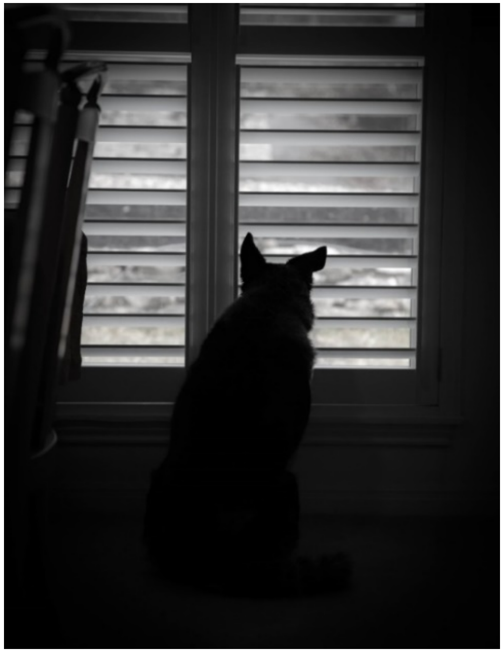
Indoor Air Quality and Aerosol Transmission Pathways for Viruses



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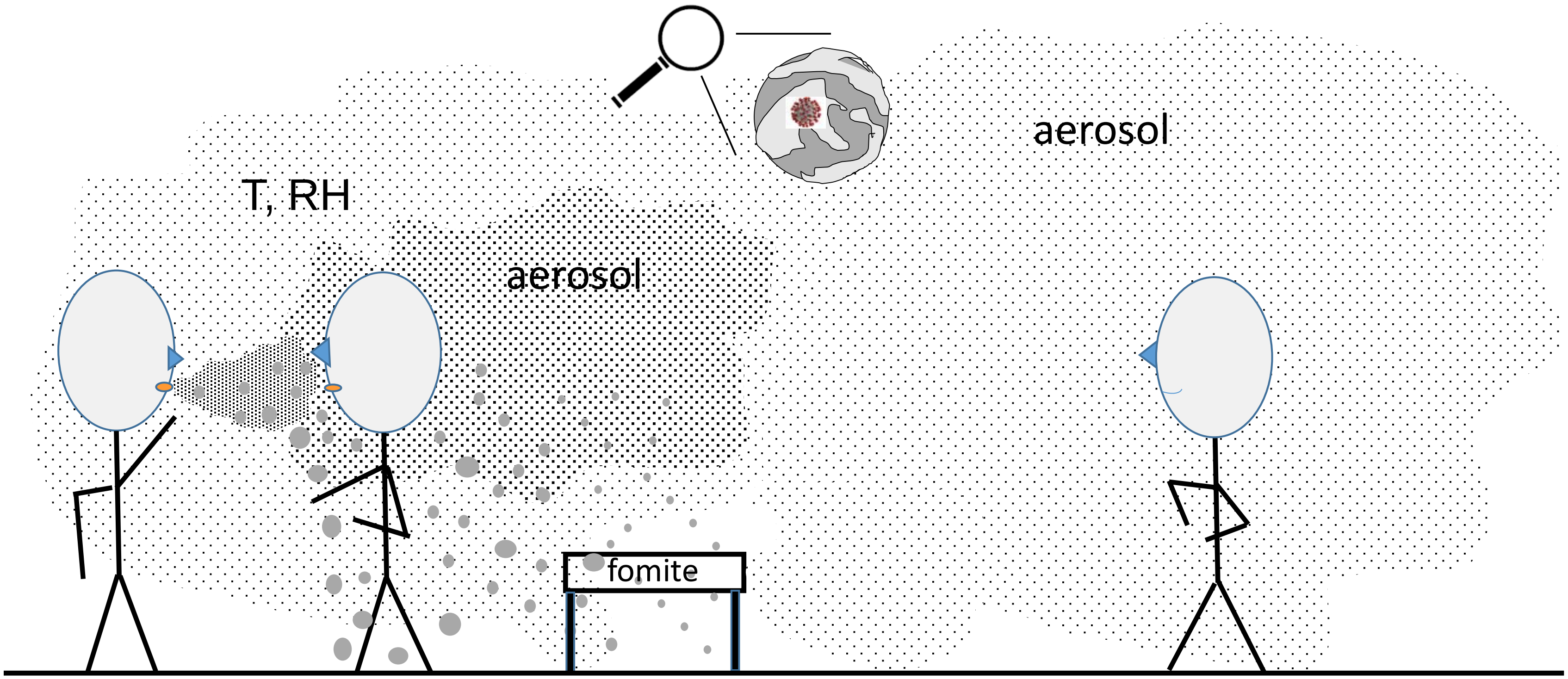
Particles as Vehicles for Exposure to SARS-CoV-2



