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On-site evaluation of pedestrian-level air quality at a U-type street canyon in an ancient city

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ABSTRACT

Urban building disposition plays an important role in determining local microclimate including air quality. Ancient cities normally have some special building dispositions to reduce the penetration of cold wind in winter, which, however, may impact adversely on air pollutant dilution today. This paper investigated the pedestrian-level air quality at a common building disposition in Chinese ancient cities, namely a U-type street canyon. On-site measurements were conducted comparatively at a U-type street canyon and a nearby open space in Xi'an China during January 2015. Three primary air pollutants (PM_{10}, $PM_{2.5}$ and NO_2) as well as wind speed and direction, air temperature and relative humidity were measured continuously from 8:00 a.m. to 8:00 p.m. for a six-day period that covered both clean and hazy days. Pedestrian-level wind condition at the U-type street canyon is mostly independent of that above the canyon, where adverse dilution condition is clearly evident for pollutants. $PM_{2.5}/PM_{10}$ ratio at the street canyon reached up to 0.9, which is nearly twice that at the nearby observatory. Overall, air quality index (AQI) in the street canyon is, on average, higher by 20% than that at the open space. These findings suggest that this ancient design should be discouraged.

1. Introduction

Air pollution is a major environmental issue in urban areas today. It is known that many cities worldwide, especially in developing countries, frequently suffer from heavy air pollution, where the hazy days account for a large portion of a year. The major pollutants in urban environment produced by vehicles and industries are particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO) and Ozone (O_3) (Kaur et al., 2007; Rakowska et al., 2014; WHO, 2005). Chemical reactions between different pollutants, with the aid of catalysts such as solar radiation, generate secondary pollutants (Meng and Seinfeld, 1996; Kikumoto and Ooka, 2012). Among all contributors, particulate matter and NO_2 are the most common and detrimental urban pollutants that are normally the first batch to exceed safe exposure limits for human (HKEPD, 2015), particularly when emissions increase or adverse meteorological condition occur. In general, exposure to air pollution is closely associated with increased morbidity and mortality for not only outdoor pedestrians but also indoor occupants (Cao et al., 2005; EEA, 2014; Ai and Mak, 2014, 2015; Ai et al., 2015; Ai et al., 2013). Particularly, fine particulate matter is associated with a broad spectrum of acute and chronic illness, such as lung cancer, chronic obstructive pulmonary disease (COPD) and cardiovascular diseases. Worldwide, fine particles are estimated to be responsible for about 16% of lung cancer deaths, 11% of COPD deaths, and more than 20% of heart disease and stroke (WHO, 2005). Therefore, research effort devoted to increased understanding and improved control of air pollution is of great significance.

Building disposition is an important parameter that influences the local wind availability and pollutants dilution (Ng, 2009; Cui et al., 2016; Chavez et al., 2012). It has been reported that winds are increasingly stagnant inside deep street canyons, while air temperature inside a street canyon is lower by 3–5 °C than the corresponding air temperature above the canyon (Georgakis and Santamouris, 2006; Allegrini et al., 2012) and is higher by nearly 2 °C than that in a suburban location (Andreou. et al., 2012). In addition, owing to increased traffic emissions and adverse dispersion conditions including low wind speeds (Weber et al., 2006; Nazridoust and Ahmadi, 2006), pollutant concentration is relatively high in street canyons (Yim et al., 2009; Ji and Zhao, 2015). Eventually,

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Fig. 1. U-type street canyons are common in ancient city Xi'an, China.

pedestrian-level concentration of air pollutants in street canyons are normally 1.2–2 times higher than the background concentrations recorded in weather stations or city parks (Ai and Mak, 2015a). Findings of previous studies generally reveal the microclimate characteristics in urban street canyons. From the perspectives of building disposition, some solutions have been explored to improve the urban air quality. For example, staggered and low-high combined building disposition are recommended designs for increasing wind availability in urban environment, which would potentially enhance the dilution of air pollution (Wong et al., 2011) and increase the pressure differences around buildings to drive indoor natural ventilation (Oke, 1987).

