# Preliminary Study of Relationship between Outdoor and Indoor Air Pollutant Concentrations at Bangkok's Major Streets

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## Abstract

This study reports results of an investigation into the relationship of outdoor and indoor air quality in Bangkok's shop and office buildings, over a 12 months period. Four ambient air monitoring stations in the Bangkok Metropolitan Region (BMR) were chosen, based on traffic density, flow conditions and wind speed. In order to characterize the indoor air quality, four shops and four office buildings in Bangkok were selected for this study. A quantitative analysis of the hourly variation of outdoor/indoor pollutants was performed. The investigated pollutants are carbon monoxide (CO), particulate matter ($PM_{10}$) and nitrogen dioxide ($NO_2$). Factors, which are considered, include diurnal variations in concentrations of various pollutants and ratios between indoor and outdoor air qualities. The hourly variation of outdoor air pollutant concentration is very well correlated with indoor air concentration. The findings show that the indoor: outdoor ratio for $PM_{10}$, CO and $NO_2$ are evaluated as 0.33, 0.51 and 0.47, respectively. The hourly average indoor concentrations of $PM_{10}$, CO and $NO_2$ are significantly higher in the shop than in the office. The pollutant levels inside the building were due to inadequate ventilation and air infiltration of outdoor air pollutants emitted from vehicular emissions. With little or no contribution from indoor sources, ambient concentrations are the primary factor in determining indoor air quality. Our analysis revealed that infiltration of outdoor air could substantially increase indoor pollutants and thereby influence the indoor air quality.

**Keywords**: Bangkok, carbon monoxide, particulate matter, nitrogen dioxide, indoor and outdoor air qualities.

## 1. Introduction

Bangkok metropolitan area (1,569 km$^2$) has a total population of about 6.2 million and registered vehicles of more than 4.2 million in 2001 and is experiencing progressively intensified air pollution problems associated with high levels of vehicular exhaust emission. Vehicle ownerships in Bangkok are estimated at approximately 400 vehicles per thousand residents. Rapid growth in vehicle population has caused frequent traffic congestion on major roads of Bangkok and has progressively intensified air pollution, causing adverse effects on human health [1].

In Bangkok, ambient air quality levels are generally acceptable at locations away from the streets. However, air quality at congested roadsides are found to exceed the national air quality standard. Since people spend most of their time indoors, it is likely that indoor air pollution is an important source of exposure for occupants [2]. Among the important indoor air pollutants that are associated with health impacts are airborne particulates, carbon monoxide and nitrogen dioxide. Previous research studies showed that the quality of the air breathed has become a significant factor in the environment [3]. Therefore, establishing relationships between the outdoor and indoor distribution of pollutants is designed to protect the population from harmful levels of pollutants [4].

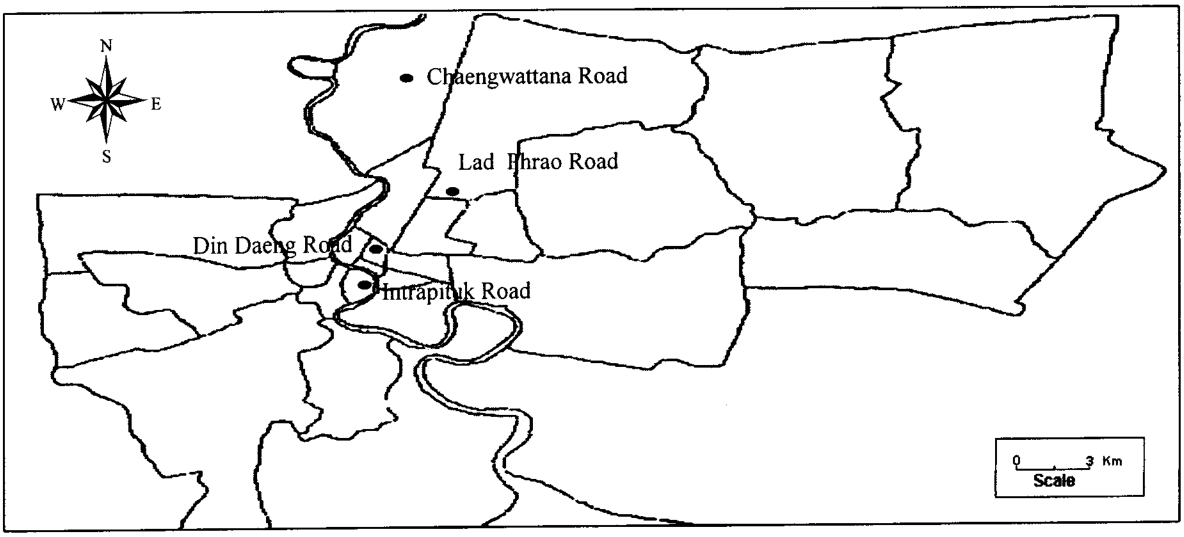
It is noticed that air pollution from traffic emission depends on traffic flow, street configuration, land use activities and the local meteorological characteristics, which govern the ability of the atmosphere to disperse air pollutants [5]. Under idling and deceleration modes, vehicles in this area will emit maximum pollutants. The heaviest pollutant concentration is close to the road surface. The shop buildings beside the road act as barriers funneling the air pollutants. This poses a potential health hazard to population who live in close proximity. Toxins may cause many immediate effects on human health, ranging from shortness of breath to eye irritation to death. Those who died or become ill were usually old or suffering from cardiovascular disease and therefore, were unable to cope with the added stress caused by the heavily polluted air. Similarly, many office workers in tight building often suffer from headaches, nausea, sore eyes and other discomforts. The cause was found to be air infiltration of outdoor air pollutants and indoor air pollutants accumulated inside the office building. Due to inadequate ventilation systems of some buildings, indoor air pollutants could not escape into the outside atmosphere and there is less chance for noxious gases and odors to escape outside. In this closed environment, poor indoor air quality has led to the phenomenon of sick building syndrome and related complaints of occupants [6].

