PM10 and CO Exposure of Hong Kong Population in Public Transit Facilities

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Abstract: Taking public transit facilities (PTFs) is the major transport style in Hong Kong. Human exposure to indoor air pollutants may cause adverse health effects to the passengers. Exposure assessment on air pollutants is important for the control of human diseases caused by indoor air pollution. In this paper, the indoor PM10, CO and CO_2 levels in various PTFs, such as public bus, subway, railway and ferry in Hong Kong, were mea-sured. Combining with the time budget survey of Hong Kong population, the human exposures were calculated through Monte-Carlo simulation.

Keywords: public transit facilities(PTFs); indoor air quality; exposure; Monte-Carlo simulation
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* Hong Kong people take PTFs frequently in their daily lives. Although the current Hong Kong population is only near 7 000 000, the daily PTFs passengers exceed 10 000 000[1].

Nowadays, several types of PTFs, such as bus, MTR (mass transit railway), KCR (Kowloon-Canton railway), LRT (light railway transit), ferry, tram, etc., are running in Hong Kong. Most of them are air-conditioned for the comfort of the passengers in the subtropical weather in Hong Kong. Until recent years, except for tram, few ferry and bus running in suburban areas, most of PTFs are air-conditioned.

PTFs are enclosed environments with high intensity of passengers. Air-conditioning could improve the thermal comfort in the PTFs; however, the indoor air quality becomes a new problem. Passengers of PTFs consider not only the comfort, but also the indoor air pollution that may have adverse effect on their health. Current air-conditioning system emphasizes energy reserve. Since there is not enough fresh air to dilute the pollutant, accumulation of pollutant causes potential health risk to the passengers and PTFs staffs.

It is a common sense that air-conditioning systems in enclosed buildings without efficient ventilation cause sick building syndrome[2-6]. Air-conditioned PTFs are special kinds of indoor environments and different from common public buildings. Since then PTFs are considered as one of the major microenvironments[7,8] and drawn more and more concern[9-14].

The objectives of this paper are: 1) Analyzing the distribution of indoor air pollutant concentrations in various PTFs through site measurements; 2) Combining with the results of time budget survey[7], estimating the daily exposures of Hong Kong population in PTFs through Monte-Carlo simulation[9]. The results of this paper could be useful to estimate the health risk of Hong Kong people in the PTFs and provide reference for the government to make more effective policy to improve the indoor air quality in PTFs.

1 Methodology

The total human exposure was considered as an indicator to estimate the health effect of air quality[15]. US EPA proposed the concept of human exposure in 1980s[16-18]. It considered the pollutant concentrations in various environments and the time spent on the corresponding environment. Eq. (1) gives the way to calculate human exposure:

$$E_j = \sum_{i=1}^{n} \bar{c}_i t_{ij} \qquad (1)$$

where E_j is the total exposure of individual j; $\bar{c}_i$, the pollutant concentration in microenvironment i; t_{ij}, the time spent on microenvironment i; n, the total number of microenviron-

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ments.

In this paper, the time budget and daily activity patterns of Hong Kong population were obtained from in-house questionnaire surveys[7]. The pollutant concentrations were provided through site measurements. Then the total exposures of Hong Kong population in various PTFs were calculated.

There is always difference between sample and population. The mean of sample may not equal the mean of the whole population. Especially when the sample was limited, the error may be unacceptable. Since the data obtained from site measurements and surveys were limited,

simulation skills were used in this project. A statistical model was found to reduce the error caused by the limitation of the original data[19,20]. Monte-Carlo simulation was used to estimate the daily total human exposure of Hong Kong population in various PTFs.

Four types of air-conditioned PTFs: public bus, MTR, KCR and LRT and ferry, were chosen to do the site measurements. The basic information of various PTFs currently used in Hong Kong was shown in Tab. 1. Eight urban and suburban bus routes, all MTR, KCR and LRT lines, and three air-conditioned ferry lines were chosen to do the site measurements. Various indoor air pollution measurements were taken 91, 15, 15 and 24 times in public bus, MTR, KCR and LRT, ferry respectively. The ave-rage measuring time was from 0.2 h to 1.5 h for each journey.

