# $PM_{2.5}$ Pollution along the Tramway

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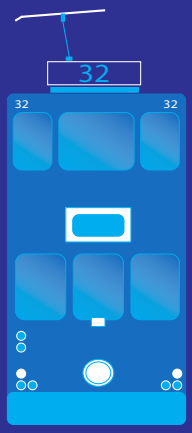



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# About Institute for the Environment, Hong Kong University of Science and Technology (HKUST)

HKUST's Institute for the Environment (IENV) is a multidisciplinary research organisation that focuses on a number of key environmental areas—air, water, solids/land, marine, and economy and society—to boost sustainable development and improve people's lives. They focus on local and regional high impact studies, but also strive to advance worldwide understanding of the way the environment works and draw attention to Hong Kong as a centre for pioneering research in this field. IENV also seeks strong partnerships with government and academic institutions in the mainland, and engages in a variety of education and outreach activities.

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# Preface & acknowledgements

The HKSAR Government has shown its commitment in its *Clean Air Plan* published in 2013 to improve Hong Kong's air quality in order to better protect public health. While it is encouraging to see the Government's measures being implemented and the amount of money being put to retire polluting vehicles that are posing a huge public health risk, it will take some time to see the impacts of these measures. It is therefore of crucial importance to reduce people's exposure to air pollutants (especially roadside air pollutants) in the meantime.

With Hong Kong's unique city landscape (many skyscrapers and narrow streets and alleys), reducing people's exposure to air pollutants may be a challenging task. It will first require a good understanding of the current picture of roadside air quality, and the relationship between street-level air quality and urban landscape. With this in mind, the Institute for the Environment, HKUST and Hong Kong Tramways Limited have worked together since March 2013 to collect air samples through a mobile air monitoring platform (ie. a tramcar) along the Northern part of Hong Kong Island, where the tram ran. With Civic Exchange's longstanding interest in air quality and public health issues, our colleagues also joined the team in identifying policy options to address the challenging issue. This paper represents our efforts in this regard.

We thank the project collaborators, including the Institute for the Environment, HKUST and Hong Kong Tramways, Limited. We would also like to thank Prof. Chak Chan and the Department of Chemical and Biomolecular Engineering on their assistance in the development of $PM_{2.5}$ measurement system. We thank Simon Ng for completing this paper, Stephen Tong, Michelle Wong, Keith Wu and Carine Lai for their contribution. We are grateful to ADM Capital Foundation for providing financial support to the publication of this paper.

Yan-yan Yip
Chief Executive Officer
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# 1 Introduction

**Road transport is a key local air pollution source. According to WHO, motor vehicle exhausts and particulate matter are carcinogenic to humans**

According to the Environmental Protection Department (EPD) of the Hong Kong Special Administrative Region (HKSAR) Government, road transport is one of the key local air pollution sources in the city, contributing 27 per cent of nitrogen oxides, 20 per cent of particulate matter, and 23 per cent of fine particulate matter ($PM_{2.5}$) in 2012.[1]

From the health perspective, the International Agency for Research on Cancer of the World Health Organization (WHO) in 2012 classified diesel engine exhausts (such as motor vehicle and ship exhausts) as carcinogenic to humans,[2] and in 2013 classified particulate matter, which is a major outdoor air pollutant, also as carcinogenic to humans.[3] It means there is sufficient scientific evidence that exposure to diesel engine exhausts and particulate matter will lead to an increased risk of lung cancer.

**Roadside air pollution is compounded by compact urban development and the street canyon effect**

Given Hong Kong's high-density, compact urban development, a large proportion of the population are living and/or working close to the main roads with heavy traffic and toxic vehicle exhausts. Street-level air pollution is further exacerbated by the 'street canyon' effect, where urban roads are lined with tall buildings on both sides, making the dispersion of vehicle exhausts extremely difficult. As such, roadside air pollution poses a serious daily health risk to the people in Hong Kong.