To date there have been no comprehensive measurements of the indoor concentrations of pollutants in Bangkok. The principal objective of this study is to establish relationships between indoor and outdoor pollutant ratios at different traffic zones in Bangkok.

## 2. Materials and Methods

**Site Description**

In this study, air pollutant measurements were carried out at four ambient air monitoring stations in the Bangkok Metropolitan Region (BMR), over the period from January to December 2002 (Figure 1). Each monitoring station will represent a particular traffic zone in the Bangkok Metropolitan Region (BMR), based on traffic density and flow conditions (Table 1). The terrain characteristics of sites are generally flat and only slightly above sea level. In normal case, air pollutants at each site can easily be dispersed by wind breezes. However, the dispersion of air pollutant at individual sites can also be effected by emission conditions, street geometry, traffic volume-speed relationship and vehicle composition.



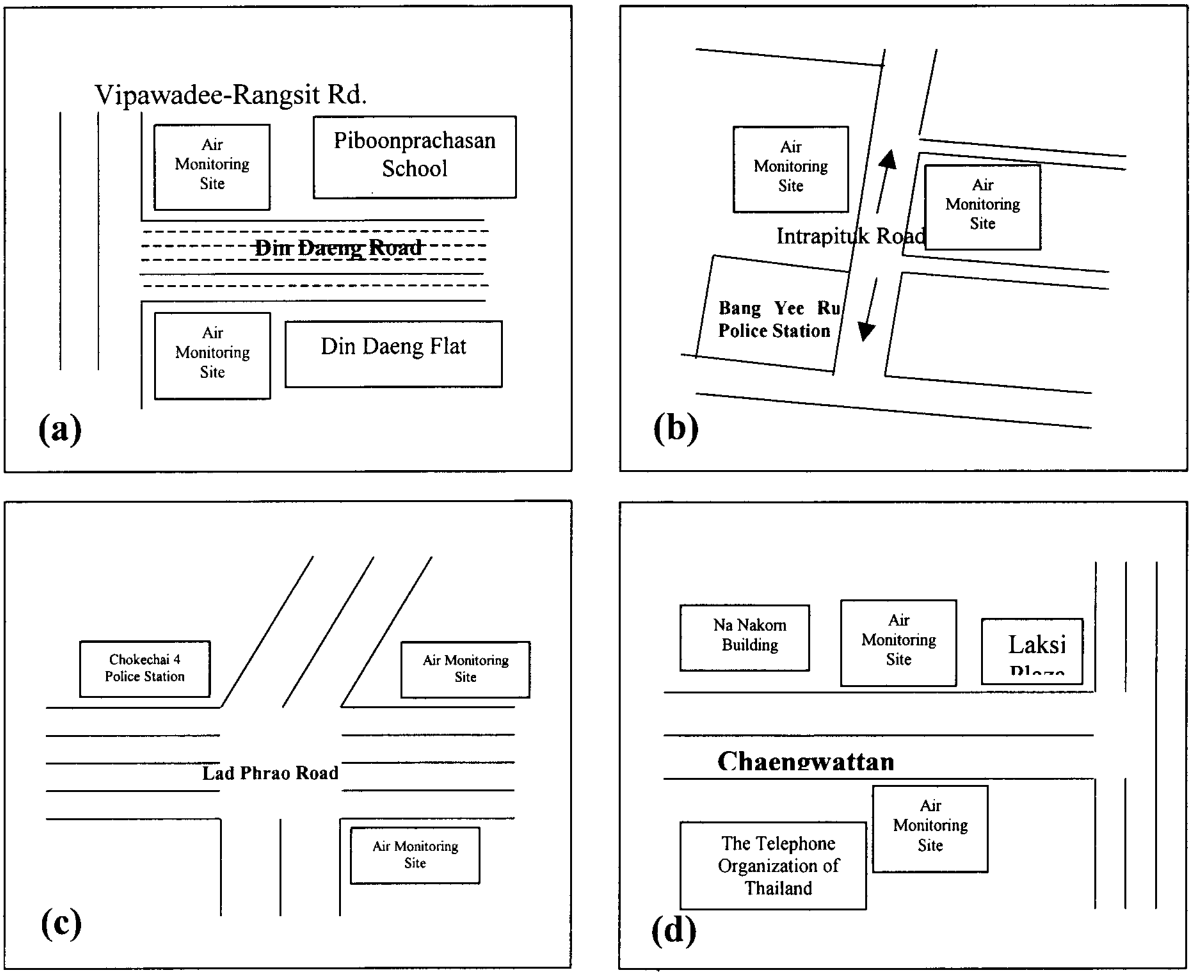



**Figure. 1** Layout of Air Monitoring Stations in Bangkok: a) Din Daeng Road, b) Intrapituk Road, c) Lad Phrao Road, and d) Chaengwattana Road.

