.7 to 9.1 μg/m^3), and translated into a reduction in systolic BP (primary endpoint) by 3.2 mm Hg (95%CI -6.1, 0.2), a trend toward lower diastolic BP (-1.5 mm Hg; 95%CI 3.3, 0.2) and improved secondary outcomes (e.g., aortic hemodynamics) (Morishita et al., 2018). The results also showed that HEPA-type and true-HEPA air filtration units mitigated median indoor $PM_{2.5}$ concentrations by 39% and 50%, respectively.

Here we present how effectively commercially available true-HEPA and HEPA-type air filtration technologies can reduce $PM_{2.5}$ indoor and outdoor source contributions. Only a few studies to date have provided complete characterization of PM sources for indoor, outdoor, and personal samples collected from high-risk subpopulations by using a receptor model such as positive matrix factorization. Furthermore, to our knowledge no studies have apportioned $PM_{2.5}$ sources for indoor and personal PM samples taken from true-HEPA and HEPA-type filtered air.

Methods

Intervention:

This study enrolled 40 non-smoking participants (mean age 67 years) from a government-subsidized low-income senior-citizen residential facility in Detroit, Michigan. In this randomized double-blind crossover intervention study, we placed 2 portable air filtration units (Fig. 1) in the bedroom and main living space of each participant's residence. Each participant served as their own control, and no two subjects from the same residence participated simultaneously. The subjects had 3 separate intervention periods, each consisting of 3 days. During each intervention period, participants were exposed to 3 blinded scenarios in random order: unfiltered air (no filter, sham), LE ("HEPA type"), and HE ("True HEPA"). Each of these intervention periods was separated by a washout period of at least one week.

Figure 1. Homes portable air filtration unit

Figure 2. pDR-1500 Aerosol monitor

Figure 3. Custom-built pump system for indoor exposure assessment

Methods (continued)

Exposure Assessment:

24-hr daily personal, indoor, and outdoor $PM_{2.5}$ concentrations were measured during each 3-day intervention period. Personal exposure samples were collected onto 37-mm Teflon filters using battery-powered particulate monitor (personal DataRAM™ pDR-1500 Aerosol Monitor). The pDR (Fig. 2) provided both real-time and 10-minute-averaged $PM_{2.5}$ concentration data. Indoor $PM_{2.5}$ samples were collected onto 37-mm Teflon filter using a custom-built pump system (Fig. 3) and Teflon-coated aluminum cyclone sample inlets at a nominal flow rate of 16.7 L/min. Outdoor $PM_{2.5}$ samples were collected using a sequential air sampler (Partisol-Plus Model 2025) located on the roof of a 3-story building 125 m from the study site. Outdoor $PM_{2.5}$ was collected on 47-mm Teflon filters for subsequent gravimetric, chemical and elemental characterization.

Mass and Chemical Analysis:

Sample handling, processing, and analysis took place in Class 100 and 1000 clean rooms at the Michigan State University Exposure Science Laboratory. Mass concentrations were determined gravimetrically using a microbalance (Model XPR6UD5, Mettler Toledo) after the filters had been conditioned for 24 hours in a temperature- and humidity-controlled environment. Quartz filters were analyzed for organic carbon (OC) and elemental carbon (EC) by the NIOSH 5040 method using a thermal-optical OC/EC analyzer (Model 5L, Sunset Labs). The concentrations of 36 trace elements were determined by inductively-coupled plasma mass spectrometry (ELEMENT2, Thermo Fisher). The Teflon filters were extracted by an acid digestion process as described previously (Morishita et al., 2009).

Data Analysis:

Source apportionment analysis was completed using 36 trace metal concentrations and uncertainties quantified by ICP-MS from 257 outdoor samples and 358 indoor samples. Major emission sources contributing to outdoor and indoor $PM_{2.5}$ levels in Detroit were determined via EPA Positive Matrix Factorization (PMF) 5.0.

Results

The mean ambient $PM_{2.5}$ concentration across all exposure periods was 9.3 ± 4.1 μg/m^3. The mean indoor $PM_{2.5}$ concentrations for sham, LE, and HE were 17.5 ± 16.9 μg/m^3, 8.4 ± 5.4 μg/m^3, and 7.0 ± 4.5 μg/m^3, respectively.

Five sources of outdoor $PM_{2.5}$ were identified by PMF (Fig. 4): secondary aerosol (34%), traffic (29%), iron/steel industries (18%), sewage/municipal incineration (12%), and oil combustion/refinery (7%). The five sources of indoor $PM_{2.5}$ included organic compounds (56%), traffic (17%), secondary aerosols (15%), smoking (8%), and iron/steel industries/urban dust (2%). 19% of the indoor $PM_{2.5}$ was unidentified. The profiles of the five indoor $PM_{2.5}$ sources are shown in Figure 5.

