Socioeconomic determinants of indoor PM exposure: understanding sources, structures and settings

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WORKSHOP ON THE HEALTH RISKS OF INDOOR EXPOSURE TO PARTICULATE MATTER
National Academies
2016
Deconstructing disparity

We need to take a multilevel view of determinants of exposure to indoor pollutants.

<table>
<thead>
<tr>
<th>Neighborhood</th>
<th>Building</th>
<th>Household</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional pollution</td>
<td>Construction style</td>
<td>Source usage and strength</td>
</tr>
<tr>
<td>Local traffic</td>
<td>Infiltration dynamics</td>
<td>Occupant density</td>
</tr>
<tr>
<td>Commercial activities</td>
<td>Common area pollutants</td>
<td>Pollutant sinks</td>
</tr>
<tr>
<td>Population density</td>
<td>HVAC</td>
<td>Smoking behaviors</td>
</tr>
<tr>
<td>Industry</td>
<td>Age / Condition</td>
<td>Time activity patterns</td>
</tr>
<tr>
<td>Weather</td>
<td>Maintenance practices</td>
<td>Comfort-related behavior</td>
</tr>
<tr>
<td>Noise</td>
<td></td>
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</tr>
</tbody>
</table>
# Exposure Disparities - Drivers

## Indoor Environments

### Sources
- **Indoor Sources**
  - Cooking appliances
  - Tobacco smoke
  - Cleaning products
  - Air fresheners
  - Personal care products
  - Furnishings
  - Pesticides
  - Pollutant reservoirs
  - Water sources

### Structure
- **Physical Structure**
  - Size/design of structure
  - Age
  - Size of living space
  - Single family vs. multifamily
  - Leakage and/or air exchange
  - Heating systems
  - Mechanical ventilation

### Behavior
- **Source use patterns**
  - Cooking appliance usage
  - Cooking practices
  - Smoking behavior
  - Consumer product usage
  - Personal care product usage

- **Activity Patterns**
  - Time spent at home
  - Interaction with sources
  - Influence on air exchange

## Settings

### Outdoor Sources
- Traffic
- Industrial Activity
- Residential Activity
- Contaminated soil

(Adamkiewicz et al., 2011)
Deconstructing disparity

BUILDINGS / SYSTEMS / VENTILATION

SOURCES
Deconstructing disparity

- Housing type / size / condition / occupancy / single vs. multifamily
- Housing type / size / condition / climate / weather / HVAC
- Cooking fuel (electric/gas/wood) / equipment / activity / spot ventilation / supplemental heating?
- Smoking prevalence / SHS via multifamily transfer
## Housing Data

<table>
<thead>
<tr>
<th>Housing Variable</th>
<th>Low Income</th>
<th>High Income</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Built before 1980 (%)</td>
<td>71.56</td>
<td>48.63</td>
<td>1.5</td>
</tr>
<tr>
<td>Area of peeling paint larger than 8 x 11 (%)</td>
<td>3.11</td>
<td>0.99</td>
<td>3.1</td>
</tr>
<tr>
<td>Any inside water leaks in last 12 months (%)</td>
<td>9.14</td>
<td>7.98</td>
<td>1.1</td>
</tr>
<tr>
<td>Neighborhood with heavy street noise/traffic (%)</td>
<td>28.19</td>
<td>16.69</td>
<td>1.7</td>
</tr>
<tr>
<td>Industry/factory within ½ block (%)</td>
<td>6.90</td>
<td>1.74</td>
<td>4.0</td>
</tr>
<tr>
<td>Unit uncomfortably cold for 24+ hrs (%)</td>
<td>10.70</td>
<td>6.71</td>
<td>1.6</td>
</tr>
<tr>
<td>Mean floor area of unit (ft²)</td>
<td>1524</td>
<td>2853</td>
<td>0.5</td>
</tr>
<tr>
<td>Mean occupant density (number per 1000 ft²)</td>
<td>2.78</td>
<td>1.82</td>
<td>1.5</td>
</tr>
<tr>
<td>Homes with cracks in floor, wall, or ceiling (%)</td>
<td>7.13</td>
<td>3.31</td>
<td>2.2</td>
</tr>
</tbody>
</table>

(Low income = <$30k/yr; High income = >$100k/yr)

(Adamkiewicz et al 2011, using data from AHS, 1999)
Volume and air exchange

Leakage /Air Exchange*

Residence Volume†

**Implications**

→ Smaller volumes will increase indoor concentrations
→ Homes with higher leakage will decrease concentrations

*(Chan et al. 2005) †(AHS 2009)
Deconstructing disparity

- Simulation study
- We varied air exchange, sources and ambient concentrations

Deconstructing disparity

All factors contribute, as expected
Air exchange and major sources matter most

Deconstructing disparity

TIME ACTIVITY

- Activity patterns matter
- This is just one example of how indoor/personal exposures are shaped by household characteristics

(Matz et al., 2015)

**Smoking**

![Box plot showing PM2.5 levels in living rooms for smokers and non-smokers.](image1.png)

