Appendix O

Effect of the Green Deck on Local Air Quality

(Final Report)

By Prof. Frank S.C. Lee

Research Centre of Urban Environmental Technology and Management

Department of Civil and Environmental Engineering

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Prof. Lee shun-cheng

Hong Kong roadside air pollution is a very severe problem, which affect human health. Especially the people have long term activities along the roadside. The bus-waiting people and many students and staffs of the Hong Kong Polytechnic University have to be exposed the roadside pollution because they need to walk through a crowded pedestrian bridge. The results show the gaseous pollutant, hourly average nitrogen dioxide (NO_2) concentration have ~10% of the total period of sampling time exceed the proposed new local 1-hour NO_2 standard (200 $\mu g/m^3$) but compare the Japan average daily NO_2 standard, none of the day have meet the lower standard limit-excellent level (40 $\mu g/m^3$). The measured NO_2 concentration has ~20% to 90% higher than the defined standard value. From the particulate matters (PM), Hong Kong Air Quality Objective (HKAQO) proposed 100 and 75 $\mu g/m^3$ as PM_{10} and $PM_{2.5}$ 24-hr average standard and seldom days have been reported exceed the local standard. But the average roadside PM_{10} and $PM_{2.5}$ concentration level in Hong Kong is ~50% to 68% higher than World Health Organization Air Quality Guideline (WHO AQG) (daily average: 50 and 25$\mu g/m^3$).

PM_{10} concentration has reduced around 48% and 38% in green deck situation than the value measured with non-green deck situation in morning and evening peak hour. The carcinogenic compounds, which including benzene, formaldehyde and acetaldehyde, have 10% to 60% improvement with green deck situation. Based on the estimation, the improvement of particulate matters and carcinogenic compounds is over 30% to 60%.

The cancer risk calculation was conducted to evaluate the chronic health impact for buses-waiting people, HK PolyU staff and PolyU student. The results shows that bus-waiting people and the PolyU staff has much higher cancer risk than PolyU students, because of long exposure time. The cancer risks of benzene and acetaldehyde were within an acceptable level, except for formaldehyde. It is indicated that cancer risk from formaldehyde was larger than the cancer risk from benzene and acetaldehyde in the Hong Kong roadside. In addition, cancer risk of bus-waiting people and PolyU staff is higher than U.S. EPA acceptable level with two scenarios (green deck and non-green deck scenarios). But the cancer risk with green deck situation has 30% to 70% reduction. After green deck being built, the cancer risk will be decrease over 50%.

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1. Introduction

Air pollution at roadside is very serious in Hong Kong. Many studies have demonstrated that vehicular emission is one of the major sources of air pollutants, such as fine particulate matters ($PM_{2.5}$), Volatile Organic Compounds (VOCs), Oxygenated Volatile Organic Compounds (OVOCs) and Nitrogen Oxidize (NO_x). The high pollutant levels at roadside draw much public attention. Recently, The International Agency for Research on Cancer, (IARC) has defined $PM_{2.5}$ as a carcinogenic pollutant, as $PM_{2.5}$ contains many kinds of chemical species cause severe impact to human health. In addition, the many carbonyls pollutants are also seriously effect on human health, since it contains many carcinogenic chemicals. The heavy traffic flow in Hung Hom Cross harbor tunnel contributes large amount of pollutants and affect the people nearby. During the morning and afternoon peak hours, many PolyU students, staffs and passengers have to take much longer time to walk through the congested footbridge and hence prolong the exposure time to air pollutants. Green deck project is proposed by PolyU to build a green deck to decrease the human exposure to the air pollutants from traffic as well as to alleviate air pollution at roadside by using new material with NO_x removal ability for building green deck. Understanding on the chemical speciation and levels of pollutants are very important for the Green deck project. From previous study, we found that the annual roadside $PM_{2.5}$ value is around 19% higher than the proposed Hong Kong $PM_{2.5}$ standard and ~75% higher than the National Ambient Air Quality Standards (NAAQS) $PM_{2.5}$ standard. In this study, a monitoring program will be conducted to investigate the concentrations and chemical speciation of different pollutants (VOCs, NO_x, PM and carbonyls) near the cross harbour tunnel.

2. Site description

2.1 Roadside monitoring station

The roadside monitoring station has established by the Hong Kong Polytechnic University (HKPU) and the site is between P core and Q core ground. It is located in a street canyon in a residential and commercial area, facing Hong Chong road, leading to the busiest cross-harbour tunnel in Hong Kong. The station is about 400 m away from the tunnel entrance. Besides restaurant/household cooking, industrial or other anthropogenic sources were not found in the vicinity (photo 2.1.1). This monitoring station was used to simulate non-green deck situation.