**Table 1.** Comparison of traffic characteristic at different monitoring stations, during peak hour

| Station | Traffic Zone | Traffic Volume (vehicle/h/lane) | Ave. Speed (km/h) | Road Layout |
|---|---|---|---|---|
| Din Daeng Rd | Inner core | 1,132 | 18 | 5 lanes + 2 bus lanes |
| Intrapituk Rd | Inner zone, section I | 920 | 11 | Near T-junction, 6 lanes |
| Lad Phrao Rd | Inner zone, section II | 1,104 | 30 | T-intersection, 7 lanes |
| Chaengwattana Rd | Middle zone | 1,176 | 28 | 4 lanes + 2 bus lanes |

**Din Daeng Road**

This monitoring station is located along Din Daeng Road (Asoke) at the inner core traffic zone in the Bangkok Metropolitan Region (BMR). Din Daeng Road accumulates air pollutants due to heavy traffic, buildings on both sides and poor traffic flow. Frequent traffic jams and low speed at rush hours are observed in the vicinity.

**Intrapituk Road**

This monitoring station is located at Intrapituk Road (Wongwan Yai) near the inner zone, section I. The traffic flow along the Intrapituk Road is mainly in four lanes except near to a T-junction controlled by traffic lights adjacent to the monitoring site where the road is six lanes. The traffic is heavy and continuous throughout the daytime with queuing and start-stop driving between traffic lights. As a result, frequent traffic congestion was exhibited in the vicinity.

**Lad Phrao Road**

This study area is situated in the inner zone, section II at a busy traffic intersection (Chokchai 4) along Lad Phrao Road. This site has long lasting traffic jams and very high density of human activities. Traffic also moves more slowly with the approach of major junctions. This makes a potential accumulation of air pollutant close to the road surface. Air monitoring was conducted near the intersection.

**Chaengwattana Road**

Chaengwattana Road is located at the middle traffic zone with an 8 lanes-two way road. This road has fewer high-rise-type buildings and no distinct topography established on both sides of the street. Traffic volumes and pollutant emissions in this area were expected to be more stable than those roads in the business center district.

## Monitoring Method

Hourly average air pollutant concentrations were measured continuously for 24 hours with receptors 1.5 m above street level to cover a period of 12 months. The ambient air sampling procedure was strictly followed according to the reference method developed by the U.S. Environmental Protection Agency for the determination of air pollutants in the atmosphere and the quality assurance requirements for air monitoring stations [7]. The following methods are used for analyses of the air pollutants:

**Outdoor Air Measurement**

Particulate matter ($PM_{10}$) samples were collected by High Volume Samplers from Precision Scientific Company, Cat No. 63091. An Anderson cascade impactor was used at each location to measure the particle size distribution of suspended particulate matter. Carbon monoxide was analysed by an Ambient CO Monitor (HORIBA Model APMA-350E). Nondispersive Infrared method (NDIR) is the recommended method of continuous analysis for carbon monoxide content of the atmosphere. This instrument has a lower detectable limit of 0.06 ppm. Nitrogen dioxide monitor (Horiba-API-200A) with a data logger was used to measure the hourly average $NO_2$ concentrations. This instrument is based on the principle of chemiluminescent, whereby NO in the sample air reacts with ozone. The beam with a wavelength in the range 600 nm to 3000 nm passes through the reaction chamber and an optical filter. The intensity is detected by photo-multiplier tube and recorded as nitric oxide, NO. The concentration of oxides of nitrogen is measured in a separate stream undergoing similar processes whereby $NO_2$ is converted to NO and together with the original NO, it is detected as $NO_X$. The difference between the $NO_X$ and NO is reported as nitrogen dioxide. The working range of the instrument is 0.1-10 ppm with a minimum detectable limit of 0.15 ppb and repeatability of $\pm$ 1.0% F.S. The working temperature range is from 10-35 $^0$C.

**Indoor Air Measurement**

Indoor air measurements for carbon monoxide, temperature and relative humidity were taken with the TSI, Q-Trak Plus IAQ-CALC Monitor, model 8854. Sample air is drawn through an electrochemical cell where the carbon monoxide level generates a proportional electrical signal for the compact detector. The meter requires calibration for zero and span concentration to give $\pm$ 3% of accuracy. A portable gas meter (Geotech, MultiRae Plus with PID) is used to measure a direct readout of nitrogen dioxide. The sample air flows through an electrochemical cell where an electrical signal is generated, in proportion to the nitrogen dioxide concentration of the air. The analytical range is 0-20 ppm with resolution of 0.1 ppm. Airborne particulate matter ($PM_{10}$) was measured by the TSI, Dust Trak Aerosol monitor. The meter provides a real-time measurement based on $90^{o}$ light scattering and a calibrated pump draws an air sample through the optics chamber where it is measured. The detection range of the system is 0.001 to 100 $mg/m^3$ with reliability of 1%.

