Computation Modeling of Dilute Two-Phase Flows - Application to Transmission of Respiratory Viruses

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Outline

- Dilute particle – laden flows
- Computational modeling
- Sample respiratory transport
- Aerosol transmission respiratory viruses (COVID-19)
- Speaking and Coughing
- Small Office
- Large Office space
- Conclusions

Air Flow Modeling

Instantaneous Turbulence Fluctuation Velocity

- Direct Numerical Simulation (DNS)
- Large Eddy Simulation (LES)
  - Subgrid Scale Model
- RANS Model
  - Filtered White Noise (CRW)
  - Eddy Life Time (DRW)

Particle Equation

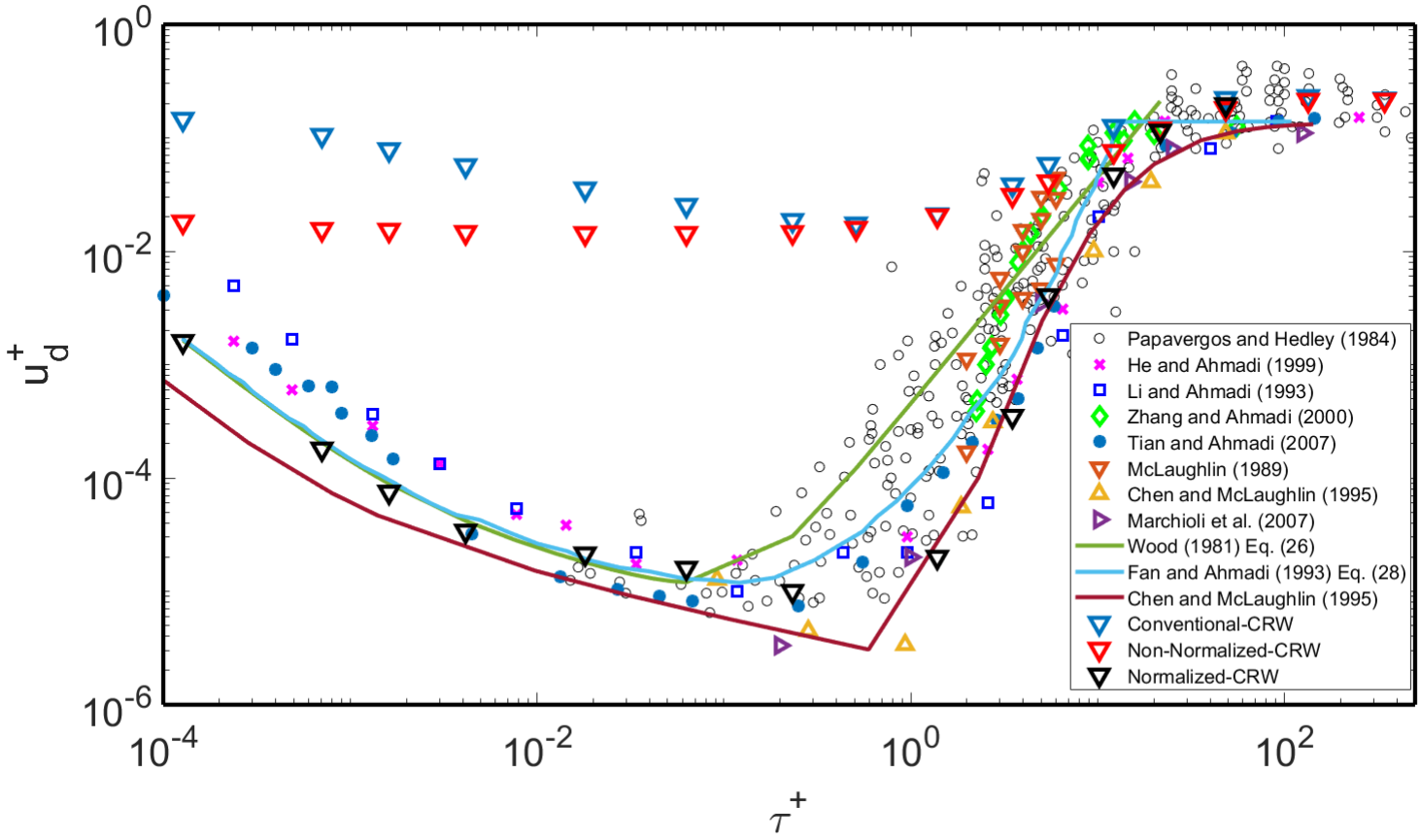
$$\frac{du_i^p}{dt} = \underbrace{\frac{C_D\,Re_P}{24}\frac{1}{\tau}\left(u_i - u_i^p\right)}_{\text{Drag force}} + \underbrace{f_i^L}_{\text{Lift force}} + \underbrace{g_i}_{\substack{\text{Gravitational} \\ \text{force}}} + \underbrace{f_i^E}_{\text{Electric force}} + \underbrace{n_i(t)}_{\substack{\text{Brownian} \\ \text{force}}}$$

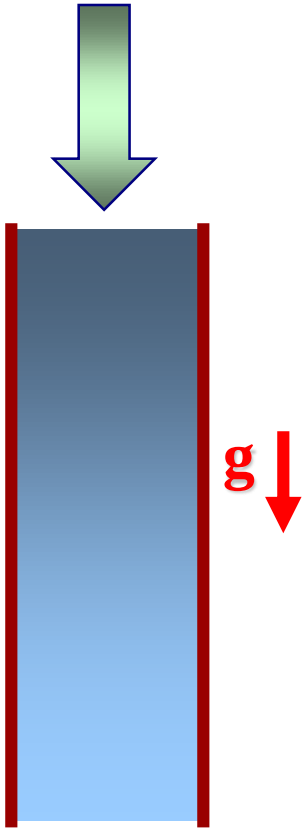
Assumptions: Dilute Flows, One-Way Interaction, Neglect Particle Collisions

$$C_D = \frac{24[1 + 0.15\,Re^{0.687}]}{Re}$$

$$1 < Re < 1000$$

Particle Deposition in a Duct





Mofakham and Ahmadi (2019,2020)

