Assessing Particle Concentration in the Breathing Zone of a Receptor Mannequin in an Indoor Environment

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August, 2024

Outline

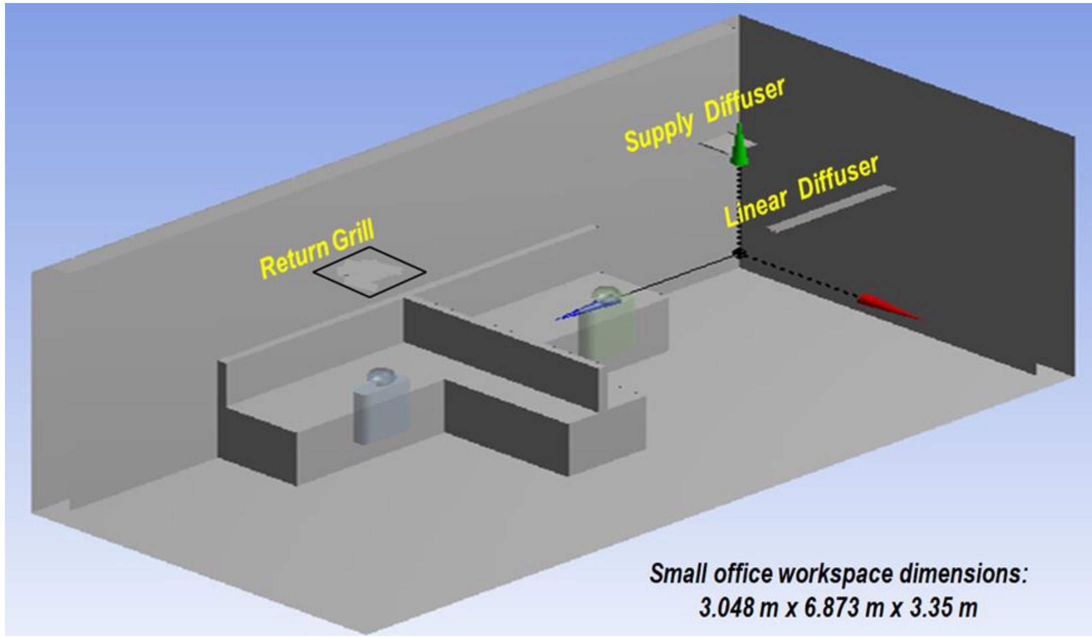
- ✓Introduction
- ✓Methodology
- ✓Results
- ✓Conclusions and future work

Introduction

- ✓COVID-19 has shown the importance of respiratory airborne droplets in spreading viruses.
- ✓Droplet emissions and airflows from sneezing, coughing, speaking and breathing are key to the respiratory virus transmission including COVID-19, influenza, and other respiratory diseases.
- ✓Designing effective ventilation systems are essential for enhancing indoor air quality and reducing transmission.
- ✓Using appropriate droplet equation of motion and turbulence models in CFD simulations are key to the model accuracy.

Methodology

- The ANSYS Fluent and MATLAB code were used in these simulations.
- Transition k-kl-ω turbulence model was used for simulations.
- The Discrete Random Walk (DRW) model was used to account for the dispersion effect of turbulence of droplet dispersion.
- Th two-way coupling model was used.
- The airflow conditions for different ventilation rates and dispersion of droplets of different sizes emitted by the emitter mannequin were evaluated.



Methodology-Governing Equations

❖ **Conservation of Mass**

- $\nabla \cdot V = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$

❖ **Balance of Momentum – RANS Equation**

- $\rho \frac{DV}{Dt} = \rho \left(\frac{\partial V}{\partial t} + V \cdot \nabla V \right) = \rho g - \nabla p + \nabla \cdot [(\mu + \mu_T)(\nabla V + \nabla V^T)]$

