Building and Environment 128 (2018) 248–259

Contents lists available at ScienceDirect

Building and Environment

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

Identifying critical building morphological design factors of street-level air pollution dispersion in high-density built environment using mobile monitoring

Yuan Shi[a,*,1], Xiaolin Xie[b], Jimmy Chi-Hung Fung[b,e], Edward Ng[a,c,d]

[a] School of Architecture, The Chinese University of Hong Kong, Shatin, NT, Hong Kong Special Administrative Region, China
[b] Division of Environment and Sustainability, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong Special Administrative Region, China
[c] Institute of Environment, Energy and Sustainability (IEES), The Chinese University of Hong Kong, Shatin, NT, Hong Kong Special Administrative Region, China
[d] Institute of Future Cities (IOFC), The Chinese University of Hong Kong, Shatin, NT, Hong Kong Special Administrative Region, China
[e] Department of Mathematics, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong Special Administrative Region, China

ARTICLE INFO

Keywords:
Air pollution dispersion
Mobile monitoring
Building morphology
Planning optimization

ABSTRACT

In high-density cities, optimization of their compact urban forms is important for the enhancement of pollution dispersion, improvement of the air quality, and healthy urban living. This study aims to identify critical building morphological design factors and provide a scientific basis for urban planning optimization. Through a long-term mobile monitoring campaign, a four-month (spanning across summer and winter seasons) spatiotemporal street-level $PM_{2.5}$ dataset was acquired. On top of that, the small-scale spatial variability of $PM_{2.5}$ in the high-density downtown area of Hong Kong was mapped. Seventeen building morphological factors were also calculated for the monitoring area using geographical information system (GIS). Multivariate statistical analysis was then conducted to correlate the $PM_{2.5}$ data and morphological data. The results indicate that the building morphology of the high-density environment of Hong Kong explains up to 37% of the spatial variability in the mobile monitored $PM_{2.5}$. The building morphological factors with the highest correlation to $PM_{2.5}$ concentration are building volume density, building coverage ratio, podium layer frontal area index and building height variability. The quantitative correlation between $PM_{2.5}$ and morphological factors can be adopted to develop scientifically robust and straightforward optimization strategies for planners. This will allow considerations of pollution dispersion to be incorporated in planning practices at an early stage.

1. Introduction

Air pollution has been identified as a major problem in high-density cities in Asia [1]. Urbanization physically changes the natural landscape into a highly artificial built environment [2]. In a high-density city environment, closely packed building groups weaken air flows and consequently limit the dispersion of pollutants [3,4]. Therefore, street-level air pollution has become a severe environmental issue in high-density cities, such as Hong Kong [5]. The $PM_{2.5}$ concentration level monitored by roadside stations shows that the air quality of Hong Kong does not fulfill the requirements of either the local air quality objectives or other international air quality standards [6]. In Hong Kong, many public health investigations have shown that air pollution are strongly connected to adverse health outcomes. For every 10 μg/m^3 increase in the daily average concentration level of $PM_{2.5}$, there will be approximately 2% more hospitalization and 2% increase in the mortality due to respiratory diseases alone [7,8]. Under such circumstances, the Environment Bureau of Hong Kong released "A Clean Air Plan" for Hong Kong in 2013, with the reduction of roadside air pollution as a major focus [9].

Enhancing the rate of pollution dispersion is an effective way to reduce its concentration [10]. A properly planned/designed urban morphology will significantly improve pollution dispersion [11], and thereby reduce the health risk of exposure. Under such context, academic research and the planning practice are increasingly focusing on enhancing pollution dispersion in cities [12]. A wide range of techniques has been used to monitor or model street-level pollutant concentrations and human exposure in the built environment [13,14]. Most current methods on pollution dispersion in an urban environment are based on complex numerical simulations [15–17]. They are advanced

* Corresponding author.
E-mail addresses: shiyuan@cuhk.edu.hk, shiyuan.arch.cuhk@gmail.com (Y. Shi).
1 Postal addresses: Rm505, AIT Building, School of Architecture, The Chinese University of Hong Kong, Shatin, NT, Hong Kong SAR, China.

https://doi.org/10.1016/j.buildenv.2017.11.043
Received 12 September 2017; Received in revised form 29 October 2017; Accepted 29 November 2017
0360-1323/