Turbulence Near Wall Model

Quadratic Variation Near Wall

Hinze (1975) $\sqrt{\overline{v'^2}} \propto y^2$ $\quad y \to 0$

$$v^+ = Ay^{+2} \qquad y^+ < 4$$

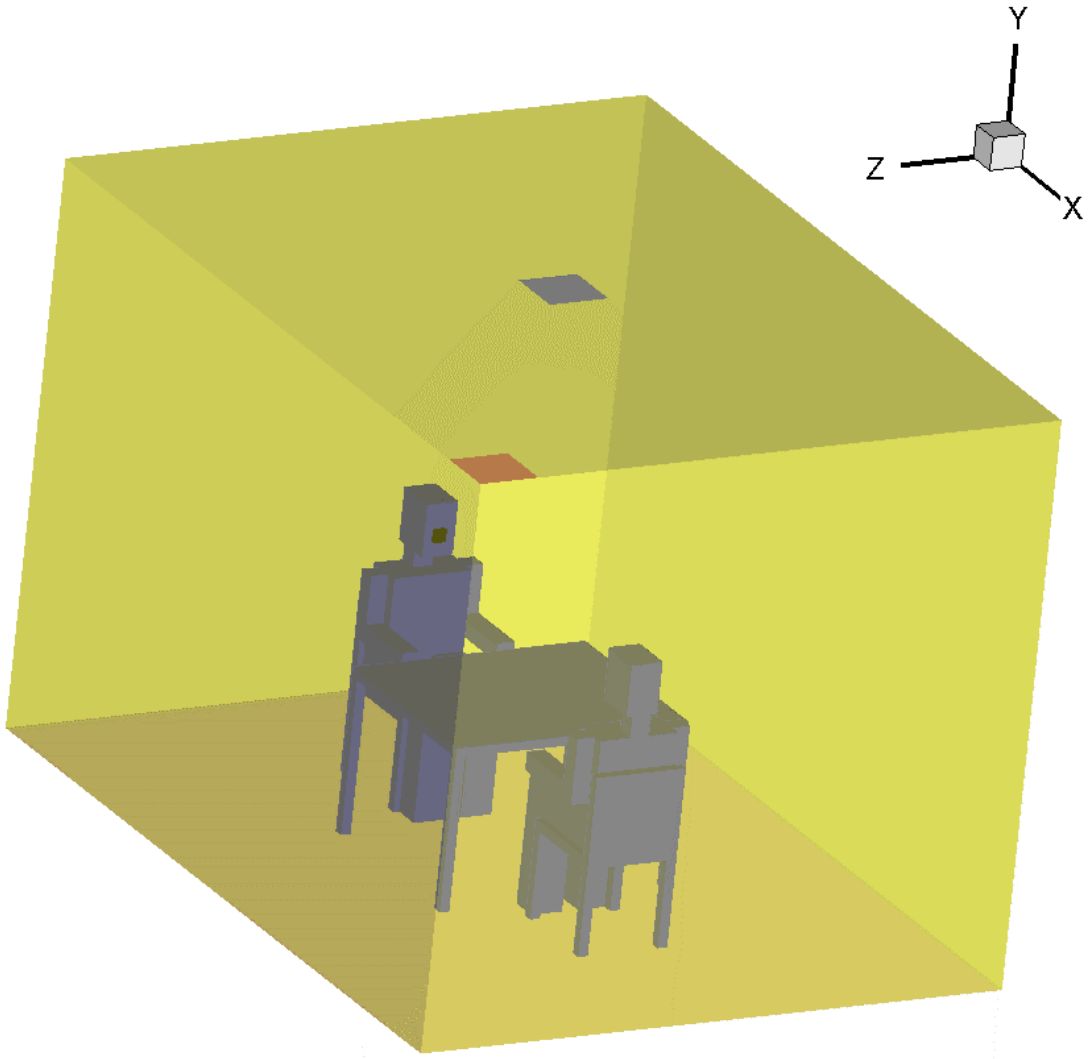
$$y^+ = \frac{yu^*}{\nu} \qquad v^+ = \frac{\sqrt{\overline{v'^2}}}{u^*} \qquad A = 0.008$$

Ounis, et al. (1993) (DNS)

New Normalized CRW and DRW models

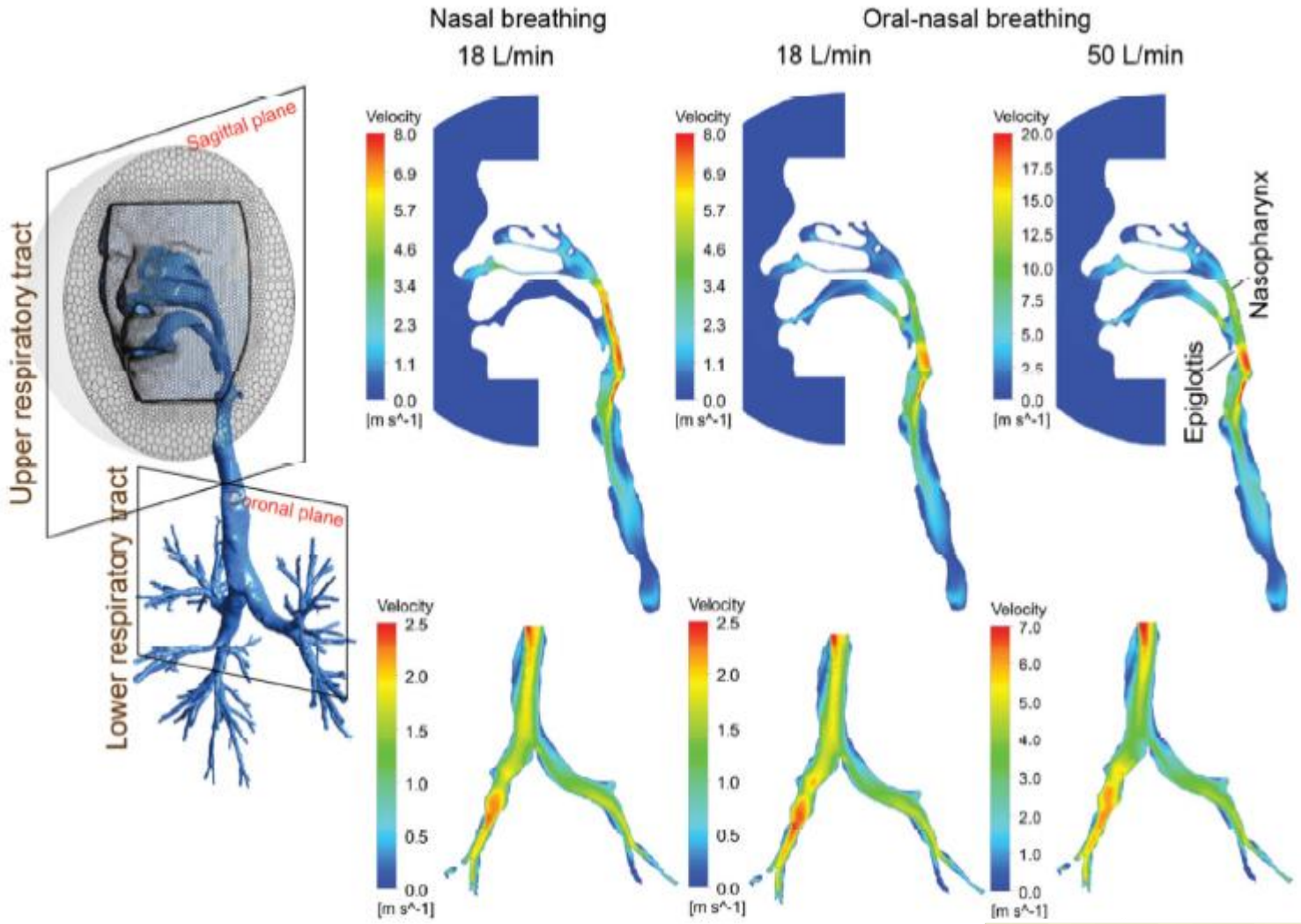
Mofakham and Ahmadi (2019, 2020)

Airflow and Pollutant Transport in a Room



Salmanzadeh and Ahmadi ((2012)

Respiratory Flows



Tian and Ahmadi (2019)

