National Energy Technology Laboratory's (NETL)
2023 Virtual Workshop on Multiphase Flow Science

Predicting Particle Dispersion through the Application of the Transition k-kl-ω Turbulence Model and Lagrangian Method

Amirmasoud Anvari[1], Sohaib Obeid[1], Andrea R. Ferro[2], Goodarz Ahmadi[1]

[1] Department of Mechanical and Aerospace Engineering, Clarkson University, Potsdam, NY 13699
[2] Department of Civil and Environmental Engineering, Clarkson University, Potsdam, NY 13699

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Outline

- Introduction
- Application
- Methodology
- Results
- Conclusions and future work

Introduction

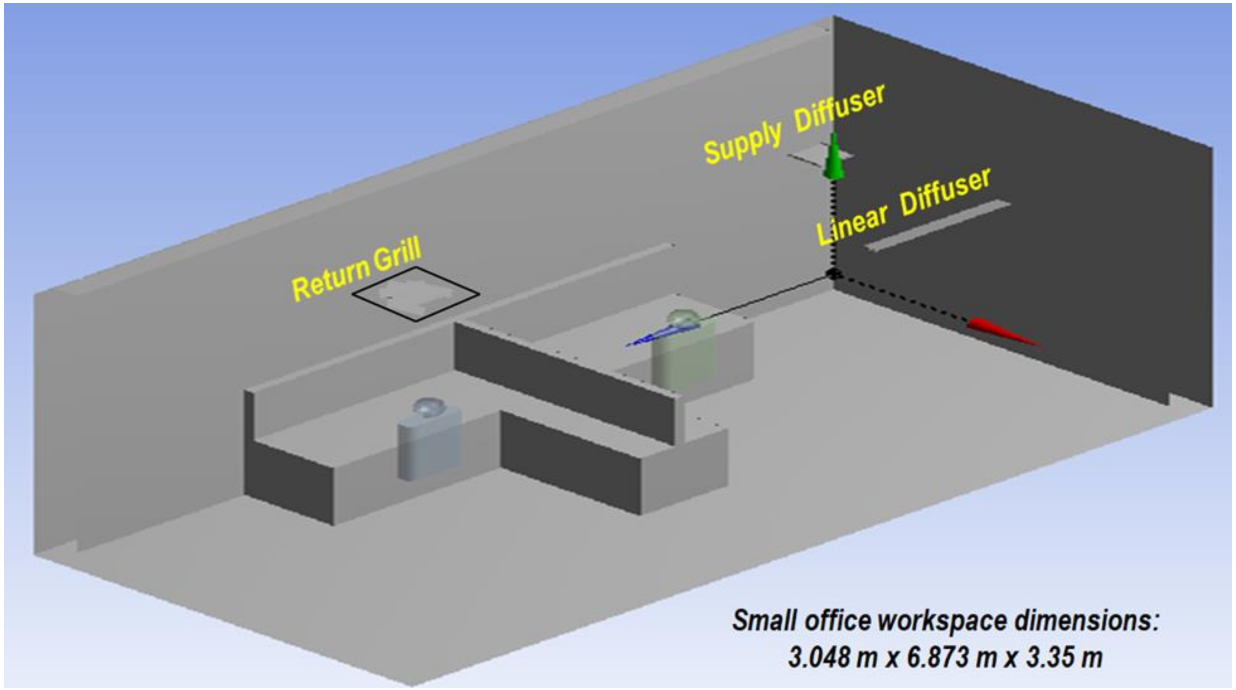
- Crucial role of airborne droplets in transmitting the respiratory viruses like COVID-19.
- Sneezing, coughing and breathing generate respiratory droplets carrying viruses.
- Design of ventilating systems for maintaining indoor air quality.
- Transport of airborne particles into the breathing zone.
- Using appropriate turbulence model for CFD simulation.

Application

- ✓Develop effective strategies to minimize exposure to respiratory droplets.
- ✓Improve indoor air quality, particularly in the context of the COVID-19 pandemic.

Methodology

- The ANSYS Fluent code and the Discrete Random Walk (DRW) model were used in these simulations.
- Transition k-kl-ω turbulence model used for simulation.
- The airflow conditions for different ventilation rates and dispersion of droplets of different sizes emitted by the mannequin were evaluated.



