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Commuter exposure to BTEX in public transportation modes in Bangkok, Thailand

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Abstract

Measurements and monitoring of volatile organic compounds (VOCs) have been conducted in the metropolitan Bangkok. However, in-vehicle levels of VOCs are still lacking. This study investigated VOCs concentrations in four public transportation modes in Bangkok, Thailand during two rush hour periods (7:00–9:00 a.m. and 4:00–7:00 p.m.). The four modes included an air-conditioned bus (A/C bus), non-air-conditioned bus (non-A/C bus), electric sky train, and a passenger boat traveling along the canal. Comparison among three important bus routes was also studied. In-vehicle air samples were collected using charcoal sorbent tubes and then analyzed by a gas chromatography-mass spectrometer. Results showed that the transportation modes significantly influenced the abundance of in-vehicle benzene, toluene, ethylbenzene, and *m,p*-xylene (BTEX). Median concentrations of BTEX were 11.7, 103, 11.7, and 42.8 $\mu g/m^3$ in A/C bus; 37.1, 174, 14.7, and 55.4 $\mu g/m^3$ in non-A/C bus; 2.0, 36.9, 0.5, and 0.5 $\mu g/m^3$ in sky train; and 3.1, 58.5, 0.5, and 6.2 $\mu g/m^3$ in boat, respectively. Wilcoxon rank sum test indicated that toluene and *m,p*-xylene in the sky trains were statistically lower than that in the other three modes at a *p*-value of 0.05. There were statistical differences in TEX concentrations among the bus routes in the non-A/C buses. In addition, the benzene to toluene ratios implied that tail-pipe emissions were important contributor to the abundance of in-vehicle VOCs.

Key words: benzene; public transportation; commuting; vehicle exhaust

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Introduction

Bangkok, the capital of Thailand and the kingdom's largest city, had a registered population of 5.7 million in 2006 (DOPA, 2006). Due to the insufficient number of roads and the rapid increase in private vehicles, traffic conditions in Bangkok have worsened significantly during the past decade. The average driving speeds of passenger cars on main roads are 17.2 and 24.2 km per hour during morning and evening rush hours, respectively (Traffic Police Bureau, 2005). Not surprisingly, Bangkokians spend an average of two hours commuting from home to work and back (NSO, 2004). As a result of severe traffic congestion, commuters are inevitably exposed to high levels of vehicle-related air pollutants.

Apart from regularly monitoring the seven criteria air pollutants of the National Ambient Air Quality Standards, the Pollution Control Department (PCD) of Thailand has recently begun to monitor levels of air toxics, particularly volatile organic compounds (VOCs) in Bangkok due to concerns about traffic-related health problems. The 24-hr average concentrations of benzene, toluene, ethylbenzene, xylene (BTEX), formaldehyde, acetaldehyde, acrolein, and propionaldehyde on roadsides and general areas were 7.0 (1.0–10.7), 36.3 (17.7–49.6), 11.2 (non-detect–17.2), 44.9 (non-detect–69.0), 8.7 (5.8–10.7), 4.4 (3.4–5.0), 1.5 (1.2–1.7), and 1.0 (0.9–1.2) $\mu g/m^3$, respectively (PCD, 2006). Levels of all VOCs measured at roadside stations, particularly BTEX were greater than those measured at residential and business areas. However, levels of VOCs in rush hours at roadsides are expected to be far greater than these 24-hr average concentrations, which may not appropriately represent actual exposure levels.

Gee and Sollars (1998) measured levels of ambient air VOCs at roadsides and locations more remote from traffic as well as inside taxi cars in six cities of Latin America and Asia, including Bangkok and Manila (Philippines). The roadside concentrations of toluene, ehtylbenzene, and *m,p*-xylene in Bangkok and Manila were similar, but approximately 7, 6, and 4 times, respectively higher than those measured in the Latin American cities. Benzene levels, however, were similar in all studied cities. Measurements within taxis showed trends similar to the roadside measurements. Benzene to toluene ratios (B/T) for Bangkok and Manila were as low as 0.1 as compared to 0.5 for typical vehicle exhaust emissions. They attributed the low B/T ratios for different types of vehicles and fuel used in those two cities.

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In Bangkok, motorcycle is very popular since it can shorten the trip time. Leong et al. (2002) studied the influence of benzene emission from motorcycles on air quality in Bangkok. Their results showed that benzene emitted from two-stroke motorcycles, which are more favored in Thailand, is five times more than that from four-stroke motorcycles. The benzene concentrations monitored at busy traffic roadsides varied from 15.1 to 42.4 $\mu g/m^3$ for rush hours and from 16.3 to 30.9 $\mu g/m^3$ for non-rush hours. They also indicated that traffic volumes and flow conditions are key factors influencing the levels of benzene at roadsides while seasonal variations are not as important as in many other cities.