Photo 2.1.1 the location of the roadside monitoring station

2.2 PQ podium

The site is located in HKPU campus (P core and Q core podium). Photo 2.2.1 shows the location of PQ podium monitoring site. It is a temporary site we choose for estimating the effect of green deck on air quality. The green deck will be built in the same floor of PQ podium and facing the Hong Chong road. The PQ podium is a better place for air quality effect for roadside monitoring station and green deck. The location was used to simulate green deck scenario.

Photo 2.2.1 surrounded view for PQ podium

3. Methodology

3.1 Instruments introduction

Particulate matters-The PM_{10}, and $PM_{2.5}$ real-time monitoring were collected (KIMOTO) with one hour per data.

Gases-CO, NO_x, NO_2 gas analyzer will be operated (TSI and Thermo) with 1 min per data.

Followed are the pictures shows that instrument used for sample collection.

OVOCs sampler

CO analyzer

NO_x analyzer

VOCs samplers

Kimoto real time monitoring analyzer

3.2 Carcinogenic compounds analysis

Volatile organic compounds (VOCs)

Andersen Instruments Inc. Series 97-300, Ambient Volatile Organic Canister Sampler (AVOCS) will be used to collected whole air samples into pre-cleaned and pre-evacuated 2-liter SUMMA stainless steel canisters at uniform flow-rates. Sampling and analysis of the samples, e.g. GC-MSD/FID/ECD analysis, will be conducted in accordance with the USEPA Method TO-14 (USEPA, 1997) with slight modifications.

Oxygenated Volatile Organic Compounds (OVOCs)

OVOCs in air will be collected by drawing air through a cartridge impregnated with acidified 2,4-dinitrophenylhydrazine (Waters Sep-Pak DNPH-silica), which was very reactive toward carbonyls. Ozone scrubber was connected before DNPH-silica cartridge in order to prevent the interference of ozone. The sampled cartridges were plugged at both ends and placed inside of glass screw-capped vials. They were further placed into a tin can for protection during shipment and storage. The exposed cartridges were stored inside a refrigerator and returned to the Air laboratory in a cooler chilled with blue ice. The cartridges were then analyzed by extraction and HPLC according to the U.S. EPA TO-11A method. Analysis was done by the laboratory of The Hong Kong University of Science and Technology.

3.3 cancer risk calculation

The risk assessment was conducted for the PolyU students, staffs and the people waiting for the buses by followed equation:

Risk=CDI×PF, where CDI is Chronic Daily Intake, which is calculated via intake rate, exposure time, and human weight. PF is potency factor which could be investigated from US Environmental Protection Agency (EPA) standard.

If the value larger than 1×10^{-6}, means people surrounded suffer the health risk.

4. Result and discussion

4.1 Real-time monitoring on gaseous and particulate matters

4.1.1 Nitrogen Dioxide (NO_2) and Carbon Monoxide (CO)

Nitrogen Dioxide (NO_2) is the reddish-brown toxic gas, which has been defined as one of the important pollutant in the worldwide countries. The emission standard of NO_2 was differently implicated based on their situation. Some countries only have 1-hour NO_2 standard and some countries has 1-hour and 24-hour standards to stringent the NO_2 emission. The 1-hour NO_2 standard of World Health Organization Air Quality Guideline (WHO AQG) and Hong Kong Air Quality Objectives (HK AQO) was 200 μg/m^3. No 24-hour NO_2 standard has been proposed in WHO and HK. But Japan has implement 24-hour NO_2 standard for many years, which is 40 ppb (excellent level) and 60 ppb (satisfactory level). The comparison between NO_2 standard and roadside

NO_2 value was conducted. From the Figure 4-1-1 and Figure 4-1-2, ~around 1/10 sampling hours of NO_2 value exceed the defined 1-hour NO_2 value of World Health Organization Air Quality Guidelines (WHO AQG) and new HK Air quality objectives (HK AQO). In addition, the NO_2 value was 20% to 90% higher than 200 μg/m^3 (1-hour NO_2 value defined by WHO and HK air quality objective). Base on the Japan 24-hour NO_2 standard, only 11 days out of 49 days meet the standard (60 ppb-satisfactory level). None has met the 40 ppb (excellent standard). The measured 24-hour NO_2 value has one to two times higher than the standard.