Methodology

❖ **Turbulence Modeling**

$$\frac{Dk_T}{Dt} = P_{k_T} + R + R_{NAT} - \omega k_T - D_{NT} + \frac{\partial}{\partial x_j}\left[\left(v + \frac{\alpha_T}{\alpha_{kT}}\right)\frac{\partial k_T}{\partial x_j}\right]$$

$$\frac{Dk_L}{Dt} = P_{k_L} - R - R_{NAT} - D_{NL} + \frac{\partial}{\partial x_j}\left[v\frac{\partial k_L}{\partial x_j}\right]$$

$$\frac{D\omega}{Dt} = C_{\omega_1}\frac{\omega}{k_T}P_{k_T} + \left(\frac{C_{\omega R}}{f_W} - 1\right)\frac{\omega}{k_T}(R + R_{NAT}) -$$

$$C_{\omega_2}\omega^2 + C_{\omega_3}f_\omega \alpha_T f_W^2\frac{\sqrt{k_T}}{\alpha^3} + \frac{\partial}{\partial x_j}\left[\left(v + \frac{\alpha_T}{\alpha_{kT}}\right)\frac{\partial \omega}{\partial x_j}\right]$$

Methodology

❖ **Particle motion equation**

$$\frac{\mathrm{d}\mathbf{u_P}}{\mathrm{dt}} = \frac{1}{\tau}\frac{C_D Re_P}{24}(\boldsymbol{u} - \boldsymbol{u_P}) + \mathbf{g}$$

❖ **Reynolds number**

$$Re_P = \frac{d_P|\boldsymbol{u} - \boldsymbol{u_p}|}{\nu}$$

❖ **Relaxation time**

$$\tau = \frac{d^2 \rho_p C_C}{18\mu}$$

Methodology

❖ **Transport Equation for the Aerosol Concentration**

$$\frac{\partial C}{\partial t} + (V + V_t) \cdot \nabla C = \nabla \cdot \left[\left(D + \frac{D_T}{Sc}\right) C\right]$$

❖ **Particle Number Concentration in the Breathing Zone of the mannequin**

Normalized Concentration

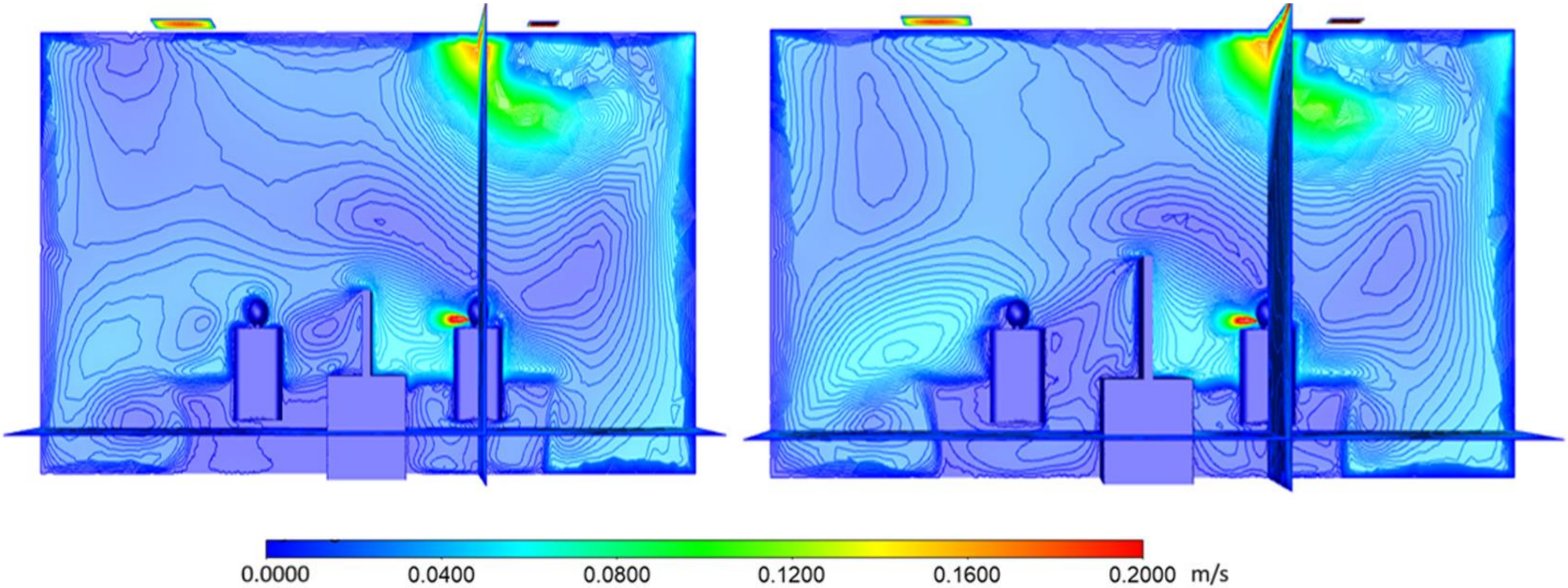
$$C^*_{pa} = \frac{\left(\sum_{i=1}^{n} \frac{1}{v_i^p}\right)/A}{\left(\frac{N}{A_{in} v_{in}^p}\right)} = \frac{\text{Concentration in the breathing zone of receptor}}{\text{Concentration at the mouth of emitter}}$$

Results: Velocity Magnitude Contours

Contours of velocity magnitude for different partition heights.