Near Field (close contact)
Large Droplets + Aerosol

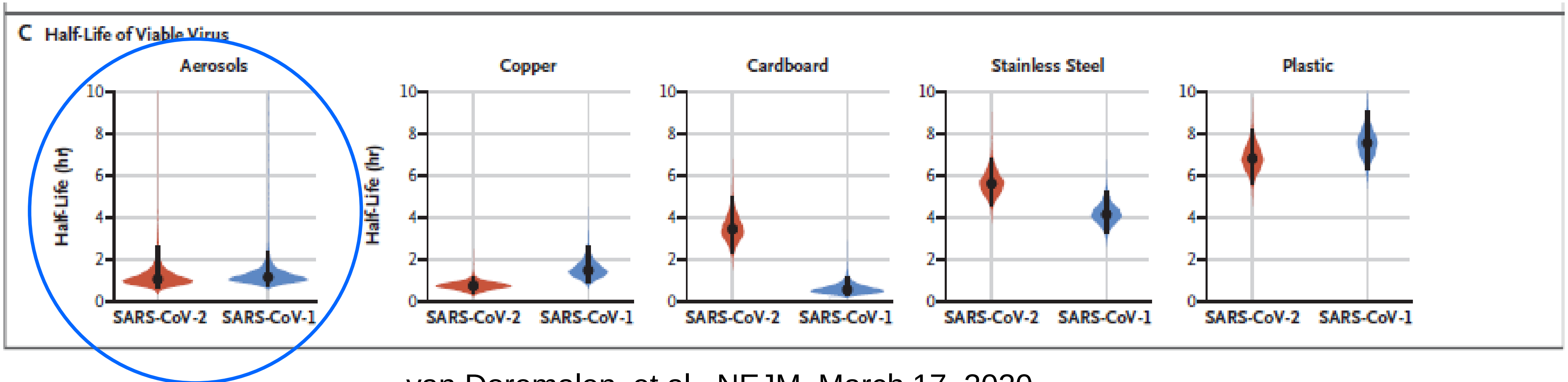
Far Field
Background Aerosol

Evidence of Transmission by Aerosols

- Near field (close contact): aerosols significant
- Asymptomatic spread prevalent (no cough; small particles)
- Detected in particles $\leq$ 4 μm
- Dense & poorly-ventilated environments
- SARS-CoV-2 relatively persistent in aerosols

See also – Allen, J.G., and Marr, L.C., “Re-Thinking the Potential for Airborne Transmission of SARS-CoV-2”, *Indoor Air* (accepted)
Preprint - doi: 10.20944/preprints202005.0126.v1

Inactivation Rates of SARS-CoV-2

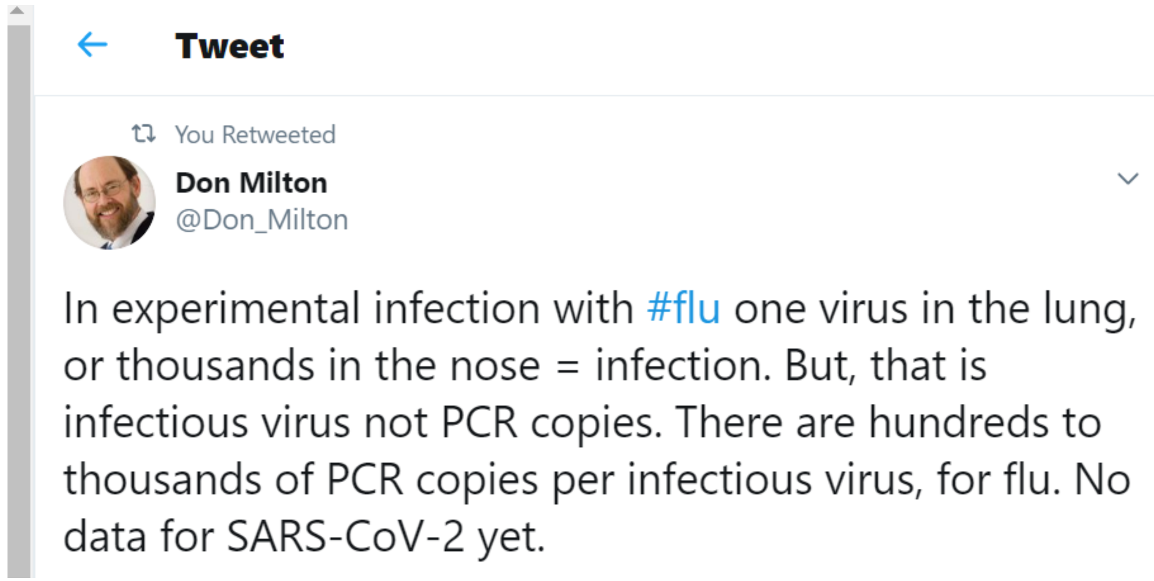


van Doremalen, et al., NEJM, March 17, 2020

- $t_{1/2}$ = 1.1 hr ⟶ k_v = 0.63/hr
- λ ≈ 0.3 to 12/hr (depending on building)

