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Direct estimation of infection risk using aerosol measurements with numerical simulations

Real-time infection risk monitoring is essential for public health, enabling early detection interventions to mitigate airborne disease spread in indoor spaces. Current infection risk models, such as the Wells-Riley model, rely on a well-mixed assumption and a constant aerosol exhalation rate, leading to inaccuracies in predicting spatial variations in airborne transmission. Similarly, existing CFD approaches assume a uniform pathogen emission rate from occupants and do not account for variability in aerosol generation due to vocal activity, the influence of ventilation and filtration on particle size distribution, or viral infectivity variations based on relative humidity. To address these limitations, this study presents a novel infection risk model that directly derives pathogen concentration from real-time aerosol sensor data and integrates CFD simulations to capture infection risk distribution as a function of particle radius. This approach provides a more accurate and flexible framework for assessing airborne transmission risk in indoor environments by modelling individual occupant exhalation dynamics and incorporating spatially varying pathogen concentrations.

The proposed model is applied to a stale air classroom environment with 22 occupants, where in situ aerosol concentration measurements are conducted. A validated CFD simulation, which realistically represents occupant breathing and is validated against measured exhaled aerosol concentrations, is utilized to extend the infection risk assessment beyond sensor locations. The CFD results incorporate aerosol with particle size distribution, enabling a more accurate representation of airborne transmission dynamics. This enables detailed spatial analysis of infection risk and maximum safe occupancy duration. By incorporating exhalation dynamics, this approach facilitates the identification of low-risk zones within the classroom and their corresponding safe exposure times, providing critical insights for optimizing indoor air quality and mitigating airborne transmission risks.

We investigated the effects of the infected occupant's position, particle radius, activity level, and age on the infection probability and occupancy time. The results reveal significant spatial variability of the infection risk, highlighting the limitations of well-mixed models in estimating the localised indoor infection risk. The study depicts that infection risk is influenced by viral load, infectivity, and activity level, with elderly individuals and adults at greater risk during high activity. At the same time, children retain a larger safety margin with a lower infection risk. Further, we demonstrate that infection probability alone is an inadequate safety metric, as it doesn't indicate when an occupant is likely to be infected. Instead, considering the maximum safe occupancy time is preferable, as it precisely determines how long an occupant can remain in the space without a significant risk of infection transmission.

This novel infection risk model represents a significant advancement in understanding and managing airborne transmission in indoor spaces. By integrating real-time aerosol sensor data with CFD simulations, it provides a more accurate and dynamic assessment of infection risk, accounting for individual exhalation dynamics, spatial variability, and the effects of ventilation and filtration. This approach offers a comprehensive framework that goes beyond current models, allowing for targeted interventions and optimized indoor air quality management. The implications of this model could dramatically change how the community perceives and calculates infection risk parameters, fostering a more nuanced approach to public health interventions and building design. By providing insights into safe occupancy durations and low-risk zones, this model could reshape infection risk strategies, ultimately improving public health outcomes in various indoor environments.

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