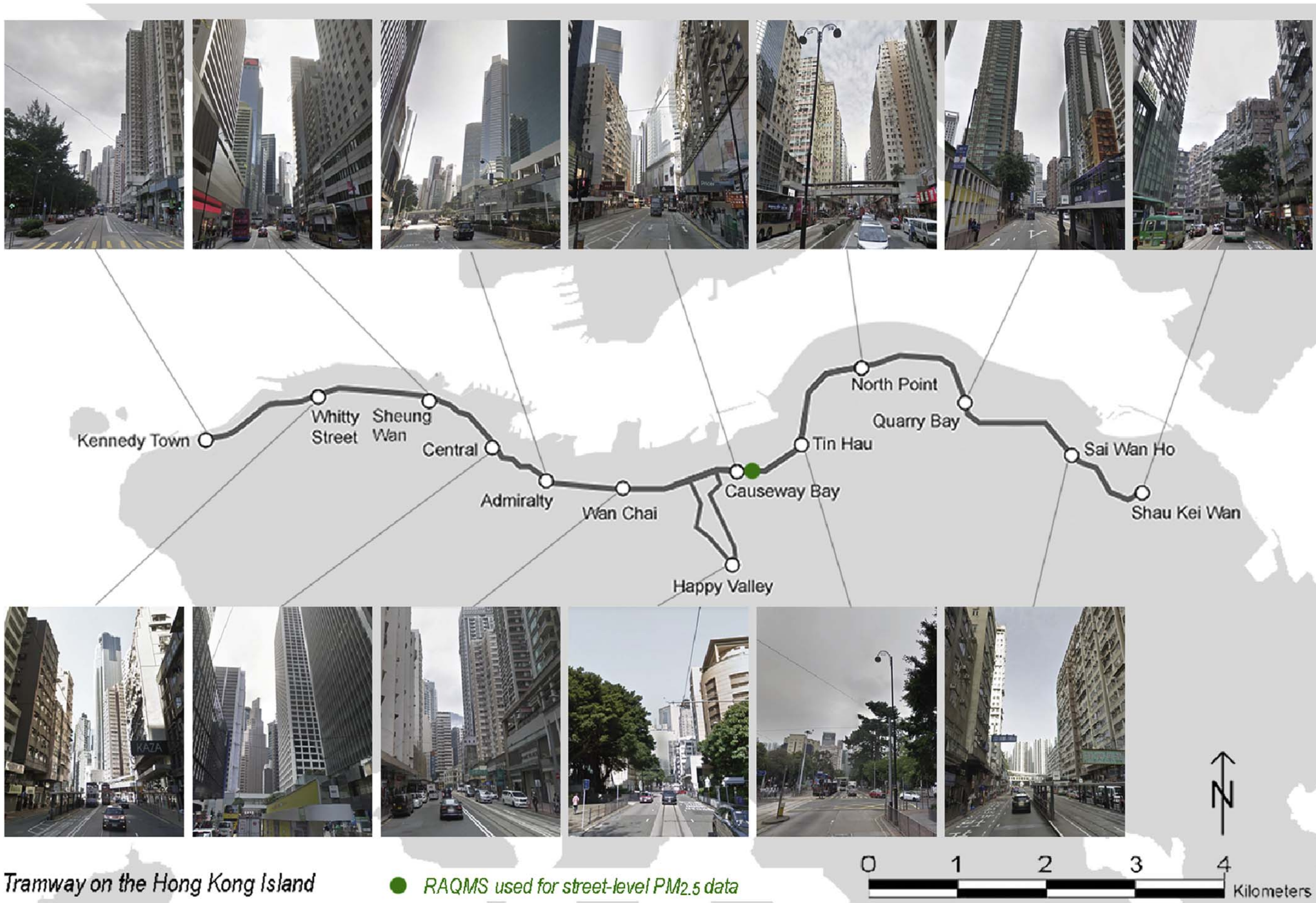

Fig. 1. Tramway on the Hong Kong Island and the building morphology of along the tram route.

and accurate, but too complicated and time-consuming to help planners and practitioners optimize the planning scheme at an early stage efficiently. For example, in the practical planning process of Hong Kong, planners need straightforward information of reasonable accuracy and quick methods at the initial strategic planning stage of urban renewal and new development areas (NDAs) projects.

It has been indicated that the densely built urban form of Hong Kong is not optimized for pollution dispersion [18,19]. It blocks ventilation and consequently retards the dispersion [3,19]. The tall building clusters and narrow roads result in deep street canyons with intensive traffic flows and high pollutant emission intensity. Besides traffic-related air pollution, many non-vehicular $PM_{2.5}$ pollution sources at the roadside [20] (such as shops, bus stops, parking entrance, cargo areas of shopping malls, and ventilation discharge outlets of restaurants/commercial cooking [21,22]) also contribute to the problem. They all emit an enormously high intensity of $PM_{2.5}$ and are a significant contribution to the street-level air pollution. However, pollution dispersion as a dimension of air pollution mitigation is not commonly considered in the daily urban planning/design practice of Hong Kong due to the lack of easy-to-use design method and practical guidance. Therefore, it is important to obtain a scientifically robust but more straightforward understanding of how to optimize urban planning for better pollution dispersion in the high-density urban context. This study focuses on quantitatively investigating the dispersion capability of different morphological configurations along the street canyons and identifying critical building morphological design factors for the development of practical planning optimization strategies. This will allow considerations of pollution dispersion to be incorporated at an early stage in the planning practice. Considering the above, $PM_{2.5}$ (particulate matters with an aerodynamic diameter < 2.5 μm, a commonly-used proxy to investigate pollution dispersion [23]), was used as a comprehensive marker to quantitatively represent the dispersion capability (of both traffic-related and non-traffic air pollution) along the street canyons.

To resolve the effects of building morphological factors on pollution dispersion, information of small-scale spatial variability of street-level air pollution needs to be observed at a very fine spatial scale. In Hong Kong, the heterogeneous building morphology and complicated traffic network make the street-level air quality vary vastly between different locations. Therefore, small-scale spatial variability of air pollution is impossible to be effectively observed using data from the only a couple of fixed roadside air quality monitoring stations (RAQMS) in Hong Kong. Mobile monitoring as a cost-effective way to cover larger study areas has been gaining popularity in air pollution research [24–26] due to its advantage of fine spatial coverage. The method uses a vehicle as a platform and its feasibility has been tested in a pilot study of mapping the spatial distribution of street-level $PM_{2.5}$ in the downtown area of Hong Kong [19]. However, the two-week dataset measured by that study possibly contains uncertainties, as the monitoring time at each position is limited. As a consistent mode of public transport of Hong Kong, trams continuously run along some fixed routes in the high-density downtown area over a long period of time. Thus, a much larger dataset can be obtained than the vehicle-based monitoring platform. It has been indicated that increasing the size of mobile monitoring dataset can greatly decrease the uncertainties in the mapping of the spatial distribution of air pollution [27]. Hence, by monitoring the air quality continuously for a long period of time on a tram, the abovementioned limitations can be overcome and the robustness of the monitoring