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Impact of traffic volume and composition on the air quality and pedestrian exposure in urban street canyon

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HIGHLIGHTS

- Mobile measurements were used to assess urban air quality and pedestrian exposure.
- Traffic impact on street canyon and roadside air quality was investigated.
- Formation of ultrafine particles in roadside environments was observed.
- Transport policy needs to consider traffic volume and composition in urban canyon.

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ABSTRACT

Vehicle emissions are identified as a major source of air pollution in metropolitan areas. Emission control programs in many cities have been implemented as part of larger scale transport policy interventions to control traffic pollutants and reduce public health risks. These interventions include provision of traffic-free and low emission zones and congestion charging. Various studies have investigated the impact of urban street configurations, such as street canyon in urban centers, on pollutants dispersion and roadside air quality. However, there are few investigations in the literature to study the impact of change of fleet composition and street canyon effects on the on-road pollutants concentrations and associated roadside pedestrian exposure to the pollutants. This study presents an experimental investigation on the traffic related gas and particle pollutants in and near major streets in one of the most developed business districts in Hong Kong, known as Central. Both street canyon and open roadway configurations were included in the study design. Mobile measurement techniques were deployed to monitor both on-road and roadside pollutants concentrations at different times of the day and on different days of a week. Multiple traffic counting points were also established to concurrently collect data on traffic volume and fleet composition on individual streets. Street canyon effects were evident with elevated on-road pollutants concentrations. Diesel vehicles were found to be associated with observed pollutant levels. Roadside black carbon concentrations were found to correlate with their on-road levels but with reduced concentrations. However, ultrafine particles showed very high concentrations in roadside environment with almost unity of roadside/on-road ratios possibly due to the accumulation of primary emissions and secondary PM formation. The results from the study provide useful information for the effective urban transport design and bus route reorganization to minimize the impact of traffic emissions on the urban air quality and public health. Observations on the elevated ultrafine particle concentrations in roadside pedestrian levels also demonstrate the urgent need to improve roadside air quality to reduce pedestrians' health risks especially inside street canyon.

1. Introduction

Extensive epidemiological evidence has shown the association between human exposures to atmospheric pollution with various

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adverse health effects and overall mortality (Pope et al., 2002; Kunzli et al., 2010). In urban areas, emissions from roadway transport are a major source of air pollution, especially particulate matter (PM), despite extensive emission control measures targeting motor vehicles (Pant and Harrison, 2013; Yuan et al., 2013). Recently, the World Health Organization classified diesel exhaust as Group I Carcinogen (WHO, 2012) and various studies have shown their adverse health impact, for example lung cancer risks (Beelen et al., 2008) and worsening respiratory health of children (Rosenlund et al., 2009). This is of particular concern in densely populated cities, where large volume of traffic is often in close proximity to the population to enhance the people's mobility, but at the same time increases the population exposure to the traffic-induced pollutants, posing a great threat to the public health.

Roadside air quality in cities has drawn increasing attention especially in areas where many roadways are lined by dense and high-rise buildings forming street canyon that greatly limits the dispersion of mobile emissions (Weber et al., 2006). Differences in canyon geometry, traffic intensity and mixture, and ambient meteorology result in variable air pollutants concentrations inside the street canyon (Kim and Baik, 2004; Liu et al., 2005). Results from field measurements and computational fluid dynamics simulations report that street canyons are generally hot-spots of air pollution in urban areas (Van Dingenen et al., 2004). For example, Zwack et al. (2011a, b) found significant increases of ultrafine particle number and $PM_{2.5}$ concentrations in street canyon versus urban background in Manhattan, New York; Liu et al. (2005) simulated deep street canyons and found enhanced pollutant entrainment with larger aspect ratios (building-height-to-street-width) worsening street level air quality. Secondary pollutant formation inside street canyons was also suggested in a few recent modeling studies (Baik et al., 2012; Kim et al., 2012; Bright et al., 2013).

