9A: Indoor Air

Meghan F. Davis, DVM MPH PhD
Assistant Professor
Environmental Health and Engineering
mdavis65@jhu.edu
Learning Objectives

• Describe differences between indoor and outdoor air
• Identify typical indoor air pollutants and their sources
• Describe diseases linked to indoor air pollution

Image source: National Academies
Time spent indoors (2019, n=187)

The vast majority of the class spent the vast majority of their time on the target day indoors.

Mean: 82%
Median: 90%

On average, students spent 6% less time indoors on the weekend, but this was not statistically significant.
Outdoor vs. Indoor Air

Indoor air pollution-caused deaths:
• 34% - stroke
• 26% - ischemic heart disease
• 22% - COPD
• 12% - acute lower respiratory infections in children
• 6% - lung cancer

Outdoor air pollution-caused deaths:
• 40% – ischemic heart disease
• 40% – stroke
• 11% – chronic obstructive pulmonary disease (COPD)
• 6% – lung cancer
• 3% – acute lower respiratory infections in children
Outdoor vs. Indoor Air

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The air that we breathe...

Lung function depends on:
- Sex
- Age
- Height

http://www.arb.ca.gov/research/resnotes/notes/94-11.htm
What makes indoor air unique?

- 87% of time spent indoors (6% in vehicles and 7% outdoors)
- Indoor emissions from air pollutants known to be hazardous
  - Off-gassing from synthetic building materials
- Indoor environments trap pollutants
  - Reliance on air ventilation systems
  - Reduction in air exchange from energy conservation
  - Crime, climate impact behaviors (opening windows)
Indoor air pollution sources: PM

- Gas stove
- Incense
- Tobacco smoke
- Cookstoves
- Fireplace

All images Wikimedia
Indoor air pollution sources: chemical

Pressed wood / formaldehyde (FEMA trailers in New Orleans)

Pesticide

Cleaning and personal care products (bleach, varnish, solvents, etc.)

Asbestos

All images Wikimedia
Indoor air pollution sources: biological

- Pest & pet allergens
- Mold
- Pollen
- Bacterial endotoxin (LPS)

All images Wikimedia
How long do particles stay in the air?

- Hair: ~100 μm, ~3-5 sec.
- Dead skin: 20-40 μm, ~15 sec.
- Pollen: ~6-50 μm, ~45 sec.
- Fly ash: 1-100 μm, ~5-30 min.
- Mold: 0.5-30 μm, ~30-60 min.
- Bacteria: ~1-3 μm, ~1-2 hr.
- Smoke: ~0.1-10 μm, ~2-10 hr.
- Soot: ~0.05-0.2 μm, ~8-24 hr.

The approximate time it takes for these particles to settle one meter (39") in undisturbed air.
Top Indoor Air Pollutants

Pollutants that increase risks of chronic health effects such as cancer and heart disease

1. Tobacco smoke.
2. Fine particles and gaseous pollutants from indoor cooking and other indoor combustion.
3. Radon from soil surrounding building foundations.
4. Formaldehyde from building materials.
5. Ozone from outdoor air.

Pollutants linked to increased allergies, asthma, and respiratory infections

1. Tobacco smoke from indoor smoking.
2. Allergens and microbial agents that cause inflammation from dampness and mold.
3. Allergens from house dust, mites, pets, cockroaches, rodents.
4. Virus and bacteria from people.
5. Moisture from indoor sources and outdoor air when it causes high indoor humidity.
# Sources of indoor pollutants

<table>
<thead>
<tr>
<th>Sources</th>
<th>Pollutants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil and groundwater</td>
<td>Radon and radioactive progeny</td>
</tr>
<tr>
<td>Building materials and furnishings (carpeting, paint, varnish, adhesives)</td>
<td>Formaldehyde, asbestos, vinyl chloride, organic fumes</td>
</tr>
<tr>
<td>Personal activities and hobbies</td>
<td>Cigarette smoking, fireplace smoke, solvents and glue fumes</td>
</tr>
<tr>
<td>Appliances, cooking and heating</td>
<td>Carbon monoxide, natural gas, cooking odors, boiler and heater fumes</td>
</tr>
</tbody>
</table>
Air exchange rate