Partition heights =1.372 m

Partition heights =1.626 m



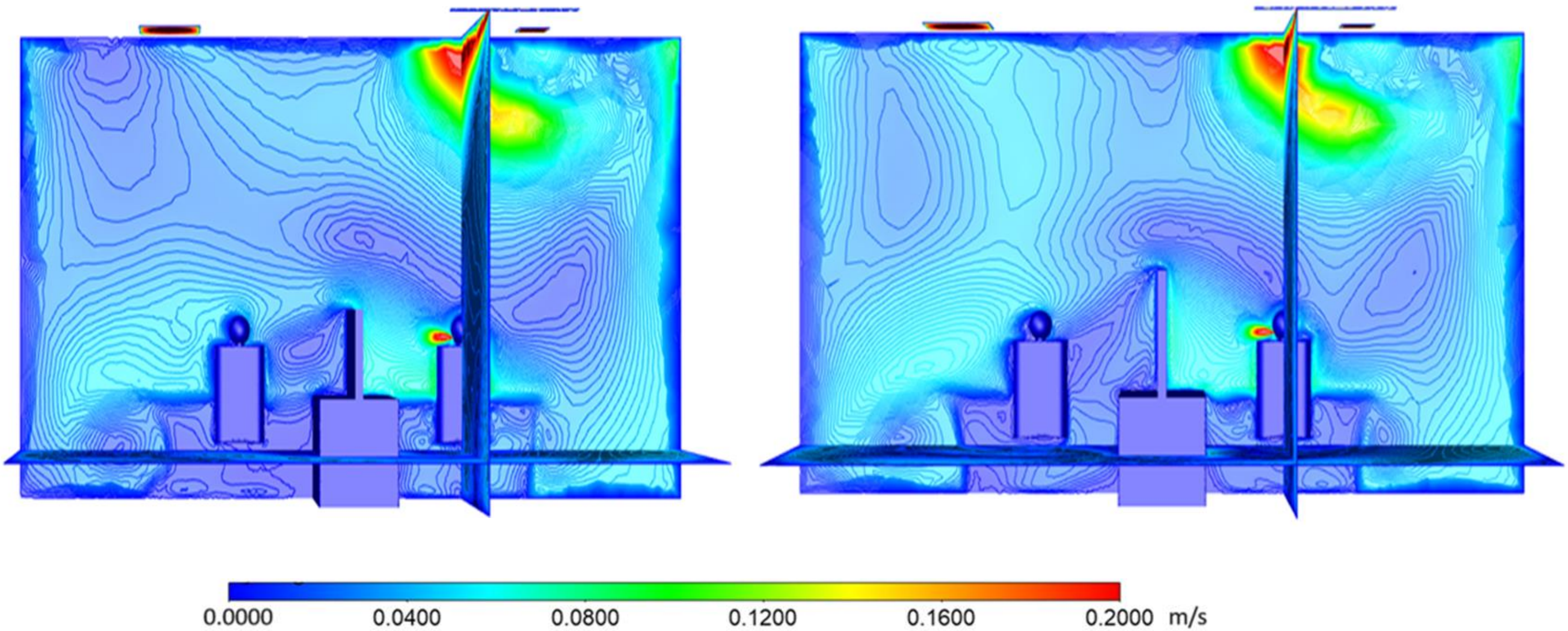
ACH = 1.975

Results: Velocity Magnitude Contours

Contours of velocity magnitude for different partition heights.