Although VOC measurements and monitoring at roadsides have been conducted in the metropolitan Bangkok area, in-vehicle levels of VOCs are still lacking. Everyday, more than 2 million people commute by public transportation, including buses, electric sky trains, and passenger boats. Therefore, this study examines concentrations of benzene, toluene, ethylbenzene, and *m,p*-xylene (BTEX) within these public transportation fleets. The study routes cover most of the center city, commercial and business areas, and heavy traffic density areas in Bangkok.

1 Materials and methods

1.1 Selected transport modes and routes

BTEX measurements were conducted in air-conditioned (A/C) buses, non-air-conditioned (non-A/C) buses, electric sky trains, and passenger boats. A/C and non-A/C buses were both full size with a seating capacity of 45, and manufactured in early 1990. Both types run on diesel fuel, but A/C buses have EURO II compliant engines. The sky trains, in service since 1999, use dual tracks and run on motors electrified via a third rail. Each train consists of three passenger compartments and contains a centrally controlled air-conditioning system with a combined capacity of 1000 passengers. The sky train services more than 400,000 people every day. The tracks are elevated about 11 meters above the study bus routes. Known as an alternative way of commuting through downtown Bangkok, 90-seat passenger boats run along the Saen Saeb canal which covers many commercial and business areas. These traditional long-tailed boats are powered by a large diesel engine with an exhaust pipe directed at the rear side. The boats have roof racks and are naturally ventilated. This canal boat service carries over 40,000 people every day. Table 1 shows measured routes for each public transportation mode, the average journey time, and the number of vehicles and samples. A total of 75 samples were collected in this study, excluding field blanks.

Routes A, B, and C were selected for A/C and non-A/C buses, while Route D was adopted for sky trains and Route E for boats. All studies routes run through downtown of Bangkok, covering the most important commercial and business areas. Figure 1 shows a map of the study routes. Characteristics of each route are the follows:

Route A (Paholyothin Road) is 8.8 km long. The buses start at the north bus terminal, passing though the park, commercial and business areas, and ending at the Victory Monument, which is one of the primary bus destinations in city. The traffic density during the rush hours is 3500 vehicles per hour (DOTAT, 2003).

Route B (Sukumvit Road) is 8.3 km long. The route passes through major business and commercial areas and crowded shopping centers. The road is surrounded by tall business buildings, shopping malls and apartments. The traffic density during rush hours is 5300 vehicles per hour (DOTAT, 2003).

Route C (Petchburi-Ramkhamheang Road) is 9.4 km long. The buses start at crowded shopping center and pass through commercial and business areas. The traffic density during rush hours is 5600 vehicles per hour (DOTAT, 2003).

Route D, a sky train route, follows route A and B. The total distance is 15 km.

Route E, a boat route, is 13.4 km long. The route follows the Saen Saeb canal path, parallel route C, and then westward into residential area located along the canal. There is no commuter boat other than the study long-tailed boats running along the canal.

Table 1 Description of sample collection for each transportation mode

Transportation mode	Route	Journey time (min)	Vehicle number	Number of samples [a]
A/C bus (windows closed)	A	41	5	10
	B	61	5	9
	C	55	5	9
Non-A/C bus (windows open)	A	46	5	9
	B	59	5	10
	C	50	5	10
Sky train [b]	D	61 [c]	4	8
Boat	E	46	5	10

[a] Field blanks were excluded; [b] samples were collected for round trips; [c] journey time represents round trips.

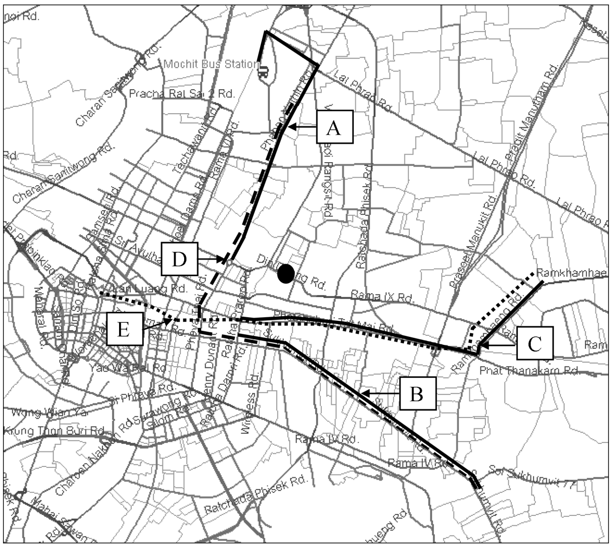

Fig. 1 Map of the study routes. Routes A, B, and C are the bus routes (solid lines); route D is the sky train route (dash line); route E is the boat route (dot line). The solid circle is the fixed monitoring site station at Dindaeng.

