Indoor Air and Air Cleaners: An Inside Look

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Outline

• Indoor air quality
• Air cleaners
• Questions and discussion
Indoor Air Quality
Indoor Air Quality

• We spend most of our time indoors (~85%)\(^1\)

• Indoor air contains a mixture of contaminants from both indoor and outdoor sources

• Can be biological, radiological, and chemical – we will focus on chemical contaminants
## Common indoor contaminants

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Description</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$</td>
<td>Liquid or solid particles smaller than 2.5 µm</td>
<td>environmental tobacco smoke (ETS), cooking, cleaning, wood stoves; wood burning, traffic, forest fires, industrial processes</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>Gas; odorous, brown, highly corrosive.</td>
<td>kerosene heaters, un-vented gas and wood stoves, ETS; traffic, industrial processes</td>
</tr>
<tr>
<td>CO</td>
<td>Gas; odorless, tasteless</td>
<td>unvented (or improperly vented) kerosene &amp; gas space heaters, gas water heaters, wood stoves, fireplaces; traffic, industrial processes</td>
</tr>
<tr>
<td>Ozone</td>
<td>Gas; highly reactive</td>
<td>Ozone generators, office equipment; traffic, industrial processes</td>
</tr>
<tr>
<td>VOCs</td>
<td>Gases; highly volatile</td>
<td>Off-gassing from paint, furniture, building materials, cleaning supplies, pesticides, office equipment, chemical manufacturing</td>
</tr>
<tr>
<td>Contaminant</td>
<td>Guideline values</td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>--------------------------------------------------------</td>
<td></td>
</tr>
</tbody>
</table>
| PM$_{2.5}$ (1987) | - 40µg/m$^3$ for 24 hr*  
|                | - 100 µg/m$^3$ for 1 hr                                |
| NO$_2$ (1987)    | - 100 µg/m$^3$ (0.05 ppm) for 24 hr  
|                | - 480 µg/m$^3$ (0.25 ppm) for 1 hr                     |
| CO (2010)        | - 11.5 mg/m$^3$ (10 ppm) for 24 hr  
|                | - 28.6 mg/m$^3$ (25 ppm) for 1 hr                     |
| Ozone (2010)     | - 40 µg/m$^3$ (20 ppb) for 8 hr                         |
| Formaldehyde (2006) | - 50 µg/m$^3$ (40 ppb) for 8 hr  
|                | - 123 µgm$^3$ (100 ppb) for 1 hr exposure              |

*Major revision underway on these guideline values; revised document will be posted to the Canada Gazette by summer 2011*

Adapted from Dales et al. 2008$^2$
Outdoor sources

- Outdoor air also impacts indoor air quality
- The fraction of contaminants that move indoors and remain in the air can be quantified: **infiltration**

Modified from Thatcher and Layton (1995)
Infiltration

\[ F_{\text{inf}} = \frac{P \ a}{a + k} \]

\( F_{\text{inf}} \) = infiltration efficiency
\( P \) = penetration
\( a \) = air exchange
\( k \) = deposition
Infiltration of contaminants

Ozone:
- penetration of ozone to indoors is low
- reacts with building materials as it moves indoors
- primarily moves through open windows in summer
- once indoors, ozone is quickly removed (half-life is 7-10 minutes)\(^4\)

\(\text{NO}_2\)
- ~ 50-70 % of \(\text{NO}_2\) infiltrates from outdoors
- Indoor sources are dominant for \(\text{NO}_2\) in homes
Infiltration: Particulate matter

- $F_{inf}$ is influenced by several factors, including particle size.