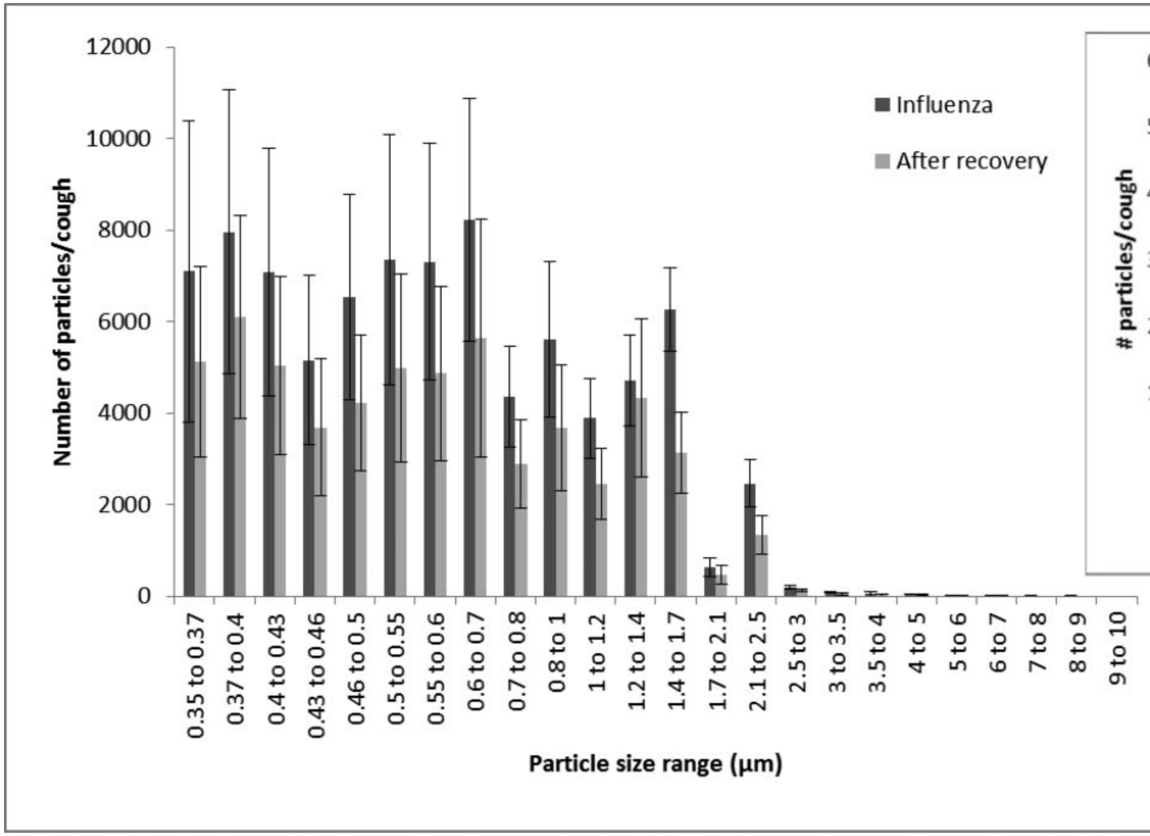
Sources

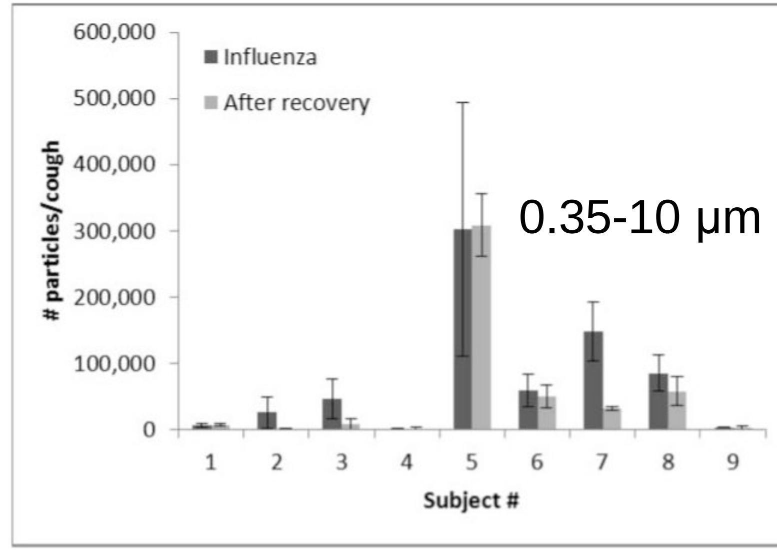
- Coughing
- Speaking
- Breathing
- Resuspension
- Flushing



