HEALTH RISK ASSESSMENT OF CARBONYL COMPOUNDS AND BTEX AMONG HIGHLY EXPOSURE WORKERS IN THE INNER CITY OF BANGKOK

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การประเมินความเสี่ยงต่อสุขภาพของกลุ่มผู้ประกอบอาชีพที่มีโอกาสรับสัมผัสสารประกอบคาร์บอนิลและบีเทคในปริมาณสูง บริเวณเขตเมืองชั้นในกรุงเทพมหานคร

นางสาวนวพร กาญจนศิรานนท์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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นวพร กาญจนศิรานนท์ : การประเมินความเสี่ยงต่อสุขภาพของกลุ่มผู้ประกอบอาชีพที่มีโอกาสรับสัมผัสสารประกอบคาร์บอนิลและบีเทคในปริมาณสูง บริเวณเขตเมืองชั้นในกรุงเทพมหานคร (HEALTH RISK ASSESSMENT OF CARBONYL COMPOUNDS AND BTEX AMONG HIGHLY EXPOSURE WORKERS IN THE INNER CITY OF BANGKOK) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร. ทรรศนีย์ พฤกษาสิทธิ์, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ดร. เดซี่ หมอกน้อย, 196 หน้า.

การศึกษาตรวจวัดสารบีเทคและสารประกอบคาร์บอนิลในตัวอย่างอากาศที่ผู้ประกอบอาชีพห้าอาชีพรับสัมผัสและในอากาศ ณ บริเวณที่ปฏิบัติงานในเขตปทุมวัน กรุงเทพมหานคร ประเทศไทย ซึ่งเป็นพื้นที่ที่มีการจราจรหนาแน่น โดยได้ดำเนินการในช่วงฤดูร้อนและฤดูฝนของปี พ.ศ.2555 ถึง 2557 พร้อมทั้งทำการประเมินความเสี่ยงของกลุ่มผู้ประกอบอาชีพทั้งห้าอาชีพ โดยแบ่งเป็น (1) กลุ่มอาชีพที่ทำงานบริเวณริมถนน ได้แก่ พ่อค้าแม่ค้า จักรยานยนต์รับจ้าง และเจ้าหน้าที่รักษาความปลอดภัย (2) กลุ่มอาชีพตำรวจจราจรที่ทำงานบริเวณแยกจราจร และ (3) กลุ่มเจ้าหน้าที่สำนักงานที่ทำงานภายในอาคาร ผลการศึกษาพบว่า ระดับความเข้มข้นเฉลี่ยของสารบีเทคในอากาศ ณ บริเวณที่ปฏิบัติงานของพ่อค้าแม่ค้า จักรยานยนต์รับจ้าง เจ้าหน้าที่รักษาความปลอดภัย ตำรวจจราจร และเจ้าหน้าที่สำนักงาน เท่ากับ 213.95±200.17, 172.42±188.26, 118.34±92.23, 2563.19±921.06 และ 439.33±176.39 ไมโครกรัมต่อลูกบาศก์เมตร ตามลำดับ สำหรับค่าความเข้มข้นของสารฟอร์มัลดีไฮด์และอะเซทัลดีไฮด์มีค่าเท่ากับ 10.65±4.77, 14.19±10.72, 8.25±3.30, 17.44±8.20, 26.48±14.18 ไมโครกรัมต่อลูกบาศก์เมตร และ 5.81±5.54, 5.70±3.21, 2.49±1.54, 43.13±35.06, 8.73±4.91 ไมโครกรัมต่อลูกบาศก์เมตร ตามลำดับ จากการเปรียบเทียบพบว่า ตำรวจจราจรได้รับสัมผัสสารบีเทคและอะเซตัลดีไฮด์ในระดับสูงที่สุด (1,990.59±942.30, 11.06±11.00 ไมโครกรัมต่อลูกบาศก์เมตร) ส่วนเจ้าหน้าที่สำนักงาน ได้รับสารฟอร์มัลดีไฮด์ในระดับสูงที่สุด (23.31±12.41 ไมโครกรัมต่อลูกบาศก์เมตร) ผลการประเมินความเสี่ยงต่อสุขภาพพบว่า ค่าความเสี่ยงรวมจากการรับสัมผัสสารที่ก่อให้เกิดมะเร็งอันประกอบด้วยบีเทค เอธิลเบนซิน ฟอร์มัลดีไฮด์ และ อะเซทัลดีไฮด์ของตำรวจจราจร มีค่าอยู่ในระดับสูงที่สุด (2.64E-04 to 4.21E-04) รองลงมาได้แก่ เจ้าหน้าที่รักษาความปลอดภัย (1.44E-05 to 3.72E-05) พ่อค้าแม่ค้า (8.77 E-06 to 2.52E-05) จักรยานยนต์รับจ้าง (5.00E-06 to 2.13E-05) และเจ้าหน้าที่สำนักงาน (8.49E-06 to 1.58E-05) ตามลำดับ สำหรับค่าความเสี่ยงรวมต่อการเกิดโรคอื่นๆ ที่ไม่ก่อมะเร็งของผู้ปฏิบัติงานทั้งห้าอาชีพ มีค่าไม่เกินค่าที่ยอมรับได้ ผลการวิเคราะห์แนวทางในการลดค่าความเสี่ยงจากการรับสัมผัสสารมลพิษอากาศเหล่านี้ พบว่า การสวมใส่หน้ากากขณะปฏิบัติงานเป็นวิธีที่สามารถลดการสัมผัสของสารเหล่านี้ได้ดีที่สุด แม้ว่าจะไม่สามารถลดได้ถึงระดับค่าที่ยอมรับได้ในอาชีพตำรวจจราจรและเจ้าหน้าที่รักษาความปลอดภัยก็ตาม จากการศึกษาการรับรู้ความเสี่ยงและการสื่อสารความเสี่ยง โดยใช้แบบสอบถามความรู้และทัศนคติ พบว่า กลุ่มผู้ประกอบอาชีพส่วนมากมีความเข้าใจและตระหนักต่อผลกระทบต่อสุขภาพมากขึ้นจากการให้ความรู้ผ่านการสื่อสารความเสี่ยง และมีแนวโน้มที่จะป้องกันตัวเองจากการรับสัมผัสสารบีเทคและสารประกอบคาร์บอนิล การประเมินผลการศึกษาทางสถิติพบว่า ในกลุ่มพ่อค้าแม่ค้า การได้รับความรู้เรื่องมลพิษอากาศส่งผลต่อทัศนคติด้านมลพิษอากาศ ส่วนความรู้เรื่องความเสี่ยงส่งผลต่อทัศนคติด้านความเสี่ยงเฉพาะในกลุ่มจักรยานยนต์รับจ้างและตำรวจจราจร และการได้รับความรู้โดยรวมทั้งด้านมลพิษอากาศ ความเสี่ยงและการปฏิบัติตนส่งผลต่อทัศนคติด้านการปฏิบัติในกลุ่มจักรยานยนต์รับจ้าง และเจ้าหน้าที่รักษาความปลอดภัย และตำรวจจราจร

สาขาวิชา	การจัดการสิ่งแวดล้อม	ลายมือชื่อนิสิต	....
ปีการศึกษา	2558	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
		ลายมือชื่อ อ.ที่ปรึกษาร่วม	....

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KEYWORDS: BTEX / HEALTH RISK ASSESSMENT / CARBONYL COMPOUNDS / BANGKOK / TRAFFIC

NAVAPORN KANJANASIRANONT: HEALTH RISK ASSESSMENT OF CARBONYL COMPOUNDS AND BTEX AMONG HIGHLY EXPOSURE WORKERS IN THE INNER CITY OF BANGKOK. ADVISOR: ASST. PROF. TASSANEE PRUEKSASIT, Ph.D., CO-ADVISOR: DAISY MORKNOY, Ph.D., 196 pp.

BTEX and CCs (carbonyl compounds) were detected for the ambient air and personal exposure of five workers who worked in Pathumwan district, Bangkok, Thailand, a traffic intensive urban area in both summer and rainy seasons of the year 2012 to 2014. Health risk assessments of the outdoor workers at roadside area (street vendors, motorcycle taxi drivers and security guards), the outdoor workers at road intersection (traffic policeman), and the indoor workers were estimated. The results showed that the mean ambient air BTEX levels of street vendors, motorcycle taxi drivers, security guards, traffic policemen and indoor workers were 213.95±200.17, 172.42±188.26, 118.34±92.23, 2563.19±921.06 and 439.33±176.39 μg/m^3, whereas, those of formaldehyde were 10.65±4.77, 14.19±10.72, 8.25±3.30, 17.44±8.20, 26.48±14.18 μg/m^3, and 5.81±5.54, 5.70±3.21, 2.49±1.54, 43.13±35.06, 8.73±4.91μg/m^3 for acetaldehyde. For personal exposure sample, traffic policemen were contained the highest concentrations of BTEX (1,990.59±942.30 μg/m^3) and acetaldehyde (11.06±11.00 μg/m^3), however, the indoor workers showed the greatest value of formaldehyde (23.31±12.41 μg/m^3). For the health risk assessment, traffic policemen had the greatest total cancer-risk level of benzene, ethylbenzene, formaldehyde and acetaldehyde (2.64E-04 to 4.21E-04) followed by security guards (1.44E-05 to 3.72E-05), street vendors (8.77 E-06 to 2.52E-05), motorcycle taxi drivers (5.00E-06 to 2.13E-05), and indoor workers (8.49E-06 to 1.58E-05), respectively. For total non-cancer risk, the values of all workers were in an acceptable level. The scenario of risk reduction was expressed that the use of mask during the working time was the best way that can be decreased these toxic pollutants, however, total cancer risk level still greater than an acceptable value for security guards and traffic policemen. In view of risk perception and risk communication, knowledge (K) and attitude (A) questionnaires were conducted, and it was found that most workers were more understand and concerned on their health effect and tended to changed their practice to protect themselves from BTEX and CCs. For statistical analysis, the correlations between knowledge of air pollution of street vendors were affected on their attitude on air pollution. For health risk assessment part, the relationships between knowledge and attitude were found for motorcycle taxi drivers and traffic policemen. The associations between all parts of knowledge (air pollution, health risk assessment and practice) and attitude on practice were found for motorcycle taxi drivers, security guards and traffic policemen.

Field of Study:	Environmental Management	Student's Signature	....
Academic Year:	2015	Advisor's Signature	....
		Co-Advisor's Signature	....

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LIST OF ABBREVIATIONS

ACGIH	The American Conference of Government Industrial Hygienists
ANOVA	The Analysis of Variance
ARC	Faculty of Architecture
ART	Faculty of Arts
ATSDR	The Agency of Toxic Substances and Disease Registry
BBL	BBL Bank
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CC	Communication Center
CP	Chaloem Phao Junction
CCs	Carbonyl compounds
EC	Faculty of Economic
ED	Faculty of Education
EG	Faculty of Engineering
ERTC	Environmental Research and Training Center
GRA	Graduate School
HD	Henry Dunant Intersection
I	Indoor worker
IRIS	Integrated Risk Information System
KA	Knowledge and attitude
KTB	KTB Bank
M	Motorcycle taxi driver
MBA	Faculty of Commerce and Accountancy
OS	Osot Sala
P	Traffic policemen
PCD	Pollution Control Department
POL	Faculty of Political Science
PT	Pathumwan Intersection
RAIS	The Risk Assessment Information System
S	Security guard

SCB	SCB Bank
SCI	Faculty of Science
SY	Samyan Intersection
V	Street vendor
VOCs	Volatile organic compounds

CHAPTER I
INTRODUCTION

1.1 Rationale background and problem addressed

Nowadays, the traffic related air pollution was tended to be the major problem of Thailand especially in Bangkok. Bangkok is a high-density population city with the population around 5.7 million in 2015 (1). In Pathumwan district, a resident registration number was 50 thousands, approximately (2). Moreover, this population's number had the tendency to increase rapidly in the future and it was affected to the traffic problems in the inner city of Bangkok. Thus, the transportation sector especially for the vehicle was concerned as a significant impact from the high density of population. This situation was impacted to the traffic related air pollution that causing in poor air quality from the burning of fuel when the incomplete combustion of fuel (3-7). Hence, one of the major problems of this city was due to the traffic density that causing in the traffic-related air pollution. Volatile organic compounds (VOCs), the air pollutants from refueling of the transporter, were the main source in the ambient air (8). The air pollution from the traffic congestion was indicated as a main factor that can cause the human health effects in the city (9-14). Therefore, people who spent their lives at the crowded area had a high tendency of human health problems from the traffic-related air pollution via an inhalation route (15, 16).

It was found that VOCs were hazardous air components generating from the fuels combustion of the vehicles. VOCs were classified as air pollutants due to its toxicity. Carbonyl compounds (CCs) and BTEX (benzene, toluene, ethyl benzene and xylene), were the important components of VOCs with the significant air pollutants because of their toxicity. CCs were generated from the transportation sector due to the inefficient motors result (17). Many CCs especially for formaldehyde and acetaldehyde were carcinogens. Formaldehyde was classified as a B1 compound, probable human carcinogen (18), whereas acetaldehyde was classified in B2 compound, probable human carcinogenic (19). Likewise, BTEX were also concerned as a carcinogenic compound especially, benzene and ethylbenzene. The exposure to benzene in the environment had the probability of leukemia (20), while ethylbenzene is a possible cancer-causing substance and causes kidney damage.

According to their toxicity and the human health effects, the outdoor workers relating to the traffic-related air pollution of CCs and BTEX were concerned. These outdoor workers were mainly exposed to both carbonyl compounds and BTEX via an inhalation route. For BTEX, benzene exposure of the outdoor workers at the highly traffic jam area was come from the automobile exhaust and it can lead to an important occupational problem. According to the study of benzene exposure of the population living in different densely traffic jam area of Bangkok showed the lifetime unit risk factor ranges from 8.30E-08 to 1.58E-06 (21). Moreover, the evidence of occupational exposure to benzene from traffic-related air pollution in Bangkok, Thailand found that benzene levels of the cloth venders and grilled-meat vendors are 22.61 and 28.19 ppb, respectively. For the traffic-related air pollution of ambient air exposure to benzene at the heavily congested areas of Bangkok was 33.71 ppb (20). Bono et. al. (2003) (22) indicated the relationship between the traffic density and human exposure concentration of benzene in the high traffic areas in Northwestern Italy was 10.3 $\mu g/m^3$ while the low traffic areas was only 2.3 $\mu g/m^3$. Another study of benzene exposure of policemen in Parma, Italy was indicated the range of airborne benzene concentration was 0.28- 9.53 $\mu g/m^3$.

The same as BTEX, CCs in the ambient air are generated from motor exhaust gas of the vehicles especially for the incomplete combustion. The types of fuel can also affect to the CCs emission. The formation of formaldehyde and acetaldehyde are from the fuel containing methanol and ethanol, correspondingly. Other directed sources of CCs are from the industrial sources. Moreover, these compounds can be indirectly generated from the atmospheric photo-oxidation of VOCs from both anthropogenic and natural sources (17, 23). The ambient air of Shanghai, China contained the highest formaldehyde and acetaldehyde comparing with Beijing and Guangzhou. This result can be suggested to a direct relationship of traffic density. The formaldehyde and acetaldehyde levels of Shanghai were 19.40±12.00 and 15.92±12.07 $\mu g/m^3$, respectively (24). The ambient air in Bangkok measuring in five roadside sites and residential areas were shown the high amount of both formaldehyde and acetaldehyde. The average concentration of formaldehyde and acetaldehyde at the roadside areas were 11.53 and 3.51 $\mu g/m^3$ comparing with at the residential areas was 9.65 and 3.11 $\mu g/m^3$ (17).

From all above details, the outdoor workers who are working at the densely traffic jam area have the potential to contact with the traffic BTEX and CCs exposure during their daily work. Therefore, this study would be focused on the concentration levels of both CCs and BTEX. Moreover, the risk assessment of these air pollutants in outdoor workers would be also concerned and compared with indoor workers. Although, the indoor workers still had the risk assessment of these air pollutants such as CCs, many studies showed the indoor carbonyl concentrations in the residential area were high levels. Thus, CCs of the indoor workers were also concerned.

For CCs, it was found that formaldehyde was the most abundant in the indoor air (18). The sources of carbonyls in the indoor air were related to the building materials including the furniture, carpet, paints, curtain, wood composite, adhesive, etc. (25-28). Wang et al (29) showed the mean indoor formaldehyde concentration of residential areas in China which were 5.25 and 1.98 mg/m^3 in summer and winter, correspondingly. Furthermore, the average indoor formaldehyde concentration of the indoor workers in Mexico was varied between 11 to 97 $\mu g/m^3$ (30).

Likewise, BTEX is also found in the indoor environment. Normally, the BTEX concentration of outdoor was higher than that showed in the indoor especially for benzene. Several studies were pay an attention to both indoor and outdoor air quality (31-33). It was showed that the urban areas (high traffic area) gave higher benzene concentration than that found in the rural (low traffic area). The mean of indoors benzene concentrations were ranging from 6.0 to 13.4 and 13.1 to 24.6 μg/m^3 for ambient and personal levels, respectively (34). On the contrary, some studies found that the indoor BTEX concentrations were greater than those detected in outdoor air due to the limitation of their movement in closed area (35, 36). Hence, this study was concerned both the outdoor and indoor air concentrations of CCs and BTEX. Both outdoor and indoor workers who worked in the intensive traffic area were also investigated in order to concerned of their health risk causing from these traffic related air pollutants.

1.2 Objectives of the study

The purpose of this research is to assess the health risk of CCs and BTEX among highly exposure workers around Pathumwan district in Bangkok, Thailand. The major route of the outdoor workers who work at high density traffic area was an inhalation exposure. In this study, the target compounds of carbonyl group were investigated including formaldehyde, acetaldehyde, propionaldehyde, crotonaldehyde, butyraldehyde, benzaldehyde, valeraldehyde and hexanaldehyde. For the target compounds of VOCs, BTEX or benzene, toluene, ethylbenzene, m,p-xylene and o-xylene were investigated. There are four sub-objectives in this study as follows:

1) To examine the ambient air concentrations and personal exposure concentration of CCs and BTEX of the workers at roadside area in the inner city of Bangkok.
2) To estimate health risk of the outdoor workers who have high potential exposure to CCs and BTEX in the traffic congested urban area of Bangkok.
3) To compare the health risk level of exposure to CCs and BTEX among outdoor and indoor workers.

4) To investigate risk perception of the workers towards air quality and their related health risk, and examine the effectiveness of risk communication on their risk perception.

1.3 Hypotheses

1) The outdoor workers possess higher risk level from the traffic-related air pollution than the indoor workers in the heavily traffic congested areas of Bangkok.
2) The workers at a high density traffic area in Bangkok tend to have risks from BTEX and CCs via an inhalation exposure in their workplace.
3) Application of risk perception analysis and risk communication would increase in knowledge, changes in attitudes and practices of the workers towards traffic-related air pollution and risk reduction.

1.4 Scopes of the study

1.4.1 Study area

The location of this study was related to the traffic congested areas around Pathumwan district in Bangkok, Thailand, representing the air polluted urban areas. Four main roads of Pathumwan area were observed which included Phaya Thai Road, Rama IV Road, Henry Dunant Road and Rama I Road.

1.4.2 Selection of study subjects

The studied subjects were concerned of three groups of workers who work at the traffic congested areas around Pathumwan district. First were the outdoor workers at roadside area including street vendors, security guards and motorcycle taxis.

Secondly, the highly exposure groups at road intersection were focused on the traffic policemen. The last group of the studied part was the indoor workers.

1.4.3 Sampling technique for occupational exposure

A personal air pump connected to 2, 4 DNPH active cartridge and a charcoal tube was used for CCs and BTEX sampling, respectively. This pump was located at fixed site at the height of 1.5 m from the ground approximately and was operated at the flow rate of 100 ml/min. The sampling period was related to the working time and it was normally for 8 hrs a day.

For personal air sampling, non-smoking workers were chosen as a representative worker. The personal exposure samples were collected at the personal breathing zone to estimate the inhalation exposure.

1.4.4 Sampling duration and period

The sampling periods in all parts were assigned for dry and rainy seasons. For outdoor workers at roadside area were collected in September 2012 (wet season) and March 2013 (dry season), while the samples of traffic police and indoor groups were observed in April to May (dry season) and August to September 2014 (wet season).

1.4.5 Analytical techniques

The CCs were analyzed by High Performance Liquid Chromatography (HPLC/UV). BTEX samples were analyzed by gas chromatography equipped with a flame ionization detector (GC-FID).

1.4.6 Ethical consideration

The ethical consideration of this study was approved by the Ethical Review Committee for Research Involving Human Research Subjects, Health Science Group, Chulalongkorn University with the code number of 089.1/57.

1.5 Expected outcomes

The four main desired outcomes are as follows:

1) The investigation of ambient air concentrations of CCs and BTEX at the roadside areas around Pathumwan district,
2) The essential baseline of inhalation exposure to CCs and BTEX of the occupational workers around Pathumwan district in Bangkok,
3) The health risk information of the workers which can be utilized for further risk management and risk communication to prevent or reduce the risk from inhalation exposure to CCs and BTEX of the workers, and
4) The background knowledge which can be applied to further studies on the exposure to these compounds in other careers in Bangkok.

CHAPTER II
LITERATURE REVIEW

2.1 Chemical properties of the pollutants

2.1.1 Carbonyl compounds

Carbonyl compounds (CCs) are the components containing carbonyl groups which are divided into two classes. There is a group attached to the acryl groups (-R) that can function as a leaving group for class I while class II has no attached group to the acryl. For class II, aldehyde and ketone are the functional groups of carbonyl compounds, which the carbon atom connected to oxygen by a double bond. This double bond are the sensitive chemical reactions and polar because the electronegativity is different. The structure of carbonyl compounds with the groups of aldehydes and ketones are depended on the attached position to the carbon. The carbonyl group is on the middle of a chain of carbon for ketone group whereas it is on the terminal carbon atom. For aldehyde, a hydrogen group and an alkyl group are bonded to carbonyl carbon. On the other hands, the carbon atom is connected to two alkyl groups for ketone (see Fig. 2.1).

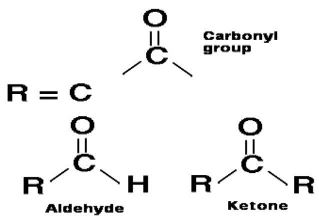


Figure 2.1 Chemical structures of carbonyl compounds
Source: U.S. EPA, 2007

1) Formaldehyde

Formaldehyde is one of the most abundant of carbonyl compounds in the atmosphere. The chemical formula of formaldehyde is CH_2O. The physical states of formaldehyde are odorous, colorless and clear gas. Furthermore, it is flammable and highly reactivity with various chemicals in order to heat, spark and flame. Moreover, it is readily polymerized under the room temperature and pressure. Normally, it is soluble in water, ether, and chloroform and miscible with diethyl ether.

2) Acetaldehyde

Acetaldehyde is an aliphatic aldehyde and the chemical formula is C_2H_4O. The physical states of acetaldehyde are pungent odor and colorless liquid. It is flammable liquid and miscible with water, ether, benzene, gasoline, solvent naphtha, toluene, xylene, turpentine, and acetone. Moreover, it is unstable in air and can dramatically polymerizes in the presence of trace amounts of metals or acids.

3) Propionaldehyde

Propionaldehyde is known as methylacetaldehyde or propanal. The chemical formula of propionaldehyde is C_3H_6O. The physical properties are clear colorless liquid and suffocating odor. This substance is a low-boiling and easily soluble in water, methanol, diethyl ether and acetone. The carbonyl group's polarity of propionaldehyde are indicated the capable of chemical reactions including an oxidation and a reduction.

2.1.2 BTEX

BTEX are aromatic hydrocarbon which consisting of benzene, toluene, ethylbenzene and the three xylene isomers. These substances are found in coal tar and petroleum products such as crude oil, and gasoline. BTEX are volatile organic compounds so they are commonly volatilized easily into the air. BTEX are indicated as hazardous pollutants due to their toxicity on both environment and human health. BTEX can dissolve in the water and most of them are floating on the water surface because of their density. The emissions from motor vehicles and aircrafts are major sources of BTEX. The chemical structures of BTEX are shown in Fig. 2.2.

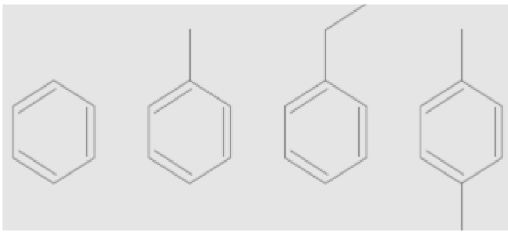


Figure 2.2 Chemical structures of BTEX
Source: U.S. EPA, 2009

1) Benzene

Benzene is an aromatic compound and the chemical formula is C_6H_6. Benzene is a highly unsaturated hydrocarbon because it has four degree of unsaturation. The physical properties of this substance are clear, colorless liquid with a sweet odor. It can slightly soluble in water and miscible with acetone, chloroform, diethylether and ethanol. Benzene is highly flammable and volatile liquid. Normally, benzene is used in many purposes especially the production process of plastic, oil, rubber and dyes.

2) Toluene

Toluene is known as toluol, methylbenzene or phenylmethane. It is a non-corrosive, flammable and volatile organic compound. Naturally, toluene is from crude oil. It is a clear, colorless with aromatic odor. It is a non-water-soluble so it is floating on the top of water. The chemical formula of toluene is C_7H_8. Toluene is used in several ways including the manufacturing of other products such as plastic, detergent, dye, perfume and inks. Furthermore, it is used as a solvent and aviation and automotive fuels.

3) Ethylbenzene

Ethylbenzene is known as ethylbenzol, α-methyltoluene and phenylethane. It is a clear and colorless organic liquid. Its odor is a gasoline and aromatic smell and also flammable. The chemical formula of Ethylbenzene is C_8H_{10}. It has a low potential to dissolve in water due to its solubility. For ethylbenzene usage, it mostly used for producing other chemical and styrene. Moreover, it is used as a fuel, solvent and for rubber and plastic production.

4) Xylenes

Xylenes or the other names are dimethyl benzene, xylol and methyltoluene. Xylenes are a mixture of meta-, ortho- and para-isomers (m-, o-, and p-Xylene). Their physical states are also clear and colorless liquid. Xylenes have strong smell the same as other aromatic solvents. They are flammable liquid and highly volatilization so they can evaporate to the air easily. Xylenes are used as solvents for paints, coatings, adhesive removers, and paint thinner production.

Meta-xylene (m-xylene) is known as 1,3-Xylol, m-xylol, m-dimethylbenzene or 3-methyltoluene. It is colorless liquid with a sweet odor. Its physical states are flammable, vaporizing liquid and its vapor is a source of flash fire and explosion when expose to heat or air. M-Xylene is insoluble in water.

Para-Xylene (p-Xylene) is known as 1,4-dimethylbenzene, 4-methyltoluene or 4-Xylene. It is clear, flammable liquid. It has an aromatic odor. Paraxylene is stable under normal conditions but its vapor can cause fire.

Ortho-Xylene (o-Xylene) is also indicated as 1,2-dimethylbenzol, 1,2-xylol, or 1,2-dimethylbenzene. It is a clear and colorless liquid. Its properties are the same as m,p-Xylene due to flammable and tend to volatile easily. It also insoluble water too.

2.2 Sources of emission of the pollutants

2.2.1 Carbonyl compounds

CCs are originated from primary and secondary sources which consisted of stationary and mobile sources. In the atmospheric environment, CCs were come from both natural and anthropogenic sources. The natural sources were volcano gases, animal excretions and forest fires, while the anthropogenic sources were comprised of petrochemistry, coal chemistry, plastics, coffee roasting, wood burning and waste incineration (37-44). The vehicles (incomplete combustion) are the primary source of CCs in an urban area, whereas the photo-oxidation of volatile organic compounds (VOCs) and anthropogenic hydrocarbons are the secondary source (45, 46). It was found that acetaldehyde was initiated from the transportation sector for 39% approximately. Mostly, carbonyls were predominantly observed in indoor air because the indoor materials are the main sources of formaldehyde and acetaldehyde. The indoor and outdoor source of CCs are concluded in Table 2.1

Table 2.1 Sources of carbonyl compounds

Source	Outdoor air	Indoor air
Mobile source	Vehicle exhaust gases, alternative fuel combustion (fuel with ethanol and methanol)	The outdoor CCs (from vehicle) penetrate into indoor
Stationary source	Industrial process, wastewater, landfill	Building materials, household cleaner, carpet, wood materials, paint color, furniture, cigarette smoking, combustion appliances

2.2.2 BTEX

Normally, BTEX is generated from both natural and anthropogenic sources. BTEX compounds are naturally occurring in crude oil, and gas emission from biomass burning, volcanic eruption, forest fires (47). The primary main-made release of BTEX compounds through the mobile and stationary sources as shown in Table 2.2. Furthermore, BTEX can be originated from the indoor source due to indoor material and furniture, however, the outdoor BTEX can infiltrated from outdoor into indoor environment (48).

Table 2.2 Source of emission of BTEX

Type of source	Outdoor air	Indoor air
Mobile source	vehicle exhaust, fuel combustion, aircraft exhaust	The outdoor BTEX (from vehicle) penetrate into indoor
Stationary source	Industrial emission (refinery, coke, paint, petrochemical), crude oil, gasoline, consumer products (thinner, rubber, adhesive, lacquer), refine petrochemical products	Building materials, household appliances, heater, organic solvent, cigarette smoke,

2.3 Atmospheric chemistry of the pollutants

2.3.1 Carbonyl compounds

CCs in the atmospheric air are the primary compounds (from incomplete combustion) and secondary compounds (from photooxidation of organic compounds or VOCs). Ordinarily, the rate of photooxidation of formaldehyde is faster than that of acetaldehyde. Beside the photooxidation, the photolysis of CCs is also occurred under the solar radiation which increasing the acryl radicals. CCs were solubility (polar) and they are dissolved in rain and fogs (wet deposition), moreover, they are adsorbed in the particles of condensed matter. The mechanisms of CCs of organic radical (R) without pairing with electron on a carbon atom, are shown in equation 1 to 3. The alkyl and peroxyalkyl nitrates are occurred along the reaction in equation 2.1 to 2.3 via the equation 2.4 and 2.5. These mechanisms are photolysis and then produced free radicals which finally form CCs. Because the rate of reaction in equation 2.1, 2.2 and 2.3 are high and therefore restrain by the free radicals generating from the organic groups that rely on the reactive species' levels and the rate constant of organic compounds (49).

$$R + O_2 \longrightarrow RO_2 \quad \text{(Eq.2.1)}$$

$$RO_2 + NO \longrightarrow RO + NO_2 \quad \text{(Eq.2.2)}$$

$$RO + O_2 \longrightarrow CCs + HO_2 \quad \text{(Eq.2.3)}$$

$$RO + NO_2 + M \longrightarrow RONO_2 + M \quad \text{(Eq.2.4)}$$

$$RO_2 + NO_2 + M \longrightarrow ROONO_2 + M \quad \text{(Eq.2.5)}$$

Normally, the RO_2 in equation 2.2 is not occurred at night due to the extremely low level of NO. Thus, the reactions are appeared via an equation 2.5 or other mechanisms as shown below. R_1 and R_2 are H_2 and organic groups. The nature of R_1 and R_2 is specified the occurred reaction of equation 2.7a, 2.7b and 2.7c.

$$RO_2 + O_3 \longrightarrow RO + 2O_2 \quad \text{(Eq.2.6)}$$

$$R_1O_2 + R_2O_2 \longrightarrow R_1O + R_2O + O_2 \quad \text{(Eq.2.7a)}$$

$$R_1O_2 + R_2O_2 \longrightarrow R_1\text{-O-O-}R_2 + O_2 \quad \text{(Eq.2.7b)}$$

$$R_1O_2 + R_2O_2 \longrightarrow \text{Alcohol} + \text{aldehyde} + O_2 \quad \text{(Eq.2.7c)}$$

Under the strong solar radiation, the degradation of peroxide is generated the alkoxy radicals which introduce CCs, hence the secondary aldehyde and ketone are very high in the morning and afternoon rather than those found at night.

Another reaction of CCs production is from carbon monoxide and methane (equation 2.8 to 2.14)

$$CO + OH \longrightarrow CO_2 + H \qquad \text{(Eq.2.8)}$$
$$H + O_2 \longrightarrow HO_2 \qquad \text{(Eq.2.9)}$$
$$HO_2 + NO \longrightarrow HO + NO_2 \qquad \text{(Eq.2.10)}$$
$$CH_4 + OH \longrightarrow CH_3 + H_2O \qquad \text{(Eq.2.11)}$$
$$CH_3 + O_2 \longrightarrow CH_3O_2 \qquad \text{(Eq.2.12)}$$
$$CH_3O_2 + NO \longrightarrow CH_3O + NO_2 \qquad \text{(Eq.2.13)}$$
$$CH_3O + O_2 \longrightarrow HCHO + HO_2 \qquad \text{(Eq.2.14)}$$

OH radicals are obtained from formaldehyde photolysis (see equation 2.15). H and HO_2 in equation 2.15 and 2.16 were then appear as shown in equation 2.9 and 2.10. The equation 2.17 express the whole reaction.

$$HCHO + h\upsilon \longrightarrow H + HCO \qquad \text{(Eq.2.15)}$$
$$HO_2 + NO \longrightarrow HO + NO_2 \qquad \text{(Eq.2.16)}$$
$$HCHO + 2O_2 + 2NO \xrightarrow{h\upsilon} CO + 2OH + 2NO_2 \qquad \text{(Eq.2.17)}$$

For the photolysis of CCs are influenced the chemistry of other chemicals in atmospheric air. These compounds are degraded under the solar radiation via the possible four reactions as illustrate in Equation 2.18 to 2.21.

Reaction 1: $R_1\text{-}CO\text{-}R_2 + h\upsilon \longrightarrow R_1 + R_2CO$; $R_1\text{-}CO\text{-}R_2 + h\upsilon \longrightarrow R_1CO + R_2$ (Eq.18)

Reaction 2: $R_1\text{-}CO\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}R_2 + h\upsilon \longrightarrow R_1\text{-}CO + CH_3 + CH_2{=}R_2$ (Eq.2.19)

Reaction 3: $R_1\text{-}CO\text{-}CH_2\text{-}CH_2\text{-}R_2 + h\upsilon \longrightarrow R_1\text{-}CHO + CH_2{=}CH\text{-}R_2$ (Eq.2.20)

Loss of CO (aldehyde only): $R\text{-}CHO + h\upsilon \longrightarrow RH + CO$ (Eq.2.21)

Typically, formaldehyde and acetaldehyde are solubility and high vapor pressure. The decomposition of acetaldehyde in atmosphere are reacted with hydroxyl radical or NO_x and give peroxyacetyl nitrate (PAN) for the latter. The photolysis of formaldehyde is faster than that observe for acetaldehyde. Moreover, the photolysis rate of acetaldehyde is very low. The production of formaldehyde photolysis is CO, whereas, acetaldehyde create organic radicals that finally form PAN. In addition, the photolysis of acetaldehyde can be originated CH_3O_2 radicals that further react with NO and finally produce formaldehyde.