Tab. 1 Brief introduction to the PTFs in Hong Kong[1]

Road transport	Registered vehicles	Average daily passengers	Notes
Franchised buses	6 178	3 971 000	Five franchised bus companies
Public light buses	4 341	1 751 000	Green minibuses: 306 routes Red minibuses: No fixed routes
Taxis	18 026	1 311 000	Three types: Urban, new territories and Lantau Island
Rail transport	**Length/km**	**Average daily passengers**	**Notes**
Mass transit railway	77	2 196 000	Tsuen Wan, Kwun Tong, Island, Tung Chung lines and airport express
Kowloon-Canton railway	34	737 000	New towns in the north-eastern new territories
Light rail transit	32	361 000	North-western new territories
Trams	16	237 000	Hong Kong Island
Harbour transport	**Vehicles**	**Average daily passengers**	**Notes**
Ferries	64	158 000	14 ferry operators provide 32 regular rates to outlying islands, southwest new territories and across the harbour

Air pollutants that may affect the indoor air quality include respirable suspended particulate (PM10), carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO_2), volatile organic compounds (VOCs), microbe etc[9]. The major sources of PM10 and CO are industries and city traffics. Although CO_2 is not a poisonous gas, contacting with high concentration CO_2 for a long time may cause discomfort. Indoor CO_2 concentration is related to occupant density and ventilation efficiency and considered as one of the indicators for estimating the indoor air quality[21].

In this project, a PM7400 (MetroSonic, U.S.) portable gas monitor was used to monitor the CO concentration; a Dust-Trak 8520 (TSI, U.S.) particulate monitor, to measure PM10 concentration; a Q-trak (TSI, U.S.), to take CO_2 levels. All the equipment was calibrated for quality assurance according to the requests of the manufacturer before measurements.

2 Results and discussions

The number of daily PTFs passengers was shown in Tab. 1. It was found that the bus, which took about 40% of the total daily PTFs passengers, was the most frequently used PTFs by Hong Kong population. The MTR was the second frequently used PTFs, which took about 22% of the total daily PTFs passengers. The descriptive statistics of average daily time spent on various PTFs were shown in Tab. 2. It was found that Hong Kong people spent over 80 min on PTFs during their daily lives.

Tab. 3 showed the result of the site measurements. Compared with the current indoor air quality guideline[22] enforced in Hong Kong, the average concentrations of PM10, CO and CO_2 were all within the acceptable level. Only when bus was running in the cross-harbour tunnel or in serious city traffics, PM10 and CO concentrations may exceed the standard.

Tab. 2 Average daily time spent on various PTFs of Hong Kong population

PTFs	Samples	Time spent on PTFs/min	
		Mean	Std. Dev.
Bus	396	45.6	56.11
MTR	396	27.6	35.39
KCR and LRT	396	8.1	21.00
Ferry	396	1.1	8.21

Tab. 3 Air pollutant concentrations in various PTFs

PTFs	Samples	PM10 concentration/ ($\mu g \cdot m^{-3}$)	
		Mean	Std. Dev.
Bus	91	124.6	87.88
MTR	15	78.0	29.78
KCR and LRT	15	58.6	14.15
Ferry	24	57.7	24.81
PTFs	Samples	CO concentration/ ($\mu g \cdot m^{-3}$)	
		Mean	Std. Dev.
Bus	91	3 011.6	1620.4
MTR	15	1 462.9	765.7
KCR and LRT	15	1 226.7	578.7
Ferry	24	2 347.6	1 902.8
PTFs	Samples	CO_2 concentration/ 10^{-6}	
		Mean	Std. Dev.
Bus	91	1 663.4	1 133.70
MTR	15	898.6	268.16
KCR and LRT	15	692.7	175.41
Ferry	24	1 817.1	1 468.08

From Tab. 3, it was found that the indoor PM10 concentration in bus was the highest among the four types of PTFs. The PM10 concentration in the MTR was the second highest. Although Hong Kong government had made strict policy to restrict the pollutant exhausting level, exhaust gas of different vehicles affected the air quality of the surrounding environment. Until the end of 2000, over 500 000 vehicles registered and about 268 vehicles were running in one kilometer of road in Hong Kong[1]. Indoor air quality of urban bus and MTR was influenced directly by the city traffic. Air pollution caused by traffic had little effects on KCR, LRT and ferry, for they ran in the suburban area or on the sea.