The mean NO_2 concentration during the two months measurement is 135.88 μg/m^3, with high standard deviation from 365.92 to 17.89 μg/m^3 (Table 4-1-1). The main NO_2 emission source can directly come from traffic and secondary emission from photochemical reaction of other gaseous in the site. Two traffic peaks have been found in daily variation. The morning peak at 9:00 a.m. and after noon peak were extend longer time, because of photo-chemical reaction.

Table 4-1-1 The variation on NO_2 concentration

(μg/m^3)	NO_2
Average	135.88
S.D.	49.13
Day and night peak hours[a]	167.03
Normal time[b]	125.4
Sampling hour on NO_2	1133 (hours)
>200 μg/m^3 (1-hour Hong Kong air quality objective)	110 (hours)[c]

[a]: the hourly average NO_2 concentration in day and night peak hours

[b]: the hourly average NO_2 concentration without NO_2 concentration in day and night peak hours

[c]: 110 hours of NO_2 concentration are higher than the 1-hour NO_2 standard from Hong Kong Air Quality Objective (HKAQO)

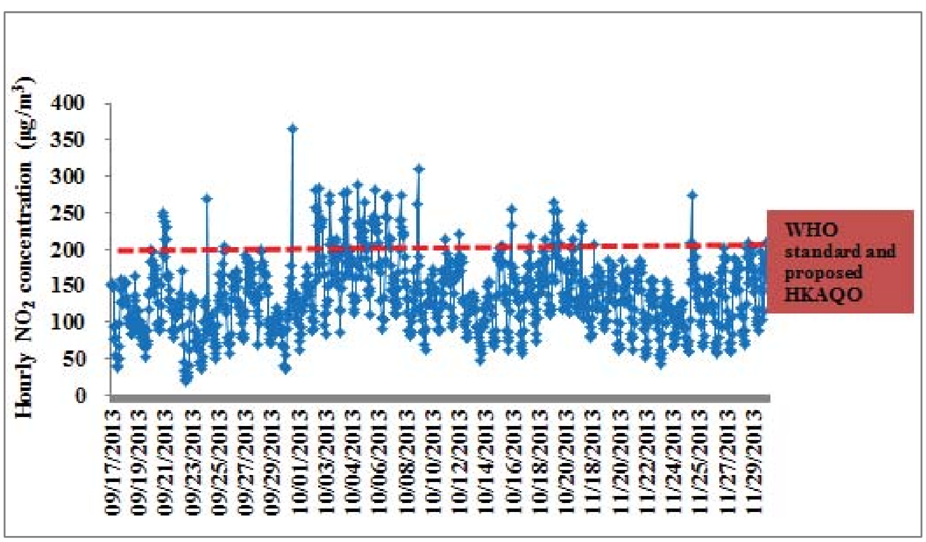

Figure 4-1-1 hourly variation on NO_2 concentration

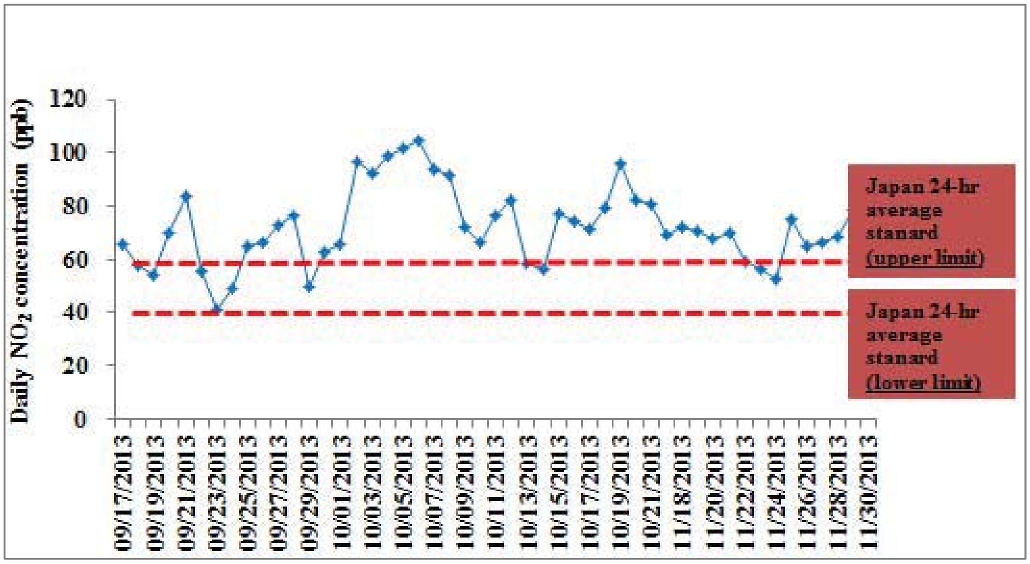

Figure 4-1-2 daily variation on NO_2 concentration

Similar as NO_2, Carbon Monoxide (CO) is the other toxic gaseous which has been defined air pollutant in worldwide countries many years ago. But the health acceptable level of CO is very high and the effect in Hong Kong roadside is very small. No sampling time exceed the Hong Kong and WHO standard (1-hour average is 30000 μg/m^3). Figure 4-1-3 shows the time series of the CO during the sampling period, the highest CO concentration is 5000 μg/m^3.