**It is essential to monitor roadside air pollution in different major locations, but the coverage of EPD's monitoring network is limited**

Before the Government can effectively reduce people's exposure to roadside air pollution, one of the first things to do is to get a better understanding about the level of roadside air quality along major traffic corridors where human activity level and pedestrian flow are also high. At the moment, roadside air quality information such as air pollutant concentrations is only collected at the roadside stations in Central, Causeway Bay and Mong Kok under EPD's air quality monitoring network. Right now, there is no roadside air quality data in heavily trafficked areas such as Wan Chai or Admiralty, where local condition can be quite different from Central or Causeway Bay.

In other words, readings from Central and Causeway Bay roadside stations may not be a good reference for Wan Chai and Admiralty.

In this regard, a number of local studies were conducted in recent years with the help of mobile air monitoring platforms to measure street-level air pollution in different parts of the city, including the Mobile Real-time Air Monitoring Platform of the Hong Kong University of Science and Technology (HKUST),[4] and the On-road Plume Chasing and Analysis System of the City University of Hong Kong.[5] These studies are crucial for filling data gaps, as well as for testing new, mobile monitoring systems.

**Recently, HKUST monitored roadside air quality with equipment installed on a tramcar. This paper provides policy options to reduce people's exposure to air pollutants, based on findings from the HKUST study**

More recently, the Institute for the Environment of HKUST conducted a study on $PM_{2.5}$ pollution and urban morphology along the tramway system on Hong Kong Island.[6] Based on the findings of the HKUST study, this paper aims to provide some insights into effective policy options for reducing people's exposure to toxic air pollutants and protecting public health in a dense urban setting.

# 2 The HKUST $PM_{2.5}$ Measurement Project

**HKUST and Civic Exchange collaborated with Hong Kong Tramways to measure year-round, real-time air quality along the tramway, and to examine the relationship between street-level air quality and urban morphology**

**An air quality monitoring unit was installed on one of the tramcars**

In early 2013, an HKUST research team together with Civic Exchange engaged Hong Kong Tramways to explore a potential research project that would measure urban air quality on the northern shore of Hong Kong Island along the tramway. The idea was to install an air quality monitoring unit on a tramcar for year-round, real-time collection of air quality samples, with the objectives of measuring $PM_{2.5}$ concentrations along the tramway, and investigating the correlation between street-level air quality and urban morphology.

## 2.1 $PM_{2.5}$ measurement

With the support of Hong Kong Tramways and their engineers, an air quality monitoring unit mainly composed of an aerosol monitor and a Global Positioning System (GPS) locator was installed on one of the tramcars (Figure 1). $PM_{2.5}$ concentrations and GPS location information were collected every second, which were then fed into a database system managed by the HKUST team for processing and analysis.

**Figure 1. Air quality monitoring unit on the tramcar**




Aerosol monitor and GPS locator (a) installed beneath the carseat (b; arrowed). Particulate (PM) inlet located on left hand side of the tram (c; arrowed)

**Measurement began in August 2013 during normal tram operating hours, except on the planned maintenance days**

Actual $PM_{2.5}$ measurement began in August 2013. The tramcar installed with the monitoring unit would operate as normal from 6:00 in the morning until midnight, except on the planned preventive maintenance (PPM) days. Data collection and monitoring unit maintenance were carried out during the PPM days to avoid unnecessary interruption to tram operation. In other words, the measurement schedule covers the morning and evening peak hours, and the off-peak period in between, but not the small hours when the trams are not in operation.

