The effects of Platform Screen Doors on air quality in underground subway platforms and train cabins

An empirical study conducted in Hong Kong's underground MTR platforms and trains using portable aerosol monitors

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1. Introduction

 Underground rapid transit system has become an essential element of urban citizens' daily lives since the world's first underground mass transportation system started operations in London in 1863. After 153 years of expansion, there are more than 150 subway systems in the world in the year of 2016, servicing commuters in New York, Beijing, Tokyo, Barcelona, Seoul and other major cities in the world (UITP statistics, 2015). Its high efficiency, large capacity and many other unique benefits enable subway system to become one of the most popular transportation modes in urban areas where residents spend an average of 1-2 hours (12.5%-25%) of a working day underground commuting to and from work (UITP statistics, 2015). Among the world's busiest subway networks, Hong Kong's Mass Transit Railway (MTR) system runs 20 hours and 8,000 train trips per day, with an average daily ridership of 4.69 million (Hong Kong Government stats, 2016). Since its first operation in 1979, MTR is

has successfully improved air quality in underground stations by implementing effective ventilation system that utilizes auto roll filters and installed full height glass Platform Screen Doors (PSDs) in every running underground MTR stations (Hong Kong Legislative Council, 2012). In a most recent study done to compare air quality in different transportation modes, the authors concluded that PM concentrations in MTR stations are almost three times lower than those near roadside bus stations, and two times lower than those in buses or trams in the constantly busy streets in Hong Kong regardless of peak or non-peak hours (Che et al., 2016).

 MTR has completed the Platform Screen Doors retrofit program by the year of 2007, successfully installed PSDs, including full-height (from platform ground to ceiling) and halfheight (from platform ground to mid-air) PSDs, on all 74 platforms in 30 underground stations and ground-level and above-ground stations (MTR sites, 2016). It is the first retrofit program that is executed on a working metro system. Even though passenger safety is the priority of the PSD program, the MTR cooperation has stated that, with the sealing off of train tunnels, screen door installations have caused an overall energy savings of 15% in the

 With this speculation in mind, the main aim of this work is to examine the effects of PSDs on air quality in underground platforms and inside subway trains by presenting

papers that studied air quality in the underground mass transportation environments around the world (Szeto, 2013). Factors that might lead to significant influence to the results of air quality measurements in underground subway systems include the year of construction, train specification and infrastructure, study timing, sampling location and consistency. In order to ensure the quality of measurements, all of the above were taken into accounts.

2.2 Sampling Locations

 An on-site study of conditions of PSDs installments and stations layout in all 87 railway stations is conducted prior to the design of sampling locations (Table 1). Among the 87 stations, 30 are underground and have full-height PSDs installed. 57 are ground-level or elevated (mostly along the East Rail Line, the oldest among the ten subway lines) with fullcommercial and core financial district, to *Chai Wan* in the Eastern District, a less populated and visited residential area with smaller commercial shopping malls (Fig 2). The line first opened on 31 May 1985, currently traveling through 10.1 miles in 34 minutes along its route,

track in two different levels allows us to minimize the influence of arrivals and departures of

 In each sampling day, the designed route started and ended in the south bus station at HKUST. The journey includes a outward trip from HKUST to Sai Wan Ho (1) , three measurements at Sai Wan Ho station, a trip from Sai Wan Ho to Causeway Bay (②), three measurements at Causeway Bay station, a trip from Causeway Bay to Sai Wan Ho (③) and a return trip from Sai Wan Ho back to HKUST (4). (Fig 4) In the outward trip from HKUST to Sai Wan Ho and the return trip from Sai Wan Ho to HKUST, researchers travel side by side for the purpose of calibrations against the two pairs of monitors.

Fig 4. Design of sampling fixed route in the Hong Kong map

2.3.1 sampling in Sai Wan Ho and Causeway Bay stations

After arrival at Sai Wan Ho station, one researcher, carrying portable equipments (Dust-Trak numbered 8530133822, Q-Trak numbered 7575X1343003) in a backpack with tubes stored in nose-level, stands in the middle of the train platform to the direction to Chai Wan, 3 feet away from the middle PSD (Fig 5). Simultaneously, another person carrying the another set of portable monitors (Dust-Trak numbered 8530143810, Q-Trak numbered 7575X1343001) departs from the adjacent underground station (Tai Koo), board the train to

Other than PM_{2.5}, this paper also studies carbon dioxide $(CO₂)$ density for many wellknown adverse health impacts caused by high concentrations of $CO₂$, including restlessness, headaches, dizziness, and increased heart rate and blood pressure. $CO₂$ in underground subways stations comes mainly from passengers' respirations. Since it has been concluded that CO2 highly correlated with the number of passengers, CO2 density is a good indication of passenger volume.)

