Measuring Air Changes per Hour with Carbon Dioxide

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Measuring room air exchange

• Measure air supply & extract
• Negative pressure: extract > supply by ~10%

Calculating ACH

• Q = room ventilation (cfm)
• V = velocity (feet/min)
• A = duct area (square feet)
• ACH = Q/room volume
Measuring room air exchange in low resource settings

\[ Q = V \times A \]

\[ \text{ACH} = \frac{Q}{\text{volume}} \]

Principles:
- Use gas that is not usually present in the room air: SF\(_6\)
- Deliver gas and mix with room air
- Measure concentration decay to calculate air exchange
- Also a continuous release methodology

Standard tracer gas technique:

Other methods: theatrical fog
Measuring natural ventilation

Measuring room air exchange using carbon dioxide as a tracer gas

- Infra-red gas analyser to measure CO₂ concentrations
- Advantages: Cheap
  CO₂ easily available (dry ice, fizzy drinks)
  Can use occupied rooms
- Disadvantages: Not perfect
  CO₂ present in air
  CO₂ produced by occupants

CO₂ release  Windows opened

<table>
<thead>
<tr>
<th>CO₂ concentration decay</th>
<th>Rapid decay with windows open</th>
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</thead>
<tbody>
<tr>
<td>Slow CO₂ concentration</td>
<td>0.5 ACH</td>
</tr>
<tr>
<td>with windows closed</td>
<td>12 ACH</td>
</tr>
</tbody>
</table>

**Closing apertures**

Images showing people closing apertures.
Small rooms, little ventilation:
- Gas cylinder
Large rooms, lots of ventilation:
- Fire extinguisher

**CO₂ release**

Very big rooms – lots of fire extinguishers

**CO₂ release**

- Gas cylinder
- Fire extinguisher

Very big rooms – lots of fire extinguishers
Mixing: Aiming for complete mixing

Mixing

no electricity
Calculation of ACH

ACH = Absolute ventilation / Room Volume
 = Q / V

Plot natural log of CO₂ concentration against time

Units: concentration (eg ppm) vs. time in hours

ACH = slope of line of best fit
Calculation of ACH

Windows and doors CLOSED
0.5 ACH

\[ y = -0.50x + 8.70 \]
\[ R^2 = 0.89 \]

Calculation of ACH

Windows and doors OPEN
12 ACH

\[ y = -12.25x + 12.30 \]
\[ R^2 = 0.88 \]
Where to stop?

- Depends on room occupants
- Within 200 ppm of baseline

**CO₂ release**

**Windows opened**

- Slow CO₂ concentration decay with windows closed
- Rapid decay with windows open

0.5 air-changes/hour
- 12 air-changes/hour

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**ACH vs. Absolute ventilation**

ACH = \( \frac{Q}{V} \)

Q = ACH x V

**V = 2x25 = 50 m³**

12 ACH = 600 m³/h

**V = 4x25 = 100 m³**

12 ACH = 1,200 m³/h

\[ C = S(1 - e^{-\text{q}_p t/Q}) \]

In models of airborne infection, it is absolute ventilation that is a major determinant of disease transmission.
Effect of room volume if ACH is constant

Wells-Riley equation: \[ C = S (1 - e^{-\frac{qpt}{Q}}) \]

- **Q** = 1,200
- \[ C = 1 \times (1 - e^{1 \times 13 \times 0.6 \times 8}) / 1,200 \]
  \[ = 0.05 \]
  **Risk = 5%**

- **Q** = 600
- \[ C = 1 \times (1 - e^{1 \times 13 \times 0.6 \times 8}) / 1,200 \]
  \[ = 0.10 \]
  **Risk = 10%**

Mechanical ventilation can’t deliver high ACH in large rooms due to cost, drafts, fan noise etc. More complex: room crowding / bed spacing / near-far effect.

Measuring room air exchange using carbon dioxide as a tracer gas

**Conclusions**

- Simple
- Easy to do
- Equipment relatively easily available
- Cheap
- A bit rough, but with inherent variability of natural ventilation (wind speed etc) and such high air exchange rates, high precision is less important
- It’s fun!
Thank you