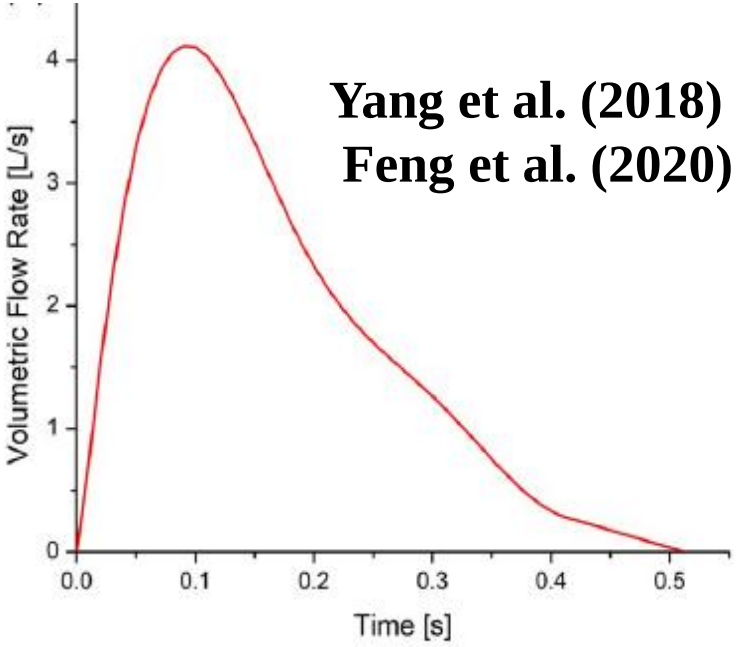
Transmission of Infectious Disease

COVID-19

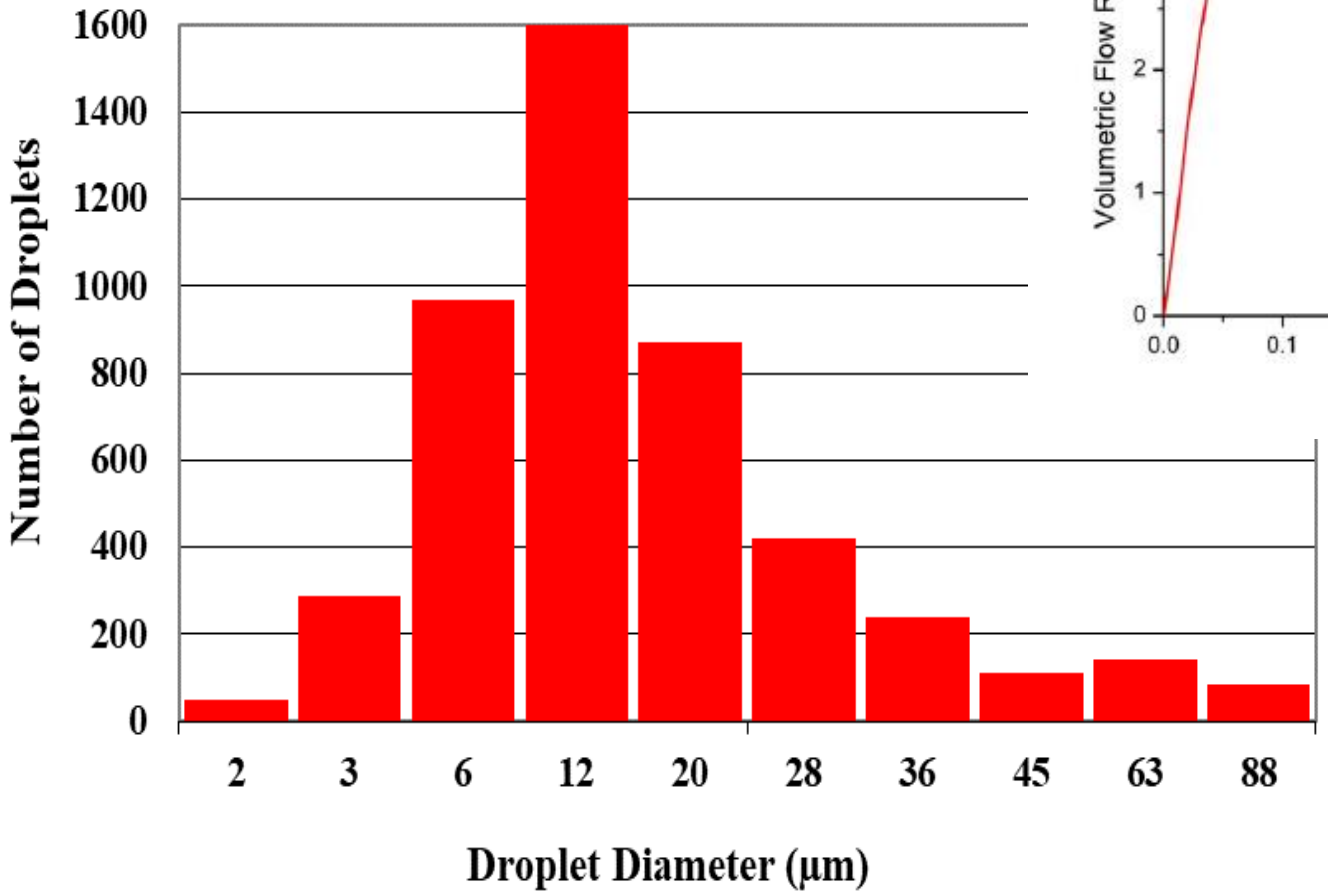
- Direct transmission (touching)
- Aerosol transmission
  - Coughing and sneezing
  - Speech

Droplets Emissions

Coughing



Yang et al. (2018)
Feng et al. (2020)

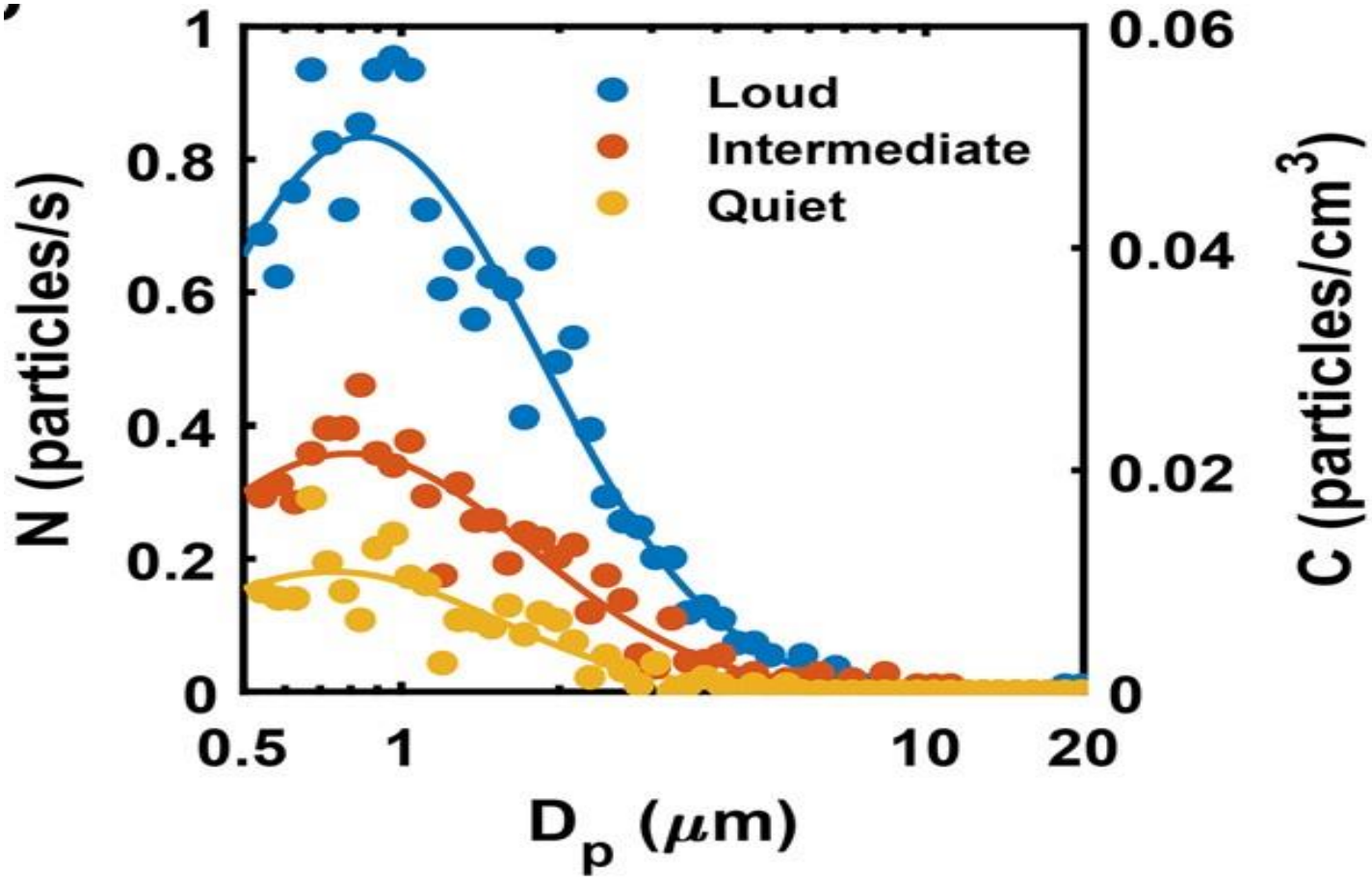


Duguid (1946)

