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

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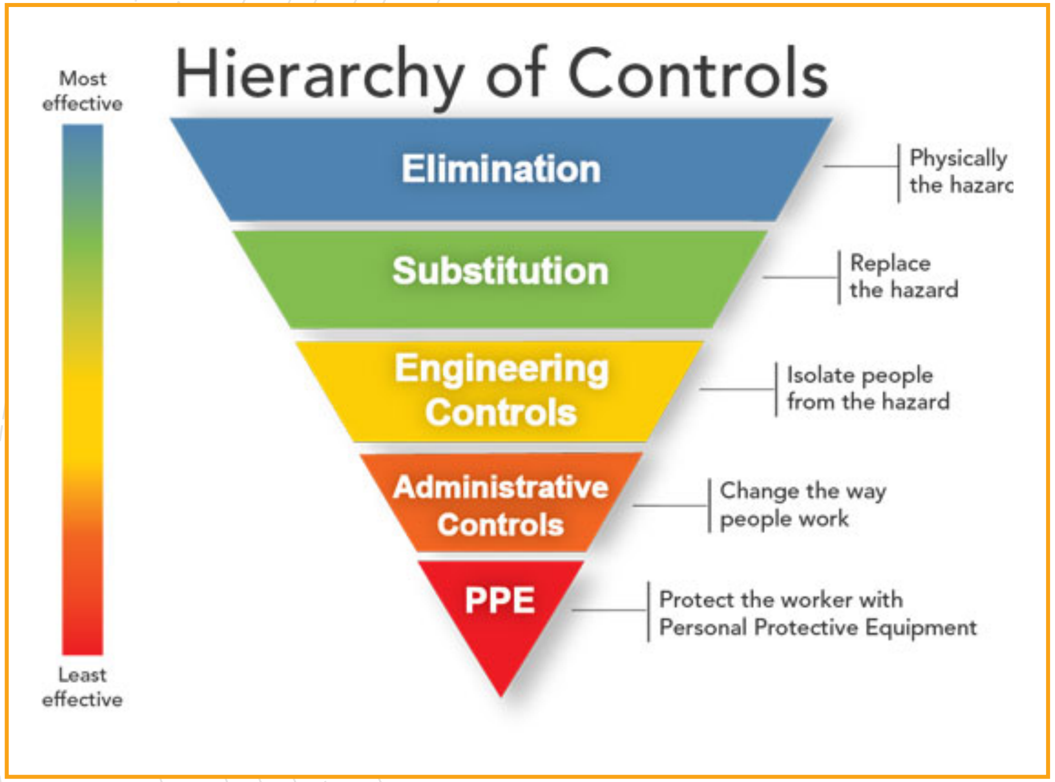
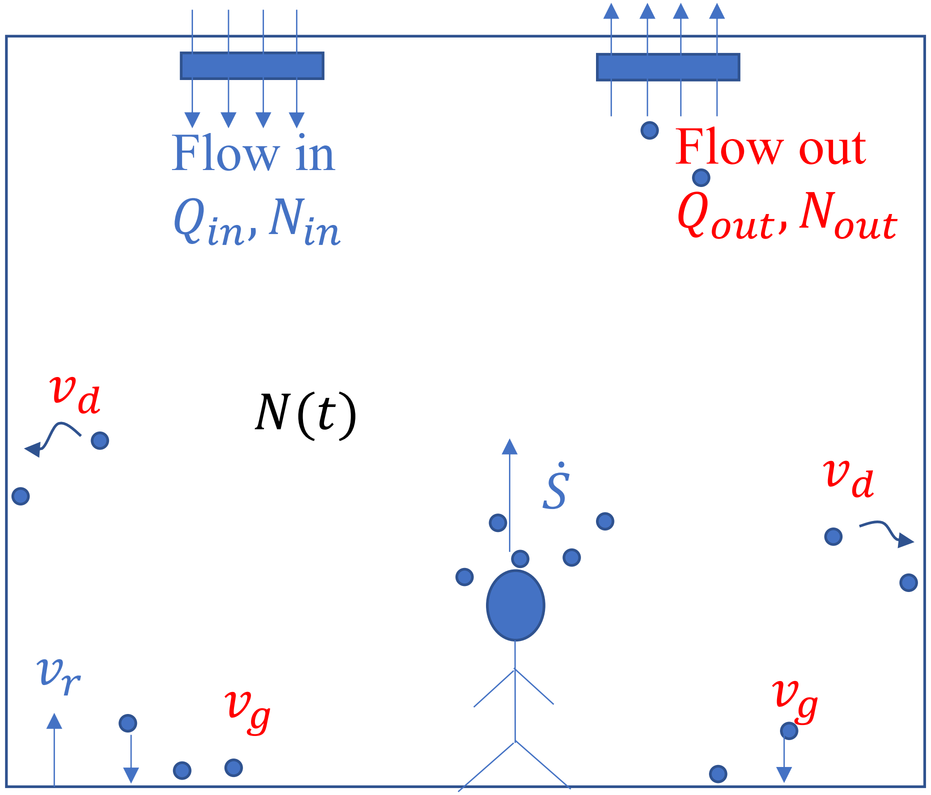
Ventilation



- **CDC: Airborne disease spread** — Engineering controls
- **DoE: Energy efficiency** — “Air-tight” buildings to minimize energy leak
- **ASHRAE: Indoor air quality** — Minimum ventilation; Focus on CO_2 mitigation