## 2.2 Urban and building morphology

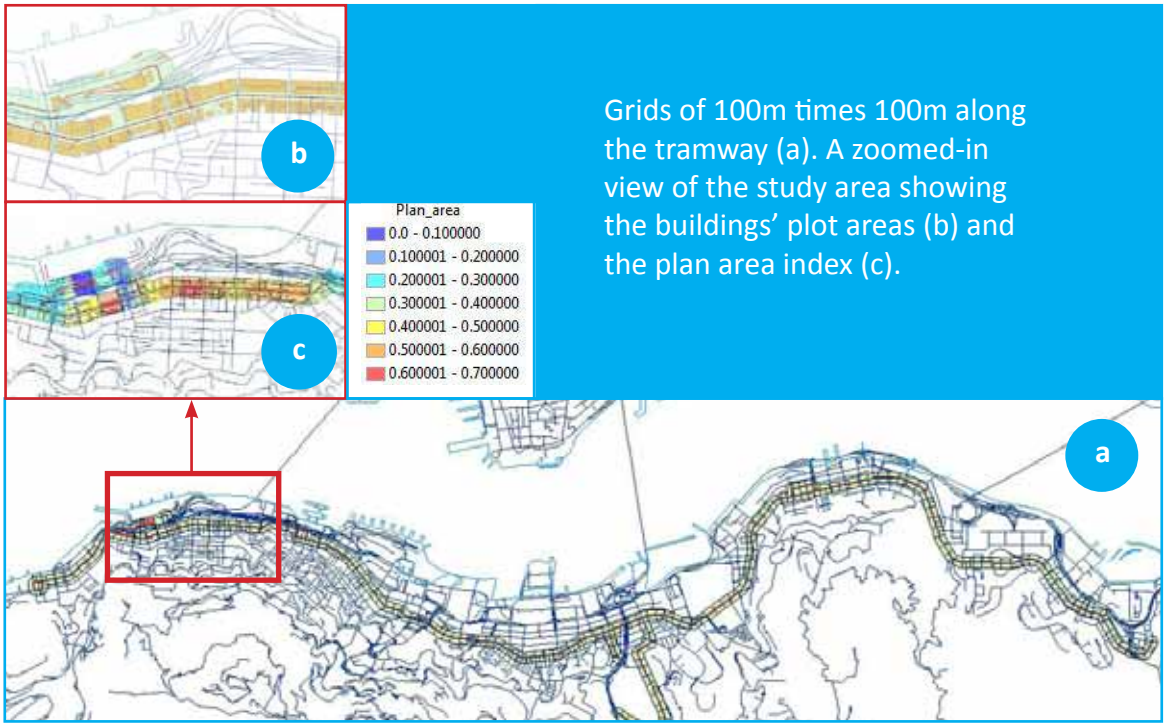
**Plan area index and frontal area index were used to examine the impact of urban morphology on wind ventilation and air pollution dispersion**

To examine the correlation between $PM_{2.5}$ concentrations and urban morphology, the HKUST study also deployed two indices, plan area index and frontal area index, to characterise urban and building morphology along the tramway and their impacts on urban wind ventilation and air pollution dispersion.

Plan area index (λp) is defined as the ratio of total building plan area inside the lot to total lot area. In the study, grids of 100m times 100m were formed along the tramway, each with an area of roughly 10,000m² (Figure 2). Plan area ratio measures the density of buildings. High building density will yield a ratio closer to one.

Frontal area index (λf) is defined as the ratio of the total frontal area of buildings facing a particular wind direction to total lot area. It measures the aerodynamic resistance of the urban surface as an indicator of wind ventilation and air dispersion.

**Figure 2. Development of the plan area index**



# 3 Key findings

**For this paper, data were extracted for the one-year period from March 2014 to February 2015**

As explained above, the HKUST study has collected $PM_{2.5}$ concentrations and GPS data since August 2013. The data discussed in this paper were extracted and analysed over a one-year period betweem March 2014 and February 2015. During this period, measurement took place consistently for at least 20 days each month (Table 1).

**Table 1: Number of measuring days per month, March 2014 to February 2015**

| Month | Number of measuring days | Month | Number of measuring days |
|---|---|---|---|
| March 2014 | 21 | September 2014 | 28 |
| April 2014 | 25 | October 2014 | 28 |
| May 2014 | 28 | November 2014 | 20 |
| June 2014 | 28 | December 2014 | 28 |
| July 2014 | 28 | January 2015 | 29 |
| August 2014 | 29 | February 2015 | 25 |

## 3.1 $PM_{2.5}$ concentrations hotspots

**Annual average $PM_{2.5}$ concentration was highest on Des Voeux Road Central and Hennessay Road/Yee Wo Street in Causeway Bay**

Figure 3 illustrates the annual average $PM_{2.5}$ concentrations along the tramway, except the Happy Valley loop, from March 2014 to February 2015. It is apparent that annual average $PM_{2.5}$ concentrations were highest along Des Voeux Road Central (the section in red on the map, with $PM_{2.5}$ concentrations close to 55 $\mu g/m^3$), followed by the section of Hennessy Road between Tonnochy Road in Wan Chai to the west and Yee Wo Street in Causeway Bay to the east (in orange on the map). As a reference, Hong Kong's annual average air quality objective (AQO) for $PM_{2.5}$ is 35 $\mu g/m^3$, whereas WHO's annual average recommended standard is 10 $\mu g/m^3$.

