Supplemental Material

Recirculating Air Filtration Significantly Reduces Exposure to Airborne Nanoparticles

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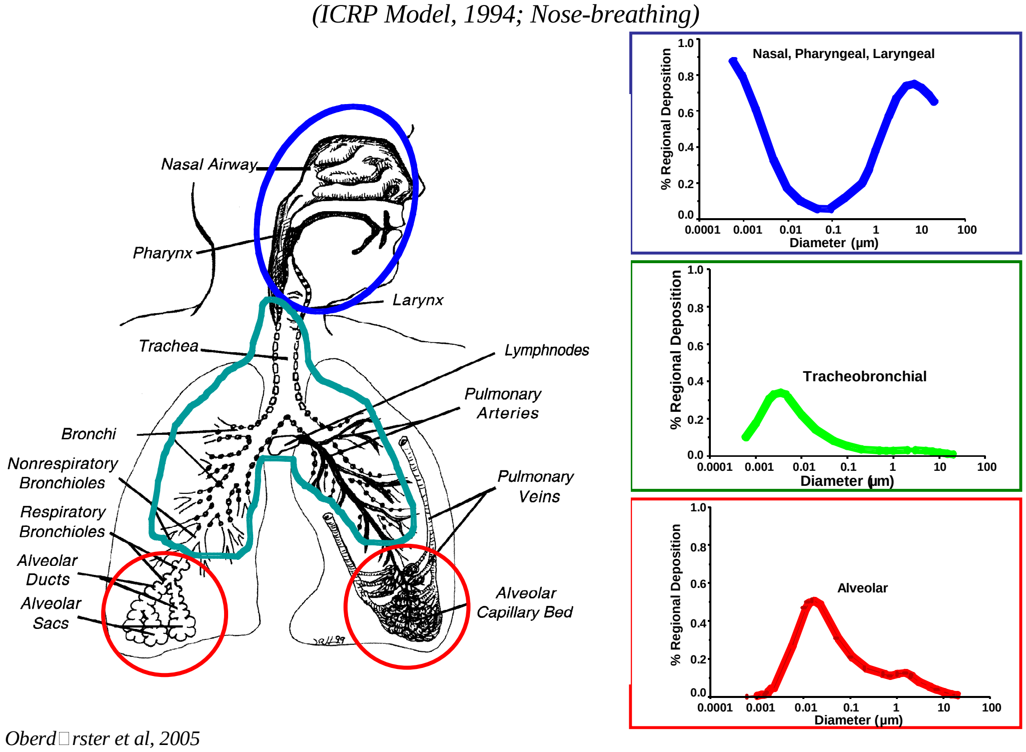
Supplemental Material, Figure 1

Fractional Deposition of Inhaled Particles in the Human Respiratory Tract

(ICRP Model, 1994; Nose-breathing)



Supplemental Material, Figure 1. Fractional deposition of inhaled particles during nose breathing in the human respiratory tract (ICRP 1994). Reproduced from Oberdörster et al. (2005) on EHP.

Supplemental Material, Figure 2.