Particle concentration modeling: Box Models



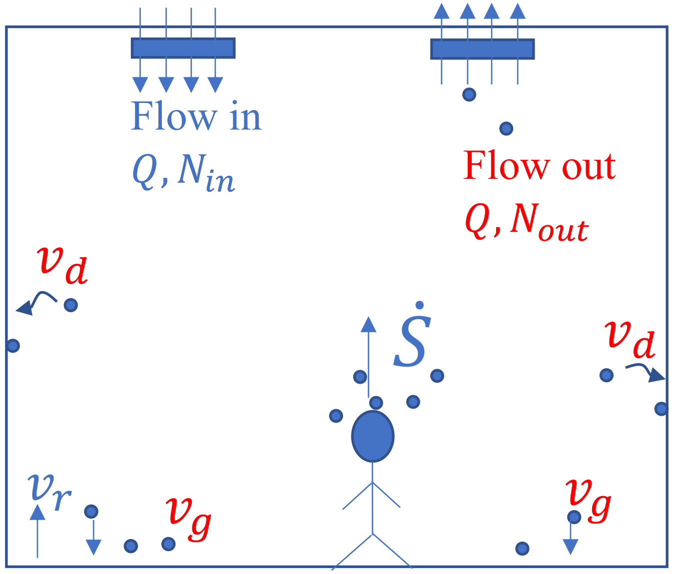
$$V\frac{dN}{dt} = \dot{S} + N_{in} * Q_{in} - N_{out} * Q_{out} - \dot{N}_{loss}$$

$$N(t) = N_0 * \exp(-\alpha t) + N_\infty$$

$$\alpha = (Q_{out} + v_w * A)/V$$

$$N_\infty = (\dot{S} + Q_{in} * N_{in})/(Q_{out} + v_w * A)$$

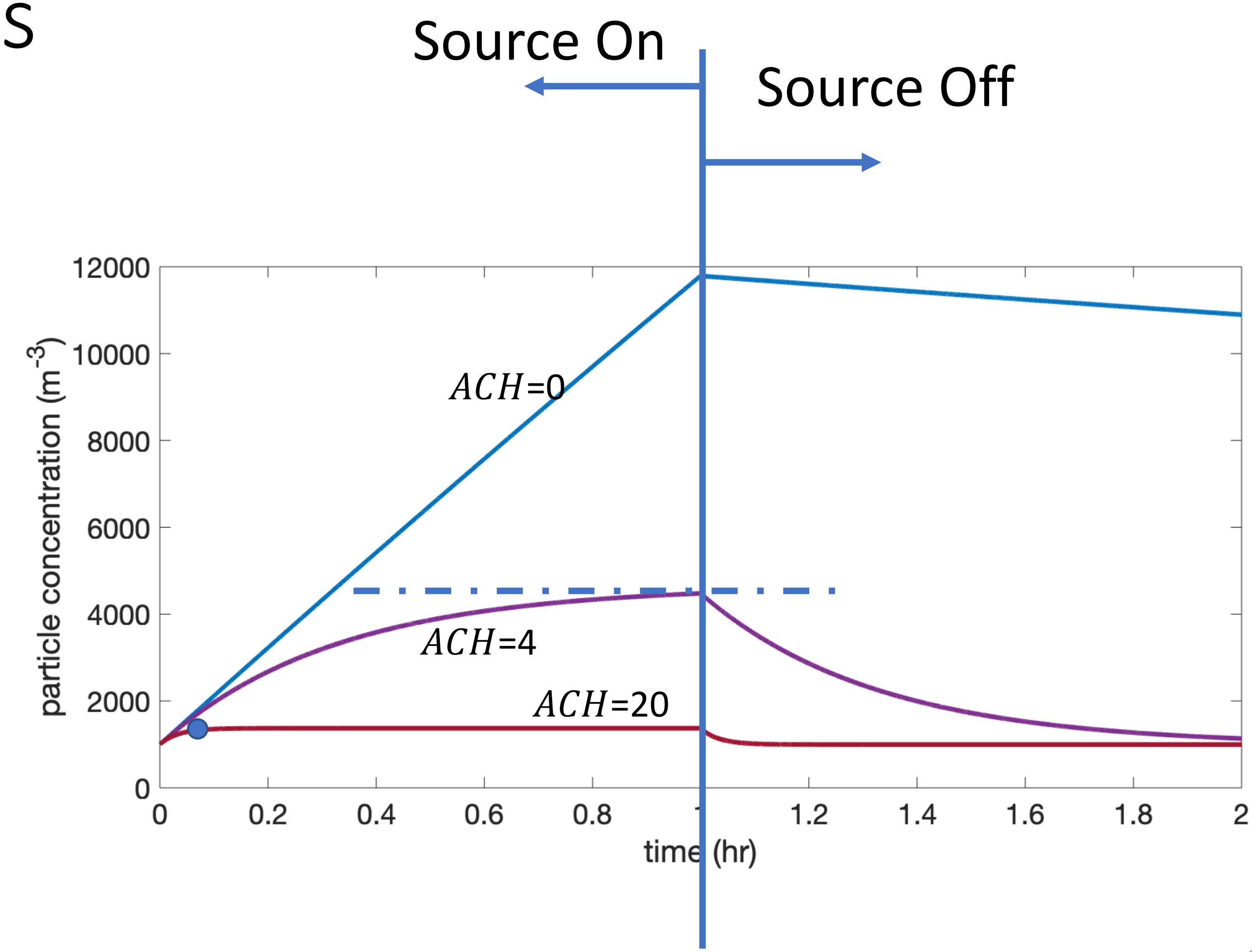
Model predictions



$$N(t) = N_0 * \exp(-\alpha t) + N_\infty$$

$$\alpha = \frac{Q}{V} = ACH$$

$$N_\infty = \left(\frac{\dot{S}}{V}\right)\frac{1}{ACH}$$



Model limitations

Simple box models are basis of existing tools such as Fatima, CONTAM to predict fate of particles in indoor spaces