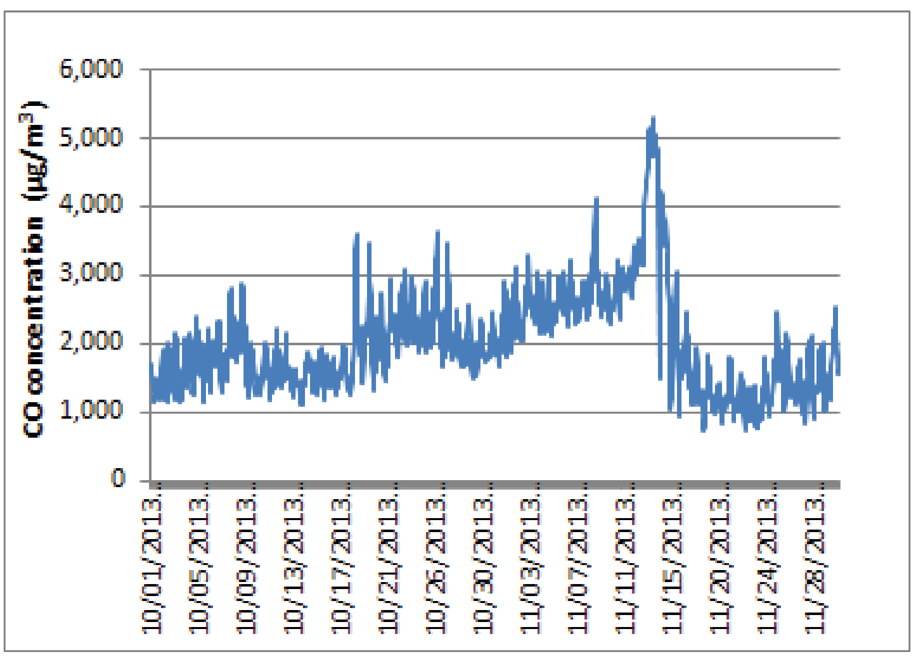

Figure 4-1-3 hourly variation on CO concentration

4.1.2 Particulate matters (PM)

From the definition of US Environmental Protection Agency, PM_{10} is defined as particle whose diameter is less than 10 µm and $PM_{2.5}$ is defined as the particle whose diameter is less than 2.5µm. because of the small size and varied chemical components, it can be inhaled into lung and cause server health problem.

The current Hong Kong air quality objective (HKAQO) doesn't have any standard on 24-hour $PM_{2.5}$ value. But the Hong Kong government has proposed a new HKAQO, which has daily $PM_{2.5}$ standard (24-hour average) and adjust the standard concentration in other pollutants. Base on the Hong Kong proposed AQO, PM concentration in roadside monitoring station is not serious. For PM_{10}, only 3 days exceed the new HKAQO and no day reported exceed the new $PM_{2.5}$ HKAQO. But use World Health Organization air quality guideline (WHO AQG) for the reference. Only one to two days not exceed the WHO standard. The average value for $PM_{2.5}$ and PM_{10} is 42.81±11.02 and 73.67±18.65 µg/m^3, which is ~68% to 50% higher than the WHO value (25 µg/m^3 and 50 µg/m^3). Although the hourly concentration for $PM_{2.5}$ and PM_{10} do not have much time exceed the HKAQO, comparing worldwide level, PM concentration still needs to be concerned.

