HEPA AIR FILTRATION: AN EFFECTIVE METHOD OF REDUCING HOUSEHOLD PM EXPOSURE

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ABSTRACT
Carpeted bedrooms of 36 asthmatic children were monitored to examine the mass concentration of indoor aerosol particulate matter (PM), from non-smoking households, and the effect high efficiency particle arresting (HEPA) air filtration had on PM concentration. Concurrent indoor and outdoor monitoring was also undertaken. Mass concentration was determined gravimetrically using time weighted concurrent virtual impaction sampling.

Indoor PM mass concentration was higher than outdoor PM mass concentration. The intervention reduced PM mass concentration in the air-filter group by approximately 50% (P<0.01); with mean indoor PM₁₀ and PM₂.₅ mass concentrations falling from 42 µg m⁻³ and 25 µg m⁻³ to 21 µg m⁻³ and 14 µg m⁻³ respectively. PM mass concentration remained low for the length of the experiment while the control group PM mass concentrations fluctuated throughout the monitoring period.

INDEX TERMS
Particulate matter, HEPA air filter; Air filter intervention, Carpet, Asthma

INTRODUCTION
Many contaminants spanning a wide range of chemical, physical and biological species impact on respiratory function. Nevertheless, in terms of air pollutants, particulates are considered by many to be one of the biggest threats to human health (Jones, 1999). The consequences of PM inhalation can be manifest in a wide range of conditions that typically decrease in incidence whilst increasing in severity. Such conditions range from the most severe, such as: cancer; leukaemia; cardio-vascular disease; respiratory hypersensitivity and infection to the less severe, such as: allergy, rashes, fatigue and general ill-health (Etkin, 1994, Wilson and Spengler, 1996).

In many Australian homes today, low indoor air exchange rates and a wide range of materials acting as sources and sinks of indoor air pollutants, means the quality of indoor air bears little resemblance to that of outdoor air (Jones, 1999). The quality of indoor air is often inferior to that of outdoor air, with the concentration of PM and many other indoor air pollutants exceeding concentrations outdoors (Samet et al., 1988). There are several major classes of indoor PM spanning combustion, plant, animal, mineral, home and personal care and radioactive particulates (Owen et al., 1990). The combustion of carbonaceous fuels produce a wide array of indoor PM species, many of which are found in high concentrations (Etkin, 1994, Lighty et al., 2000). Most combustion particles are elemental carbon followed by a significant percentage of condensed volatiles. Because of their high surface areas: carbonaceous particles tend to be ideal respiratory delivery vehicles for a range of bound substances, particularly aromatic hydrocarbons and transition metals (Lighty et al., 2000).

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Several studies have shown that the fine fraction of combustion particles easily penetrates indoors (Hansen and Burroughs, 1999) and can reach concentrations of up to 70% of outdoor levels (Legislate Assembly, 1998).

From a respiratory focus, other problematic indoor PM species include: pollen, spores, fungi, mould animal fibres such as hair and fur, insect body parts, dog, cat, dust mite and cockroach allergen, epithelial cells, endotoxin and viruses (Owen et al., 1990).

Compounding the risk to health from poor indoor air quality is the fact that people spend more than 80% of their time indoors (Wiley et al., 1990, Dingle et al., 1993). For children the risk from indoor air is further elevated because they breathe more air per body weight than adults and are generally more susceptible to toxins than adults.

Given the links between PM and respiratory irritation, it may be possible to reduce the risk of adverse health effects by improving indoor air quality and thereby reducing exposure to PM. Indoor air quality can be improved by physically removing contaminants via air filtration. Several recently conducted studies have demonstrated the benefits of high efficiency particulate arresting (HEPA) air filtration as a way to reduce exposure to allergens and respirable particles (Kildeso et al., 1998, van der Heide et al., 1999).

In assessing the hazards from PM exposure, the mass concentration of three particle sizes is usually measured: with particle size related to the probability of deposition within the respiratory system. Particles smaller than 2.5 microns (PM$_{2.5}$) tend to penetrate the alveoli region of the lungs while particles smaller than 10 microns (PM$_{10}$) tend to penetrate only as far as the tracheo-bronchial region. Inhalable particles larger than 10 microns (PM$_{10}$) tend to be captured in the head airways region (Stone and Donaldson, 1998). Filters classified as HEPA are designed to be most efficient at removing particles smaller than 2µm and must be capable of removing particles as small as 0.3µm with a minimum efficiency of 99.97% from an air-stream (Singh, 1990).