Bangkok is influenced by two seasonal monsoons including the southwest (March–October) and northeast monsoons (November–February). Thus, air samplings on all study routes were conducted during May, July, August 2007, and February 2008 to cover both seasonal monsoons. Routes were not simultaneously monitored due to limitation of equipment. However, each vehicle cruising on the same route was monitored in both morning and evening rush hours. In-bus samplings during these two sampling rush-hour periods were conducted for both inbound and outbound ways. The average ambient temperature was 27–30°C. The average relative humidity was relatively constant between 70% and 77% which should correct for any possible humidity effect on adsorption efficiency. It was not raining during sample collection periods.

1.2 Sampling and analysis

Glass tubes (70 mm long, 6 mm O.D.), containing two sections of 100/50 mg of 20/40 mesh size charcoal carbon (SKC Inc., USA), were placed at 1 m height within the breathing zone of commuter to collect BTEX in the study vehicles as shown in Fig. 2. The sampling location was chosen to be at the middle front of all vehicle cabins to reduce the direct effects of bus/train doors and boat engine emissions. A personal sampling pump (Model 224-PCXR4, SKC Inc., USA) was used to draw air of approximately 8–12 L, depending on each journey time, at a flow rate of 0.2 L/min. Flows were measured using a thermal mass flowmeter (TSI Inc., USA) and variation in sampling flow between the starting and ending periods was less than 6%. The tubes were then stored at 4°C until analysis. BTEX adsorbed in the charcoal tubes were desorbed with 1 mL of carbon disulfide (Merck & Co., Inc., USA). The vials were then sealed immediately and horizontally shaken for 24 hr. A 4-μL aliquot was then injected on a gas chromatography-mass spectrometer (Shimadzu Co., Japan) with helium as the carrier gas for separation in a Rtx®5-ms fused silica column with 0.25-μm thickness of stationary phase and 30-m length (Restek Co., USA). The oven temperature was raised from 35 to 60°C at 5°C/min and held for 4 min, and then raised to 80°C at 5°C/min and held for 1 min.

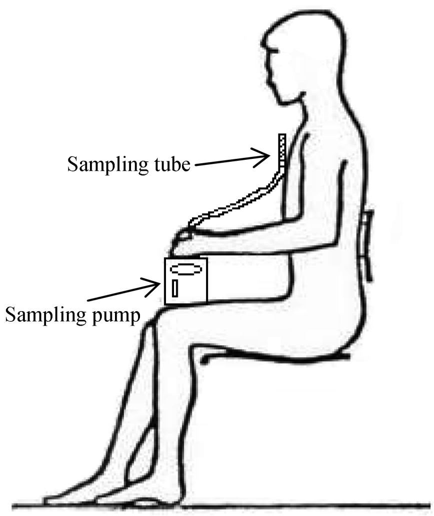

Fig. 2 A sketch of sampling system.

Duplicate samples were collected on each vehicle to assure the reliability of sampling and analytical methods. Field blank samples were also included in the study. Sorbent in back section of the sample tubes was analyzed with no breakthrough. Field blanks were tested with no significant contamination for BTEX. The method detection limits (MDL) followed the US EPA (2004) guideline procedure. The MDLs of measured benzene, toluene, ethylbenene, *m,p*-xylene were 1.96, 0.49, 0.50, 0.48 $\mu g/m^3$, respectively, based on air volume of 12 L. Sample recovery efficiency for extraction process was (76 ± 19)% for toluene. Analytical precision was found to be 15.6% for benzene and less than 3.8% for TEX. In this study, SPSS® version 12.0 for Windows was used to perform all statistical analyses. Values of non-detects were set to be MDLs.

2 Results and discussion

2.1 Temporal variation of ambient VOC levels

Meteorological and traffic conditions can influence dispersion and levels of vehicle-related pollutants in particularly non-A/C buses. Although diurnal variations of ambient BTEX levels were not performed in present study, results by Leong et al. (2002) showed that average benzene hourly concentrations measured at four busy roads in Bangkok were high during morning and evening peak hours (7:00–9:00 a.m. and 4:00–6:00 p.m.). The concentrations during these two peak hours were not significantly different. In addition, there is little difference in benzene ambient concentrations during weekdays (January–December), but high variation between weekdays and weekends.