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

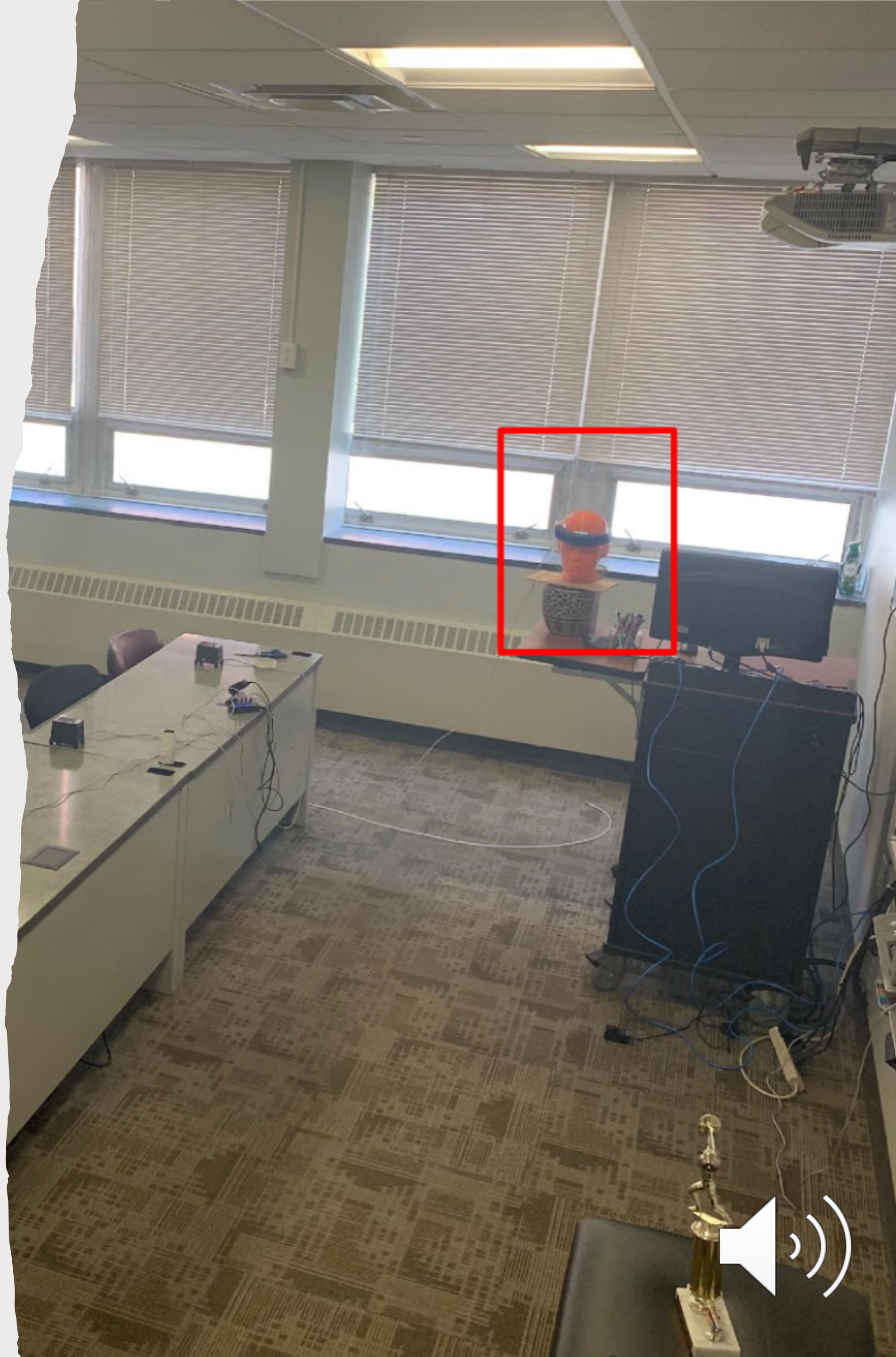
Varied locations

Low-cost Sensor Network