## 3. Results and Discussion

### Outdoor Air Quality

Figure 2 represents the mean results of the air sample analysis in four Bangkok air monitoring stations, during rush and non-rush hours. Generally, most of the pollutants such as $PM_{10}$, CO and $NO_2$ for each of the four roads gave almost the same diurnal patterns. There were higher values for the pollutant concentrations during morning (07.00 - 09.00) and evening (16.00-18.00) rush hours. A slight decrease in pollutant concentration occurred during non-rush hour (11.00-15.00). The levels then tended to reduce, reaching a minimum at night time (19.00-24.00 and 01.00-06.00). It was revealed that during rush hour a comparably higher traffic volume occurred for all the monitoring stations resulting in higher pollutant emissions. In contrast, lower pollutant emissions could be expected during non-rush hour due to higher vehicle speeds.

**Airborne Particulate Matter ($PM_{10}$)**

From the analyses, the mean concentrations for suspended particulate matter in various monitoring stations were found to be in the range of 25.73 – 71.12 $ug/m^3$ (24 hr average). Figure 2 shows that $PM_{10}$ concentrations in all monitoring stations were well below the ambient air quality standard of 120 $ug/m^3$ (24 hr average). Airborne particulate matter in Bangkok is produced from diesel soot, road or agricultural dust, or particles resulting from construction or manufacturing processes. Exposures to particulate matter are associated with higher mortality risks ranging from severe acute asthma attacks and chronic bronchitis to mild acute symptoms such as coughing, wheezing and congestion. This indicates seriousness of the $PM_{10}$ problem to residents in the area, as they fall into inhalable size ranges. The Royal Thai Government, Pollution Control Department [8] reported that at current $PM_{10}$ concentrations in Bangkok, there may be as many as 4,000 to 5,500 premature deaths each year in the metropolitan area attributable to short term exposure to outdoor airborne particulate matter (assuming a total population of 7 million). In addition, hospital admissions for respiratory and cardiovascular illnesses are higher when $PM_{10}$ concentrations are higher.

**Carbon Monoxide (CO)**

Throughout the monitoring period, the level of carbon monoxide at various monitoring sites ranges from 3.90 - 6.90 $mg/m^3$ which is below the ambient air quality standard of 10.26 $mg/m^3$ (8 hr average). Figure 2 showed that carbon monoxide levels on Din Daeng Road, Intrapituk Road and Lad Phrao Road are higher than Chaengwattana Road. These locations accumulate CO pollutant due to heavy traffic, tall buildings on both the sides and narrow streets. The danger caused by carbon monoxide to human health is due to its affinity for haemoglobin 240 times greater than that of oxygen and that carboxyhaemoglobin is therefore a more stable compound than oxyhaemoglobin [9]. There are many studies showing that high concentrations of carbon monoxide can cause physiological and pathological changes and ultimately death.

**Nitrogen Dioxide ($NO_2$)**

Levels of nitrogen dioxide in the ambient air of all monitoring stations were found to be 24.00 – 32.60 $ug/m^3$, which is below the ambient air standard of 320 $ug/m^3$ (1 hour average). Likewise, the World Health Organization [9] proposed an outdoor exposure to nitrogen dioxide of 400 $ug/m^3$ (1 hr average) and 150 $ug/m^3$ (24 hr average). In Figure 2, the diurnal pattern of $NO_2$ was clear. The morning peak was linked with the morning commuter rush and similarly for the evening peak. The ambient $NO_2$ concentrations of Din Daeng road with frequent traffic jams and low speed were contrasted to the wider and more open radial routes of Chaengwattana Road with free-flowing traffic. Similarly, the influence of street geometry on $NO_2$ levels for Intrapituk Road and Lad Phrao Road has also been demonstrated where heavy traffic and poor traffic flow record higher concentrations.