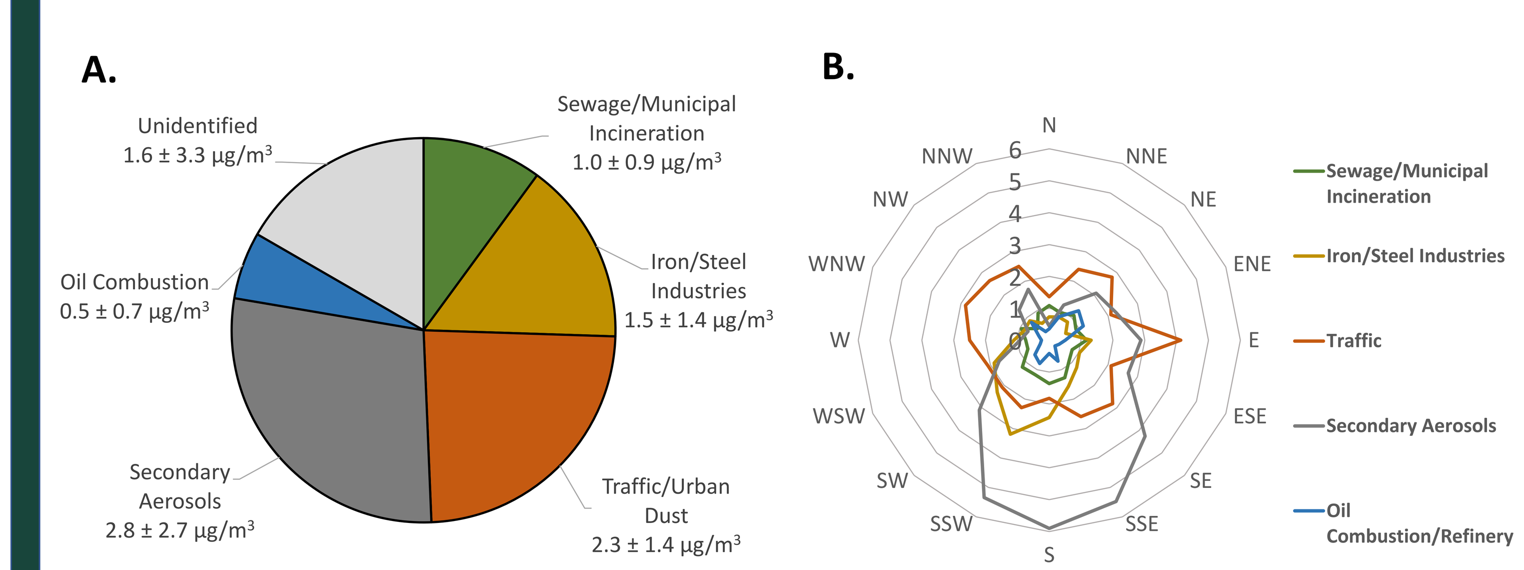

Figure 4. **(A)** Average factor contributions to outdoor $PM_{2.5}$ and **(B)** Average outdoor $PM_{2.5}$ sources as a function of wind direction during the sampling period (units: μg/m^3).

Results (continued)