Droplets Emissions

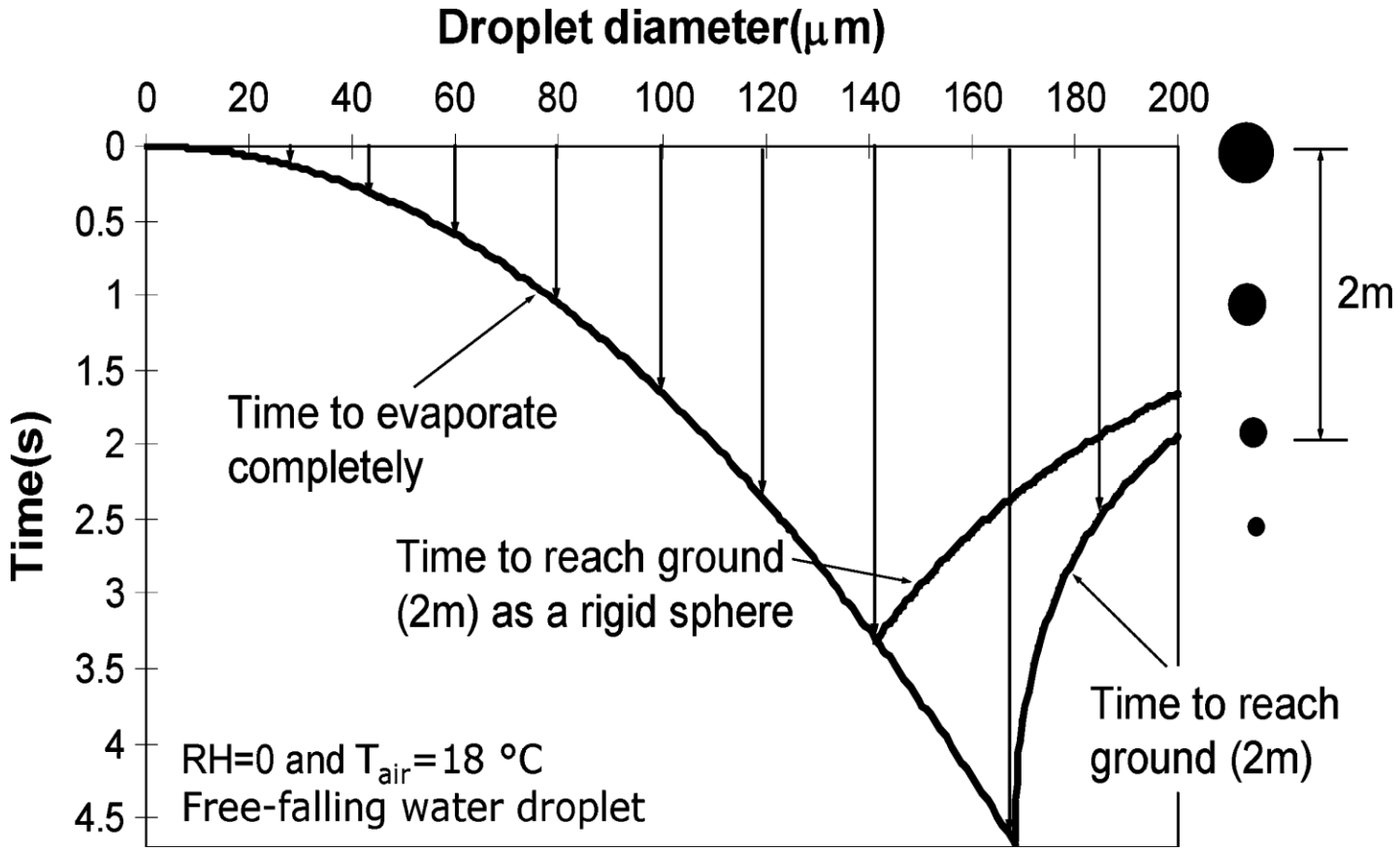
Speaking

Asadi, Wexler et al. (2019)

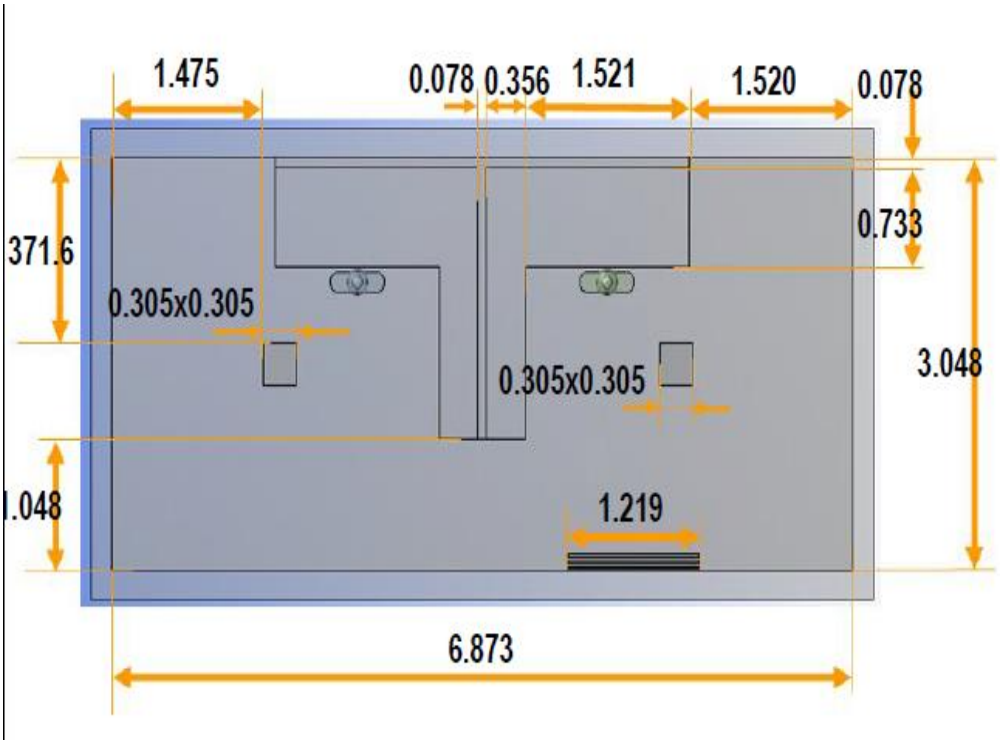


Simplified Exposure Model

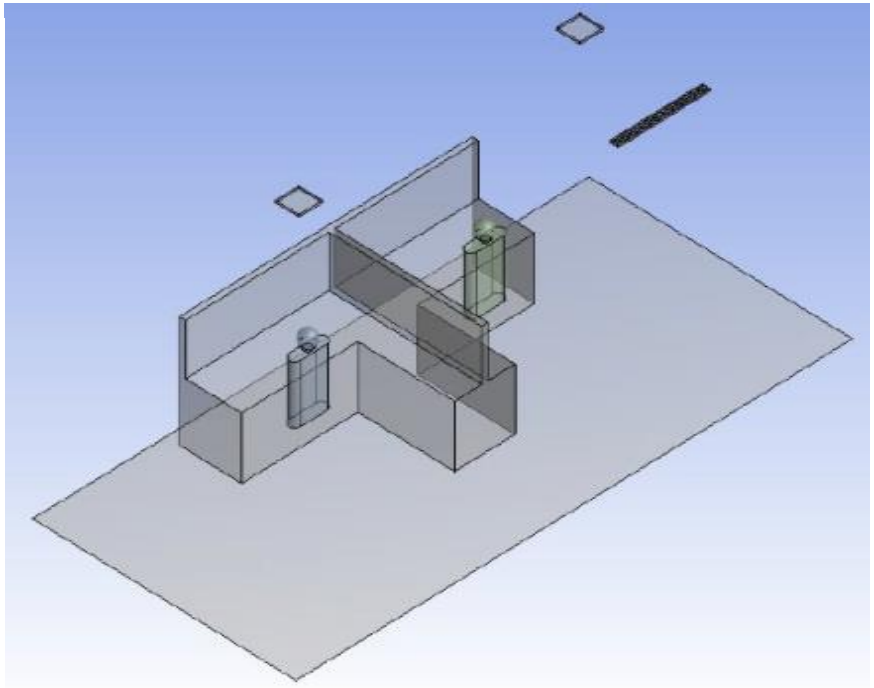
Wells (1934)