- Still unknown
  - Viral load
  - Infectious fraction

Emissions via Coughing

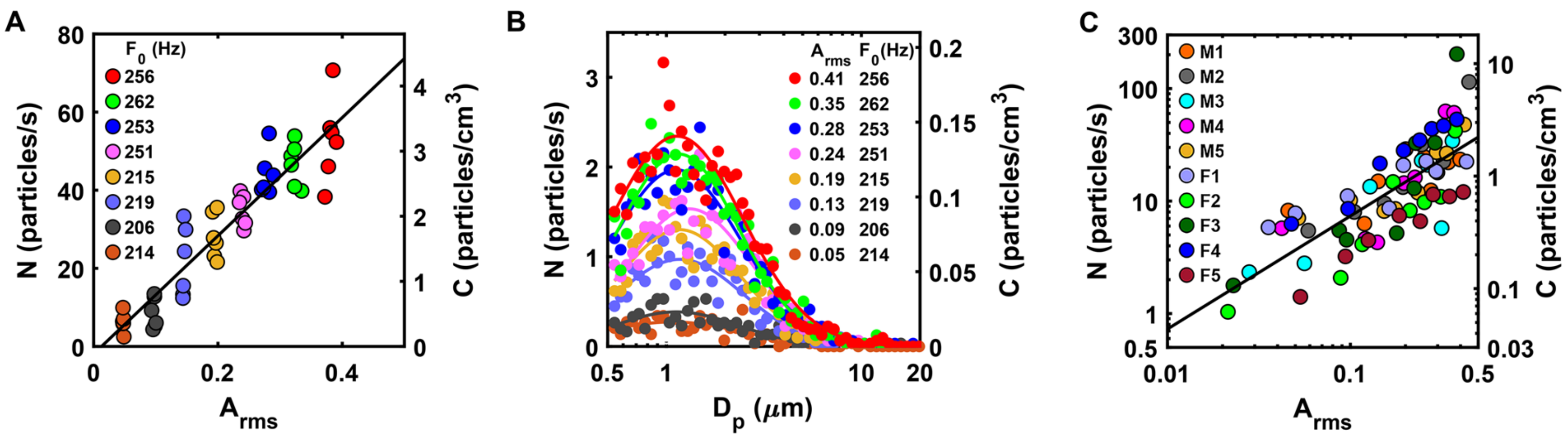




Lindsley, W.J., *et al., J of Occupational and Environmental Hygiene*, 9: 443–449 (2012)

- Mean = 75,400 SD = 97,300 / cough
  - Range: 900 – 302,000 / cough
- 63% of particle volume ≤ 4 µm (d_a)

Emissions via Speaking



Asadi, S. *et al*. *Scientific Reports*, *9:2348 (2019)* doi.org/10.1038/s41598-019-38808-z

- Reasonable range = 300 to 3,000/min (some super-emitters to 12K /min)
- Super-emitter: 6 min of speaking loudly ≈ mean emission of single cough
- Breathing ≈ order of magnitude lower than speaking

Screening Model

$$\frac{dC_i}{dt} = \frac{E_i}{\forall} - \beta_i C_i$$

Particles of diameter *i*

$$E_i = \dot{n} E_{c,i} + \alpha_s E_{s,i} + \alpha_b E_{b,i}$$

(cough) (speak) (breathe)