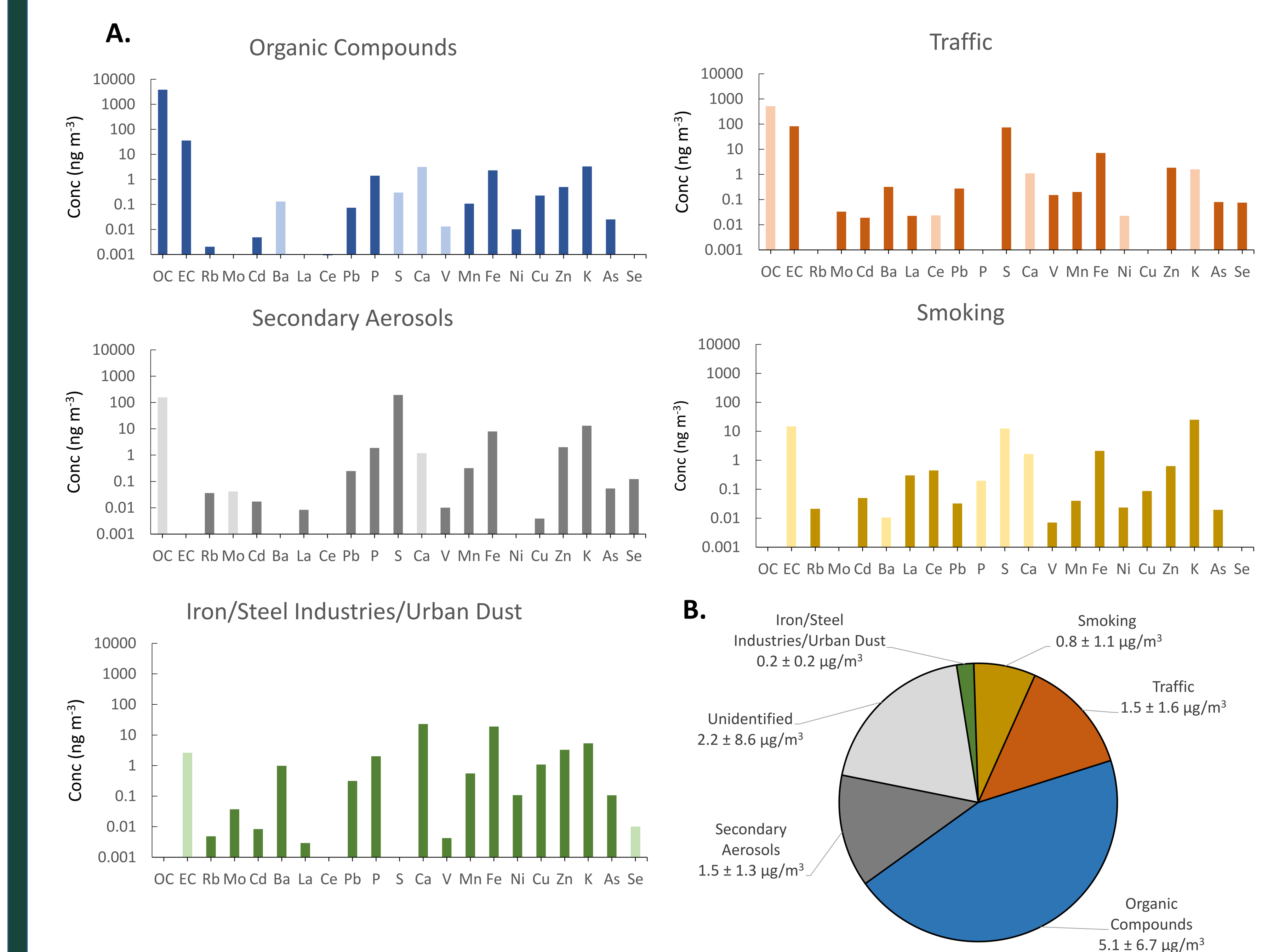

Figure 5. **(A)** Indoor $PM_{2.5}$ factor profiles. Highlighted elements are statistically significant according to the 5th percentile of the bootstrap analysis. **(B)** Average factor contributions to indoor $PM_{2.5}$.

Infiltration of outdoor $PM_{2.5}$ for sham, LE and HE air filtration was calculated based on the secondary aerosol source. This is an outdoor source and is commonly recognized to include emissions from regional coal-fired utility boilers/power plants as they have been associated with the highest contributions to sulfur and selenium. The infiltration of secondary aerosols for sham, LE, HE was 69%, 49%, and 40%, respectively (Fig. 6).

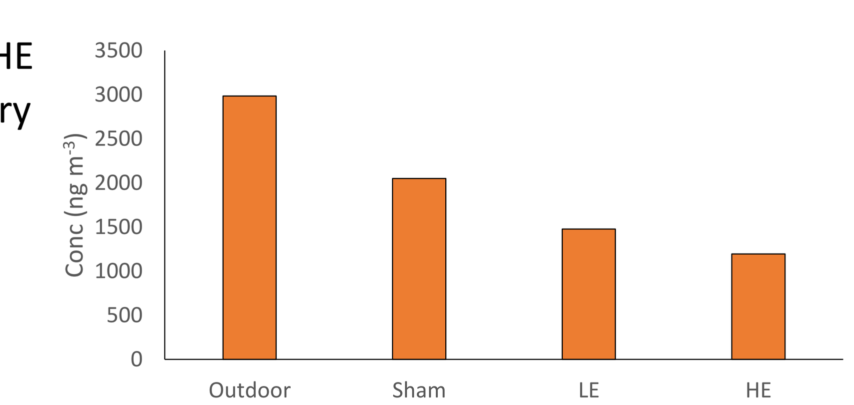

Figure 6. Infiltration of outdoor secondary aerosols across the three intervention types: sham, LE, and HE.

Future Direction

The results show that commercially-available portable air filtration units can effectively reduce $PM_{2.5}$ concentrations from both indoor and outdoor sources in older adults' residences in Detroit, Michigan. Personal $PM_{2.5}$ filters collected during this study are currently being analyzed, and source apportionment analysis will follow.

Acknowledgements & References

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