The two ways of the photolysis of formaldehyde are demonstrated in equation 2.15 and 2. 22

$$HCHO + h\upsilon \longrightarrow H_2 + CO \qquad (Eq.2.22)$$

The three ways of acetaldehyde photolysis are possibly appeared in equation 2.23, 2.24 and 2.25.

$$CH_3\text{-}CHO + h\upsilon \longrightarrow CH_3 + HCO \qquad (Eq.2.23)$$

$$CH_3\text{-}CHO + h\upsilon \longrightarrow CH_3CO + H \qquad (Eq.2.24)$$

$$CH_3\text{-}CHO + h\upsilon \longrightarrow CH_4 + CO \qquad (Eq.2.25)$$

2.3.2 BTEX

The pollutants of the secondary products originating from BTEX is very concerned due to their toxicity such as the photochemical smog and greenhouse effect. Broadly, the reaction of BTEX in winter is much less than those investigate in summer because the weather conditions in winter are steady comparing to the conditions in summer (50). Normally, benzene is more stable than toluene, m,p-Xylene and o-Xylene due to their long half-life (51) as express in Table 2.3. Basically, the atmospheric mechanisms of toluene and xylenes are initiated O_3. This aromatic hydrocarbon can travel 15 to 20 km from the place that it is originated because of their short half-lives. Thus, it is recommended that the sampling of BTEX should be collected closely to their sources (52). Henry's constant of BTEX is extremely low; hence, this compound is rarely dissolved in the water or any precipitation (wet deposition).

Table 2.3 Half-life of BTEX

Chemical	$t_{1/2}$	τ
Benzene	50.1-501 hrs	9.1 days
Toluene	10-104 hrs	2.2 days
Ethylbenzene	8.56-85.6 hrs	20 hrs
m-Xylene	2.6-26 hrs	0.51 day-5.9 hrs
p-Xylene	4.2-42 hrs	0.8 day-10 hrs
o-Xylene	4.4-44 hrs	0.84 day–10 hrs

Source: (Mackay, D. et al, 2006) (53)

With the presence of atmospheric radicals (O_3, hydroxyl radical and nitrogen radical), BTEX can be degraded and produced the toxic chemicals which more dangerous than their mother compounds (36) (see equation 2.26).

$$VOCs + NO_x \xrightarrow{h\nu} O_3 + PAN \qquad (Eq.2.26)$$

The alkyl radical is originated from the first step of VOCs degradation and then BTEX is reacted to this radical (especially for the hydroxyl) and the reactions of toluene are shown in Fig. 2.3. The reaction of VOCs degradation with NO radicals is expressed in Fig 2.4

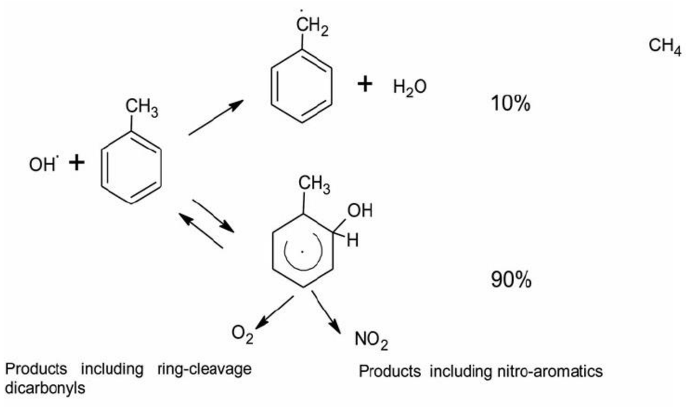


Figure 2.3 The reaction of toluene with hydroxyl radicals

Source: Atkinson, 2008 (54)

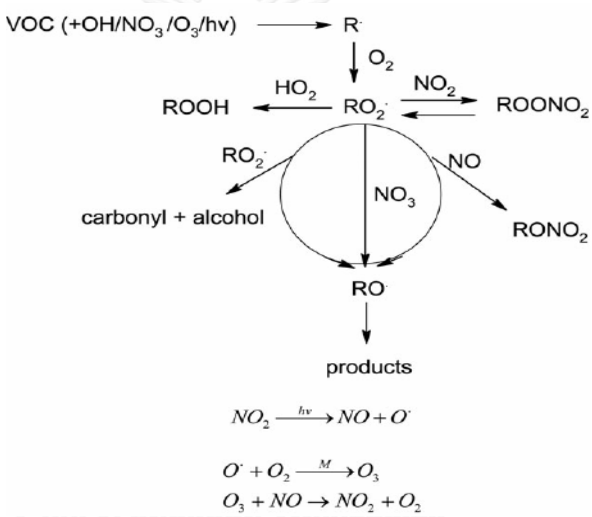


Figure 2.4 The reaction of VOCs degradation

Source: Atkinson, 2008 (54)

2.4 Traffic-Related Air Pollution

The traffic-related air pollution is mainly generated by human activities especially, the transportation sectors. The air pollutant emission sources are commonly from the vehicles. Likewise, the main emissions of benzene are also from vehicles (77%), gasoline storage and transportation (16%), industrial combustion source (6%), and other sources

(1%), respectively (PCD, 2008). These results are caused by the increase of private vehicles. Moreover, the traffic condition is playing an important role in air pollutions from traffic. The high traffic situations will result in high levels of vehicles related air pollutions. Thus, the high traffic density areas are found greater levels of BTEX concentrations as illustrated in Table 2.4.

Table 2.4 BTEX monitoring data of Bangkok and vicinity area in August 2006

VOCs	Concentration Range (μg m^{-3})		
	Near Bangkok area	Roadside area	Residential area
Benzene	0.45-19	1.8-20	1.2-13
Toluene	1.9-120	5.9-100	5.0-135
Ethylbenzene	0.34-14	0.34-13	0.20-6.7
m-Xylene	0.27-34	-	-
p-Xylene	0.04-16	-	-
o-Xylene	0.13-18	0.71-18	0.38-3.8

Source: PCD, 2006

Nowadays, the alternative fuels are widely used as energy sources such as gasohol. These alternative energy sources are the use of ethanol as fuel or fuel additives by adding into gasoline to control the emission of carbon monoxide (CO) and create more complete combustion. The addition of ethanol to gasoline will reduce the emission of CO but it will increase the emission carbonyl compounds especially, formaldehyde and acetaldehyde. Normally, carbonyl compounds are naturally generated by photooxidation processes of aldehydes and ketones. The use of ethanol is affected by increasing the aldehyde emissions and finally leading to produce formaldehyde and acetaldehyde in the environment (see Table 2.5).

Table 2.5 Changes in emissions when ethanol is blended with conventional gasoline

Pollutant	Effect of ethanol on emissions	
	Increase	Decrease
Benzene		✓
Toluene		✓
Xylene		✓
Formaldehyde	✓	
Acetaldehyde	✓	

Source: Brown, 2008 (55)

The combustion of gasoline and diesel fuel are released toxic air pollutants which included BTEX. Nevertheless, alcohols (ethanol or methanol) are added to gasoline as an alternative fuel, and the combustion of ethanol-gasoline and methanol gasoline are emitted acetaldehyde and formaldehyde, respectively (56). Several studies reviewed that the high traffic density contained high formaldehyde and acetaldehyde levels. In Bangkok, the roadside area showed greater formaldehyde and acetaldehyde concentrations than those at residential area (17) and the results are demonstrated in Fig. 2.5.

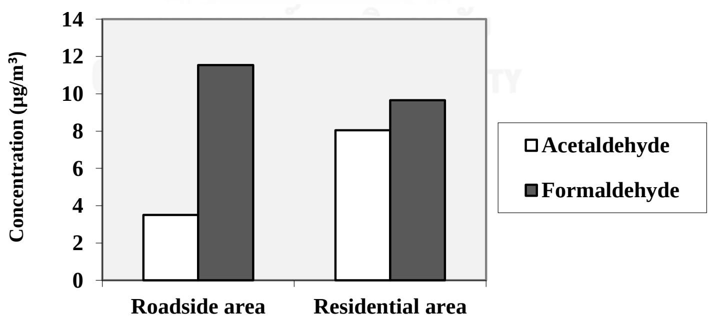


Figure 2.5 CCs levels in roadside and residential areas (17)

Recently, the increasing use of gasohol is discovered in many countries including Thailand. Gasohol is the mixture of gasoline and ethanol which using as an alternative fuel, hence the emission of acetaldehyde is extremely high comparing to formaldehyde. The CCs concentrations of ambient air in urban area of Brazil were investigated by Grosjean (57). They found that the use of ethanol was elevated the acetaldehyde level which much greater than formaldehyde. Likewise, the concentration of acetaldehyde in ambient air of Rio de Janeiro (Brazil) were greater than the level of formaldehyde (58).

Vehicles and industries are the main man-made sources of BTEX. Many studies were discovered that the ambient BTEX in an urban area were emitted from the transportation sectors especially for vehicles (59-61). Giang (62) was found that the traffic volume was related to the pollutant concentrations and high density of traffic was generated high pollutant levels. Thus, the source of BTEX in the city, is mainly come from the vehicles. In India, Dutta (2009) (63) explained that the area with the intensive traffic was determined high BTEX concentration than that in residential area and the results are illustrated in Figure2.6.

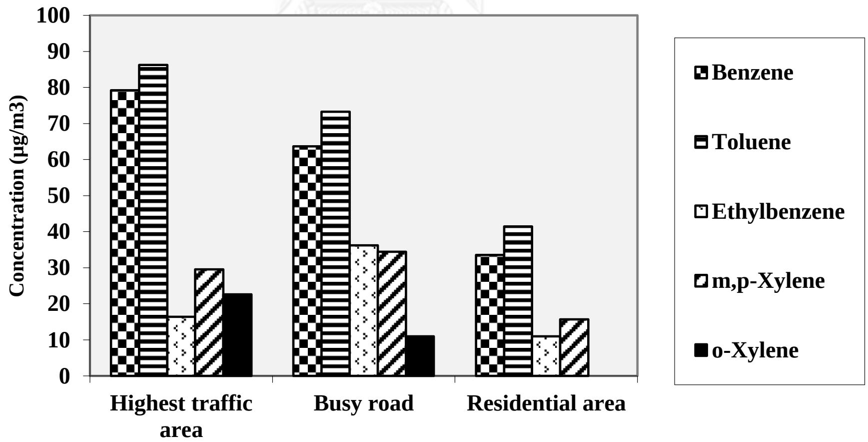


Figure 2.6 BTEX levels in the different traffic area (63)

2.5 Indoor air of carbonyl compounds and BTEX

Consideration of indoor CCs, several researchers revealed that the CCs levels in the indoor are greater than those in outdoor air (64). The data of indoor and outdoor

CCs in residential areas in Rome are demonstrated in Table. 2.6 which obtained from Fuselli (64).

Table 2.6 Indoor and outdoor CCs in residential areas in Rome

Basic descriptive statistics of indoor/outdoor carbonyl compounds concentrations [μg/m^3]

Variables	N[a]	Mean	Std Dev	Minimum	Maximum
kitchenacetaldehyde	40	9.37500	3.68752	0.80000	19.70000
living-roomacetaldehyde	40	8.03250	3.61772	3.20000	20.90000
outdooor$_{\text{acetaldehyde}}$	40	2.34250	1.30342	1.10000	7.60000
kitchenacetone+acrolein	40	9.44125	8.84437	0.05000	58.00000
living-room$_{\text{acetone+acrolein}}$	40	8.44375	8.62706	0.05000	57.30000
outdoor$_{\text{acetone+acrolein}}$	40	2.46375	1.44905	0.05000	6.10000
kitchen$_{\text{propionaldehyde}}$	40	2.63375	0.92247	0.05000	4.60000
living-room$_{\text{propionaldehyde}}$	40	2.47875	1.24287	0.05000	6.00000
outdoor$_{\text{propionaldehyde}}$	40	1.00125	0.49981	0.05000	2.30000
kitchen$_{\text{n-butyaldehyde}}$	40	10.97875	8.67891	0.05000	34.60000
living-room$_{\text{n-butyraldehyde}}$	40	10.78875	11.52723	0.05000	44.40000
outdoor$_{\text{n-butyraldehyde}}$	40	4.91375	5.28897	0.05000	26.20000
kitchen$_{\text{benzalaldehyde}}$	40	0.84125	0.59105	0.05000	2.20000
livingroom$_{\text{benzalaldehyde}}$	40	0.55625	0.41728	0.05000	1.80000
outdoor$_{\text{benzalaldehyde}}$	40	0.23625	0.17431	0.05000	0.70000
kitchen$_{\text{isovaleraldehyde}}$	40	0.90375	0.67400	0.05000	2.20000
livingroom $_{\text{isovaleraldehyde}}$	40	0.63875	0.50959	0.05000	2.00000
outdoor$_{\text{isovaleraldehyde}}$	40	0.21875	0.17346	0.05000	0.70000
kitchen$_{\text{isovaleraldehyde}}$	40	3.24500	1.68111	0.70000	7.80000
living-room$_{\text{valeraldehyde}}$	40	2.17436	1.29100	0.10000	7.00000
outdoor$_{\text{valeraldehyde}}$	40	0.48375	0.42988	0.05000	1.60000
kitchen$_{\text{formaldehyde}}$	40	13.17750	4.28135	6.90000	23.00000
living-room$_{\text{formaldehyde}}$	40	12.31000	6.26184	4.80000	32.90000
outdoor$_{\text{fomaldehyde}}$	40	2.74500	1.12545	1.20000	7.00000

[a]N = number of observations ((10 apartments in the considered 10-day samplings of June, July, September, December and February); [b]detection limit for carbonyl compound concentration is 0.05μg/m^3.

Source: Fuselli et al., 2007 (64)

In view of indoor air, it was found that BTEX level in indoor air is sometimes greater than that at the outdoor air (52, 65). The new building or the newly renovated building tend to have high levels of toluene, ethylbenzene and xylenes due to the emission of materials (66). In Italy, the measuring of BTEX levels for both outdoor and indoor air in offices were studied and the results were expressed in Fig. 2.7.

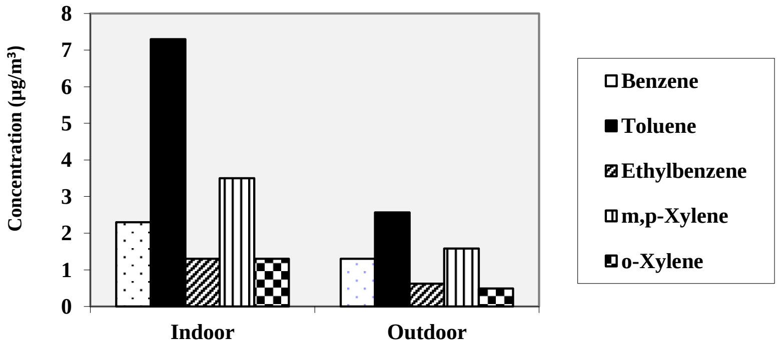


Figure 2.7 Indoor and outdoor BTEX levels in offices (66)

2.6 Seasonal variation

The concentration of CCs and BTEX are shown in different range among the seasons. Several studies are observed the seasonal variation of these compounds in many countries. Generally, the conditions of each season are different such as solar radiation, precipitation, humidity and temperature. These data are the important factors which impact to VOCs levels in the atmospheric air. The results of other studies are investigated the same trend seasonal, however, various studies are expressed the different data and it is depended on the meteorological data of the sampling date. Other factor is the properties of the chemical which include water soluble, degradation, reactivity and retention time. In summary, the seasonal comparison of air pollutant levels is relied on both seasonal conditions and the chemical properties.

2.6.1 Carbonyl compounds

Morknoy et al, 2008 (17) found that the concentrations formaldehyde and acetaldehyde in winter was showed the highest level followed by dry and wet seasons, respectively. The explanation was the seasonal condition in winter was stable than those of other seasons. Moreover, formaldehyde and acetaldehyde were dissolved in rain droplets and the solar radiation can bring to the photolysis of these CCs. Therefore, the concentrations of formaldehyde and acetaldehyde in dry and wet seasons were lower than that found in winter as shown in Fig. 2.8.

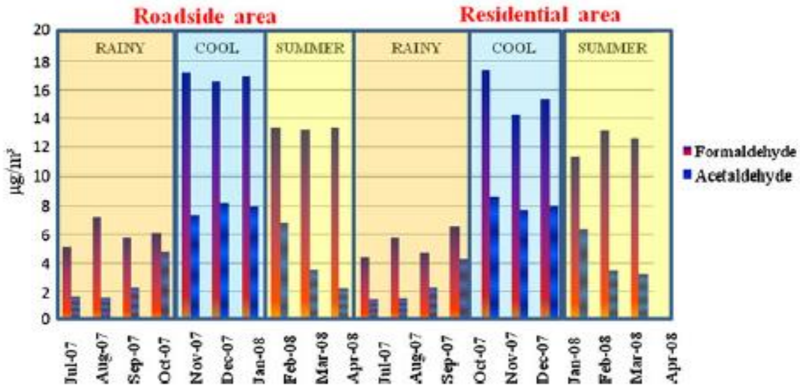


Figure 2.8 Seasonal variation of CCs
Source: Morknoy et al, 2008 (17)

The study of carbonyls in residential area (China) was compared the seasonal variation of CCs at several sampling sites (Xi an, Beijing, Shanghai and Guangzhou). The results illustrated that the concentrations of CCs in summer were greater than those found in the winter as shown in Fig. 2.9 (67) due to the photolysis and the direct source (from vehicle) was strongly emitted in summer.

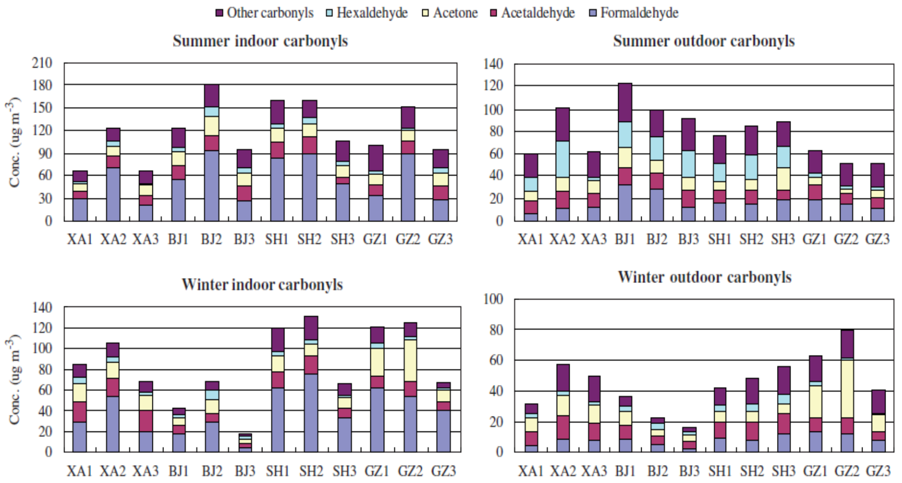


Fig. 1. Concentrations of indoor and outdoor carbonyls in twelve dwellings (*n* = 3 at each dwelling). Noted: (1) XA: Xi'an; (2) BJ: Beijing; (3) SH: Shanghai; (4) GZ: Guangzhou.

Figure 2.9 Seasonal variation of CCs in China

Source: Wang et al., 2007 (67)

2.6.2 BTEX

Another study in New Jersey, two communications were observed in summer and winter seasons(68). Benzene concentration in summer was a bit greater than that found in winter for both ambient and personal exposure samples. This result was complied with other studies because the stable condition in winter. For toluene, ethylbenzene and xylenes, the levels of these chemicals in the ambient samples were greater than those in summer, while the personal air of these substances were insignificant difference between the seasons (as showed in Table 2.7)

Table 2.7 Seasonal variation of BTEX

Sample	Compound	Season	
		Summer	Winter
Ambient air	Benzene	1.55	1.15
	Toluene	2.29	2.77
	Ethylbenzene	0.36	0.47
	m,p-Xylene	1.11	1.45

	o-Xylene	0.40	0.50
Personal air	Benzene	2.20	2.28
	Toluene	5.48	5.75
	Ethylbenzene	0.82	0.95
	m,p-Xylene	2.50	2.68
	o-Xylene	0.82	0.83

2.7 Health risk assessment

There are four steps of health risk assessment which comprised of hazard identification, dose- response assessment, exposure assessment and risk characterization. Each step was separately explained in detail.

2.7.1 Hazard identification

The first step of risk assessment is to identify the concerned chemicals and their adverse health effects that make a significant contribution to exposure and risk to humans. For the toxic substances of concern, the scientific data and chemical properties are provided to characterize the chemical agents. Moreover, the information of the possible adverse health effects from the chemicals are listed and classified. The data of the health effects deriving from toxic exposure are different because they are depended on the exposure routes. The toxicokinetics and toxicodynamics of the chemicals are used for supporting the hazard identification analysis.

2.7.2 Dose-response assessment

The dose-response assessment is the second step of risk assessment. This step is provided the relationship between the amount of chemical dose and the adverse health effect in exposed populations. For the dose, it refers to the chemical quantification in order to measure the amount of exposed substances. In term of response, it commonly expresses the effect of the hazard substances once administered. These two factors are related in term of concentration and response. Normally, as the dose of toxic agent increase, the incidence of adverse health effect will increase the same as the severity of the response.

2.7.3 Exposure assessment

The process of exposure assessment is to identify the exposure routes to the toxic agents of concern. Typically, there are three main exposure routes consist of dermal, oral and inhalation.

Moreover, the estimation of the duration, intensity and frequency to hazard substances are presented.

2.7.4 Risk characterization

Risk characterization is the process of the risk evaluation by incorporating the information of the proceeding steps for the potential risk estimation. The weight of evidence is applied to assess the risk posed by the toxic substances.

2.8 Risk Perception and risk communication

In general, people always assess and estimate the hazard that they might be received or confronted, even though they face to that risk or not (69). The views on their risk are relied on their experience and belief, in addition, the major factors of their perception are based on norms, values system and cultural idiosyncrasies of societies (70-72). The factors which influence on the risk perception were demonstrated in Fig. 2.10. Risk perception is an important element of risk communication by informing the people who are exposed or harmed to concern about their risk. This process makes the effected peoples knowing and understanding of the environmental hazard and the effect of the exposure. The increasing of people's perception is a tool for changing their behavior due to the awareness of the environmental risk. Therefore, the perception will encourage people to concern the risk factors and conceive the ways of reducing risk.

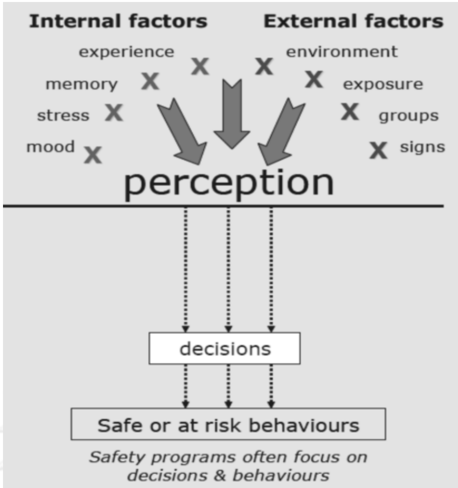


Figure 2.10 The impact factors of risk perception
Source: Safety Institute of Australia (73)

Risk communication is the strategy involved the effected persons to know and realize their health risk assessment more clear and efficient. This communication is contained the determination and reaction of the communication concerns. Moreover, it is a way of risk management in order to complete the goal of the risk minimization. The hazard or risk is informed to people who involved in that situation in order to make them more understand and perceive in the risk assessment and management. Fig. 2.11 showed big picture of risk communication.

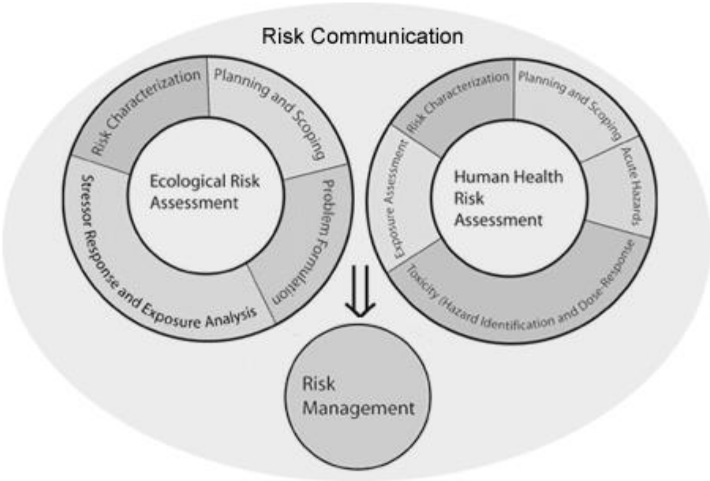


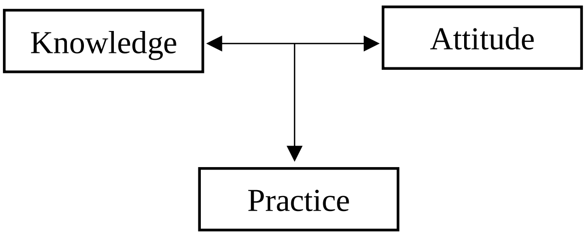
Figure 2.11 Risk communication

Source: US. EPA (74)

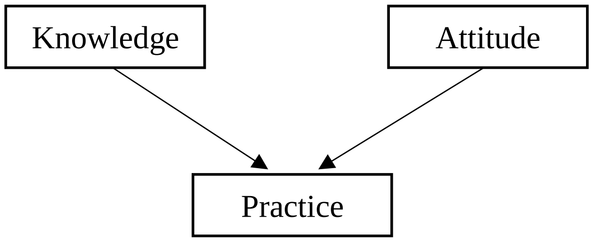
Knowledge, attitude and practice questionnaire (KAP) is used for risk perception and communication. KAP is applied for investigating the change of the study subject in these three parts that can be estimated their understanding, opinion and how these people behave to the hazard. The steps of KAP study are 1. Identifying the domain subject and risk, 2. drawing up the questionnaire, conducting the KAP study, collecting the data and analyzing the data. The study subjects should be classified as a small group because the different groups of people are expressing in different education, culture and perspective which expressed their actions. For data analysis, the possible ways of KAP study were included four cases.

1. Knowledge is related to attitude and practice

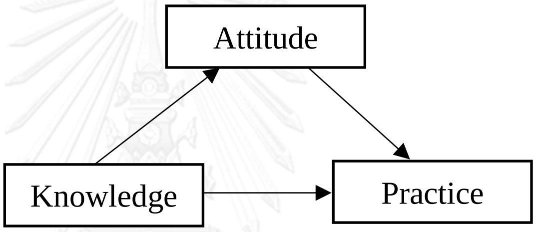
2. Knowledge and attitude affect to practice (knowledge is correlated to attitude



3. Knowledge and attitude affect to practice (there is no association between knowledge and attitude)



4. Knowledge is directly and indirectly impacted to practice. Attitude is a factor that affect to practice for the indirect case.



2.9 Related research articles

Ilgen et al. (2011), the BTEX was measured both indoor and outdoor sources with the different traffic density. This study showed a relationship between the traffic density and BTEX concentration. The sampling sites were located around the high traffic density area were shown a greater average benzene value than the lower traffic density. For indoors, the average concentration of benzene in the city was 3.1 μg/m^3 while 1.8 μg/m^3 for the rural area. Moreover, toluene was a dominant in indoor sources at a low traffic density area whereas the outdoor pollutions are the main sources of ethylbenzene and xylenes. For benzene concentrations, the sampling sites with high traffic problems were presented high values for both outdoors and indoors (52).

Wang et al. (2007) showed the characteristics of carbonyl compounds of four residential areas in China. For indoor air, it was found that formaldehyde had the highest concentration while other carbonyl compounds including propionaldehyde, crotonaldehyde and bezaldehyde were shown the lowest amounts. In contrast to outdoor air, formaldehyde, acetaldehyde and acetone were the major species of the outdoors area. For seasonal variation, the concentrations of carbonyl compounds for both indoors and outdoors in summer were greater than in winter. For indoor air, the concentrations of certain carbonyls were depended on the activities of inhabitants (ventilation and incense burning) and the building materials. Thus, the concentrations of certain carbonyls were varied between 19.3 and 92.8 $\mu g/m^3$, correspondingly (67).

Wang et al. (2010) measured carbonyl compounds of two sites in Kaosiung city which had six industrial complexes. Formaldehyde was the most abundant in two sites followed by acetaldehyde. Formaldehyde had the average concentration of 18.33 and 18.74 $\mu g/m^3$ for the Nan-Chie and Hsiung-Kong sites, respectively. It also showed that the concentration of carbonyl compounds in summer were higher in winter because of the photochemical activities (29).

Huang et al. (2008) characterized carbonyl groups in Shanghai, China. Eighteen carbonyl compounds were determined in winter, spring, summer and autumn. The results illustrated that formaldehyde, acetaldehyde and acetone were found the greatest numbers in every seasons. Formaldehyde and acetaldehyde concentrations were expressed higher levels in summer, spring, autumn and winter, respectively. On the other hands, acetone concentrations were abundant in winter comparing to the others. These results were related the variation of seasons. In summer, the photochemical activities were an important factor for generating the carbonyl groups except the primary emissions (24).

Wiwanikit (2008) estimated the risk assessment of benzene in Bangkok. The sampling sites were located in urban and heavy traffic problems around Bangkok. The main source of benzene came from the primary emission and the vehicle exhaust was playing an important role in this case. The results illustrated that the people who worked or stayed around the high traffic area were have a high potential to benzene exposure and the cancer risk of benzene were high too (21).

Manini et al. (2008) monitored the benzene exposure of traffic policemen in Italy. The study subjects were focused on both non-smoker and smoker traffic policemen. The benzene concentrations of ambient air were ranged from 0.28 to 9.53 $\mu g/m^3$ and the average benzene level was 6.07 $\mu g/m^3$. The cancer risk of benzene was 5.6 x 10^{-7} approximately at an air benzene concentration of 1 $\mu g/m^3$. For benzene biomarkers, the urinary toluene was depended on smoking activity and it showed that the urinary toluene of smokers were greater than non-smokers (75).

Navasumrit et al. (2005) studied on benzene exposure of the occupation in Thailand. The several workers were concerned consisting of cloth vendors, grill-meat vendors, factory workers and gasoline service attendants. The results indicated that grill-meat vendors (28.19 ppb) had a higher benzene concentration comparing to cloth vendors (22.61 ppb). The gasoline service attendants (121.67 ppb) were exposed to benzene greater than factory workers (73.55 ppb). Thus, the workers who spent their working time around the main road traffic had more cancer risk than the others. Furthermore, the work activities of the occupation were the one of factors affected to the risk of benzene exposure (20).

Hinwood et al. (2007) determined BTEX exposure of the population in Australia. The non-occupational people at different traffic density were selected. Benzene concentrations were ranging from 0.04-23.8 ppb. The ranging of toluene, ethylbenzene and xylenes were 0.03-2120 ppb, 0.03-119 ppb and 0.04-697 ppb, correspondingly. These wide ranges of BTEX levles were according to the activities and locations (76).

Bono et al. (2003) investigated the ambient air and occupational exposure to BTX in two cities in Italy with the different traffic intensity and amount of population. The three occupational workers were concerned included petrol pump attendants, traffic policemen and municipal employees. The maximum concentration of benzene in both summer and winter was belonged to the petrol pump attendants with the value of 1 mg m^{-3}. The concentrations of ambient air in a suburban were 2.3 μg/m^3 whereas 10.3 μg/m^3 in an urban area(22).

Cavalcante et al. (2006) focused on carbonyl groups of the university in Brazil. The libraries, classrooms, laboratories and offices were chosen for the study. Acetone had the greatest concentration in both outdoor and indoor air compared to other carbonyl species and its concentration was 52.48 μg/m^3. Acetone was major specie contributed in laboratories and offices while formaldehyde was playing an important role in libraries and classroom. The levels of formaldehyde, acetaldehyde, benzaldehyde, butyraldehys and acrolein were 12.42, 2.90, 2.35, 2.31 and 2.02 μg/m^3, respectively(46).

Morknoy et al. (2011) explained the diurnal and seasonal variations of formaldehyde and acetaldehyde concentrations of both roadside and residential sites in Bangkok. In this study, the concentrations of formaldehyde and acetaldehyde were different based on seasonal climate. The levels of these substances were lowest in rainy season because both chemicals were water solubility. Therefore, they will go or dilute with water. In contrast to winter, these two compounds were greatest levels in this season because of stable atmospheric conditions. For summer, the concentrations of these two chemicals were shown a bit lower than the ones in winter due to the photolysis reaction. For overall results, the average concentration of formaldehyde and acetaldehyde were 11.53 and 3.51 μg/m^3 at the roadside sampling even if 9.65 and 3.11 μg/m^3 at the residential area(17).

Moussa et al. (2006), the carbonyl compounds measured at two urban universities in Lebanon. The most prevalent carbonyl species were formaldehyde and acetaldehyde with the concentrations of 12.2 and 5.2 ppbv, correspondingly. The diurnal variation had an impact on the concentration of the compounds and it emphasized that the morning levels were greater than the afternoon levels because of photochemical reaction. The major source of these compounds was from the vehicle exhaust (77).

Lu et al. (2009) showed the results of carbonyl compounds in ambient air of misty and sunny day in Guangzhou, China. The same as other researches, formaldehyde, acetaldehyde and acetone play the important in overall atmospheric environment roles compared to others carbonyl species. The summation of these three chemical compounds was higher in sunny day than the ones in misty day with the results of 92.0 μg/m^3 in the misty day whereas 32.6 μg/m^3 in the sunny day. However, the respective average concentrations of total carbonyls were high in misty day compared to the ones in sunny day. The transporter section was the predominant of carbonyl compounds in the ambient air (78).

Pang and Mu (2006) illustrated the impacts of seasonal and diurnal trends to carbonyl compounds in Beijing ambient air. The three carbonyl species were intense in the atmospheric air consisted of formaldehyde, acetaldehyde and acetone. The concentrations of formaldehyde were 19.51±6.34 μg/m^3 in summer and 5.14±2.56 μg/m^3 in winter. For acetaldehyde, the intensities were 17.18±4.57 μg/m^3 in summer and 8.68±3.48 μg/m^3 in winter. On the other hand, acetone levels were 22.14±5.98 μg/m^3 in summer and 9.18±3.27 μg/m^3 in winter. The principle caution of carbonyl compounds in summer was photo-oxidation of volatile organic compounds while vehicle exhaust for the winter (79).