Partition heights =1.372 m

Partition heights =1.626 m



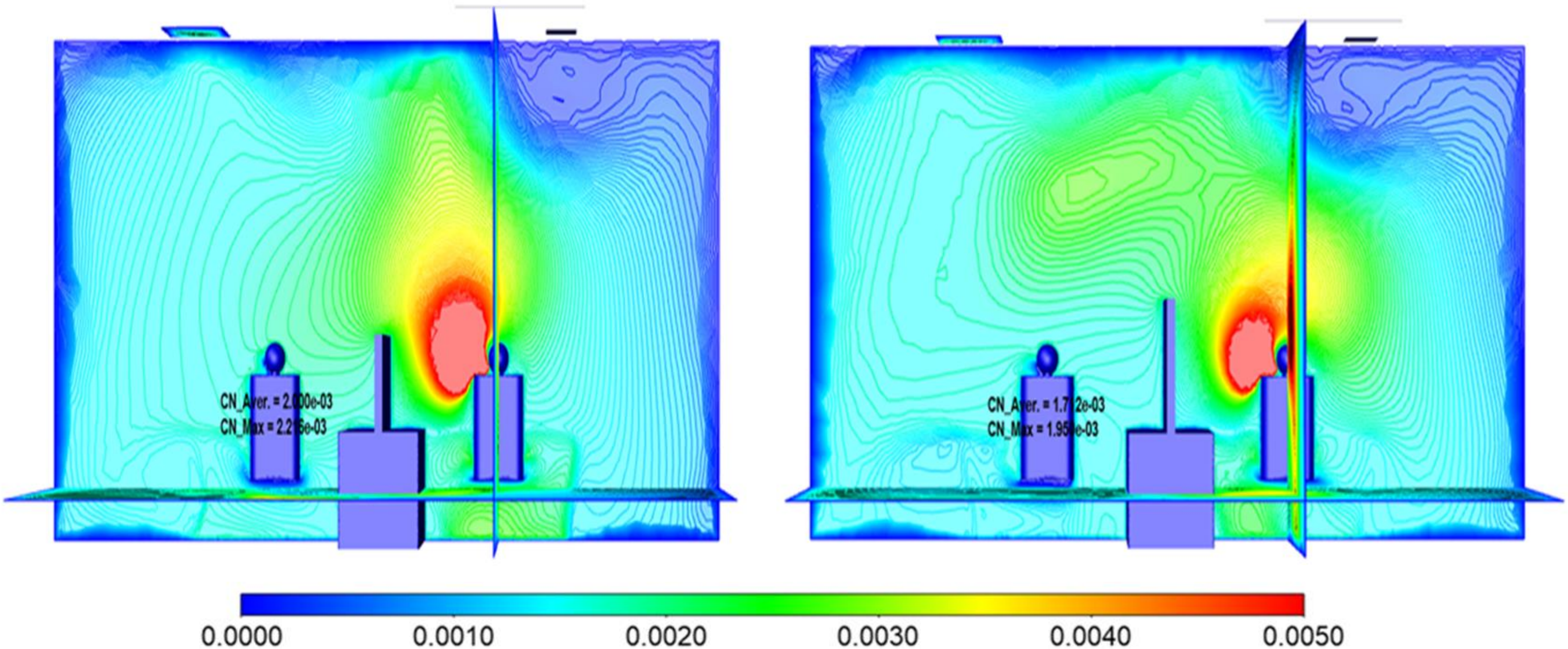
ACH = 2.800

Results: Particle Dispersion

Concentration contours for 10-μm particle size for ACH=3.95

Partition heights =1.372 m

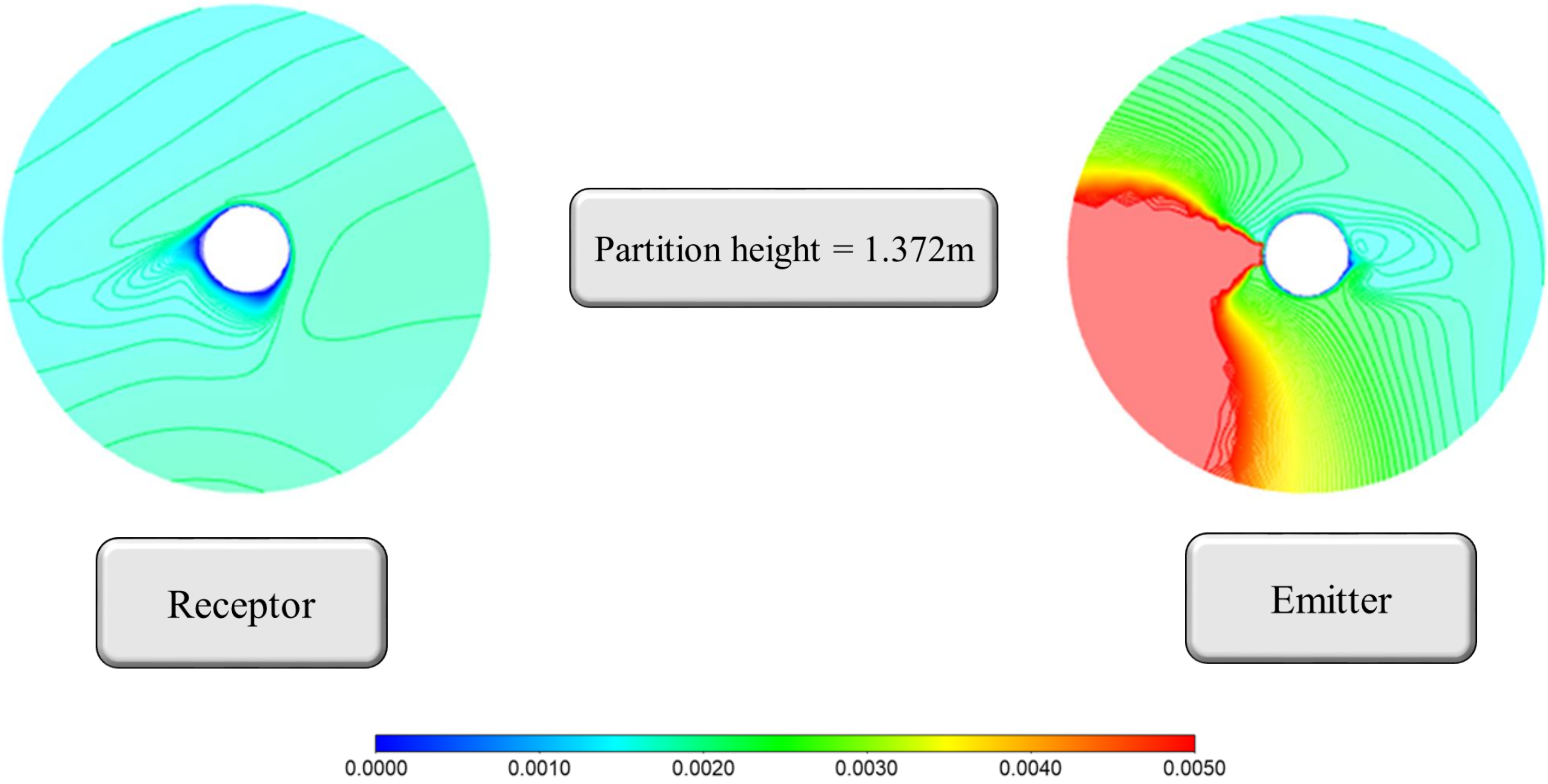