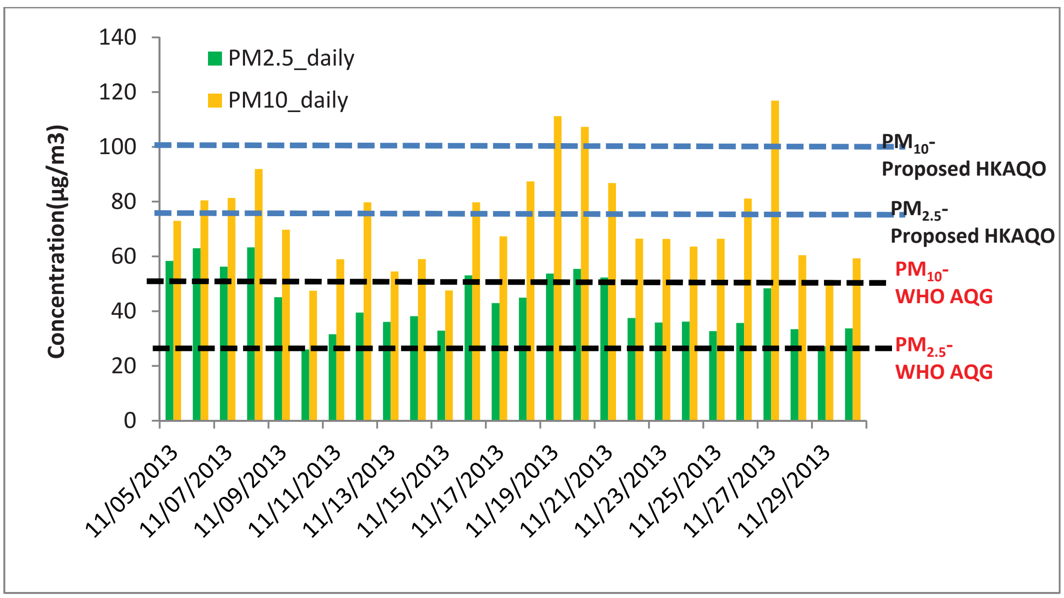

Figure 4-1-4 daily variation on PM_{10} and $PM_{2.5}$

4.2 Effect of green deck on local air quality

4.2.1 Particulate Matters

Figure 4-2-1 shows the comparison of PM_{10} concentrations at non-green deck situation and green deck situation during morning peak hours. The PM_{10} concentrations with green deck ranged from 40.0 to 102.8 µg/m^3 with the mean value of 57.7 µg/m^3, while the mean concentration of PM_{10} was 29.9 µg/m^3 with non-green deck. It was found that there was a significant decline of PM_{10} concentrations with green deck situation compared to the values with non-green deck. The mean reduction rate of PM_{10} concentrations with green deck situation was around 48.2% during morning peak hours. The comparison of PM_{10} concentrations during evening peak hours gives the similar result (Figure 4-2-2). The mean concentration of PM_{10} was 70.5 which was ~38.3% lower than that with non-green deck situation during evening peak hours.

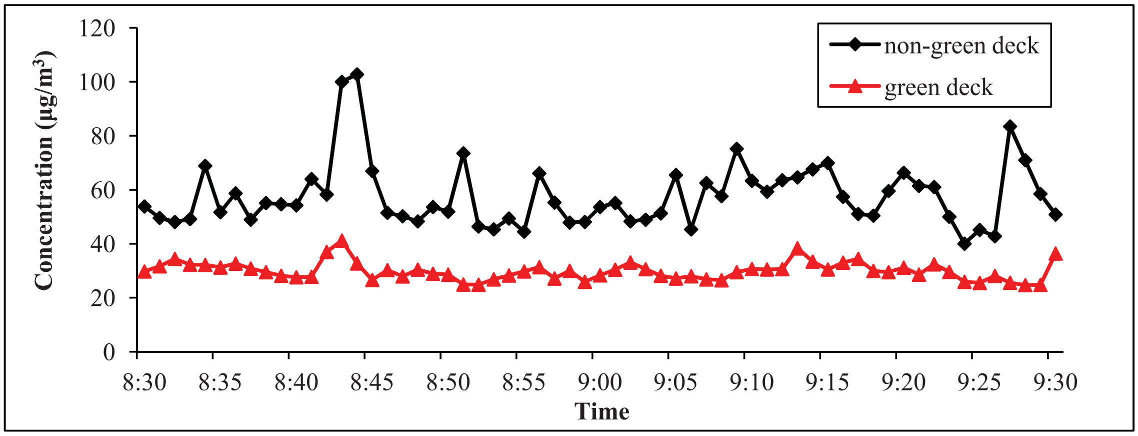

Figure 4-2-1 Comparison of PM_{10} concentrations with non-green deck and green deck situation during morning peak hours