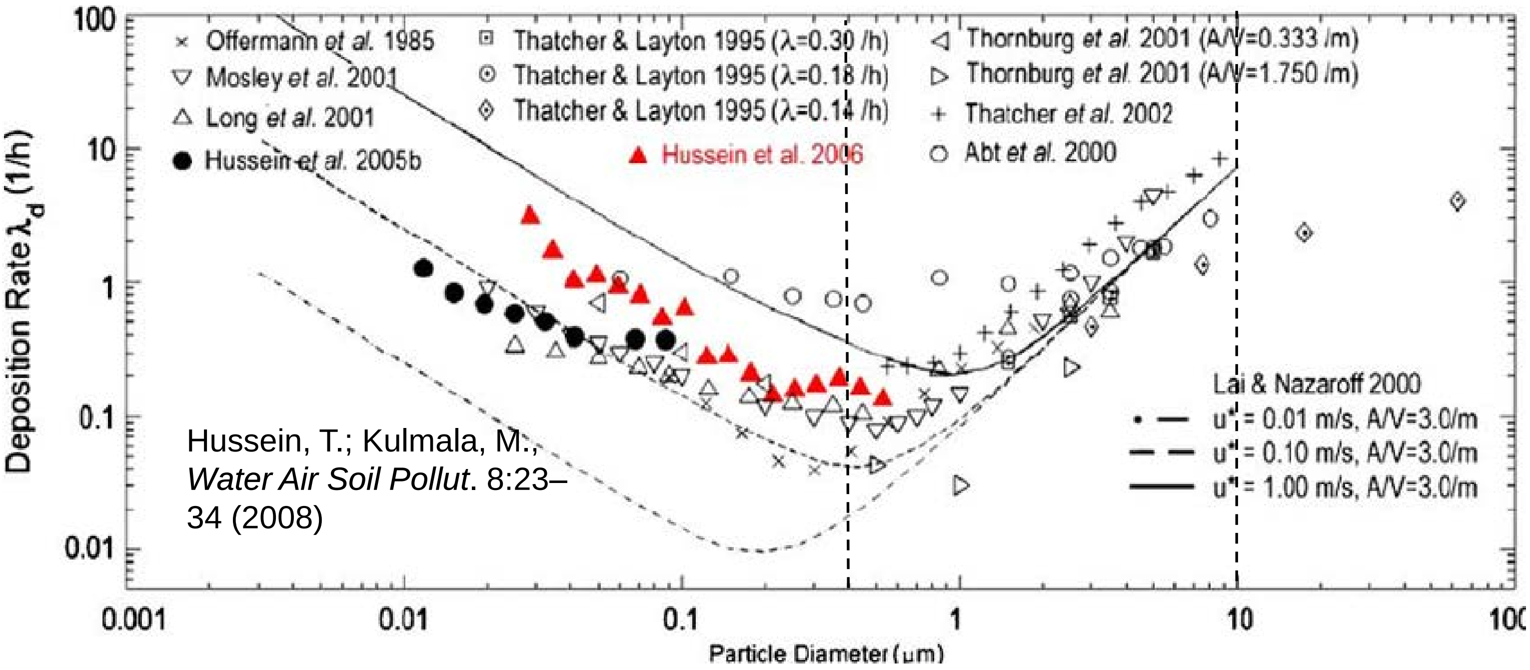
$$\beta_i = \lambda + k_{dep,i} + \sum \frac{2_i Q_{c,i}}{\forall} + f_{dep,i} \frac{Q_b}{\forall}$$

(Ventilation) (Deposition) (Control) (Inhalation)

$\text{Dose}_{inhal,i}$ = **C_i** (#/L) x **B** (L/min) x **t** (min) x $f_{dep,i}$

- Important to understand magnitudes of variables & factors that influence
- Aerosol = vehicle of SARS-CoV-2 (greater dose_i = greater # viruses for i)

Deposition onto Indoor Surfaces



Hussein, T.; Kulmala, M., *Water Air Soil Pollut*. 8:23–34 (2008)

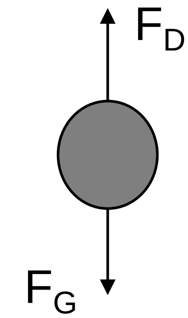
- Range of k_{dep} for 0.4 to 10 µm particles: 0.05 to 7/hr
- Context: λ ≈ (0.3 to 12/hr) – fn (type of building)

How far Can Particles Travel?

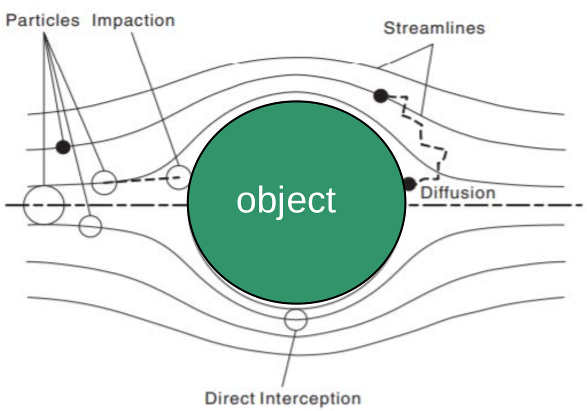
At air speed of 5 cm/s in free stream

d_a (μm)	V_{TS} (m/s)	k_d (1/hr)	$X_{1.5m}$ (m) -GS	$X_{50\%}$(m) - PF
0.5	7.5E-06	0.05	10000	2500
1	3.0E-05	0.1	2500	1200
5	7.5E-04	1.5	100	80
10	3.0E-03	7	25	20
50	7.5E-02	100	1	1