Lu et al. (2010), the different areas in Guangzhou, China were selected for measuring the concentration of carbonyl compounds in several seasons (summer, spring, autumn and winter). The seasonal variation showed that the mean total concentrations of carbonyl compounds were reduced in summer, spring, autumn and winter, respectively. The twenty-one carbonyl species were observed with the range from 2.64 to 103.6 μg/m^3 in Liwan (industrial and traffic area) while 5.46 to 89.9 μg/m^3 in Wushan (lower traffic and industrial than Liwan). The most abundant carbonyls were belonged to formaldehyde, acetaldehyde and acetone as usual (80)

CHAPTER III
RESEARCH METHODOLOGY

3.1 Study area

Bangkok, the capital city of Thailand was the congested area with the population around 5.7 million in 2015 (DOPA, 2015)(1) was chosen for this study. The location of this study was related to a high traffic density area around Pathumwan district which representing the air polluted urban area. The sampling sites of three groups of workers at roadside area were settled in Pathumwan district and the locations of each group were separately explained. For outdoor group at roadside area, the sampling locations of street vendors and motorcycle taxi drivers were consisted of five sites as shown in Fig. 3.1, which included Faculty of Science (SCI), Osot Sala (OS), BBL Bank (BBL), KTB Bank (KTB), SCB Bank (SCB). On the other hand, six sampling sites of security guards were taken from Faculty of Commerce and Accountancy (MBA), Faculty of Science (SCI), Faculty of Architecture (ARC), Graduate School (GRA), Faculty of Arts (ART) and Faculty of Political Science (POL).

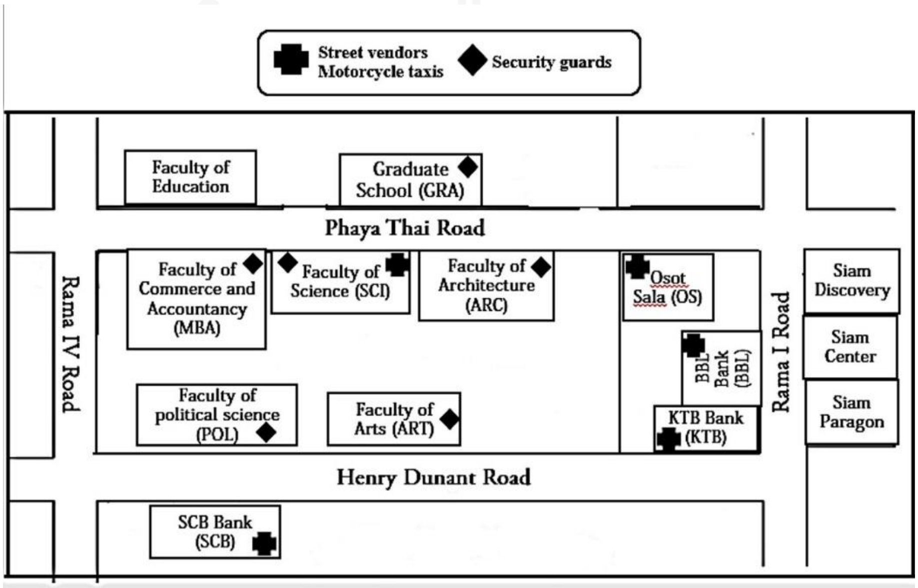
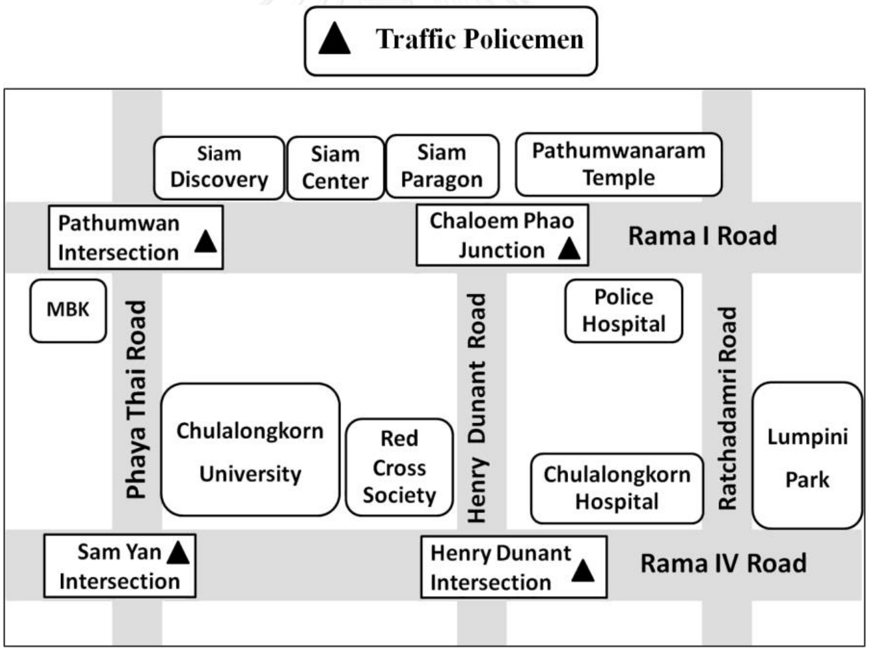


Figure 3.1 The sampling sites of outdoor workers at roadside area

The sampling sites of traffic policemen (high exposure group) were comprised of Sam Yan Intersection (SY), Pathumwan Intersection (PT), Henry Dunant Intersection (HD) and Chaloem Phao Junction (CP). These sampling sites were the major intersections of Pathumwan District which located closed to the department stores, university and hospital as demonstrated in Fig. 3.2. Normally, the red light traffic duration at each intersection (see Table 3.1) was automatically performed only non-rush hour (from 10.30a.m. to 14.00p.m.). However, the red light duration of rush hour traffic (from 06.00 a.m. to 10.30 a.m.) was depended on the traffic situation each day and it commonly greater than the average traffic red light duration of non-rush hour. The intersection configurations were also provided in Fig.3.2.



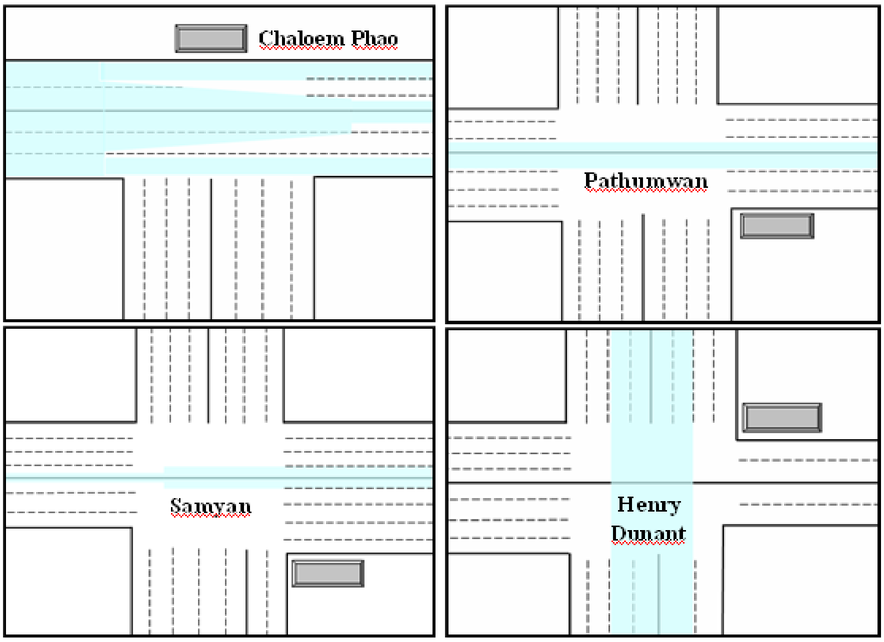


Figure 3.2 The sampling sites of traffic policemen at road intersection

Table 3.1 The characteristic of sampling sites of traffic policemen

Site	Traffic lane numbers at intersection (lane)			Red light duration (second)			Covered area of the building (%)	Traffic volume (vehicle/day)*
	Total	Min	Max	Average	Min	Max		
Chaloem Phao	14	2	4	94	80	105	35	30,341.66
Pathumwan	29	3	4	158	120	185	14	24,561.16
Henry Dunant	26	2	4	124	120	135	27	45,507.80
Sam Yan	31	2	5	120	115	125	10	61,293.60

*The traffic volume was calculated from the observation data from 2007 to 2014 by Traffic and Transportation Department, Bangkok

In view of indoor workers, four sampling sites were investigated in Chulalongkorn University which composed of Communication Center (CC), Faculty of Education (ED), Faculty of Engineering (EG) and Faculty of Economic (EC). These faculties were situated near the main road as shown in Fig.3.3. Both personal and indoor air samples were collected at each sites.

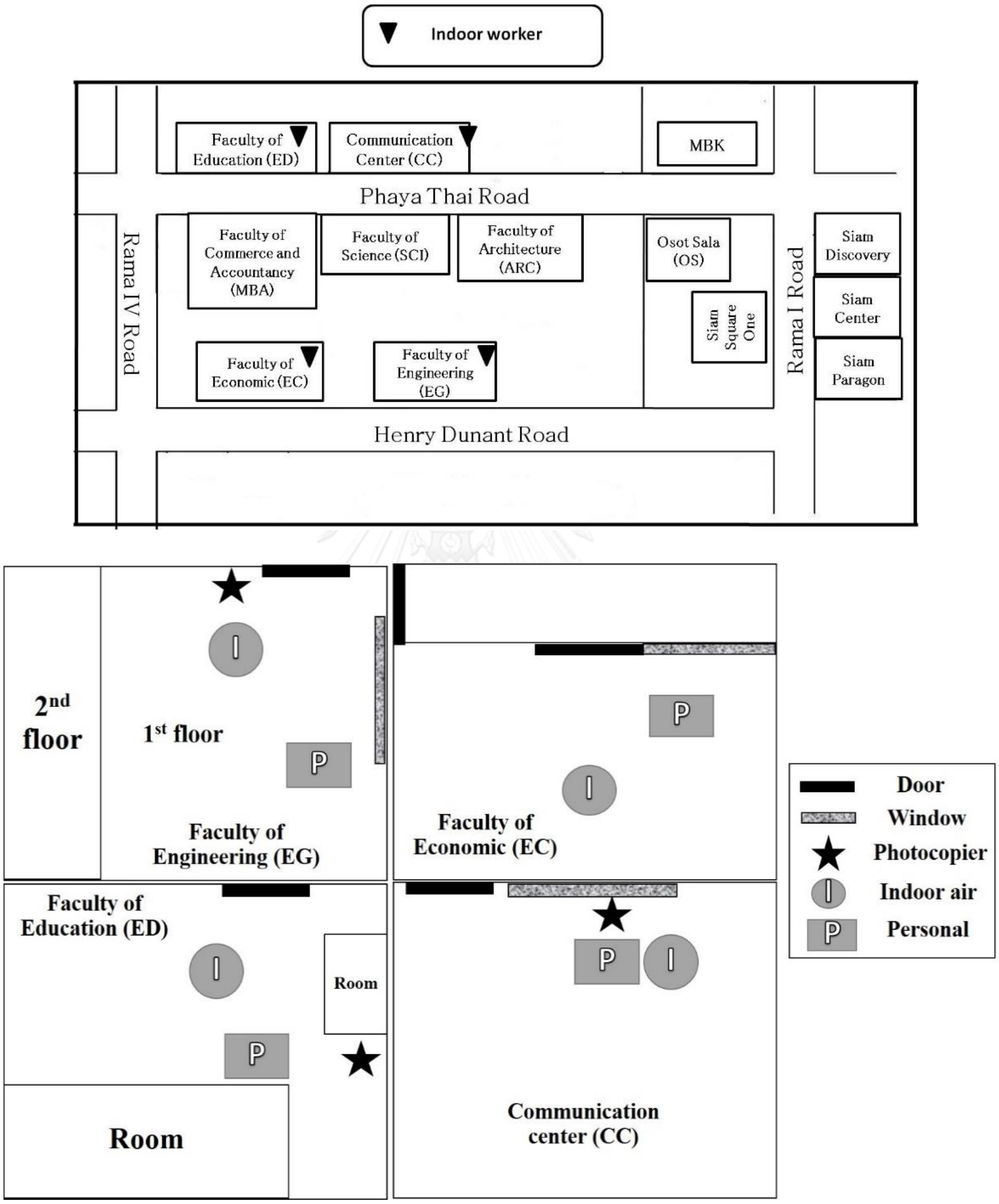


Figure 3.3 The sampling sites of indoor workers

Table 3.2 The characteristic of sampling sites of indoor workers

Site	Ventilation	Floor	Smoking allowed	Location
Communication center	Air condition	1st	No	-Phaya Thai Road -Road in university
Faculty of Education	Air condition	1st	No	-Phaya Thai Road -Road in university -Car park
Faculty of Engineering	Air condition	1st	No	-Henry Dunant Road -Road in university -Car park
Faculty of Economic	Air condition	1st	No	-Henry Dunant Road -Road in university

3.2 Study subject

The studied subjects were concerned of three groups of workers. First was the outdoor workers at roadside area were included street vendors, motorcycle taxi drivers and security guards. Secondly, the highly exposure groups of carbonyl compounds (CCs) and BTEX were focused on the traffic policemen. The last group of the studied part was the indoor workers. These study subjects were non-smoking and healthy with the age of 20-60 years old.

The study subjects of this study were divided into three parts including outdoor workers (the moderate-exposure group), traffic policemen (the high-exposure group), and indoor workers (the low-exposure group). The sampling periods in all parts are assigned as dry and wet seasons. For the outdoor group at roadside area, the samples were collected in September 2012 (wet season) and March 2013 (dry season), while the samples of traffic police and indoor group were observed in April to May (dry season) and August to September 2014 (wet season). The sampling of each group was randomly collected. The sampling of traffic police and indoor workers which contained four sites for each group, were collected at the same day, whereas the sampling of outdoor workers were attributed in different days.

During the sampling, the personal questionnaires were applied for collecting their general information and some factors were utilized for calculating their exposure to CCs and BTEX including activities data, gender, body weight and age. This obtained information was applied for the health risk assessment.

For risk perception and communication, the number of samples per subjects in each type of workers were equally 30 persons. Knowledge and attitude questionnaires (KA) were conducted for pre-test and post-test as explained in 3.7 below.

3.3 Analysis instruments

3.3.1 High Performance Liquid Chromatography (HPLC)

The CCs were analyzed by High Performance Liquid Chromatography with UV-VIS detector, model Shimadzu SPD 20A, and the integrator of Shimadzu CBM 20A at Environmental Research and Training Centre (ERTC). The mobile phases including acetonitrile (HPLC grade) and water (HPLC grade) manufactured by Fisher Company, Canada was used in the system. Both mobile phases were filtered with nylon filters (Advantec, USA), 0.22 µm pore size and pumped by the Shimadzu LC pumps AB20. CCs were separated by a column RP Amide Discovery C16 250 cm x 4.6 mm i.d. with 0.5 µm packing from SUPELCO Company, USA and the samples were pumped to the system with a linear gradient program. The oven temperature was 40^{o}C throughout the analysis. The standard solution of T011/IP-6A Aldehyde/Ketone-DNPH Mix (Supelco, USA) is consisting of 15 CCs including formaldehyde, acetaldehyde, acetone, acrolein, propionaldehyde, crotonaldehyde, butyraldehyde, benzaldehyde, isovaleraldehyde, valeraldehyde, o- tolualdehyde, m,p- tolualdehyde, hexanaldehyde and 2,5-

dimethylbenzaldehyde was already analyzed. The optimum condition for analysis of CCs, following the study of Morknoy (2008) (17), is illustrated in Table 3.3.

Table 3.3 The condition for analysis of carbonyl compounds (Morknoy, 2008) (17)

Main Column	RP Amide Discovery C16 250 cm x 4.6 mm i.d. with 0.5 µm packing
Pre-Column	RP Amide C16 2 cm x 4.0 mm i.d. with 0.5 µm packing
Mobile Phase	A: Water HPLC grade B: (45%) Acetonitrile HPLC grade (55%)
Column Temperature	40°C
Flow rate	1.0 ml/min
Detector	UV detector
Wavelength	360 nm
Injection volume	25 µL
Gradient Program Acetonitrile: 55% Acetonitrile 65% Acetonitrile 55%	Time (min) 20 5 5

3.3.2 Gas Chromatography (GC)

Benzene, toluene, ethylbenzene, m,p-xylene and o-xylene (BTEX) samples were analyzed by gas chromatography equipped with a flame ionization detector (GC-FID) at King Mongkut's University of Technology Thonburi (KMUTT) for the outdoor worker group. The high-exposure and indoor worker were analyzed by GC-FID at Chulalongkorn University.

For BTEX separation of part 1 (outdoor workers), the column of CP-Wax 52 CB size 30 m × 0.25 mm × 0.25 µm (CP8713) was used. The type of injector was spitless and the volume of injector was 2 µL. The injector's temperature was set at 225 °C. The flow rate of Helium (He) was 1.0 ml/min. For the detector, a Flame Ionization Detector (FID) was used with the temperature of 225 °C. The flow rate of Helium (He), hydrogen (H_2) and air zero were 28, 30 and 300 ml/min correspondingly. For the condition of column oven was shown in Table 3.4 below.

Table 3.4 The condition for BTEX analysis of part 1

Column	CP-Wax 52 CB size 30 m × 0.25 mm × 0.25 µm (CP8713)			
Injection -Type of injector - Injection volume Injector temperature - Flow rate of He	 Spiltless 2 µL 225ºC 1.0 ml/min			
Detector -Type of detector Detector temperature	 Flame Ionization Detector (FID) 225ºC			
Column Oven -Enable coolant -Coolant timeout -Stabilization	 50ºC 20 min 0.1 min			
	Temperature	Rate (ºC/min)	Hold (min)	Total (min)
		40.00	1.00	1.00
	100.00	10.00	3.00	10.00

For part 2 and 3 (traffic policemen and indoor workers), GC-FID (model 6890N, Agilent) G1530N with capillary column at Hazardous Substance and Waste Management Laboratory on 10th floor of Research Building, Chulalongkorn University was used and the conditions were shown in Table 3.5. The capillary column of HP-5 size 30 m x 0.32 mm x 0.25 µm (19091J-413) was performed and the carrier gases were consisted of Nitrogen (N_2), Helium (He), Hydrogen (H_2) and Air zero.

Table 3.5 The condition for BTEX analysis of part 2 and 3

Column	HP-5 size 30 m x 0.32 mm x 0.25 µm (19091J-413)			
Injection -Type of injector - Injection volume -Injector temperature - Flow rate of He	 Spiltless 1 µL 300 ºC 1.0 ml/min			
Detector -Type of detector Detector temperature	 Flame Ionization Detector (FID) 300 ºC			
Oven Ramp	ºC/min	Next ºC	Hold (min)	Run Time (min)
Initial		45	5.00	5.00
Ramp 1	3.00	80	0.00	16.67
Ramp 2	5.00	85	0.00	17.67

3.4 Preliminary experiments

3.4.1 Standard curves

The mixed standard solution of 15 CCs, which consists of formaldehyde, acetaldehyde, acetone, acrolein, propionaldehyde, crotonaldehyde, butyraldehyde, benzaldehyde, isovaleraldehyde, valeraldehyde, o-tolualdehyde, m,p-tolualdehyde, hexanaldehyde and 2,5-dimethylbenzaldehyde was utilized for calibration curve of CCs. The concentrations of mixed standard solution were 0.010, 0.050, 0.100, 0.500 and 1.000 ppm.

The mix of aromatic hydrocarbons 2 were used for BTEX calibration with the concentration of 0.05, 0.1, 0.5, 1, 5 and 10 ppm.

The reliability of the CCs and BTEX calibration curve were needed to clarify; $R^2 > 0.99$ for all compounds.

3.4.2 Limits of detection (LOD) and Limit of quantification (LOQ)

LOD and LOQ of HPLC/UV were calculated from the obtained value of the standard CCs solution after the injection of 0.05 ppm for 10 times. Standard deviation (SD) were received and LOD, LOQ and %RSD were calculated using equation 3.1, 3.2 and 3.5

$$\text{LOD} = 3\times\text{SD} \qquad \text{(Eq. 3.1)}$$

$$\text{LOQ} = 10\times\text{SD} \qquad \text{(Eq. 3.2)}$$

For BTEX, LOD and LOQ of GC-FID were estimated by injection of 25 ppm for 5 times. Then, SD were evaluated and LOD, LOQ and %RSD were calculated from equation 3.3, 3.4 and 3.5.

$$\text{LOD} = 3\times(\text{the lowest concentrations used}\times\delta)/\bar{X} \qquad \text{(Eq. 3.3)}$$

$$\text{LOQ} = 3\times(\text{the lowest concentrations used}\times\delta)/\bar{X} \qquad \text{(Eq. 3.4)}$$

$$\delta = \sqrt{\sum_{i=1}^{n}(\text{Xi} - \bar{x})^2/(\text{n}-1)} \qquad \text{(Eq. 3.5)}$$

where;

δ	=	Standard deviation
Xi	=	Peak area of target compound observed
$\bar{X}$	=	Average peak area of these observation
N	=	Number of observations

3.5 Study on ambient air concentration and personal exposure of carbonyl compounds and BTEX

3.5.1 Air sampling Instrument

For collecting and analysis of CCs, the method TO -11A for the Determination of Formaldehyde in Ambient Air Using Adsorbent Cartridge Followed by High Performance Liquid Chromatography (HPLC) was applied. The 2,4-Dinitrophenyl-hydrazine (2,4-DNPH) active cartridge (Wako Pure. Chemicals, Japan) was used for CCs sampling.

BTEX in the ambient air was sampling by a personal air pump and collecting with a charcoal glass tube which divided into two sorbent parts including the upper part with 400 mg of activated charcoals, and the lower with 200 mg. BTEX was collected to a charcoal glass tube by physically adsorbed into the activated charcoal.

The sampling train was designed for collecting both CCs and BTEX at the same air stream by connecting 2, 4 DNPH active cartridges, charcoal tube and a personal air pump together. For the sampling train design, an active cartridge was connected to a charcoal glass tube and a personal air pump, respectively.

3.5.2 Ambient air sampling and personal exposure

For ambient air sampling, a personal air pump connected to a charcoal tube and 2, 4 DNPH active cartridges were used for BTEX and CCs sampling, respectively. The personal air pump was calibrated individually before and after using with Primary Standard Airflow Calibrator (SIS Inc., USA). This pump was located at fixed site at the height of 1.5 m from the ground approximately and operated at the flow rate of 100 ml/min. The sampling period was related to the working time and it was normally for 8 hrs a day. The cartridge was extracted immediately after sampling whereas the charcoal tube was kept in the freezer with a temperature less than $4^{0}C$. The ambient samples were collected near the workplace for street vendors, motorcycle taxi drivers and security guards, while the ambient air samples of the traffic policemen were taken outside the police booth. For indoor workers, the ambient air samples were placed in the office room.

For personal air sampling, non-smoking workers were chosen as a representative worker. The sample was collected at the personal breathing zone to estimate the inhalation exposure. The personal pump was attached to the worker during their working time. The sampling method and condition were the same as the ambient air sampling as above mentioned.

3.5.3 Sample preparation

3.5.3.1 Carbonyl compounds

The 10 ml glass syringe, luer lock was used to hold 2, 4 DNPH active sampler cartridges. The sampler cartridges were eluted and adjusted the volume into 5 ml volumetric flask before keeping in the amber colored PTFE screwed vial. Finally, the samples were stored in freezer until the further analysis by HPLC.

3.5.3.2 BTEX

The charcoal glass tube is consisted of two parts including the 400 mg upper and 200 mg lower of activated charcoal. The upper part was used to analyze the actual amount of BTEX while the lower part was used to check breakthrough. Thus, these two parts of the tube was analyzed separately.

For an upper activated charcoal glass tube, 100 µL of internal was spiked to the sample and keep it for 30 min. After that, 2 ml of CS_2 was added and then kept for an hour. Finally, the samples were extracted to the vial and stored in the freezer before analysis with GC.

For a lower activated charcoal glass tube, the procedure was similar to the upper part except the amount of the added chemicals. Thus, the volume of internal and CS_2 are 50 µL and 1 ml, respectively.

3.5.4 Calculation of carbonyl compounds and BTEX concentrations

3.5.4.1 Carbonyl compounds

The calculation of the mass of CCs after analyzing with HPLC could be determined by using the provided equation 3.6 and 3.7

$$M_S = (X_A - X_B) \times V_S \qquad \text{(Eq. 3.6)}$$

where:

M_S (µg/sample)	=	Mass of carbonyl compounds
X_A (µg/ml)	=	Concentration of carbonyl compounds in sample
X_B (µg/ml)	=	Concentration of carbonyl compounds in blank
V_S (ml)	=	Sample volume 5 ml

$$\text{Concentration of carbonyls } (\mu g/m^3) = \frac{\text{Mass of Carbonyls } (\mu g)}{\text{Volume of air } (m^3)} \qquad \text{(Eq 3.7)}$$

3.5.4.2 BTEX

For BTEX calculation, the obtained values from GC-FID were used equation 3.8 and 3.9 below;

$$M_S = \frac{P_A - P_B}{P_S} \times C_S \times \frac{V_S}{V_I} \qquad \text{(Eq 3.8)}$$

where;

M_S (μg/sample) = Mass of BTEX

C_S (μg/ml) = Concentration of the mixed standard solution

P_A (unitless) = Peak area of BTEX per peak area of Toluene d-8 in sample

P_B (unitless) = Peak area of BTEX per peak area of Toluene d-8 in blank

P_S (unitless) = Peak area of BTEX per peak area of Toluene d-8 in mixed standard solution

V_S (μl) = Sample volume 2 ml

V_I (μl) = Injection volume 1 μl

$$\text{Concentration of BTEX } (\mu g/m^3) = \frac{\text{Ms } (\mu g)}{\text{Volume of air } (m^3)} \quad \text{(Eq. 3.9)}$$

3.6 Health Risk Assessment

The adverse health effect of CCs and BTEX on the outdoor worker was estimated via the inhalation exposure using risk assessment. There are four steps of risk assessment based on Environmental Protection Agency (EPA) approach including hazard identification, dose-response assessment, exposure assessment and risk characterization, respectively.

3.6.1 Hazard identification

The hazard identification was provided the substances of concern and their adverse effects. The hazard of CCs and BTEX were illustrated in Table 3.6.

Table 3.6 The adverse health effects of the chemicals (EPA and IRIS)

Substances	EPA Cancer Classification	Cancer Classification	Adverse Health Effect
Formaldehyde	B1	Probably carcinogenic to humans	Squamous cell carcinoma
Acetaldehyde	B2	Probable human carcinogen	Nasal squamous cell carcinoma
Benzene	A	Human carcinogen	Leukemia
Toluene	D	Not classifiable as to human carcinogenicity	Nervous system, the kidneys, the liver, and the heart
Ethylbenzene	B2	Probable human carcinogen	Liver and kidney toxicity
Xylenes	D	Not classifiable as to human carcinogenicity	Neurological effects

3.6.2 Dose-response assessment

The second step of risk assessment was to estimate the health problems from the different exposures. Normally, the basic concept of dose-response assessment was to analyze a cause–effect relationship by estimating the quantitative risk and the adverse health effect. For CCs and BTEX, a major route of exposure was an inhalation. Hence, the dose response relationship was provided the information between the airborne concentration of these chemicals and the severity of adverse health effects. For the risk estimation, the inhalation reference dose and cancer slope factor were provided for non-carcinogen and carcinogen, correspondingly. The inhalation cancer slope factor and inhalation reference dose were provided by RAIS and OEHHA are shown in table 3.7 and 3.8.

Table 3.7 Inhalation toxicity values for carcinogenic effect

Substances	Inhalation Slope Factor (mg/kg-day)	
	RAIS	OEHHA
Formaldehyde	-	$2.1x10^{-2}$
Acetaldehyde	-	$1x10^{-2}$
Benzene	$2.73x10^{-2}$	$1x10^{-1}$
Ethylbenzene	$3.85x10^{-3}$	$8.7x10^{-3}$

Table 3.8 Inhalation toxicity values for non-carcinogenic effect

Substances	Inhalation Slope Factor (mg/kg-day)	
	RAIS	OEHHA
Propionaldehyde	$8x10^{-3}$	-
Toluene	5	$3.01x10^{-1}$
Xylene	$1x10^{-1}$	-

3.6.3 Exposure assessment

Exposure assessment is to determine the intensity, and the duration or frequency of exposure to an agent. This method was based on the original Risk Assessment Guidance for Superfund (RAGS) Part A approach (1989). The calculation of this step was to obtain a realistic estimate of total human exposure was related to the chemical. For carcinogenic compounds, the risk equation was shown below;

$$CDI = \frac{CA \times IR \times ET \times EF \times ED}{BW \times AT} \quad \text{(Eq. 3.10)}$$

Recently, the calculation of inhalation exposure of pollutants was referred to RAGS Part F approach. Thus, the risk equation for non-carcinogenic compounds was shown below;

$$EC = \frac{CA \times ET \times EF \times ED}{AT}$$ (Eq. 3.11)

The definition and the input values of variables in risk equation were shown in Table 3.9.

Table 3.9 The variable of risk equation

Variable	**Definition**	**Source**
CA (µg/ m^3)	Chemical concentration	Sampling
IR (m^3/hrs)	Inhalation rate	0.875 for adults
BW(kg)	Body weight	Questionnaire
ET (hrs/d)	Exposure time	8 hrs
EF (d/yrs)	Exposure frequency	Questionnaire
ED (yrs)	Exposure duration	Questionnaire
AT (d)	Averaging time	70 years × 365 days for cancer (ED × d × hrs) for non-cancer
CSFi $(mg/kg\cdot day)^{-1}$	Cancer slope factor	As shown in Table 3.4
RfC (mg/m^3)	Inhalation reference concentration	As shown in Table 3.5

3.6.4 Risk characterization and interpretation

This step was to quantify the risk to human health. Normally, it was calculated by using the exposure level from the exposure assessment step and the slope factor

(CSFi) or the inhalation reference concentration (RfC) for cancer and non-cancer risk, respectively. Both CSFi and RfC values are provided by Integratd Risk Information System (IRIS) and Risk Assessment Information System (RAIS).

The cancer risk was characterized by the provided equation 5 below;

$$\text{Cancer risk} = \text{CDI} \times \text{CSF}_i \qquad \text{(Eq. 3.12)}$$

The value of cancer risk can be interpreted by

Cancer risk > 10^{-6} means Carcinogenic effects of concern

Cancer risk ≤ 10^{-6} means Acceptable level

The non-cancer risk was estimated by the equation 6 below;

$$\text{HQ} = \text{EC}/(\text{RfC} \times 1000\ \mu\text{g/mg}) \qquad \text{(Eq. 3.13)}$$

The non-cancer risk can be interpreted with the Hazard Quotient (HQ) where;

HQ > 1 means Adverse non-carcinogenic effects of concern

HQ ≤ 1 means Acceptable level (of no concern)

3.7 Risk perception and communication

3.7.1 The study of risk perception and communication

Risk perception and risk communication of this study were consisted of three steps and all three groups of workers were engaged as the participants. The study subjects of workers were equally 30 persons in each group of workers. Three steps of risk communication were shown in Fig. 3.4. The first step was conducted the knowledge and attitude questionnaire (KA questionnaire) as the pre-test. The questionnaire was included the characteristics of participants and the various questions on the traffic air pollution. The questions of knowledge were contained three parts which consisted of air pollution (K_A), health risk assessment (K_H) and the practice for preventing the health problems (K_P). The same as knowledge, the questions on the attitude were comprised of air pollution (A_A), health risk assessment (A_H) and practice (A_P). The second step was risk communication using a media (document) by giving the knowledge and notifing the obtained results of risk assessment to the workers. Moreover, the concept of risk in their situation was explained to the exposed people. Finally, the suggestions of the solutions of minimized risk were informed to motivate the personal perception and awareness of environmental problems of the workers. The explanation of a media in this study was illustrated in Table 3.10 and Appendix F. For the third step, KA questionnaires were immediately conducted as the post-test in order to compare the results between pre-test and post-test by using T-test (see Fig. 3.5). Furthermore, the correlation between knowledge and attitude was examined by using Pearson's correlation (see Fig 3.6).

Figure 3.4 Steps of the evaluation of KAP questionnaires

Table 3.10 Explanation of media for risk communication

Topic	Page	Explanation
Air pollutant	1-4	The knowledge of traffic air pollution
Health risk assessment	5-8	The knowledge of health risk casuing from the traffic air pollutants
Prevention practice	9-11	The practical ways for risk reduction from the traffic air pollutants

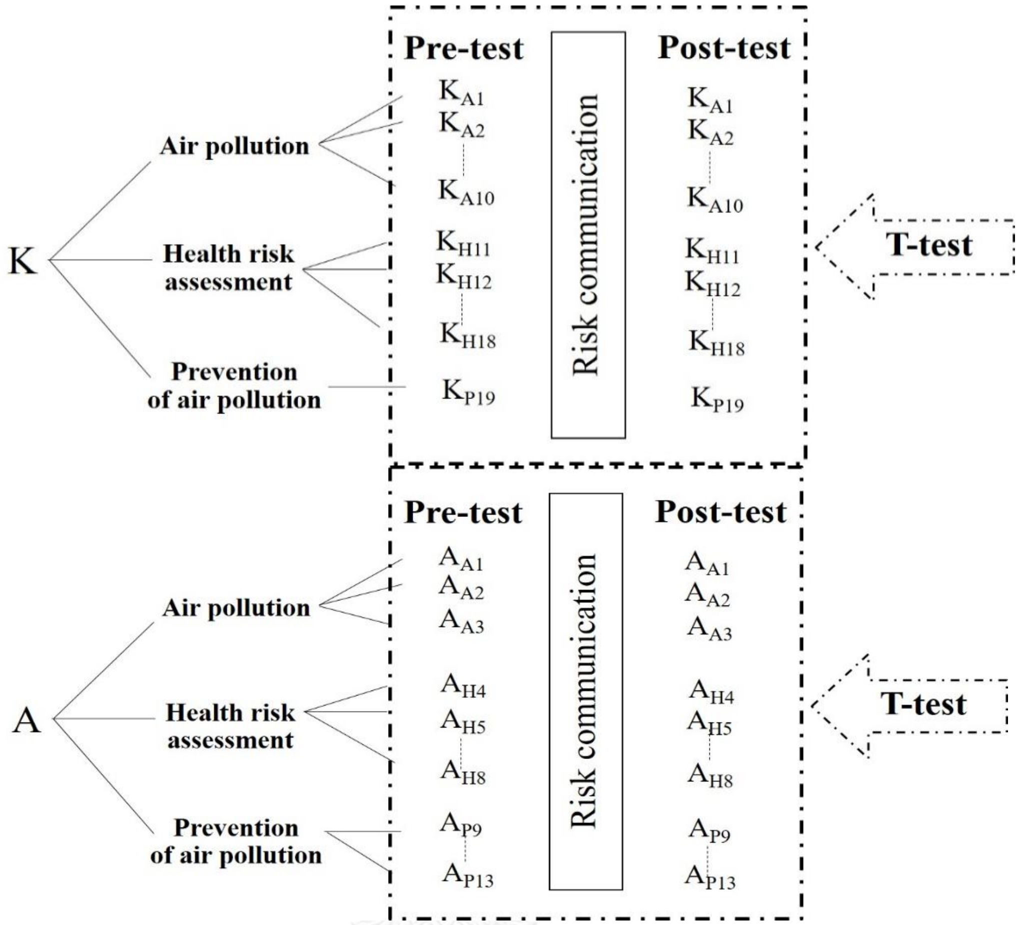


Figure 3.5 The comparison between pre-test and post-test of questionnaire

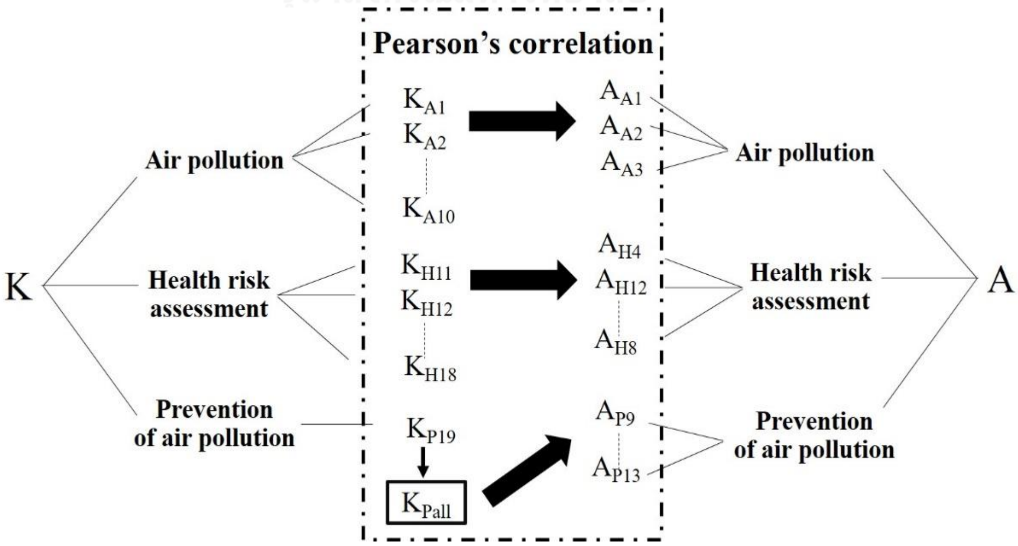


Figure 3.6 The correlation between pre-test and post-test of questionnaire

3.7.2 Evaluation of KA data

Risk communication was observed by conducting the knowledge and attitude questionnaire and the steps of KA questionnaire evaluation were shown in Fig.3.7. The general information of risk communication was shown in Table 3.11.

