How much time do we spend inside?

Problem:
To save energy (heating, AC) today’s homes are well insulated → longer pollutant residence times!

Where do indoor pollutants come from?

Indoor Air Pollutant Gases

<table>
<thead>
<tr>
<th>Gas</th>
<th>Emission Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>Metabolic activity, combustion, garage exhaust, tobacco smoke</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>Boilers, gas or kerosene heaters, gas stoves, wood stoves, fireplaces, tobacco smoke, garage exhaust, outdoor air</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>Outdoor air, garage exhaust, kerosene and gas space heaters, wood stoves, gas stoves, tobacco smoke</td>
</tr>
<tr>
<td>Ozone</td>
<td>Outdoor air, photocopy machines, electrostatic air cleaners</td>
</tr>
</tbody>
</table>

Table 9.3
### Indoor Air Pollutant Gases

<table>
<thead>
<tr>
<th>Gas</th>
<th>Emission Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur dioxide ( \text{SO}_2 )</td>
<td>Outdoor air, kerosene space heaters, gas stoves, and coal appliances</td>
</tr>
<tr>
<td>Formaldehyde ( \text{HCHO} )</td>
<td>Particleboard, insulation, furnishings, paneling, plywood, carpets, ceiling tile, tobacco smoke</td>
</tr>
<tr>
<td>Volatile org. carbon ( \text{VOC} )</td>
<td>Adhesives, solvents, building materials, combustion appliances, paints, varnishes, tobacco smoke, room deodorizers, cooking, carpets, furniture, draperies</td>
</tr>
<tr>
<td>Radon ( \text{Rn} )</td>
<td>Soils</td>
</tr>
</tbody>
</table>

**Table 9.3**

---

### Sick Building Syndrome

The term “sick building syndrome” is used to describe situations in which building occupants experience acute health and comfort effects that appear to be linked to time spent in a building.

**Causes of sick building syndrome:**
- Inadequate ventilation
- Chemical contaminants from indoor sources (adhesives, carpeting, copy machines, cleaning agents)
- Chemical contaminants from outdoor sources
- Biological contaminants (Bacteria, molds, pollen, and viruses are types of biological contaminants)

---

### Radon

- \(^{238}\text{U} \) \( t_{1/2} = 4.5 \text{ billion yr} \) (Uranium)
- \(^{226}\text{Ra} \) \( t_{1/2} = 1622 \text{ yr} \) (Radium)

50% Uranium remains from the formation of earth, both Uranium and Radium are in the ground.

Radon: is a gas that can escape the ground and enter homes it attaches to particles which can be deposited in the lung.
Types of Radioactive Decay

\( \alpha \) decay

\[ ^{226}\text{Ra} \rightarrow ^{222}\text{Rn} + \alpha \]

\( \beta \) decay

\[ ^{214}\text{Bi} \rightarrow ^{214}\text{Po} + \beta \]

\( \gamma \) decay

\( \gamma \) ray (highly energetic photon)

How does radon enter your home?

Radon enters from the ground through the foundation into homes.

\[ ^{238}\text{U} \rightarrow ^{222}\text{Rn} \]

Why is Radon dangerous?

\[ ^{222}\text{Rn} \quad t_{1/2} = 3.8 \text{ days} \]

\[ ^{218}\text{Po} \quad t_{1/2} = 3 \text{ min} \]

\[ ^{214}\text{Pb} \quad t_{1/2} = 27 \text{ min} \]

\[ ^{214}\text{Bi} \quad t_{1/2} = 20 \text{ min} \]

\[ ^{214}\text{Po} \quad t_{1/2} = 0.00016 \text{ sec} \]

\[ ^{210}\text{Pb} \quad t_{1/2} = 22 \text{ yr} \]

Radon-222 decays into Lead-210 in ~50 minutes radiating 3 \( \alpha \) particles and 2 \( \beta \) particles.
Health Effects of Radon

Radon attaches to particles that get deposited in the lung
→ radon decays in the lung
→ radioactive decays (ionizing radiation)
  destroys lung tissue
→ Lung Cancer

EPA: Radon
Low potential, moderate potential, and highest potential for elevated indoor radon levels.

EPA: Radon WA
What can we do about Radon?