ON-ROAD EVALUATIONS – NON-RECIRCULATION MODE

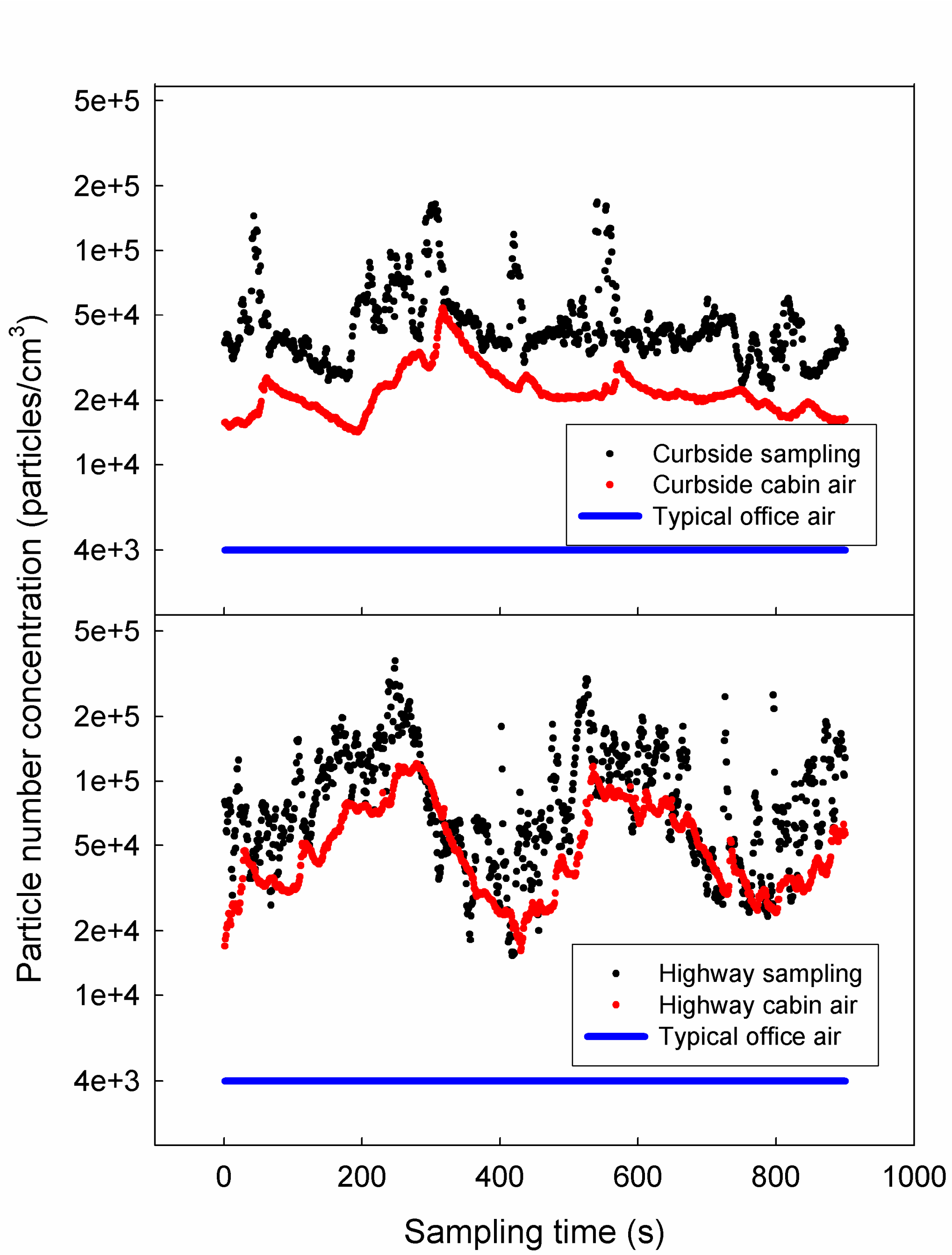
On-road evaluations were conducted in a Saab 93 (2003 model). Two portable condensation particle counters (CPC, TSI 3007, TSI Inc., USA) were used to measure particle number concentration outside and inside of the vehicle's cabin, while it was driven through traffic. The CPC measures the number concentration of particles larger than 10 nm in diameter, and smaller than approximately 1 µm. Particle removal efficiency was evaluated with the car either parked on the curbside during heavy traffic (with both engine and ventilation systems running), or while driving through heavy traffic.

For the measurements, air recirculation was turned off, meaning that cabin air was continuously being replenished with outside air that had passed through the cabin air filter. The ventilation system was set to level 2, (medium), corresponding to 10.8 cm/s face velocity for the filter. For the tested Saab 93, the ventilation flow rate at level 2 is 60 l/s and the cabin volume is 2.55 m^3, giving an air change rate of 43 s.