Particles ≤ 10 μm not substantially removed within 6 ft



Gravitational settling



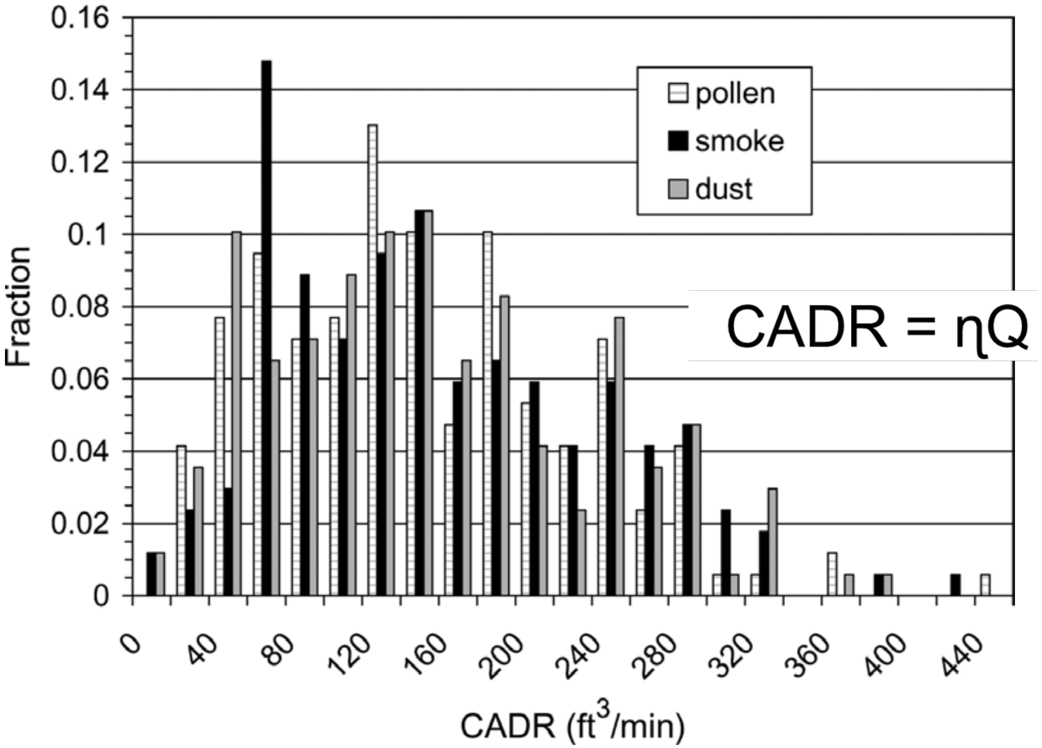
Modified from Wang, W., *et al. Aerosol Sci & Technol*, 46:843–851, 2012

Dose Reduction: Engineering Controls

- Increase outdoor air supply rate (100% if possible)
- Minimize or (preferably) eliminate recirculation
  - Effective in-system filtration (e.g., MERV13+)
- Consider portable HEPA filtration (high CADR)
- Consider UltraViolet Germicidal Irradiation (studies needed)

$$C_i = \frac{E_i / \lambda \forall}{1 + k_{dep,i}/\lambda + \eta_i Q_c / \lambda \forall}$$

Role of Portable Air Cleaners



CADR = ηQ

EPA.gov

Shaughnessy, R.J., and Sextro, R.G., *J of Occupational and Environmental Hygiene*, 3: 169–181(2006)

$$C_i = \frac{E_i/\lambda\forall}{1 + k_{dep,i}/\lambda + \eta_i Q_c/\lambda\forall}$$

