Carbon monoxide (CO), nitrogen dioxide (NO2) and particulates (PM10 and PM2.5) levels in underground and elevated car parks in Kota Kinabalu City

J. Sentian & L. B. Ngoh
School of Science and Technology, Universiti Malaysia Sabah

Abstract

The concentration levels of carbon monoxide (CO), nitrogen dioxide (NO2) and particulates (PM10 and PM2.5) in underground and elevated car parks in Kota Kinabalu city were studied for a period of six months. The maximum 15-min average concentration of CO in the underground car parks was found to be higher than in elevated car parks, both during weekends and weekdays. Meanwhile for NO2, the maximum concentrations were comparatively higher in elevated car parks than in underground car park. Results have shown that none of the CO and NO2 concentration levels exceeded the Swedish STEL (15-min average) of 100 ppm and 5 ppm respectively. However, based on an 8-hr average, only CO concentration (26.0 to 29.5 ppm) in the WP underground car park during weekends has exceeded the Swedish Hygienic Limit (20 ppm). Most of the time, the maximum concentrations of PM10 and PM2.5 in the WP underground car park during weekends and weekdays were observed to be higher than in the CP elevated car park. Generally, the highest concentration levels of all the pollutants were observed to occur during rush hours. The concentrations of CO and particulates (PM10 and PM2.5) in both car parks have indicated good correlations with the number of cars entering and leaving the car parks. These results have suggested that there is a relationship between the pollutants and the number of cars. Meanwhile, weak correlations between the NO2 concentrations with the number of cars in both car parks were found and this could suggest that other factors have influenced the pollutant concentrations.
1 Introduction

In most built-up cities, there is a great demand for but short supply of land and building space. Kota Kinabalu, a developing city in the northern part of Borneo (Sabah) is experiencing a similar problem. The rapid development of the city and its surrounding, have shown a significant increased of vehicles population in the last ten years commensurate with the increased of urban population. The increase of vehicles in most cities coupled with space constraints as well as the high cost of land, have led to more off-street car parks being built. Probably, the parking problem in most cities has been fairly eased by constructing multi-storey car parks, however on the other hand concern about the environment within enclosed car parks embraces fire safety, and thermal comfort and air quality have increased.

Carbon monoxide (CO) is generally regarded as the major indicator of air pollution in an underground car park, and as an index of satisfactory ventilation [1]. Studies of air quality in car park areas usually have concentrated solely on CO, because it is generally considered to be the major factor influencing health [3, 6-8]. In depth discussion of studies reporting CO-associated health effect can be found in a number of excellent reviews [2, 15, 22]. In four underground car parks in Japan, the maximum CO concentration of 108 ppm was observed [18]. Elsewhere, in one of the enclosed car parks in Finland, the maximum CO concentration of 90 ppm was recorded [16]. Chan et al. [6] have found that CO level in six out of 22 sites at the underground car parks in Hong Kong has exceeded the National Institution of Occupational Safety and Health USA and Occupational Safety and Health Association USA permissible limits.

Similarly nitrogen dioxide (NO$_2$) is an important pollutant as at sufficiently large concentrations, has the capacity to cause disruption to the respiratory system. In urban areas emission of oxides of nitrogen (NO$_x$) are dominated by motor vehicle emissions. Vehicles typically emit 90% by mass nitric oxide (NO) and 10% NO$_2$ [27]. Once released from the exhaust of vehicles, the NO is rapidly converted to NO$_2$ through reaction with oxidants. The final concentration of NO$_2$ observed in the car parks has three primary origins: directly emitted from vehicles, formation through rapid atmospheric chemistry involving oxidant, and a “background” component. Study by Colbeck [10] in two multi-storey car parks in Colchester has found that none of the measured NO$_2$ exceeded the occupation exposure criteria.

Particulate matter (PM) has been implicated in human health effect. Mobile sources emit particulate matter and contribute significantly to the ambient levels [14]. Particulate emission source from vehicles include their exhaust [20, 26], the mechanical wear of tires, brakes and clutch, and the ejection of particles from the pavement by resuspension processes [29]. The products of tire and brake wear and the resuspended pavement dust are dominated by particles >10µm. Particulate matter in the vehicle exhaust is dominated by particles smaller than PM$_{10}$ [4, 24].

