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The airborne transmission of infection between flats in high-rise residential buildings: A review

Jiachen Mao, Naiping Gao*

Institute of Thermal and Environment Engineering, College of Mechanical Engineering, Tongji University, Shanghai, China

A R T I C L E I N F O

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A B S T R A C T

The inter-flat airborne cross-transmission driven by single-sided natural ventilation has been identified recently in high-rise residential buildings, where most people live now in densely populated areas, and is one of the most complex and least understood transport routes. Given potential risks of infection during the outbreak of severe infectious diseases, the need for a full understanding of its mechanism and protective measures within the field of epidemiology and engineering becomes pressing. This review paper considers progress achieved in existing studies of the concerned issue regarding different research priorities. Considerable progress in observing and modeling the inter-flat transmission and dispersion under either buoyancy- or wind-dominated conditions has been made, while fully understanding the combined buoyancy and wind effects is not yet possible. Many methods, including on-site measurements, wind tunnel tests and numerical simulations, have contributed to the research development, despite some deficiencies of each method. Although the inter-flat transmission and dispersion characteristics can be demonstrated and quantified in a time-averaged sense to some extent, there are still unanswered questions at a fundamental level about transient dispersion process and thermal boundary conditions, calling for further studies with more advanced models for simulations and more sound experiments for validations.

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* Corresponding author. Institute of Thermal and Environment Engineering, College of Mechanical Engineering, Tongji University, No. 4800 Cao'an Road, Shanghai 201804, China.
E-mail address: gaonaiping@tongji.edu.cn (N. Gao).

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Nomenclature

C	tracer gas concentration (ppm)
C^*	number of infection cases
H_c	recirculation cavity height (m)
I	number of infectors
k	turbulent kinetic energy (m^2/s^2)
L	length of the building (m)
L_r	distance of the recirculation zone (m)
M_{i-j}	mass fraction
P	probability of infection
p	pulmonary ventilation rate of a person (m^3/h)
Q	room ventilation rate (m^3/h)
Q_e	a portion of the infected airflow which escapes from the upper part window of the lower room
q	quanta generation rate
R	scaling length that characterizes the building's influence on wind flow (m)
R_k	re-entry ratio (%)
S	number of susceptibles
t	exposure time interval (h)
U_H	mean speed of wind approaching the building at H (m/s)
v_1, v_2, v_3, v_4	approaching wind speed (m/s)
V	flat volume (m^3)

Greek symbol

ε	turbulence viscous dissipation rate (m^2/s^3)
θ	incident wind angle (°)
ν	kinematic viscosity (m^2/s)

Abbreviation

ACH	hourly air exchange rate (h^{-1})
CFD	computational fluid dynamics
HRR	high-rise residential
IAQ	indoor air quality
LES	large-eddy simulation
MERS	middle east respiratory syndrome
RANS	Reynolds-averaged Navier–Stokes
RNG	renormalization group
SARS	severe acute respiratory syndrome

Subscript

i	source flat
j	target flat

1. Introduction

Since people spend about 80%–90% of their time indoors [1–3], the indoor air quality (IAQ) affected by particulate matter and gaseous concentration level is of great importance for human health. Poor IAQ may cause various health problems leading to morbidity, disability, disease, or even death [4,5]. In addition to indoor contaminant sources, incursion of outdoor pollutants through ventilation or infiltration is another significant factor in IAQ [5], especially for natural ventilation through open windows in residential buildings [6]. Meanwhile, many new environmental problems has emerged in densely populated areas because of the increasing presence of high-rise residential (HRR) buildings, even though the housing problem is solved to some extent [7]. A good understanding of the mechanism and characteristics of airborne pollutant transmission and dispersion in and around the building is thus the perquisite for architects and building managers to employ effective indoor air pollution control strategies [8], particularly during the outbreak of severe infectious diseases.

Airborne transmission is known to be a long-range route of infection, which refers to the situation that agents may be carried long distances, within a room or even between rooms (generally greater than 1 m), by airflows [9]. It is reported to be a major person-to-person respiratory transmission route by many epidemiological and engineering studies [10–14]. Besides, recent outbreaks of SARS [15,16], bird flu [17], A(H1N1) influenza [18] and MERS [19] have increased the scientific attention to airborne transmission in the built environment, especially in high density communities.

A special airborne transmission route called inter-flat (or inter-unit) transmission, namely air cross-contamination between flats within the same building, was identified during the outbreak of SARS in Hong Kong and started to be investigated in 2003. Using epidemiologic analysis, experimental studies and airflow simulations, Yu et al. [20] first revealed the high probability of an airborne spread of the SARS virus in one residential block. Then, Li et al. provided further analyses in an HRR building [21] and a hospital [22], where the largest outbreak happened, to show the dispersion through interior doors and window leakage. On the other hand, smaller-scale SARS clusters occurred in several other HRR buildings, such as in Wing Shui House and Hing Tung House [23], where the most affected households were located along the same vertical blocks on different floors. Similar case can also be observed in Germany [24], and it is common for residents to detect the cooking odors from neighbors. Based on these facts, Niu et al. [25] first proposed the possible transmission of inter-flat air cross-contamination under the condition of single-sided natural ventilation through openings. Such single-sided case usually exists in densely occupied residential buildings where there may be only one open window for one small cellular room. This inter-flat transmission and dispersion, driven by wind turbulence and/or temperature differences between indoor and outdoor air, may be a valid route due to the short dispersion distances between flats and the large openings involving considerable airflow exchanges.

Since then, the proposed dispersion through open windows within the same building has attracted increasing attention. Previous on-site measurements [25,26] and numerical simulations [27–30] on buoyancy-dominated inter-flat transmission well explained and quantified the upward vertical transport of gaseous pollutants. Later, a series of wind tunnel tests [31–34] and numerical simulations [35–40] was carefully performed to study the inter-flat airborne transmission and dispersion dominated by wind effect. In addition, a few studies [26,29,39] provided some preliminary work on the dispersion mechanism driven by combined buoyancy and wind effect.

In general, the inter-flat transmission and dispersion presented above involves two basic problems:

- coupled indoor and outdoor airflow driven by single-sided natural ventilation
- gaseous dispersion in and around a naturally ventilated building