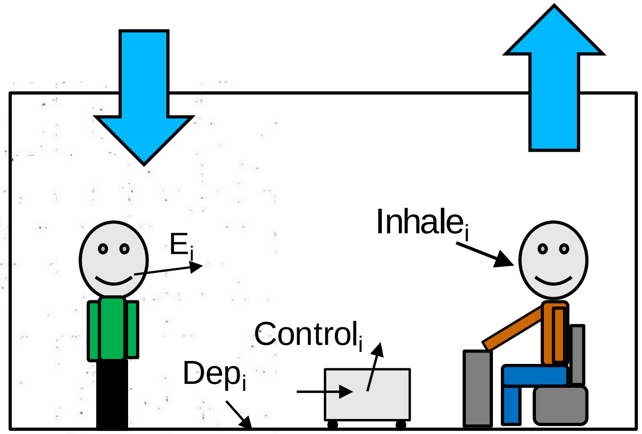
CADR

Classroom Model

$$\frac{dC_i}{dt} = \frac{E_i}{\forall} - \beta_i C_i$$

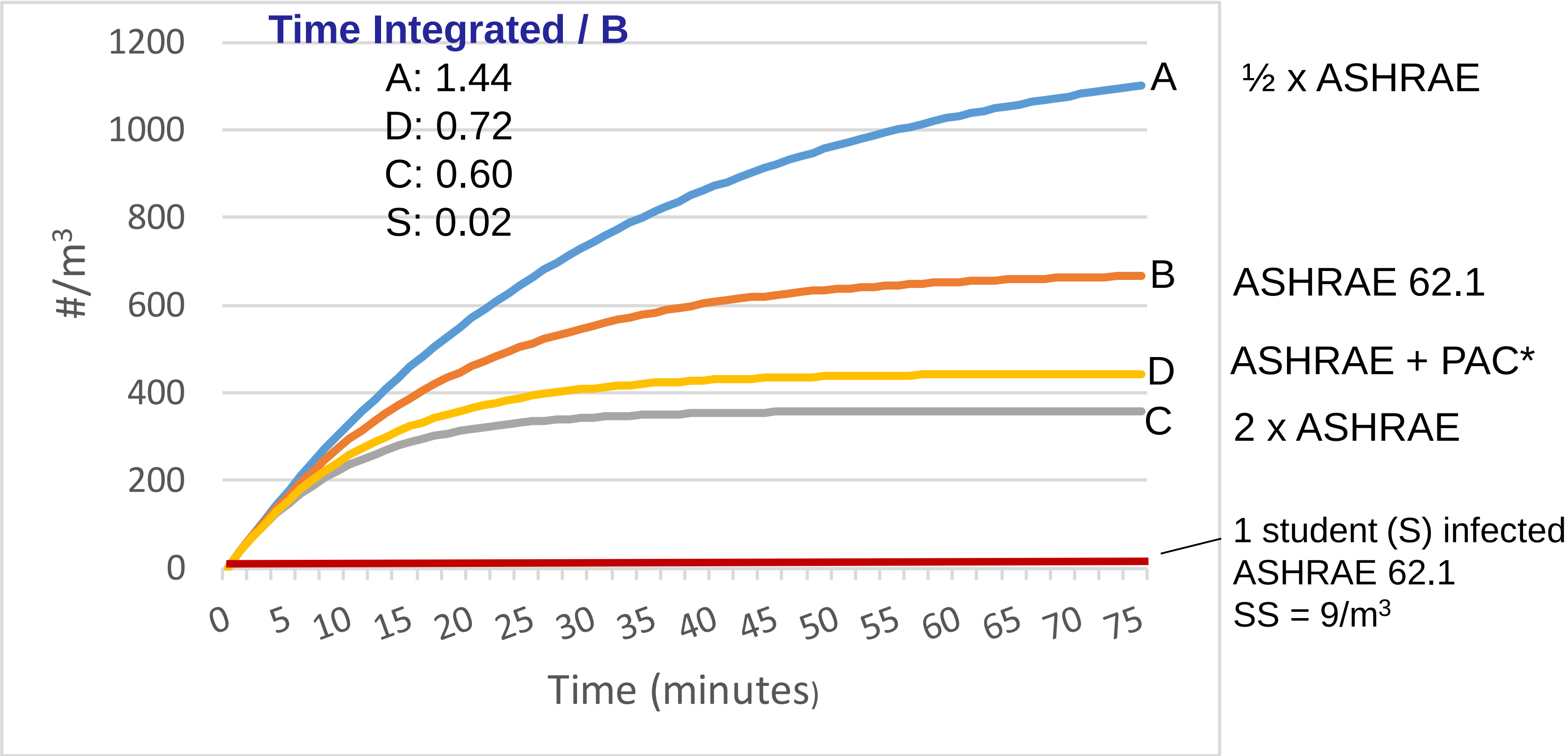
$$E_i = \underset{\text{(cough)}}{\dot{n} E_{c,i}} + \underset{\text{(speak)}}{\alpha_s E_{s,i}} + \underset{\text{(breathe)}}{\alpha_b E_{b,i}}$$

$$\beta_i = \underset{\text{(Ventilation)}}{\lambda} + \underset{\text{(Deposition)}}{k_{dep,i}} + \underset{\text{(Control)}}{\sum \frac{\eta_i Q_{c,i}}{\forall}} + \underset{\text{(Inhalation)}}{f_{dep,i} \frac{Q_b}{\forall}}$$



- Classroom: 100 m^2 x 2.8 m; 34 students
- Emissions: Infected instructor (super-emitter) 0.5 to 4 μm droplet nuclei
- Ventilation: λ = Q/V - Q based on ASHRAE 62.1 (w/ 100% outdoor air)
- Other parameters: Literature