Two-Person Room



Two-person office geometry - plan view with length measurements (m)



Two-person office geometry - three-dimensional view

Two-Person Room

Ventilation with Supply Diffuser and Linear Diffuser at 45 degree

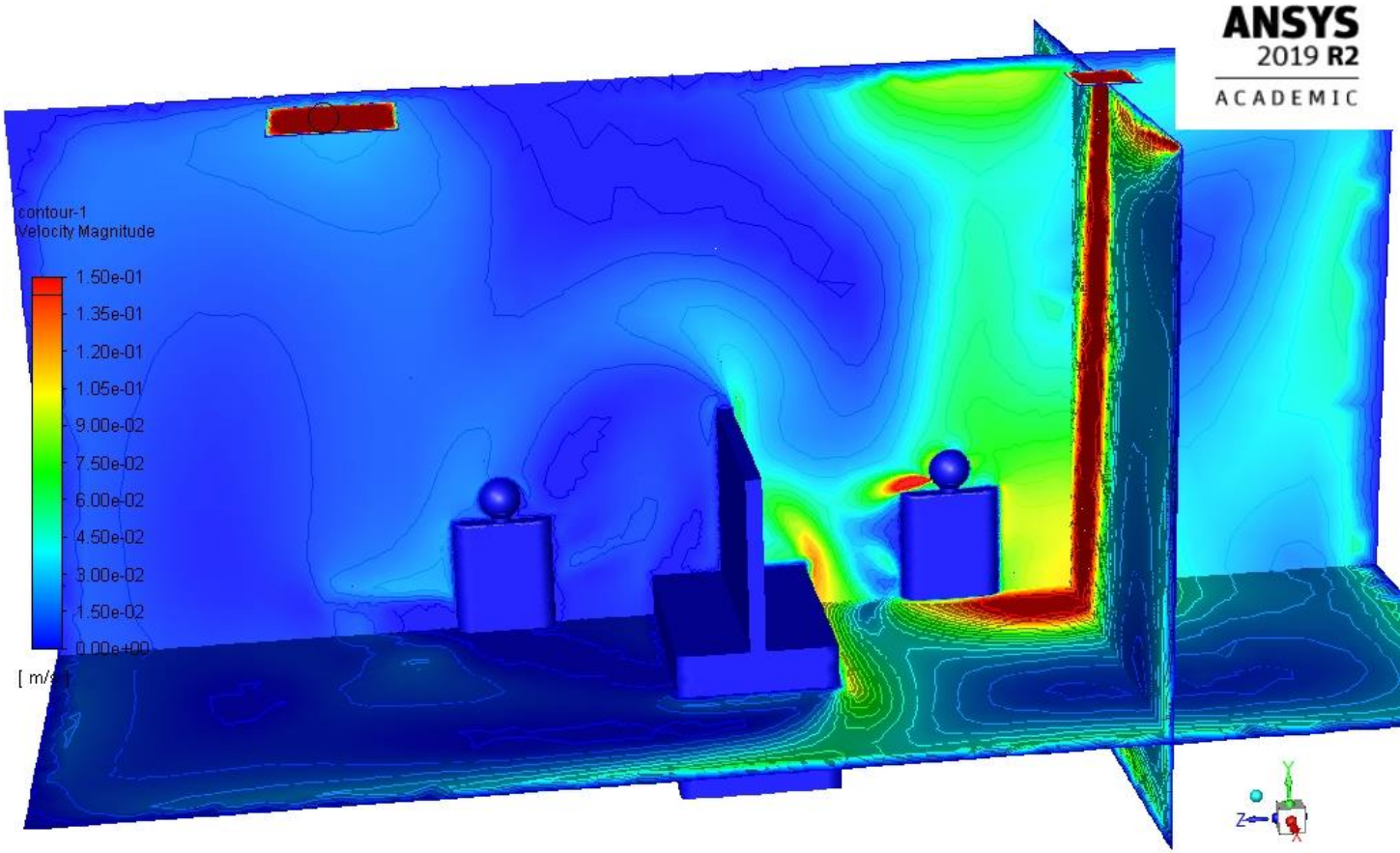
Supply Diffuser
Velocity =0.47 m/s

Linear Diffuser
Velocity =0.312 m/s

ACH=2.4

64 in Partition

Velocity magnitude Contours



EPA

Two-Person Room

Ventilation with Supply Diffuser and Linear Diffuser at 45 degree

Supply Diffuser Velocity =0.47 m/s

Linear Diffuser Velocity =0.312 m/s

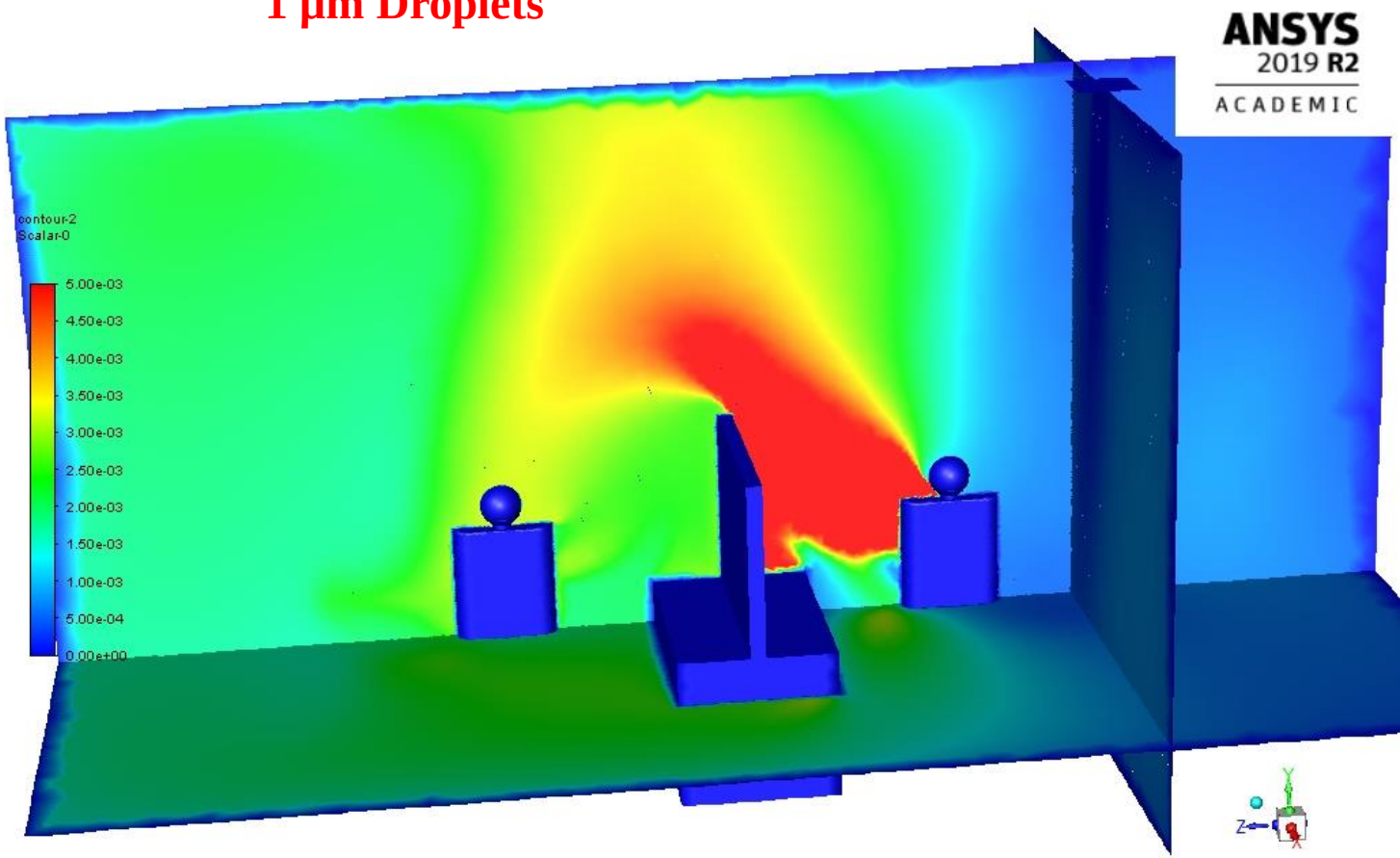
ACH=2.4

64 in Partition

Concentration Contours

Con LM = 0.003 to 0.0035

1 µm Droplets



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Two-Person Room

Ventilation with Supply Diffuser and Linear Diffuser at 45 degree (2-person Room)