**METHODS**

Participants from non-smoking households were recruited through local primary schools within an area of 40km$^2$. Seventeen participants were assigned to a placebo group (referred to as control group) while 19 were assigned to the intervention group (referred to as the air-filter group). Allocation to any group was random, however geographic distribution needed to be approximately equal; this was achieved by clustering the location of participants on a map.

Participants of both the placebo and intervention groups had a Defender™ air filter placed in their bedroom, in the case of the placebo group the filter media was removed. The filter media exceeded HEPA standards, having an efficiency of more than 99.99% for particles larger than 0.1µm and greater than 99.97% efficiency for particles between 0.09µm and 0.1µm in diameter. Air filters were operated continuously over the 15-week intervention period: on low during the night and medium during the day. Based on an operation of 10hrs at low and 14hrs at medium, average airflow equates to approximately 93m$^3$ hr$^{-1}$. The air exchange rate of the filter to the bedroom ranged from approximately 2hr$^{-1}$ to 5hr$^{-1}$ with a mean of 4hr$^{-1}$.

Starting in April 2000, every three weeks, for 15 weeks, the participant’s bedroom was monitored to determine the time-weighted gravimetric mass concentration of airborne particulates. Monitoring took place between 11am and 7pm, 4hrs during and 4hrs after
school. Some homes were monitored both indoors and outdoors. Outdoor sampling was conducted within 2m of the building envelope. Using a TSI Respicon™, three size fractions of airborne particles were simultaneously collected onto individual filters, PM$_{2.5}$, PM$_{10}$ and PM$_{TI}$. Respicon’s were coupled to SKC Aircheck™ (224-PCXR8) sample pumps: calibrated to 3.11L min$^{-1}$ using a 1-litre soap film calibration tube. Monitoring equipment was set-up before 10am. The equipment was placed approximately one metre from any wall, with the sample head one metre above the ground and at least two metres from an air filter. Pallflex Emfab™ TX40H120 filters were used in the Respicon’s.

Weighing took place in a humidity controlled (RH<40%) ‘balance room’ with an air temperature variation of less than 3°C. Filters were weighed on a six-figure Sartorius™ 4g micro-balance. Before being weighed, filters were conditioned for at least two-hours, both before and after use. The balance was calibrated weekly and filter blanks regularly used to ensure weighing accuracy. The weight of the filters before and after sampling was determined and the mass concentration of each size fraction calculated as per instrument specifications.

Statistical analysis was undertaken using paired t-test and ANOVA with a CI of 95%.

RESULTS

No significant variations were observed across the initial data set for all: PM$_{2.5}$ (P=0.39); PM$_{10}$ (P=0.31) and PM$_{TI}$ mass concentrations (P=0.27).

Over 400 sets of samples were collected during the study. During the course of the intervention no significant fall, in any size fraction was detected in the control group, however, a significant decrease was observed in every size fraction of the air-filter group when the first and last monitored values were compared (P≤0.03). Over the 15-week period, PM$_{TI}$ mass concentration fell by approximately 40%, PM$_{10}$ by 52% and PM$_{2.5}$ by 48%. PM$_{ET}$ and PM$_{TB}$ fell by approximately 33% and 60% respectively.

Table 1 summarises the changes in PM mass concentration between the first and last monitored paired data. For example, in the air-filter group, the mean concentration for the PM$_{TI}$ size fraction was 58µg m$^{-3}$, during the course of the intervention it decreased to 35µg m$^{-3}$. PM$_{TB}$ refers to particles greater 2.5µm and less than 10µm in aerodynamic diameter, while PM$_{ET}$ refers to inhalable particles larger than 10µm.