Figure 3 shows month-to-month variation of target BTEX levels in non-A/C buses. The datasets were obtained from two sample collections in May 2007 and February 2008, which covered two seasonal monsoons. During the southwest monsoon (March–October), the weather is generally cloud and rain. These conditions can limit dispersion. In contrast, during the northeast monsoon (November–February), the weather is clear and sunshine which can enhance dispersion. In this study, however, there is no statistical difference in concentration in non-A/C bus between the two seasonal monsoons. The results may have also been affected by the limited number of samples. Little temporal variation in ambient and in-bus concentrations in Bangkok could be due to its tropical location (13.75°N, 100.51°E), of which the weather is fairly consistent. Traffic conditions may be a more important contributor to levels of vehicle-related pollutants than meteorological conditions.

2.2 Comparison among in-vehicle levels

The levels of BTEX measured in four transportation modes were found to vary significantly during rush hours. Table 2 shows the median and mean concentrations of in-vehicle BTEX and standard deviations. Benzene levels were found to be higher in A/C and non-A/C buses and

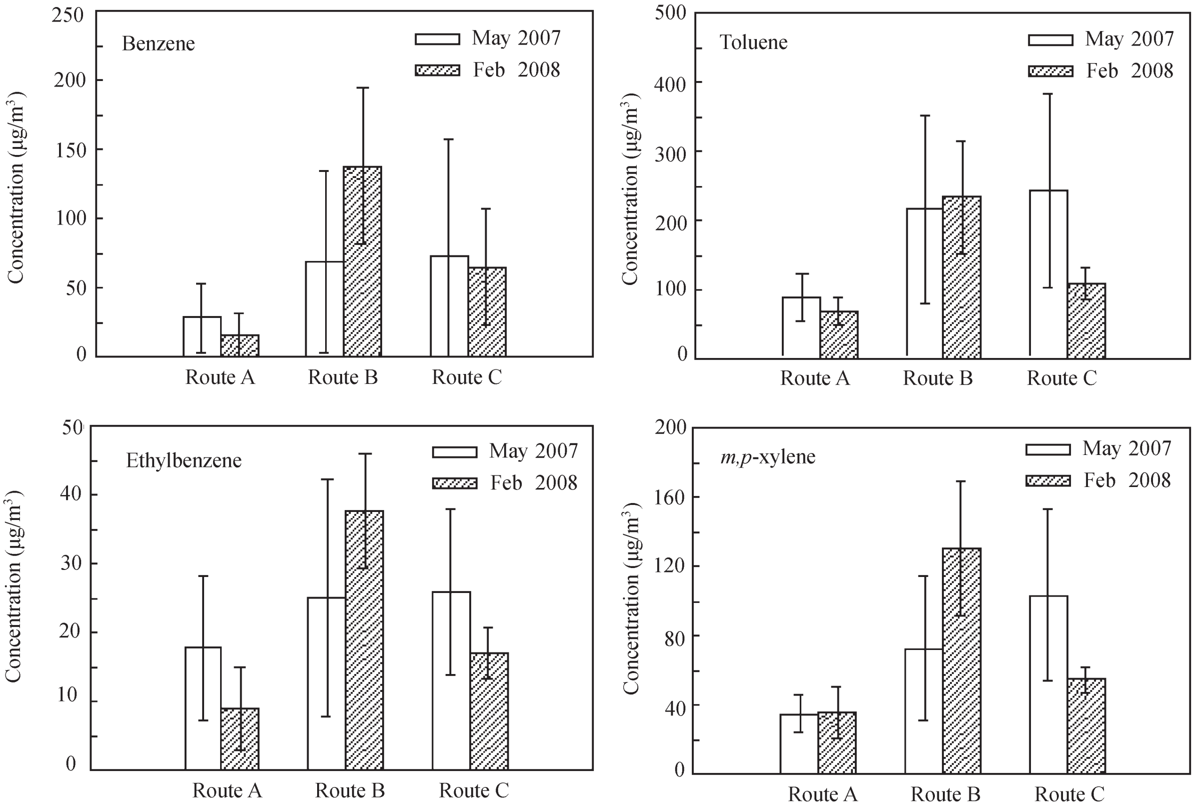

Fig. 3 Month-to-month variation of BTEX concentrations in non-A/C bus on each bus route. Uncertainty range shown is based on one standard deviation of measured samples.

