Building and Environment 143 (2018) 138–162

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

The impacts of viaduct settings and street aspect ratios on personal intake fraction in three-dimensional urban-like geometries

Jian Hang[a,b], Zenan Xian[a], Dongyang Wang[a], Cheuk Ming Mak[c], Baomin Wang[a,*], Yifan Fan[d,**]

[a] School of Atmospheric Sciences, Sun Yat-sen University, Guangzhou, PR China
[b] Guangdong Province Key Laboratory for Climate Change and Natural Disaster Studies, Sun Yat-sen University, Guangzhou 510275, PR China
[c] Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong
[d] Department of Mechanical Engineering, The University of Hong Kong, Hong Kong

ARTICLE INFO

Keywords:
Street aspect ratio
Viaduct setting
Noise barrier
Numerical simulation
Personal intake fraction (*IF*_P)
Particle dispersion

ABSTRACT

High vehicular pollutants exposure to residents in near-road buildings raises special concerns in micro-scale urban science, as it causes severe health problems for those residents. This paper integrates a new parameter, i.e. personal intake fraction (*IF*_p), into computational fluid dynamics (CFD) simulations to investigate the flow and the resulted personal exposure of two-phase pollutants (CO and particular matters) in three-dimensional (3D) urban-like models. The impacts of street aspect ratios (building height/street width $H/W = 0.5–1.5$), viaduct settings, noise barriers and pollutant source locations were considered.

3D downward helical flows exist in the secondary streets perpendicular to the parallel approaching wind, which produces lateral pollutant transport across the interface between the main street and secondary streets. Therefore, the overall average *IF*_p ($<IF\_p>$) of CO (~0.23–0.59 ppm) in our current 3D urban models ($H/W = 1$) is much smaller than that in two-dimensional (2D) street canyon (~3.25–5.21 ppm) models. Although narrower 2D street canyons usually present greater $<IF\_p>$, our current 3D urban models do not show this monotone decreasing trend due to the complicated flow structures. $<IF\_p>$ of fine particles are always smaller than that of CO. Furthermore, if a single pollutant source is placed on the viaduct, $<IF\_p>$ become much smaller than that in cases with a single ground-level source. If the source location changes to the upstream secondary street, $<IF\_p>$ significantly decreases due to stronger local wind. Finally, $<IF\_p>$ of leeward-side cases usually exceeds that of windward-side cases by several times, but with viaduct settings, this leeward-to-windward ratio significantly decreases.

1. Introduction

Apart from regional air pollution [1,2], traffic pollutant emissions have become one of the main pollutant sources in cites due to the rapid urbanization [3]. Exposing to serious urban air pollution is one of the major factors resulting in adverse health impacts on city dwellers [4–6]. Moreover, on average, people spend more than 90% of their time indoors [4–6]. Outdoor air pollutants usually penetrate into indoor via doors/windows and ventilation systems [5,6]. Particularly, vehicular pollutant exposure for residents living nearby the busy main roads should be paid more attention, because their health risk from vehicular emissions is relatively higher than other urban microenvironments. Improving urban ventilation is effective for reducing urban air pollution [7–13] and the related pollutant exposure [14–19].

In urban climate science, vehicular population intake fraction (*IF*) has been adopted to quantify human exposure for a population to air pollutants released by vehicles, which is dimensionless and independent of vehicular emission rate. Population *IF* is expressed in [ppm] (i.e. part per million or 10^{-6}), where 1 ppm means 1 mg inhaled by a specific population if 1 kg pollutants emitted. Vehicular population *IF* depends on several factors, such as the exposed population size and spatial density, meteorological conditions, and the distance between sources and receptor domains etc. City-scale population *IF* (~1 km-10 km) are relatively small (e.g. 1–10 ppm in US cities [20] and 270 ppm in Hong Kong with large population density [19]). Regional-scale population *IF* (~100 km-1000 km) are even smaller (e.g.

* Corresponding author.
** Corresponding author.
E-mail addresses: wangbm@mail.sysu.edu.cn (B. Wang), u3002019@connect.hku.hk (Y. Fan).

https://doi.org/10.1016/j.buildenv.2018.07.001
Received 19 February 2018; Received in revised form 21 June 2018; Accepted 1 July 2018
Available online 05 July 2018

Table 1
Breathing rate and time spent in indoor at home for various age group.

Population age subgroups	Time percentage for "Indoor at home" (j = 1)
Children	61.7%
Adults	59.5%
Elderly	71.6%
Population age subgroups	Breathing rate Br (m^3/day) for "Indoor at home"
Children	12.5
Adults	13.8
Elderly	13.1

0.12–25 ppm in the entire United States [21]). So far, a few studies confirmed street-scale population *IF* (~100 m) can be much larger due to human's close proximity to vehicular sources in local streets [14–17]. For instance, by analyzing the concentration monitor data, street-scale population *IF*s were estimated as 3000 ppm in a typical street canyon in midtown Manhattan [14] and 371 ppm in a street of central Athens Greece [15].