**Annual average $PM_{2.5}$ concentration was also very high on Des Voeux Road West, and part of King's Road in North Point**

Other than areas known for poor roadside air quality, such as Central and Causeway Bay, it is important to note that Figure 3 also identifies Des Voeux Road West in Western District and a section of King's Road in North Point with very high annual average $PM_{2.5}$ concentrations (in yellow colour). In general, roadside air pollution was relatively lower along the tramway near Tin Hau and in Eastern District, with $PM_{2.5}$ concentrations closer to 30 $\mu g/m^3$.

## 3.2 $PM_{2.5}$ concentrations and air quality standards

To plot the $PM_{2.5}$ concentration data against Hong Kong's air quality standards, Figure 4 shows the number of days when $PM_{2.5}$ concentrations exceeded Hong Kong's daily (24-hour) AQO for $PM_{2.5}$ (75 $\mu g/m^3$). It is observed that at the hotspots in Central and

**Figure 3: Spatial distribution of annual average $PM_{2.5}$ concentrations along the tramway, March 2014 to February 2015**




**Figure 4. Number of days when daily average $PM_{2.5}$ concentrations exceeded Hong Kong's air quality objective, March 2014 to February 2015**

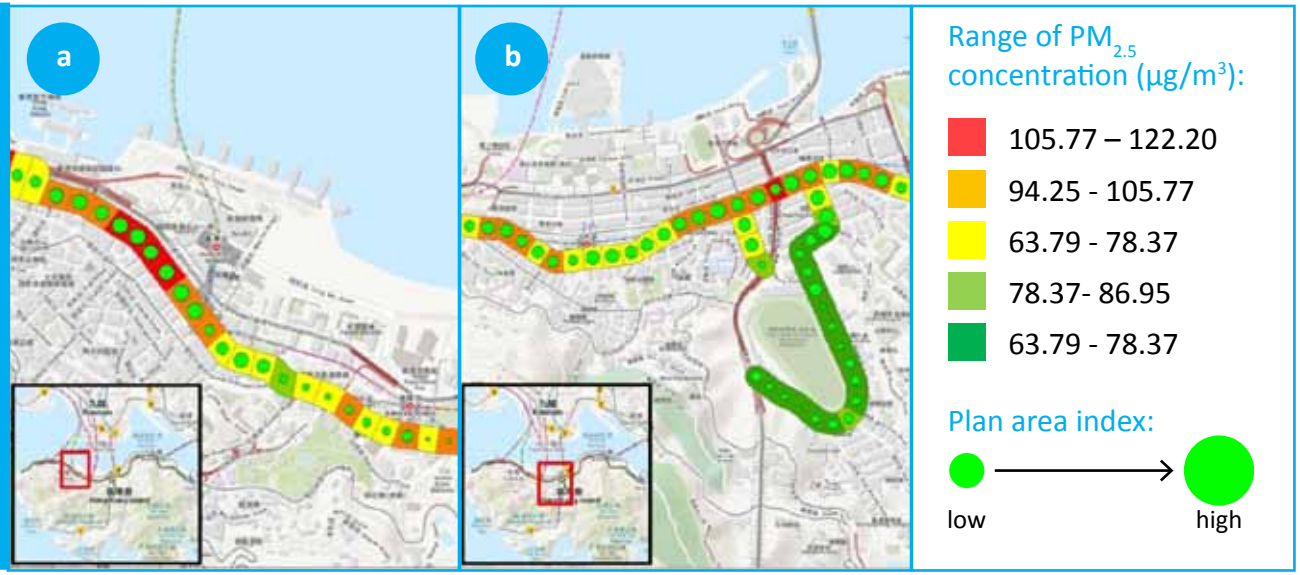


**Figure 5: Number of days when daily average $PM_{2.5}$ concentrations exceeded WHO's air quality guidelines, March 2014 to February 2015**