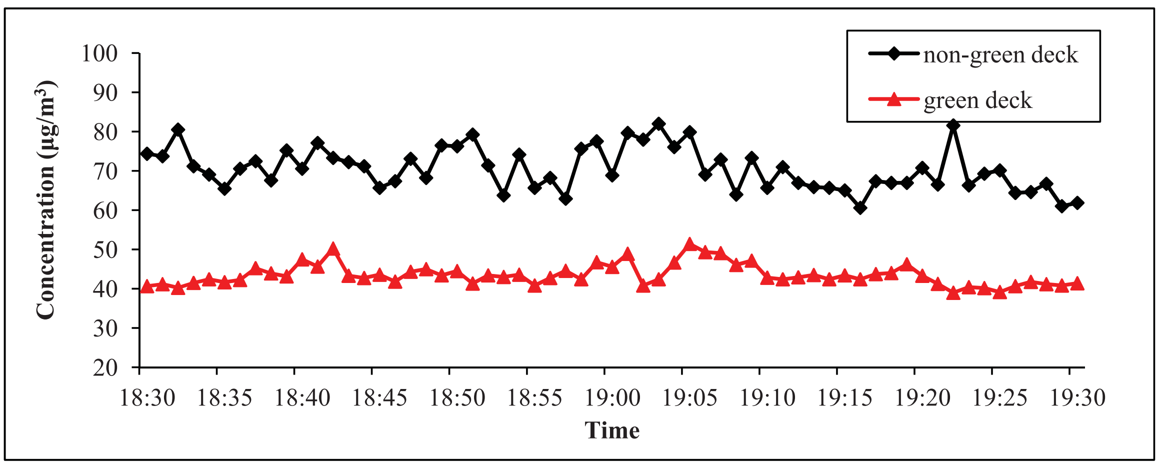

Figure 4-2-2 Comparison of PM_{10} concentrations with non-green deck and green deck situation during evening peak hours

4.2.2 Carcinogenic compounds

The Volatile Organic Compounds (VOCs) and Oxygenated Volatile Organic Compounds (OVOCs) were measured. From definition of different countries, e.g. U.S., Canada, European Union, Volatile Organic Compounds (VOCs) are organic chemicals which have low boiling point and high vapor pressure, which evaporates from natural sources and anthropogenic sources, e.g. painting and coating. VOCs including many different species, Oxygenated Volatile Organic Compounds (OVOCs) are the product of VOCs via photochemical reaction. The chemical characteristics of some VOCs and OVOCs are dangerous to human health and have cancer risk, which was called by carcinogenic pollutants, e.g. benzene, formaldehyde, acetaldehyde. Formaldehyde is the one of the important carcinogenic pollutants defined by the U.S. Environmental Protection Agency (EPA), the guideline of many U.S. states for ambient formaldehyde concentration should be lower than 3-30 μg/m^3 (U.S.EPA), based on the acute or chronic exposure. U.S. Occupational Safety & Health Administration (OSHA) have defined that chronic formaldehyde intake rate should be lower than 0.2 mg/kg/day, the PolyU roadside level have almost reached this health guideline (US EPA).

Table 4-2-1 shows the concentrations of main carcinogenic compounds measured with non-green deck and green deck situation during morning and evening peak hours. It can be seen in Table 4-2-1 that the benzene, formaldehyde and acetaldehyde concentrations with green deck situation were 0.97, 7.57 and 3.18 μg/m^3, respectively, which were much lower than that with non-green deck situation where the values were1.45, 9.10 and 4.48 μg/m^3 during morning peak hours. As shown in Figure 4-2-3 and Figure 4-2-4, the concentrations of carcinogenic compounds determined were decreased with green deck situation in both morning and evening peak hours. The reduction rates of concentrations for benzene, formaldehyde, and acetaldehyde were 33%, 16.8%, and 29.0% during morning peak hours and 33%, 11.0% and 27% during evening peak hours.

Table 4-2-1 Comparison of concentrations of carcinogenic compounds at Roadside station and PQ Podium during morning and evening peak hours (μg/m^3)

	Morning peak hours			**Evening peak hours**		
Sampling site	**Non-green deck**	**Green deck**	**Improvement**	**Non-green deck**	**Green deck**	**Improvement**
Benzene	1.45	0.97	33%	1.65	1.11	33%
Formaldehyde	9.10	7.57	17%	9.17	8.17	11%
Acetaldehyde	4.48	3.18	29%	3.85	2.82	27%