- Rate at which air is replaced in the structure by external air
  - average for American home: 0.7 to 1.0 air changes/hr (ACH)
  - tightly sealed homes without provisions for and exchange: ~0.2 air changes/hr (ACH)
  - Bloomberg SPH: offices 2-4; labs 6-8 air changes/hr (ACH)
- Make-up air (from outside)
  - before 1973: 15 CFM/person
  - after 1973: 5.0 CFM/person
Biological exposures in indoor air

- Molds/Fungi, incl. *Aspergillus*
- Culturable bacteria
  - Specific pathogens, *e.g.* MRSA ST398, *Campylobacter*
- Endotoxin (LPS), superantigens, and other bacterial products
- Allergens, pollens, etc.
Indoor aeropathogens

• Bacteria
  – *Staphylococcus aureus*
  – *Legionella*
  – *Escherichia coli*
  – *Salmonella spp.*
  – *Pseudomonas aeruginosa*
  – *Mycobacteria tuberculosis*
  – *Klebsiella pneumoniae*

• Yeasts
  – *Candida albicans*
  – *Saccharomyces cerevisiae*

• Viruses

• Fungi
  – *Aspergillus niger*
  – *Penicillium funiculosum*
  – *Trichophyton spp.*

• Amoeba
Measuring exposure of workers to airborne animal bacteria (*S. aureus*) using a button sampler
Odors

Table 4
Selected odour thresholds (ng/m³), alphabetic order of compound.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Devos et al. (1990)</th>
<th>Nagata (2003)¹</th>
<th>State-of-the-science odour thresholds according to (CEN std.) and new studies²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia</td>
<td>4070</td>
<td>1043</td>
<td>1800 (Woodfield and Hall, 1994)</td>
</tr>
<tr>
<td>Acetic acid</td>
<td>363</td>
<td>15</td>
<td>5 (Wise et al., 2007): 88 (Cain et al., 2010)</td>
</tr>
<tr>
<td>1-Butanol</td>
<td>1510</td>
<td>115</td>
<td>(90) (Woodfield and Hall, 1994); 1047 (Cain et al., 2010)</td>
</tr>
<tr>
<td>2-Butoxyethanol</td>
<td>166</td>
<td>208</td>
<td>5 (Woodfield and Hall, 1994)</td>
</tr>
<tr>
<td>Butyric acid</td>
<td>15</td>
<td>0.7</td>
<td>0.4 (Wise et al., 2007)</td>
</tr>
<tr>
<td>n-Butyl acetate</td>
<td>933</td>
<td>76</td>
<td>9.5 (Cain and Schmidt, 2009); 47 (Woodfield and Hall, 1994)</td>
</tr>
<tr>
<td>t-Butyl acetate</td>
<td></td>
<td>337</td>
<td>38 (Cain and Schmidt, 2009)</td>
</tr>
<tr>
<td>2-Ethylhexanol</td>
<td>1320</td>
<td>50³</td>
<td>500 (Woodfield and Hall, 1994)</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>1000</td>
<td>200-300</td>
<td>110 (Berglund et al., 2012)</td>
</tr>
<tr>
<td>Hexanal</td>
<td>58</td>
<td>1</td>
<td>(3)⁴, 102⁸</td>
</tr>
<tr>
<td>Hexanoic acid</td>
<td>60</td>
<td>3</td>
<td>5 (Wise et al., 2007)</td>
</tr>
<tr>
<td>R-limonene</td>
<td>2450</td>
<td>211</td>
<td>45⁵ (Cain et al., 2007b)</td>
</tr>
<tr>
<td>Octanoic acid</td>
<td>24</td>
<td></td>
<td>11 (Wise et al., 2007)</td>
</tr>
<tr>
<td>1-Octanol</td>
<td>32</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Ozone</td>
<td>102</td>
<td>6</td>
<td>14⁶ (Cain et al., 2007b)</td>
</tr>
<tr>
<td>Phenol</td>
<td>427</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Styrene</td>
<td>631</td>
<td></td>
<td>160 (Woodfield and Hall, 1994)</td>
</tr>
<tr>
<td>Toluene</td>
<td>6000</td>
<td>1239</td>
<td>644 (Woodfield and Hall, 1994)</td>
</tr>
<tr>
<td>Triethylamine</td>
<td>1320</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>p-Xylene</td>
<td>1410</td>
<td>161</td>
<td>78 (Woodfield and Hall, 1994)</td>
</tr>
</tbody>
</table>