Figure 2 shows in-car and outside-car particle number concentrations as a function of time, for the car parked on the curbside (top panel), and driving in heavy traffic (bottom panel). The average particle removal efficiency from these data is about

46%. For comparison, the aerosol concentration measured using a Condensation Particle Counter (CPC, Model 3007, TSI Inc., USA) in a well-ventilated office (averaging 4000 particles/cm^3) has been indicated on the plot. This is a typical concentration for such an environment measured in this study.

Obviously, in-car ventilation system with a cabin air filter operating at non-recirculation mode is capable of reducing on-road UFP exposure. However, the in-cabin particle concentration is still significantly higher than the typical office condition. Exposure reduction higher than 46% is more desirable.



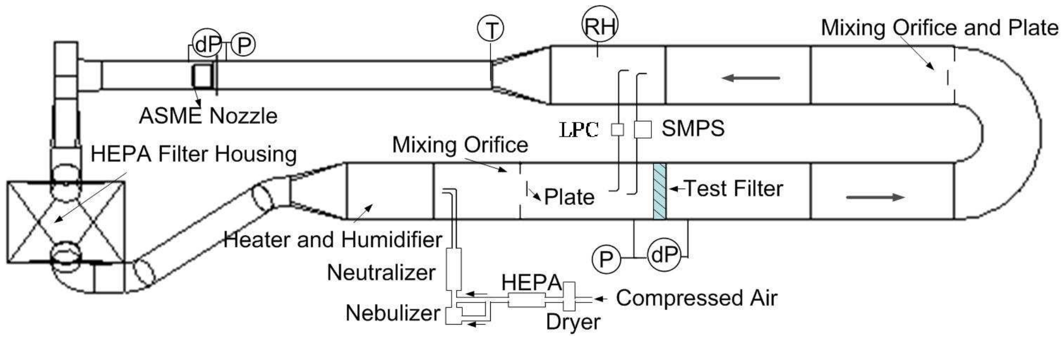
Supplemental Material, Figure 2. Measured particle concentration inside and outside a Saab 93 (2003 model) with ventilation recirculation turned off, and with the ventilation level set to level 2. The top panel shows particle number concentrations while parked by the curbside, while the bottom panel shows particle number concentrations while driving through heavy traffic on highway. For comparison, aerosol number concentration measured in a well-ventilated office is also shown (4000 particles/cm^3).

Supplemental Material, Figure 3 and 4

LABORATORY EVALUATIONS – WIND TUNNEL FILTER TEST

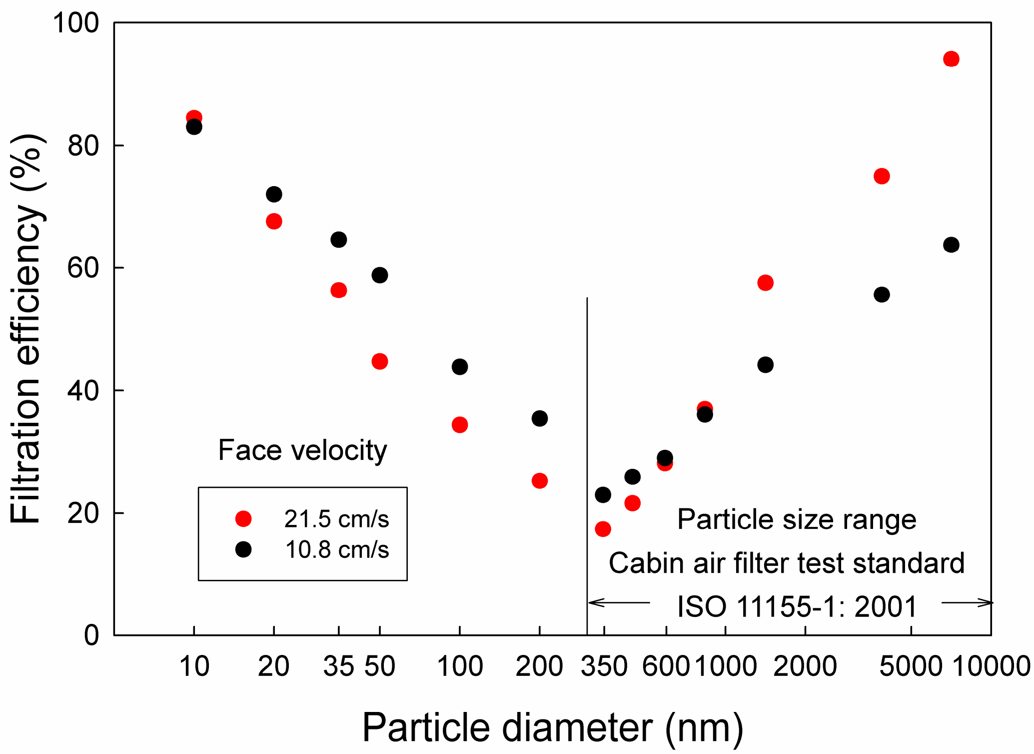
Wind tunnel filter efficiency measurements were made on the cabin air filter from the Saab 93 – which was considered to be representative of a typical cabin air filter.