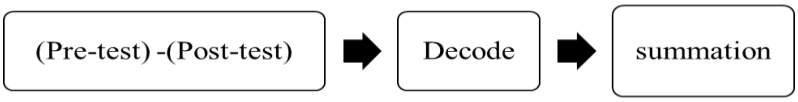


Figure 3.7 Steps of the evaluation of KAP questionnaires

Table 3.11 Explanation of the data of risk perception and risk communication

Part	General information	Data analysis
1	Age, gender, education, occupation	Descriptive statistic
2	Knowledge's questions -Knowledge of traffic air pollution (K_A) -Knowledge of health risk assessment (K_H) -Knowledge of prevention of air pollution (K_P)	Test of risk communication -T-test analysis (compare between pre-test and post-test) -Pearson's correlation (association between knowledge and attitude)
3	Attitude's questions -Attitude of traffic air pollution (A_A) -Attitude of health risk assessment (K_H) -Attitude of prevention of air pollution (K_P)	Test of risk communication - T-test (compare between pre-test and post-test) -Pearson's correlation (association between knowledge and attitude)

The analysis of KA questionnaire was evaluated by given 1 score for a correct answer while 0 score for an incorrect answer. After evaluation, the total points in each part (air pollution, health risk assessment and practice) of questions were summed them up for both pre-test and post-test questionnaires. Next, the gain scores of pre-test was minus the total point of post-test in each part. Then, the number decoding of residual scores were recode where -3, -2, -1, 0, 1, 2, 3 were substituted to 0.125, 0.25, 0.5, 1, 2, 4, 8, respectively (see Table 3.12). The calculated scores of pre-test and post-test were used for the effectiveness of risk communication in this study. If the post-test scores were greater than those of pre-test, the tool of risk communication of this study was successful. In addition, the relationships between knowledge and attitude were examined which included K_A&A_A, K_H&A_H and K_{All}&A_P. For K_{All}&A_P, the knowledge of all parts (K_{All}) were used as a substitute for K_P in the correlation of knowledge and attitude of practices due to the limitation of amount of practice's question.

Table 3.12 The number decoding of residual scores

Score	Decode
-3	0.125
-2	0.25
-1	0.5
0	1
1	2
2	4
3	8

3.8 Data Analysis

All observed data were analyzed using SPSS for Windows version 18 as follows:

1) Spatial concentrations of CCs and BTEX in the ambient air of three group workers were analyzed by using one-way ANOVA

2) Personal exposure to CCs and BTEX of all workers were analyzed by one-way ANOVA

3) The correlation between ambient air and personal exposure concentrations were analyzed by Pearson's correlation

4) The significance of difference of CCs and BTEX between dry and wet season were analyzed by T-Test

5) The significance of difference in the pollutants levels among all group of workers were tested by one-way ANOVA

6) The comparison of non-cancer and cancer risk levels among the workers were analyzed by one-way ANOVA

7) For questionnaire, T-test was used for comparing the difference between pre-test and post-test questionnaires in each part consisted of knowledge, attitude and practice

8) Person's correlation was used to find the relationship between knowledge and attitude in each part consisted of knowledge, attitude and practice

9) P-values to determine statistical significance in this study were $p<0.05$ and $p<0.01$

From overall methodology mentioned above, the conceptual framework can be illustrated as Fig. 3.8.

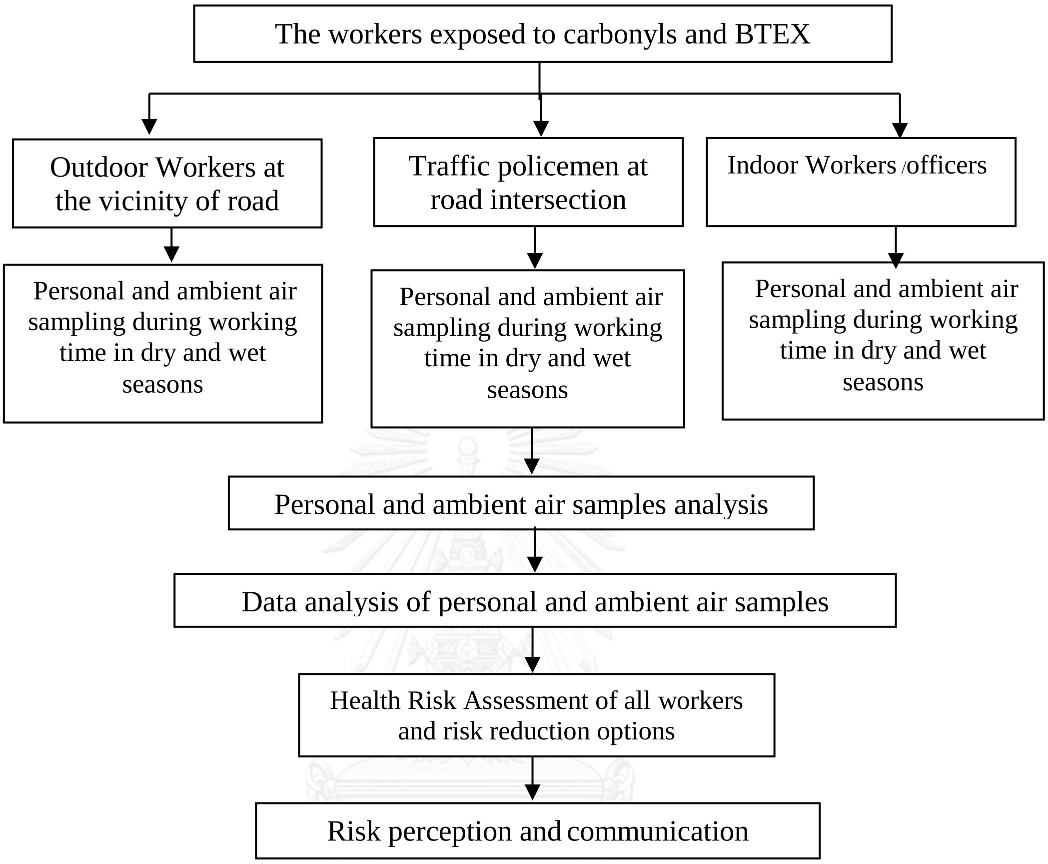


Figure 3.8 Conceptual framework diagram of this study

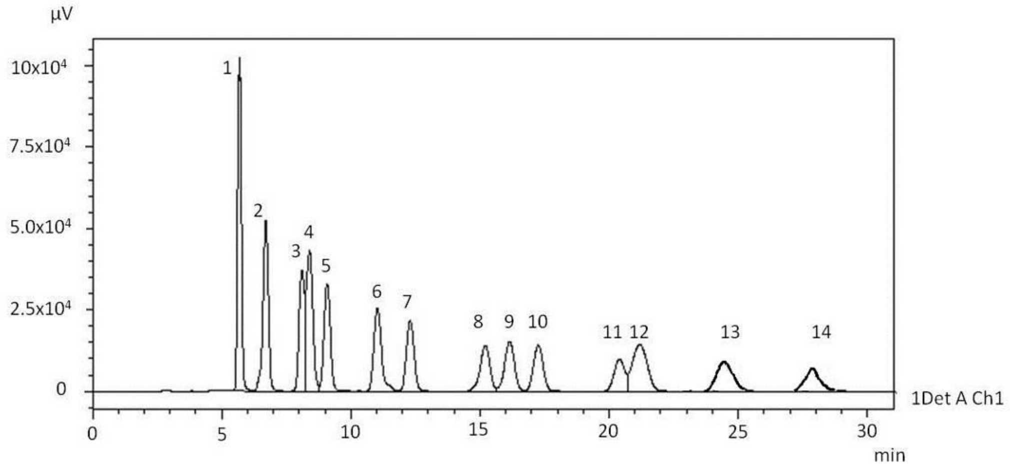
CHAPTER IV

Inhalation exposure of the outdoor workers at the roadside area to BTEX and carbonyl compounds

4.1 Preliminary study

4.1.1 The conditions of instruments for BTEX and Carbonyls analysis

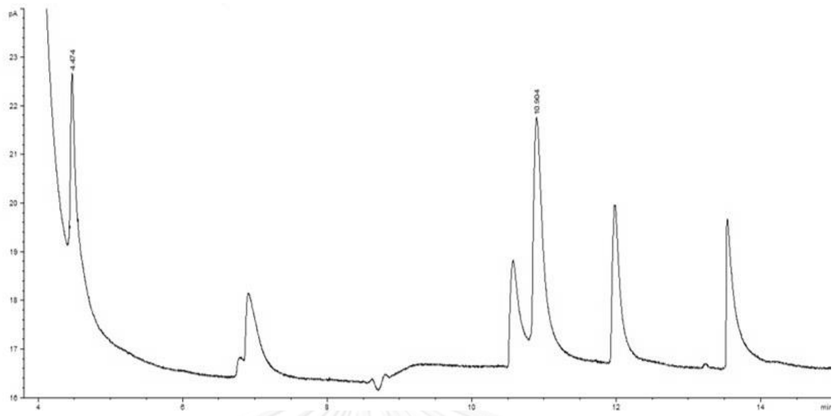
The optimum condition of HPLC-UV for carbonyl compounds (CCs) determination was set up according to Morknoy's study (2008), and the mixed standard of carbonyls was used. Fourteen peaks of carbonyls had total runtime of 30 minutes approximately which included formaldehyde, acetaldehyde, acetone, acrolein, propionaldehyde, crotonaldehyde, butyraldehyde, benzaldehyde, isovaleraldehyde, valeraldehyde, o-tolualdehyde, m,p-tolualdehyde, hexanaldehyde and 2,5-dimethylbenzaldehyde as shown in Figure 4.1



1. Formaldehyde (5.5-6.0)	2. Acetaldehyde (6.2-6.5)	3. Acetone (8.0-8.5)
4. Acrolein (8.6)	5. Propionaldehyde (8.9-9.3)	6. Crotonaldehyde (11.0-11.2)
7. Butyraldehyde (13.81)	8. Benzaldehyde (14.59-15.0)	9. Isovaleraldehyde (16.0-16.2)
10. Valeraldehyde (17.6-18.4)	11. o-Tolualdehyde (20.8-21.3)	12. m,p-Tolualdehyde (21.5-22.1)
13. Hexanaldehyde (23.5-24.0)	14. 2,5-Dimethylbenzaldehyde (26.8-27.3)	

Figure 4.1 Chromatogram of standard 14 carbonyl compound at the concentration of 0.100 ppm (The number in bracket represented retention time)

For BTEX analysis, standard solution of BTEX and 4-bromofluorobenzene was used as an internal standard to find the optimum condition for GC- FID. The total retention time was about 15 minutes. (Figure 4.2)



1. Benzene (3.8-4.0) 2. Toluene (7.0-7.2) 3. Ethylbenzene (10.9-11.2)

4. m,p-Xylene (11.3-11.6) 5. o-Xylene (12.4-13.0) 6. 4-bromofluorobenzene (13.5-13.9)

*The number in the blanket is the retention time of the compounds and
* means an internal standard

Figure 4.2 Chromatogram of 8,000 ng/ml BTEX standard with the concentration of 8,000 ng/ml 4-bromofluorobenzene as internal standard. (The number in bracket represented retention time)

4.1.2 Calibration curves

For calibration curve analysis of CCs, the mix CCs standard including five concentrations were consisted of 0.005, 0.010, 0.050, 0.100, 0.500, and 1.000 mg/L were applied. For BTEX, the BTEX standard was applied for calibration curves which included seven concentrations as follows 125, 250, 500, 1000, 2000, 4000 and 8000 ng/ml. Both CCs and BTEX had the R^2 of the calibration curves in the range of 0.9991-0.9999 (Table 4.1).

Table 4.1 Concentrations of carbonyl compounds and BTEX standards in calibration curves

Standard Solution	**Concentration of Standard Solution**	**Concentration in air (μg/m³)**
Standard CCs	0.005 mg/L	0.10
	0.010 mg/L	0.21
	0.050 mg/L	1.03
	0.100 mg/L	2.07
	0.500 mg/L	10.33
	1.000 mg/L	20.66
Standard BTEX	125 ng/ml	3.04
	250 ng/ml	6.08
	500 ng/ml	12.15
	1000 ng/ml	24.30
	2000 ng/ml	48.65
	4000 ng/ml	97.24
	8000 ng/ml	194.40

4.1.3 Limit of Determination and Limit of Quantification of HPLC and GC

4.1.3.1 LOD and LOQ of High Performance Liquid Chromatography

LOD and LOQ of CCs were calculated based on the standard deviation (SD). LOD and LOQ were 3 SD and 10 SD, respectively. For the percentage of RSD, the results were in an acceptable value. The values of LOD, LOQ, %RSD and %recovery were capable to applied for this study (Table 4.2). For %recovery of acetone and acroline were not applied in this study due to the variation of these chemicals.

Table 4.2 Results of LOD and LOQ for carbonyl compounds analysis

Compound	LOD (mg/l)	LOQ (mg/l)	%RSD	%Recovery
Formaldehyde	0.002	0.008	1.869	92.00
Acetaldehyde	0.002	0.008	1.944	87.56
Acetone	0.002	0.007	1.664	-
Acroloine	0.002	0.007	1.704	-
Propionaldehyde	0.002	0.006	1.513	82.67
Crotonaldehyde	0.006	0.019	4.548	81.33
Butyraldehyde	0.005	0.011	4.227	63.78
Benzaldehyde	0.003	0.017	2.756	88.89
Isovaleraldehyde	0.003	0.009	2.130	83.22
Valeraldehyde	0.002	0.005	1.270	80.22
o-Tolualdehyde	0.004	0.014	3.526	85.78
m,p-Tolualdehyde	0.002	0.007	1.804	90.67
Hexanaldehyde	0.003	0.010	2.342	84.89
2,5-Dimethylbenzaldehyde	0.002	0.008	2.074	87.11

4.1.3.2 LOD and LOQ of Gas Chromatography

The concentration of 25 ng/ml of BTEX standard was injected into GC-FID for 5 times to find LOD and LOQ. The calculated values of LOD and LOQ were demonstrated in Table 4.3. The sample's values were less than LOQ was classified as non-detected (ND). %RSD and recovery of BTEX were in an acceptable value as shown below. The overall results of preliminary study were expressed in Appendix A.

Table 4.3 Results of LOD and LOQ for BTEX analysis

Compound	LOD (ng/mL)	LOQ (ng/mL)	%RSD	%Recovery
Benzene	2.30	7.67	4.22	96.33
Toluene	2.07	6.91	4.33	100.12
Ethylbenzene	4.29	14.30	3.85	103.39
m,p-Xylene	6.21	20.70	2.81	99.71
o-Xylene	3.30	11.01	6.84	100.56

4.2 Ambient and personal BTEX concentrations of outdoor workers at roadside area

The first samplings were collected at several locations around Pathumwan district in order to compare the concentration of CCs and BTEX among three groups of workers including street vendors, motorcycle taxi drivers and security guards. There were five sampling sites including Faculty of science (SCI), Osot Sala (OS), BBL Bank (BBL), KTB Bank (KTB), SCB Bank (SCB) for both street vendors and motorcycle taxi drivers. Whilst, the sampling sites of security guards were included Faculty of Commerce and Accountancy (MBA), Faculty of Political Science (POL), Faculty of Architecture (ARC), Faculty of Arts (ART), Faculty of Science (SCI) and Graduate School (GRA). Both personal and ambient air sampling were collected at each location. The samplings were carried out in September 2012 and March 2013. For each season**,** the numbers of samples of personal exposure concentrations of street vendors, motorcycle taxi drivers and security guards were 9, 10 and 12, respectively. For the ambient concentration, the total samples of street vendors, motorcycle taxi drivers and security guards were 5, 5, 6, correspondingly. The overall results were provided in Appendix B.

4.2.1 Comparison on personal exposure and ambient BTEX concentration of street vendors at all sampling sites

The 8-hr averages of personal exposure and ambient concentration of street vendors were shown in Figure 4.3. The comparison of sampling sites was included OS, SCB, SCI, KTB and BBL. The average benzene concentrations of personal exposure were found at SCI followed by SCB, BBL, OS and KTB, respectively. For personal exposure to toluene, the greatest average concentration was found at BBL followed by SCB, SCI, OS, and KTB, respectively. In contrast to toluene, the highest average concentration of personal exposure to ethylbenzene was observed at SCB, KTB, SCI, OS and BBL. However, KTB was provided the highest level of m,p-Xylene, followed by SCB, OS, BBL and SCI, respectively. For o-Xylene, the greatest level was found at KTB, followed by SCB, SCI, BBL and OS, correspondingly.

For the ambient air concentrations, the highest value of benzene was found at SCI followed by OS, BBL, SCB and KTB, respectively. For toluene, the highest level was found at BBL followed by SCI, OS, KTB and SCB, correspondingly. Whilst, the greatest value of ethylbenzene was shown at SCB, BBL, SCI, OS and KTB, correspondingly. For m,p-Xylene, the highest levels was obtained from SCB, BBL, KTB, SCI, and OS, correspondingly. In contrast to m,p-xylene, the greatest level of o-Xylene was illustrated at BBL followed by SCB, KTB, OS, and SCI, respectively.

For BTEX, the highest personal exposure level was found at BBL followed by SCI, SCB, KTB and OS, respectively. For the highest BTEX concentration of ambient air concentrations, the sequence levels were BBL, SCI, OS, SCB, and KTB, correspondingly. The BTEX concentrations of all sampling sites were shown in Table 4.4.

Table 4.4 BTEX concentrations of street vendor at all sampling sites

Sample	Compound	Concentration (µg/m^3)				
		OS	SCB	SCI	KTB	BBL
Personal air	Benzene	16.99±4.68	28.79±26.66	42.09±11.60	15.29±0.78	23.52±9.13
	Toluene	37.20±9.72	74.23±18.03	72.70±13.86	2551±1.24	110.90±135.12
	Ethylbenzene	2.86±1.08	7.47±2.98	4.53±1.16	4.56±1.94	2.85±1.03
	m,p-Xylene	4.66±2.49	7.26±6.30	4.13±4.13	12.48±1.94	4.47±4.47
	o-Xylene	7.86±6.95	15.38±16.90	14.39±21.71	31.65±6.95	8.26±7.21
	BTEX	69.55±16.83	132.92±44.63	137.83±8.35	73.83±29.08	149.95±125.36
Ambient air	Benzene	27.53±12.84	23.66±1.40	49.18±7.94	14.09±1.46	26.75±6.62
	Toluene	83.10±49.38	54.80±5.00	196.32±79.07	56.99±55.14	394.41±6.62
	Ethylbenzene	3.58±1.22	6.99±1.23	4.35±13.9	2.08±1.88	6.41±5.44
	m,p-Xylene	2.51±0.29	17.61±18.52	3.06±0.06	5.54±6.17	11.53±10.19
	o-Xylene	11.39±12.13	23.02±26.39	2.98±1.02	18.36±25.96	23.57±29.64
	BTEX	128.09±75.86	126.07±40.09	255.88±73.48	97.05±19.67	462.66±403.36

Toluene was found the most abundant among BTEX compounds followed by benzene. At BBL, the highest BTEX values were observed for both ambient and personal exposure values, and these may be caused by the intensive of traffic around the area. Moreover, this site was situated close to T-junction (Chaloem Phao) and along the street of BBL site was covered by several shopping malls (Siam Paragon, Siam Square, and Digital Gateway); hence the crowd traffic causing from these shopping malls was affected to this site in order to increase the number of vehicles. Furthermore, BBL site was covered approximately 80% by BTS station, thus the pollutants were tended to accumulate in this area greater than observed in those sites. On the other hand, OS were contained the lowest BTEX levels for both ambient and personal samples and the possible reason might be due to the lower traffic density. In addition, there was no the overpass or skytrain station (Siam Station) covered around this area. Therefore, the air pollutants can freely spread into the atmospheric air which caused the dilution of

BTEX concentration, so BTEX levels in this site was lower than those found for the other sites.

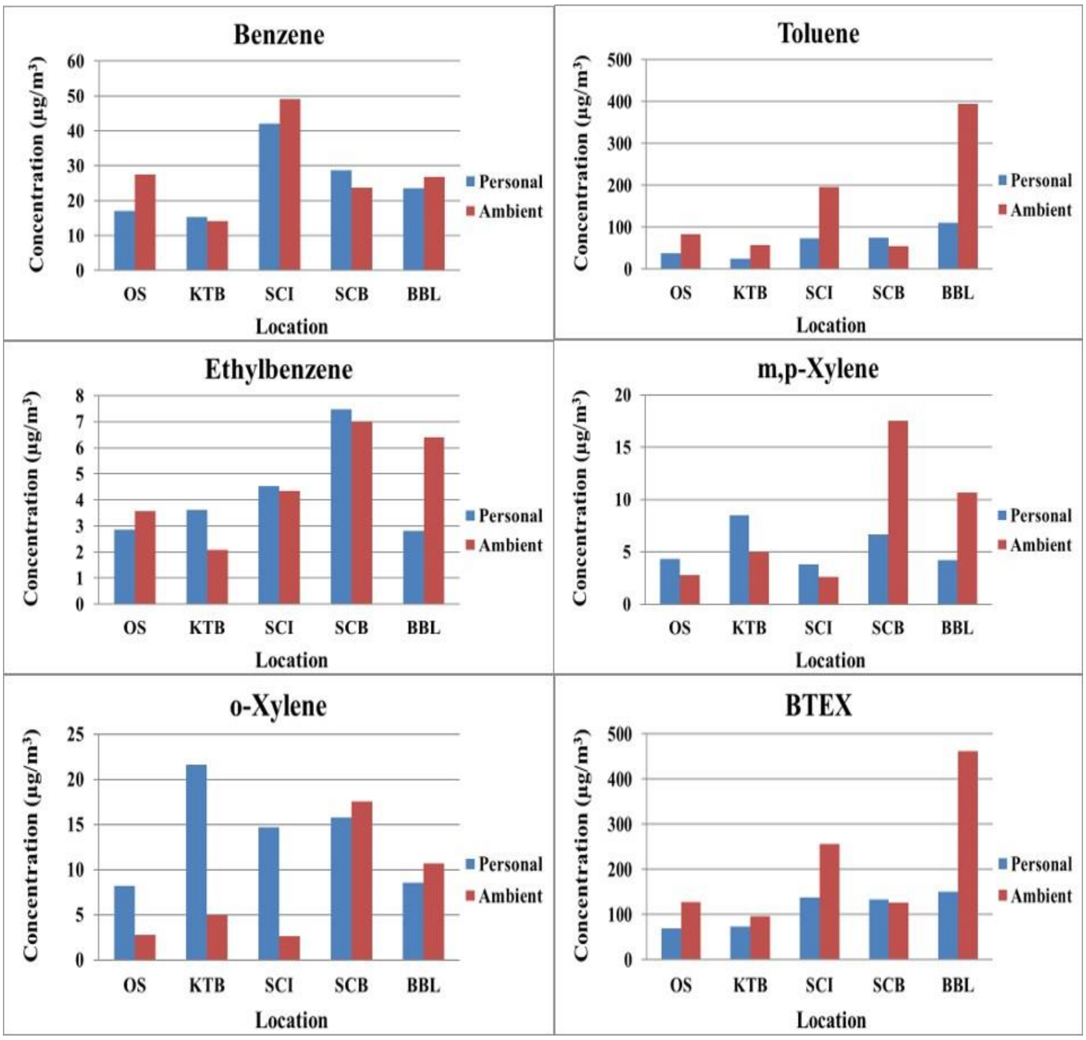


Figure 4.3 Comparison on BTEX of street vendors at all sampling sites

To compare BTEX level of street vendors in this study with another research, the study of Mexico was considered. It was found that the personal concentration of street vendors who worked in Mexico was greater than that measured in Thailand (this study). The study area of Mexico was located at the intensive traffic and there were a lot of the old inefficient vehicles which elevated the traffic air pollutants of the occupational group exposed to high VOCs level (81). (Table 4.4). Thus, the old vehicles were concerned as a major BTEX concentration along with the high traffic volume in their study.

Table 4.5 Comparison of the mean personal exposure concentrations of street vendors in Thailand and Mexico

Compound	Mean concentration ($\mu g/m^3$)	
	Thailand[1]	Mexico[2]
Benzene	26	77
Toluene	66	160
Ethylbenzene	4	28
m,p-Xylene	6	93
o-Xylene	15	35

[1]Data obtained from this study
[2]Data obtained from Romieu et al, 1999

4.2.2 Comparison on personal exposure and ambient BTEX concentration of motorcycle taxis drivers at all sampling sites

The personal exposure and ambient air concentrations of motorcycle taxis were shown in Figure 4.4. The highest average personal exposure concentration of benzene was found at KTB followed by BBL, SCI, SCB and OS, correspondingly. Additionally, the greatest toluene value was found at KTB followed by SCI, BBL, SCB and OS, respectively. The same as benzene and toluene, KTB showed the highest ethylbenzene level followed by BBL, SCB, SCI and OS, correspondingly. Moreover, the greatest m,p-xylene concentration was provided at KTB, followed by BBL, SCB, SCI and OS, respectively. For the highest o-xylene concentration, the sequence levels were observed at SCI, followed by SCB, BBL, KTB and OS, correspondingly. For personal samples, KTB showed the greatest levels of most BTEX compounds and it was difficult to discuss on this worker group because they always traveled over several places depending on the customers' request. The possible reason for this explaination was the motorcycle drivers of this site traveled to the high density traffic area throughout their working time, thus they exposed to the high pollutant levels.

For the ambient air concentration of benzene, SCI had the greatest level which followed by KTB, BBL, OS and SCB, respectively. For toluene, the highest value was found at SCI, BBL, SCB, KTB and OS, correspondingly. Nevertheless, the highest ethylbenzene concentration was investigated at BBL followed by SCI, KTB, SCB and OS, respectively. In contrast to ethylbenzene, the highest level of m,p-xylene was shown at SCI followed by BBL, SCB, KTB and OS, correspondingly. In addition to m,p-xylene, the greatest o-xylene was shown at SCI followed by SCB, BBL, KTB, and OS, respectively.

For total BTEX, the greatest BTEX level of personal exposure air was provided at KTB followed by BBL, SCI, SCB and OS, while the highest concentration of ambient air level was illustrated at SCI, SCB, BBL, KTB and OS, respectively. The CCs concentrations of all sampling sites were shown in Table 4.6.

Table 4.6 BTEX concentrations of motorcycle taxi driver at sampling sites

Sample	Compound	Concentration (μg/m^3)				
		OS	SCB	SCI	KTB	BBL
Personal air	Benzene	27.22±2.33	28.12±4.01	30.49±6.68	37.35±13.58	35.51±0.35
	Toluene	15.57±7.79	48.21±24.22	54.98±24.26	94.86±30.26	51.43±1.88
	Ethylbenzene	3.43±1.67	6.36±3.12	4.66±3.46	7.86±2.33	6.69±0.07
	m,p-Xylene	3.03±1.40	5.13±2.24	3.14±3.51	10.07±3.13	6.82±0.85
	o-Xylene	4.38±2.39	19.27±16.13	25.49±27.98	10.55±4.56	16.50±5.60
	BTEX	71.53±19.87	107.10±23.49	118.76±46.39	160.68±42.99	131.30±36.14
Ambient air	Benzene	24.59±5.20	20.78±1.72	41.77±28.33	33.75±6.44	30.33±7.25
	Toluene	22.22±17.78	76.00±47.52	257.61±290.06	70.00±22.32	82.25±46.27
	Ethylbenzene	2.58±2.82	4.94±1.15	5.57±3.05	5.12±0.44	7.97±1.00
	m,p-Xylene	2.57±2.68	3.40±0.29	8.94±7.56	3.13±2.43	8.39±2.08
	o-Xylene	4.74±5.45	52.37±70.38	70.16±94.40	8.71±3.81	14.32±8.91
	BTEX	56.68±23.53	157.49±118.19	384.04±423.40	120.69±14.94	143.23±33.19

As well as street vendors, the major substance of BTEX was toluene which followed by benzene. Nevertheless, the greatest BTEX levels of ambient and personal samples were found at the different sites because motorcycle taxi drivers did not stay at their workplace during their working time that in contrast to street vendors. The highest BTEX level of ambient air sample was demonstrated at SCI and it might be caused by the location of SCI was situated in front of Chulalongkorn University, so the traffic density was high. Furthermore, the groups of motorbike drivers spotted congregating in groups at the sites, then the motorcycle exhaust gases were increase the concentrations of pollutants. The bus station was located extremely closed to this area. Consequently, the ambient air samples were depended on the amount of motorcycle at that area. However, there was no significant difference in the BTEX concentration found between the sites.

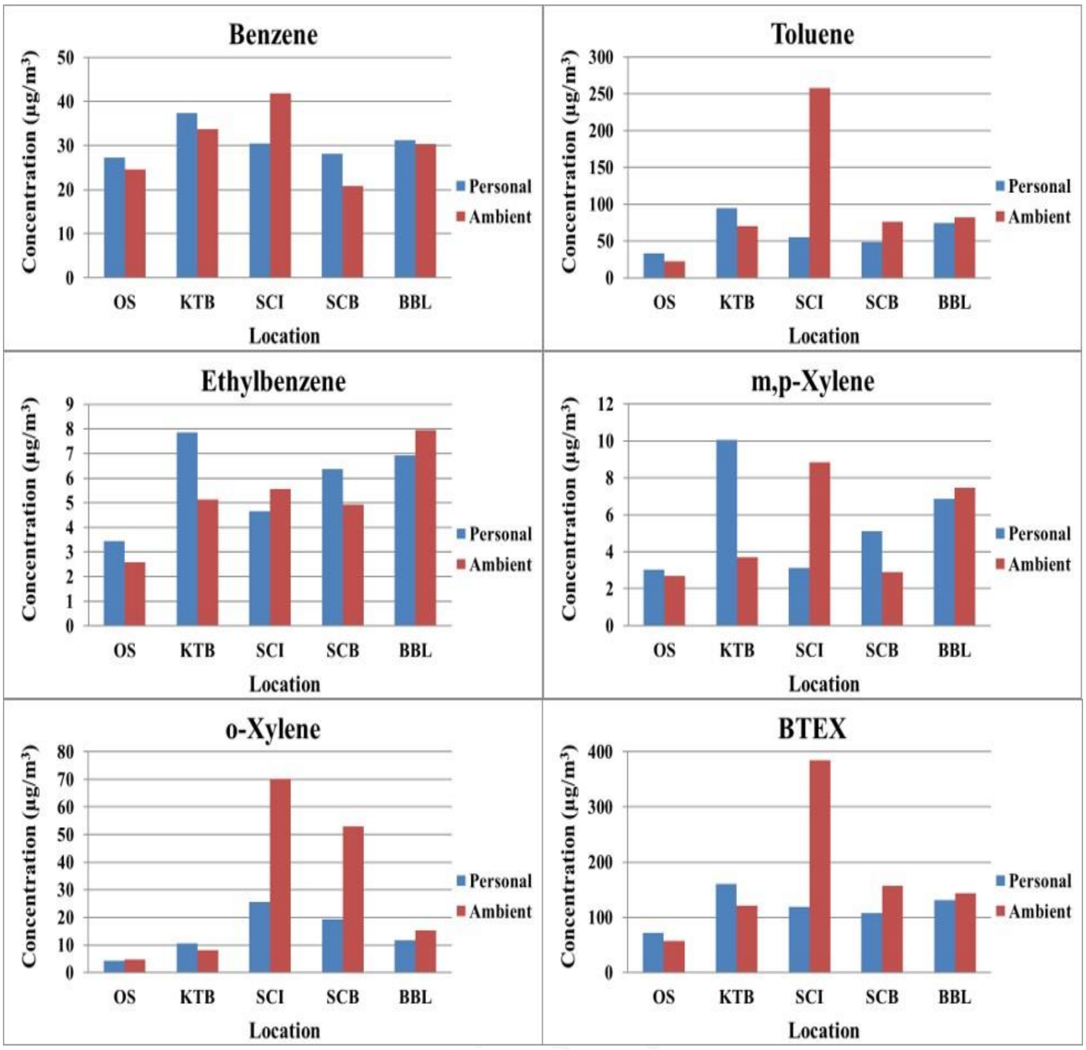


Figure 4.4 Comparison on BTEX of motorcycle taxi drivers at all sampling sites

4.2.3 Comparison on personal exposure and ambient BTEX concentration of security guards at all sampling sites

The personal exposure levels and ambient concentration were shown in Figure 4.5. The highest personal exposure concentration of benzene was shown at ART followed by SCI, ARC, GRA, MBA and POL, respectively. The greatest concentration of toluene was found at MBA, followed by POL, ART, ARC, SCI and GRA, correspondingly. The highest workers' exposure to ethylbenzene was found at POL, MBA, SCI, GRA, ART and ARC, correspondingly. Whilst, the sequence of m,p-xylene concentration were investigated at SCI, GRA, POL, MBA, ART and ARC, respectively. At POL site was shown the highest concentration which followed by SCI, ARC, ART, GRA and MBA, correspondingly.