Bus also had the highest indoor CO concentrations, while ferry and MTR were in the second and third position respectively. Ferry had a high people density and almost kept closed during the whole trip. Although the ambient air might be cleaner, insufficient ventilation led to the pollutant accumulations. The highest CO_2 concentration also proved the lower ventilation efficiency of the ferry. KCR and LRT had relatively lower indoor PM10 and CO concentrations.

Large-scale measurements or surveys were always restricted by funds and human resources. Monte-Carlo simulation was used to calculate the exposures of passengers in various PTFs. A statistical model was found based on the site measurements in PTFs and the questionnaire surveys of Hong Kong population. The data of pollutant concentrations and time were processed to fit the model. Then random variables were drawn from the statistical model for simulated calculation of exposures.

The pollutant concentrations in PTFs and the time passengers spent on PTFs were independent and obtained from the site measurements and the questionnaire survey. The probability frequency distribution of the pollutant concentration and time were fit for a Gamma distribution. Then the frequency distribution histograms and fitted Gamma curve of pollutant concentrations were plotted. Since the time distributions in various PTFs consisted of two parts: one for everyday commuters, the other for non-commuters. For example, some people that participated in the time budget survey took bus everyday and the time distribution histograms could be fitted to a Gamma curve; other people did not take bus and the time distribution histogram was a high column at zero. Therefore, the time frequency distribution was a mixed distribution. The Gamma PDF (probability density function) could be expressed as

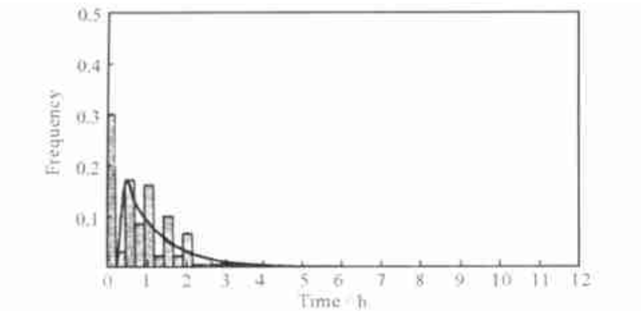
$$f(x, r, \lambda) = \frac{1}{\lambda \Gamma(r)} x^{r-1} e^{-x/\lambda} \tag{2}$$

where r and λ are the shape and scalar value of the fitted Gamma curve. Matlab statistical toolbox was used to calculate the shape and scalar value of the corresponding Gamma curve. Tab. 4 showed r and λ of twelve fitted Gamma curves.

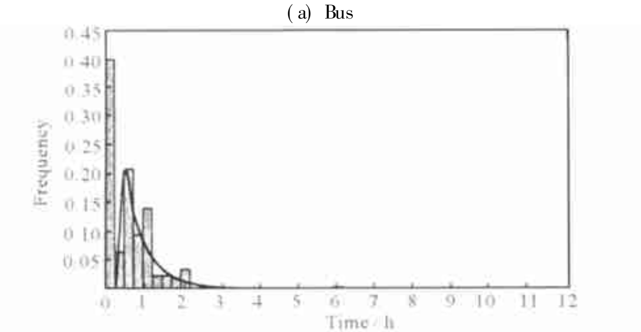
Tab. 4 Shape and scalar of the fitted Gamma curve

PTFs	PM10		CO		Time	
	r	λ	r	λ	r	λ
Bus	2.27	54.80	4.20	733.40	2.14	0.51
MTR	8.17	9.55	4.75	308.12	2.18	0.35
KCR and LRT	19.53	3.00	4.47	274.34	2.03	0.32
Ferry	4.31	13.40	2.88	816.13	2.60	0.24

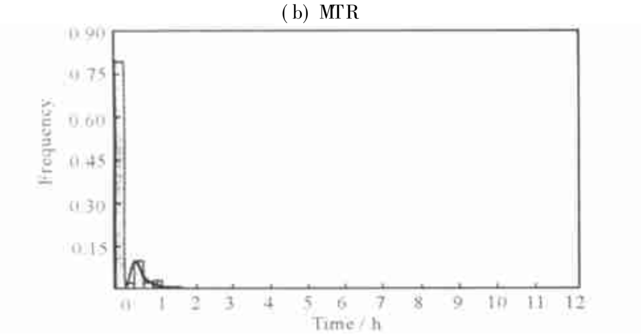
Fig. 1 showed the histograms and fitted mixed Gamma curve of daily time spent on PTFs. Fig. 2 and Fig. 3 showed the histograms and fitted Gamma curve of PM10 and CO concentrations in different PTFs.