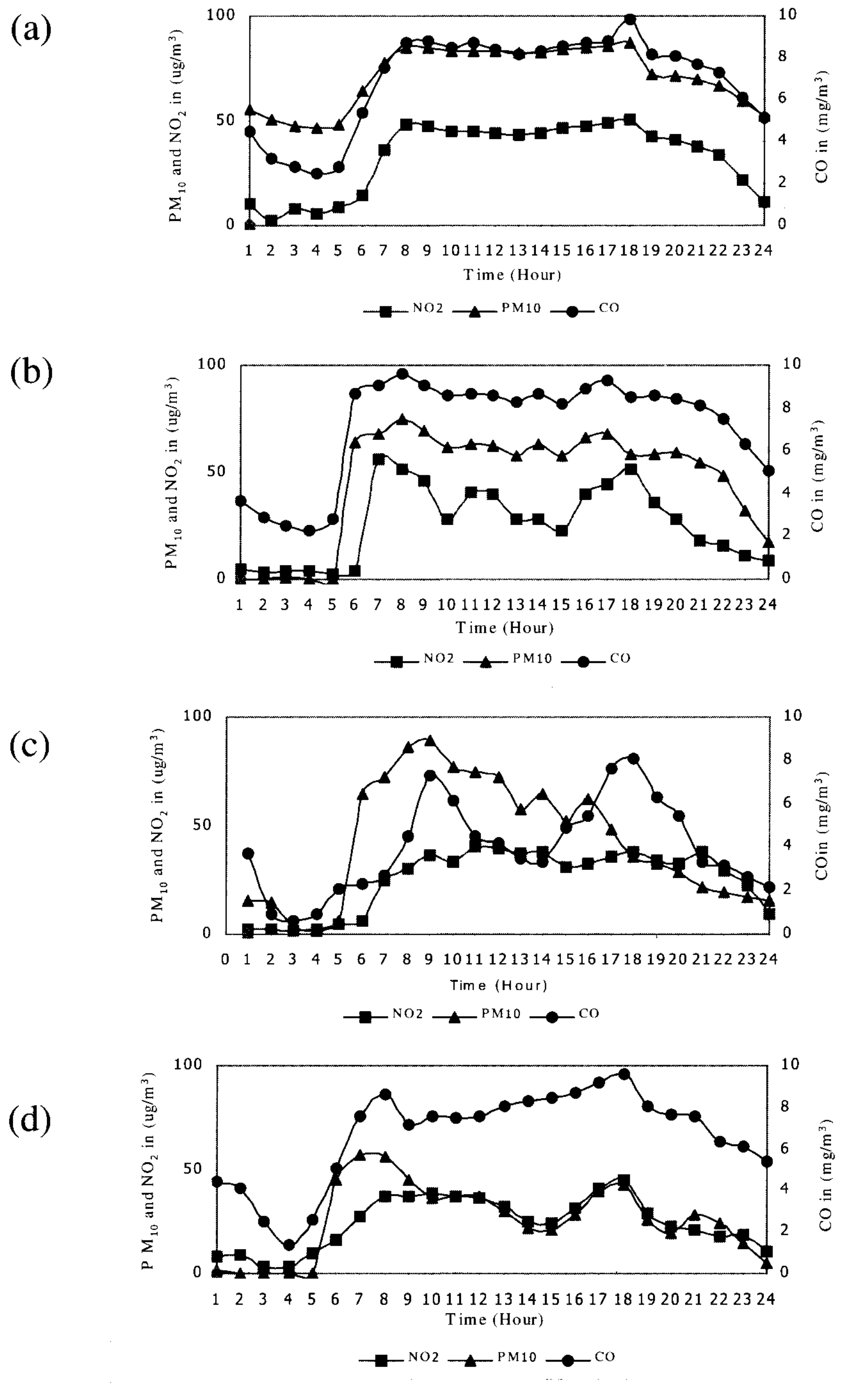



**Figure 2.** Average hourly air pollutant concentration at (a) Din Daeng Road, (b) Intrapituk Road, c) Lad Phrao Road and d) Chaengwattana Road, for 26 March 2002.

**Note:** Thai ambient air quality standard (PCD, 1999); PM10 = 120 ug/m3 (24 hr average);
CO = 10.26 mg/m3 (8 hr average); NO2 = 320 ug/m3 (1 hr average).

**Indoor Air Quality**
**Shops**

In this study, four shops were selected as representative of the curbside buildings at respective monitoring sites to carry out the indoor air quality measurement. The selected shops had street level entry doors at approximately 2 m from roadside and were left opened onto nearby heavy traffic roads providing direct access to both shoppers and outdoor air. The shops have natural ventilation. In addition, the shops were comparatively small in size with a ceiling height of approximately 3 m. This can easily result in poor fresh air movement and distribution.

Figure 3 shows the variation of indoor air pollutant concentrations in the shops at different monitoring sites. The average CO levels at the surveyed shops ranged from 1.78 to 4.47 mg/m$^3$. The highest CO concentration was observed the Din Daeng site. At present, no indoor air quality standards exist in Thailand so that outdoor air quality standards are used to compare the results obtained in this study. All of the measured CO concentrations in the shops were below the Thai air quality standards of 10.26 mg/m$^3$ (8 -h average). Outdoor carbon monoxide concentrations were found to be higher than indoors. The CO concentrations recorded indoors can also be due to sources inside the shop as well as infiltration of outdoor air. Possible sources of indoor CO are from cigarette smoking and gas appliances (kitchen or restaurant).

The average particulate levels at the surveyed shops ranged from 13.20 to 18.87 *ug*/m$^3$. The results show that outdoor particulate concentrations were usually higher than the respective indoor levels in shops (Figure 4). This can be explained in that the airborne particulate concentrations at the shops were probably due to air infiltration of outdoor airborne particulates emitted from vehicular emissions. This is supported by the findings that the outdoor $PM_{10}$ were more likely to get direct access into the shop. Several recent studies have shown that there is a relationship between $PM_{10}$ particulate concentration and various health indicators such as hospital admissions, frequencies of respiratory illness, reduced lung capacity and death. $NO_2$ concentrations in shops ranged from 12.08 to 13.62 *ug*/m$^3$. To an extent, outdoor $NO_2$ levels influence indoor levels because $NO_2$ can easily penetrate indoors. Figure 3 shows the variation of $NO_2$ levels in the shops on Din Daeng Road, which are comparable with other roadside sites, with similar traffic densities in Bangkok. The finding shows that shops exhibited higher indoor $NO_2$ levels than offices. This phenomenon is not surprising since the doorways of shops were always left open during business hours providing easy access not only for customers but also for outdoor air. With little or no contribution from indoor sources, ambient $NO_2$ concentrations are the primary factor in determining indoor levels.