- Annoyance
- Perceived risk and bad health
- Mood
- Multiple chemical sensitivity
- Exacerbation of existing asthma
Biomass and indoor air pollution

• Proportion of use of solid fuels decreased from 62% to 41% between 1980 and 2010.

• Major fuels are biomass, coal and kerosene (paraffin wax)

  biomass • organic material used as fuel
  – Major biomass used is dried dung
  – Coal powder pressed into blocks

EHP 121:784-790, 2013.
Chest 142:1308-1315, 2012
Mortality from biomass burning

HOUSEHOLD AIR POLLUTION

3.8 million die prematurely every year from household air pollution from cooking (2016). Household air pollution is mostly created by using kerosene and solid fuels such as wood with polluting stoves, open fires and lamps.

- 18% from stroke
- 27% from ischaemic heart disease
- 20% from chronic obstructive pulmonary disease (COPD)
- 8% from lung cancer
- 27% are due to pneumonia

Women and children are the most at risk.
## Energy equivalency

<table>
<thead>
<tr>
<th></th>
<th>PM</th>
<th>SO\textsubscript{x}</th>
<th>NO\textsubscript{x}</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>2,170</td>
<td>Fuel</td>
<td>110</td>
<td>18,790</td>
</tr>
<tr>
<td>Coal</td>
<td>520</td>
<td>1,200</td>
<td>270</td>
<td>2,380</td>
</tr>
<tr>
<td>Oil</td>
<td>11</td>
<td>1,170</td>
<td>71</td>
<td>20</td>
</tr>
<tr>
<td>Gas</td>
<td>7</td>
<td>neg</td>
<td>38</td>
<td>10</td>
</tr>
</tbody>
</table>

Air pollution emissions (in kg)
Adapted from DeKoning 1985
# Indoor air pollution from biomass

<table>
<thead>
<tr>
<th>Location</th>
<th>Measurement Period</th>
<th>TSP as a multiple of the WHO peak guideline</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>cooking</td>
<td>11</td>
</tr>
<tr>
<td>Gambia</td>
<td>average over day</td>
<td>4-11</td>
</tr>
<tr>
<td>India</td>
<td>cooking</td>
<td>16-91</td>
</tr>
<tr>
<td>Kenya</td>
<td>space heating</td>
<td>12-34</td>
</tr>
<tr>
<td>Nepal</td>
<td>cooking</td>
<td>9-38</td>
</tr>
<tr>
<td>Papua</td>
<td>space heating</td>
<td>5-39</td>
</tr>
</tbody>
</table>

TSP • Total Suspended Particulate  
Table adapted from KR Smith
Population using solid fuels (%), 2010
Total

The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted and dashed lines on maps represent approximate border lines for which there may not yet be full agreement.

Data Source: World Health Organization
Map Production: Public Health Information and Geographic Information Systems (GIS)
World Health Organization
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Household Cooking with Solid Fuels Contributes to Ambient PM$_{2.5}$ Air Pollution and the Burden of Disease

Zoë A. Chafe,$^{1,2}$ Michael Brauer,$^3$ Zbigniew Klimont,$^4$ Rita Van Dingenen,$^5$ Sumi Mehta,$^6$ Shilpa Rao,$^4$ Keywan Riahi,$^4$ Frank Dentener,$^5$ and Kirk R. Smith$^2$

Percentage of population-weighted ambient PM$_{2.5}$ attributable to household cooking with solid fuels

EHP 2014
Health issues related to biomass

- **Pneumonia**: children under 5 (leading cause of death)
- **Other infections**
  - Tuberculosis: air pollution – infectious agent interaction
- **Asthma**: children and adults
- **COPD**: women who cook in the home (unrelated to smoking)
Unimproved cookstove use in Guatemala