Table 2 In-vehicle concentrations of BTEX and standard deviations

Transportation mode	Route	Benzene (μg/m^3)	Toluene (μg/m^3)	Ethylbenzene (μg/m^3)	*m,p*-Xylene (μg/m^3)
A/C bus	A	10.9/2.6/14.3	84.6/81.5/13.6	4.7/0.5/5.1	28.0/27.7/14.1
	B	55.7/49.5/59.4	503/189/690	24.1/24.2/14.4	70.0/81.2/27.2
	C	50.7/66.4/39.1	139/129.3/71.5	16.2/13.6/17.2	45.2/44.7/39.8
Non-A/C bus	A	24.7/22.2/24.2	88.5/90.1/32.9	9.9/10.2/9.2	36.4/37.6/12.1
	B	82.9/87.1/64.6	216/188/126	24.6/30.0/18.9	97.1/91.4/52.9
	C	63.2/64.3/75.9	212/155/142	22.2/19.5/10.3	86.0/61.1/45.9
Sky train	D	13.2/2.0/17.4	39.5/36.9/21.5	0.5/0.5/4.2	1.0/0.5/8.3
Boat	E	45.5/3.1/63.3	65.7/58.5/27.7	3.9/0.5/5.6	8.4/6.2/9.6

Data are expressed as mean/median/standard deviation.

passenger boats. The median concentrations of toluene ranged from 36.9 in the sky trains to 189 μg/m^3 in A/C buses. The in-bus levels of ethylbenzene and *m,p*-xylene were also higher than that in the sky trains and boats. Note that self-contamination in each vehicle cabin was not evaluated in this study. However, both studied A/C and non-A/C buses with the same models were selected. They were all the most recent models, operating properly while cruising. The use of the same bus models helps to correct for the possibility of self-contamination and differences among buses (Batterman et al., 2002).

The Kolmogorov-Smirnov one sample test showed that some of the datasets were not normally distributed at the significant level of 0.05 (Hayter, 2007). Thus, all comparisons were statistically evaluated using Wilcoxon rank sum test since it is a nonparametric test designed for the evaluation of datasets that are not normally distributed (Hayter, 2007). Table 3 shows the *p*-values for Wilcoxon rank sum test indicating the different levels of BTEX among the transportation modes. The in-sky train levels of toluene and *m,p*-xylene were statistically less than that in both A/C and non-A/C buses. Although the benzene and

Table 3 *p*-Values for Wilcoxon rank sum test indicating significant differences between a pair of transportation modes

Mode	Non-A/C bus				Sky train				Boat			
	B	T	E	X	B	T	E	X	B	T	E	X
A/C bus[a]	0.31	0.26	0.35	0.03*	0.72	0.01*	0.29	0.01*	0.75	0.09	0.17	0.01*
Non-A/C bus[a]					0.07	0.04*	0.08	0.01*	0.61	0.11	0.24	0.01*
Sky train									0.23	0.33	1.00	0.69

* Significant difference at the 0.05 level; [a] *p*-values were calculated from in-bus concentrations of all routes.

ethylbenzene levels in the sky trains and non-A/C buses were not statistically different ($p < 0.05$), the p-values were lower than those obtained from the comparisons of the sky trains with other transportation modes. This may indicate that vehicle-traffic-generated BTEX only weakly contributes to the in-sky train levels due to its elevation above the traffic.

The in-boat levels of BTEX were not as high as those of the buses due to the strong wind while the boat was moving. This helped to reduce peak concentrations of the exhaust. However, we observed that air quality decreased significantly when the boat was motionless at piers. The exhaust smoke was not dispersed and it could enter the boat cabin. Thus, exposure to pollutants in boats may be more episodic and peak concentrations may be high in this transportation mode.

2.3 Route-to-route variation

Figures 4 and 5 are box plots of BTEX levels in the A/C and non-A/C buses, respectively, for routes A, B, and C. The sky train and boat routes are not taken into consideration since they do not actually represent the ground-traveling route. The figures also indicate a p-value obtained from comparison among three bus routes for each compound.

Comparison among bus routes indicated that there was no statistical difference among A/C buses on all study routes for benzene, toluene, and *m,p*-xylene ($p < 0.05$). Ethylbenzene concentration was found to be statistically lower in A/C buses on route A than that on routes B and C. In contrast to A/C buses, levels of TEX in non-A/C bus were statistically different among the three bus routes. The median concentrations in non-A/C bus on route A were lower than that on routes B and C. This could be due to less flow conditions and traffic density of 3500 vehicles per hour on route A as compared with 5300 and 5600 vehicles per hour on routes B and C, respectively (DOTAT, 2003). Although the in- and out-A/C bus relationships were not performed to determine relative strength of sources in this study, similar results were found between A/C and non-A/C buses. Both A/C and non-A/C buses on route A appear to have the lowest median concentrations of BTEX. Thus, traffic conditions may influence BTEX levels in A/C bus.

2.4 Fixed site

The Environmental Research and Training Center of the Pollution Control Department had monitored ambient VOCs at five roadside fixed site stations in Bangkok during November 2006 to August 2007. Air samples were collected for 24 hr once a month using the TO-14A and TO-15 methods (US EPA, 1999a, 1999b). Table 4 shows BTEX concentrations obtained from the Dindaeng roadside station centrally located within area of the study vehicle routes. Ratios of the in-bus study average to fixed site 10-month average concentrations were also provided in Table 4. For all VOCs, in-bus concentrations were significantly greater than fixed site levels. The average concentrations of in-bus BTEX also exceeded the maximum levels of the roadside monitoring station.