Partition heights =1.626 m



10-μm Particle Size

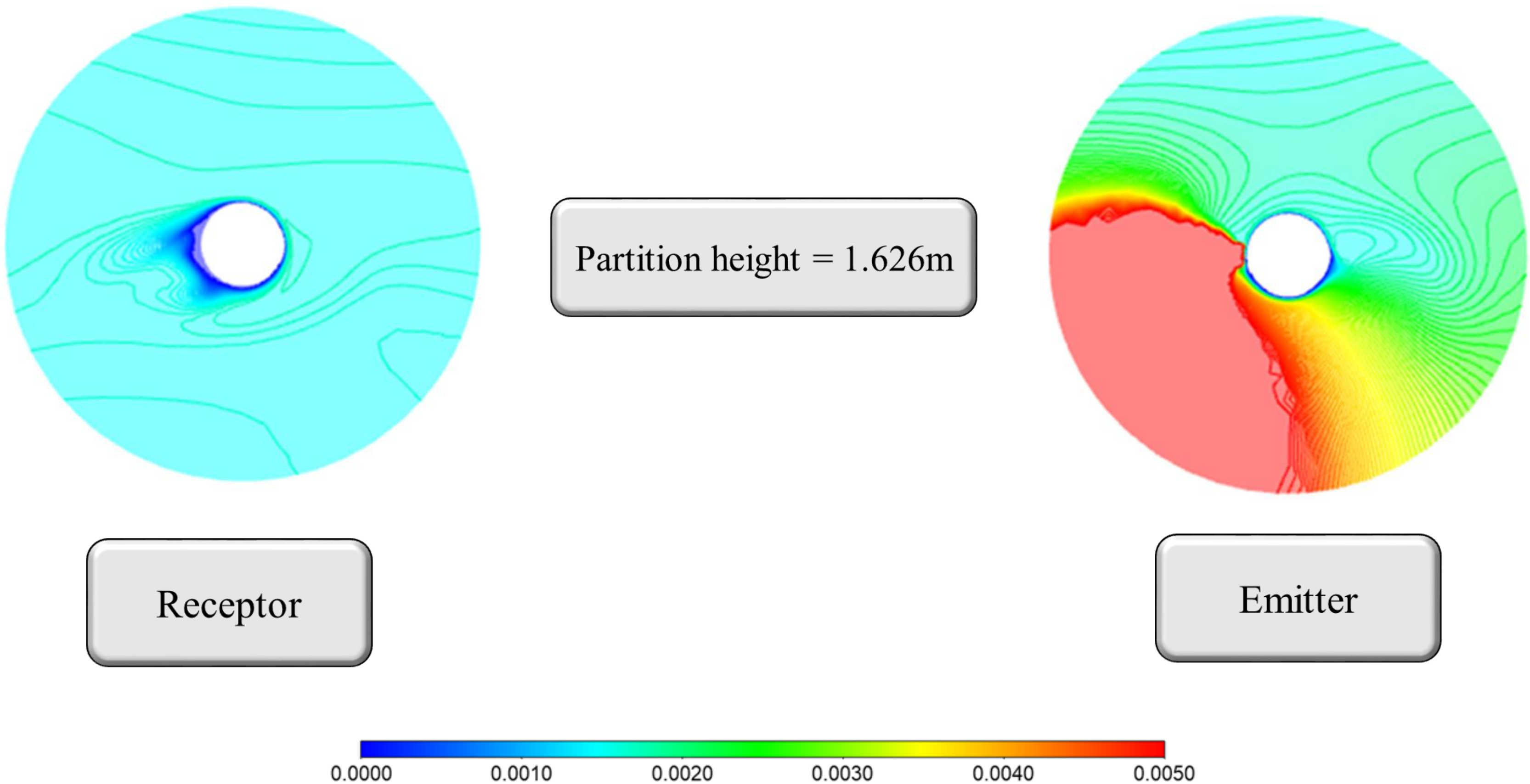
Results: Particle Dispersion

Concentration contours in the horizontal plane in the breathing zones of the receptor and emitter mannequins for 10-μm aerosols for partition heights of 1.372 m (ACH= 3.95)