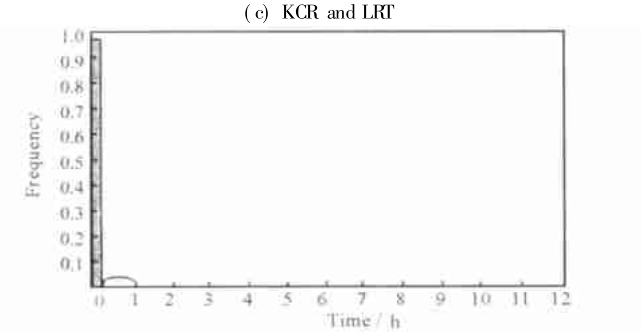
(a) Bus



(b) MTR

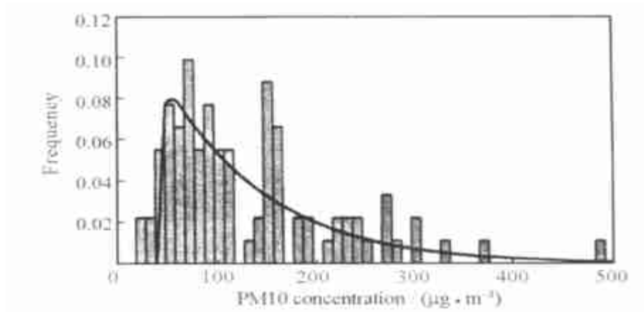


(c) KCR and LRT

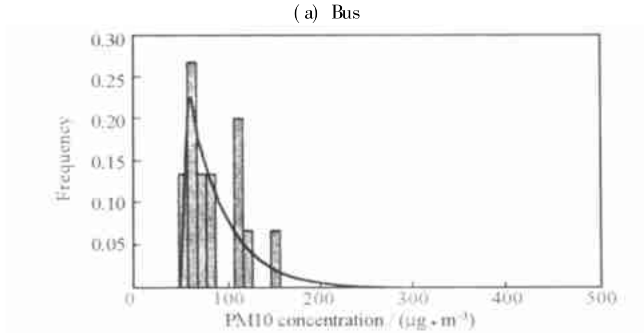


(d) Ferry

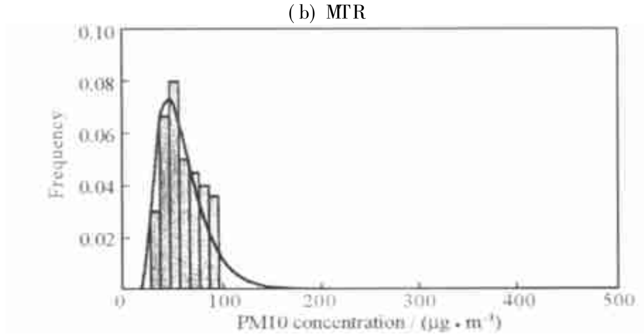
Fig. 1 Histograms of time spent on PTFs and fitted Gamma curves