For the ambient air concentrations, the greatest level of benzene was illustrated at POL, GRA, SCI, ARC, MBA and ART, respectively. The POL site had the greatest level of toluene which followed by ART, MBA, GRA, ARC and SCI, respectively. The sequence of ethylbenzene level was POL, MBA, GRA, SCI, ART and ARC, correspondingly. For m,p-Xylene, the highest value was found at SCI, GRA, POL, MBA, ART and ARC, respectively. The greatest o-Xylene levels were shown at GRA, POL, ARC, SCI, MBA and ART, respectively. For personal exposure value of BTEX were observed at MBA, POL, SCI, ARC, ART and GRA, respectively. In contrast to personal exposure level, the highest ambient air concentration of BTEX were found at POL, GRA, ARC, ART, SCI and MBA, correspondingly. The results of BTEX concentrations of security guard at all sampling sites were in Table 4.7.

Table 4.7 BTEX concentrations of security guard at all sampling sites

Sample	Compound	Concentration (μg/m^3)					
		ART	ARC	GRA	POL	SCI	MBA
Personal air	Benzene	45.81±8.28	42.79±16.63	42.76±26.63	24.61±20.56	44.29±26.43	40.50±27.60
	Toluene	24.71±8.22	28.85±17.34	16.92±3.90	40.85±3.62	20.88±5.65	58.09±34.47
	Ethylbenzene	1.34±0.87	2.08±1.20	1.56±0.46	8.54±9.42	2.76±0.43	6.70±2.23
	m,p-Xylene	2.67±3.88	1.20±0.72	5.90±8.47	4.49±3.96	10.75±9.74	4.28±3.76
	o-Xylene	17.55±21.17	18.70±35.98	15.49±16.58	32.42±35. 79	23.33±36.40	5.67±4.73
	BTEX	92.08±39.39	93.62±65.56	82.62±50.29	110.91±44.03	102.01±59.18	115.23±51.92
Ambient air	Benzene	25.93±0.78	43.69±0.14	61.45±57.41	87.97±94.41	46.16±32.31	32.84±8.41
	Toluene	48.70±65.12	19.49±13.15	27.95±18.69	51.36±4.54	11.53±1.08	31.37±4.31
	Ethylbenzene	0.78±1.10	0.52±0.65	3.94±2.67	10.90±13.98	1.97±0.12	4.48±1.57
	m,p-Xylene	1.07±1.39	0.58±0.53	5.27±5.66	5.26±5.70	9.87±12.14	2.29±1.85
	o-Xylene	5.38±5.83	28.72±40.09	61.65±85.15	59.47±72.83	11.26±13.89	8.25±7.86
	BTEX	81.85±58.23	93.00±51.93	160.24±169.58	214.95±152.08	80.77±57.38	79.22±17.16

The same as motorcycle taxi drivers, the greatest BTEX level of ambient and personal samples were shown in the different sampling sites which caused by the guards performed several activities and they did not work at the checkpoint throughout their working time. Hence, the greatest BTEX values were expressed in different sites. For the ambient air samples, POL revealed the greatest BTEX value due to the total amounts of vehicle at the entry box of POL site was very high. Furthermore, this place was situated near Henry Dunant Road that had the intensive traffic. For personal exposure samples, the BTEX level was relied on the activities of security guards. Nonetheless, there was no significant difference in the BTEX concentration found between the sites for both types of samples.

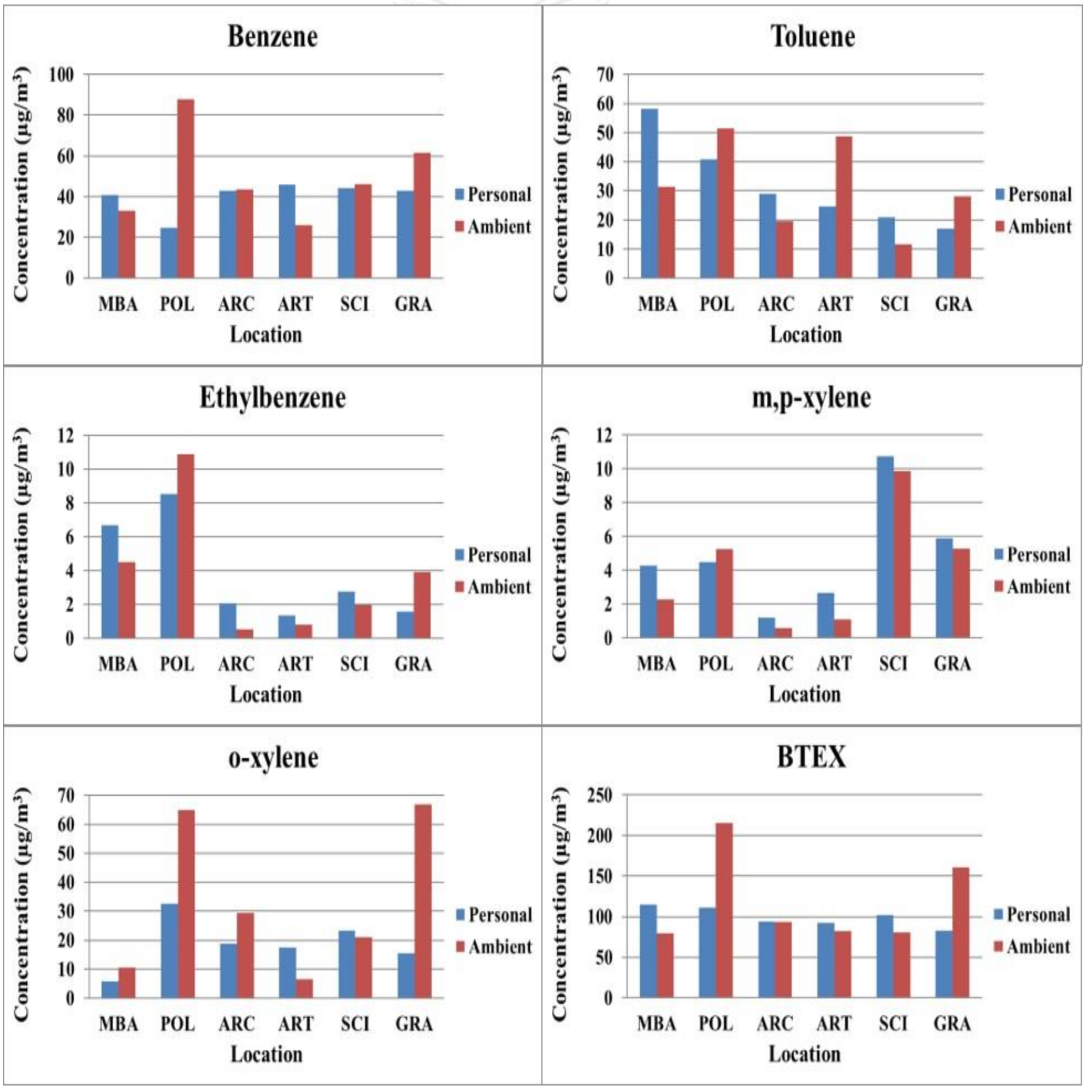


Figure 4.5 Comparison on BTEX of security guards at all sampling sites

4.2.4 Comparison on personal exposure and ambient BTEX concentration of the outdoor workers at roadside area

One-way ANOVA was applied to calculate the mean difference among all sampling sites and the results of all workers were illustrated in Table 4.8. For street vendors, the personal exposure concentration of the average benzene, toluene, ethylbenzene, m,p and o-Xylene were 25.86±16.01, 66.03±63.91, 4.30±2.40, 5.62±4.65 and 13.07±14.29 μg/m^3, respectively. For motorcycle drivers, the personal exposure concentration of average benzene, toluene, ethylbenzene, m,p and o-xylene were 31.74±7.52, 56.59±28.47, 5.80±2.70, 5.64±3.45 and 15.24±15.14 μg/m^3, respectively. For security guards, the personal exposure concentration of average benzene, toluene, ethylbenzene, m,p and o-Xylene were 40.13±20.88, 31.72±20.37, 3.83±4.53, 4.88±6.09 and 18.86±25.96 μg/m^3, respectively. In the topic of ambient air concentrations, the street vendors had the value of average benzene, toluene, ethylbenzene, m,p and o-Xylene were 28.24±13.34, 157.12±207.27, 4.68±2.81, 8.05±9.52 and 15.86±18.27 μg/m^3, respectively. For motorcycle taxi drivers, the mean levels of benzene, toluene, ethylbenzene, m,p and o-Xylene were 30.24±12.74, 101.61±131.10, 5.23±2.34, 5.28±4.11 and 30.06±48.18 μg/m^3, correspondingly. Considering the average values of benzene, toluene, ethylbenzene, m,p and o-Xylene of security guards were 49.67±40.82, 31.73±25.75, 3.76±5.68, 4.05±5.56 and 29.12±43.74 μg/m^3, severally.

Comparing on the personal exposures measured from three groups of outdoor workers by considering total BTEX level was found that street vendors (117.87±43.45 μg/m^3) had the highest concentration followed by motorcycle taxi drivers (114.87±65.60 μg/m^3) and security guards (99.41±47.81 μg/m^3), respectively. Likewise, BTEX ambient air concentration of street vendors (213.95±200.17 μg/m^3) was shown the highest BTEX concentration followed by motorcycle taxi drivers (172.42±188.26 μg/m^3) and security guards (118.34±92.23 μg/m^3), respectively. However, there were no significance differences among the workers for both personal exposure and ambient air concentrations. Comparing among the workers, street vendors showed the highest BTEX level because they worked at the roadside (their stalls) all the time so they received these pollutants throughout their working time. In contrast to street vendors, motorcycle taxi drivers were the public transportor, so they always went around the city which depending on the customers. Total air pollutants of motorcycle taxi drivers were relied on the places they visited each day. In the interest of security guards, their workplaces (gateman's box) were located in the university which did not close to the street as well as the worplaces of street vendors and motorcycle taxi drivers; hence they could be exposed to the lower BTEX levels than those of the others. Moreover, they went around their workplaces for ensuring the safety of those cars and sometimes directing the traffic in the university, so they might be go to the places that had lower pollutants concentration than the guardman's box. Correspondingly, this worker was exposed to BTEX at lower level.

Table 4.8 Comparison on personal exposure and ambient BTEX concentration of the outdoor workers at roadside area

Worker	Compound	Sample	Average conc. ($\mu g/m^3$)[1]	Conc. Range ($\mu g/m^3$)	Concentration Ranking (High to Low)[2]
Street vendor	Benzene	-Personal	25.86±16.01	5.12-66.70	SCI^{a}>SCB^{ab}>BBL^{ab}>OS^{b}>KTB^{b}
		-Ambient	28.24±13.34	13.05-54.79	SCI^{a}>OS^{b}>BBL^{b}>SCB^{b}>KTB^{b}
	Toluene	-Personal	66.03±63.91	16.53-304.73	BBL^{a}>SCB^{a}>SCI^{a}>OS^{a}>KTB^{a}
		-Ambient	157.12±207.27	18.00-716.32	BBL^{a}>SCI^{a}>OS^{a}>KTB^{a}>SCB^{a}
	Ethylbenzene	-Personal	4.30±2.40	1.30-10.55	SCB^{a}>SCI^{b}>KTB^{b}>OS^{b}>BBL^{b}
		-Ambient	4.68±2.81	0.75-10.26	SCB>BBL>KTB>SCI>OS
	m,p-Xylene	-Personal	5.62±4.65	0.51-17.97	KTB^{a}>SCB^{a}>OS^{a}>BBL^{a}>SCI^{a}
		-Ambient	8.05±9.52	1.18-30.70	SCB^{a}>BBL^{a}>KTB^{a}>SCI^{a}>OS^{a}
	o-Xylene	-Personal	13.07±14.29	0.84-46.84	KTB^{a}>SCB^{a}>SCI^{a}>BBL^{a}>OS^{a}
		-Ambient	15.86±18.27	0.00-44.53	BBL^{a}>SCB^{a}>KTB^{a}>OS^{a}>SCI^{a}
	Total BTEX	-Personal	117.87±43.45	42.55-334.45	BBL^{a}>SCI^{a}>SCB^{a}>KTB^{a}>OS^{a}
		-Ambient	213.95±200.17	74.45-747.88	BBL^{a}>SCI^{a}>OS^{a}>SCB^{a}>KTB^{a}

Motorcycle taxi driver	Benzene	-Personal	31.74±7.52	23.87-57.41	KTB^{a}>BBL^{a}>SCI^{a}>SCB^{a}>OS^{a}
		-Ambient	30.24±12.74	19.56-61.80	SCI^{a}>KTB^{a}>BBL^{a}>OS^{a}>SCB^{a}
	Toluene	-Personal	56.59±28.47	21.42-133.78	KTB^{a}>SCI^{b}>BBL^{b}>SCB^{b}>OS^{b}
		-Ambient	101.61±131.10	9.64-462.71	SCI^{a}>BBL^{a}>SCB^{a}>KTB^{a}>OS^{a}
	Ethylbenzene	-Personal	5.80±2.70	1.45-9.59	KTB^{a}>BBL^{ab}>SCB^{ab}>SCI^{ab}>OS^{b}
		-Ambient	5.23±2.34	0.58-8.67	BBL^{a}>SCI^{ab}>KTB^{ab}>SCB^{ab}>OS^{b}
	m,p-Xylene	-Personal	5.64±3.45	0.00-12.25	KTB^{a}>BBL^{ab}>SCB^{bc}>SCI^{bc}>OS^{c}
		-Ambient	5.28±4.11	0.67-14.28	SCI^{a}>BBL^{a}>SCB^{a}>KTB^{a}>OS^{a}
	o-Xylene	-Personal	15.24±15.14	1.09-61.52	SCI^{a}>SCB^{a}>BBL^{a}>KTB^{a}>OS^{a}
		-Ambient	30.06±48.18	0.88-136.91	SCI^{a}>SCB^{a}>BBL^{a}>KTB^{a}>OS^{a}
	Total BTEX	-Personal	114.87±65.60	54.39-199.13	KTB^{a}>BBL^{ab}>SCI^{abc}>SCB^{bc}>OS^{c}
		-Ambient	172.42±188.26	40.04-683.43	SCI^{a}>SCB^{a}>BBL^{a}>KTB^{a}>OS^{a}
Security guard	Benzene	-Personal	40.13±20.88	6.01-81.86	ART^{a}>SCI^{a}>ARC^{a}>GRA^{a}>MBA^{a} >POL^{a}
		-Ambient	49.67±40.82	20.85-154.72	POL^{a}>GRA^{a}>SCI^{a}>ARC^{a}>MBA^{a} >ART^{a}
	Toluene	-Personal	31.72±20.37	12.74-107.25	MBA^{a}>POL^{ab}>ARC^{b}>ART^{b}>SCI^{b} >GRA^{b}
		-Ambient	31.73±25.75	2.65-94.74	POL^{a}>ART^{a}>MBA^{a}>GRA^{a}>ARC^{a} >SCI^{a}
	Ethylbenzene	-Personal	3.83±4.53	0.40-2.40	POL^{a}>MBA^{ab}>SCI^{ab}>ARC^{b}>GRA^{b}>ART^{b}
		-Ambient	3.76±5.68	0.00-20.78	POL^{a}>MBA^{a}>GRA^{a}>SCI^{a}>ART^{a}> ARC^{a}
	m,p-Xylene	-Personal	4.88±6.09	0.00-22.13	SCI^{a}>GRA^{ab}>POL^{ab}>MBA^{ab}> ART^{ab}>ARC^{b}
		-Ambient	4.05±5.56	0.08-18.45	SCI^{a}>GRA^{a}>POL^{a}>MBA^{a}>ART^{a}> ARC^{a}
	o-Xylene	-Personal	18.86±25.96	0.19-82.27	POL^{a}>SCI^{a}>ARC^{a}>ART^{a}>GRA^{a}> MBA^{a}
		-Ambient	29.12±43.74	0.37-121.86	GRA^{a}>POL^{a}>ARC^{a}>SCI^{a}>MBA^{a} >ART^{a}
	Total BTEX	-Personal	99.41±47.81	27.08-191.71	MBA^{a}>POL^{a}>SCI^{a}>ARC^{a}>ART^{a}> GRA^{a}
		-Ambient	118.34±92.23	40.19-322.48	POL^{a}>GRA^{a}>ARC^{a}>ART^{a}>SCI^{a}> MBA^{a}

[1]Data were reported as the mean ± 1SD which obtained from 19 (personal) and 10 (ambient air) for street vendors and 20 (personal) and 10 (ambient air) for motorcycle taxi drivers, and 24 (personal) and 12 (ambient air) for security guards.
[2]Sampling site codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, and c) having significant different ($p < .05$) mean levels.

Comparing the personal exposure to benzene of this study with another research. It was found that the personal benzene levels of this study were slightly higher than those observed in the study of Chatiz et al., 2005 (82) (see Table 4.9). This results might be due to the activities of their work and the location of their working place. The workers who worked at the high density area tended to exposed to greater benzene level than other workers.

Table 4.9 Comparison on personal benzene levels of outdoor worker

Worker	Benzene Level (µg/m^3)
Bus driver[1]	22.1
Postmen[1]	18.2
Traffic policemen[1]	19.1
Street vendor[2]	25.9
Motorcycle taxi driver[2]	31.7
Security guard[2]	40.1

[1]Data were obtained from Chatiz et al., 2005
[2]Data were obtained from this study

4.3 Carbonyl compound concentrations of outdoor workers at roadside area

4.3.1 Comparison on personal exposure and ambient carbonyl compounds concentration of street vendors at all sampling sites

For carbonyl compounds, the 8-hr averages of personal exposure and ambient concentration were illustrated in Figure 4.6. Carbonyl compounds were composed of 14 substances which were formaldehyde, acetaldehyde, acetone, acrolein, propionaldehyde, crotonaldehyde, butyraldehyde, benzaldehyde, isovaleraldehyde, valeraldehyde, o- Tolualdehyde, m,p- Tolualdehyde, hexanaldehyde, and 2,5-Dimethylbenzaldehyde. However, only formaldehyde, acetaldehyde and propionaldehyde were considered and discussed in this study due to the major compositions of carbonyls and their toxicity. The average formaldehyde concentrations of personal exposure were found at OS, followed by SCB, SCI, BBL and KTB, severally. For acetaldehyde, SCI provided the greatest concentration, followed by SCB, OS, BBL and KTB, correspondingly. SCB also demonstrated the highest concentrations of propionaldehyde, followed by SCI, OS, BBL and KTB, respectively.

For ambient air samples, the highest average concentration of formaldehyde was shown at BBL followed by SCI, SCB, OS and KTB, correspondingly. For acetaldehyde, the greatest average concentration was occurred at SCB followed by BBL, SCI, OS and KTB, respectively. SCI had the highest level of propionaldehyde followed by BBL, SCB, OS and KTB, correspondingly. Comparing among CCs, formaldehyde was showed the highest levels in all sampling sites followed by acetaldehyde and propionaldehyde, respectively. Carboyl compounds concentrations of street vendors at all sampling sites were demonstrated in Table 4.10

Table 4.10 Carbonyl compounds concentrations of street vendor at all sampling sites

Sample	Compound	Concentration ($\mu g/m^3$)				
		OS	SCB	SCI	KTB	BBL
Personal air	Formaldehyde	22.42±4.95	20.89±11.30	19.64±12.25	7.92±3.61	14.52±10.36
	Acetaldehyde	9.66±2.73	9.80±9.07	11.19±6.45	5.09±5.01	6.29±5.49
	Propionaldehyde	1.30±0.91	2.64±1.41	2.56±1.46	0.43±0.43	1.24±1.03
Ambient air	Formaldehyde	9.90±0.47	10.80±1.53	10.88±3.80	4.08±0.45	17.61±1.84
	Acetaldehyde	3.69±1.53	13.88±10.22	5.76±0.45	2.56±0.45	5.18±0.15
	Propionaldehyde	0.45±0.49	1.16±0.58	1.79±1.71	0.22±0.30	1.30±0.28

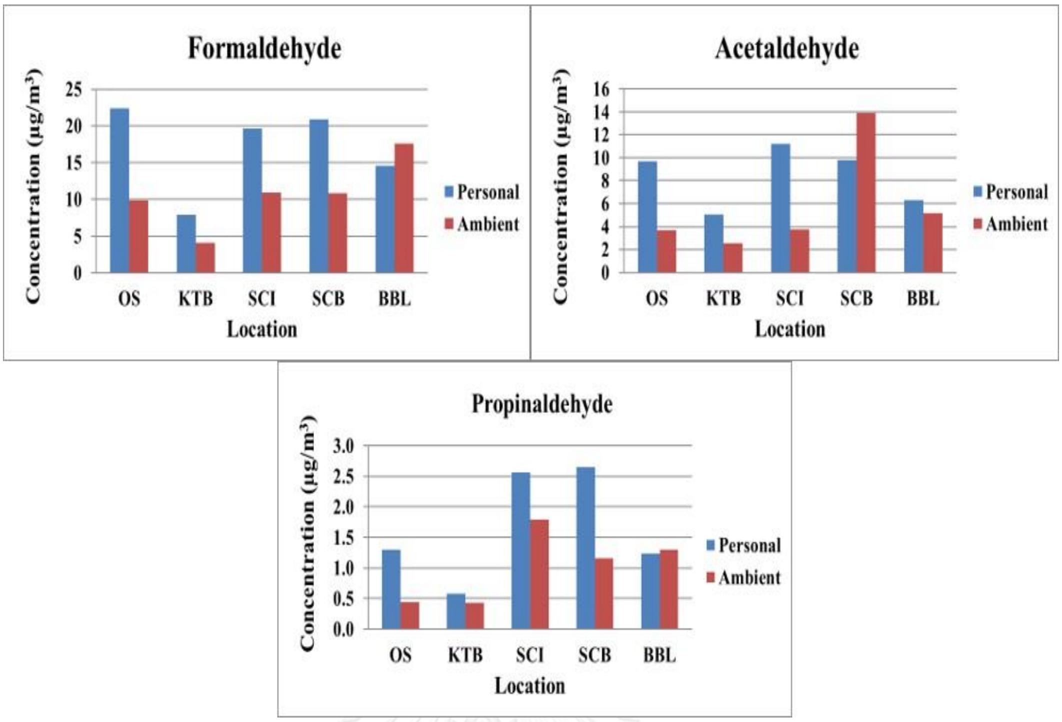


Figure 4.6 Comparison on CCs of street vendors at all sampling sites

4.3.2 Comparison on personal exposure and ambient carbonyl compounds concentration of motorcycle taxi drivers at all sampling sites

The average personal exposure concentration of formaldehyde was found at BBL, followed by OS, KTB, SCB and SCI, severally. The personal exposure sequence of acetaldehyde was BBL, KTB, SCB, OS and SCI, correspondingly. The sequence of propionaldehyde was OS, BBL, SCB, KTB and SCI, respectively.

The highest ambient air value of formaldehyde was provided at BBL, KTB, OS, SCB and SCI, respectively. For acetaldehyde, BBL had the greatest level, KTB, OS, SCB and SCI, correspondingly. BBL site showed the highest propionaldehyde concentration followed by OS, KTB, SCB and SCI, correspondingly. The same as street vendors, formaldehyde was revealed the greatest level followed by acetaldehyde and propionaldehyde, correspondingly. (see Table 4.11 and Fig. 4.7)

Table 4.11 Carbonyl compounds concentrations of motorcycle taxi driver at all sampling sites

Sample	Compound	Concentration (µg/m^3)				
		OS	SCB	SCI	KTB	BBL
Personal air	Formaldehyde	15.76±9.08	9.63±6.85	9.11±2.72	11.65±6.89	18.05±7.00
	Acetaldehyde	6.94±6.94	6.9±4.80	4.07±1.29	7.01±3.84	7.06±2.25
	Propionaldehyde	2.22±2.77	1.33±0.88	0.59±0.79	1.27±0.73	1.79±0.66
Ambient air	Formaldehyde	16.82±8.05	5.68±1.15	4.82±0.70	20.96±19.85	22.67±1.92
	Acetaldehyde	7.00±5.26	4.48±0.40	2.01±0.59	7.14±7.14	7.87±0.94
	Propionaldehyde	1.67±0.92	0.93±0.76	0.14±0.19	1.20±1.41	2.08±0.26

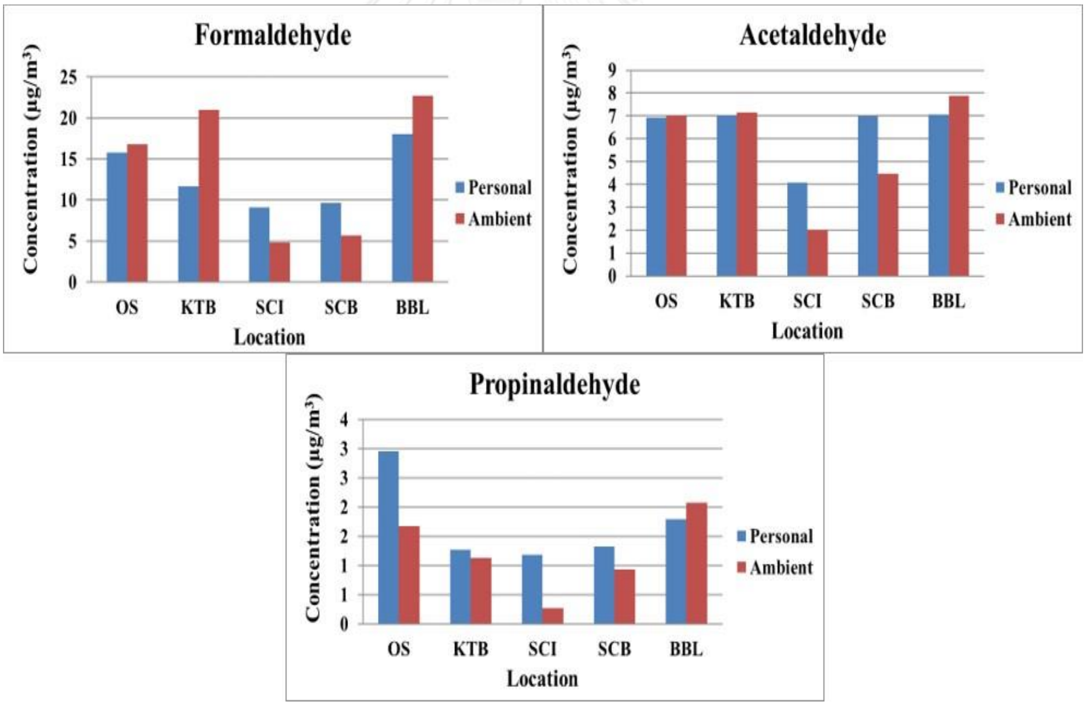


Figure 4.7 Comparison on CCs of motorcycle taxi drivers at all sampling sites

4.3.3 Comparison on personal exposure and ambient carbonyl compounds concentration of security guards at all sampling sites

The highest average concentration of formaldehyde was observed at MBA followed by POL, GRA, ART, SCI and ARC, severally. POL was illustrated the greatest value of acetaldehyde followed by MBA, ART, SCI, ARC and GRA, respectively. POL still contained the highest propionaldehyde level followed by ARC, MBA, GRA, ART and SCI, correspondingly.

The ambient air samples of ART were not considered in this study due to the limitation of sample at this site. For ambient air concentration of formaldehyde, GRA showed the highest value followed by POL, MBA, SCI and ARC, correspondingly. The greatest acetaldehyde level was obtained from POL followed by GRA, MBA, ARC, SCI, respectively. POL had the greatest propionaldehyde concentration followed by MBA, GRA, ARC and SCI, severally. The same as two workers, formaldehyde showed the highest value followed by acetaldehyde and propionaldehyde, respectively. (see Table 4.12 and Fig. 4.8)

Table 4.12 Carbonyl compounds concentrations of security guard at all sampling sites

Sample	Compound	Concentration (µg/m^3)					
		ART	ARC	GRA	POL	SCI	MBA
Personal air	Formaldehyde	9.63±2.24	6.76±2.80	10.17±2.18	12.26±1.15	8.25±3.23	13.4±1.88
	Acetaldehyde	3.19±0.81	2.87±1.33	2.74±0.85	5.70±1.42	2.99±1.86	5.06±1.11
	Propionaldehyde	0.50±0.58	1.03±1.11	0.75±0.87	1.34±0.32	0.21±0.23	0.78±0.42
Ambient air	Formaldehyde	ND	4.04±0.11	11.43±0.66	10.67±1.81	6.89±4.07	9.86±1.44
	Acetaldehyde	ND	2.42±0.11	2.90±1.95	1.33±0.05	1.58±1.40	2.90±2.54
	Propionaldehyde	ND	00.62±0.15	0.67±0.94	1.33±0.05	0.26±0.36	1.06±0.09

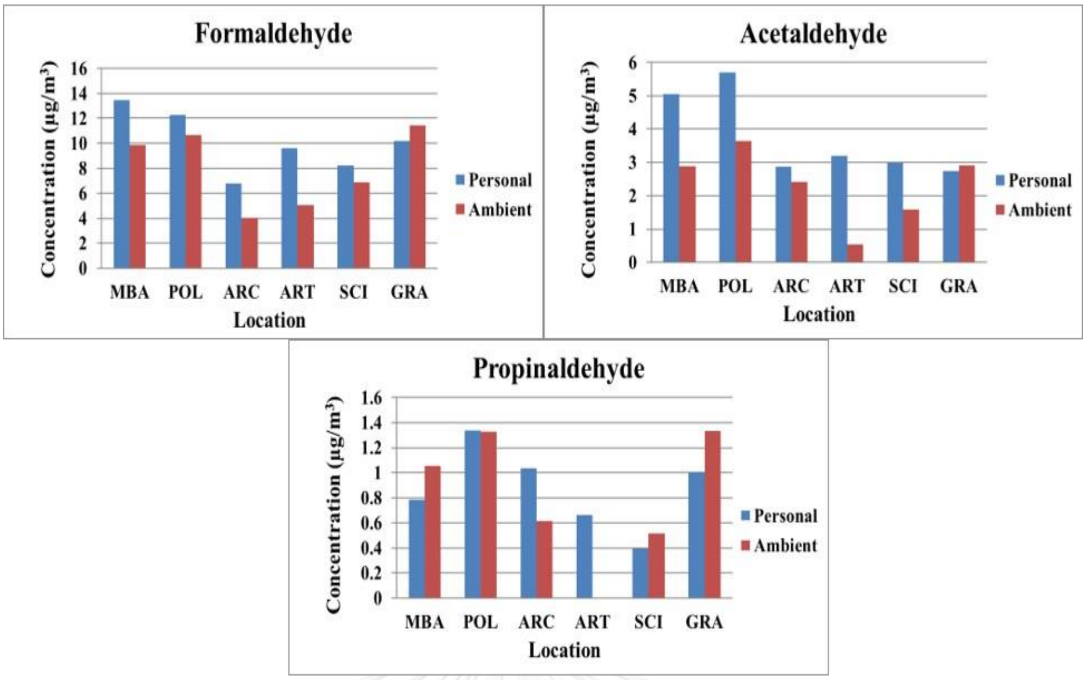


Figure 4.8 Comparison on CCs of security guards at all sampling sites

4.3.4 Comparison on personal exposure and ambient carbonyl compounds concentration of the outdoor workers at roadside area

Table 4.13 was demonstrated CCs value of outdoor workers at roadside area. For street vendors, the average personal exposure concentration of the formaldehyde, acetaldehyde and propionaldehyde were 17.14±9.43, 8.46±5.68 and 1.70±1.31 µg/m^3, respectively. However, the mean concentrations of motorcycle taxi drivers were 12.84±7.05, 6.41±3.54 and 1.44±1.38 µg/m^3 for formaldehyde, acetaldehyde and propionaldehyde correspondingly. Security guards showed the mean formaldehyde, acetaldehyde and propionaldehyde were 10.09±3.11, 3.76±1.65 and 0.77±0.69 µg/m^3, severally. For all worker groups, street vendors had the highest personal exposure levels of all carbonyls (formaldehyde, acetaldehyde and propionaldehyde) followed by security guards and motorcycle taxi driver, respectively. However, there were no significant differences between the workers. Not surprisingly, street vendors contained the highest levels of CCs that was the same as BTEX due to their stalls were situated at the street side and they always stayed at their stalls, while motorcycle taxi drivers and guards did not. The toxic air pollutant concentrations of the latter worker groups were decided on their work in each day.

In view of ambient air concentration of street vendors, the mean levels of formaldehyde, acetaldehyde and propionaldehyde were 10.65±4.77, 5.81±5.54 and 0.98±0.88 µg/m^3, respectively. On the other hands, the average of formaldehyde, acetaldehyde and propionaldehyde of motorcycle taxi drivers were 14.19±10.72, 5.70±3.21 and 1.20±0.94 µg/m^3, correspondingly. For security guards, the mean concentrations of formaldehyde, acetaldehyde and propionaldehyde were 8.25±3.30, 2.49±1.54 and 0.71±0.55 µg/m^3, severally. Comparing among the workers, the highest average formaldehyde and propionaldehyde levels were found for motorcycle taxi drivers, street vendors and security guards, respectively. However, street vendors had the highest concentration of acetaldehyde followed by motorcycle taxi drivers and security guards, correspondingly.