<table>
<thead>
<tr>
<th>Particle Size</th>
<th>Penetration Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM &gt; 10 μm</td>
<td>0 %</td>
</tr>
<tr>
<td>PM 2.5 - 10 μm</td>
<td>Penetration efficiency</td>
</tr>
<tr>
<td>PM &lt; 2.5 μm</td>
<td>100 %</td>
</tr>
<tr>
<td>Mean $F_{\text{inf}}$</td>
<td>Season</td>
</tr>
<tr>
<td>------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>Non-A.C. = 0.86</td>
<td>Summer</td>
</tr>
<tr>
<td>A.C. = 0.69</td>
<td></td>
</tr>
<tr>
<td>0.74</td>
<td>Summer</td>
</tr>
<tr>
<td>0.74</td>
<td>Spring-Summer &amp; Fall-Winter</td>
</tr>
<tr>
<td>0.70</td>
<td>Fall</td>
</tr>
<tr>
<td>0.66</td>
<td>Summer &amp; Winter</td>
</tr>
<tr>
<td>0.65</td>
<td>Annual</td>
</tr>
<tr>
<td>0.62</td>
<td>Annual</td>
</tr>
<tr>
<td>0.59</td>
<td>Annual</td>
</tr>
<tr>
<td>0.50</td>
<td>Winter</td>
</tr>
<tr>
<td>0.48</td>
<td>Annual</td>
</tr>
<tr>
<td>0.30</td>
<td>Winter</td>
</tr>
<tr>
<td>0.61</td>
<td>Summer</td>
</tr>
<tr>
<td>0.27</td>
<td>Winter</td>
</tr>
</tbody>
</table>
Improving indoor air quality

1. Reduce indoor-generated pollution

2. Modify air exchange rate (AER)

3. Filter indoor air
Air Cleaners
Air cleaner use as a public health intervention

Air cleaners can increase deposition of particles leading to a reduction in exposure
Air cleaner set up

• In-duct:
  – part of HVAC system
  – designed to clean air from whole house

• Portable:
  – clean air from a single room

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Operating technologies
<table>
<thead>
<tr>
<th>Design</th>
<th>Pollutants targeted</th>
<th>How they work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical filters</td>
<td>Particles</td>
<td>Particles move across filter and are removed based on particle size. Filters can be flat, pleated or high efficiency particulate air (HEPA).</td>
</tr>
<tr>
<td>Electrostatic precipitators</td>
<td>Particles</td>
<td>Charge an incoming stream of particles and collect them within the device on an oppositely charged plate.</td>
</tr>
<tr>
<td>Ion generators</td>
<td>Particles</td>
<td>Charge particles in the air to increase their deposition onto room surfaces.</td>
</tr>
<tr>
<td>Activated carbon filters</td>
<td>Gases</td>
<td>Gases move across the filter and adsorb onto the filter.</td>
</tr>
<tr>
<td>Ozone generators</td>
<td>Gases</td>
<td>Release ozone into the air to react with indoor pollutants. Use is associated with health concerns in residential settings.</td>
</tr>
</tbody>
</table>
Air cleaner effectiveness

• Exposure reduction
  – gases
  – particles

• Health impacts
  – particles
Exposure reduction - gases

• Very limited data from chamber studies
• Effectiveness depends on: filter density, flow rate of air through the filter, filter material
• Activated carbon filters effective at removing some gases
  – Denser gases removed more effectively versus “lighter” gases
Exposure reduction – particles

• Handful of studies on electronic precipitators and ion generators\textsuperscript{5}

• Most studies have investigated use of portable HEPA filters
HEPA filters and exposure reduction

• Particulate pollutants
  – Indoor sources: ETS, fungal spores, dust, allergens
  – Outdoor sources: Traffic, wood smoke, forest fire smoke

• In homes, studies have found substantial decreases in particle levels, with use
  – 90 % decrease in baseline dog allergen concentrations in a room within 24 hours
  – 80 % decrease in baseline fungal spore concentrations in a room within 24 hours
  – 30-70 % reductions in baseline ETS particles in a home after a 2 month period

• Effectiveness varies among studies
  – Number of devices, time period, AER, air cleaner placement
In-duct filters

• Few studies have evaluated in-duct filters outside of chamber tests

• Comparison of in-duct vs. portable units showed higher particle removal rates for in-duct
  – Portable units may not effectively draw air from other rooms, hallways

• Electrostatic in-duct filters more effective than HEPA in-duct filters
Air cleaner effectiveness

Depends on both:

• Efficiency of device (filter) at removing pollutant
  – Some industry developed standards for particles; MERV (in duct) or CADR (portable) ratings
  – None available for gases

• Amount of air “cleaned” by device (filter)
  – AER, room size, time
Are air cleaners useful under certain conditions?