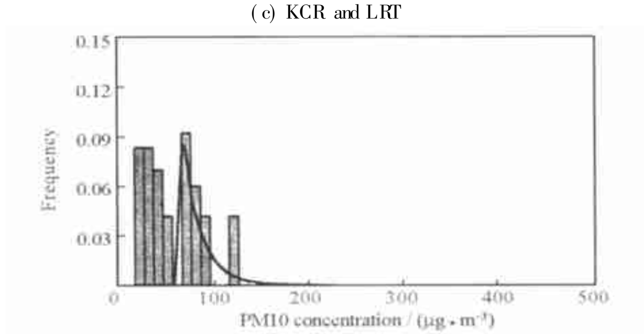
(a) Bus



(b) MTR



(c) KCR and LRT

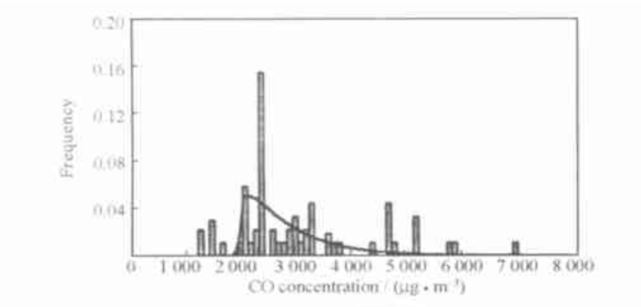


(d) Ferry

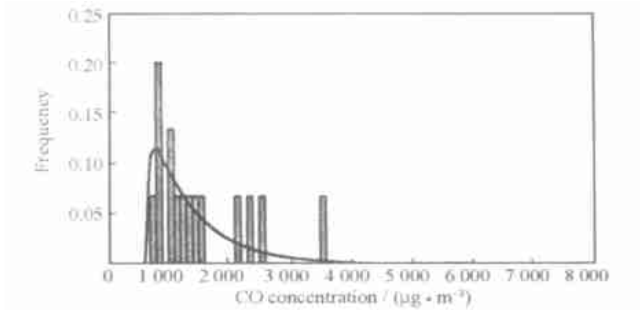
Fig. 2 Histograms of PM10 concentrations in PTFs and fitted Gamma curves

Tab. 5 Daily exposure in different PTFs and total exposure in PTFs through Monte-Carlo simulation

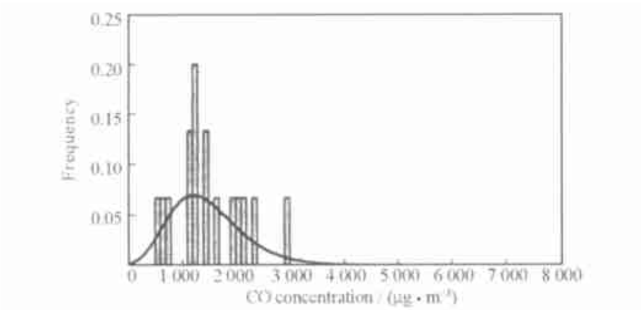
Exposure		Bus	MTR	KCR and LRT	Ferry	Total
PM10 exposure/ ($\mu g \cdot m^{-3} \cdot h$)	Mean	102. 7	35. 3	7. 6	1. 1	146. 7
	Percentage/ %	70. 0	24. 1	5. 2	0. 7	100. 0
	95th quantile	417. 7	140. 0	48. 5	0. 0	475. 3
CO exposure/ ($\mu g \cdot m^{-3} \cdot h$)	Mean	2 672. 6	649. 7	146. 5	39. 8	3 508. 6
	Percentage/ %	76. 2	18. 5	4. 2	1. 1	100. 0
	95th quantile	9 525. 7	2 842. 5	898. 0	0. 0	11 227. 8



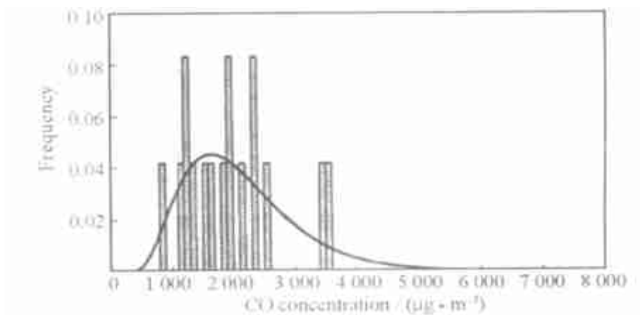
(a) Bus



(b) MTR



(c) KCR and LRT



(d) Ferry

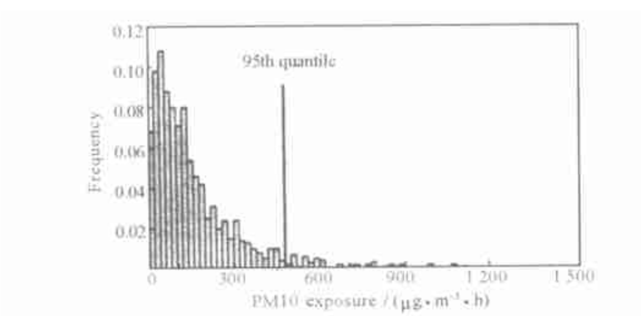
Fig. 3 Histograms of CO concentrations in PTFs and fitted Gamma curves

