Aerosol fate in a room: Using low-cost sensors to study impact of ventilation

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Ventilation

CDC: Airborne disease spread

Engineering controls

DoE: Energy efficiency

“Air-tight” buildings to minimize energy leak

ASHRAE: Indoor air quality

Minimum ventilation

Focus on CO₂ mitigation
Particle concentration modeling: Box Models

\[ V \frac{dN}{dt} = \dot{S} + N_{in} \times Q_{in} - N_{out} \times Q_{out} - \dot{N}_{loss} \]

\[ N(t) = N_0 \times \exp(-\alpha t) + N_\infty \]

\[ \alpha = \frac{Q_{out} + v_w \times A}{V} \]

\[ N_\infty = \frac{\dot{S} + Q_{in} \times N_{in}}{Q_{out} + v_w \times A} \]
Model predictions

\[ N(t) = N_0 \cdot \exp(-\alpha t) + N_\infty \]

\[ \alpha = \frac{Q}{V} = ACH \]

\[ N_\infty = \left(\frac{S}{V}\right) \frac{1}{ACH} \]
Simple box models are basis of existing tools such as Fatima, CONTAM to predict fate of particles in indoor spaces.

Model limitations

Critical assumption: Well-mixed room

- Everywhere in the room identical concentrations and trends
- Social distancing within a room is not possible
Experiments

Map aerosol concentrations
- Classrooms around campus
- Varying volumes
- Different air exchange rates

Steady aerosol injection
- Nebulized Ammonium Sulfate
- Size range: 0.5 to 5 µm
- Varied locations

Low-cost Sensor Network
- TelosAir – Duet Sensors
- Aerosol (PMS 5003), CO2, VOCs, air properties
- LoRa wireless; Data API
Sensor evaluation
Classroom deployment
Air exchange rate determination

\[ N(t) = N_0 \exp(-\alpha t) + N_\infty \]
Spatial trend: Air exchange rate

\[ N(d_0, t) = N_0 \times \exp(-\alpha t) + N_\infty \]
Spatial trend: peak concentration

\[ N(d_0, t) = N_0 \times \exp(-\alpha t) + N_{\infty}(d_0, \alpha) \]
Conclusions

• Box models provide an average picture of aerosol fate in a room
  • Would suggest indoor social distancing for particles smaller than 10 µm not possible
  • Reasonable for spaces with air exchange rates less than 6

• A more realistic model would be like a flow in a turbulent tube
  • As particles travel downstream, they will be diluted
  • At high air-exchange rates (> ~6) concentrations decay with distance
    • Even for an air exchange rate of ~ 10, 50% concentrations were only achieved at a distance of 5m
Final observations

• Ventilation standards based on amount of fresh air to be delivered per person
  • Assumption - everyone is an emitter (true for CO$_2$
  • With more people present, more fresh air required.
  • Thus, high ACH when occupancy is high.

• If there is only one emitter, as maybe possible with biological aerosol, then, by current indoor air standards, a more crowded room might be better!
  • Higher ACH and hence greater dilution
  • Typical standards of 10L/s/person in a lecture type hall would only result in an air exchange of ~ 5.