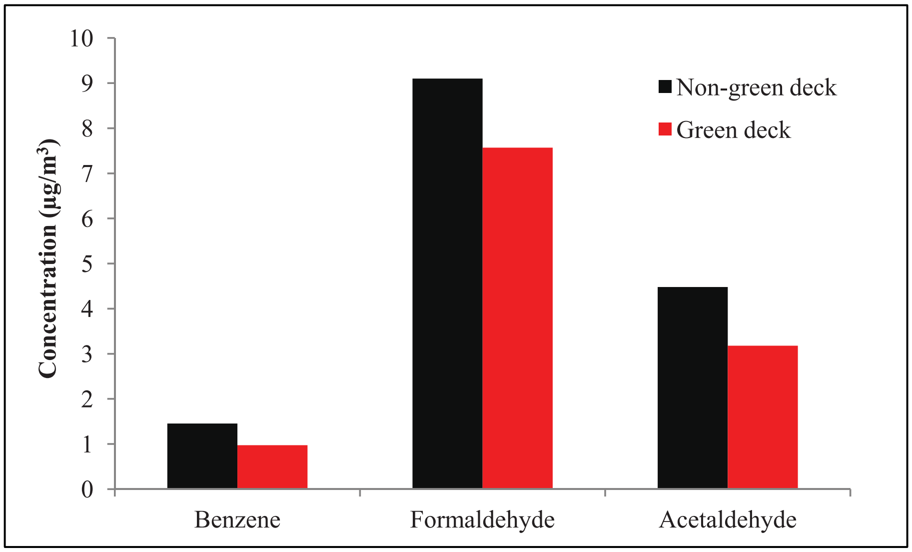

Figure 4-2-3 Comparison of concentrations of carcinogenic compounds with non-green deck and green deck situation during morning peak hours

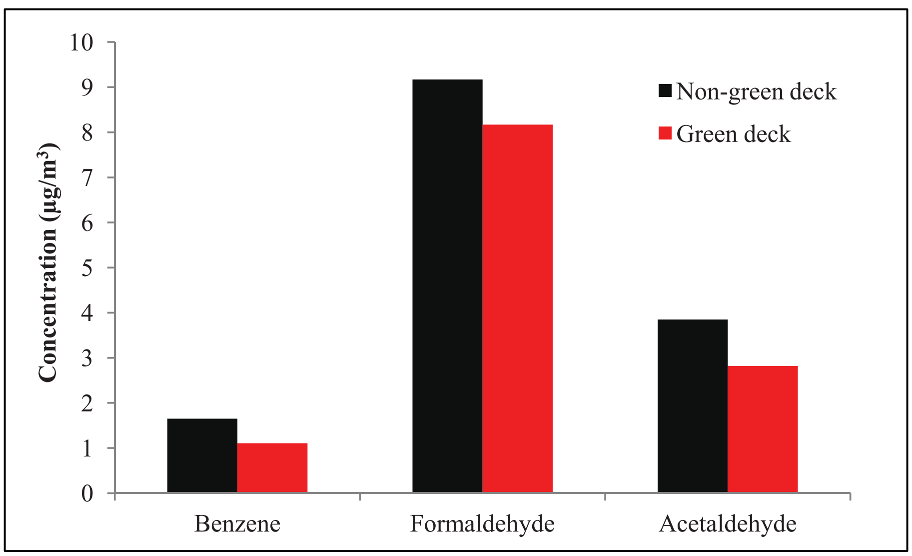

Figure 4-2-4 Comparison of concentrations of carcinogenic compounds with non-green deck and green deck situation during evening peak hours

4.3 Cancer risk calculation of carcinogenic compounds in green deck and non-green deck scenario

From the toxicological point of view, benzene exhibits cancer risk and can cause aplastic anemia and polycythemia. According to the U.S. EPA's weight-of-evidence classification system for carcinogenicity, benzene, formaldehyde and acetaldehyde is designated as human carcinogen (Group A) with sufficient evidence of carcinogenicity in humans.

Cancer risk is calculated based on the following:

Cancer risk = CDI × CPF

where CDI is the chronic daily intake (mg/kg/day) and CPF is the carcinogen potency factor. Cancer risk > 1.00E-6 means Carcinogenic effects of concern

Cancer risk < 1.00E-6 means Acceptable level

The following generic equation is used to calculate the chronic daily intake (CDI):

$$CDI = \frac{\text{Concentration (mg/m}^3\text{)} \times \text{Intake rate (m}^3\text{/day)} \times \text{Exposure (days/life)}}{\text{Body weight (kg)} \times 70\text{(yr/life)} \times 365\text{(day/yr)}}$$

where the average body weight and the intake rate for adults are 70 kg and 20 m^3/day as the US EPA recommends. The exposure duration is $(0.5\ \mathrm{hr/day} \times 260\mathrm{day/yr} \times 40\mathrm{yr/life})/(24\mathrm{hr/day}) = 216.7\mathrm{days/life}$ for bus-waiting people and PolyU staff; $(0.5\ \mathrm{hr/day} \times 260\mathrm{day/yr} \times 4\ \mathrm{yr/life})/(24\mathrm{hr/day}) = 21.7\mathrm{days/life}$ for PolyU students.