Supply Diffuser Velocity =0.47 m/s

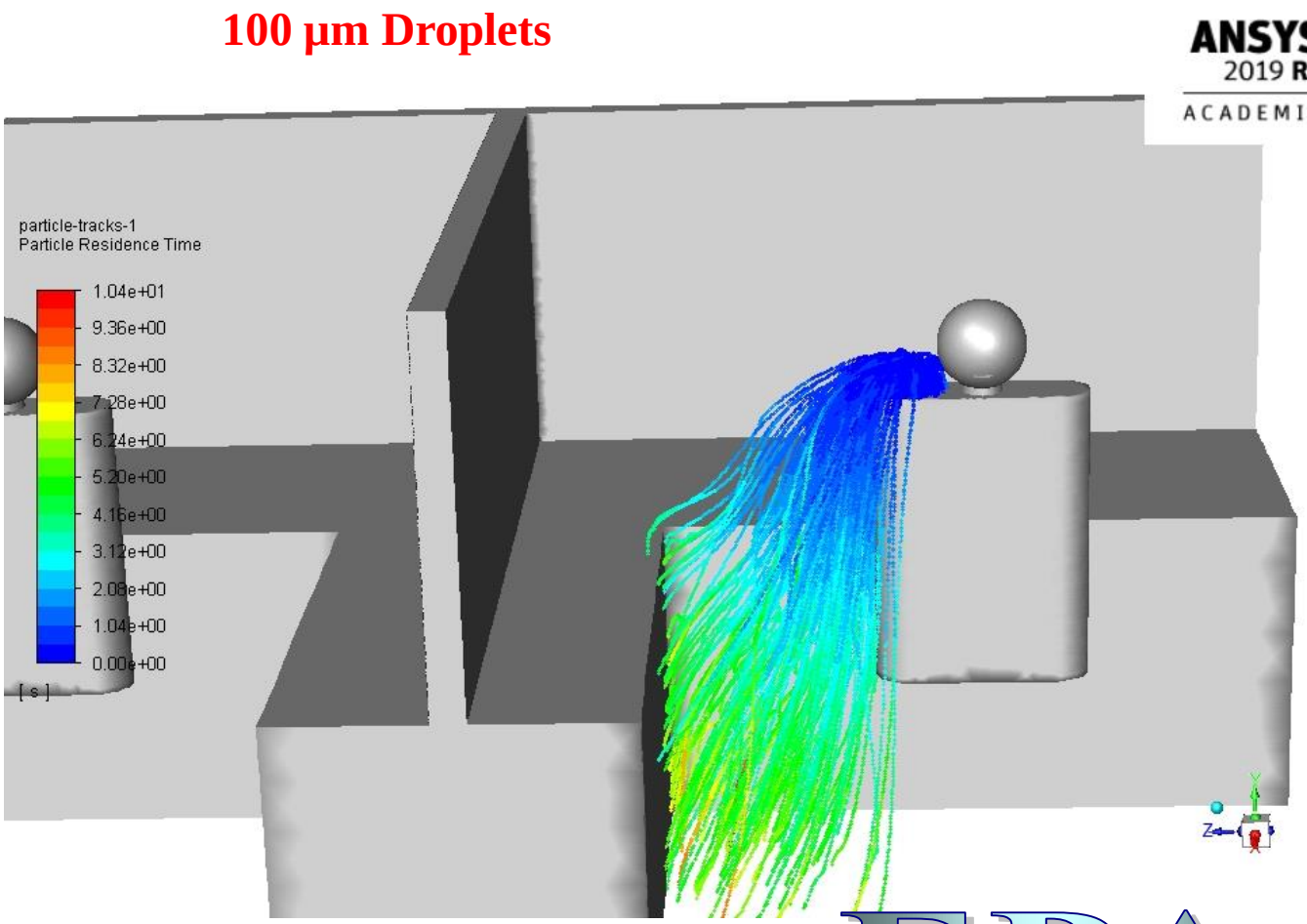
Linear Diffuser Velocity =0.312 m/s

ACH=2.4

64 in Partition

Trajectory of 100 Microns Particles/Droplets

100 µm Droplets



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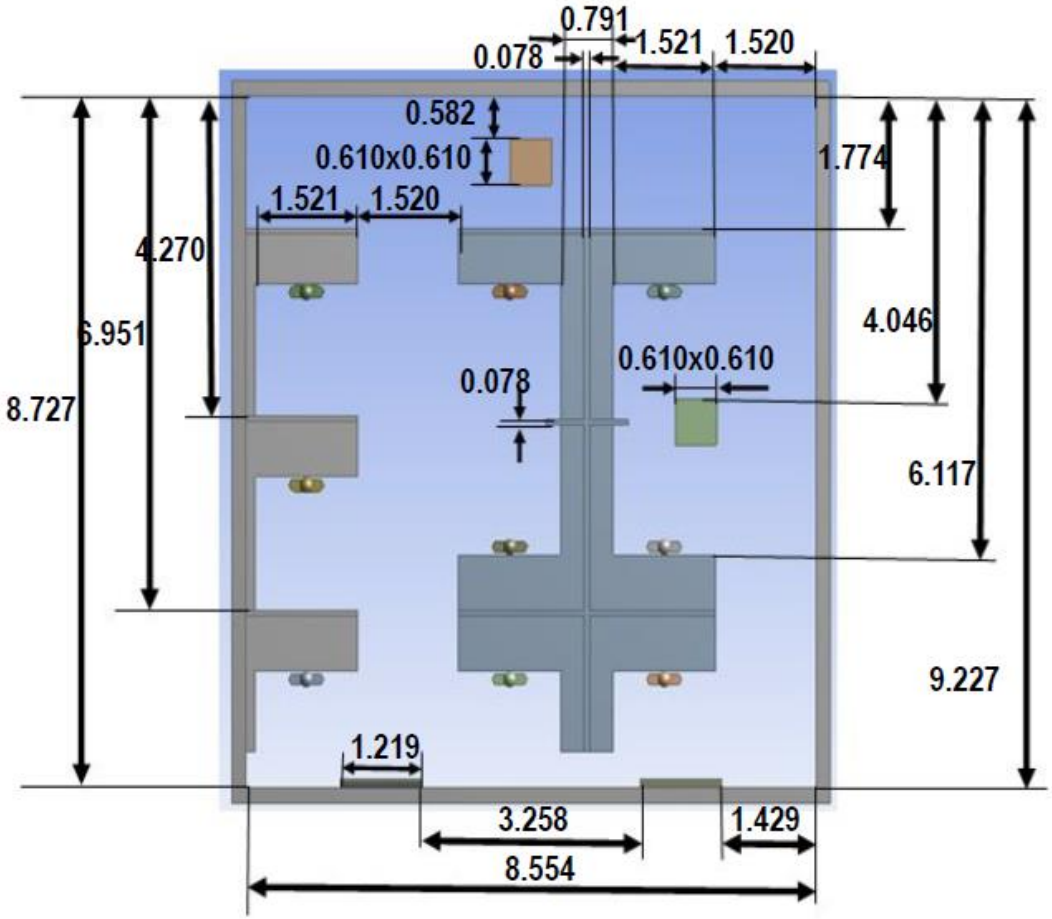
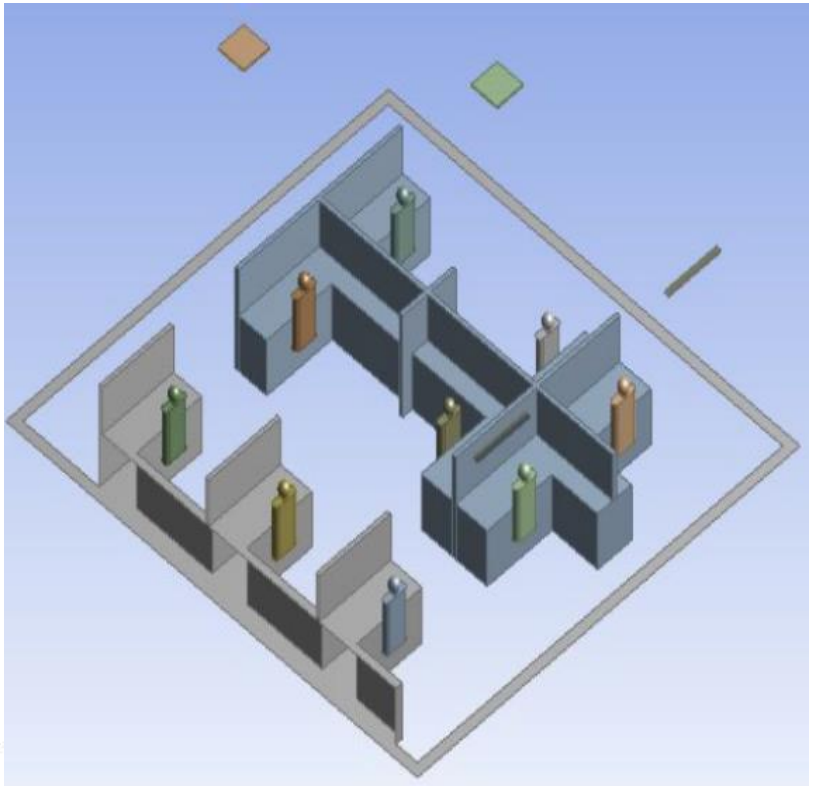