Table 4.13 Comparison of personal exposure and ambient carbonyl compounds concentration detected at all sampling sites of outdoor workers at roadside area

Worker	Compound	Sample	Average conc. (µg/m^3)[1]	Conc. Range (µg/m^3)	Concentration Ranking (High to Low)[2]
Street vendor	Formaldehyde	-Personal	17.14±9.43	3.84-37.26	OS^a>SCB^{ab}>SCI^{ab}>BBL^{ab}>KTB^b
		-Ambient	10.65±4.77	3.76-18.91	BBL^a>SCI^b>SCB^b>OS^b>KTB^c
	Acetaldehyde	-Personal	8.46±5.68	0.27-19.92	SCI^a>SCB^a>OS^a>BBL^a>KTB^a
		-Ambient	5.81±5.54	2.24-21.10	SCB^a>BBL^a>SCI^a>OS^a>KTB^a
	Propionaldehyde	-Personal	1.70±1.31	0.00-4.71	SCB^a>SCI^a>OS^{ab}>BBL^{ab}>KTB^b
		-Ambient	0.98±0.88	0.00-3.00	SCI^a>BBL^a>SCB^a>OS^a>KTB^a
Motor-cycle	Formaldehyde	-Personal	12.84±7.05	3.14-24.77	BBL^a>OS^a>KTB^a>SCB^a>SCI^a
		-Ambient	14.19±10.72	4.32-34.99	BBL^a>KTB^a>OS^a>SCB^a>SCI^a

taxi driver	Acetaldehyde	-Personal -Ambient	6.41±3.54 5.70±3.21	1.05-11.28 1.59-10.72	BBL^{a}>KTB^{a}>SCB^{a}>OS^{a}>SCI^{a} BBL^{a}>KTB^{a}>OS^{a}>SCB^{a}>SCI^{a}
	Propionaldehyde	-Personal -Ambient	1.44±1.38 1.20±0.94	0.00-6.27 0.00-2.32	OS^{a}>BBL^{a}>SCB^{a}>KTB^{a}>SCI^{a} BBL^{a}>OS^{a}>KTB^{a}>SCB^{a}>SCI^{a}
Security guard	Formaldehyde	-Personal -Ambient	10.09±3.11 8.25±3.30	4.86-14.73 3.96-11.95	MBA^{a}>POL^{ab}>GRA^{abc}>ART^{bc}>SCI^{c}>ARC^{c} GRA^{a}>POL^{a}>MBA^{a}>SCI^{ab}>ARC^{b}
	Acetaldehyde	-Personal -Ambient	3.76±1.65 2.49±1.54	0.59-7.61 0.54-4.82	POL^{a}>MBA^{ab}>ART^{b}>SCI^{c}>ARC^{c}>GRA^{c} POL^{a}>GRA^{a}>MBA^{a}>ARC^{a}>SCI^{a}
	Propionaldehyde	-Personal -Ambient	0.77±0.69 0.71±0.55	0.00-2.62 0.00-1.36	POL^{a}>ARC^{ab}>MBA^{ab}>GRA^{ab}>ART^{ab}>SCI^{b} POL^{a}>MBA^{a}>GRA^{a}>ARC^{a}>SCI^{a}

[1]Data were reported as the mean ± 1SD which obtained from 20 (personal) and 10 (ambient air) for street vendors and 20 (personal) and 10 (ambient air) for motorcycle taxi drivers, and 24 (personal) and 10 (ambient air) for security guards.
[2]Sampling site codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, and c) having significant different ($p < .05$) mean levels.

4.4 Correlation between personal exposure and ambient air levels of BTEX and carbonyl compounds

The association between personal exposure and ambient air levels was statistically analyzed using Pearson's correlation. Total samples of personal and ambient air concentrations of street vendors, motorcycle taxi drivers, security guards, were 10, 10 and 11, respectively. On the other hand, the ambient air samples of street vendors, motorcycle taxi drivers, security guards were 5, 5 and 6, correspondingly. The results were showed in Table 4.14.

Table 4.14 Pearson's correlation of personal and ambient air CCs and BTEX levels

Worker	Pearson's coefficient (*r*)								
	Ben-zene	Tolu-ene	Ethylb enzene	m, p-Xylene	o-Xylene	BTEX	Formal dehyde	Acetal dehyde	Propinal-dehyde
Street vendor	0.683*	0.897**	0.520	0.585	0.677**	0.807**	0.284	-0.369	0.685*
Motorcycle taxi driver	-0.338	0.026	0.068	0.132	0.031	0.481	0.663*	0.516	0.728*
Security guard	0.426	0.053	0.933**	0.972**	0.713**	0.514	0.787**	0.596	0.699*

* mean significantly different ($p < .05$) mean levels
** mean significantly different ($p < .01$) mean levels

For street vendors, ethylbenzene and m,p-Xylene were no correlation between personal and ambient air concentrations, while benzene, toluene and o-Xylene showed the correlation between two types of samples. However, the personal exposure of street vendors to BTEX was directly related to the working environment. For CCs, only propionaldehyde showed the correlation between personal and ambient levels, whereas formaldehyde and acetaldehyde were not. For motorcycle taxi drivers, there was no relationship between personal and ambient air concentrations to benzene, toluene, ethylbenzene, m,p-Xylene, o-Xylene and total BTEX. On the other hand, both formaldehyde and propionaldehyde had the correlation between the sampled with the exception of acetaldehyde. For security guards, only ethylbenzene, m,p-Xylene and o-Xylene were shown the correlation between personal and ambient air samples while the other substances were not. The same as motorcycle taxi drivers, formaldehyde and propionaldehyde showed the association of the two samples while acetaldehyde was not.

Considering on BTEX, the dominant species of this compound were benzene and toluene and the concentrations of these two substances of workers who spent their working time at their workplaces (street vendors) tended to showed the relationship between the samples. For ethylbenzene and xylenes, the associations of the two samples were shown significantly differences for security guards and this might be due to the atmospheric air around the sampling sites of this worker (in Chulalongkorn university) was also contained ethylbenzene and xylenes. These sampling sites of security guards were collected a little bit far from roadside area comparing to the other outdoor workers. Thus, the results may slightly different from the others. For CCs, these compounds were very active in atmospheric air so the levels of CCs were varied all the time. However, the worker who worked at roadside (motorcycle taxi drivers and security guards) showed the correlation between personal and ambient air samples for formaldehyde and it might be due to these workers did not stay at their workplaces all the time, so they were exposed to formaldehyde from the other places. Hence, the relationships of CCs species between the samples were likely depended on the activities of the workers.

4.5 Seasonal variations of BTEX and carbonyl compound

For the outdoor workers who performed their job at the roadside area, the personal exposure and ambient air concentrations were collected in September 2012 (rainy season) and March 2013 (summer season). In each season, the total personal exposure samples of street vendors, motorcycle taxi drivers and security guards were 10, 10 and 12, respectively. The total ambient air samples of street vendors, motorcycle taxi drivers, security guards were 5, 5 and 6, correspondingly. The meteorological data of all worker groups were shown in Table 4.15.

Table 4.15 Meteorological data of the sampling day

Workers	Season	Solar radiation*	Temperature*	Precipitation*	Humidity*
Outdoor workers	Summer	491.45±95.80	35.65±0.66	0.11±0.32	65.00±4.39
	Rainy	332.24±100.20	32.44±1.91	0.89±1.42	82.69±6.45

* The data was obtained from Thai Meteorological Department

The statistical analysis between two seasons were investigated using T-test and the results were demonstrated in Table 4.16.

Table 4.16 The mean difference between dry and wet seasons of carbonyl compounds and BTEX

Compound	Sig. (2-tailed)					
	Ambient air sample			Personal exposure sample		
	Street vendor	Motorcycle taxi driver	Security guard	Street vendor	Motorcycle taxi driver	Security guard
Formaldehyde	0.429	0.227	0.916	0.243	0.938	0.926
Acetaldehdye	0.297	0.127	0.008**	0.104	0.797	0.035*
Propionaldehyde	0.412	0.477	0.320	0.514	0.374	0.001**
Benzene	0.448	0.241	0.091	0.427	0.556	0.001**
Toluene	0.471	0.396	0.748	0.162	0.361	0.820
Ethylbenzene	0.179	0.521	0.358	0.746	0.954	0.127
m,p-Xylene	0.112	0.588	0.503	0.013*	0.842	0.304
o-Xylene	0.025*	0.128	0.044*	0.004**	0.016*	0.003**
BTEX	0.634	0.287	0.120	0.363	0.681	0.001**

* mean significantly different ($p < .05$) mean levels

** mean significantly different ($p < .01$) mean levels

For ambient air samples, only o-Xylene was shown the significant difference between dry and wet season, while benzene, toluene, ethylbenzene, m,p-Xylene and BTEX were not. However, there were significant differences between seasons of m,p-Xylene and o-Xylene for street vendors. Nevertheless, there were no significant difference between seasons of formaldehyde, acetaldehyde and propionaldehyde that found for both samples. For BTEX samples of motorcycle taxi drivers, there was no significant difference between dry and wet season for all substances and total BTEX. Similar to street vendors, it had no different between seasons for all CCs compounds for ambient air, while o-Xylene showed the significance between seasons of personal samples.

The same as street vendors, the ambient air concentrations of security guards was found for o-Xylene that only showed the significantly different between dry and wet seasons, while benzene, toluene, ethylbenzene, m,p-Xylene and BTEX were not. The results of seasonal variation of BTEX were provided in Fig. 4.9 and 4.17.

Personal exposure sample

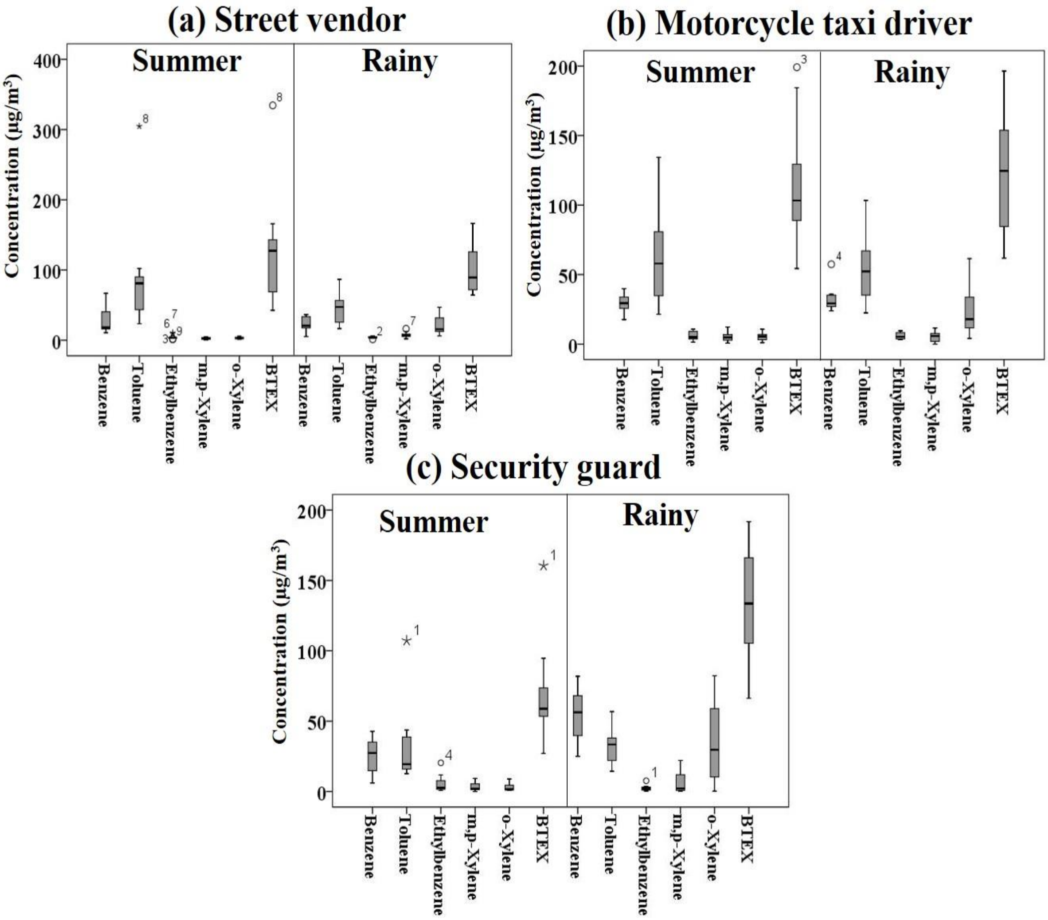


Figure 4.9 Seasonal variation of personal BTEX concentration

Ambient air samples

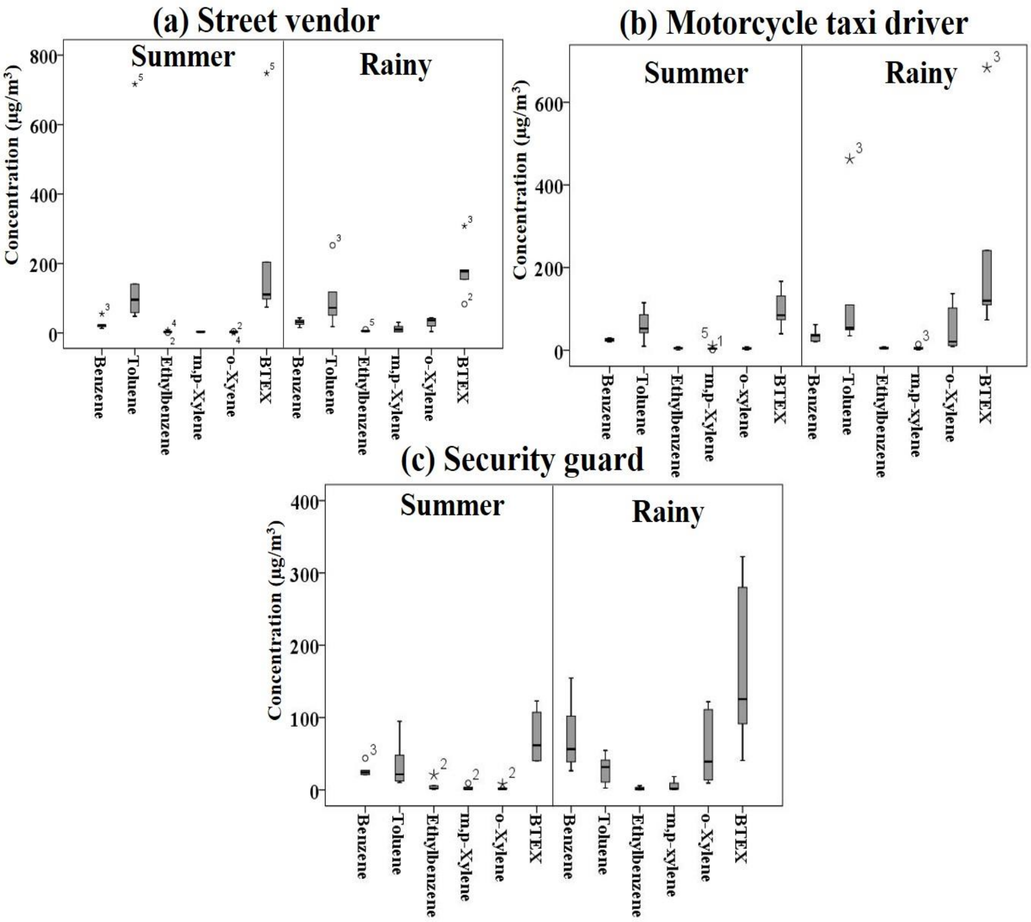


Figure 4.10 Seasonal variation of ambient air BTEX concentration

For CCs, only acetaldehyde was shown the significant difference between seasons. On the contrary, the personal exposure samples were found that benzene, o-Xylene, BTEX, acetaldehyde and propionaldehyde showed the significant differences between wet and dry seasons.

The statistical analysis using Pearson's Correlation was found that the meteorological data was not related to the substances. Nevertheless, the possible theory which can be explained why CCs levels in summer were lower than those in rainy. CCs was the primary and secondary products at the same time (83-87). Vehicles were the directly released CCs as a primary source in atmospheric air, while the photooxidation of VOCs was originated CCs as a secondary product. Moreover, the photolysis of CCs was the major reaction for aldehyde reduction (80, 88). Of these reasons, total CCs in summer were considered both photooxidation and photolysis (63), and it seemed that photolysis was stronger than photooxidation. Thereby, CCs in summer which had strong solar radiation was easily degraded better than the photooxidation. The same reason as CCs, the photolysis of BTEX was playing an important role in summer due to the solar radiation. Furthermore, BTEX was an insoluble chemical (low henry's constant) so they did not dissolve in the precipitation in rainy season (47). These facts were clearly demonstrated that the concentration of BETX in summer was lower than that in rainy season. The results were presented in Fig. 4.11 and 4.12.

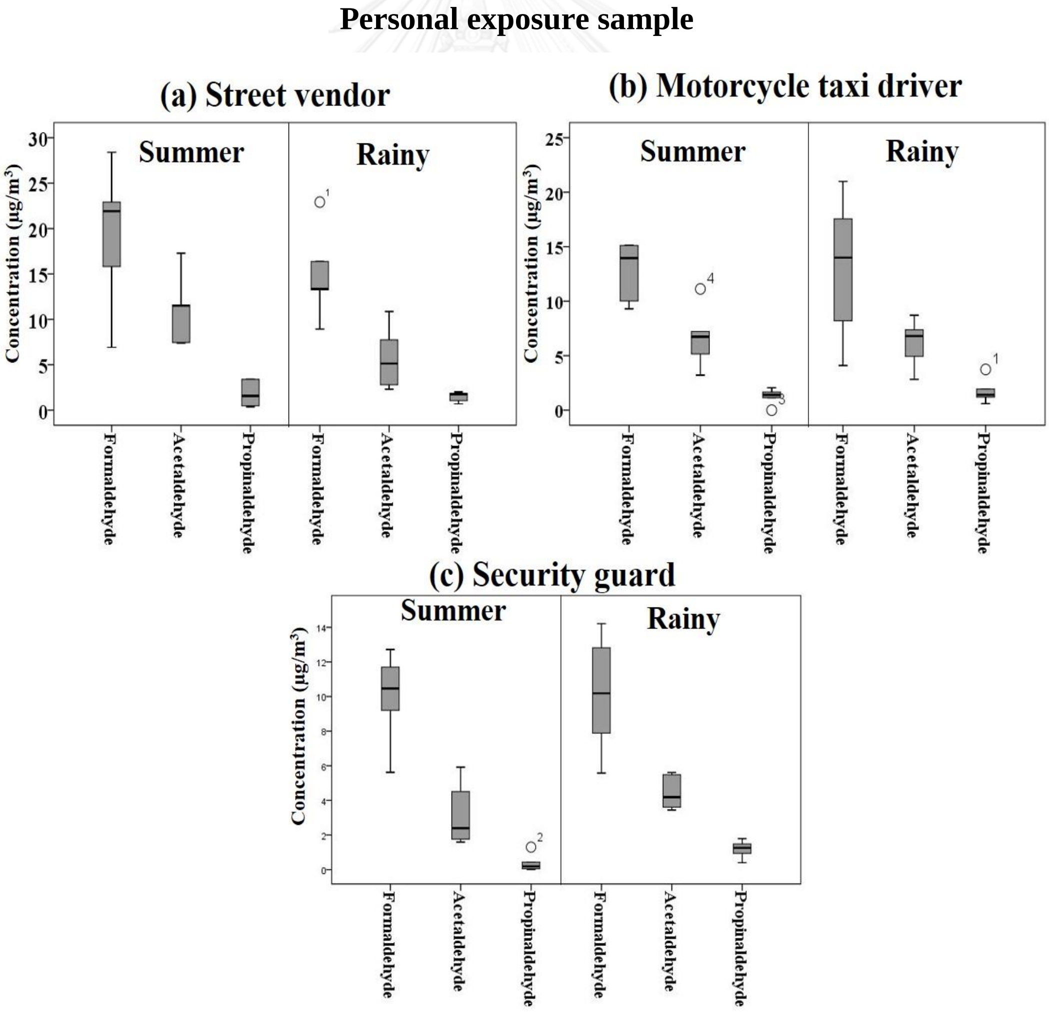


Figure 4. 11 Seasonal variation of personal CCs concentration

Ambien air samples

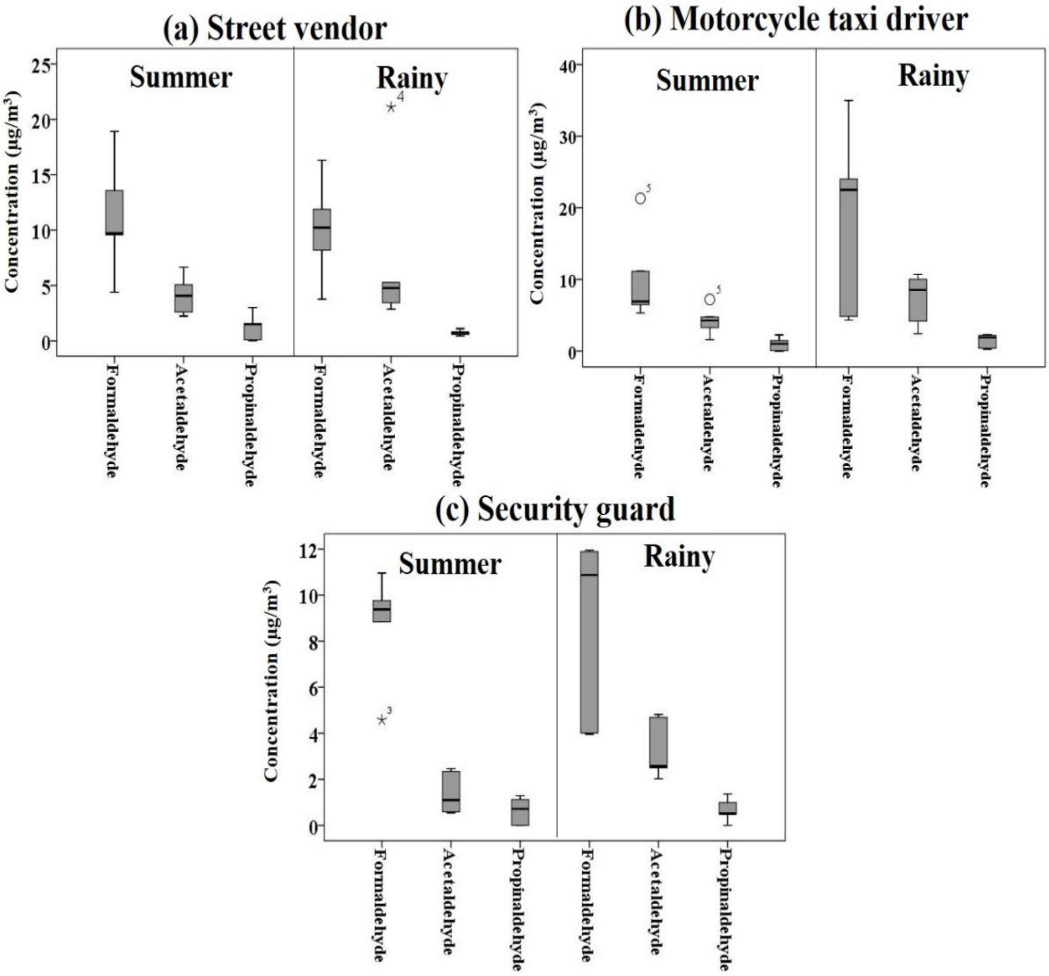


Figure 4.12 Seasonal variation of ambient air CCs concentration

From overall results, BBL (BBL Bank) site had the highest BTEX concentrations for street vendors and motorcycle taxi drivers according to this sampling site was located near Chaloem Phao Junction and skytrain station. Thus, BTEX was relaesd from the intensive traffic and BTEX cannot spreaded into the atmospheric air because it was blocked by sky train station. For security guards, POL site contained the greatest BTEX levels because this site was very closed to Henry Dunant Road and POL had high numbers of vehicles than those the other sites. However, carbonyls were varied among the sampling sites due to their reactivity and they were the secondary substances that generated from VOCs. For the association between personal exposure and ambient air samples, the workers who did not stay at their workplace throughout their working time (motorcycle taxi drivers), had no correlation between two types of samples for all air pollutants. For seasonal variation, most of air pollutants in wet season were greater than those of dry season because of the photodegradation under strong solar radiation in summer.

CHAPTER V
Inhalation exposure of the traffic policemen at the road intersection to BTEX and carbonyl compounds

5.1 Ambient and personal BTEX concentrations of traffic policemen at road intersection

Three intersections and one T-junction which located in Pathumwan district, were investigated which included Pathumwan Intersection (PT), Samyan Intersection (SY), Henry Dunant Intersection (HD) and Chalerm Phao Junction (CP). The total samples of personal exposure levels were 48 samples and ambient air concentrations were 48 samples. The overall data of traffic policemen were demonstrated in Appendix C. For personal exposure concentrations of benzene, CP had the highest concentration, followed by HD, PT and SY, respectively. However, the greatest average toluene level was shown at HD followed by PT, CP, and SY, correspondingly. Whilst, the HD intersection contained the highest value of ethylbenzene and followed by CP, PT and SY, respectively. The greatest m,p-Xylene level was found at HD followed by PT, CP and SY, correspondingly. Nevertheless, the highest o-Xylene value was shown at PT followed by SY, HD and CP, respectively. The personal exposure results were expressed in Fig 5.1

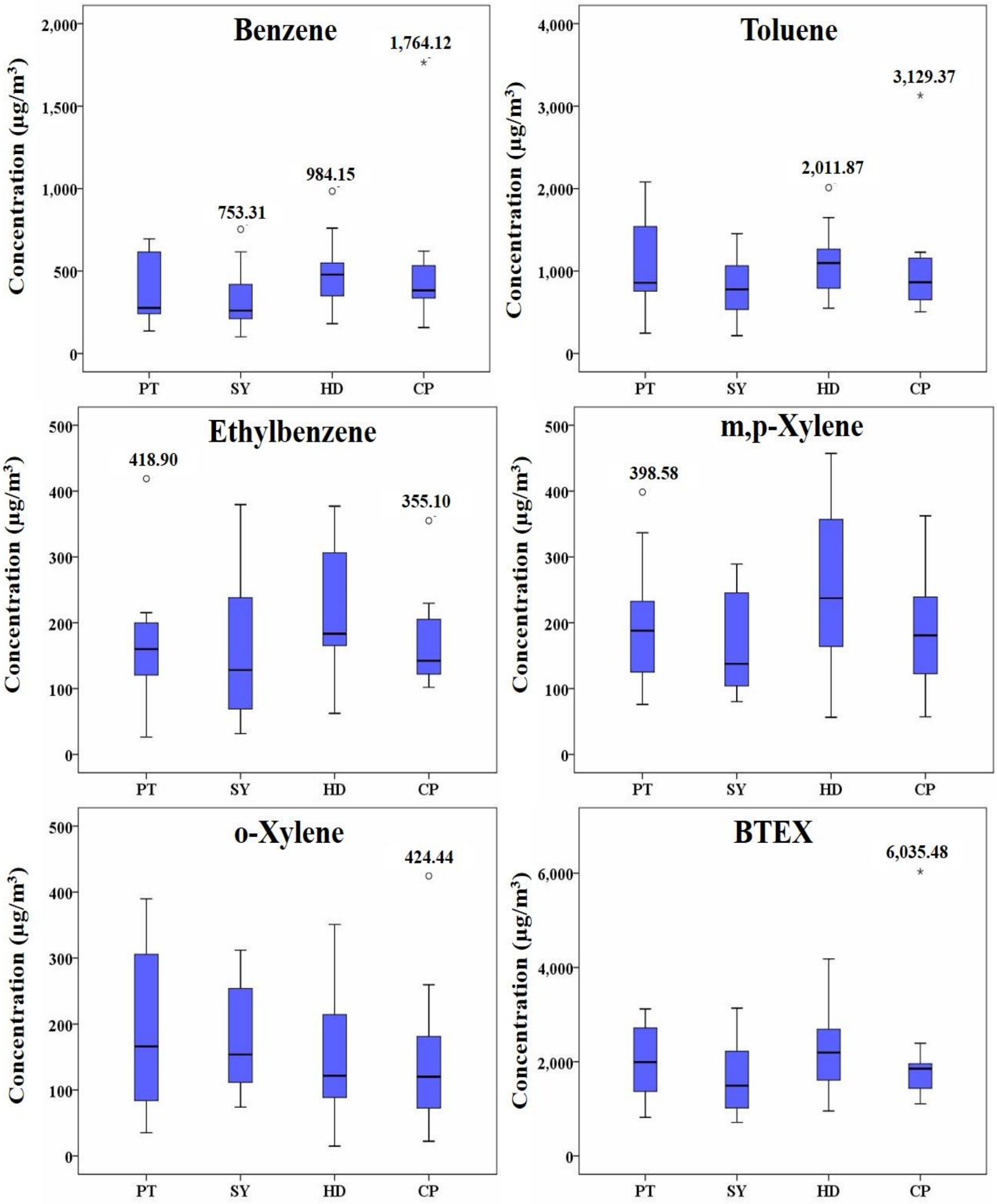


Figure 5.1 Personal exposure of traffic policemen to BTEX at all sampling sites

For the ambient air concentrations, the sequence levels of benzene and toluene, m,p-Xylene and o-Xylene were HD, PT, CP and SY, respectively. On the other hand, the sequence ethylbenzene level was CP, PT, HD and SY, correspondingly. For total BTEX concentrations, the highest level of personal exposure concentration was illustrated at HD followed by CP, PT and SY, respectively. In contrast to personal samples, the greatest ambient air concentration was found at HD, PT, CP and SY, correspondingly. The ambient air results were illustrated in Fig.5.2 and Table 5.1.

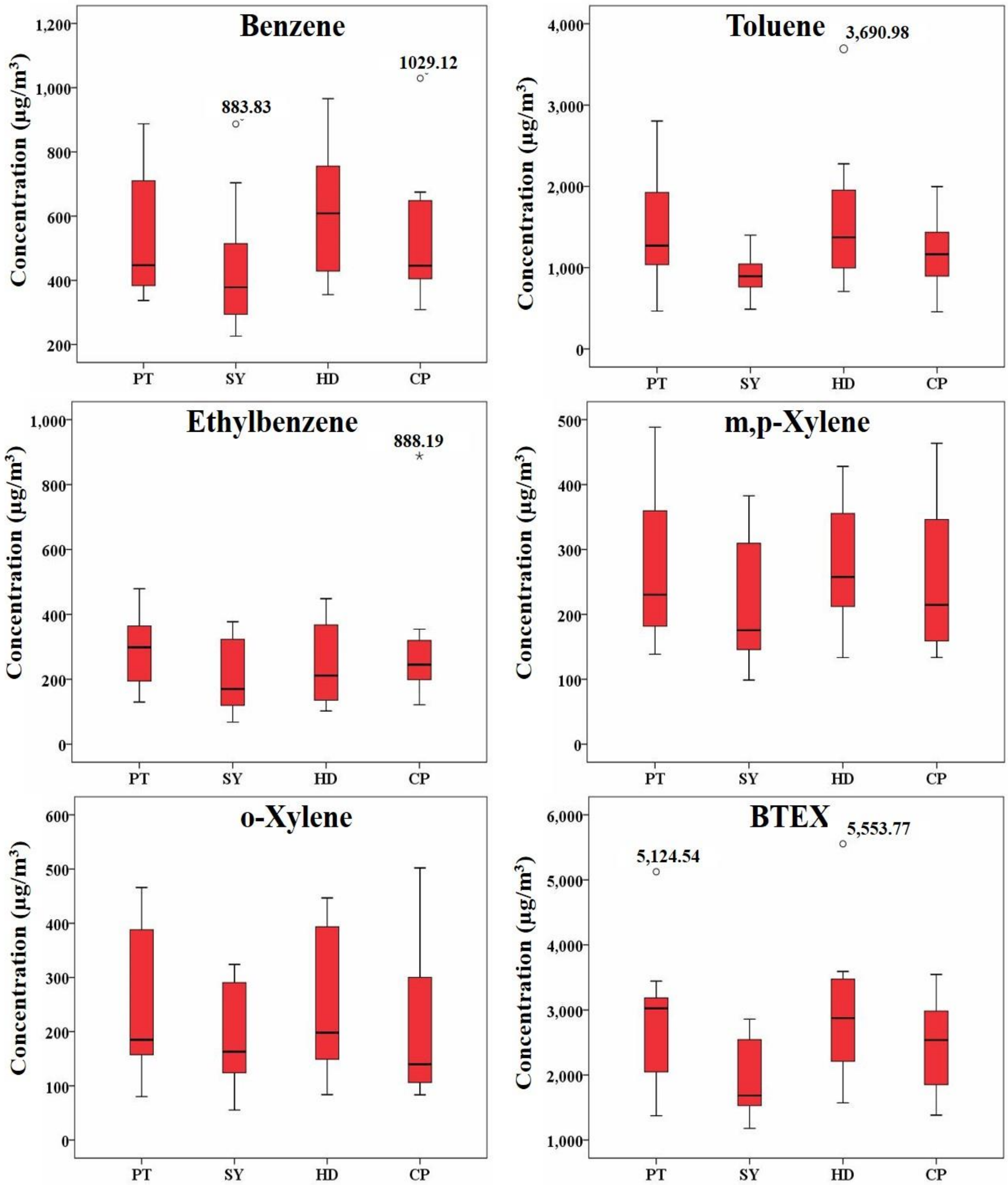


Figure 5.2 Ambient air of traffic policemen to BTEX at all sampling sites

Table 5.1 BTEX concentrations of traffic policemen at all sampling sites

Sample	Compound	Concentration (μg/m^3)			
		PT	SY	HD	CP
Personal air	Benzene	388.81±204.41	329.19±193.62	486.38±223.24	500.79±419.88
	Toluene	1078.72±547.70	822.07±378.62	1107.48±416.58	1055.95±696.32
	Ethylbenzene	167.53±95.96	154.57±106.17	221.45±98.92	170.53±72.12
	m,p-Xylene	198.25±95.66	168.34±76.83	258.99±120.91	186.09±86.24
	o-Xylene	192.04±129.12	174.94±84.48	157.54±106.23	142.71±111.89
	BTEX	2025.35±783.16	1649.11±746.49	2231.85±845.79	2056.07±1308.14
Ambient air	Benzene	546.75±203.75	432.30±199.60	619.09±204.29	521.43±202.02
	Toluene	1485.71±650.28	914.39±271.48	1576.83±828.57	1194.84±451.93
	Ethylbenzene	287.48±110.80	209.25±110.90	244.45±127.33	296.77±200.50
	m,p-Xylene	270.69±112.35	220.61±98.86	279.99±96.03	254.11±108.43
	o-Xylene	249.36±129.48	187.98±90.96	248.61±135.87	212.14±135.68
	BTEX	2840.00±975.56	1964.52±617.73	2968.96±1055.77	2479.28±717.59

For personal exposure and ambient air samples of traffic police, toluene showed the greatest level in all sampling sites. Most of pollutants were expressed at HD site because the traffic density along HD was extremely high causing the vehicles were stayed longer at HD. Normally, the average red light duration of HD was around 124 seconds for non-rush hour (10.30 a.m. to 2 p.m.), however, the duration of red light was much higher than 124 seconds from 0.6.00 a.m. to 10.30 a.m.). Lower traffic flow was affected to increase the emitted pollutants from vehicles which caused higher toxic substances accumulated in that area (89). In addition, there were a lot of cars were pulled over along the road side of HD which increased the pollutant levels from the baseline concentrations. Therefore, HD site was attributed the highest concentrations of almost pollutants, consequently, the policemen who worked at HD site were also exposed to high BTEX levels. Traffic policemen were performed their jobs in both outdoor (at the roadside) and indoor (in police's booth), but most of time they worked in their office rather than at the roadside. Ilgen et al (2001) (52)discovered that the outdoor pollutants filtrated into indoor air and this result can be explained why the policemen working in the booth also received high pollutants levels. With respect to physical conditions of sampling sites, HD intersection was surrounded by the overpass (27%) which blocked the dispersion of pollutants to the atmospheric air. Similarly, benzene concentrations of CP site were appeared to be high due to the narrow road which enclosed by high buildings and skytrain stations (Siam station) (35%). But if considered total road lane numbers, PT and HD and CP sites were consisted of 29, 26 and 14 road lanes and these could be supported that why CP showed lower concentrations of BTEX with the exception of benzene than those found at PT and HD, respectively. In view of SY, this site was tended to observe the lowest BTEX concentrations and it might be caused by minimum length of a red traffic light and this site was the open road comparing to the others; hence the efficient dispersion producing lower BTEX (60). SY had 31 traffic lanes which greater than those of PT, HD and CP, correspondingly. Some study revealed that lower number of road lanes might be increased the traffic density in order to release the exhaust gas from the vehicles (90). In conclude, both traffic lane and density were considered for the discussion in this study. The mean differences among the sampling sites were analyzed using one-way ANOVA and the results were showed Table 5.2.