**Figure 6: $PM_{2.5}$ concentration and plan area index in Central and Wan Chai districts**

Central $PM_{2.5}$ and plan area index (a); Wan Chai PM2.5 and plan area index (b)



Causeway Bay as well as some areas in Western District, $PM_{2.5}$ daily average concentrations exceeded Hong Kong's AQO in 15 to 20 days each year.

**Against WHO's AQG of 25 µg/m³, daily average $PM_{2.5}$ concentration was in exceedance in 280 days in Central and Causeway Bay, and over 200 days in Western District, Admiralty and most of Wan Chai**

Similarly, $PM_{2.5}$ concentration data were plotted against WHO's daily air quality guidelines (AQG), which is 25 µg/m³ (Figure 5). From the map, $PM_{2.5}$ daily average concentrations exceeded WHO AQG's recommended standard in almost 280 days in Central and Causeway Bay. The number of days of exceedance were over 200 for Western District, Admiralty, and most of Wan Chai, and over 150 for North Point. Even in Eastern District, where roadside air quality was relatively better, $PM_{2.5}$ daily average concentrations exceeded WHO AQG for more than 80 days.

## 3.3 $PM_{2.5}$ concentrations and urban morphology

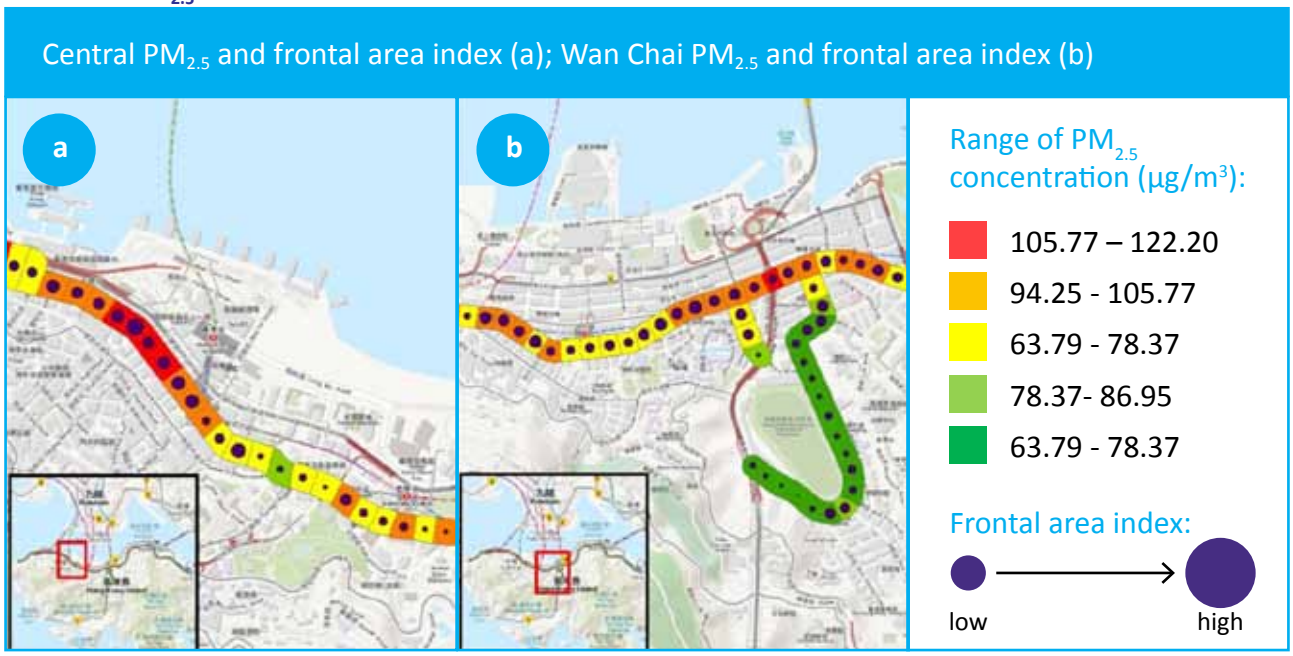
**There is a moderately positive correlation between plan area index and $PM_{2.5}$ concentrations in Central and Wan Chai districts**