Nine-Person Room



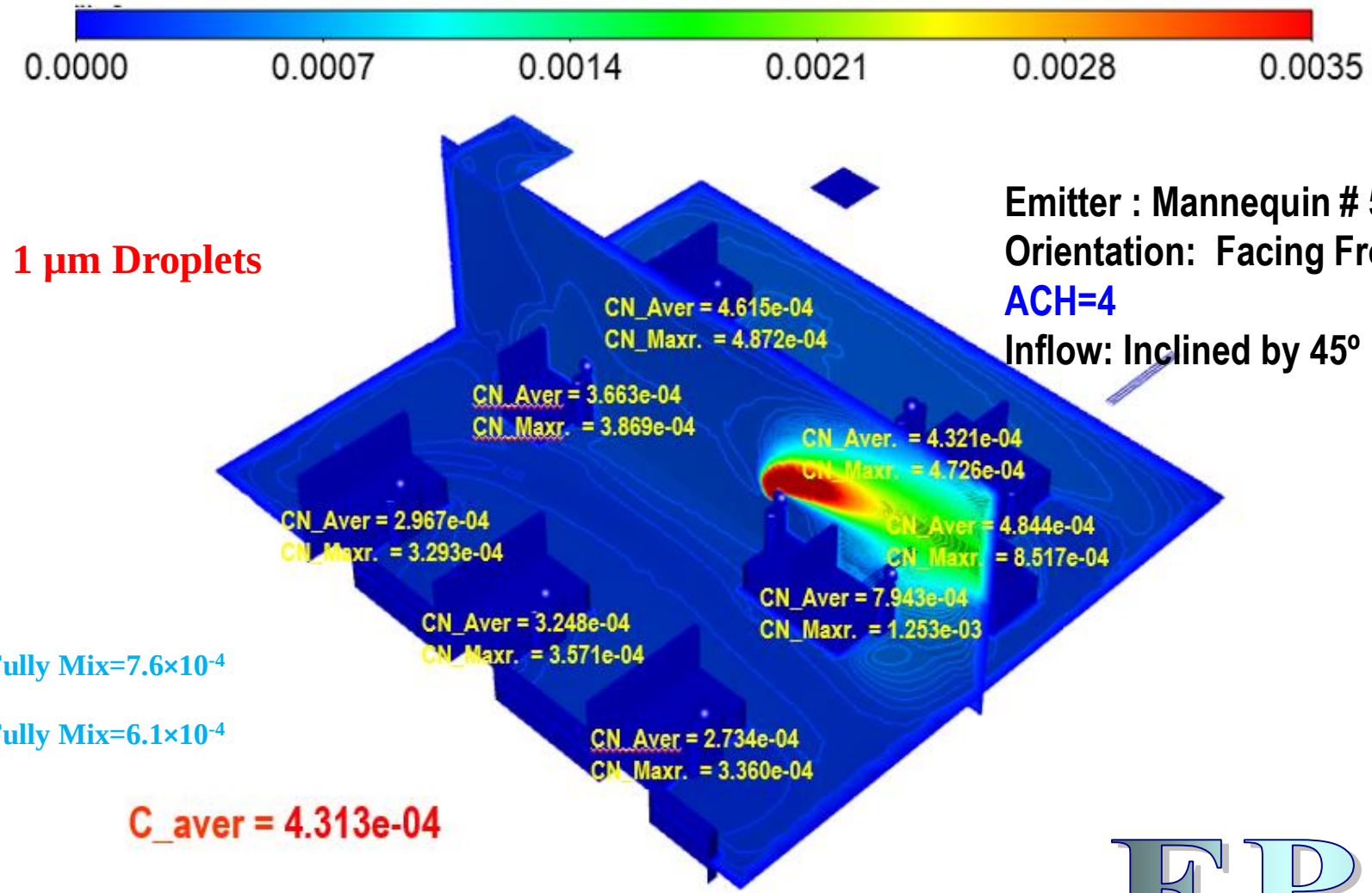


Nine-person office geometry - plan view with length measurements (m)

Nine-person office geometry - three-dimensional view

Nine-Person Room

Concentration Contours



1 µm Droplets

Emitter : Mannequin # 5
Orientation: Facing Front Partition
ACH=4
Inflow: Inclined by 45º