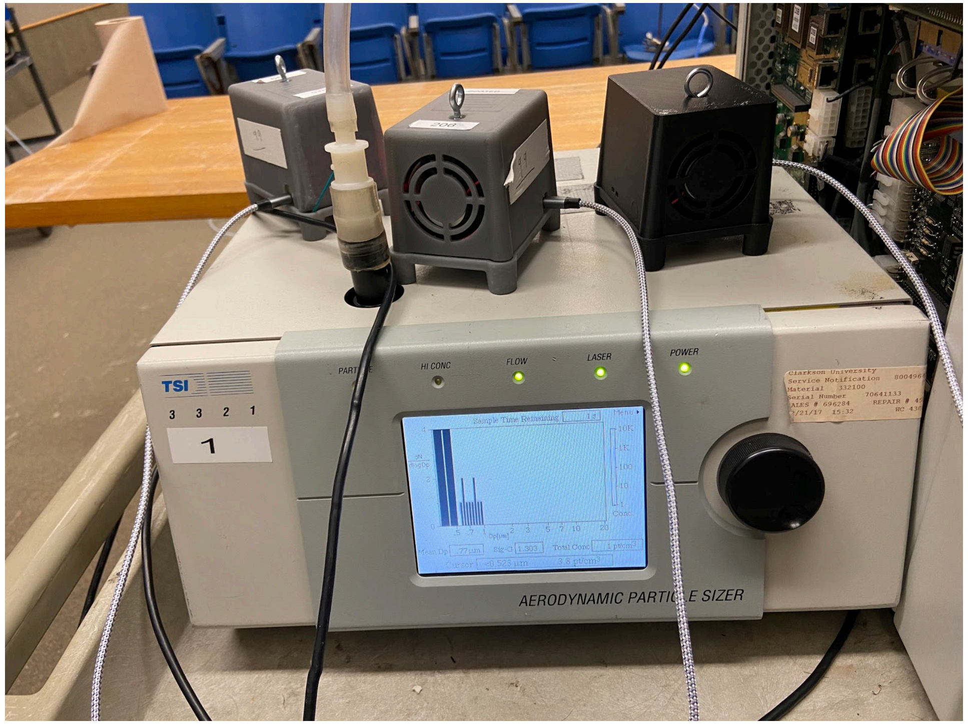
TelosAir – Duet Sensors

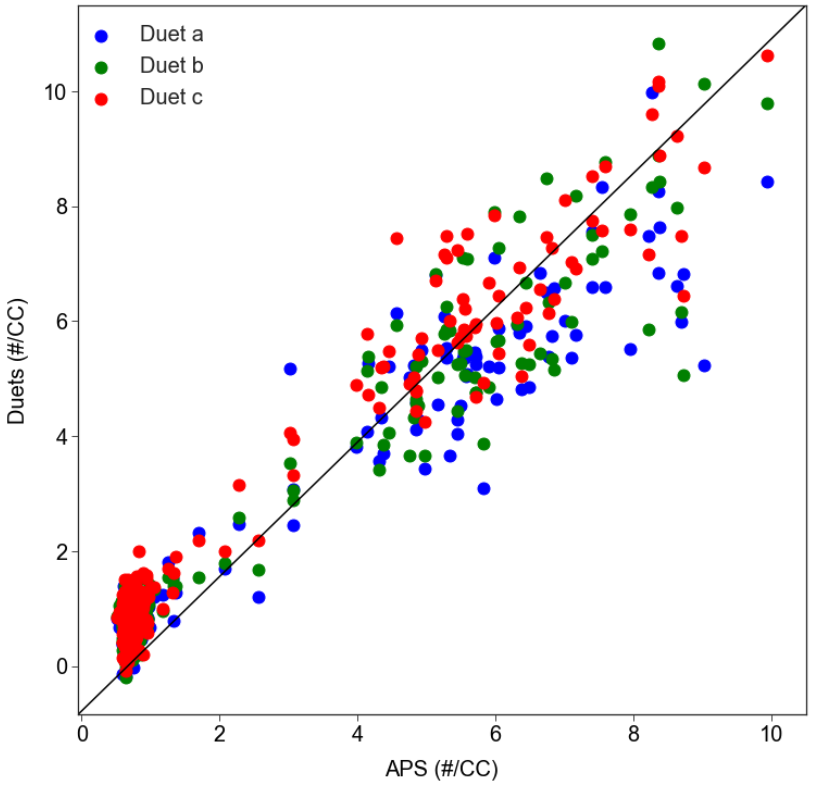
Aerosol (PMS 5003), CO_2, VOCs, air properties