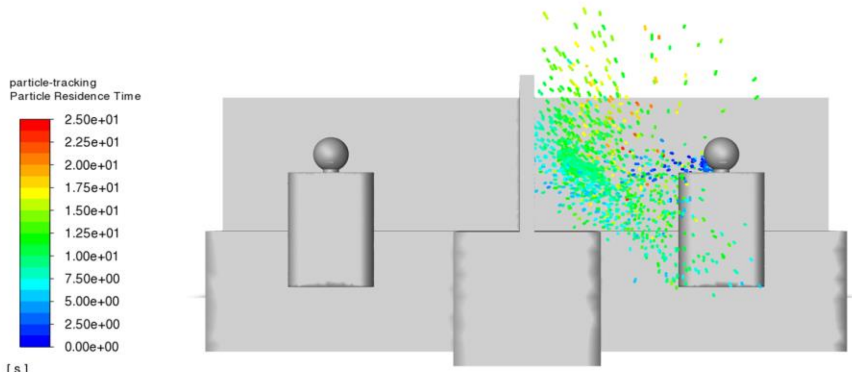
Results: Particle Dispersion

Concentration contours in the horizontal plane in the breathing zones of the receptor and emitter mannequins for 10-μm aerosols of for partition heights of 1.626 m (ACH= 3.95)

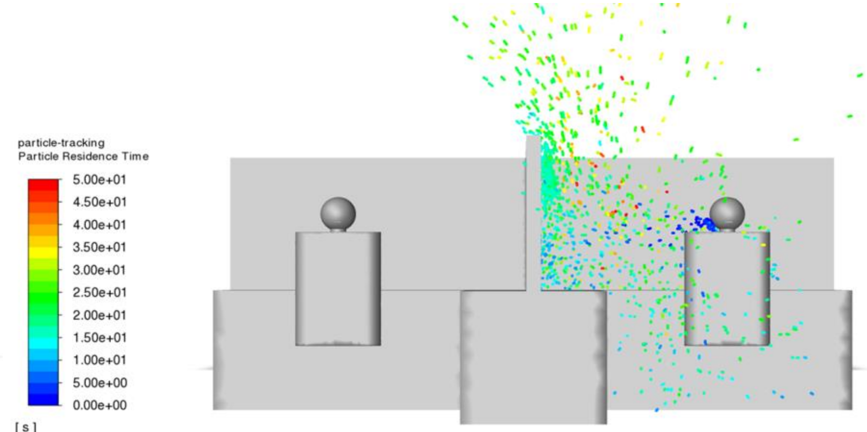


Results: Particle Tracking

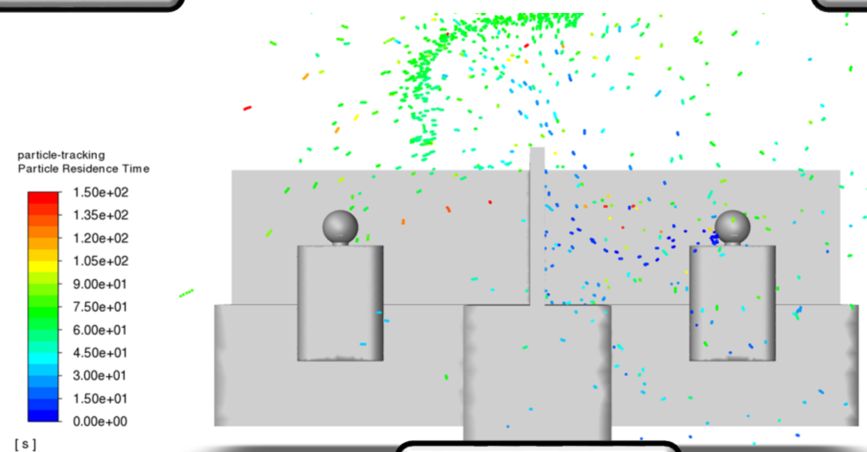
Distribution of 10-μm particles in the room for ACH=2.59 at different time after emission from the emitter mannequin.



