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Numerical simulations of the effect of outdoor pollutants on indoor air quality of buildings next to a street canyon

Fang Yang, Yanming Kang, Yongwei Gao, Ke Zhong*

School of Environmental Science and Engineering, Donghua University, Shanghai 201620, China

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ABSTRACT

To explore the effect of traffic pollution on indoor air quality of naturally ventilated buildings in the vicinity of a street canyon, the wind flow and pollutant distributions in and around buildings with different window opening percentages (i.e. WOP, the percentage of the total window opening area to the total facade area) were investigated by three-dimensional numerical simulations. The numerical results show that the WOP changes the pressure distribution around the downstream building, which is due to the infiltration of air into the street canyon through the opening windows of both the upstream and downstream buildings. When the indoor air of the downstream building is supplied by the outdoor air from the street canyon, the ventilation flux will be increased with increasing WOP. If the indoor air is taken in from the leeward side of the downstream building, however, the trend of the ventilation flux is found reverse. The results also indicate that the effective source intensity, which is introduced to quantify the amount of traffic pollutant entering into buildings through unit ventilation area, decreases as the WOP increases. When the WOP reaches 10%, the averaged effective intensity is reduced by 30% compared to the reference case when all windows are closed. It means that if a naturally ventilated room in the downstream building has a fixed ventilated area over different seasons, the room will take in more pollutants from outdoors in winter than in other seasons.

1. Introduction

Supply of fresh air with appropriate temperature and humidity is believed to be essential for indoor comfort and occupants' health in buildings. Natural ventilation is the simplest and most economic way to provide sufficient fresh air and achieve indoor thermal comfort. Therefore, in temperate climate time periods in China, building occupants are likely to open windows on both sides of a room for cross-ventilation. On the other hand, natural ventilation is also an effective tool to dilute and eliminate indoor pollutants emitted from indoor sources, and then improve indoor air quality. However, when the outdoor air pollution is severe, natural ventilation may cause unacceptable levels of indoor pollutants in a building. Traditionally, many roadside buildings are natural-ventilated buildings in most cities of China, and the occupants are used to opening windows for room ventilation during transition seasons and even for night time ventilation in summer. However, it has been known that air pollution is now an important environmental issue in China, and traffic emission is one of the major sources of urban air pollution [1–3]. To minimize the ingress of outdoor traffic pollution into buildings while taking fresh air by natural ventilation, it is necessary to thoughtfully understand the impact of outdoor traffic pollution on indoor air quality inside naturally ventilated buildings flanking the streets.

Traffic pollutant transmission into built environment has been widely studied over the past few decades. Most of these studies focused on the ventilation and pollutant removal properties of street canyons, and the indoor and outdoor pollutant concentration ratios (I/O ratios), and these investigations have been reviewed by Vardoulakis et al. [4] and Chen and Zhao [5]. According to existing work, there exists a coupling between the outdoor wind flow around the buildings and the indoor air flow in the buildings. The threat of outdoor traffic pollution to indoor air quality of a naturally ventilated building is influenced by several interactive determinants including the types of building layout, the structure of street canyons, the pollutant concentration distributions inside the canyons, and the rates and the directions of the ventilation flows. Even if the I/O ratios of the rooms at different locations in a building are exactly the same, the ingress of traffic pollution from outdoors to indoors may still be different. However, to the best of our knowledge, studies

* Corresponding author.
E-mail address: zhongkeyx@dhu.edu.cn (K. Zhong).

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are lacking about the effect of outdoor pollutants in street canyons on the indoor air environment, specifically such studies that comprehensively consider the ventilation performance of a room and the pollutant concentrations at the ventilation windows.

When ambient wind blows over buildings around a street canyon, it can hardly reach some regions behind the upstream buildings, and low pressure is therefore engendered in the canyon, which causes pressure differences across the buildings flanking the streets. Natural ventilation occurs when the vents (such as doors or windows) of the rooms are open. The ventilation rate and the direction of the ventilation flow are strongly dependent on the pressure difference across the buildings, and, moreover, the window opening percentage (i.e., WOP) which is defined as the ratio of the building windows' opening area to the total facade area. Therefore, the WOP plays an important role in the room ventilation and then affects the flow field in the canyon. Because of the cross-ventilation, a large amount of wind-induced airflow passes through the upstream buildings and enters into the street canyon. This airflow has an effect on the flow field, pressure and pollutant distributions inside the street canyon, which in turn influences the ventilation performance of the buildings in the vicinity of the canyon, the pollutant concentrations near the ventilation windows and contribution of outdoor traffic pollution on the indoor air quality.