2.5 Benzene to toluene ratio

The toluene levels measured in buses running on three study routes were relatively high than benzene levels. The benzene to toluene ratios (B/T) for A/C and non-A/C bus were 0.16 and 0.32, respectively. These ratios were calculated from the average benzene and toluene concentrations obtained from all three-bus routes. According to the study of Suwattiga and Limpaseni (2005), who conducted the

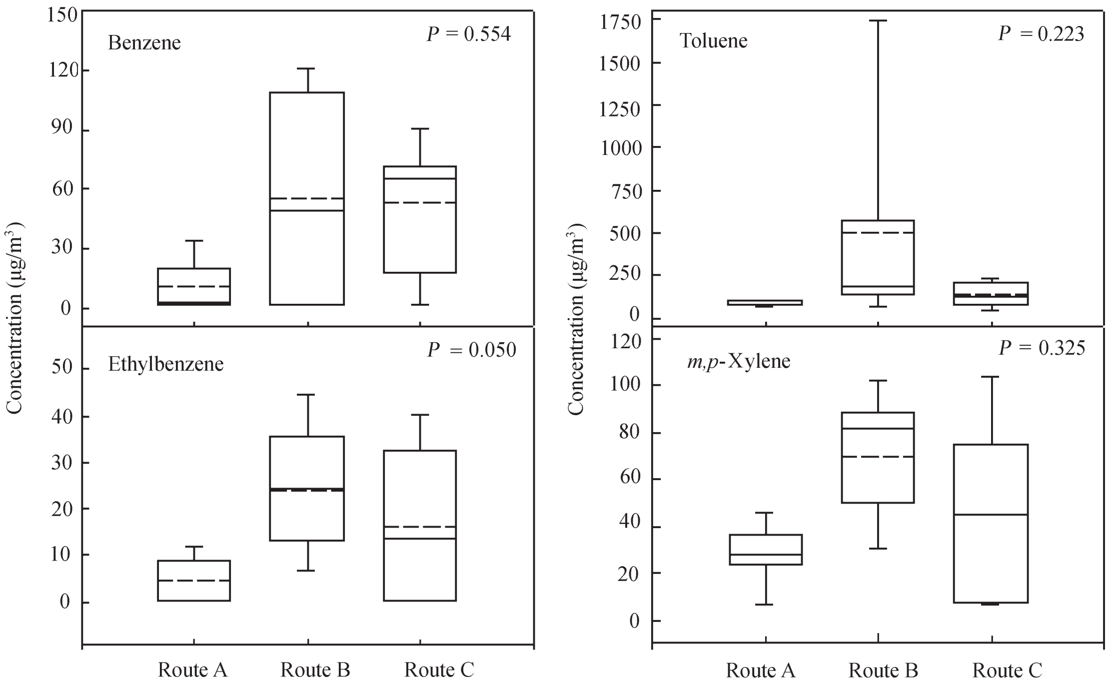

Fig. 4 Box plots of levels in A/C bus with respect to each bus route. The boundary of the box indicates the 25th and 75th percentile. The solid and dash lines within the box mark the median and mean, respectively. The solid bars indicates the 10th and 90th percentile.