Tests were conducted in an American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) 52.2–1999 wind tunnel (ASHRAE 1999, Figure 3). New filters purchased from a Saab dealership were mounted in a filter holder and inserted into the tunnel. Two test face velocities (10.8 cm/s and 21.5 cm/s) were selected to maintain the same face velocity of air flow through the filter as occurred in the vehicle when its ventilation flow rate was set at level 2 (medium) and level 5 (high) respectively. Following the ISO 11155-1 test standard for cabin air filter (ISO 2001), test particles were generated using a 10% (volume base) potassium chloride solution in a Six-jet Atomizer (TSI 9306A, TSI Inc., USA). Particles upstream and downstream of the filter were counted by laser particle counters (LASAIR and LASAIR II, Particle Measuring Systems Inc., USA) in 8 size bins from 0.3-10 μm. Filter efficiency as a function of particle size was obtained from the ratio of measured upstream and downstream particle number concentrations. Filter efficiency over the lower particle size range 10-300 nm was measured using a Differential Mobility Analyzer (DMA, TSI 3081, TSI Inc., USA) and an Ultrafine Condensation Particle Counter (UCPC, TSI 3025A, TSI Inc., USA). Upstream and downstream particles were classified within six discrete size ranges using the DMA. Particle number concentration within each size bin was measured using the UCPC, and filter efficiency calculated as a function of particle size from the ratio of upstream and downstream measurements.



Supplemental Material, Figure 3. Laboratory filter test facility: ASHRAE 52.2 – 1999 Classified Wind Tunnel

Laboratory measured filtration efficiencies of the cabin air filter as a function of particle size shown in Figure 4 demonstrate a characteristic "V" shape curve (Hinds 1999), with a minimum filtration efficiency at approximately 350 nm. This particle size is commonly referred as the Most Penetrating Particle Size (MPPS). Smaller particles (10-100 nm) are captured mainly by diffusion, and larger particles (1-10 μm) by interception and impaction mechanisms. The minimum measured efficiency was 22.9% at a flow rate equivalent to a medium ventilation system setting (filter face-velocity of 10.8 cm/s), and 17.4% at a flow rate equivalent to the highest ventilation system setting (filter face-velocity of 21.5 cm/s). This result indicates that the cabin air filter installed by the car manufacture is relatively inefficient (compared to HEPA filter). As is seen in Figure 4, the ISO Test Standard evaluates cabin air filter performance above the MPPS, and provides no information on performance when challenged with nanoparticles.



Supplemental Material, Figure 4. Measured filtration efficiency of a Saab 93 cabin air filter. The lower and higher filter face velocities correspond to in-car ventilation settings of 2 (medium) and 5 (high) respectively.

References:

ASHRAE. 1999. Method of testing general ventilation air cleaning devices for removal efficiency by particle size. American Society of Heating, Refrigeration, and Air Conditioning Engineers.

Hinds WC. 1999. Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles. 2nd ed. New York: Wiley-Interscience.

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