1) 25 s



2) 50 s

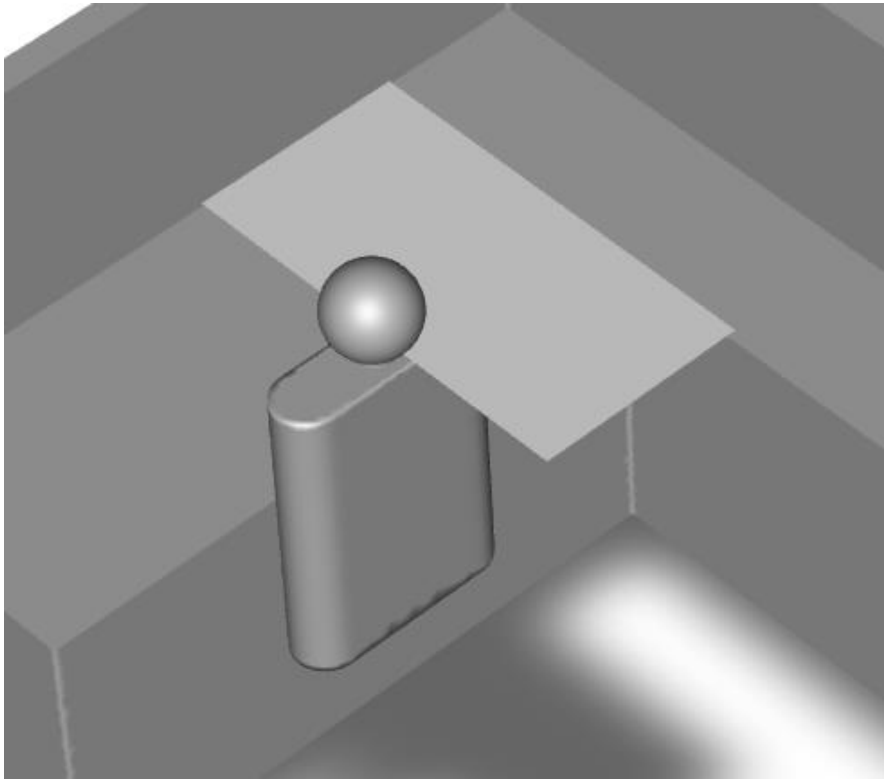


3) 150 s

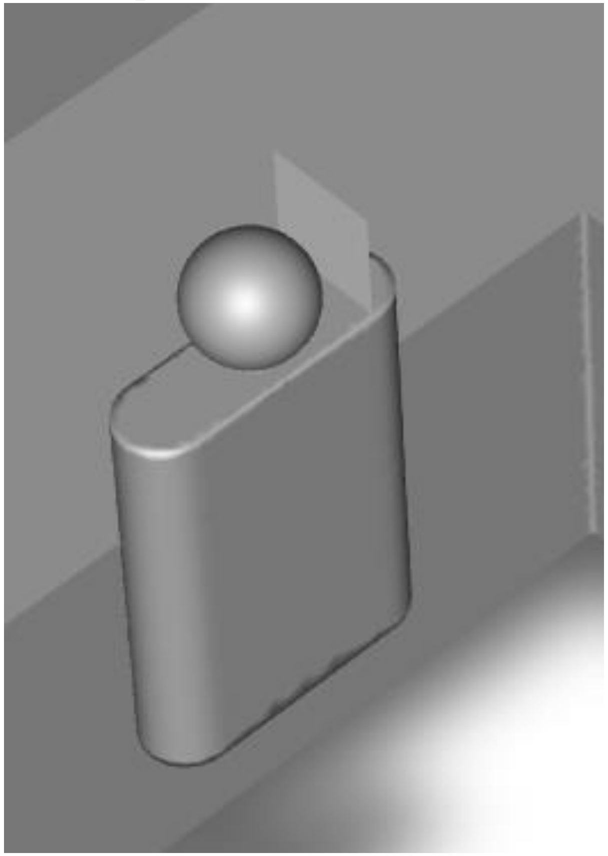
Results: Particle Tracking

- Normalized particle number concentration in the breathing zone of the receptor mannequin