❖ **Eddy viscosity, μ_T, is a function of k_T, k_L and ω.**

Methodology-Turbulence Modeling

❖**Transition k-kl-ω turbulence model**

Transport equations for k_T, k_L and ω

- $\frac{Dk_T}{Dt} = P_{k_T} + R + R_{NAT} - \omega k_T - D_{NT} + \frac{\partial}{\partial x_j}\left[\left(v + \frac{\alpha_T}{\alpha_{kT}}\right)\frac{\partial k_T}{\partial x_j}\right]$
- $\frac{Dk_L}{Dt} = P_{k_L} - R - R_{NAT} - D_{NL} + \frac{\partial}{\partial x_j}\left[v\frac{\partial k_L}{\partial x_j}\right]$
- $\frac{D\omega}{Dt} = C_{\omega_1}\frac{\omega}{k_T}P_{k_T} + \left(\frac{C_{\omega R}}{f_W} - 1\right)\frac{\omega}{k_T}(R + R_{NAT}) - C_{\omega_2}\omega^2 + C_{\omega_3} f_\omega \alpha_T f_W^2 \frac{\sqrt{k_T}}{\alpha^3} + \frac{\partial}{\partial x_j}\left[\left(v + \frac{\alpha_T}{\alpha_{kT}}\right)\frac{\partial \omega}{\partial x_j}\right]$

Methodology-Particle Equation

- **Newton's second law**

$$\frac{du_P}{dt} = \frac{1}{\tau}\frac{C_D Re_P}{24}(u - u_P) + g$$

Particle Reynolds number

$$Re_P = \frac{d_P|u - u_P|}{v}$$

Particle relaxation time

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

Methodology- Particle Concentration

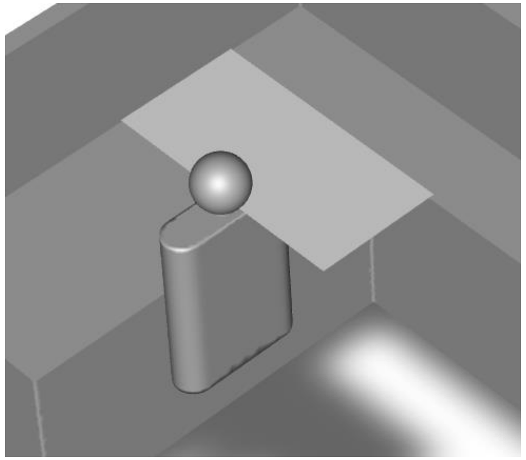
❖ **Generalized Diffusion Equation for Aerosol Concentration**

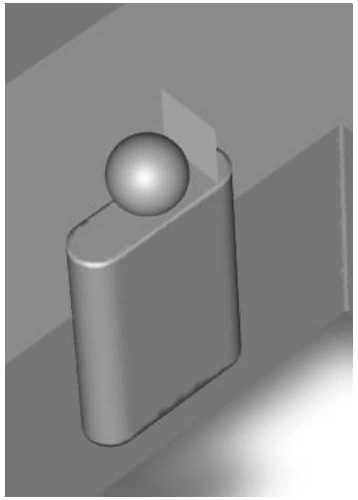
- $\frac{\partial C}{\partial t} + (V + V_t) \cdot \nabla C = \nabla \cdot [\left(D + \frac{D_T}{Sc}\right) \nabla C]$

❖ **Particle Number Concentration in the Breathing Zone of the Receptor Mannequin**

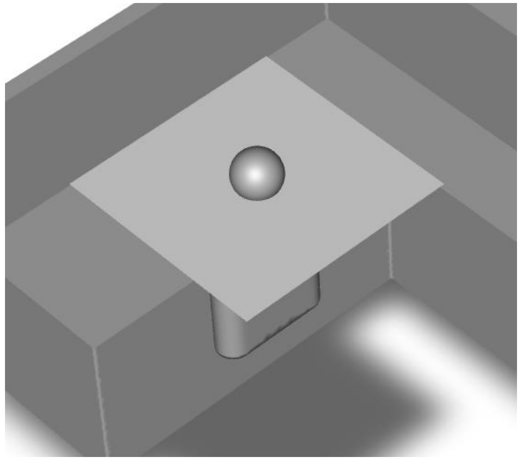
- **Normalized Concentration**
- $C_{pa}^{*} = \frac{(\sum_{i=1}^{n} \frac{1}{v_i^p})/A}{(\frac{N}{A_{in} v_{in}^p})} = \frac{Concentration\ in\ the\ breathing\ zone\ of\ receptor}{Concentration\ at\ the\ mouth\ of\ emitter}$