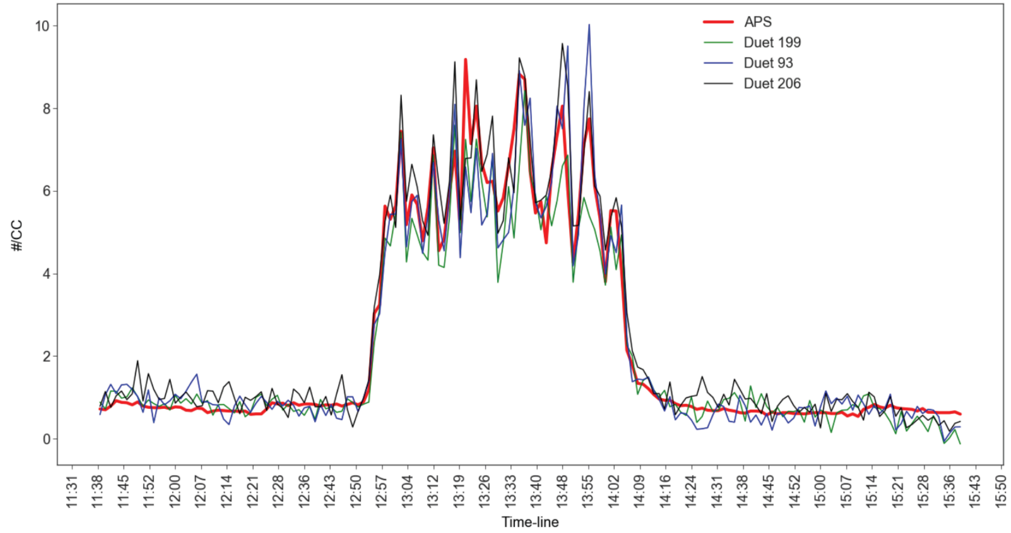
LoRa wireless; Data API



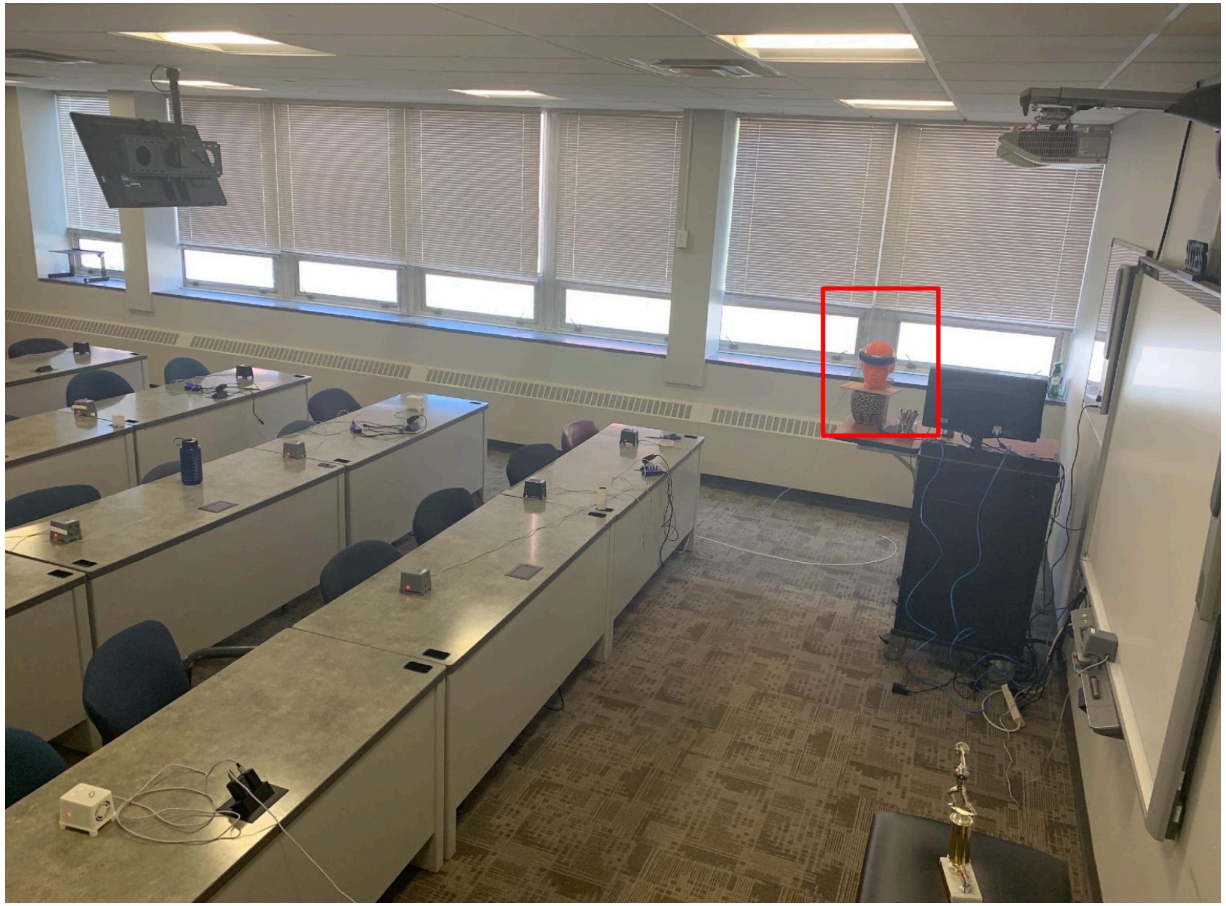
Sensor evaluation



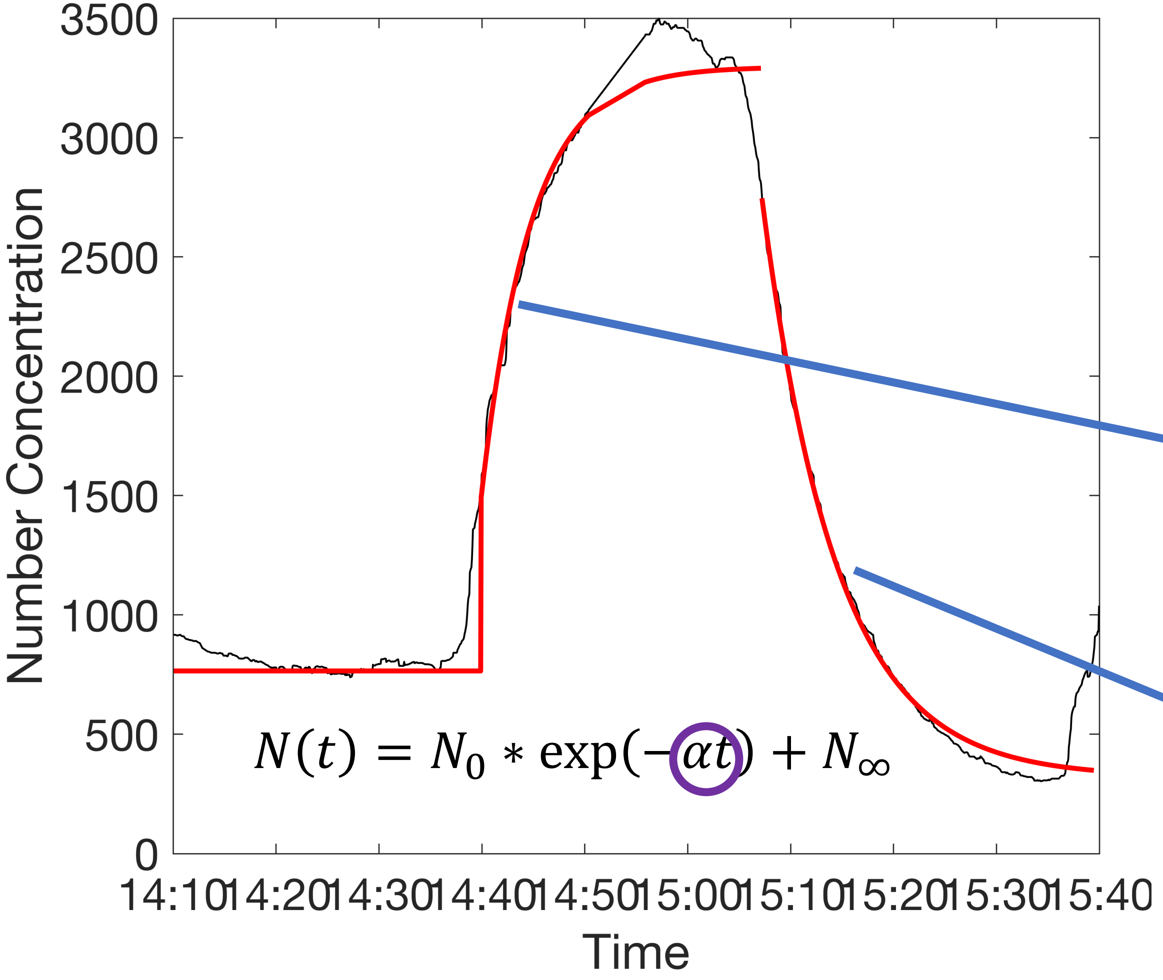