According to U.S. EPA Integrated Risk Information System (IRIS), the CPF for formaldehyde, acetaldehyde and benzene is 0.0455, 0.0077 and 0.0273 $(\mathrm{mg/kg/day})^{-1}$, respectively.

Based on the above equations, the cancer risk for PolyU students and bust-waiting people, PolyU staff in non-green deck and green deck scenario were estimated and listed in

Table 4-3-2 and Table 4-3-3. Regarding the health's risk assessment, bus-waiting people and the Polyu staff has much higher cancer risk than PolyU students, because of long exposure time. For the cancer risk of bus-waiting people and PolyU staff in Table 4-3-3 the findings revealed that the cancer risk of formaldehyde exposures via inhalation was higher than acceptable criteria of 1.00E-06. The cancer risks of benzene and acetaldehyde were within an acceptable level. It is indicated that cancer risk from formaldehyde was larger than the cancer risk from benzene and acetaldehyde. But the cancer risk in green deck and non-green deck scenario for bus-waiting people and PolyU staff is higher than U.S. EPA acceptable level. But the cancer risk with green deck situation has 30% to 70% reduction.

Table 4-3-2 Cancer risk for PolyU students

Students			
	Non-green deck	**Green deck**	**Reduction**
Benzene	1.96E-08	7.33E-09	-62.60%
Formaldehyde	1.34E-07	9.01E-08	-32.76%
Acetaldehyde	8.9E-09	5.93E-09	-33.37%
cancer risk	1.63E-07	1.03E-07	-36.39%

Table 4-3-3 Cancer risk for bus-waiting people and PolyU staff

Bus-waiting people and PolyU staff			
	Non-green deck	**Green deck**	**Reduction**
Benzene	1.96E-07	7.33E-08	-62.60%
Formaldehyde	1.34E-06	9.01E-07	-32.76%
Acetaldehyde	8.90E-08	5.93E-08	-33.37%
cancer risk	1.63E-06	1.03E-06	-36.39%

5. Conclusion

Hong Kong roadside air pollution is a very severe problem, which affect human health. Especially the people have long term activities along the roadside. The bus-waiting people and many students and staffs of the Hong Kong Polytechnic University have to be exposed the roadside pollution because they need to walk through a crowded pedestrian bridge. The results show the gaseous pollutant, hourly average nitrogen dioxide (NO_2) concentration have ~10% of the total period of sampling time exceed the proposed new local 1-hour NO_2 standard (200 μg/m^3) but compare the Japan average daily NO_2 standard, none of the day have meet the lower standard limit-excellent level (40 μg/m^3). The measured NO_2 concentration has ~20% to 90% higher than the defined standard value. From the particulate matters (PM), Hong Kong Air Quality Objective (HKAQO) proposed 100 and 75 μg/m^3 as PM_{10} and $PM_{2.5}$ 24-hr average standard and seldom days have been reported exceed the local standard. But the average roadside PM_{10} and $PM_{2.5}$ concentration level in Hong Kong is ~50% to 68% higher than World Health Organization Air Quality Guideline (WHO AQG) (daily average: 50 and 25μg/m^3).

In order to evaluate the effect of green deck on local air quality, the comparison monitoring has been conducted in roadside and PQ podium during the morning and evening peak hours to simulate the non-green deck and green deck scenarios. All pollutants have significantly decreased. PM_{10} concentration has reduced around 48% and 38% in green deck situation than the value measured with non-green deck situation in morning and evening peak hour. The carcinogenic compounds, which including benzene, formaldehyde and acetaldehyde, have 10% to 60% improvement with green deck situation. Based on the estimation, the improvement of particulate matters and carcinogenic compounds is over 30% to 60%.

The cancer risk calculation was conducted to evaluate the chronic health impact for buses-waiting people, HK PolyU staff and PolyU student. The results shows that bus-waiting people and the PolyU staff has much higher cancer risk than PolyU students, because of long exposure time. The cancer risks of benzene and acetaldehyde were within an acceptable level, except for formaldehyde. It is indicated that cancer risk from formaldehyde was larger than the cancer risk from benzene and acetaldehyde in the Hong Kong roadside. In addition, cancer risk of bus-waiting people and PolyU staff is higher than U.S. EPA acceptable level with two scenarios (green deck and non-green deck scenarios). But the cancer risk with green deck situation has 30% to 70% reduction. After green deck being built, the cancer risk will be decrease over 50%.

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