The HKUST study also examined the correlation between $PM_{2.5}$ concentrations and urban morphology along the tramway. Figure 6 combines $PM_{2.5}$ concentrations in Central and Wan Chai with the plan area index derived for each grid. The warmer the colour of the grid, the higher the $PM_{2.5}$ concentration. The larger the size of the green circle, the higher the plan area index. It is found that there is a moderately positive correlations between plan area index and $PM_{2.5}$ concentration in both Central and Wan Chai districts (r = 0.615 and 0.620, respectively).

**Frontal area index explains about 38% of the variations of $PM_{2.5}$ concentrations in Central and Wan Chai districts**

Similarly, Figure 7 shows the correlation between $PM_{2.5}$ concentrations and frontal area index of each grid in Central and Wan Chai districts. The warmer the colour of the grid, the higher the $PM_{2.5}$ concentration. The larger the size of the purple circle, the higher the frontal area index. A simple regression model showed that frontal area index explains approximately 38% of the variations of $PM_{2.5}$ concentrations in both districts ($R^2$ = 0.379 and 0.384, respectively).

**Figure 7: $PM_{2.5}$ concentration and frontal area index in Central and Wan Chai districts**



# 4 Discussions and policy recommendations

## 4.1 Discussions

**Calibrated tram data show $PM_{2.5}$ concentrations in a wider area not covered by the AQMS, which helps to identify other emissions hotspots**

First, the calibrated tram data (see Box 1) are very useful in showing $PM_{2.5}$ concentrations in a much wider area with more data points and in locations not covered by the air quality monitoring station (AQMS).

For example, it now becomes clear that apart from the main emission hotspots along Des Voeux Road Central (Central District) and Yee Wo Street (Causeway Bay), $PM_{2.5}$ concentrations are consistently high along Des Voeux Road West (Western District), Hennessy Road (Wan Chai) and part of King's Road (North Point). In other words, any measures to improve roadside air quality on the northern shore of Hong Kong Island should focus on all the locations listed above, not just the usual focal points in Central and Causeway Bay.

**$PM_{2.5}$ annual and daily average concentrations are alarmingly unhealthy along the tramway, with serious health consequences among elderly people**

Second, it is worrying that both $PM_{2.5}$ annual and daily average concentrations along the tramway, perhaps with the exception of the section in Quarry Bay and Shau Kei Wan, often fail to comply with local standards and international guidelines. For example, according to the data collected in the HKUST study, $PM_{2.5}$ daily average concentrations were higher than WHO's AQG recommended value for almost half of the year. In the worst locations, WHO's AQG was exceeded in 280 days a year. Even when Hong Kong's AQO for PM2.5, which is less stringent than WHO's AQG, was used for comparison, which is less stringent than WHO's AQG, there were still almost 20 days of exceedance in the badly affected areas. In short, roadside air quality along the tramway is unhealthy.

According to the latest research led by the School of Public Health of the University of Hong Kong,[7] an increase of 10 $\mu g/m^3$ in $PM_{2.5}$ concentrations will lead to a 22 per cent increase in deaths caused by cardiovascular causes, a 42 per cent increase in coronary heart disease, and a 24 per cent increase in strokes among senior citizens aged 65 or above.

**There is a connection between air quality and urban morphology, but the solutions lie outside EPD's responsibility**

Third, it is demonstrated that there is a connection between poor air quality and urban morphology due to the size, height and density of development, which in turn have a negative impact on wind circulation and the dispersion of air pollutants. However, it requires an integrated urban planning approach that takes into consideration factors such as land use pattern, building morphology, local traffic and pedestrian flow, wind ventilation, and other factors to solve the problem in the longer term, and the responsibility for which lies beyond EPD.