Since the risk of pollutants exposure on human in an enclosed or semi-enclosed environment such as car park is high, proper design of car park in order
to control ventilation must be met. Currently, in Malaysia, there is no available
guideline or standard for air quality in enclosed environment such as enclosed
car park. Normally comparison will be made against applicable health risk
criteria such as those of the WHO, Swedish Hygienic Limits Exposure (SHLE),
and other standards and guidelines.

CO has been the target of investigation in most studies concerning air quality
in car parks [3, 6-9, 30] and NO₂ at some extent [10]. This paper investigates the
concentration levels of CO, NO₂, and particulates (PM₁₀ and PM₂₃) in
underground and elevated car parks in a developing city of Kota Kinabalu. The
relationships between the level of pollutants with the number of cars entering and
leaving the car parks were also examined.

2 Methodology

2.1 Description of experimental sites

Kota Kinabalu (06°05’30”N; 116°07’30”E) with an estimated population of
400,000, is a developing city in the State of Sabah, Malaysia. The city center is
narrow and built-up on reclaimed sea. The major commercial and business
activities are concentrated in the city center. Measurements of selected air
quality parameters were carried out at two different types of car park for a period
of six months (July- December 2002), namely WP underground car park and CP
elevated car park. Measurements were carried out during weekdays and
weekends. Due to the restrictions from the car park management, the duration of
the measurements has been limited for 12 hours (08:00-20:00).

Elevated multi-storey car park at CP shopping complex comprises of six
levels of semi-enclosed car park, mainly open at the edges and thus, well
exposed to winds and physically allowed good dilution and dispersal of vehicle
exhaust gases. The sampling was carried out at level two. The number of
parking stalls at each level is 214 and the whole car park is capable of
accommodating up to 1284 cars. Meanwhile, the underground car park at WP
shopping complex has two levels of spacious underground car park. The
sampling was carried out at the lowest level (level 2). The number of parking
stalls at each level is 350 and the whole underground car park is capable of
accommodating 700 cars. Both car parks have a separate entry and exit points.
The WP car park is equipped with two units of mechanical ventilation system
(supply and exhaust fan).

2.2 Measurement techniques

The CO concentration was measured using Carbon Monoxide Analyzer Model
416 NDIR portable continuous CO monitor with detection range of 0-100 ppm.
The sample gas flow rate is 0.5 ± 0.25 L/min. The zero gas was flowed and
warmed-up the instrument. The warm-up is completed when the zero point
stabilizes (about 4 hours). It was calibrated by a standard CO span gas and zero
air before and after each field measurement. Meanwhile the nitrogen oxides
concentration was measured using Chemiluminescent NO-NO\textsubscript{2}-NO\textsubscript{x} Analyzer Analysis Model 447 with the detection range of 0-10 ppm and detection limit of 2 ppb. PM\textsubscript{10} and PM\textsubscript{2.5} mass concentrations were measured using Turnkey Instruments TOPAS Environmental Dust Monitor. TOPAS uses a light scattering technique to determine the concentration of airborne particles and dust size ranging from about 0.4 microns to about 20 microns in diameter. The air sample is continuously drawn into the instrument by a pump with a flow rate set by microprocessor at 600 cc/min. The measuring range is from \(0 - 6000.0 \text{ ug/m}^3\) with resolution of 0.1 or 0.01 (calibration factor). The data logger was programmed to store 15 min averaged data. At the end of the measurement period, the results stored in the TOPAS memory were uploaded in the PC-Link interface lead using AirQ software. For quality control the instrument was calibrated periodically as specified by the manufacturer. The monitoring instruments were positioned at about 1.5 m from the ground and at least 3 m from any object or wall. The number of car entering and leaving the car park was also counted at every 30 minutes to examine the role of the car in contributing to the pollutant level in the car parks.