Table 5.2 Comparison of BTEX detected at all sampling sites of traffic policemen at road intersection

Compound	Sample	Average conc. (μg/m^3)[1]	Conc. Range (μg/m^3)	Concentration Ranking (High to Low)[2]
Benzene	-Personal -Ambient	426.29±276.74 529.89±207.15	101.51-1764.12 226.31-1029.12	CP^a>HD^a>PT^a>SY^a HD^a>PT^a>CP^a>SY^b
Toluene	-Personal -Ambient	1016.05±520.58 1292.94±627.54	217.71-3129.37 457.16-3690.98	HD^a>PT^a>CP^a>SY^a HD^a>PT^a>CP^{ab}>SY^b
Ethylbenzene	-Personal -Ambient	178.52±94.68 259.48±142.17	26.40-418.90 67.82-888.19	HD^a>CP^a>PT^a>SY^a CP^a>PT^a>HD^a>SY^a
m,p-Xylene	-Personal -Ambient	202.92±99.35 256.35±103.32	56.29-457.14 98.74-488.42	HD^a>PT^a>CP^a>SY^b HD^a>PT^a>CP^a>SY^a

o-Xylene	-Personal -Ambient	166.81±107.20 224.52±123.19	14.82-424.44 55.38-502.10	$PT^{a}>SY^{a}>HD^{a}>CP^{a}$ $PT^{a}>HD^{a}>CP^{a}>SY^{a}$
Total BTEX	-Personal -Ambient	1990.59±942.30 2563.19±921.06	711.38-6035.48 1179.99-5553.77	$HD^{a}>PT^{a}>CP^{a}>SY^{a}$ $HD^{a}>PT^{a}>CP^{ab}>SY^{b}$

[1]Data were reported as the mean ± 1SD which obtained from 48 (personal) and 48 (ambient air).
[2]Sampling site codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, and c) having significant different ($p < .05$) mean levels.

Comparing BTEX levels of traffic police in this study and the traffic police in several studies was investigated. Total BTEX level of traffic police in Lebanon showed the greatest concentrations followed by Thailand, Italy (Milan) and Italy (Parma) as demonstrated in Table 5.3. Not only the traffic density was concerned, but the configuration of road, the performance of traffic police, the meteorological data were also the impacted factors for the discussion. For the study of Lebanon, the intensive traffic was the major factor that increased BTEX levels, while the traffic density in Italy in both cities were tended to lower than those found in Lebanon and Thailand, respectively.

Table 5.3 The average personal exposure levels of traffic police exposure to BTEX

Compound	Average BTEX conc. (μg/m^3)	Source
Thailand	1990.59	This study
Lebanon	2247.1	Borgie et al., 2014 (91)
Italy(Parma)	45.8	Manini et al., 2008 (75)
Italy (Milan)	115.9	Cattaneo et al., 2010 (92)

5.2 Ambient and personal carbonyl compounds concentrations of traffic policemen at road intersection

For personal exposure samples, the greatest mean personal exposure to formaldehyde was found at SY, followed by CP, PT and HD, respectively. CP showed the highest level of acetaldehyde followed by SY, HD, and PT, correspondingly. Nevertheless, PT demonstrated the greatest concentration of propionaldehyde followed by SY, HD and CP, severally. Considering the personal samples, the highest levels of formaldehyde, acetaldehyde and propionaldehyde were found in the different sites and it might be due to the environment of the sites and the stability of the substances. Generally, CCs were directly released from the vehicle combustion, anyhow, they were the secondary pollutants and unstable (93). Furthermore, the traffic police performed several duties and they did not only work in their booth but they also directed the traffic on the road. Thus CCs were varied in levels between the sites which decided on their duties in each day. The sources of CCs were not only emitted from outdoor but indoor also the main sources of CCs, therefore, the traffic police were exposed to CCs in both outdoor and indoor air. Total CCs levels of traffic policemen were depended on the concentrations in outdoor and indoor for this study. Nevertheless, there was not significant difference for CCs. The personal exposure values of CCs were demonstrated in Fig. 5.3.

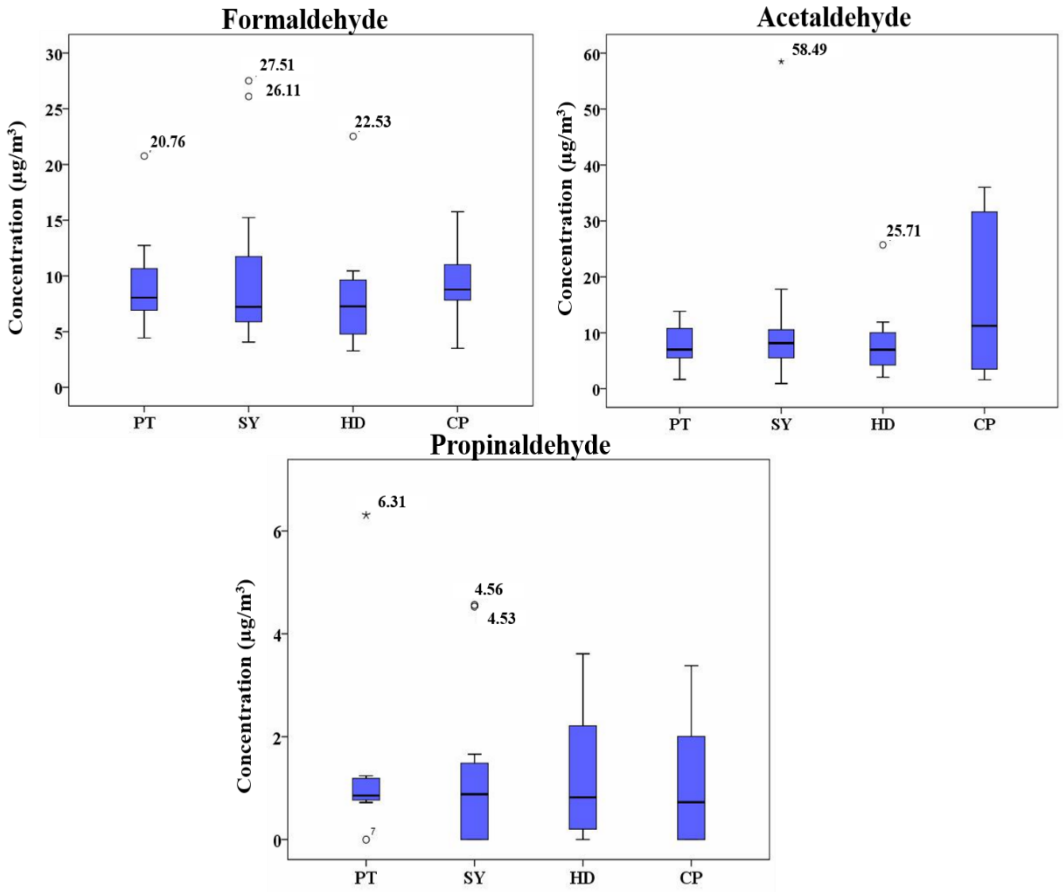


Figure 5.3 Personal exposure of traffic policemen to CCs at all sampling sites

For ambient air samples, the highest level of formaldehyde was found at HD followed by PT, SY and CP, respectively. Likewise, HD still showed the greatest value of acetaldehyde followed by PT, SY and CP, correspondingly. However, the highest propionaldehyde level was discovered at PT followed by HD, SY and CP, severally. The greatest levels of formaldehyde and acetaldehyde of ambient air samples were observed at HD, whereas propionaldehyde was found at PT. The same as personal exposure samples, HD tended to have the intensive traffic, so these major CCs were appeared in this site greater than those found in other places. Focusing on HD site, total lane numbers were 24 which lower than that observed at PT for 3 road lanes. Otherwise, the traffic condition was played an important role in this case and HD tended to have the highest traffic density than others. Additionally, the overpass of HD site was covered the road area 27% approximately; therefore, these two factors were the major problems that brought HD site contained the highest air pollutant level. (see Fig. 5.4 and Table 5.4)

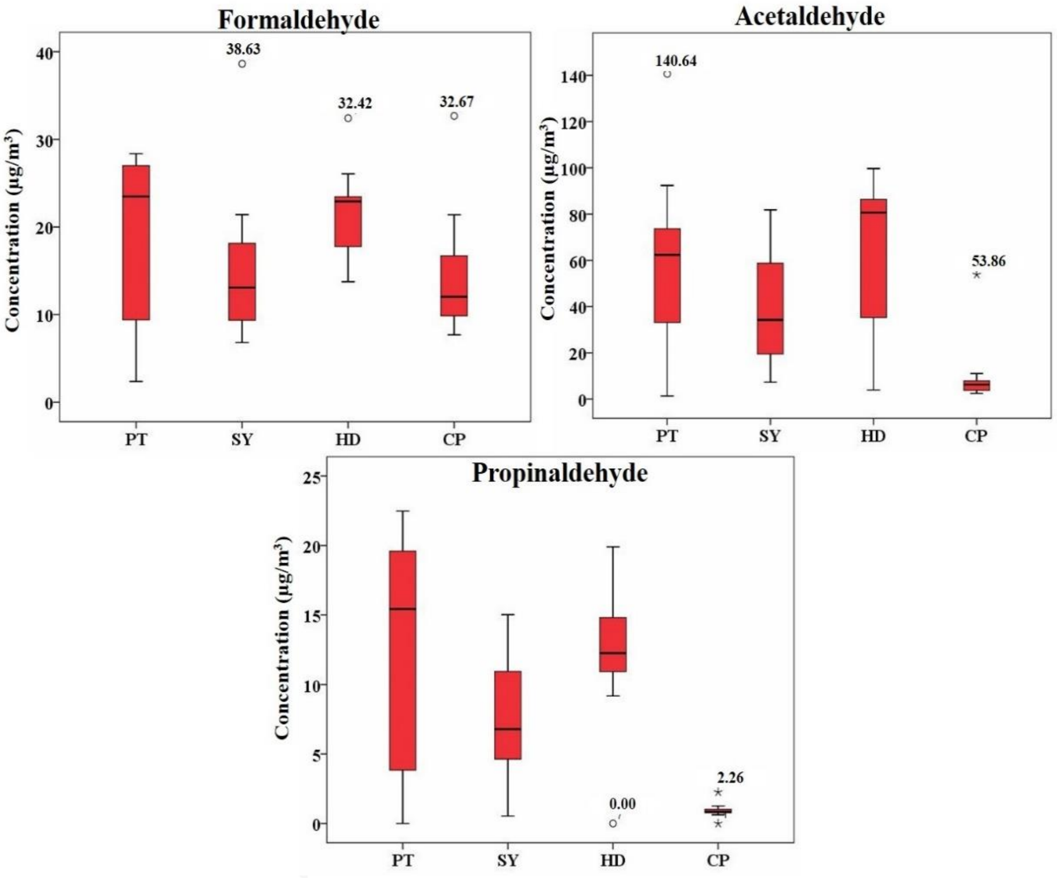


Figure 5.4 Ambient air of traffic policemen to CCs at all sampling sites

Table 5.4 Carbonyl compounds concentrations of traffic policemen at all sampling sites

Sample	Compound	Concentration (µg/m^3)			
		PT	SY	HD	CP
Personal air	Formaldehyde	9.25±4.27	10.61±8.06	8.29±5.06	9.40±3.09
	Acetaldehyde	8.00±3.75	12.10±15.19	8.14±6.37	16.03±13.58
	Propionaldehyde	1.32±1.61	1.30±1.62	1.22±1.19	1.07±1.20
Ambient air	Formaldehyde	18.70±10.04	15.22±8.66	21.50±5.19	14.34±7.01
	Acetaldehyde	58.30±37.91	39.51±25.01	64.82±31.72	9.89±14.06
	Propionaldehyde	12.66±8.71	7.71±4.46	12.30±5.02	0.92±0.52

The average concentrations of CCs for both personal exposure and ambient air levels of traffic policemen were shown in Table 5.5.

Table 5.5 Comparison of CCs detected at all sampling sites of traffic policemen at road intersection

Compound	Sample	Average conc. (µg/m^3)[1]	Conc. Range (µg/m^3)	Concentration Ranking (High to Low)[2]
Formaldehyde	-Personal -Ambient	9.39±5.33 17.44±8.20	3.28-27.51 2.36-38.63	SY^a>CP^a>PT^a>HD^a HD^a>PT^{ab}>SY^{ab}>CP^b
Acetaldehyde	-Personal -Ambient	11.06±11.00 43.13±35.06	0.93-58.49 1.32-140.64	CP^a>SY^a>HD^a>PT^a HD^a>PT^{ab}>SY^b>CP^c
Propionaldehyde	-Personal -Ambient	1.23±1.38 8.40±7.16	0.00-6.31 0.00-22.48	PT^a>SY^a>HD^a>CP^a PT^a>HD^a>SY^b>CP^c

[1]Data were reported as the mean ± 1SD which obtained from 48 (personal) and 48 (ambient air).
[2]Sampling site codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, and c) having significant different ($p < .05$) mean levels.

5.3 Correlation between personal exposure and ambient air levels of BTEX and carbonyl compounds

The association between personal exposure and ambient air levels was statistically analyzed using Pearson's correlation. Total samples of personal and ambient air concentrations of traffic policemen were 24 for each sample. The results of Pearson's coefficient were shown in Table 5.6.

Table 5.6 Pearson's correlation of personal and ambient air CCs and BTEX levels

Compound	Pearson's coefficient (*r*)
Benzene	0.854**
Toluene	0.436**
Ethylbenzene	0.271
m, p-Xylene	0.638**
o-Xylene	0.723**
BTEX	0.635**
Formaldehyde	0.161
Acetaldehyde	0.048
Propionaldehyde	0.089

* mean significantly different ($p < .05$) mean levels

** mean significantly different ($p < .01$) mean levels

For high-exposure group, the ambient air and personal exposure to benzene, toluene, m,p-Xylene, o-Xylene and total BTEX were found the relationship between personal and ambient air samples. In view of CCs, there were no correlations of all substances. Considering on BTEX concentrations, the levels of these compounds were found very much higher than those measuring for CCs. Thus, the concentrations of CCs were varied in two types of samples, whereas BTEX were not. These results were reasonable because the ambient air of the traffic police's workplace were observed in high level, so the personal exposure samples of traffic police were also high. On the other hands, CCs levels were expressed at low-level and the properties of CCs themselves were generally reactivity in the atmospheric air. Hence, the association between two types of samples were found insignificant differences. Moreover, the relationship between personal and ambient air samples were not found in CCs compounds because the ambient air samples of traffic police were collected at the roadside, while the personal samples were attached to the policemen who mostly performed their jobs in the indoor. Although, BTEX was found correlation between samples because the concentrations BTEX were extremely high for both samples (outdoor pollutants penetrated into indoor air), whereas the levels of CCs were much lower especially for formaldehyde and propionaldehyde; thus they were varied in both samples.

5.4 Seasonal variations of BTEX and carbonyl compounds

The samplings of traffic policemen were contributed in April to May 2014 (summer season) and August to September 2014 (Rainy season). In each season, the total personal exposure samples of traffic policemen were 24 that equally to the ambient air samples. The meteorological data of this worker group was shown in Table 5.7. The correlation between pollutants and meteorological data of traffic policemen was only found for total BTEX (both personal exposure and ambient air levels) and temperature.

Table 5.7 Meteorological data of the sampling day

Meteorological data*	Season	
	Summer	Rainy
Solar radiation	324.85±138.11	261.75±113.96
Temperature	31.85±0.56	29.28±0.69
Precipitation	4.00±0.00	10.20±18.18
Humidity	71.00±3.63	75.68±3.68

* The data was obtained from Thai Meteorological Department

The mean difference between dry and wet seasons of carbonyl compounds and BTEX of traffic policemen were shown in Table 5.8. For both personal and ambient air samples, seasonal variation of traffic policemen was discovered that all chemicals in rainy season, including benzene, toluene, ethylbenzene, m,p-Xylene, o-Xylene and

BTEX were significantly higher than those of summer season. However, there was no significant difference between wet and dry season of formaldehyde, acetaldehyde and propionaldehyde.

Table 5.8 The mean difference between dry and wet seasons of carbonyl compounds and BTEX

Compound	Sig. (2-tailed)	
	Ambient air sample	Personal exposure sample
Formaldehyde	0.351	0.848
Acetaldehdye	0.114	0.517
Propionaldehyde	0.252	0.147
Benzene	0.000**	0.000**
Toluene	0.004**	0.000**
Ethylbenzene	0.017*	0.000**
m,p-Xylene	0.000**	0.000**
o-Xylene	0.000**	0.000**
BTEX	0.000**	0.000**

* mean significantly different ($p < .05$) mean levels
** mean significantly different ($p < .01$) mean levels

All substances of BTEX in wet season were significantly higher than those of dry season for personal and ambient air concentrations for both personal and ambient air concentrations. There were statistically significant differences between summer and rainy seasons of BTEX levels. BTEX values in summer of these workers were lower than those of rainy season. The explanation was previously discussed for outdoor workers at roadside area due to the photolysis of BTEX under the solar radiation in summer. The solar radiation and temperature in summer were higher than those of rainy season, while the humidity and precipitation in rainy were greater than those found in summer. Nevertheless, the wet deposition of BTEX was minimally occurred in rainy season. The results were provided in Fig. 5.5.

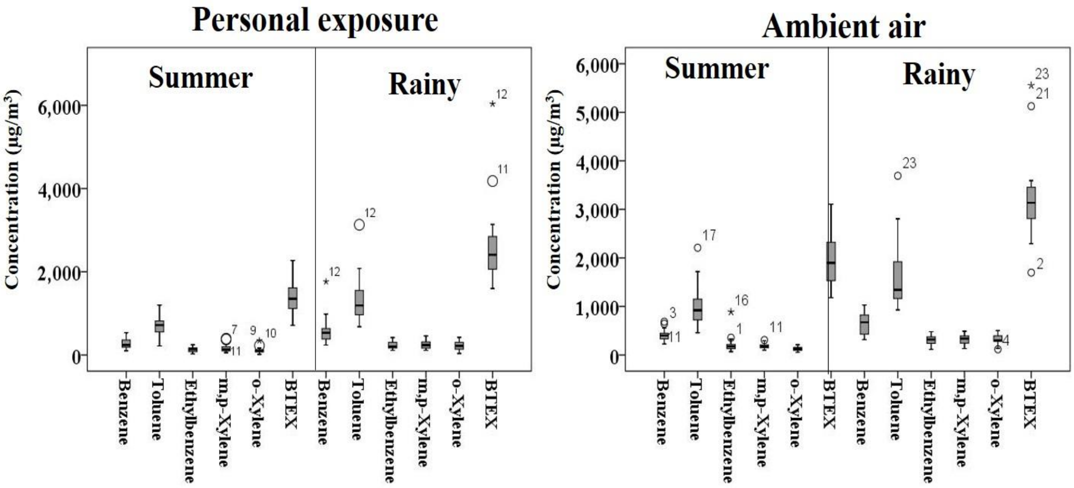


Figure 5.5 Seasonal variation of BTEX concentration

For CCs, the levels of these compounds in dry season were greater than those of wet season for both personal and ambient air samples. Nonetheless, there were no significant differences of formaldehyde, acetaldehyde and propionaldehyde between seasons for ambient air samples. Normally, CCs were dissolved in the water and the wet deposition was the major mechanism of CCs in rainy season, however, the wet deposition was a minor factor comparing to the photolysis in dry season in this study. The degradation of CCs in dry season via the photolysis reaction was playing an important role in this study; hence the concentrations of CCs in dry season were much lower than those of rainy season. The results were shown in Fig. 5.6

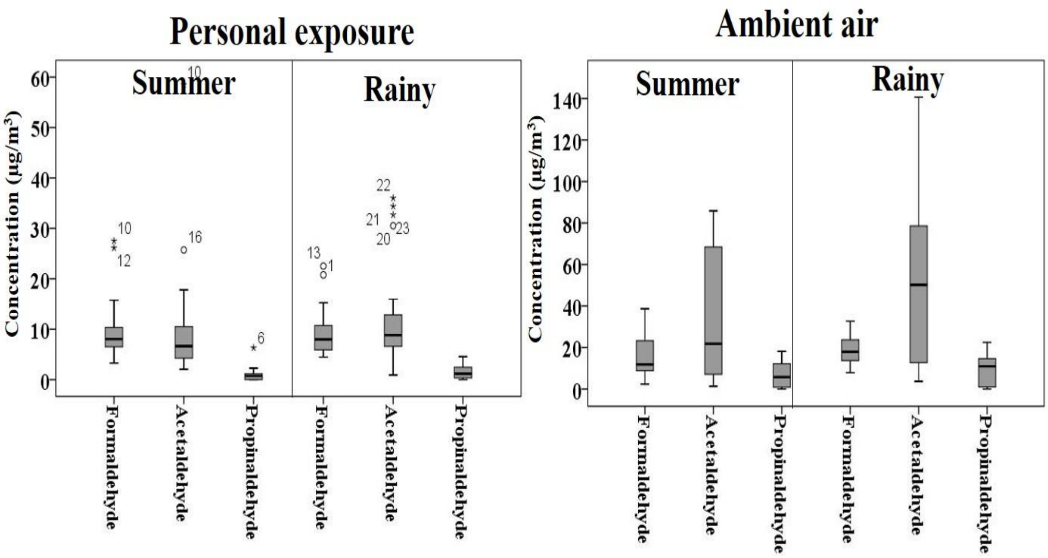


Figure 5.6 Seasonal variation of CCs concentration

From overall results, Henry Dunant Intersection (HD) showed the highest BTEX concentrations of both personal exposure and ambient air samples because the high density of traffic, number of vehicles and configuration of road at this site. The correlations between personal exposure and ambient air samples were found for all BTEX compounds with the exception of ethylbenzene due to the high BTEX level. Moreover, BTEX was very stable in the atmospheric air comparing to carbonyl compounds, therefore, the concentrations of personal exposure and ambient air were related for each other. For seasonal variation, the concentrations of both BTEX and carbonyl compounds in rainy season were greater than those of summer due to the photolysis under the strong solar radiation.

CHAPTER VI
Inhalation exposure of the indoor workers to BTEX and carbonyl compounds

6.1 Personal exposure and indoor air of indoor workers

Four sampling sites of indoor workplaces were located in Chulalongkorn University which consisted of Communication Center (CC), Faculty of Education (ED), Faculty of Engineering (EG) and Faculty of Economic (EC), respectively. The overall data of indoor workers were provided in Appendix D. The statistical analysis using SPSS of traffic policemen were provided in Appendix E.

Forty-eight samples for both personal exposure and indoor air concentrations were conducted and the results were shown in Fig 6.1. For personal exposure values of benzene, the ED site was contained the highest level followed by CC, EG and EC, respectively. In the opposite of benzene, the greatest toluene level was found at CC, EC, EG and ED, correspondingly. In spite of toluene, the highest ethylbenzene was shown at CC, EG, ED and EC, respectively. ED had the highest m,p-Xylene concentration followed by EG, CC and EC, correspondingly. However, the greatest o-Xylene concentration was revealed at CC, EG, EC and ED, respectively. For total BTEX, the highest personal exposure concentration was obtained at CC followed by EC, EG and ED, correspondingly.

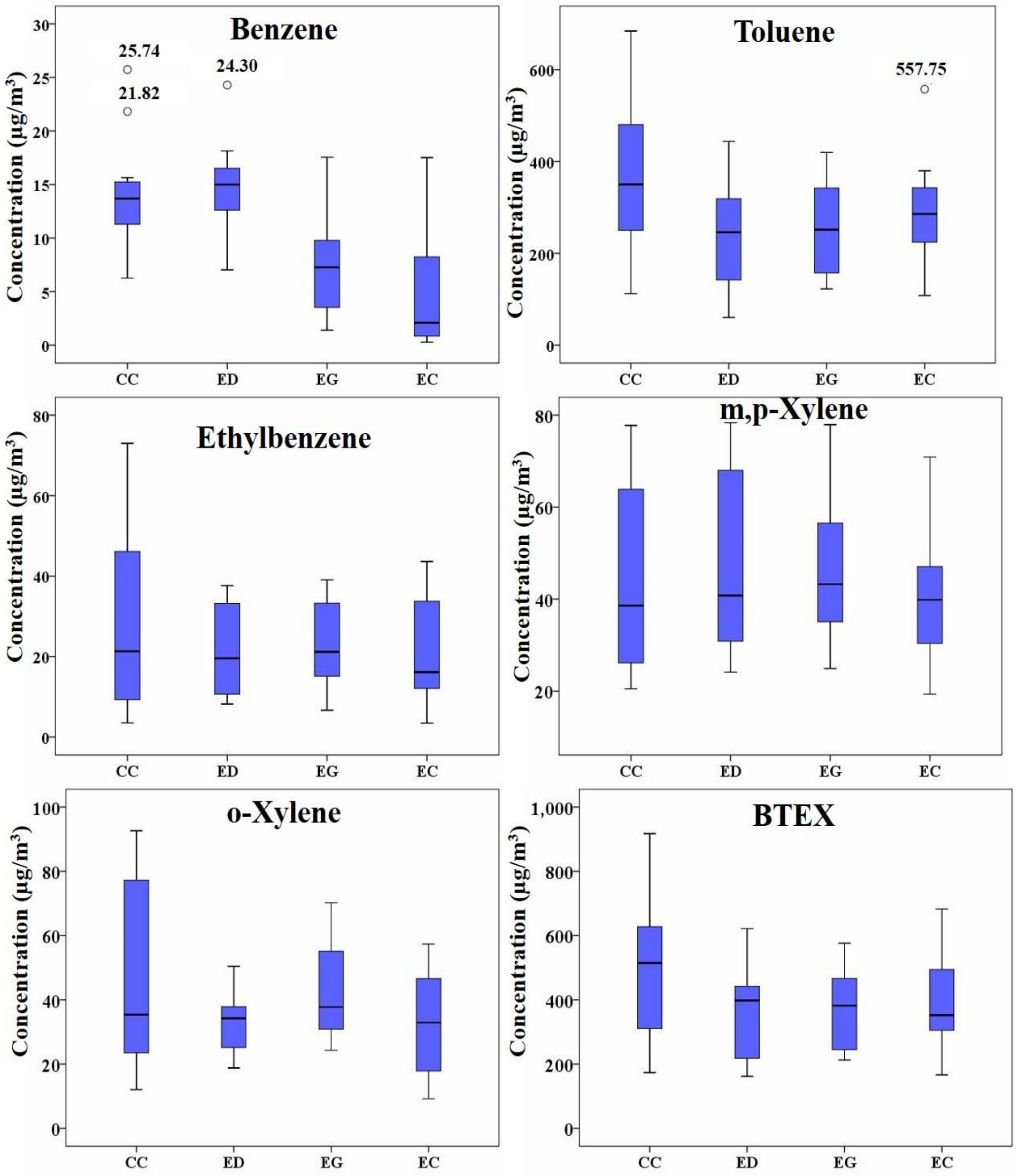


Figure 6.1 Personal exposure of indoor worker to BTEX at all sampling sites

For the indoor air samples, the highest value of benzene was shown at CC, ED, EG and EC, respectively. CC was detected the greatest toluene value followed by EC, EG and ED, respectively. On the other hands, the sequence concentrations of ethylbenzene were CC, EC, ED and EG, correspondingly. For m,p and o-Xylene, the sequence concentrations were EG, CC, ED and EC, respectively. For total BTEX level, the greatest mean of ambient BTEX value was found at CC, EG, EC and ED, respectively (see Figure 6.2). BTEX concentrations of indoor workers at all sampling sites were expressed in Table 6.1.

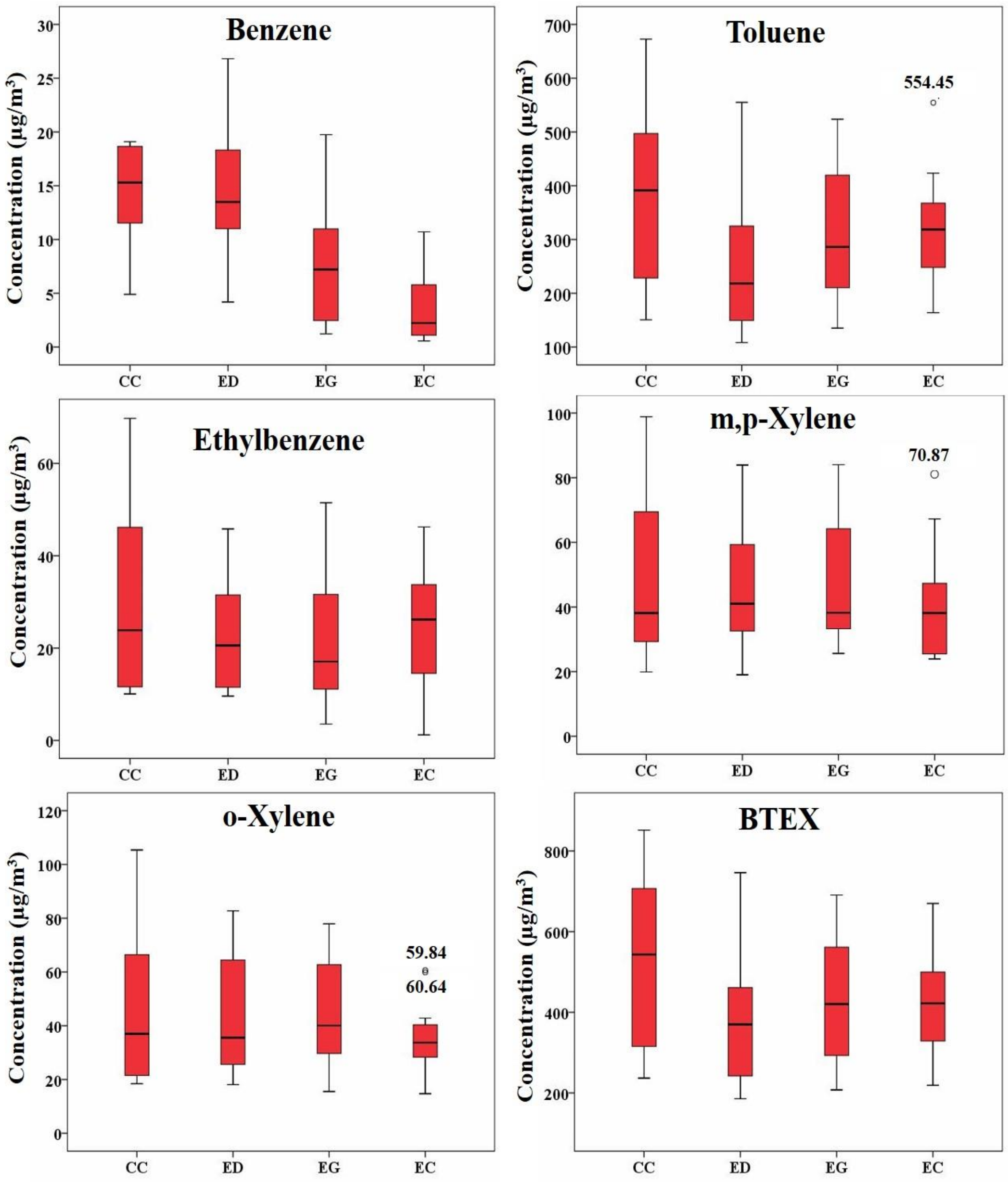


Figure 6.2 Indoor air of indoor worker to BTEX at all sampling sites

Table 6.1 BTEX concentrations of indoor worker at all sampling sites

Sample	Compound	Concentration (µg/m³)			
		CC	ED	EG	EC
Personal air	Benzene	13.95±5.46	14.72±4.46	7.82±5.28	4.64±5.18
	Toluene	369.97±172.90	241.37±128.16	257.44±105.07	285.98±118.88
	Ethylbenzene	28.10±23.18	21.88±11.82	23.01±10.84	21.65±13.98
	m,p-Xylene	43.10±19.84	49.04±20.36	47.08±17.53	41.06±15.14
	o-Xylene	47.42±29.59	32.99±9.45	42.51±15.23	33.06±15.72
	BTEX	502.54±232.42	360.00±157.10	377.86±130.78	386.39±147.37
Ambient air	Benzene	14.86±4.36	14.71±6.31	7.65±5.58	3.63±3.33
	Toluene	382.63±168.66	247.08±129.59	315.04±131.39	321.58±103.41
	Ethylbenzene	29.25±19.62	22.57±11.99	21.02±14.37	23.87±13.23
	m,p-Xylene	48.23±26.99	45.85±19.66	48.68±21.12	41.25±17.81
	o-Xylene	45.01±27.91	43.97±23.22	45.13±19.18	35.32±14.16
	BTEX	519.99±221.30	374.18±165.22	437.53±170.32	425.64±125.38

The overall data of both personal and ambient air concentrations of indoor workers were demonstrated in Table 6.2. For personal exposure concentrations, CC site showed the greatest value of almost BTEX compounds (toluene, ethylbenzene, o-Xylene and BTEX) as well as the indoor air concentrations (benzene, toluene, ethylebenzene, o-Xylene and BTEX). These results might be caused by the location of this site was situated near the main road of the university which closed to Phaya Thai Road. BTEX could infiltrate from the outdoor air (vehicle) into the indoor air (office building) so the BTEX level in the office room of CC was also impacted by the traffic density in the university and Phaya Thai Road. Photocopier and printer were suspected as the indoor sources of VOCs which comprised of BTEX and several studies were researched about this fact (94-97). The office workers of CC and ED were worked close to the copy machines, so the personal exposure samples of these sites were higher than those of another.

In addition, the indoor sources of VOCs were the building materials which comprised of carpet, paints, paper, solvent, adhesive, etc. (98-101). Thus, these materials in each office room were taking into account and the new products were released VOCs in higher level than the old ones. Therefore, the concentrations of xylenes at EG were found at high levels. Focusing on the position of the samples of personal and indoor air, the personal samples of workers at CC site were collected very closed to the indoor air samples (see Fig. 3.3 in chapter 3). Hence, the concentrations of pollutants did not vary between the personal exposure and indoor air samples.