Many previous studies dealt with air quality inside street canyons assuming the buildings as concrete blocks [6–10], i.e., the effect of cross-ventilation through buildings was not considered. This is a suitable approximation in winter, but not for the other seasons. Several researchers have attempted to study the natural ventilation in buildings flanking the streets, especially wind-driven flow through buildings [11–18]. For example, Yaghoubi and Zamankham [13] studied the turbulence distributions in and around cross-ventilated buildings. Cheung and Liu [14] revealed how neighboring tall buildings (with opened windows) modify the natural ventilation performance in a building group using CFD techniques. Lai [15] discussed the relationship of indoor and outdoor air qualities in an isolated building using large eddy simulation. These studies considered the effects of outdoor air on either the ventilation performance in a building or on air flow indoors. Few studies have been reported in the literature on the impact of outdoor traffic pollution on indoor air quality of a multi-room building using models that couple transport of pollutants between indoor and outdoor environments in the vicinity of a canyon.

In practice, the averaged total window opening area of a building varies with both time of day and season of the year, and the effects of outdoor traffic pollution on the indoor air quality are different in different time periods even if the ventilated area are the same. In the present study, the flow fields and pollutant distributions in and around buildings with different WOPs are estimated by employing computational fluid dynamic (CFD) simulations. With some appropriate assumptions, i.e., an isolated regular street canyon layout, traditional configurations of buildings in China, typical window opening states and other geometrical parameters in the buildings, the combined effects of natural ventilation performance of the buildings and pollutant concentration distributions around the buildings are analyzed numerically. Furthermore, the contributions of outdoor traffic pollutants to indoor air quality during different seasons are discussed by using the numerical results.

2. Descriptions of building arrangement and computational details

2.1. Street canyon configurations and computational domain

Fig. 1 shows a schematic of the building arrangement investigated in the present study. For simplicity, all building models are assumed to have the same dimensions with length (L) × width (B) × height (H) = 66 m × 15 m × 15 m. The nearby buildings may distort streamlines and modify the local flow field in a street canyon [14,19,20]. However, some previous studies [19–21] showed that when the street width to building height ratio exceeds about five, the flow field is likely to be perturbed by isolated building, i.e., the incoming flow can be considered as uniform flow. To investigate the coupling process between outdoor wind flow and indoor air flow, it is assumed that the buildings are set on the two sides of the street and infinitely repeated in the span-wise direction (i.e., y-direction), and the building separation (S) is set as 10 m or 20 m, as shown in Fig. 1(a). In realistic urban areas, many buildings in the vicinity of canyons are office or dorm buildings, and two

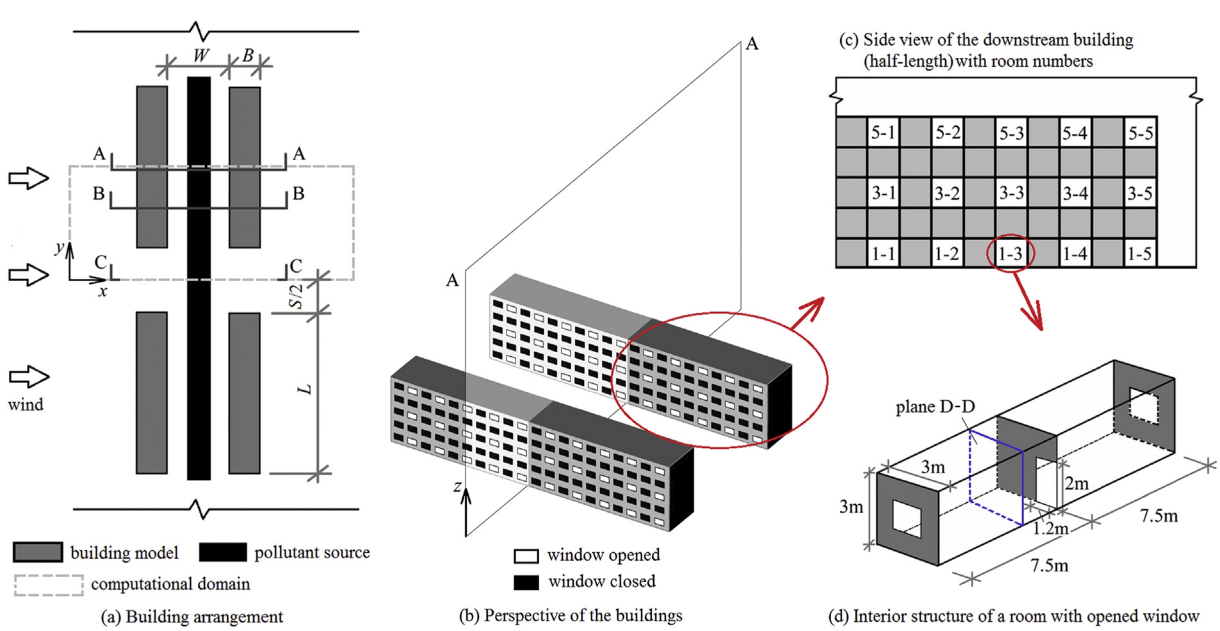

Fig. 1. Schematics of the street canyon, building arrangement and room geometrical configuration.