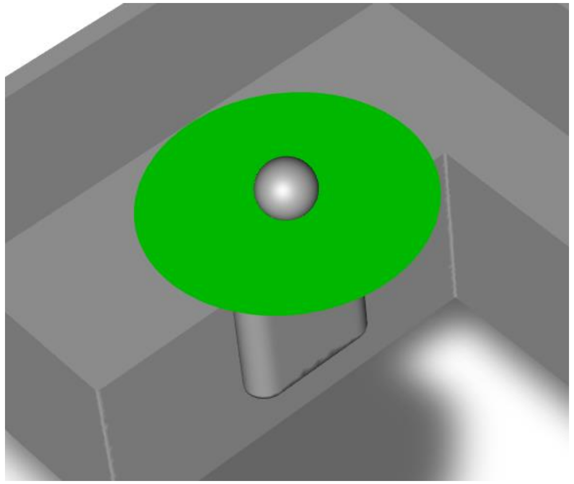
Results





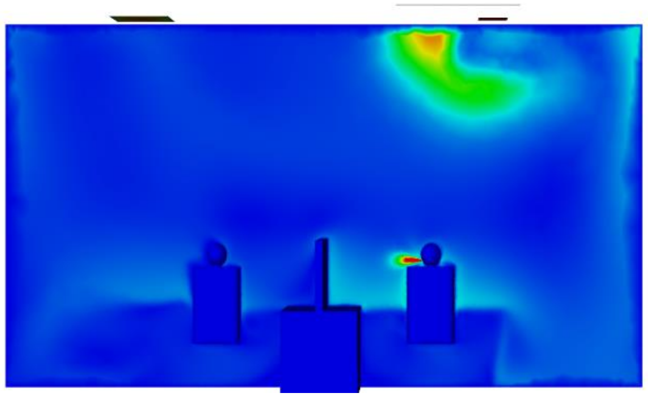
- Sampling Planes



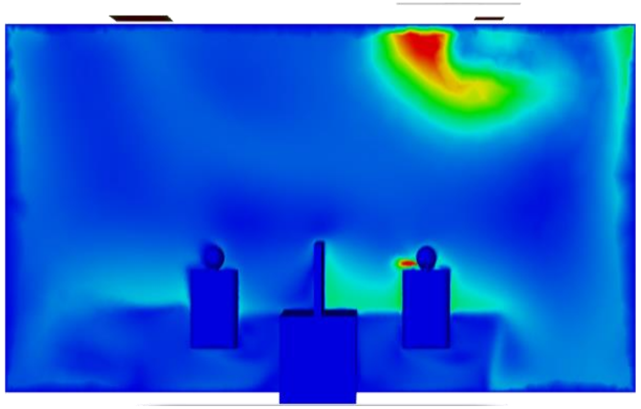


Results: Velocity Magnitude Contours

Velocity magnitude contours for different ACHs for partition height of 1.372 m



ACH=1.975



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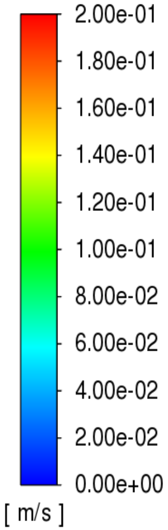
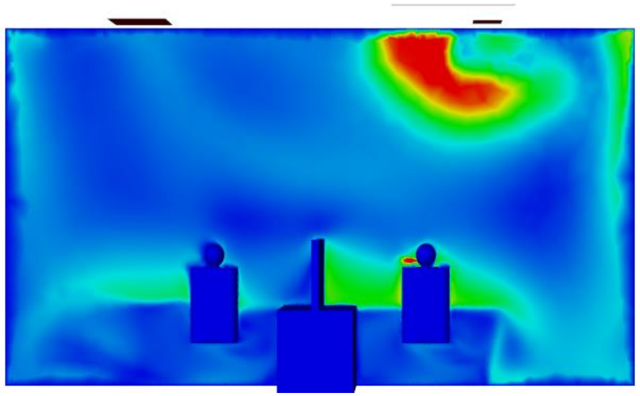
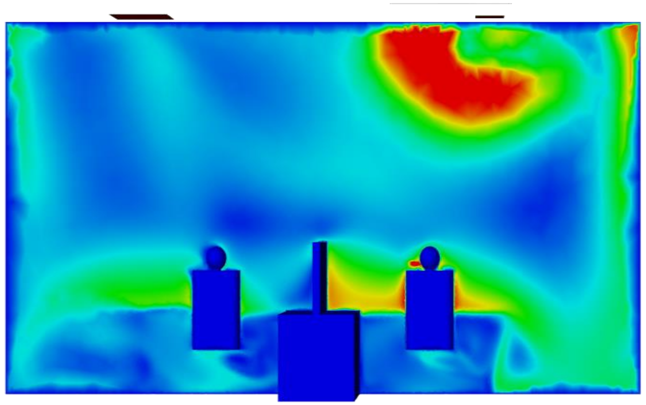