Hourly average ratios between indoor and outdoor concentrations of air pollutants for four sites in Bangkok were calculated for all data available between January to December 2002. This analysis provides the baseline for comparison of indoor : outdoor ratio for $PM_{10}$, CO and $NO_2$ during episode conditions and provides a means of comparing these ratios between the different sites. At all the monitoring sites, the relationship between outdoor and the indoor pollutant concentrations was investigated and the indoor: outdoor ratio for $PM_{10}$, CO and $NO_2$ were 0.33, 0.51 and 0.47, respectively. The ratio depends on infiltration rate of outdoor air, as well as operation and business hours of the shops. The finding shows that the average indoor air pollutant concentrations for the three urban sites are noticeably higher than the suburban (Chaengwattana Road) site. The sequence of indoor air pollutant levels at various monitoring sites is Din Daeng Road > Intrapituk Road > Lad Phrao Road > Chaengwattana Road.

**Office Buildings**

Four representative office buildings were selected for the indoor air quality measurement. The selected office buildings were located on a commercial street, which has a traffic flow of above 1000 vehicle per hour. The entrance door of the buildings was approximately 1 m wide and 2 m high and was adjacent to traffic lights. The working hours of the buildings is 9.00 a.m. to 12.00 noon and 2.00 to 4.00 p.m. All the offices had some form of air conditioning.

(a) (b) (c)

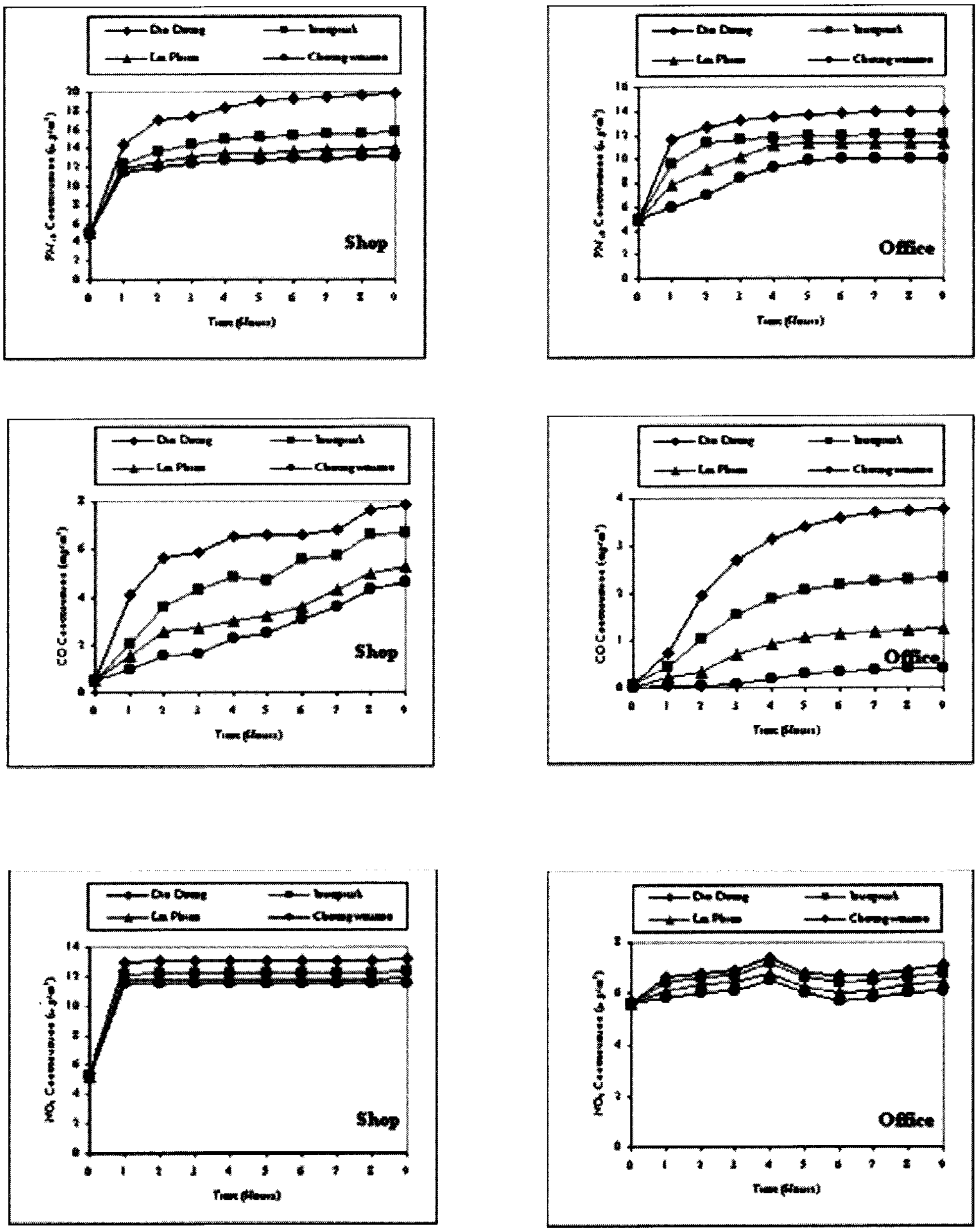



**Figure 3.** Hourly variation of (a) particulate, (b) carbon monoxide and (c) nitrogen dioxide levels at selected shop and office buildings in Bangkok.