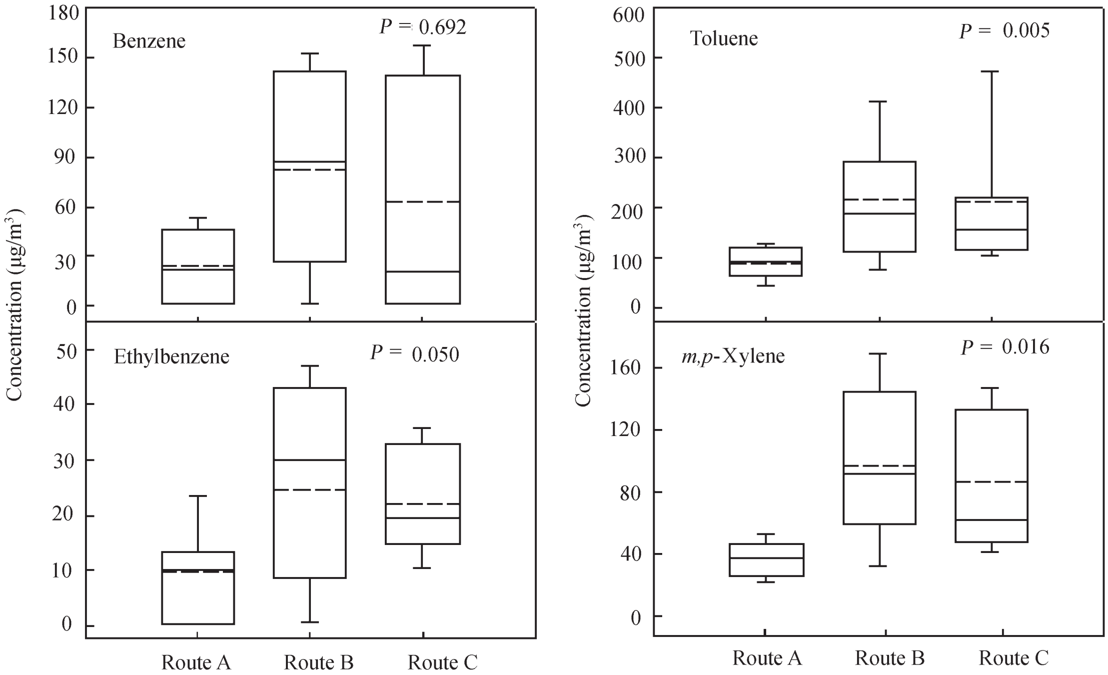

Fig. 5 Box plots of bus BTEX levels in non-A/C with respect to each bus route. The boundary of the box indicates the 25th and 75th percentile. The solid and dash lines within the box mark the median and mean, respectively. The solid bars indicates the 10th and 90th percentile.

Table 4 BTEX 24-hr concentrations measured at the fixed site monitoring station (Dindaeng) and BTEX ratios of the study average to fixed site 10-month average concentrations

	Concentration[a] (μg/m^3)			Ratio[b]		
	Mean	Max	Min	(1)	(2)	(3)
Benzene	10.1	15	5.5	4.6	3.1	8.5
Toluene	44	71	11	4.7	2.9	18.8
Ethylbenzene	5.2	9.2	1.4	3.3	1.8	12.1
m,p-Xylene	20.3	37	8.3	3.0	1.6	7.3

[a] Measurements were conducted by the Environmental Research and Training Center, Pollution Control Department of Thailand once a month during Nov 2006 to Aug 2007 (PCD, 2008b).
[b] (1) ratio of in-bus mean to fixed site mean; (2) ratio of in-bus mean to fixed site max; (3) ratio of in-bus mean to fixed site min.

emission inventory of VOCs in Bangkok ambient air, in which the emission source profiles showed that benzene, toluene, and *m,p*-xylene made up most of the fractions of total 18 study VOCs for tail-pipe emissions from gasoline vehicles. The B/T ratio obtained from this emission inventory was 0.35, while the B/T ratio determined from roadside station measurements was 0.20 (PCD, 2006). In this study, the B/T ratio for the concentrations in non-A/C bus was relatively close to the range of 0.20–0.35. Thus, the major sources of BTEX in non-A/C buses may be exhaust emissions from gasoline vehicles.

The B/T ratio of A/C buses was relative low to that reported for exhaust emissions and roadside measurements, which suggests that in-bus sources may contribute to the high abundance of toluene. Toluene is emitted from many consumer products including paints, coatings, adhesives, and cosmetics (IPCS, 1986). The B/T ratio of the sky trains was 0.33, and 0.81 for the passenger boats. The relatively close ratio of the sky trains to those of the non-A/C buses and tail-pipe emissions indicate that the influence of traffic-related air pollution on indoor air quality of the sky trains is not negligible even though the concentrations were much lower than that in the buses. The elevated tracks are right above the bus routes A and B. The infiltration of outdoor air pollutants could occur mainly during door opening at the train stations that are about 7 m high above the ground level. The boat B/T ratio was found to be the highest. This may be due to different fuel types used, diesel versus gasoline. The similar study of Suwattiga and Limpaseni (2005) showed that the fraction of benzene was higher than that of toluene in tail-pipe emissions from diesel vehicles and the B/T ratio was 1.4.