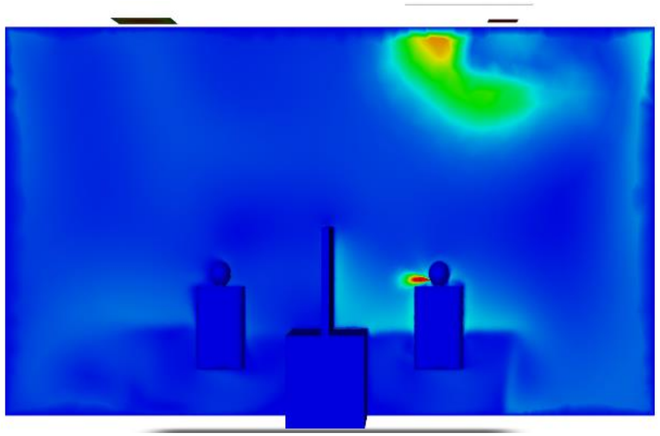
ACH=3.95



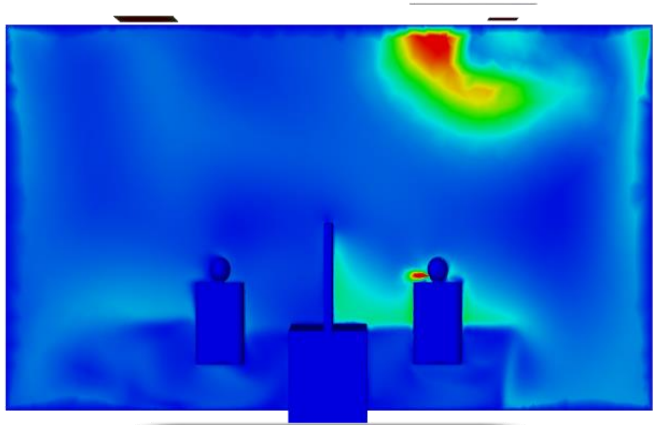
ACH=5.6

Results: Velocity Magnitude Contours

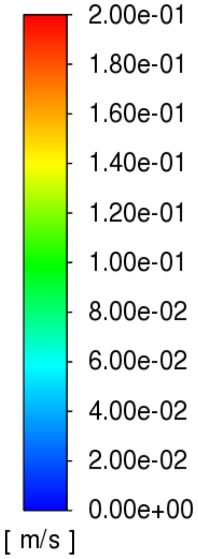
Velocity magnitude contours for different ACHs for partition height of 1.626 m