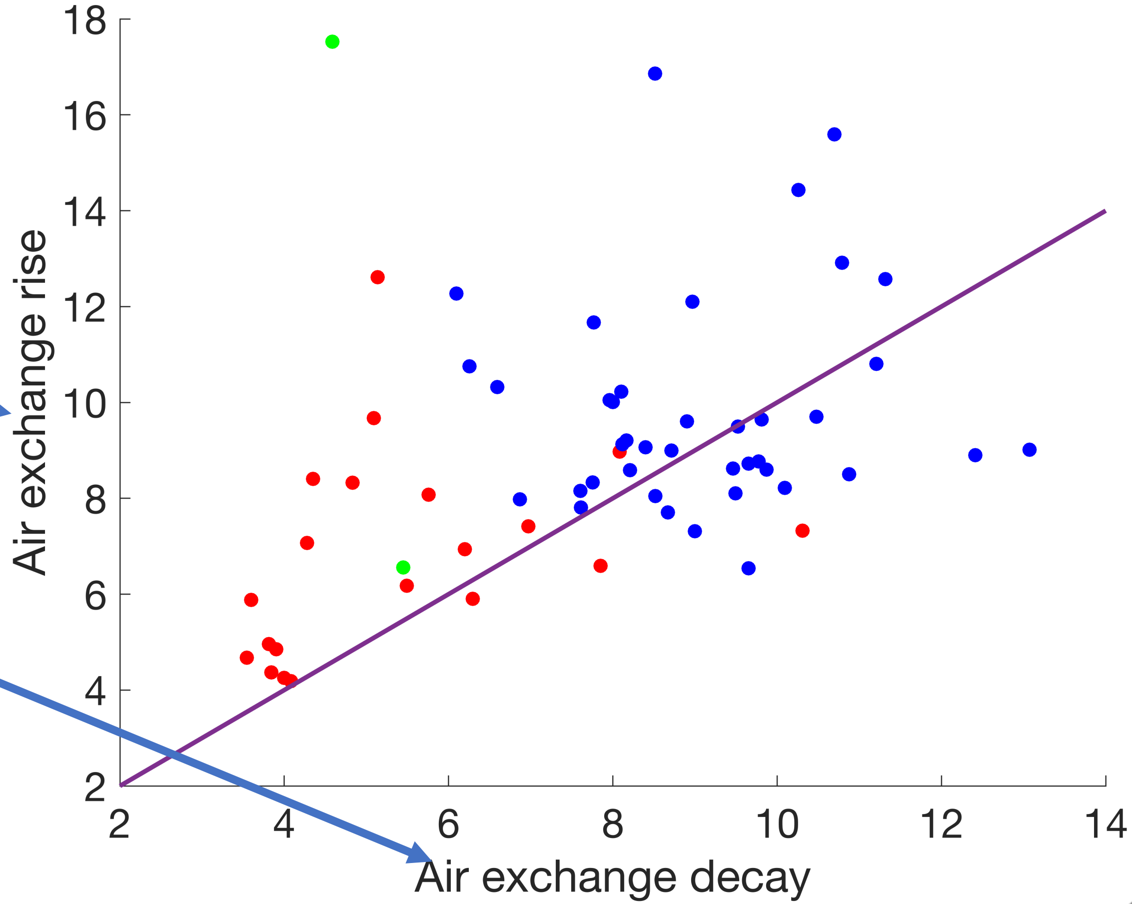


Classroom deployment

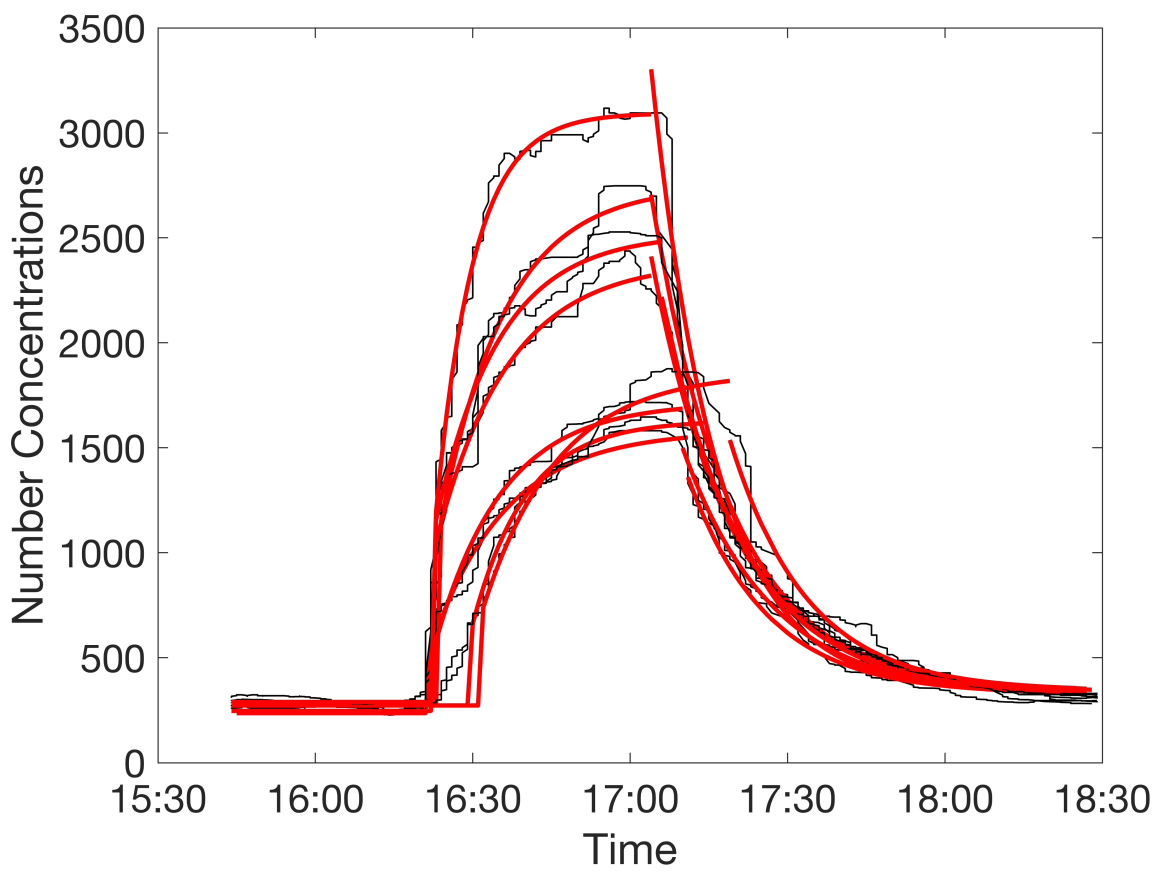


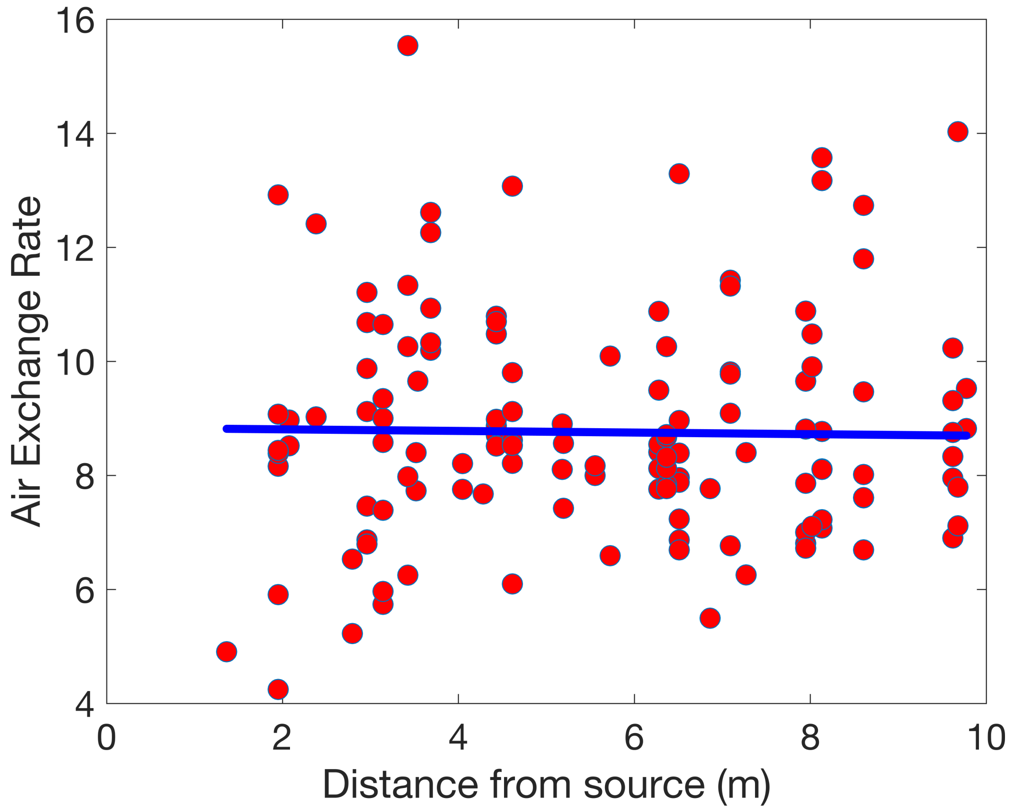