2.5 Instrumentation and quality control

 Modeled after a recent study done in Hong Kong that compares air quality in different transportation modes, including buses, trams and MTR stations, this study utilizes available portable air quality monitors provided by the Environment Studies division in Hong Kong University of Science and Technology. Two TSI Dust-Trak II (model 8530) aerosol monitors were used to monitor PM_{2.5} concentrations and two TSI Q-Trak (model 7575) were used to collect data of $CO₂$ density. Each Dust-Trak paired with a Q-Trak and stored in a padded backpack designed to minimize instrument tilt and vibration, and the sampling tubes were situated at nose level to measure at a typical breathing level for a standing passenger. There are two identically designed backpacks with the same instrument setup for the purpose of obtaining simultaneous measurements in different locations. The TSI Dust-Trak II aerosol monitor model 8530 is a battery-oper 0.2 () 4-0.2 (us) 59.9 (a) 2-135 ((i) 0.2 (t)) TJ Em5Tm /T Tm/T

 Previous studies have reported that the Dust-Trak monitor overestimates PM2.5 by a factor of two to four compared to reference methods that use mass balance method, a more reliable method (Che et al., 2016). Therefore, before measurements started on July 30th, the two pairs of monitors were calibrated against monitors in Air Quality Research Supersite at Hong Kong University of Science and Technology, located in Clear Water Bay, Sai Kung, Hong Kong. The reference instrument in HKUST is a Thermo Fisher Scientific SHARP,

resolution,this study analyzes a total sample size of $15480²$ All sets of data for the purpose of comparison are tested using the t-test assuming homoscedastic (equal variance) at a significance level of 0.05. The differences of all comparative sample means after calibrations are proven to be statistically significant. Therefore, we are able to draw conclusions about the data we obtained. Data are analyzed using Microsoft Excel and MATLAB.

 Measurements of ambient air quality from fixed-site monitors are used as a reference for inter-daily variability near Causeway Bay (the Central district) and Sai Wan Ho (the Eastern district). The measurements are provided by the Hong Kong Environmental Protection Department (HKEPD) and they are collected in one-hour resolution. The accessibility of air quality monitoring data from the HKEPD provides a valuable opportunity to investigate the relationship between underground indoor air quality and ambient air quality. Data collected underground from portable equipments were adjusted to one-hour resolution to perform data comparison.

3. Results and discussion

3.1 Comparison between air quality in the platforms and in train cabins

A summary of the simultaneous $PM_{2.5}$ concentrations in the platforms and train cabins in Sai Wan Ho and Causeway Bay station is presented by Fig 8 and Table 2. In Sai Wan Ho station, the means of $PM_{2.5}$ concentrations in train cabins in three sampling days all exceed the means of PM_{2.5} concentrations in the platform, with an average difference of 2.09 $\mu q/m^3$. A similar observation can be made in Causeway Bay, with an average difference of 4.24 µg/ m³. Based on the five-number summary of sampling data, the positive difference between PM2.5 concentrations in train cabins and in platforms is consistent. Almost all minimums, first quartiles, medians, third quartiles and maximums in the train cabins are higher than those in the platforms in each corresponding sampling session. It is also interesting to note that while the $PM_{2.5}$ concentrations in train cabins are higher than the $PM_{2.5}$ concentrations in both Sai Wan Ho and Causeway Bay station, the average difference in Causeway Bay is nearly two times higher than in Sai Wan Ho.

possible explanations for this result, the influences of platform screen doors are of notable account. Many studies have acknowledged the significant role Piston effect plays in renewing air between tunnels and platforms in underground subway stations.() However, with the installation of platform screen doors, the natural air circulation crated by piston wind is obstructed. Particulate matters generated and accumulated in the tunnels are harder to escape.

approaching the platform (doors not yet opened). When the doors opened, the PM2.5 concentrations experienced a sudden decrease almost every time. There are also discernible pulses of $PM_{2.5}$

Bay station appears to be higher than the $PM_{2.5}$ concentrations in Sai Wan Ho station in the first day, while the PM2.5 concentrations in Sai Wan Ho station appears to be higher than the PM_{2.5} concentrations in Causeway Bay station in the second and the third day. In the first day of sampling, while PM_{2.5} concentrations in Sai Wan Ho station has a mean of 13.24 μ g/m³, PM_{2.5} concentrations in Causeway Bay station has a higher mean of 15.65 µg/m³ compared to Sai Wan Ho. In the second and third day, while PM_{2.5} concentrations in Sai Wan Ho station has a mean of 20.16 $\mu q/m^3$ and 24.57 $\mu q/m^3$ respectively, PM_{2.5} concentrations in Causeway Bay station has a lower mean of 16.18 µg/m

Table 3. Five-number summary of PM2.5 concentrations in Sai Wan Ho and Causeway Bay station and comparisons between mean indoor air and mean ambient air.