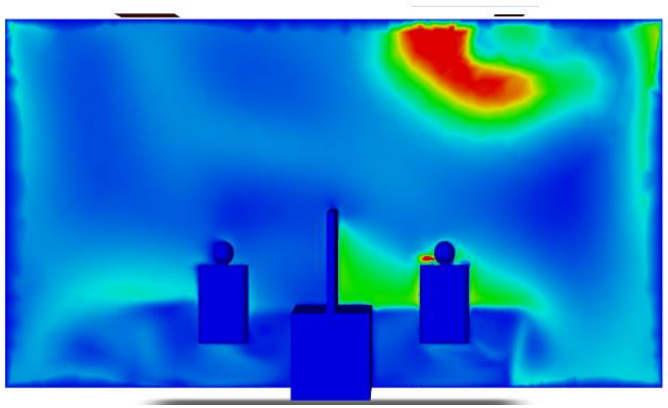


ACH=1.975

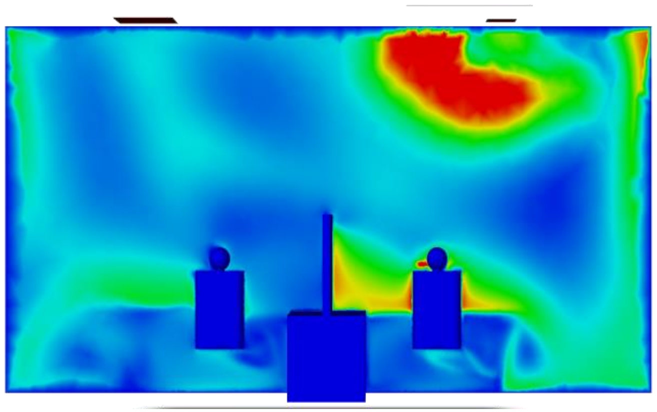


ACH=2.8





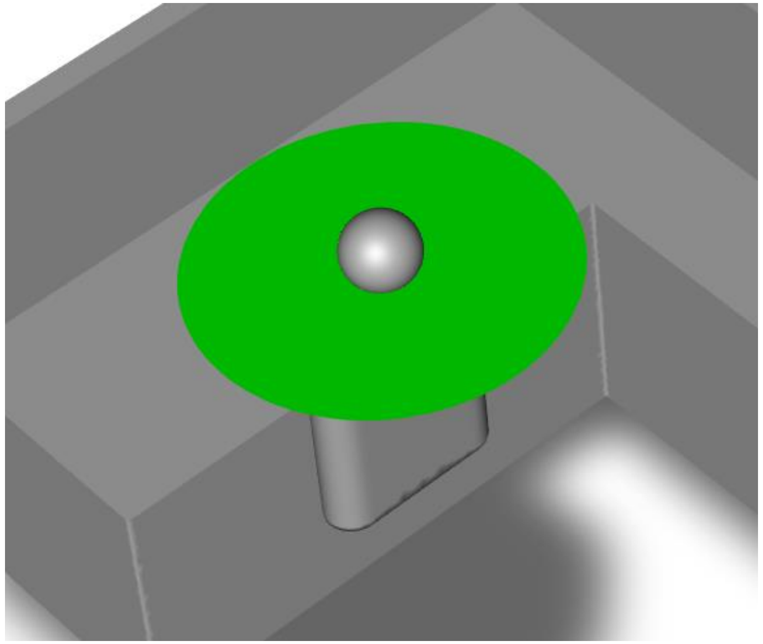
ACH=3.95



ACH=5.6

Results: Particle Tracking

Normalized 1-μm particle number concentration in the breathing zone of the receptor mannequin for ACH=3.95.