3 Results and discussions

3.1 Carbon monoxide (CO)

The variations of CO concentrations (15-min average) at WP underground and CP elevated car parks during weekdays and weekends are shown in Figure 1. Comparatively, the CO concentration levels were found higher during weekends than weekdays in both car parks. In WP underground car park, the peak of CO concentration during weekends can be observed clearly between 11:45 and 14:00, with the highest concentration of 44.63 ppm. Meanwhile during weekdays, the peak of CO concentration has been observed between 11:00 and 12:00 with the highest concentration of 23.28 ppm. Meanwhile in CP elevated car park, two peaks were observed during weekends occurred between 11:00 and 13:00, and 16:00 and 16:30 with the highest concentrations of 18.69 ppm and 29.29 ppm respectively. Meanwhile during weekdays, two peaks were also observed between 13:30 and 14:30, and 16:30 and 17:15, with highest concentrations of 11.48 ppm and 12.77 ppm respectively. Based on STEL (15-min average) \[28\], none of the CO levels in both car parks exceeded the SHLE of 100 ppm. However, based on SHLE (TWA, 8-hr average) \[28\], the CO concentration level (26 to 30 ppm) in WP underground car park during weekends has exceeded the limits of 20 ppm.

The high concentration of CO during weekend was mostly attributed by the increase of car entering and leaving the car park. During weekends, the number of cars increased of about 18% compared to the number of cars during weekdays. A strong correlation \((r = 0.9)\) was found between CO levels and number of cars in WP underground car park, suggesting that there is a strong relationship between CO levels and the number of cars at the site for that period of time. A similar observation was also reported by Donan et al. \[12\] in the large
underground car park in Hong Kong. Another possibility that could contribute to the CO levels was the ventilation system, where the two units of supply and exhaust fan installed might not be sufficient to ventilate the entire car park areas. Management factor as highlighted by Barker and Fox [3] could also contribute to the increase of CO level during the weekends. During the weekends, there was congestion at the entry (ticket collecting) and exit (processing charges) kiosks as well as within the car park. This condition of idle or very low speed could emit high concentration of CO as found in previous studies [18, 25]. A moderate correlation ($r = 0.6$) was found between CO levels and the number of cars in CP elevated car park. Even though there was an increase (about 25%) of the number of cars entering and leaving the car park during the weekends compared to the number of cars during the weekdays, the CO level has not increased significantly. This has been influenced greatly by the design of the car park itself, where the CP car park is an elevated and semi-enclosed car park, and this provides better ventilation and allowed relatively good air mixing within the car park compared with the WP underground car park.

![Variation of carbon monoxide (CO) concentrations (15-min Average) during weekdays and weekends in WP underground and CP elevated car parks.](image)

**Figure 1:** Variation of carbon monoxide (CO) concentrations (15-min Average) during weekdays and weekends in WP underground and CP elevated car parks.

### 3.2 Nitrogen dioxides (NO$_2$)

The variations of NO$_2$ concentrations in WP underground and CP elevated car parks during weekdays and weekends are shown in Figure 2. The NO$_2$ concentrations during the weekends in both types of car park were higher than during weekdays. Comparatively, NO$_2$ concentrations were higher in CP elevated car park than WP underground car park, both during the weekends and weekdays. The highest concentrations at WP underground and CP elevated car parks during weekends were 0.18 ppm and 0.23 ppm respectively and at any time none have exceeded the SHLE (STEL 15-min) of 5 ppm [28]. Meanwhile, during weekdays, the highest concentrations at WP underground and CP elevated car parks were 0.10 ppm and 0.11 ppm respectively. The TWA (8-hr) of NO$_2$ at
WP underground car park during weekends and weekdays were in the range of 0.045 to 0.050 ppm and 0.018 to 0.024 ppm respectively. Meanwhile in CP elevated car park, the NO₂ concentrations during weekends and weekdays were in the ranges of 0.061 to 0.072 ppm and 0.039 to 0.046 ppm respectively. None of these values exceeded the SHLE (TWA 8-hr) of 1 ppm [28]. Despite some factors such as the car park design (enclosed system), the increased number of cars, the ventilation system capacity and some extent on management factor particularly at WP underground car park, the level of NO₂ was still comparably low. These findings are consistent with the fact that NOₓ emissions are small particular from petrol engine at idle and low speed [25].

In both car parks, correlation analysis has shown a weak correlation (both \( r=0.3 \)) between NO₂ and the number of cars, suggest that there was no strong relationship between the NO₂ and the number of cars for that time period. The relationship between NO₂ levels and the number of cars indicated that time to time variations resulted not only from changes in car parks use but also due to other factors such as the air circulation within the car parks.