2.6 Comparison among cities

The average in-bus concentrations of BTEX in current study were significantly higher than those in oversea studies, particularly benzene and toluene. For example, the benzene level in Bangkok buses was 11, 8, and 2 times, while the toluene level was 23, 3, and 2 times higher than those in Detroit, Hong Kong, and Mexico City, respectively (Table 5). Gee and Sollars (1998) studied the ambient air levels of VOCs in Bangkok during 1995 and 1996. They found a significantly high level of toluene up to 186 μg/m^3 as compared to much low levels of 15–30 μg/m^3 measured in the cities of Latin America. They suggested that the high abundance of toluene in Bangkok was particularly due to the higher aromatic content in unleaded fuel. Schuetzle et al. (1994) indicated that a higher aromatic content can increase tail-pipe emission levels of benzene, toluene, and other aromatic fuel components due to a dealkylation reaction and the release of unburned fuel. In Thailand, aromatic compounds and benzene account for 35% and 3.5% by volume of unleaded fuel, which is much higher than the 24% and 0.48% for gasoline used in

Table 5 Comparison of mean in-bus concentrations of BTEX among cities (μg/m^3)

City	Benzene	Toluene	Ethylbenzene	*m,p*-Xylene	Reference
Bangkok, Thailand	46.5 (39.0, 54.9)	207 (242, 174)	17.0 (15.0, 19.0)	60.9 (47.8, 73.6)	Current study
Hong Kong, China	5.5 (6.1, 4.8)	63.6 (72.9, 54.3)	5.0 (6.9, 3.1)	6.4 (8.9, 3.8)	Lau and Chan, 2003
Guangzhou, China	12.4 (13.5, 11.3)	56.3 (63.6, 48.9)	8.3 (8.2, 8.3)	10.6 (10.5, 0.6)	Chan et al., 2003
Mexico City, Mexico	23.6	110	17.8	54.0	Shiohara, 2005
Taegu, Korea	21.1	79.0	7.1	17.6	Jo and Yu, 2001
Detroit, Michigan	4.1	9.0	2.1	9.1	Batterman et al., 2002
Dublin, Ireland	7.0[a]				O'Donoghue et al., 2007

Numbers in parentheses denote concentrations in A/C and non-A/C buses, respectively.
[a] Converted from 2.21 ppb.

the United States, respectively (DOEB, 2008; Harley and Kean, 2004). In addition, gasohol with octane of 95, which is increasingly used in Thailand, was allowed aromatic content up to 42% before 1 January 2008 due to limitations of the refinery system. However, new rules reduce the aromatic content to 35%.

The two million motorcycles in Bangkok are also a major contributor to benzene emissions (DLT, 2006). PCD (2008a) reported that 37% of annual benzene emission from vehicles was from motorcycles, while 16% from passenger cars. Leong et al. (2002) found that the two-stroke units, which are more prevalent in Thailand, emit benzene at rates five times greater than that from four-stroke units. Light and duty diesel vehicles also contributed to 47% of annual benzene emission from vehicles (PCD, 2008a). Other contributors to the high abundance of BTEX include massive traffic congestion. In this study, route A had a lower traffic density than the other two bus routes, and lower concentrations were observed for route A (Table 2). Traffic conditions appeared to be a very important contributor to levels of vehicle-related pollutants. Leong et al. (2002) also indicated that ambient benzene concentrations measured in each traffic zone of Bangkok metropolitan region during rush and non-rush hours were significantly different. They found the higher benzene concentrations among roadside stations with slow movement of vehicles than those with fast moving traffic. During the rush hours, traffic moves more slowly, and thus, larger amounts of vehicle-related pollutants are emitted. Similarly, Tamsaya and Chungpaibulpatana (2009) indicated that the idle mode accounts for the highest proportion of 37.7% of the Bangkok driving characteristic. In addition, the narrow roads surrounded by tall buildings and platforms of the sky train stations, which is referred to as street canyons, can reduce natural dispersion by the atmosphere, which in turn could enhance the levels of tail-pipe emissions at the roadsides (Vardoulakis et al., 2003).

3 Conclusions

This study investigated the actual commuter exposure to BTEX in four transportation modes in Bangkok. The results showed significantly higher levels of BTEX in both A/C and non-A/C buses than in sky trains or passenger boats. The air inside sky trains had significantly low concentrations of toluene and *m,p*-xylene. There were statistical differences in TEX concentrations among the bus routes in the non-A/C buses based on the limited number of samples in large vehicle-to-vehicle variation. Comparison among metropolitan cities revealed that Bangkok bus commuters are exposed to the high levels of BTEX compounds. This may be due to the high aromatic content fuel and severe traffic congestion.

The PCD of Thailand has implement control measures for air pollution caused by VOCs in Bangkok. These measures are part of a policy framework on VOC management in Thailand. The measures include VOC monitoring along roadsides and other areas since 2003, development of new emission standards for gasoline- and diesel-engine vehicles and motorcycles, reformulation of fuel properties, and implementation of control ordinance for petroleum storage facilities located in Bangkok and urban area. However, the traffic problems, which are a major contributor, have been alleviated little by construction of more surface road area in past decades. This is because the number of private vehicles on the roads has increased much more rapidly. A complete network of mass transit systems along with control measures for private vehicles is necessary to alleviate traffic congestion and air pollution in Bangkok.

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