As reviewed by the literature [7–13], in the last three decades, urban airflows and pollutant dispersion have been widely investigated by carrying out computational fluid dynamic (CFD) simulations, outdoor field measurement and controlled laboratory experiments. Atmospheric conditions, buoyancy force and urban morphologies (e.g. street aspect ratio H/W or building packing densities) are verified key factors to influence the flow and pollutant dispersion in urban models [7–13,16–18,22–41]. Most studies so far mainly investigated turbulent flow characteristics and spatial distribution of pollutant concentration in street canyons and at the pedestrian level [7–13,16–18,22–41]. However, people spend about 90% of their time indoor. The impacts of urban morphologies on vehicular pollutant exposure to urban residents in near-road buildings for the entire street canyon should be further emphasized and quantified. By performing CFD simulations validated by wind tunnel data, Hang et al. [16] reported that, with a normal background wind speed of 3 m/s, the population intake fraction (*IF*) in 2D idealized street canyons (H/W = 0.5–1) can be 230–913 ppm as only one main vortex exists. Then He et al. [17] further found that the population *IF* can reach ~10^5 ppm in 2D high-rise deep street canyons (H/W = 5–6) as two-main-vortex structure appears. The extremely large population *IF* in He et al. [17] results from the weak pollutant dispersion capacity in such deep street and the high population density locally. The population intake fraction (*IF*) increases linearly if the population size and density rise. Personal intake fraction (*IF_p*) is a good concept to emphasize the impacts of urban layouts and atmospheric condition on the average pollutant exposure for each person which is independent of population size and density [16,17]. Larger street aspect

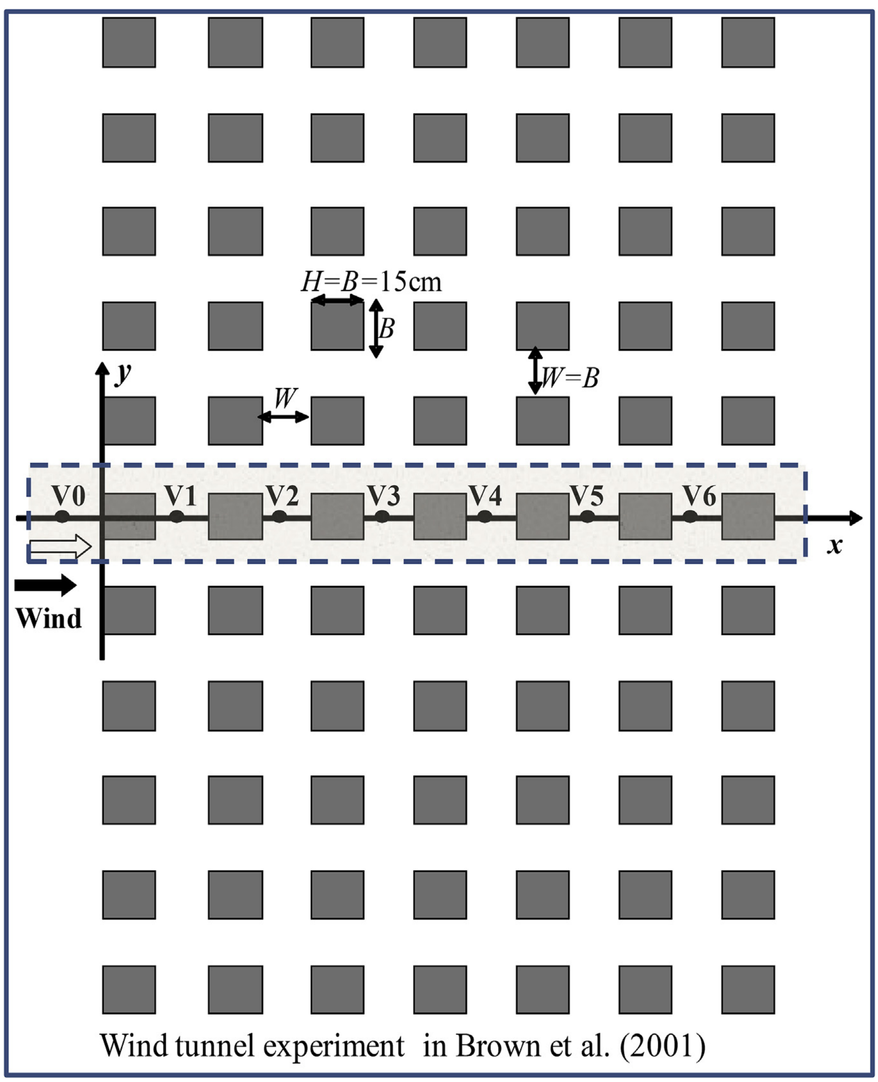

Fig. 1. (A) Model in wind tunnel test, (b) setups in the CFD validation case.