Photo: Berkeley News, ex Nigel Bruce, U. Liverpool
RESPIRE Trial

- Objectives: impact of household air pollution reduction on pneumonia incidence in children <18 mos
- Rural, highland Guatemala
- Poor indigenous (Mayan) rural population using open woodfires for cooking
- 518 homes (pregnant woman, child <4 months) using open fire
- Randomized to (i) keep open fire or (ii) use chimney wood stove
Household fuels & climate I

- Climate impacts come from non-renewable biomass and coal, i.e., from net CO$_2$ emissions
- Poor combustion also leads to other emissions such as the relatively well-understood – methane and nitrous oxide
- In addition, a wide range of less well-understood short-lived GH-related emissions are emitted including
  - CO and black carbon – warming agents
  - Ozone precursors – warming agents
  - sulfates and organic carbon particles – cooling agents
Household fuels & climate II

- Indirect climate impacts of these pollutants:
  - Reducing carbon capture of forests by ozone damage
  - Darkening of snow/ice by black carbon
2020 Climate Warming

Unger et al. 2010
Recap: Building-related illness

• Discrete, identifiable disease or illness
• Can be traced to a specific pollutant or sources within a building
• Cough, chest tightness, fever, chills, muscle aches or more serious outcomes
• Legionnaires disease, hypersensitivity pneumonitis, humidifier fever
Recap: Sick Building Syndrome

• Set of symptoms associated with time spent in building
  – respiratory tract irritation, skin irritation, headache, dizziness, nausea, fatigue, concentration problems
• Symptoms diminish or cease when occupants leave the building
• Cannot be traced to specific pollutants or sources within the building
• Related to multiple chemical sensitivity (MCS)
Case: Legionnaire’s Disease

1976 American Legion Convention
- 200 ill, 29 dead
- chest pain & high fever

Months later, a CDC microbiologist identified *Legionella*, traced to the building’s water cooling towers
Legionnaires’ cluster in Washington Heights rises to 22 cases: health officials

WASHINGTON HEIGHTS, Manhattan — The NYC Health Department is investigating a community cluster of 22 cases of Legionnaires’ disease in a section of Lower Washington Heights in Manhattan, health officials said on Friday.

On Tuesday, health officials reported there was one fatality from the disease.
Control of indoor air pollution

• Ventilation
• Source removal
• Source modification
• Air cleaning (pollutant removal)
• Education
Worker Protection

Hierarchy of Controls

- Elimination: Physically remove the hazard
- Substitution: Replace the hazard
- Engineering Controls: Isolate people from the hazard
- Administrative Controls: Change the way people work
- PPE: Protect the worker with Personal Protective Equipment

Image source: CDC
World Radon Risk

http://www.fixradon.com/maps/images/D_01_world_radon_by_country.gif
EPA Map of Radon Zones

The purpose of this map is to assist National, State, and local organizations to target their resources and to implement radon-resistant building codes. This map is not intended to be used to determine if a home in a given zone should be tested for radon. Homes with elevated levels of radon have been found in all three zones. All homes should be tested regardless of geographic location.

IMPORTANT: Consult the EPA Map of Radon Zones document (EPA-402-R-93-071) before using this map. This document contains information on radon potential variations within counties. EPA also recommends that this map be supplemented with any available local data in order to further understand and predict the radon potential of a specific area.

Zone designation for Puerto Rico is under development.
Engineering control for radon

Image: Colorado State Extension
Regulatory Jurisdictions

- Outdoor air - EPA; Clean Air Act (CAA)
- Occupational air - OSHA
- Indoor air (apart from occupational air)
  - no specific federal laws
  - state and local jurisdictions regulate public buildings
- Standards in ventilation and air exchange rates
- Behavior controls (e.g., smoking)
- Limit use of products that affect air quality
- Private residence
  - must rely on education
Key Points

• Indoor air pollution has gotten worse because of energy conservation measures that reduce air exchange with outdoor air.

• Indoor air pollutants include VOCs, allergens, and environmental tobacco smoke (ETS).

• Intervention strategies to control air pollutants include emissions standards, process standards, filtration, and education.