 This difference is interesting because previous studies have shown that indoor air in underground subway stations is positively correlated to ambient air quality. In addition, Causeway Bay is located in the busy central district of the Hong Kong Island with much more visitors and traffics than the residential area where the Sai Wan Ho station locates. There are far more passengers in Causeway Bay station than Sai Wan Ho station. Therefore, it is not irrational for one to expect that the indoor air quality in Causeway Bay is worse than that in Sai Wan Ho. However, based on the data collected for this study, while the ambient $PM_{2.5}$ concentrations of Sai Wan Ho station are lower than the ambient $PM_{2.5}$ concentrations of Causeway Bay, the indoor PM2.5 concentrations of Sai Wan Ho station are observed to be higher than the ambient PM_{2.5} concentrations of Causeway Bay. The correlation coefficient obtained from this data set is as small as 0.016298478. This interesting result can be explained by the difference in ventilation systems, air conditioning systems, depths and designs of the two stations, train speed and frequency and other operational conditions. Since Causeway Bay is a more visited commercial area in Hong Kong, the MTR might installed a more effective ventilation mechanism to the station. Furthermore, Causeway Bay station has more exits than the Sai Wan Ho station, which might dilute the platform $PM_{2.5}$ concentrations. The small sample size can also contribute to this interesting result different from conclusions reached by previous studies with much larger sample sizes.()

In addition, in the three sampling days, ambient $PM_{2.5}$ concentrations seem to be higher than the PM2.5 concentrations in both Sai Wan Ho and Causeway Bay station, with the greatest difference as high as 41.49 µg/m³ observed in the third day of measurements in Causeway Bay station. The ambient PM2.5 concentrations in Causeway Bay are higher than the ambient PM2.5 concentrations in Sai Wan Ho in each sampling day, with an average differenceof 16.07 μ g/m³.⁴ The average difference between ambient PM_{2.5} concentrations and underground $PM_{2.5}$ concentrations is 7.34 μ g/m³

cabins are observed to be 2-4 μ g/m³ higher than PM_{2.5} in platforms depending on which station. Such consistent difference could be explained by the difference of air quality in underground platforms and tunnels.

- There are many possibilities that might caused the $PM_{2.5}$ concentration difference between platforms and tunnels. One of the most prominent accounts is the installation of PSDs, which interferes the natural air circulation generated by the piston effect in underground subway systems.
- There are discernible pulses in $PM_{2.5}$ concentration when the train doors open for passengers to board and get off the subway train. This phenomenon is more obvious near the train doors than in the middle of the cabin, which is closer to the tunnel air.
- \bullet PM_{2.5} concentrations are consistently higher near the train doors than in the middle of the cabins along the round trip between Sai Wan Ho and Causeway Bay. This higher concentration near train doors can also be explained by the closer distance to the tunnel air.
- In-train air quality deteriorate when the subway train travels from one station to the other and ameliorate when train cabins are reconnected to the platform air.
- $PM_{2.5}$ concentration significantly differs between MTR underground stations' air quality and ambient air quality. MTR successfully maintained a lower PM_{2.5} concentration in underground subway stations compared to the outdoor air.
- Ambient PM_{2.5} concentration near Causeway Bay are higher than the ambient PM_{2.5} concentrations near Sai Wan Ho, with a mean difference of 16.07 $\mu q/m^3$ in all sampling days.
- \bullet In this study, ambient PM_{2.5} concentration and indoor PM_{2.5} concentration show a poor correlation while previous studies suggest otherwise. This can be caused by the different ventilation system used in Sai Wan Ho and Causeway station, among other equally accountable operational differences between the two stations.

 While this study fell short of sample size due to the small time frame, the availability of resources and the small scope of the project, the methodology can be applied to subway network systems outside of Hong Kong to conduct simultaneous measurements in train cabins and platforms. Results drawn from this study can serve as a start point for researchers

7. References

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Appendix A - Logsheet A

Equipments Check: to be completed before and after measurement

DustTrak SN: 8530143810 . QTrack SN: 8530143810 . QTrack SN: 7575

Start Time (hh:mm:ss): . End Time (hh:mm:ss): .

date (dd/mm/yyyyy): . Researcher: . Researcher: . Researcher: . Researcher: . Researcher: . Researcher: . Rese
Experiments: . Researcher: . Researcher: . Researcher: . Researcher: . Researcher: . Researcher: . Researcher:

Appendix B - Logsheet B

Comparative measurement: Platform

Weather conditions: a. Temperature: ;

b. Humidity: ;

DustTrak SN: 8530133822 . QTrack SN: 7575X1343003 .

date (dd/mm/yyyyy): . Researcher: . Researcher: . Researcher: . Researcher: . Researcher: . Researcher: . Rese
Experiments: . Researcher: . Researcher: . Researcher: . Researcher: . Researcher: . Researcher: . Researcher:

2. First Station: Sai Wan Ho (round trip starts here)

Note: only take down train arrival and departure times when you are face to face with another researcher in train cabins.

Fig 1: In platforms

Fig 2: In trains

Platform and train spontaneous measurement: Train

Weather conditions: a. Temperature: ;

d: Sunny Cloudy Rainy (Circle one that applies).

date (dd/mm/yyyyy): . Researcher: . Rese

DustTrak SN: 8530143810 . QTrack SN: 8530143810 . QTrack SN: 7575

1. From UST to Tai Koo:

3. Travel from Sai Wan Ho to Tin Hau:

5. Travel from Causeway Bay to Sai Wan Ho (round trip completed)