• build a system that ventilates radon from the ground under a home
• seal cracks in foundation

Indoor Air Pollutant Particles

<table>
<thead>
<tr>
<th>Particle</th>
<th>Emission Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allergens</td>
<td>House dust, domestic animals, insects, pollen</td>
</tr>
<tr>
<td>Asbestos</td>
<td>Fire retardant materials, insulation</td>
</tr>
<tr>
<td>Fungal spores</td>
<td>Soil, plants, foodstuffs, internal surfaces</td>
</tr>
<tr>
<td>Bacteria, viruses</td>
<td>People, animals, plants, air conditioners</td>
</tr>
<tr>
<td>PAHs (Polyaromatic hydrocarbons)</td>
<td>Fuel combustion, tobacco smoke</td>
</tr>
<tr>
<td>Other</td>
<td>Resuspension, tobacco smoke, wood stoves, fireplaces, outdoor air</td>
</tr>
</tbody>
</table>

What is in cigarette smoke?

in mg/cigarette (with filter)

<table>
<thead>
<tr>
<th>Component</th>
<th>Mainstream</th>
<th>Sidestream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tar</td>
<td>10.2</td>
<td>34.5</td>
</tr>
<tr>
<td>Nicotine</td>
<td>0.46</td>
<td>1.27</td>
</tr>
<tr>
<td>CO</td>
<td>18.3</td>
<td>86.3</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>--</td>
<td>1.44</td>
</tr>
<tr>
<td>Phenols</td>
<td>0.23</td>
<td>0.6</td>
</tr>
<tr>
<td>Toluene</td>
<td>0.11</td>
<td>0.6</td>
</tr>
<tr>
<td>benzopyrene</td>
<td>0.00025</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Some health effects of tobacco smoke

Mouth, nose, throat cancer in mouth, tongue, sinus, larynx, loss of taste and smell

Pulmonary tract lung cancer, coughing, asthma attacks

Cardiovascular tract restricted blood supply to internal organs → coronary, pulmonary heart disease, congestive heart failure strokes

Skin premature aging

In 1990 estimated death due to smoking
- Lung cancer 130000
- Cardiovascular diseases 160000
- Other pulmonary diseases 80000

Comparison of Indoor with Outdoor Standards

<table>
<thead>
<tr>
<th>Gas</th>
<th>Indoor (ppmv)</th>
<th>Outdoor California Standard (ppmv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide</td>
<td>35</td>
<td>9.5 (8-h) 9 (8-h)</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>1 (15-m)</td>
<td>0.053 (annual) 0.25 (1-h)</td>
</tr>
<tr>
<td>Ozone</td>
<td>0.1</td>
<td>0.08 (8-h) 0.09 (1-h)</td>
</tr>
</tbody>
</table>

Outdoor standards tougher to protect entire population. Outdoor standards for NO2(g) tougher since ozone forms outdoors, but not indoors, from NO2(g).

Deaths Attributed to Solid Fuel Use

More than 3 billion people worldwide depend on solid fuels for their energy needs.
Removing Indoor Air Pollution after Emission?

House plants (NASA Plant Studies):

- Show that some house plants can absorb common indoor air pollutants such as formaldehyde, benzene, and carbon monoxide (CO).
- Pollutant removal thought to occur from soil bacteria, rather than from the plant itself.
- Critics argue that the rate of removal may not be sufficient, and that other methods (such as ventilation) are more effective.

Air Cleaners (Ozone Generators)

Ozone (O₃) air generators are NOT recommended. Manufacturers can refer to ozone as "activated oxygen" or "energized oxygen." The claim is that ozone can react with pollutants such as particles, mold, and viruses cleaning the air. In fact this is not an effective way to remove these pollutants, except at very high (extremely unsafe) concentrations of ozone.

Ionizers and electrostatic precipitators can emit ozone as a byproduct, but at levels lower than ozone generators. No government agency has the authority to fully regulate such devices.

For a list of air cleaners to avoid, and to find safe air cleaners, go to:

http://www.arb.ca.gov/research/indoor/ozone.htm

Example of an air cleaner (ozone generator) that is NOT recommended:

http://www.air-zone.com/
London Smog of 1952

Fog + smoke from coal burning
Worst single pollution episode in the UK. December 5-8 1952: 4,000 people died, another 8,000 died in the weeks-months that followed

Los Angeles smog (1940s+1950s)

Factories + cars

Colors in Los Angeles Smog (Dec. 2000)
The Chemistry of Ozone (O₃) Formation

O₃, in both the stratosphere and troposphere, forms from the following reaction:

\[ O + O₂ + M \rightarrow O₃ + M \]

where M = inert “third body” (such as N₂) that absorbs excess energy from the reaction of O and O₂.

There is plenty of O₂ everywhere in the atmosphere (21%). The key is how “atomic oxygen” (O) forms. The difference between how stratospheric and tropospheric O₃ forms is how O (“atomic oxygen”) is generated.