**Note:** Ambient air quality standard (PCD, 1999); PM10 = 120 ug/m3 (24 hr ave);
CO = 10.26 mg/m3 (8 hr ave); NO2 = 320 ug/m3 (1 hr ave).

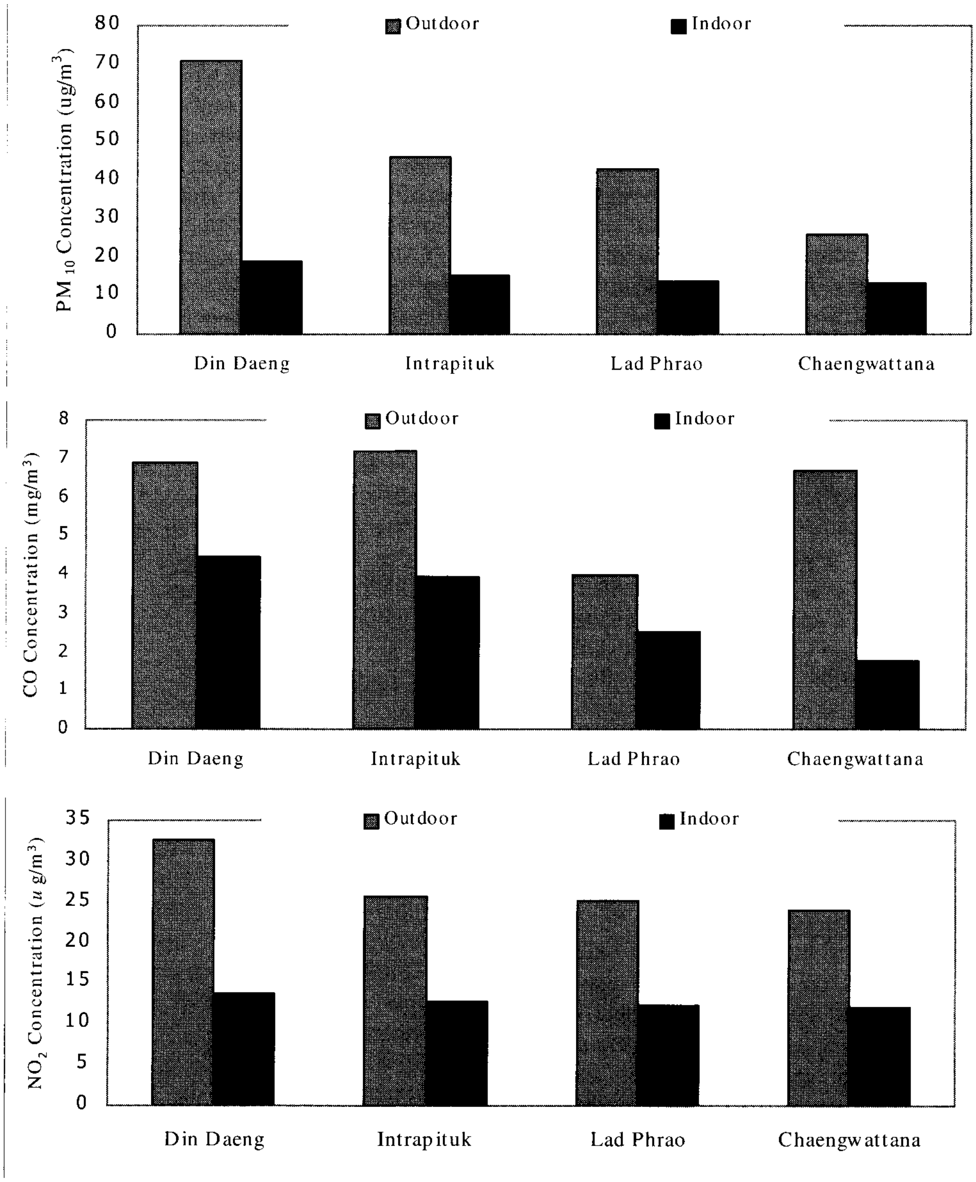



**Figure 4**. Indoor / outdoor air pollutant concentrations at various monitoring sites during January to December 2002.

**Note:** Thai ambient air quality standard (PCD, 1999); PM10 = 120 ug/m3 (24 hr average); CO = 10.26 mg/m3 (8 hr average); NO2 = 320 ug/m3 (1 hr average).

