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Research Article

Numerical study of the lock-up phenomenon of human exhaled droplets under a displacement ventilated room

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Abstract

This paper adopts an Eulerian-Lagrangian approach to investigate the lock-up phenomenon (or trap phenomenon) of human exhaled droplets in a typical office room under displacement ventilation (DV). A particle-source-in-cell (PSI-C) scheme is used to correlate the concentration with the Lagrangian particle trajectories in computational cells. Respiratory droplets with sizes of 0.8 μm, 5 μm and 16 μm are released from a numerical thermal manikin (NTM). The influence factors including indoor temperature gradient, heat source configuration and exhalation modes are studied. It is found that large temperature gradient would result in trap phenomenon of small exhaled droplets (smaller than 5 μm). The intensive heat source near the NTM could help to transport the small droplets to the upper zone and decrease the concentration level in the trapped zone. Both nose-exhaled and mouth-exhaled small droplets would be trapped at the breathing height when temperature gradient is sufficiently high. However, the trap height of the droplets from mouth is a little bit higher. Because of large gravitational force, it is difficult for the thermal plume to carry 16 μm respiratory droplets to the upper zone.

Keywords

displacement ventilation,
human exhaled droplets,
thermal plume,
trap phenomenon,
Lagrangian simulation

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1 Introduction

Human exhaled droplets may act as an agent of infectious diseases. The airborne transmission route of infectious diseases through respiratory droplets in enclosed environments was reported by Han et al. (2009), Mangili and Gendreau (2005) and Wagner et al. (2009). Displacement ventilation (DV) is one of the thermally stratified systems where temperature gradient is created. If the heat sources are also the gaseous contaminant sources, the contaminants will be transported to the upper level of the room by buoyant forces, and therefore guarantee a better ventilation efficiency than mixing ventilation (Bjorn and Nielsen 1996, 2002).

Some recent work has been carried out to assess the dispersion of exhaled particle/droplet in indoor environment. Chen and Zhao (2010) answered some key questions on dispersion of human exhaled droplets by numerical simulations and clarified the effect of evaporation, ventilation rate, ventilation pattern, relative humidity, temperature level, initial exhaled velocity, and droplet nuclei size on the transport of droplets. Seepana and Lai (2012) measured and modeled the temporal and spatial distribution of sneezed droplets in a full-scale chamber. The normalized peak concentrations in the breathing height in DV were higher than in mixing ventilation (MV). They attributed it to thermal stratification, room size and high sneezing velocity. Mui et al. (2009) compared the interpersonal exposure in DV and MV. For one sneezing process, the time integral exposure in DV is 2.5 times of that in MV for face-to-face scenario.

As to the indoor environment with vertical temperature gradient such as in displacement ventilation, previous studies demonstrate that at certain conditions human exhaled pollutants would be trapped or locked at the breathing height due to the temperature stratification. Skistad et al. (2004) believed that if the heat source was too weak, the plume might disintegrate at a certain level due to a stronger heat plume nearby. Then the contaminants would be trapped at this level and be slowly transported indirectly by the stronger

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