Generation of atomic oxygen in the stratosphere (10-50 km altitude)

Atomic oxygen (O) in the stratosphere is generated from photolysis of O₂. “Photolysis” means that sunlight breaks apart a molecule.

\[ O₂ + \text{sunlight (UV)} \rightarrow O + O \]

This photolysis reaction requires ultraviolet (UV) light. There is not enough UV light in the troposphere for this reaction to be significant.

The atomic oxygen (O) then reacts with abundant O₂ to produce O₃:

\[ O + O₂ + M \rightarrow O₃ + M \]

Generation of atomic oxygen in the troposphere (0-10 km altitude)

Atomic oxygen (O) in the troposphere is generated from photolysis of NO₂. “Photolysis” means that sunlight breaks apart a molecule.

\[ NO₂ + \text{sunlight (visible)} \rightarrow NO + O \]

This photolysis reaction requires visible light. There is plenty of visible light in the troposphere during the day (or else we could not see).

The atomic oxygen (O) then reacts with abundant O₂ to produce O₃:

\[ O + O₂ + M \rightarrow O₃ + M \]
Now we know that we need \( \text{NO}_2 \) to generate tropospheric \( \text{O}_3 \).

**How do we get \( \text{NO}_2 \)?**

\( \text{NO}_2 \) is formed by oxidizing \( \text{NO} \). \( \text{NO} \) is emitted directly from the tailpipe of our cars. \( \text{NO} \) is oxidized by \( \text{HO}_2 \) or \( \text{RO}_2 \).

\[
\text{NO} + \text{HO}_2 \rightarrow \text{NO}_2 + \text{OH} \\
\text{or} \\
\text{NO} + \text{RO}_2 \rightarrow \text{NO}_2 + \text{RO}
\]

**How do we get \( \text{HO}_2 \) and \( \text{RO}_2 \)?**

\( \text{HO}_2 \) forms from the oxidation of \( \text{CO} \). \( \text{CO} \) is emitted from the tailpipes of our cars.

\[
\text{CO} + \text{OH} \rightarrow \text{CO}_2 + \text{H} \\
\text{H} + \text{O}_2 \rightarrow \text{HO}_2
\]

\( \text{RO}_2 \) forms from the oxidation of hydrocarbons (HC or RH). Hydrocarbons have many sources, such as motor vehicles, solvents, and plants.

\[
\text{RH} + \text{OH} \rightarrow \text{R} + \text{H}_2\text{O} \\
\text{R} + \text{O}_2 \rightarrow \text{RO}_2
\]

**Summary of \( \text{O}_3 \) formation in the troposphere**

There are 3 steps in the chemistry of tropospheric \( \text{O}_3 \) formation:

1) Formation of \( \text{HO}_2 \) (a) or \( \text{RO}_2 \) (b):

(a) \[
\text{CO} + \text{OH} \rightarrow \text{CO}_2 + \text{H} \\
\text{H} + \text{O}_2 \rightarrow \text{HO}_2
\]

(b) \[
\text{RH} + \text{OH} \rightarrow \text{R} + \text{H}_2\text{O} \\
\text{R} + \text{O}_2 \rightarrow \text{RO}_2
\]

2) Conversion of \( \text{NO} \) to \( \text{NO}_2 \):

\[
\text{HO}_2 + \text{NO} \rightarrow \text{NO}_2 + \text{OH} \\
\text{or} \\
\text{RO}_2 + \text{NO} \rightarrow \text{NO}_2 + \text{OH}_v
\]

2) Photolysis of \( \text{NO}_2 \) to generate atomic oxygen:

\[
\text{NO}_2 + \text{sunlight (visible)} \rightarrow \text{NO} + \text{O}
\]

Atomic oxygen (O) then reacts with molecular oxygen (\( \text{O}_2 \)) to form \( \text{O}_3 \):

\[
\text{O} + \text{O}_2 + \text{M} \rightarrow \text{O}_3 + \text{M}
\]
Air Quality standards

National primary ambient air standards:
Levels of air quality which the Administrator (of EPA) judges are necessary, with an adequate margin of safety, to protect the public health.

National secondary ambient air standards:
Levels of air quality which the Administrator (of EPA) judges are necessary to protect the public welfare (visibility, animals, crops, buildings) from any known or anticipated adverse effects of a pollutant.

Is the air clean or dirty?