**Airborne particulate matter ($PM_{10}$)**

Source of indoor particulate matter include dusts, fumes, smoke and organisms. Particulate matter is classified as total suspended particulate (TSP) or respirable suspended particulate (RSP), which consists of those with particle size under 10 *u*m. The major indoor source of airborne particulate matter is tobacco smoke and has the diameter of 0.01 to 0.1 micron. Throughout the monitoring period, average indoor particulate matter ($PM_{10}$) concentration of 10.06 – 14.03 *u*g/$m^3$ was observed in office buildings adjacent to traffic lights. This value was lower than the Thailand ambient air quality standard for particulate matter of 120 *u*g/$m^3$ (24hr average). Normally, indoor air has less airborne particulate than outdoor due to the filters of ventilation systems (Figure 4). However, cigarette smoking in the room will significantly increase the particulates in the air. Spengler [10] reported that higher airborne particulate concentrations were likely to be detected at the time when more cigarettes were actually smoked in a crowded room (70 to 193 *u*g/$m^3$). ASHRAE Standard 62-1989 has adopted the U.S. Environmental Protection Agency $PM_{10}$ standard of 50 *u*g/$m^3$ for annual exposure and 150 *u*g/$m^3$ for 24-hour exposure [11]. Analytical results show that indoor particulate concentrations in studied rooms were below the ASHRAE recommended value.

**Carbon monoxide (CO)**

In the office building, carbon monoxide emissions may come from gas appliances (kitchen or restaurant), cigarette smoking and vehicles in attached garages. The hourly average concentration of carbon monoxide emerged from the study ranged from 0.24 to 2.98 mg/$m^3$ which were relatively low, when it is compared to the ASHRAE Standard 62-1989 of 9 mg/$m^3$ (8-hour average) [11]. The elevated outdoor carbon monoxide concentration in the nearby roads of the office building can subsequently influence the indoor carbon monoxide level. In this case, the doorways provide an easy access for outdoor carbon monoxide to transport into the office building. At low concentration, carbon monoxide can cause headaches, nausea, sore eyes and runny noses. When exposed to high levels of carbon monoxide, people may experience chronic bronchitis and asthmatic wheezing. Ventilation is the best way to remove carbon monoxide from indoor air. However, the concentration of carbon monoxide in the air will increase if people smoke cigarettes in the room.

**Nitrogen dioxide ($NO_2$)**

The average indoor nitrogen dioxide concentration of surveyed office building ranged from 6.06 to 7.10 *u*g/$m^3$ which were below the ambient air quality standard of Royal Thai Government, Pollution Control Department (PCD, 1999) of 320 *u*g/$m^3$ based on 8 hours per day or 40 hour per week. Figure 3 shows that slightly higher nitrogen dioxide is emitted during the fourth hour of the working day (lunch break hour). This suggests that an increase in indoor nitrogen dioxide levels is mainly due to some indoor activities such as gas cooking stoves inside the catering zones of the office building. Nitrogen dioxide can increase respiratory illnesses such as bronchitis and asthma. Exposure to high levels of nitrogen dioxide can trigger attacks of shortness of breath and wheezing.

## 4. Conclusion

Experimental results demonstrated that ambient air quality at congested roadsides is found to be at significant levels as compared to the national air quality standard ($PM_{10}$: 25.73 – 71.12 *u*g/$m^3$, CO: 3.90 - 6.90 mg/$m^3$ and $NO_2$: 24.00 – 32.60 *u*g/$m^3$). Considerable levels of indoor air pollutants ($PM_{10}$: 13.20 to 18.87 *u*g/$m^3$, CO: 1.78 to 4.47 mg/$m^3$ and $NO_2$: 12.08 to 13.62 *u*g/$m^3$) were observed at the surveyed shops. Likewise, the levels of indoor air pollutants ($PM_{10}$: 10.06 – 14.03 *u*g/$m^3$, CO: 0.24 to 2.98 mg/$m^3$ and 6.06 to 7.10 *u*g/$m^3$) in the office were found to be well below the air quality standards. In most cases, the findings show that outdoor air pollutant concentrations are usually higher than those inside surveyed shops and offices. The study implies that infiltration of outdoor pollutant concentrations have contributed significant levels of pollutants to indoor air quality in both shop and office buildings. There is also clear indication that indoor activities, inadequate ventilation and emission sources, adversely affected the air quality inside buildings.

## 5. Recommendation

The indoor air quality problem is rapidly becoming a major concern of the public. The public interest in controlling the levels of indoor pollutants is very keen. Inadequate air distribution and presence of indoor combustion sources cause ventilation problems. Indoor air quality of existing shop or office buildings can be improved by use of proper filtration systems and regular maintenance of ventilation systems. Pre- office hour ventilation is another mitigation measure to reduce accumulated pollutant concentrations from the previous night. Installation of automatic swing doors at entrances is encouraged to minimize the amount of outdoor air that can leak into the building. Restrictions on cigarette smoking in tight office building have been at the forefront of efforts to reduce indoor particulate and carbon monoxide concentrations. There should be increasing awareness of consequences of polluting indoor air quality and a developmental program by responsible authorities should be implemented in maintaining a healthy and comfortable working environment in shop or office buildings.

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