![Figure 2: Variation of nitrogen dioxide (NO₂) concentrations (15-min Average) during weekdays and weekends in WP underground and CP elevated car parks.](image)

3.3 Particulates (PM₁₀ and PM₂.₅)

The 1-hr average concentrations of PM₁₀ in WP underground and CP elevated car parks are shown in Figure 3. The PM₁₀ in WP underground car park during weekends and weekdays were also observed to be higher than in CP elevated car park. The highest concentration levels during weekends and weekdays in WP underground car park were 351.20 µg/m³ and 237.43 µg/m³ respectively. In CP elevated car park, the highest PM₁₀ concentration levels during weekends and weekdays were 178.30 µg/m³ and 198.65 µg/m³ respectively. High concentrations of PM₁₀ were occurred in the afternoon.

The PM₂.₅ concentration (1-hr average) in both types of car parks also showed a similar trend with that of PM₁₀ as shown in Figure 4. During the weekends in
WP underground car park, the PM$_{2.5}$ levels increased steadily and reached the peak at 14:30 with highest concentration of 66.60 µg/m$^3$. Meanwhile during the weekdays, the peak was observed to be between 13:15 and 14:00 with the highest concentration of 35.14 µg/m$^3$. Whereas in CP elevated car park during weekends and weekdays, there were no distinctive peaks observed throughout the measurement. However, the highest PM$_{2.5}$ concentration level during weekends was 28.08 µg/m$^3$ at 13.30. Meanwhile during weekdays the highest concentration of 32.46 µg/m$^3$ was observed at 17:00 hours. For comparison, none of the PM$_{2.5}$ values exceeded the Canadian Exposure Guidelines of 100 µg/m$^3$ (1-hr)[11](Note: the guideline is for residential indoor air quality and not directly applicable for car park).

Correlation analysis has found that there were strong correlations between particulates and the number of cars in WP car parks ($r = 0.8$ for PM$_{2.5}$ and $r = 0.7$ for PM$_{10}$). Similar results was obtained in CP elevated car park, where strong correlation was found between particulate (PM$_{2.5}$) and the number of cars ($r = 0.7$ for PM$_{2.5}$). Meanwhile good correlation was found between PM$_{10}$ and the number of cars ($r = 0.6$). These results have suggested that particulates levels in both car parks were mainly contributed from the vehicles. Previous study by Keary et al. [14] in the city of Dublin has observed a weak correlation ($r = 0.48$) between PM$_{10}$ level and the traffic density. Emission of PM$_{2.5}$ would be mainly from vehicles exhaust. Previous studies by Baumgard and Johnson [4] and Ristovski et al. [24] have concluded that particulate matter in the vehicle exhaust is dominated by particles smaller than PM$_{10}$. In Norway, it has been reported that car exhaust contributes approximately 40% of PM$_{10}$ emission [21]. Gillies et al. [13] have also found that the PM$_{2.5}$ emission factor was 74% of the PM$_{10}$ factor from the vehicles in the enclosed environment.

![Figure 3: Variation of PM10 concentrations (1-hr average) during weekdays and weekends in WP underground and CP elevated car parks.](image)

### 4 Conclusion

The concentration levels of CO and particulates (PM$_{10}$ and PM$_{2.5}$) pollutants in WP underground car park were generally higher than in CP elevated car park.
However, for nitrogen oxides, most of the time the concentrations was higher in CP elevated car park than WP underground car park. Comparatively, the concentrations of pollutants during the weekends were higher than during the weekdays in both types of car parks. The maximum concentrations for all pollutants normally occurred during rush hours in the afternoon. Among the pollutants, only CO has exceeded the Swedish Hygienic Limit (20 ppm) which was observed at WP underground car park during the weekends.

![Figure 4](image_url)

Figure 4: Variation of PM$_{2.5}$ concentrations (1-hr average) during weekdays and weekends in WP underground and CP elevated car parks.

Higher concentration of pollutants in WP underground car park has been partially attributed to the fact that WP underground car park is built in an enclosed environment, thus restricting the dispersal of pollutants. The number of cars entering and leaving the car parks has also played an important role in the increase of pollutant levels in both types of car parks. From correlation analyses, it was found that there was a reasonably strong correlation between the number of cars and pollutants such as CO and particulate, suggesting that the cars were the main source of pollutants (CO and particulate) in both car parks. However, weak correlations were found between the number of cars and concentration levels of nitrogen oxides (NO and NO$_2$), suggesting that there was no strong correlation between the parameters at the sites of study for that time period.

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**References**


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