$$C^*_{pa} = 0.00535$$



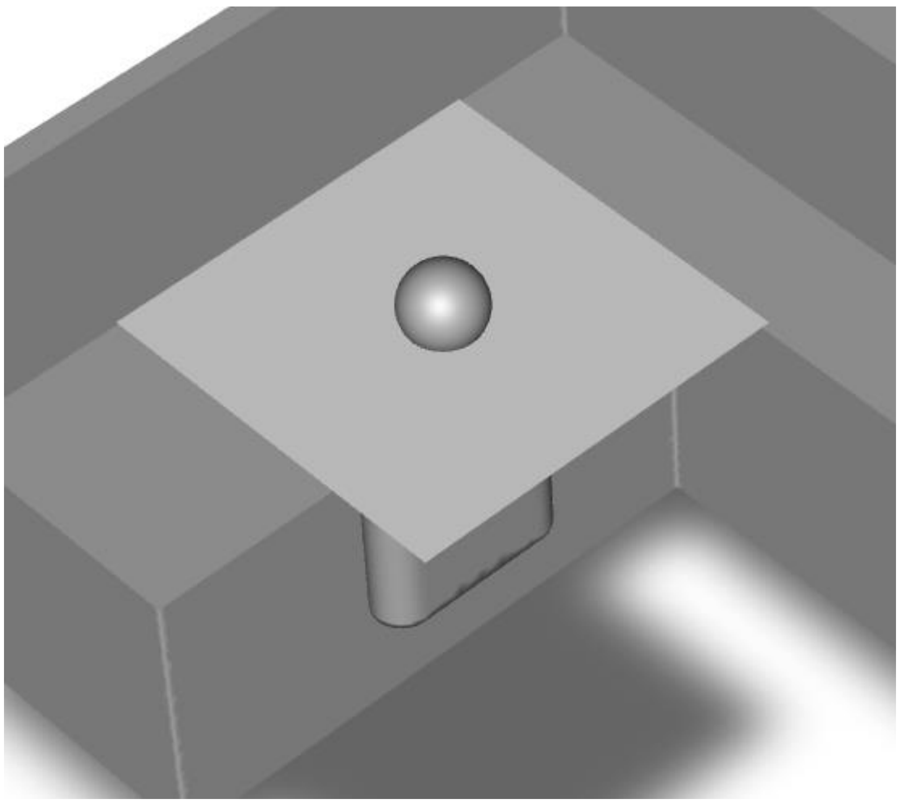
$$C^*_{pa} = 0.00131$$



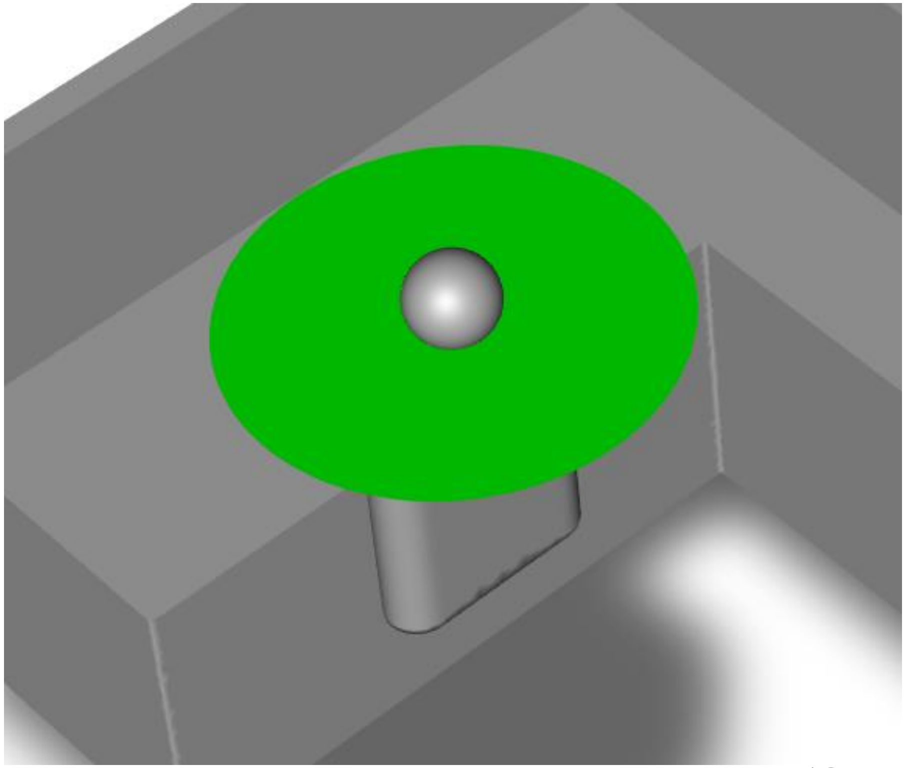
Results: Particle Tracking

- Normalized particle number concentration in the breathing zone of the receptor mannequin

$C^{*}_{pa} = 0.003635$



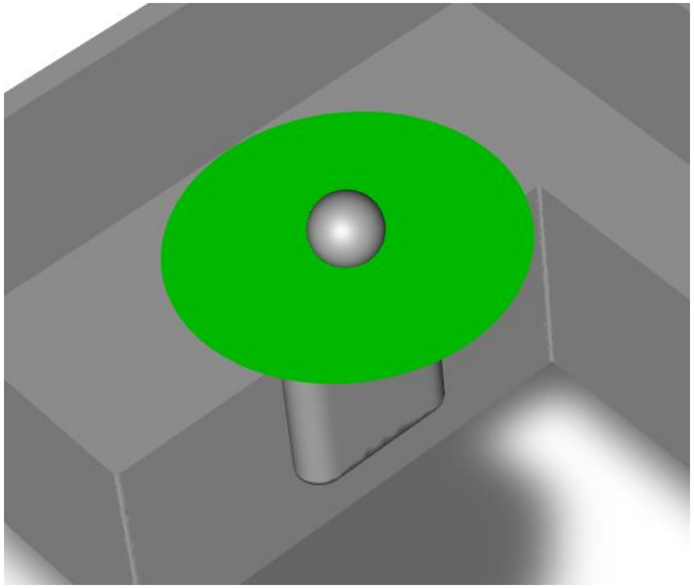
$C^{*}_{pa} = 0.0043$



Results: Particle Tracking

- Normalized particle number concentration in the breathing zone of the receptor mannequin

N	C^*_{pa}
12125	0.0041
24250	0.0043
72750	0.0044



Conclusions and Future Work

- ✓ The results demonstrated that the presence of a partition significantly impacted airflow patterns and particle distribution in the room.
- ✓ A 0.25 m change in the partition height had a negligible effect on the droplet dispersion and concentration near the receptor mannequin.
- ✓ Increased air change rate reduces the concentration levels, resulting in a lowered likelihood of exposure.
- ✓ For future studies, the influence of thermal plume on distribution and dispersion of particles will be included.

Thank You

Questions?