Air exchange rate determination





Spatial trend: Air exchange rate

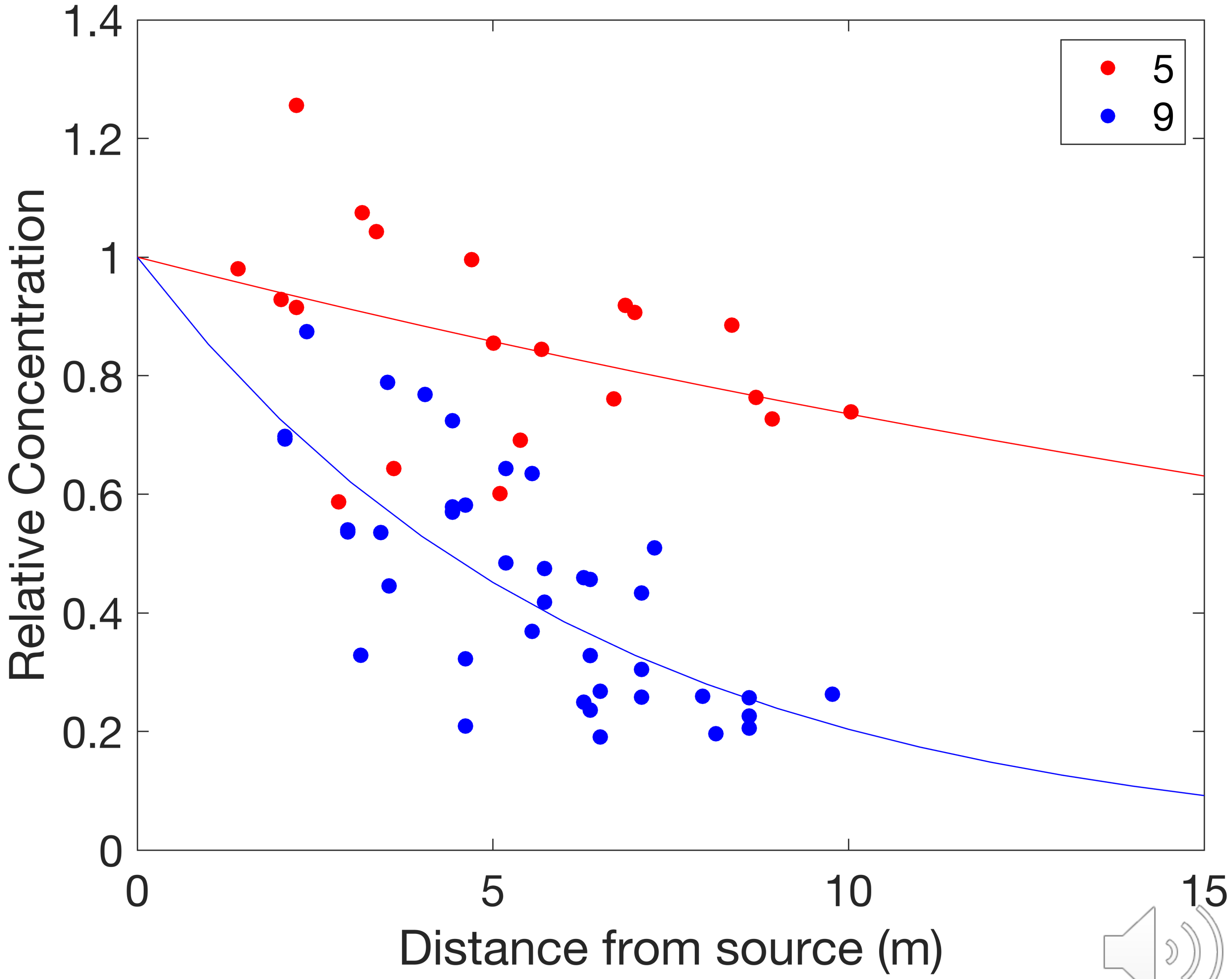




$$N(d_0, t) = N_0 * \exp(-\alpha t) + N_\infty$$

Spatial trend: peak concentration

$$N(d_0, t) = N_0 * \exp(-\alpha t) + N_\infty(d_0, \alpha)$$



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.