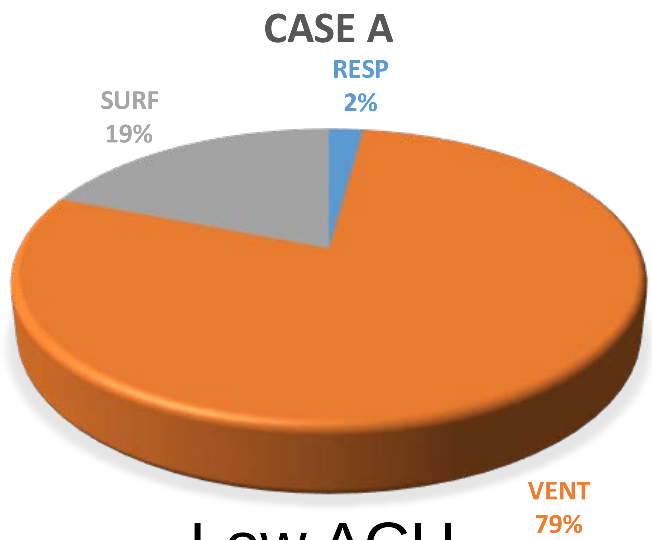
Particles from Infector in Classroom Air



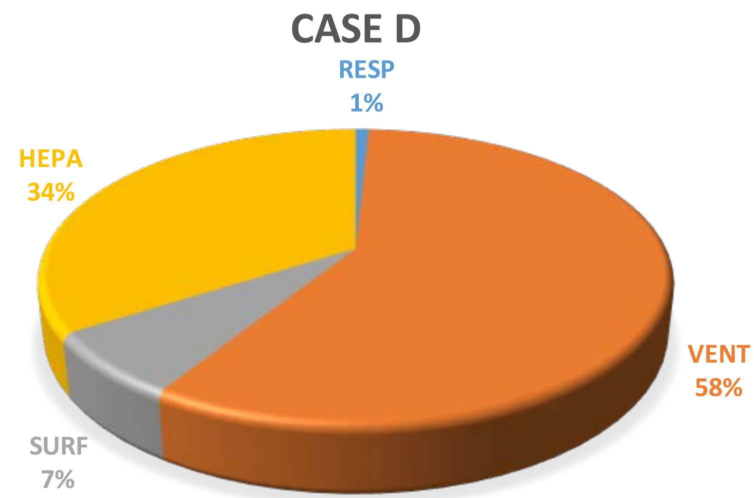
* PAC: HEPA w/ CADR = 300 scfm

Air contaminated at end of lecture (time to 95% reduction = 30 – 100 min)

Pathways & Dose/Student



Low ACH



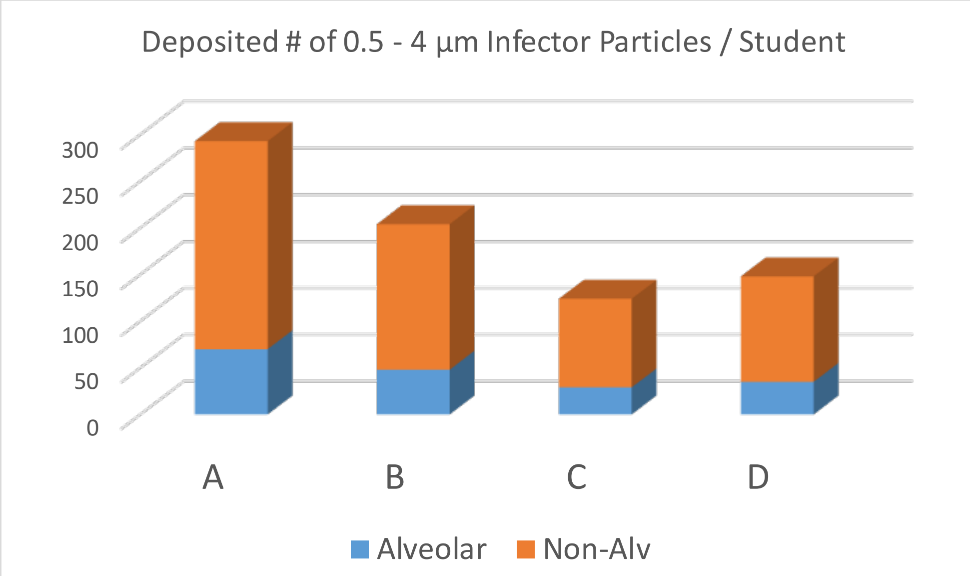
ASHRAE + PAC

A: ½ ASHRAE

B: ASHRAE

C: 2 x ASHRAE

D: ASHRAE + PAC



Moving Forward

- Viral loads & infectious virus fraction [= fn(d_p)?]
- Dose-response relationship (to help w/ control strategies)
- More field sampling to explore far field potential
  - In-situ sampling in buildings w/ infectors (filter collection)
- Less disciplinary trench digging (interdisciplinary collaboration)
- Apply what we learn to reduce extent of next wave/pandemic