Fully Mix=7.6×10^{-4}

Fully Mix=6.1×10^{-4}

C_aver = 4.313e-04

EPA

Nine-Person Room

3D Bar Chart of Average and Max Concentration

Emitter : Mannequin # 5

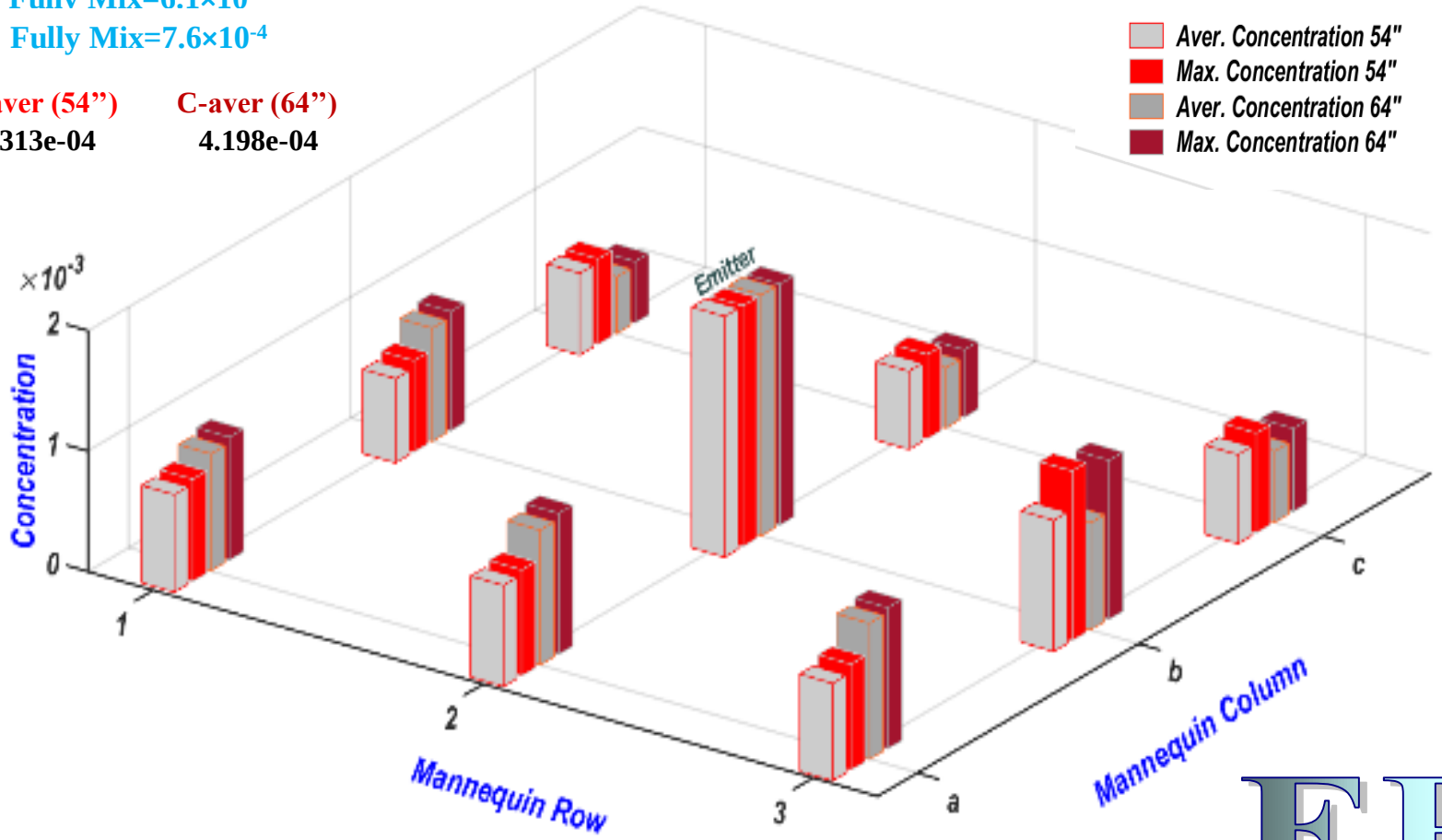
ACH=4

1 µm Droplets

Fully Mix=6.1×10^{-4}

Fully Mix=7.6×10^{-4}

C-aver (54”)	C-aver (64”)
4.313e-04	4.198e-04



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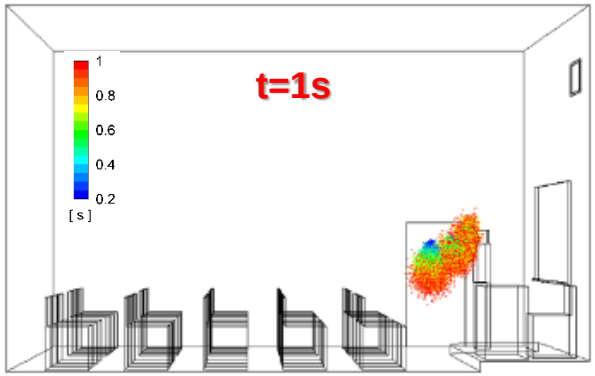
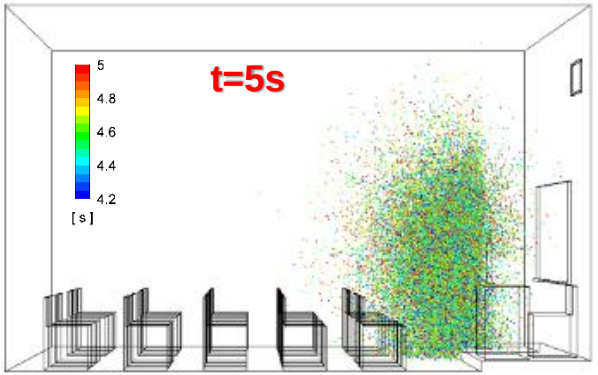
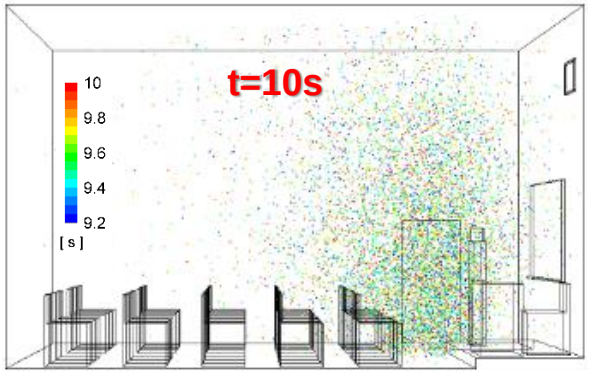
Transmission in a Class Room

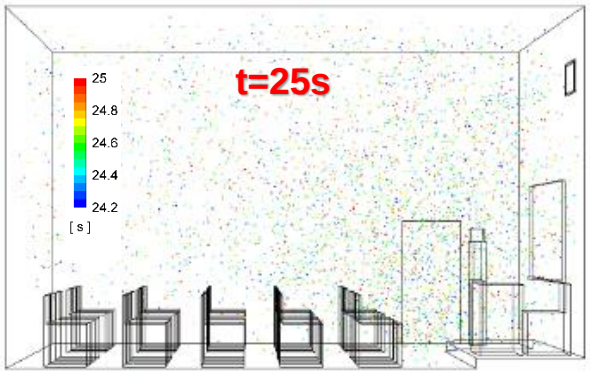
Coughing in a classroom

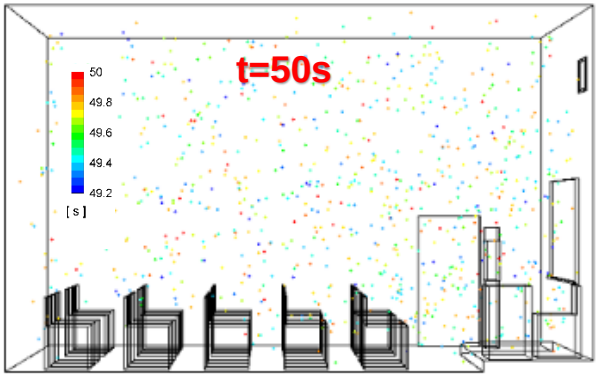
Coughing velocity = 10m/s











Mirzaie, Lakzian, et al. ((2021)

Cough droplet distribution in the classroom at different times.

Concluding Remarks

- Aerosol transmission is the main mechanism for spreading of respiratory viruses (COVID-19).
- Concentration of droplet decreases with the distance from source and with the increase of ACH.
- Computational modeling could provide insight into developing mitigation measure against aerosol transmission.

Thank You!

Questions?

Please contact gahmadi@clarkson.edu