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Evaluation of the risk of airborne transmission in an elementary school classroom under intermittent ventilation through large eddy simulation

Introduction:
The Wells-Riley (W-R) models are commonly used to estimate the risk of airborne transmission in indoor environments, balancing model fidelity and computational efficiency. These models rely, to varying degrees, on the well-mixed hypothesis. Based on this assumption, a mass balance equation for pathogen or quanta concentration can be formulated and solved, incorporating additional assumptions about ventilation and emission rates. The W-R models have been applied to both steady-state and transient conditions, including intermittent ventilation in naturally ventilated spaces such as school classrooms.

Computational fluid dynamics (CFD) simulations have been applied in numerous contexts, including the evaluation of airborne infection risks in various indoor spaces, under different uses and ventilation configurations. To model the presence of pathogens, two primary strategies have been employed: Eulerian and Lagrangian approaches. The literature indicates that, despite their potential to underestimate risks in certain scenarios, W-R models are a practical and efficient alternative for estimating the overall risk of airborne transmission. However, to the best of our knowledge, a direct comparison between W-R models and CFD simulations under intermittent ventilation conditions has not yet been performed.

Aim:
The objective of this study is to compare the risk of airborne transmission estimated using the W-R model with the risk calculated from CFD simulations under intermittent ventilation conditions.

Methodology:
A naturally ventilated classroom in an elementary school in Montevideo, Uruguay, was chosen as the case study. The classroom dimensions are 8 m × 6 m × 3.5 m (length, width, and height, respectively). It features four windows on one side wall, as well as a door and an upper window on the opposite wall. The classroom typically accommodates up to 30 students and one teacher.

The airflow pattern within the classroom was simulated using Large Eddy Simulation (LES), with the occupants represented using the immersed boundary condition method. Ventilation was modeled as occurring between windows on one wall and a door and window on the opposite wall. Two ventilation cycles—low and high rates—were considered, with fixed durations for each phase. The ventilation rate was imposed by prescribing air velocity at the open windows. Pathogen and carbon dioxide concentrations were modeled as passive tracers, and the scenario assumed the presence of three infected individuals in the classroom.

Results:
The velocity field as well as the passive tracers fields, including CO2, are evaluated. From those results, it is clear that the airflow pattern is governed by the interaction of the ventilation, for both ventilation rates levels, and the thermal plumes generated by the presence of the persons within the space. Inhomogeneities in the passive tracers fields are visualized and characterized, considering the different phases of the ventilation cycle.
Regarding the risk of airborne transmission, despite local under and overpredictions, the overall results of the W-R model are in an acceptable agreement with the ones from the CFD simulation, at least for the simulated scenario.

Conclusions:
Both W-R models and high-fidelity CFD simulations are valuable tools for estimating the risk of airborne

transmission. While the latter is more time-consuming, it is particularly useful for analyzing complex or sensitive scenarios. Intermittent ventilation appears to be an effective strategy for reducing infection risk.

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