To improve urban air quality, many local governments have responded by introducing various mitigation strategies and traffic policies intended to reduce the impact of traffic on roadside air pollution levels on busy urban roads. For example, low emissions zones (LEZ) designed to limit high emitters in city centers have been implemented in over 150 cities in EU countries (Wolff and Perry, 2010). Congestion Charging Schemes (CCS) directed to restrict certain types of cars from entering the inner city have been implemented in many cities, such as Milan, London and New York. Various studies have also demonstrated the effectiveness of different mitigation measures in the reduction of air pollution levels (Invernizzi et al., 2011; Boogaard et al., 2012). However, for cities and areas with complex urban built environment and roadway infrastructure, there was also a report that showed no substantial benefits on the change of certain pollution levels (Ruprecht and Invernizzi, 2009). The limited understanding of the quantitative influence of marginal changes in traffic volume and mix on roadside air quality complicates cost-effective transport policy formulation and implementation. This is especially true for urban street canyons where there are both high traffic and pedestrian flows in close proximity, and evaluation of potential reduction of roadside pedestrian exposure to the traffic pollutants is of great significance and special interests for environmental and health benefits analysis.

There are few studies in the literature that have investigated the impact of change in traffic volume/composition on both air quality and pedestrian exposure to the traffic pollutants. This study presents an experimental investigation on the traffic-related gas and particulate pollutants in Central district, one of the most developed business districts in Hong Kong. Both street canyon and open roadway configurations were covered in the study design and mobile measurement techniques were deployed to investigate both on-road and roadside pedestrian area pollutants concentrations. Multiple traffic counting points along the sampling routes were implemented concurrently to monitor the change of traffic volume and mix in individual streets and to investigate their relation with the measured pollutants concentrations.

2. Methodology

2.1. Experimental site

The study was conducted in Central district, Hong Kong, located along the north shore of Hong Kong Island as shown in Fig. 1. It is one of the busiest commercial and business districts in the city, characterized with heavy traffic conditions, high roadside pedestrian usage and dense, high-rise buildings along the streets. The study area encompasses the busy west–east traffic corridor connecting Island West and Causeway Bay. To investigate the street level and roadside pedestrian area air pollutant concentrations, the sampling routes were designed to include streets with different traffic and built environmental conditions. Three main streets included in the study are Connaught Road Central (CRC), Des Voeux Road Central (DVRC) and Queen's Road Central (QRC). A detailed description of the streets and their features is included below:

- The section of Connaught Road Central in this study is a wide roadway of 8 lanes – 4 in each direction-parallel to the north shore as shown in Fig. 1. The north side of Connaught Road is open to the harbor coast with only scattered single tall buildings present, allowing easier dispersion of air pollutants than the more inland roads. The south side is dominated by dense high-rise buildings. The traffic is dominated by private vehicles and taxis;
- The section of Des Voeux Road Central is parallel to Connaught Road with 4 traffic lanes, 2 in each direction, and two tram tracks as shown in Fig. 1. Both sides of the street are lined with dense high rise buildings forming a typical urban street canyon of the Central area. The traffic mainly consists of buses and diesel goods vehicles;
- The section of Queen's Road Central has similar street canyon features as Des Voeux Road with only two to three lanes in total as shown in Fig. 1. The very narrow streets with high rise buildings along both sides greatly confine the dispersion of on-road pollutants. Traffic mainly consists of private vehicles and taxis.

2.2. Design of sampling protocol

Four full sampling days were investigated in summer and fall 2013, with three weekdays of July 31, August 3 and October 27 and a Sunday of October 28, 2013. Prior to the actual sampling campaign, one day of trial sampling was carried out (June 30, 2013) but the data were not included in the analysis due to instrument malfunctioning and incomplete pollution data. The traffic pattern observed on Saturday of October 27 is similar to other weekdays so it is counted as a weekday. This is consistent with business practices in Hong Kong, where Saturday commerce is very much as what is seen during the five conventional weekdays. For each sampling day, two to three matched time periods were selected for investigation covering morning rush hour from 0730 to 0930 h, noon time from 1200 to 1400 h, and evening rush hour from 1830 to 2030 h. During each sampling period, nine traffic counting points for traffic volume and fleet composition recording were deployed along the three roadway sections. Two mobile sampling routes were developed to include major overlaps along the three mains streets for