- AQ advisory days?
- Wood heating season?
- Forest fire season?

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<table>
<thead>
<tr>
<th>Study</th>
<th>Exposure</th>
<th>Air cleaner</th>
<th>Study Period</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brauner et al. 2008(^{12})</td>
<td>Traffic</td>
<td>Portable HEPA</td>
<td>+ filter: 48 hr - filter: 48 hr</td>
<td>Lower PM(_{2.5}) levels during + filter period (GM: 4.7 ± 0.8 µg/m(^3)) vs. - filter period (GM: 12.6 ± 1.4 µg/m(^3)) across homes (n= 21)</td>
</tr>
<tr>
<td>Allen et al. 2011(^{11})</td>
<td>Wood smoke</td>
<td>Portable HEPA</td>
<td>+ filter: 7d - filter: 7d</td>
<td>Lower PM(<em>{2.5} F</em>{\text{inf}}) during + filter period (0.20 ± 0.17) vs. - filter period (0.34 ± 0.17) across homes (n=25)</td>
</tr>
<tr>
<td>Barn et al. 2008(^{12})</td>
<td>Forest fire &amp; wood smoke</td>
<td>Portable HEPA</td>
<td>+ filter: 24hr - filter: 24hr</td>
<td>Lower PM(<em>{2.5} F</em>{\text{inf}}) on + filter days (0.13 ± 0.14) vs. - filter days (0.42 ± 0.27) across homes (n= 29)</td>
</tr>
<tr>
<td>Henderson et al. 2005(^{13})</td>
<td>Fire smoke</td>
<td>Portable ESP</td>
<td>24 - 48hr</td>
<td>Indoor PM(<em>{2.5}) levels 63-88 % lower in treatment vs. matched control homes (n= 4 pairs) ; mean 24 hr indoor PM(</em>{2.5}) ≤ 3 µg/m(^3) in treatment homes vs. 5.2 – 21.8 µg/m(^3) in control homes</td>
</tr>
</tbody>
</table>
Health benefits
Health - respiratory effects

• Results are mixed

• Some reduction of **asthma and allergy-related symptoms** with HEPA filter use\(^5\)

• Greater benefits when used with other interventions, including removal of sources, removal of carpets, use of impermeable bed coverings, and reduced AER\(^14\)
<table>
<thead>
<tr>
<th>Study</th>
<th>Exposure</th>
<th>Study Period</th>
<th>Study Population</th>
<th>Health outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brauner et al. 2008¹⁰</td>
<td>Traffic</td>
<td>+ HEPA filter: 48 hr</td>
<td>21 non-smoking elderly couples (60-75 yrs)</td>
<td><strong>Blood vessel health:</strong> 8.1% (95% confidence interval, 0.4–16.3%) improvement in microvascular function</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- HEPA filter: 48 hr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allen et al. 2011¹¹</td>
<td>Wood smoke</td>
<td>+ HEPA filter: 7d</td>
<td>45 healthy adults</td>
<td><strong>Blood vessel health:</strong> 9.4 % (95% CI, 0.9-18%) increase in reactive hyperemia index</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- HEPA filter: 7d</td>
<td></td>
<td><strong>Inflammation:</strong> decrease in C-reactive protein by 32.6 % (95 % CI, 4.4-60.9%)</td>
</tr>
</tbody>
</table>


Key Points

• Indoor air a complex mixture of indoor and outdoor sources
• Reducing sources and modifying AER can help to improve indoor air quality
• Use of air cleaners is useful but benefits are limited
• HEPA filter air cleaners can lower indoor particle levels and thereby reduce exposure
  – AER and room size are important determinants
  – Linked with some respiratory and cardiovascular health benefits
• Air cleaners can be particularly useful when outdoor AQ is poor
Thank You

Questions?
Comments?

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References


References cont.