**Box 1: Tram data versus air quality monitoring station data**

The tramcar used by the HKUST study travelled a regular route along major traffic corridors that cut through some of Hong Kong's biggest street canyons. This is a very innovative idea to collect more data points under much more stable conditions compared to other mobile platforms. However, it is still different from a stationary AQMS in many ways. For example, AQMS collects air samples round the clock. The tramcar platform can only collect data during operating hours. As a result, the tram data will lean towards the higher end, as the low concentrations data are more likely to happen during the small hours with less traffic.

In light of these issues, the HKUST team calibrated the air quality monitoring unit regularly with AQMS, so that the tram data are comparable to the AQMS data.

## 4.2 Policy recommendations

**The Government needs to move beyond end-of-tailpipe solutions to improve roadside air quality in major urban street canyons in order to reduce people's exposure risk**

It has been known for a long time that roadside air quality, especially in an urban street canyon environment, is very unhealthy in Hong Kong. However, government actions so far, which are mostly led and delivered by the Environment Bureau and EPD, focussed mainly on reducing emissions from road vehicles. This is an important part of the solution, but not the only solution. To date, very little has been considered to improve air pollutant dispersion in urban street canyons and to reduce people's exposure to roadside emissions through planning and transport management measures. This is simply not good enough, as millions of people are put at risk almost every day.

It is therefore argued here that the Government should make it a policy priority to improve roadside air quality in major urban street canyons, such as the main traffic corridors along the tramway, to a level where people's health can be protected. Specifically,

**Specifically, air quality targets in concentration should be set for roadside emission hotspots to drive improvement**

(a) The Government should make reference to health-based guideline, such as the WHO AQG, and set air quality targets in concentration (in $\mu g/m^3$) for major roadside air pollution hotspots, which is directly related to people's exposure and health implications. This is an ambitious move and a real challenge for any government, but probably the best (and perhaps only) way to drive change and improvement;

**Road traffic should be removed from urban street canyons at every opportunity through pedestrianisation and other traffic management schemes**

(b) In order to achieve the air quality targets, the Government should take away road traffic from urban street canyons whenever opportunities arise. One recent example is the opening of the West Island Line, which has reduced demand for road-based transport and led to public transport rationalisation in Western District, Sheung Wan and Central. This is exactly the type of opportunities that the Government should grasp to reduce or remove road traffic, which can be achieved by implementing pedestrian-only areas and other traffic management schemes. Service vehicles and other business activities such as loading and unloading can be re-directed to side streets or re-scheduled to different time of the day when impact on people will be minimal. Another option is to only allow zero or low emission vehicles in these areas during restricted hours. In any case, people's wellbeing should take top priority over other considerations;

**Future discussions on these measures should not be limited to Central, Causeway Bay and Mong Kok, as this paper illustrates that roadside air quality is also poor in other locations**

(c) Related to the previous point, future discussions of any government measures such as pedestrianisation schemes and low emission zones should not just focus on Central, Causeway Bay and Mong Kok where the roadside air quality monitoring stations are making these emission hotspots better known. As pointed out in this paper, there are other locations where roadside air quality is equally bad and therefore require swift government action, such as Des Voeux Road West, Hennessy Road and King's Road, as well as other street canyons like Nathan Road which was not covered in the study;

**Long-term strategy to improve wind ventilation and air dispersion in urban street canyons are needed**

(d) The Government should devise a long-term strategy to improve wind ventilation and air dispersion in urban street canyons with every new development and urban re-development opportunity; and

**New monitoring systems to provide more detailed data should be considered to complement EPD's air quality monitoring network**

(e) The Government should explore the possibility of deploying new monitoring techniques, mobile and stationary, with university partners and other research organisations in order to expand both the temporal and spatial coverage of air quality monitoring. It is demonstrated in this paper that by paying due attention to data collection, quality assurance and calibration, new monitoring systems can play an important complementary role in supporting EPD's air quality monitoring network.

**Swift government action and intra-governmental collaboration are essential**

The Government should take actions now before the social and health costs become unbearable, and it has to be a collaborative effort between relevant bureaux and departments, including the environmental protection, transport, development, planning, and health agencies.

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