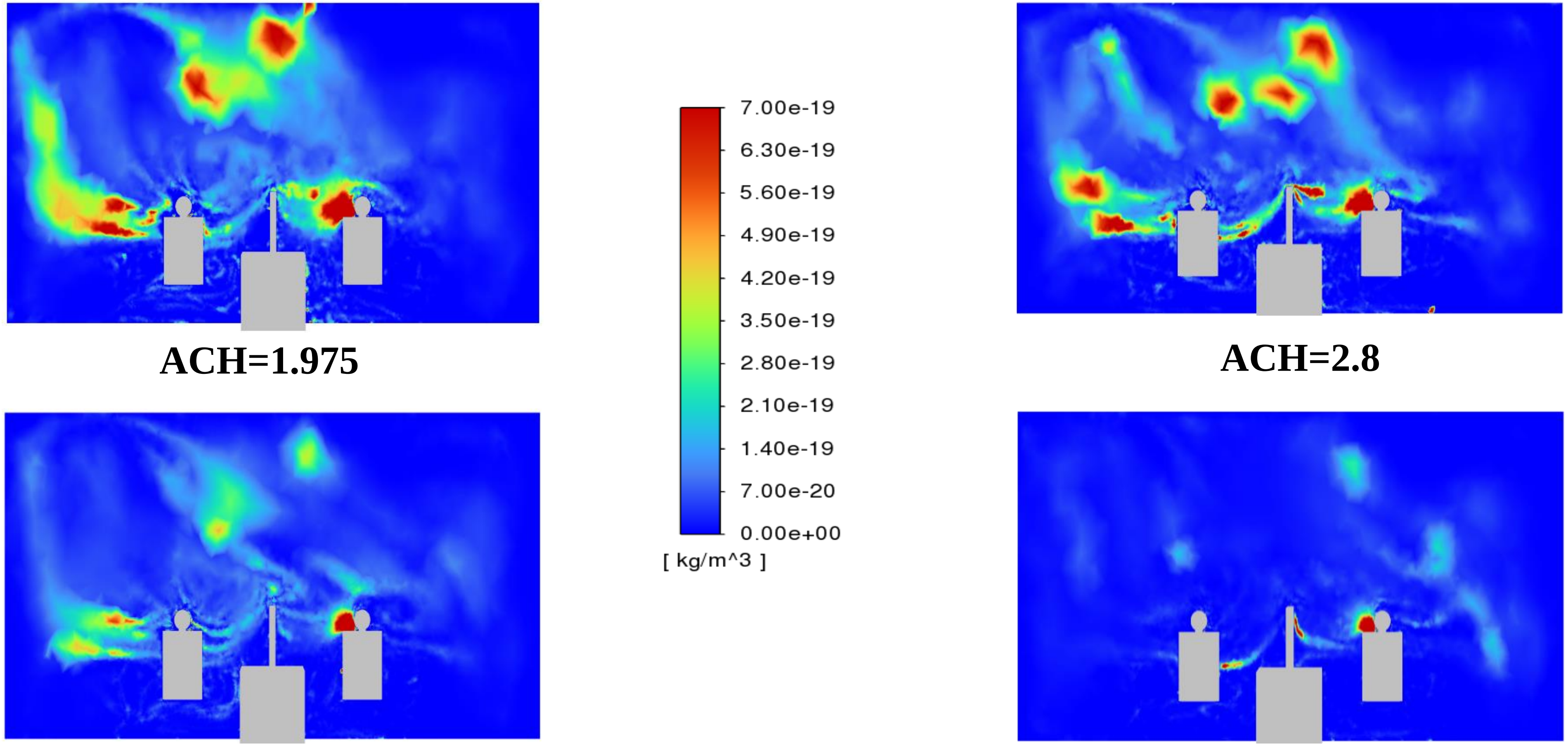


Sensitivity to the number of particles tracked

N	C^{*}_{pa}
12125	0.001984
24250	0.001995
72750	0.001996

Results: Particle Concentration Contours

Concentration contours of 1 µm particles for different ACHs for a partition height of 1.372 m