National Primary Air Quality Standards

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Standard 1 hour average</th>
<th>Standard 8 hour average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone</td>
<td>35 ppbv (not to be exceeded more than once/year)</td>
<td>9 ppmv</td>
</tr>
<tr>
<td>CO</td>
<td>120 ppbv (not to be exceeded more than once/year)</td>
<td>75 ppbv</td>
</tr>
<tr>
<td>NO₂</td>
<td>53 ppbv</td>
<td></td>
</tr>
<tr>
<td>SO₂</td>
<td>140 ppbv</td>
<td></td>
</tr>
<tr>
<td>Pb (lead)</td>
<td>1.5 μg/m³</td>
<td></td>
</tr>
<tr>
<td>PM₁₀</td>
<td>24 hour average 150 μg/m³</td>
<td></td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>24 hour average 35 μg/m³</td>
<td></td>
</tr>
</tbody>
</table>

Air Quality Index (AQI)

A numerical scale vs. air quality criteria, normalized for the different pollutants, scale of 0-500

<table>
<thead>
<tr>
<th>AQI</th>
<th>Scale relative to standard</th>
<th>Example: O₃ mixing ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>Half standard</td>
<td>37.5 ppbv</td>
</tr>
<tr>
<td>100</td>
<td>Standard</td>
<td>75 ppbv</td>
</tr>
<tr>
<td>150</td>
<td>50% larger than standard</td>
<td>112.5 ppbv</td>
</tr>
<tr>
<td>200</td>
<td>Factor of 2 larger than standard</td>
<td>150 ppbv</td>
</tr>
<tr>
<td>300</td>
<td>Factor of 3 larger than standard</td>
<td>225 ppbv</td>
</tr>
<tr>
<td>500</td>
<td>Factor of 5 larger than standard</td>
<td>475 ppbv</td>
</tr>
</tbody>
</table>

For 75 ppbv 8-hour standard
### Air Quality Index (AQI)

<table>
<thead>
<tr>
<th>AQI</th>
<th>Health warnings</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50</td>
<td>Good</td>
</tr>
<tr>
<td>51-100</td>
<td>Moderate</td>
</tr>
<tr>
<td>101-150</td>
<td>Unhealthy for sensitive groups</td>
</tr>
<tr>
<td></td>
<td>Active children and adults, and people with respiratory disease, should limit outdoor exertion.</td>
</tr>
<tr>
<td>151-200</td>
<td>Unhealthy</td>
</tr>
<tr>
<td></td>
<td>Active children and adults, and people with respiratory disease, should avoid outdoor exertion; everyone else, especially children, should limit outdoor exertion.</td>
</tr>
<tr>
<td>201-300</td>
<td>Very unhealthy</td>
</tr>
<tr>
<td></td>
<td>Active children and adults, and people with respiratory disease, should avoid all outdoor exertion; everyone else, especially children, should limit outdoor exertion.</td>
</tr>
<tr>
<td>301-500</td>
<td>Hazardous</td>
</tr>
<tr>
<td></td>
<td>Everyone should avoid all outdoor exertion</td>
</tr>
</tbody>
</table>

### Good Air Quality Days in Puget Sound

![Graph showing number of days air quality was rated as "good" per year](image)

Highest pollutant level determines ranking

### CO in King County (8 hour)

![Graph showing CO levels in King County](image)

Puget Sound Air Quality Agency
http://www.pscleanair.org/ds04/docs/2006AQD5FINAL.pdf
Trapping of pollution in inversion: a Smog Watch was issued July 20-July 24, 2006 particularly for the downwind foothill areas south and east of the Everett-Seattle-Tacoma urban corridor.
Air Quality Maps: Forecasts and archives
http://www.airnow.gov/

July 22, 2006
Peak 1-hour ozone

Ozone (8-hour) non-attainment areas in US

Non-attainment areas for 2003

EPA 2003 ozone report
http://www.epa.gov/airtrends/aqtrnd04/2003ozonereport
Maximum Pollutant concentration in Major U.S. Metropolitan Areas (2002)

South Coast AQMD


Jacobson, Figure 8.3


http://www.eia.doe.gov/emeu/aer/eh/frame.html
Electricity sources in Washington State

Where our energy comes from
In 2004, Washington customers got about 56 percent of their electricity needs from hydro and 33 percent from coal, nuclear and natural gas. The rest came from the renewable resources advocated by 1957 supporters, such as wind, solar and biomass.

Note: Numbers do not add up to 100 percent because of rounding.
Source: Washington State Department of Community, Trade and Economic Development

Alternative energy

Solar  Wind  Nuclear

Geothermal  Hydroelectric  Biomass

Alternative fuels for cars

Electric cars  Ethanol  Natural gas

Electricity  Biodiesel  Ethanol  Methanol  Natural gas  Hydrogen  Hydrogen car (BMW)
Biodiesel and Pollution

Figure 1: Tailpipe Emissions of Biodiesel relative to Conventional Diesel