<table>
<thead>
<tr>
<th>PM size fraction</th>
<th>First µg m$^{-3}$</th>
<th>Last µg m$^{-3}$</th>
<th>First µg m$^{-3}$</th>
<th>Last µg m$^{-3}$</th>
</tr>
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<tbody>
<tr>
<td>PM$_{TI}$</td>
<td>58</td>
<td>35 (P&lt;0.01)</td>
<td>44</td>
<td>35 (P=0.09)</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>40</td>
<td>19 (P&lt;0.01)</td>
<td>32</td>
<td>27 (P=0.15)</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>25</td>
<td>13 (P=0.03)</td>
<td>19</td>
<td>19 (P=0.49)</td>
</tr>
<tr>
<td>PM$_{TB}$</td>
<td>15</td>
<td>6 (P&lt;0.01)</td>
<td>13</td>
<td>8 (P=0.07)</td>
</tr>
<tr>
<td>PM$_{ET}$</td>
<td>18</td>
<td>12 (P&lt;0.01)</td>
<td>13</td>
<td>8 (P=0.05)</td>
</tr>
</tbody>
</table>

Ninety-eight paired sets of samples were collected concurrently in the bedroom and outdoors. Mean PM mass concentrations were higher indoors than outdoor. The mean outdoor PM$_{TI}$, PM$_{10}$ and PM$_{2.5}$ mass concentration was 31µg m$^{-3}$, 26µg m$^{-3}$ and 11µg m$^{-3}$ respectively.
Unlike the control group, indoor PM mass concentrations fell to near ambient mass concentrations in the air-filter group.

**DISCUSSION**

The intervention significantly reduced airborne PM concentration with air-filter indoor PM mass concentrations reduced to near ambient concentrations. For example, indoor versus outdoor mean PM$_{2.5}$ mass concentrations were 35 µg m$^{-3}$ and 31 µg m$^{-3}$ respectively, while PM$_{2.5}$ concentrations were 13 µg m$^{-3}$ and 11 µg m$^{-3}$ respectively. PM concentration in the air-filter group fell quickly and plateaued out after approximately eight weeks. The results further indicate that the intervention was most effective at reducing PM$_{TB}$ mass concentration (particles >2.5 <10 microns in aerodynamic diameter)

Several studies have demonstrated reductions in airborne PM concentration via the use of HEPA air filtration. Reisman et al. (1990) demonstrated a reduction in concentration of particles smaller than 0.3 µm by 70% (throughput 8.5 m$^{3}$ min$^{-1}$). Pierce et al. (1996) demonstrated an 80% reduction of PM$_{10}$ in a smoking lounge (throughput ~30 m$^{3}$ min$^{-1}$). Wiser (2000) demonstrated a 73% reduction in PM$_{10}$ in a restaurant (air exchange rate 9.5 m$^{3}$ hr$^{-1}$). Miller-Leiden et al. (1996) demonstrated that increased filter throughput resulted in an increased PM reduction. Throughput and air exchange was considerably lower in this study at approximately 2 m$^{3}$ min$^{-1}$ and 4-air exchanges per hour. Despite lower air exchange rates this study demonstrated that HEPA air filtration at lower air exchange rates can effectively reduce indoor aerosol PM concentrations to near ambient levels. The air filters used could be operated at higher rates, however to do so would have increased operational noise at the expense of participant’s comfort.

The mean mass concentrations of PM$_{2.5}$, PM$_{10}$ and PM$_{10}$ were higher indoors than outdoors both before the interventions started and after the interventions finished. Such findings are consistent with previous research that reports indoor airborne PM mass concentrations often exceed outdoor PM mass concentrations (Lachenmyer and Hidy, 2000, Gras et al., 2000) and that ambient PM mass concentrations vary seasonally.

**CONCLUSION AND IMPLICATIONS**

This study examined the characteristics of airborne particulate matter within the carpeted homes of 36 Perth asthmatic children and the effectiveness of HEPA air filtration in reducing PM mass concentration. The mean mass concentrations of PM$_{2.5}$, PM$_{10}$ and PM$_{10}$ were higher indoors than outdoors both before the intervention started and in the control group after the intervention finished. The intervention significantly reduced the aerosol PM mass concentration of all measured size fractions to near ambient concentrations thereby reducing the potential for PM exposure and inhalation. Such an intervention may prove beneficial to asthmatic sufferers, particularly children, who can be sensitive to coarse and fine PM.

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REFERENCES