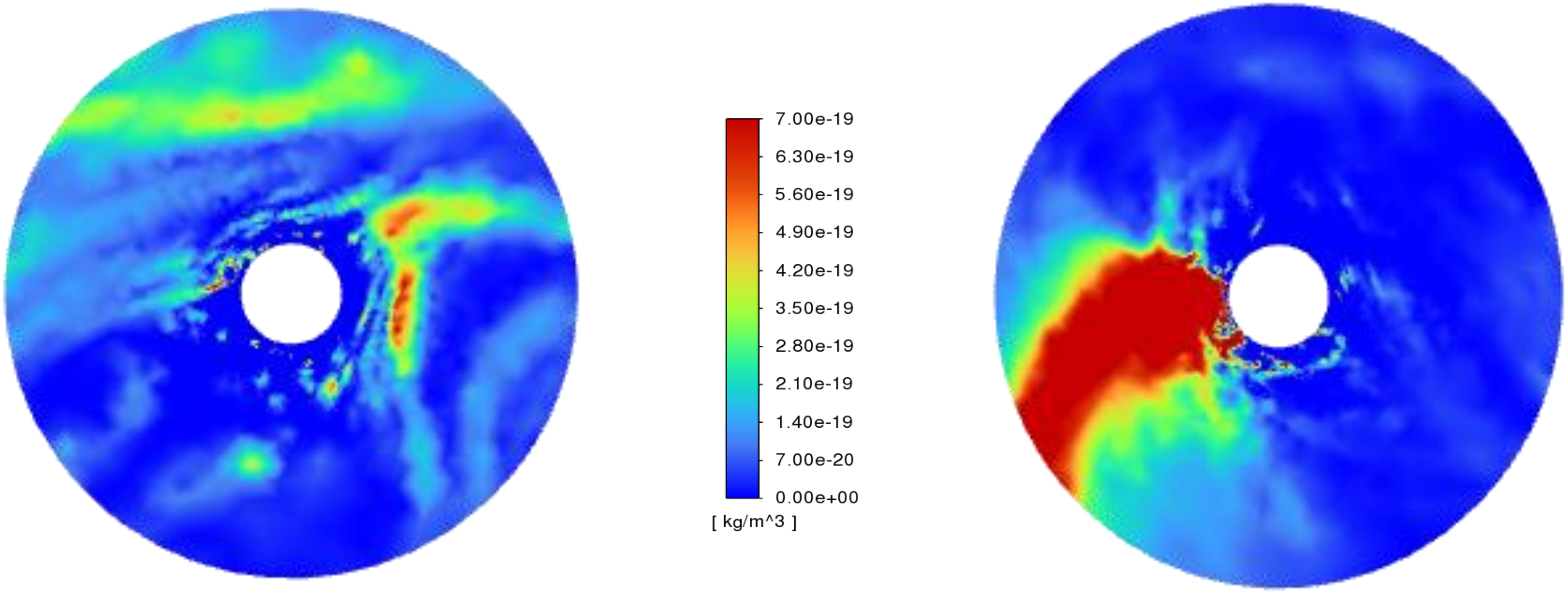


ACH=1.975 **ACH=2.8**

ACH=3.95 **ACH=5.6**

Results: Particle Concentration Contours

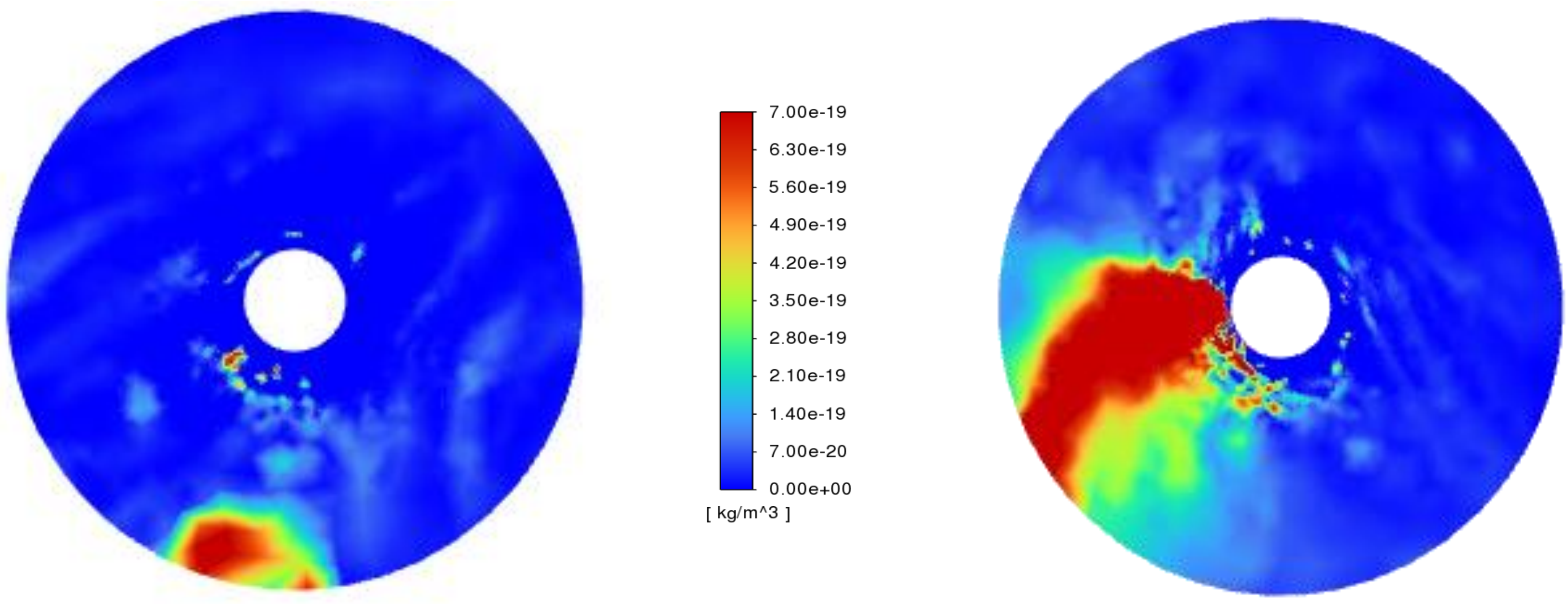
Concentration contours in the horizontal plane in the breathing zones of the receptor and emitter mannequins for 1-µm aerosols for partition heights of 1.372 m (ACH= 3.95)



Receptor **Emitter**

Results: Particle Concentration Contours

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)



Receptor **Emitter**

Conclusions and Future Work

- The presence of a partition influenced airflow patterns and particle distribution in the room. However, a 0.25 m change in partition height showed minimal impact on droplet dispersion and concentration near the receptor mannequin.
- Increasing the air change rate reduced particle concentration levels, thus lowering the likelihood of exposure.
- The ventilation airflow significantly affect the droplet concentration contours in the room.
- In related studies the DRW model was found to overestimate particle deposition.
- Future studies will incorporate the influence of thermal plumes on particle distribution and dispersion. Additionally, improvements to the DRW model will be pursued to enhance the accuracy of particle deposition estimations.

Thank you for your attention!

Questions?