The human exposure in various PTFs could be calculated by

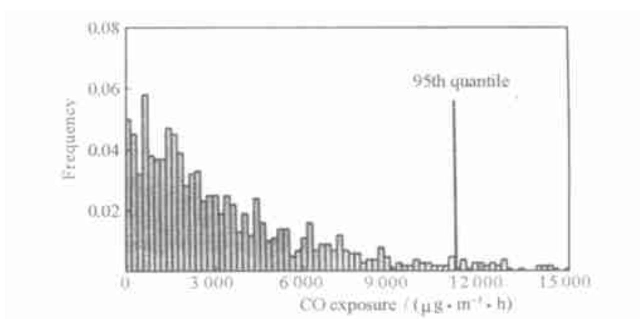
$$\tilde{E}_i = \sum_{j=1}^{p} \tilde{c}_{ij} \tilde{t}_{ij} \tag{3}$$

where $\tilde{c}_{ij}$ is a random variable drawn from the corresponding Gamma PDF of the air pollutant concentration distribution in the jth PTFs; $\tilde{t}_{ij}$, another random variable drawn from the corresponding cumulative density function (CDF) of the mixed distribution of time spent on the jth PTFs; p, the number of the random draw.

The random draw was duplicated for 1 000 times, the PM10 and CO exposures in different PTFs were calculated according to Eq. (3). Using Eq. (1), the daily PM10 and CO exposures in PTFs were obtained. The results of Monte-Carlo simulation of PM10 and CO daily exposures in different PTFs and total exposure in all PTFs were shown in Tab. 6. Fig. 4 showed the daily PM10 and CO exposure of PTFs passengers by Monte-Carlo simulation. The straight line in the figure meant the 95th quantile of the total daily PM10 or CO exposure.



(a) Histogram of PM10 exposure in PTFs



(b) Histogram of CO exposure in PTFs

Fig. 4 Daily exposure histograms of PTFs passengers through Monte-Carlo simulation

Bus and MTR had more passengers and passengers spent more time on them. From Tab. 5, it was found that bus accounted for about 70.0% of daily PM10 exposure, while MTR accounted for about 24.1%. The summary of PM10 exposure in these two PTFs is over 94% of daily PM10 exposure in PTFs. The indoor PM10 level in KCR and LRT was relatively lower than that in the other PTFs. Ferry had the least passengers everyday. Their PM10 exposure added up to less than 6%

of daily PM10 exposure in PTFs. The average daily PM10 exposure was about 146.7 μg·m^{-3}·h. The 95th quantile of daily PM10 exposure, which meant the 950th largest value of all the 1 000 exposure values obtained from Monte-Carlo simulation, was 475.3 μg·m^{-3}·h.

The passengers in bus also had the highest daily CO exposure among four types of PTFs. The CO exposure in bus accounted for 76.2% of daily CO exposure; the MTR accounted for about 18.5%. Although the CO concentration was the second highest in ferry, the average time that passengers spent on it was much less. Ferry, KCR and LRT only accounted for less than 6% of daily CO exposure. The average daily CO exposure of passengers in PTFs was about 3 508.6 μg·m^{-3}·h. The 95th quantile value was 11 227.8 μg·m^{-3}·h.

3 Conclusions

In general, the current indoor air quality was acceptable in the PTFs of Hong Kong. Only short-term pollutant concentrations occasionally exceeded the indoor air quality standard when the vehicles were running in the cross-harbour tunnel or in the rush hours of city traffic. The indoor air quality problem in public bus was even serious comparing with KCR and LRT, and required more concern.

Public bus was the first contributor to the daily PM10 and CO exposure. The indoor pollutant concentrations in bus were higher than those in the other PTFs. Hong Kong people also spent more time on bus. The PM10 and CO exposures in bus accounted for 70.0% and 76.2% of daily exposure in PTFs respectively. The PM10 and CO exposures in MTR were the second contributor to the daily exposure in PTFs. The PM10 and CO exposures in bus and MTR added up to over 94% of the daily total exposure in PTFs. Although the daily time spent on PTFs was much shorter than that on other indoor environments, the exposure in PTFs was a major part of the total daily exposure. The improvement of indoor air quality in PTFs, especially in bus and MTR, may do great benefit to reduce the health risk to the passengers and staffs of PTFs.

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