![Scatter plot showing PM2.5 indoor/outdoor ratios for non-smokers and smokers.](image2.png)

**SMOKERS**
Case Studies - Smoking

- Common-area measurements show differences by
  - resident characteristics
  - smoking policy
  - season

- Highest levels in winter
- Higher levels for elder/disabled units
- Higher levels for buildings without smoke-free policies

(Arku et al., 2014)
Case Studies - Smoking

- Common-area measurements $\rightarrow$ seasonal trends

- Highest levels of PM$_{2.5}$ are correlated with nicotine

(Arku et al., 2014)
Smoking

CDC Green Housing Study

PM 2.5

μg/m³

100
50
20
10

1 1 2 2 3 3

visit

GREEN

CONTROL

Cincinnati
n = 51 apartments
Green improvements don’t necessarily lower PM levels without source control.
Modeling study using housing and census data

The highest exposure likelihood was in the South and Midwest regions, rural populations, and low-income households.

Case Studies - Smoking

(Russo et al., 2014)
In-unit and common area measurements collected in Boston Public Housing

Smokers and nonsmokers enrolled

PM$_{2.5}$ and nicotine

Smoking activity recorded for smokers
Case Studies - Smoking

Adjacency should matter.
Do we see observe transfer of SHS coincident with smoking events?
### Case Studies - Smoking

(Russo et al., 2014)

<table>
<thead>
<tr>
<th></th>
<th>Nonsmoking hours</th>
<th>Smoking hours</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SMOKERS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25&lt;sup&gt;th&lt;/sup&gt; %ile</td>
<td>3.7</td>
<td>8.1</td>
</tr>
<tr>
<td>Median</td>
<td>9.2</td>
<td>29.6</td>
</tr>
<tr>
<td>75&lt;sup&gt;th&lt;/sup&gt; %ile</td>
<td>23.4</td>
<td>113.1</td>
</tr>
<tr>
<td>90&lt;sup&gt;th&lt;/sup&gt; %ile</td>
<td>92.6</td>
<td>230.2</td>
</tr>
</tbody>
</table>

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<tr>
<th></th>
<th>Nonsmoking hours</th>
<th>Smoking hours</th>
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<tbody>
<tr>
<td><strong>NON-SMOKERS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25&lt;sup&gt;th&lt;/sup&gt; %ile</td>
<td>2.2</td>
<td>2.6</td>
</tr>
<tr>
<td>Median</td>
<td>3.3</td>
<td>5.9</td>
</tr>
<tr>
<td>75&lt;sup&gt;th&lt;/sup&gt; %ile</td>
<td>8.8</td>
<td>24.2</td>
</tr>
<tr>
<td>90&lt;sup&gt;th&lt;/sup&gt; %ile</td>
<td>27.1</td>
<td>64.8</td>
</tr>
</tbody>
</table>
‘System’ Effect - Scenarios

MULTIFAMILY HOUSING – BUILDING PHYSICS

- Structural versus *functional* air exchange
  - overheating
  - windows/AC
- Behavior / preference
- ‘Small space’ effects
  - sources → exposures
  - reduced volume (doors/clutter)

Density-driven flow patterns can be significant

Source: Building Control Systems, Vaughn Bradshaw
Cohort studies (TEACH)

Los Angeles
Cohort studies (TEACH)

New York
Cooking was likely the primary source of indoor PM

Where to intervene?

- **people**
  - education
  - case management
  - clinical intervention

- **places**
  - maintenance
  - renovation
  - construction
  - systems

- **policies**
  - maintenance
  - purchasing
  - tenant policies
  - regulatory
Green Housing – BRIGHT Study

Public housing intervention study
New, green units vs. Conventional

Why?
• Reduction of SHS
• Ventilation in kitchen
• Reduced infiltration of ambient PM

↓ 41.1 %*

Other findings: 47% fewer symptoms and 66% lower indoor NO₂


*p < 0.05
Green Housing – BRIGHT Study

Other findings: 47% fewer symptoms and 66% lower indoor NO₂


↓ 41.1 %*

*p < 0.05* indicates reduced infiltration of ambient PM₂.₅
Within a small geographic area, we have seen:

- **Significant between-household variability**
- **Indoor > Outdoor concentrations**
- Exposures strongly influenced by:
  - Sources
  - Building design/age
  - Occupant activity
Where next?

• Multiple determinants can increase risk of exposure
• We need a mechanistic, ‘systems’ view of exposure disparities; including behavior/perception
• We need to understand how exposure disparities are related to conditions or activities that can be mitigated
• We need to recognize sub-populations
  • Rural v. Urban
  • Elderly
  • Managed/public housing
  • Environmental justice communities
• We need new tools and approaches
  • Real time data / big data
Where next?

• Intervention research
  • Housing improvements
  • Weatherization / green
  • Smoke-free policies
• We need to focus on:
  • links between energy/housing/health
  • better exposure assessment
  • exposures of indoor and outdoor origin
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BRIGHT Study
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