Previous studies regarding urban microclimate focus mostly on typical building dispositions in modern urban environment, whereas those in ancient cities are rarely investigated. There are many ancient cities in China and the rest of the world which are located in places surrounded by mountains and rivers so as to prevent the incursion of outsiders and the penetration of cold wind in winter (Hong et al., 2007). Xi'an is a typical Chinese ancient city, where the streets are mostly along an east-to-west direction and the buildings face south. There are buildings located at the west or east ends of building communities, which form many street canyons like U-type; see for example Fig. 1. While this kind of building disposition worked well for reducing cold wind penetration and thus heat loss, it is expected that these U-type street canyons may have negative effects on pollutant dilution. Since safety and heating are no longer primary concerns today, feeding the wind to ventilate the city sufficiently is critically important to dilute air pollutants.

This study investigates the pedestrian-level air quality in a U-type street canyon in the ancient city, Xi'an China. On-site measurements of some urban pollutants including (PM_{10}, $PM_{2.5}$ and NO_2; WHO, 2005) as well as other meteorological parameters (including air temperature, relative humidity, wind speed and wind direction) were conducted. As a comparison, an open space near the U-type street canyon was selected, where similar measurements were conducted. In order to examine the influence of building disposition on the penetration of ambient wind down to the pedestrian level, further measurements were conducted above the building roof at both the street canyon and the open space. Apart from the cross comparison of pedestrian-level air quality between the U-type street canyon and the open space, comparison of pollutant concentration between these pedestrian-level results and those measured at nearby governmental observatories is made. Considering that the weather forecasts and reports are made based on the observatory data, such a comparison is useful to indicate their accuracy in representing the pedestrian-level conditions. Particularly, the $PM_{2.5}/PM_{10}$ ratio at each location is determined, while its relationship with air quality (including clean air days and hazy days) is analyzed. In addition, Pearson correlation analysis is conducted to examine the correlation between pollutant concentration and other meteorological parameters, while air quality index (AQI) values at each location are calculated based on both Chinese and U.S. methods, which are described in Section 2. The findings of this study are expected to increase our understanding on the influence of building disposition on pedestrian-level air quality and raise public awareness of the environmental conditions in ancient cities.

2. Materials and methods

2.1. Measurement site

The on-site measurements were conducted in Xi'an city, the capital of

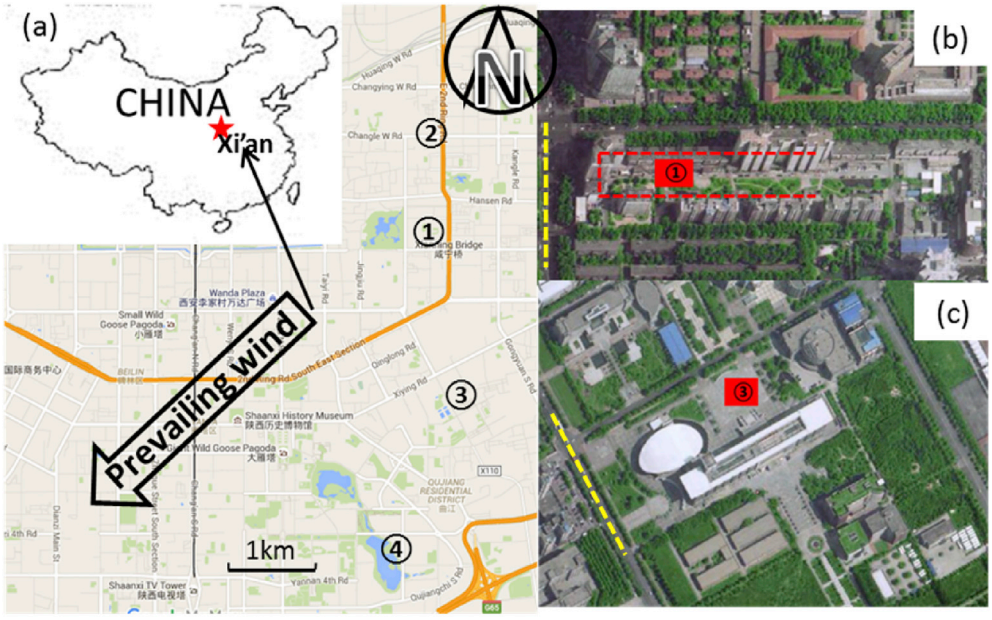

Fig. 2. On-site measurement locations in Xi'an, China; (a) map of test locations and their corresponding observatories; (b) Test location of Street Canyon; (c) Test location of Open Space.