Table 6.2 Comparison of BTEX detected at all sampling sites of indoor worker

Compound	Sample	Average conc. (µg/m^3)[1]	Conc. Range (µg/m^3)	Concentration Ranking (High to Low)[2]
Benzene	-Personal - Indoor	10.28±6.52 10.21±6.86	0.29-25.74 0.56-26.82	$ED^a>CC^a>EG^b>EC^b$ $CC^a>ED^a>EG^b>EC^b$
Toluene	-Personal - Indoor	288.69±138.71 316.58±139.59	60.60-684.36 108.31-672.57	$CC^a>EC^{ab}>EG^b>ED^b$ $CC^a>EG^{ab}>EC^{ab}>ED^b$
Ethylbenzene	-Personal - Indoor	23.66±15.45 24.18±14.93	3.45-73.01 1.21-69.74	$CC^a>EG^a>ED^a>EC^a$ $CC^a>EC^a>ED^a>EG^a$
m,p-Xylene	-Personal - Indoor	45.07±18.02 46.00±21.18	19.34-78.33 19.04-98.84	$ED^a>EG^a>CC^a>EC^a$ $EG^a>CC^a>ED^a>EC^a$
o-Xylene	-Personal - Indoor	39.00±19.43 42.36±21.41	9.20-92.65 14.71-105.39	$CC^a>EG^a>EC^a>ED^a$ $EG^a>CC^a>ED^a>EC^a$
Total BTEX	-Personal - Indoor	406.70±175.28 439.33±176.39	161.78-917.75 185.50-851.81	$CC^a>EC^{ab}>EG^{ab}>ED^b$ $CC^a>EG^{ab}>EC^{ab}>ED^b$

[1]Data were reported as the mean ± 1SD which obtained from 48 (personal) and 48 (ambient air).
[2]Sampling site codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, and c) having significant different ($p < .05$) mean levels.

The personal exposure concentrations of BTEX of indoor workers in this study were compared to those observed in Mexico as shown in Table 6.3. Benzene, toluene and m,p-Xylene concentrations of indoor workers in Mexico were higher than those found in Thailand. However, the factors which affected to the levels of BTEX in these two studies were possibly depended on the location of the office, the traffic conditions near the office, the indoor sources and the activities of study subjects. From these results, BTEX values of office workers in Mexico were greater than that found in this study that might be caused by the traffic condition and the number of vehicles in Mexico study were higher comparing to this study. The researcher explained that both traffic and the old vehicle were the major factors that increased BTEX levels in Mexico(81).

Table 6.3 Comparison of mean personal exposure concentrations of office workers in Thailand and Mexico

Compound	Mean concentration (μg/m^3)	
	Thailand[1]	Mexico[2]
Benzene	10	44
Toluene	289	470
Ethylbenzene	24	17
m,p-Xylene	45	59
o-Xylene	39	22

[1]Data obtained from this study
[2]Data obtained from Romieu et al, 1999

6.2 Personal exposure and indoor air carbonyl compounds concentrations of indoor workers

Considering on personal exposure concentrations, the highest level of formaldehyde was provided at EG followed by EC, ED and CC, respectively. Nonetheless, the greatest acetaldehyde value was illustrated at EC followed by CC, EG and ED, correspondingly. CC contained the greatest level of propionaldehyde followed by ED, EC and EG, severally (see Fig. 6.3).

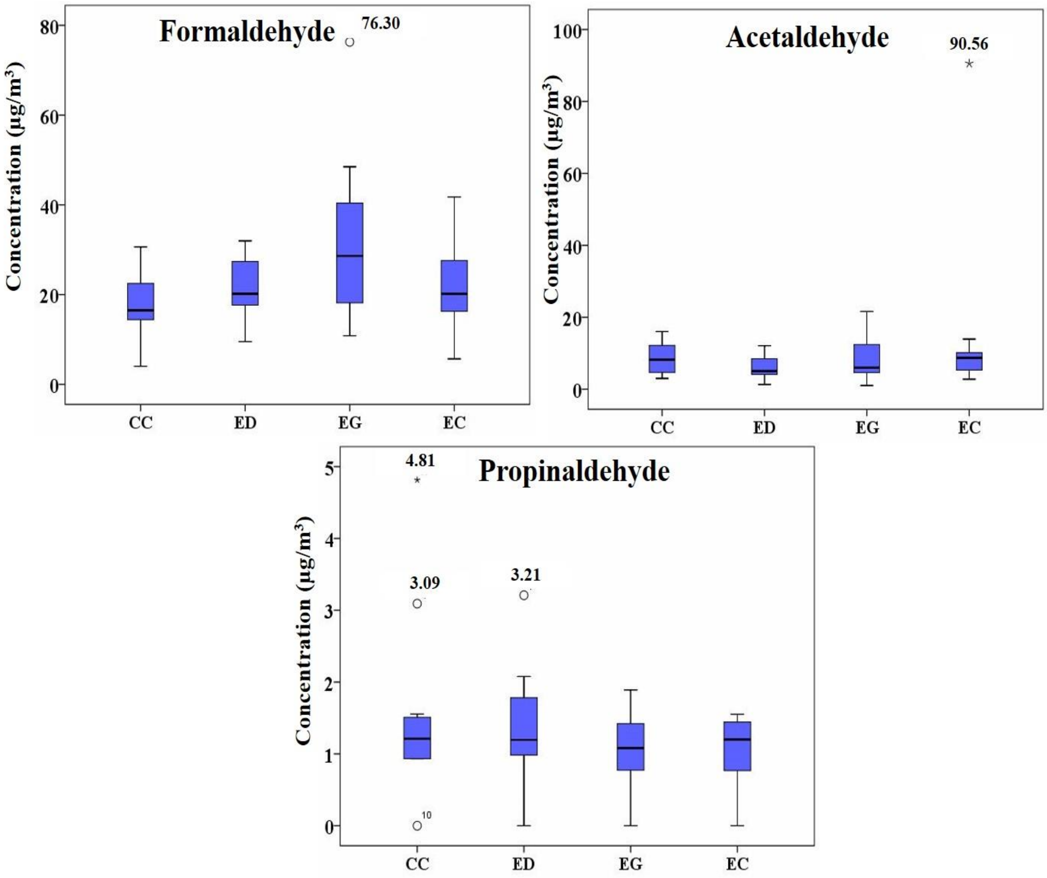


Figure 6.3 Personal exposure of indoor worker to CCs at all sampling sites

In view of indoor air samples, the greatest level of formaldehyde was found at EG followed by EC, ED and CC, respectively. The greatest value of acetaldehyde was observed at EC followed by CC, ED and EG, correspondingly. The sequence order of propionaldehyde was EG, ED, EC and CC, severally (see Figure 6.4 and Table 6.4).

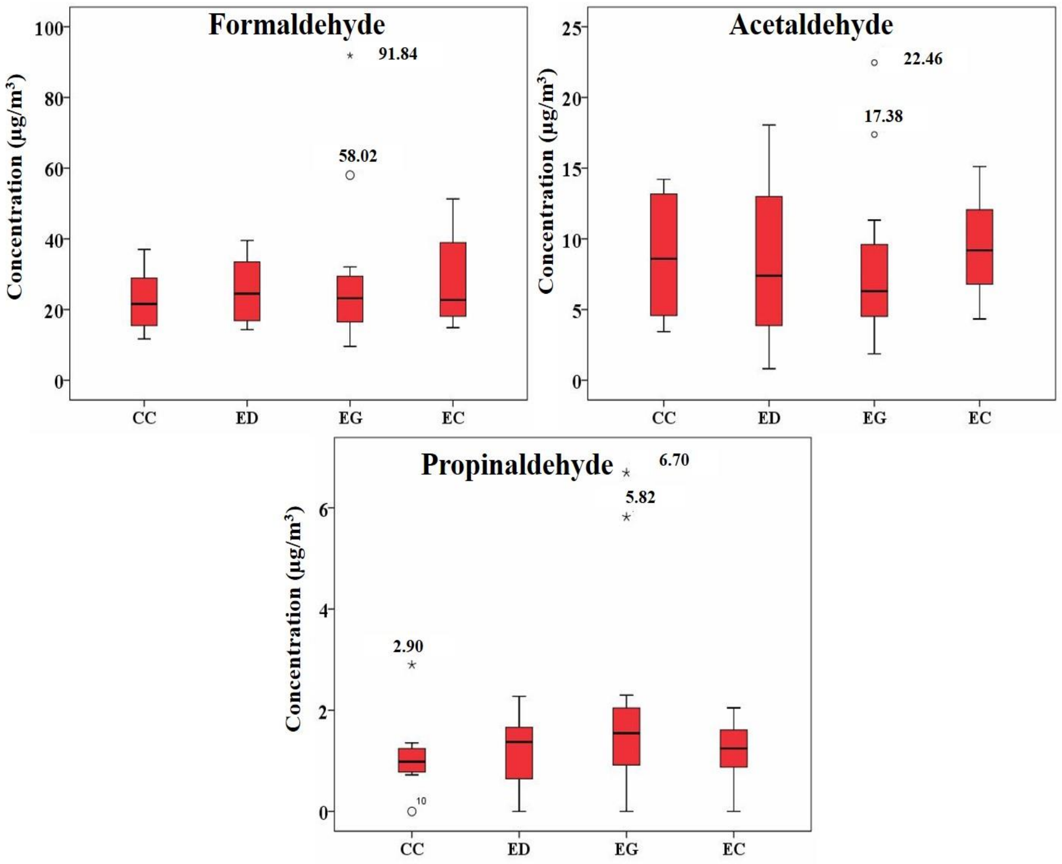


Figure 6.4 Indoor air CCs concentration of indoor worker at all sampling sites

Table 6.4 Carbonyl compounds concentrations of indoor worker at all sampling sites

Sample	Compound	Concentration (µg/m^3)			
		CC	ED	EG	EC
Personal air	Formaldehyde	17.48±6.79	21.60±6.84	31.72±18.33	22.46±10.56
	Acetaldehyde	8.80±4.53	6.10±3.23	8.12±5.95	14.64±24.11
	Propionaldehyde	1.55±1.25	1.33±0.88	1.04±0.54	1.08±0.47
Indoor air	Formaldehyde	22.35±7.89	25.51±9.06	29.79±23.09	28.27±12.12
	Acetaldehyde	8.74±4.38	8.60±5.79	8.19±6.07	9.38±3.56
	Propionaldehyde	1.08±0.68	1.19±0.76	2.11±2.04	1.19±0.67

For the personal samples, the highest CCs concentrations were varied in different sites but there were insignificant differences among the places for acetaldehyde and propionaldehyde. Thus, formaldehyde was only considered in this case and EG contained the greatest value of this substance followed by EC. The explanation was due to the age of building or the renovation because the major sources of formaldehyde came from the furniture and office appliances.

Indoor source of the newly renovated building was contained high CCs levels from the refurbish products (102, 103). EG and EC sites were renovated for years, whereas CC and ED were the old building without the renovation. It was very clear that the greatest formaldehyde and acetaldehyde levels were detected at EG and EC, respectively. The data of personal and ambient air concentrations of CCs were shown in Table 6.5.

Table 6.5 Comparison of CCs detected at all sampling sites of indoor worker

Compound	Sample	Average conc. ($\mu g/m^3$)[1]	Conc. Range ($\mu g/m^3$)	Concentration Ranking (High to Low)[2]
Formaldehyde	-Personal air -Indoor air	23.32±12.41 26.48±14.18	4.04-76.30 9.60-91.84	$EG^a>EC^{ab}>ED^b>CC^b$ $EG^a>EC^a>ED^a>CC^a$
Acetaldehyde	-Personal air -Indoor air	9.41±12.72 8.73±4.91	1.04-90.56 0.82-22.46	$EC^a>CC^a>EG^a>ED^a$ $EC^a>CC^a>ED^a>EG^a$
Propionaldehyde	-Personal air -Indoor air	1.25±0.84 1.39±1.22	0.00-4.81 0.00-6.70	$CC^a>ED^a>EC^a>EG^a$ $EG^a>ED^{ab}>EC^{ab}>CC^b$

[1]Data were reported as the mean ± 1SD which obtained from 48 (personal) and 48 (ambient air).
[2]Sampling site codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, and c) having significant different ($p < .05$) mean levels.

The indoor office environment of Chulalongkorn (Thailand) in this study and the Universidade Federal do Ceara, Campus do Pici (Brazil) were compared. The average CCs concentrations in this study were greater than those of Cavalcante (2006)(46) as illustrated in Table 6.6. The location of these two studies were situated in high density area of population, and highway. Furthermore, the traffic inside these universities were slightly high. Thus, the effects of both indoor and outdoor sources were impacted to the indoor environment.

Table 6.6 Ambient air of carbonyls in academic environment

University	Average conc. (µg/m^3)	
	Formaldehyde	Acetaldehyde
Chulalongkorn[1]	26.48	8.73
Universidade Federal do Ceara[2]	11.82	5.94

[1]Data was obtained from this study
[2] Data obtained from the study of Cavalcante (2006) (46)

6.3 Correlation between personal exposure and indoor air levels of BTEX and carbonyl compounds

The relationship between personal exposure and indoor air levels was statistically analyzed using Pearson's correlation. Total samples of personal and indoor air concentrations of indoor workers were 24. and the indoor air samples of indoor workers were also 24. The results were shown in Table 6.7.

Table 6.7 Pearson's correlation of personal and indoor air CCs and BTEX levels

Compound	Pearson's coefficient (*r*)
Benzene	0.818**
Toluene	0.863**
Ethylbenzene	0.866**
m, p-Xylene	0.820**
o-Xylene	0.740**
BTEX	0.891**

Formaldehyde	0.723**
Acetaldehyde	0.387**
Propionaldehyde	0.11

* mean significantly different ($p < .05$) mean levels
** mean significantly different ($p < .01$) mean levels

For indoor group, the office workers also showed the significance difference between personal exposure and ambient air samples to benzene, toluene, ethylbenzene, m,p-Xylene, o-Xylene and total BTEX. Nonetheless, formaldehyde and acetaldehyde showed the significant relationship between personal and ambient air samples, while propionaldehyde had no association. From overall results, indoor workers showed the relationship between personal and ambient air samples of all substances with the exception of propionaldehyde, and it might be explained by the indoor workers worked in their office throughout their working period and the indoor air samples were also collected in the office for 8 hours which was similar to personal samples. Therefore, the statistical analysis was shown the association between these samples.

6.4 Seasonal variations of BTEX and carbonyl compounds

The samples of indoor workers were taken in April to May 2014 (summer season) and August to September 2014 (Rainy season). In each season, the total personal exposure and ambient air samples of indoor workers were 24 for each type of sample. The meteorological data of indoor workers was shown in Table 6.8.

Table 6.8 Meteorological data of the sampling day

Meteorological data*	Season	
	Summer	Rainy
Solar radiation	303.32±121.99	130.16±107.54
Temperature	30.82±1.36	29.40±0.69
Precipitation	11.00±0.00	17.22±14.59
Humidity	71.67±6.31	78.83±2.93

* The data was obtained from Thai Meteorological Department

The mean differences between personal exposure and ambient air concentrations between wet and dry season were expressed in Table 6.9. Indoor workers showed the same seasonal trend of BTEX compounds (ambient and personal exposure samples) and they were statistically significant difference between summer and rainy seasons. The explanation of this results were the same as traffic police that had already shown in the previous chapter. The results were shown in Fig. 6.5.

Table 6.9 The mean difference between dry and wet seasons of carbonyl compounds and BTEX

Compound	Sig. (2-tailed)	
	Indoor air sample	Personal exposure sample
Formaldehyde	0.082	0.029*
Acetaldehdye	0.087	0.935
Propionaldehyde	0.827	0.679
Benzene	0.007**	0.013*
Toluene	0.000**	0.000**
Ethylbenzene	0.000**	0.000**
m,p-Xylene	0.000**	0.000**
o-Xylene	0.000**	0.000**
BTEX	0.000**	0.000**

* mean significantly different ($p < .05$) mean levels

** mean significantly different ($p < .01$) mean levels

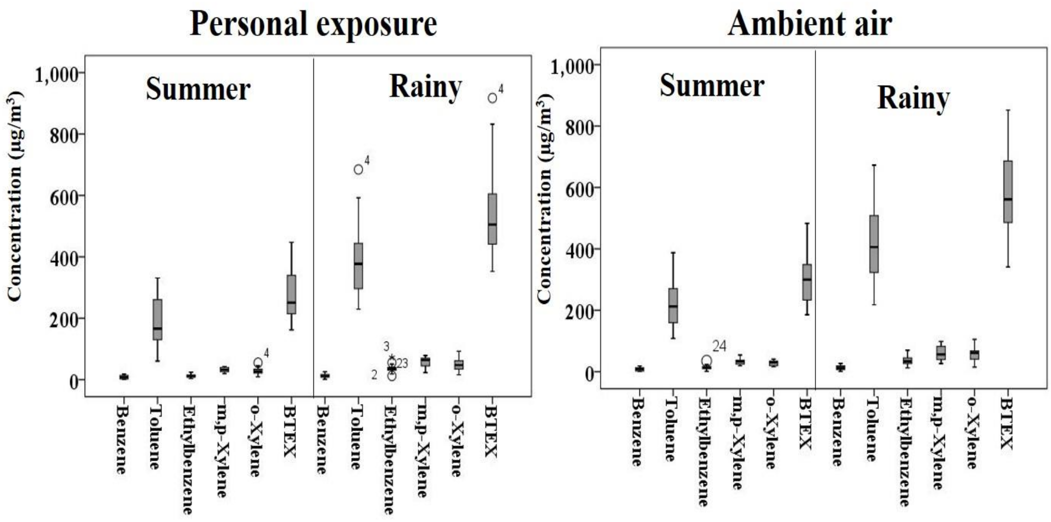


Figure 6.5 Seasonal variation of BTEX concentration

For formaldehyde of indoor workers, formaldehyde levels of personal samples in rainy were higher than those of summer causing by the photolysis as explained before. Although, formaldehyde was water soluble but the concentrations of this chemical in rainy were still greater than those of summer. Thus, the net formaldehyde levels were depended on the photolysis, wet deposition and the activities of indoor workers. From overall results, it was found that the degradation of BTEX and CCs via the photolysis reaction in summer was the main factor for both compounds, while the wet deposition of these compounds in rainy season was very low. Thus, the concentrations of both BTEX and CCs in rainy season were greater than those of summer. The results were illustrated in Fig.6.6.

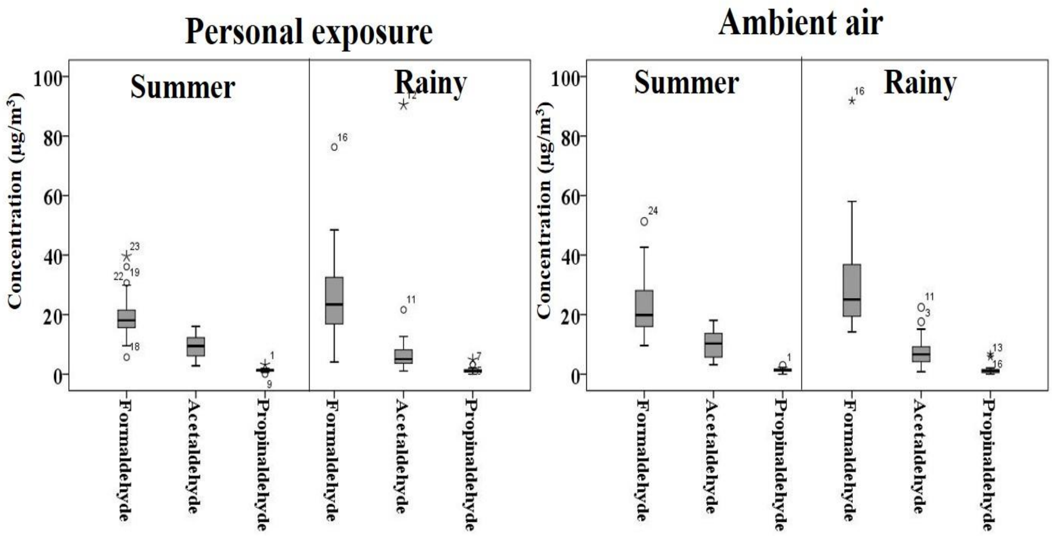


Figure 6.6 Seasonal variation of CCs concentration

From overall results, Communication Center (CC) site had the greatest BTEX concentrations for both personal exposure and ambient air samples because this site was located very closed to the main road in university and Phaya Thai Road. On the other hands, Faculty of Economic (EC) and Faculty of Engineering (EG) showed the highest CCs concentrations due to the indoor sources. These sites were renovated for years in contrast to CC and ED and then the indoor sources causing from the refurbish materials of EC and EG were elevated carbonyls levels. For the relationship between two types of samples were shown for all substances because these workers were stayed at their workplace throughout their working time. For seasonal variation, BTEX and carbonyls in wet season were higher than those of dry season according to the degradation under strong solar radiation in summer.

6.5 Comparison on personal and ambient/indoor air BTEX concentration of all worker groups

Overall personal and ambient air samples of all worker groups were collected which consisted of the moderate-exposure group (street vendors, motorcycle taxi drivers and security guards), high-exposure group (traffic police) and low-exposure group (indoor workers). The abbreviation of street vendor, motorcycle taxi driver, security guard, traffic policemen and indoor worker were V, M, G, P and I, respectively.

Comparing on the personal exposure concentrations among all workers exposed to benzene was found that the traffic police showed the highest level followed by security guards, motorcycle taxi drivers, street vendors and indoor workers, respectively. For toluene, traffic police had the greatest value followed by indoor workers, street vendors, motorcycle taxi drivers and security guards, correspondingly. In view of ethylbenzene and m,p-Xylene, the sequence order were traffic policemen, indoor workers, motorcycle taxi drivers, street vendors and security guards, respectively. However, the traffic police showed the highest level of o-Xylene followed by indoor workers, security guards, motorcycle taxi drivers and street vendors, respectively. For BTEX, traffic police still showed the greatest value which followed by officers, motorcycle taxi drivers, street vendors and security guards, correspondingly. Discussion on personal expose samples among workers, traffic policemen demonstrated the greatest substance levels due to the duties of their jobs and location of their workplace. Chatzis (2005) presented that the workers who performed their job outdoor (at roadside) were received greater benzene concentrations and thus the personal exposure level was associated with the occupation. BTEX was not only generated from the outdoor sources (mainly from vehicles) but it also originated from the indoor sources such as building materials (paints and floor coverings), organic solvents (cleaning products) and smoking. Of this fact, the personal levels of indoor workers exposed to BTEX with the exception of benzene were higher than the outdoor workers, however, there was no significant difference of pollutant levels indoor and outdoor workers with the exception of toluene and m,p-Xylene. (Figure 6.7)

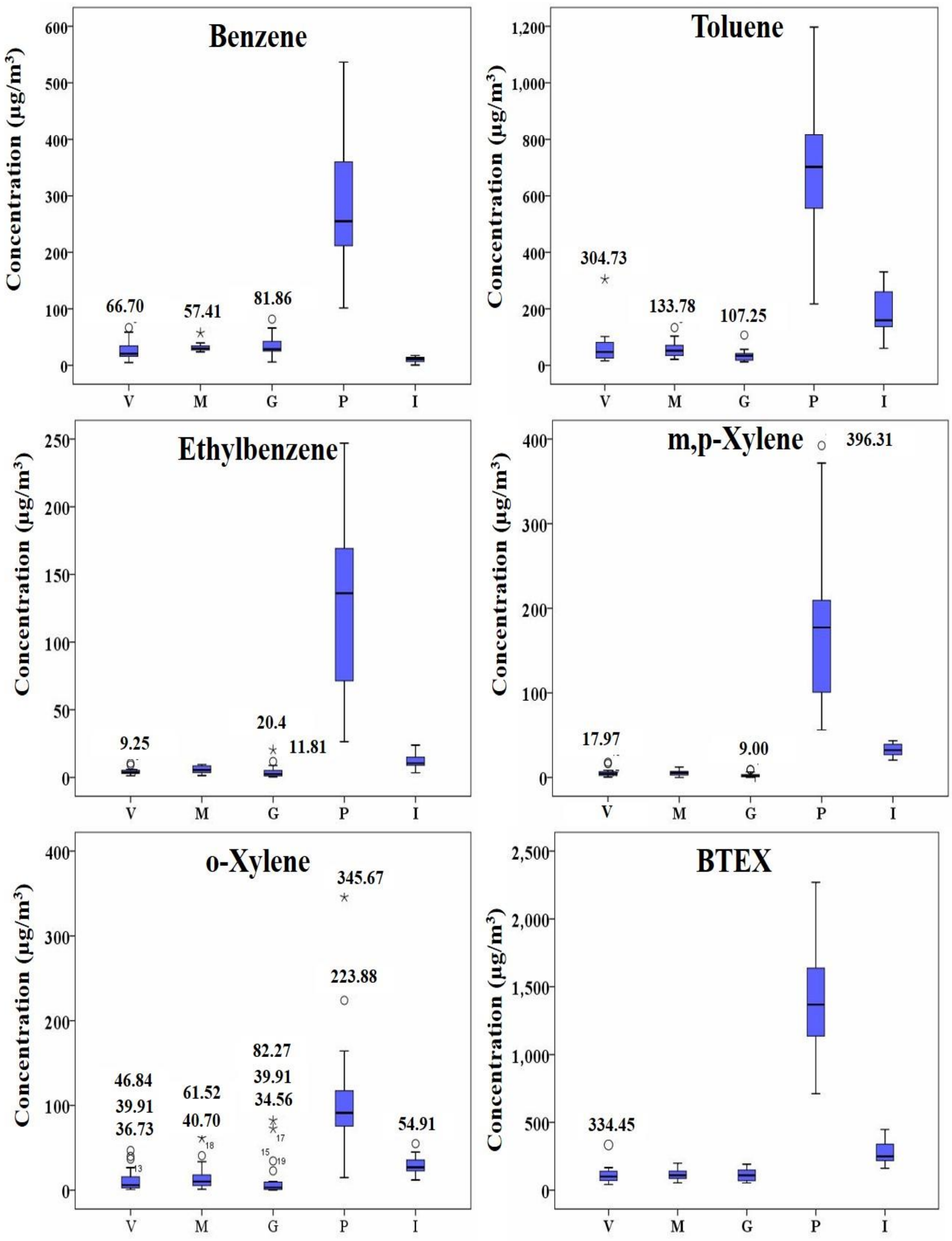


Figure 6.7 Personal exposure of all workers to BTEX at all sampling sites

For ambient air samples of benzene, traffic policemen had the greatest level followed by security guards, motorcycle taxi drivers, street vendors and indoor workers, respectively. For toluene, m,p-Xylene and total BTEX, the highest concentrations was found for traffic policemen followed by indoor workers, street vendors, motorcycle taxi drivers and security guards, correspondingly. For ethylbenzene, the greatest concentration was traffic policemen followed by indoor workers, motorcycle taxi drivers, street vendors and security guards, respectively. Nevertheless, traffic policemen showed the greatest level of o-Xylene followed by indoor workers, street vendors, motorcycle taxi drivers and security guards, correspondingly. (Figure 6.8)

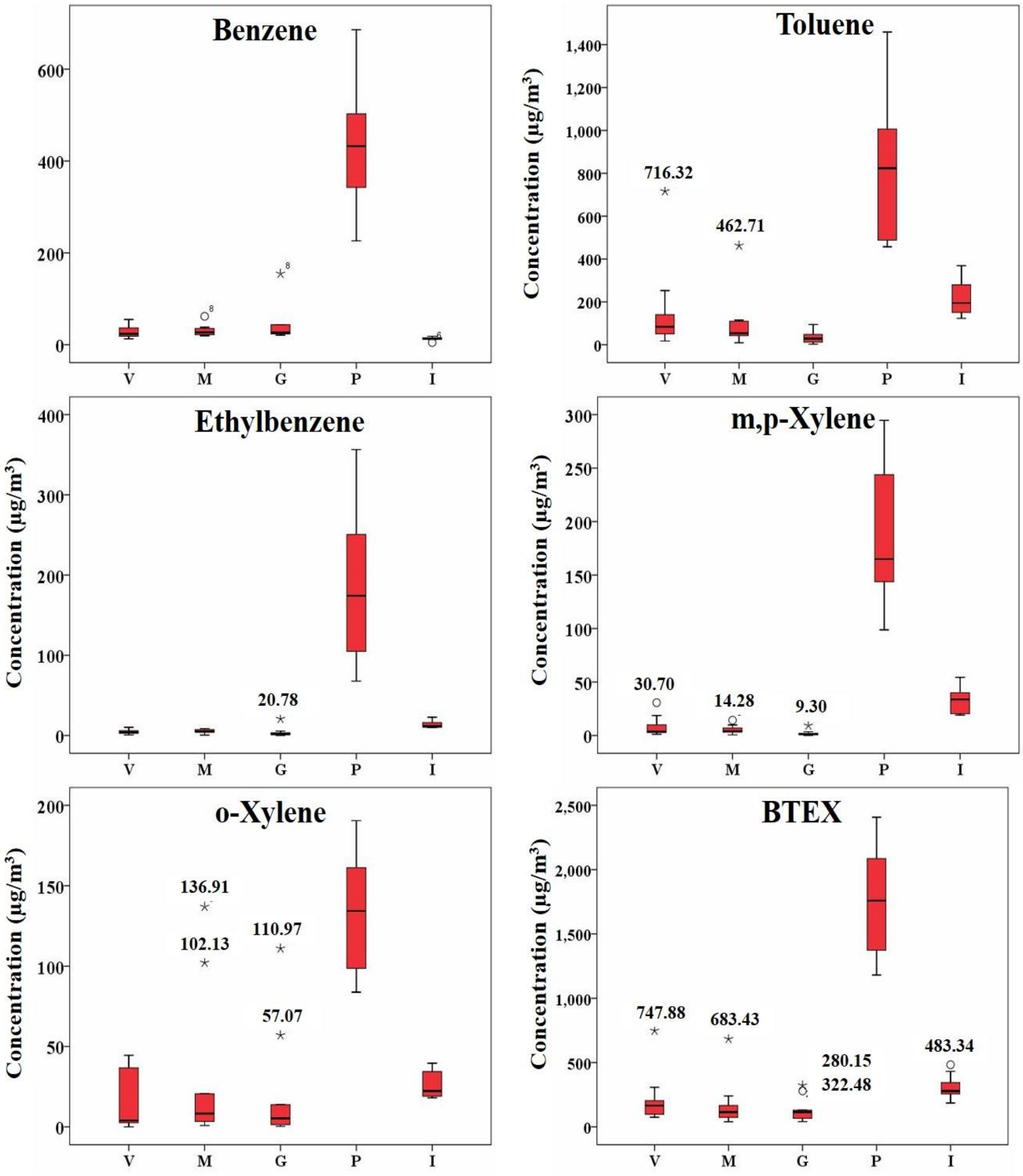


Figure 6.8 Ambient/indoor air of all workers to BTEX at all sampling sites

The results of BTEX of all worker groups were established in Table 6.9. From all results of total BTEX, traffic policemen showed the highest concentration than those found in the others and this may be due to the location of workplace. Normally, traffic police worked in the police booth that located at the intersection; hence, the pollutants which generated from vehicles were extremely high comparing to the working place of the others. Moreover, the performance was involved because traffic policemen did their jobs in both indoor (booth) and outdoor to control the traffic. Nonetheless, they spent a lot of their work in the police booth and the concentrations of pollutant from the road can be penetrated in police office, so both personal exposure and ambient air samples of traffic police were absolutely high than those of the others. For ambient air samples, the locations of traffic policemen were investigated at the intersection, while the sampling locations of moderate-exposure group were situated at the roadside. Of these facts, the ambient air concentrations of traffic police were greater than those observed in the outdoor workers. In contrast to these workers, the ambient air samples of indoor workers were examined in the office rooms, so benzene levels were lower than others. Nevertheless, toluene and xylenes of indoor workers for both personal and indoor air were greater than those found in the outdoor workers and this might be due to the indoor sources which consisted of furniture, paints, and organic solvent (47). Qu et al., 2006 (36) demonstrated that the indoor air was greater than that observed in the outdoor air which due to the movement of BTEX in the indoor was limited.

Table 6.10 BTEX concentrations of all worker groups

Sample	Compound	Average conc. ($\mu g/m^3$)					Concentration Ranking (High to Low)[3]
		Street vendor (V)	Motor-cycle taxi driver (M)	Security guard (G)	Traffic policemen (P)	Indoor worker (I)	
Personal exposure[1]	Benzene	25.86± 16.01	31.74± 7.52	40.13± 20.88	426.29± 276.74	10.28± 6.52	$P^a>G^b>M^b>V^b>I^b$
	Toluene	66.03±63.91	56.59± 28.47	31.71± 20.37	1016.05± 520.58	288.69± 138.71	$P^a>I^b>V^c>M^c>G^c$
	Ethylbenzene	4.29± 2.40	5.80± 2.70	3.83± 4.53	178.52± 94.68	23.66± 15.45	$P^a>I^b>M^b>V^b>G^b$
	m,p-Xylene	5.62± 4.65	5.64± 3.45	4.88± 6.09	202.92± 99.35	45.07± 18.02	$P^a>I^b>M^c>V^c>G^c$
	o-Xylene	13.07±14.29	15.24± 15.14	18.86± 25.96	166.81± 107.20	39.00± 19.43	$P^a>I^b>G^b>M^b>V^b$

	BTEX	114.87±65.60	117.87±43.45	99.41±47.81	1990.59±942.30	406.70±175.28	$P^a>I^b>M^c>V^c>G^c$
Ambient/ indoor air[2]	Benzene	28.24±13.34	30.24±12.74	49.67±40.82	529.89±207.15	10.21±176.39	$P^a>G^b>M^b>V^b>I^b$
	Toluene	157.12±207.27	101.61±131.10	31.73±25.75	1292.94±627.54	316.58±139.59	$P^a>I^b>V^{bc}>M^{bc}>G^c$
	Ethylbenzene	4.68±2.80	5.23±2.34	3.76±5.68	259.48±142.17	24.18±14.93	$P^a>I^b>M^b>V^b>G^b$
	m,p-Xylene	8.05±9.52	5.28±4.11	4.05±5.56	256.35±103.32	46.00±21.18	$P^a>I^b>V^{bc}>M^{bc}>G^c$
	o-Xylene	15.86±18.27	30.06±48.18	29.12±43.74	224.52±123.19	42.36±21.41	$P^a>I^b>M^b>G^b>V^b$
	BTEX	213.95±200.17	172.42±188.26	118.34±92.23	2563.19±921.06	439.33±176.39	$P^a>I^b>V^b>M^b>G^b$

[1]Data were reported as the mean which obtained from 19, 20, 24, 48 and 48 of street vendor, motorcycle taxi driver, guard, traffic police and indoor worker, respectively

[2]Data were reported as the mean which obtained from 10, 10, 12, 48 and 48 of street vendor, motorcycle taxi driver, guard, traffic police and indoor worker, respectively

[3]Worker codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, and c) having significant different ($p < .05$) mean levels.

6.6 Comparison on personal and ambient/indoor air carbonyl compounds concentration of all worker groups

For CCs (Figure 4.14), the highest formaldehyde concentration of personal sample was found for the indoor workers followed by street vendors, motorcycle taxi drivers, security guards and traffic policemen, respectively. In contrast to formaldehyde, traffic police expressed the greatest acetaldehyde level followed by indoor workers, street vendors, motorcycle taxi drivers and security guards, severally. Street vendors had the highest level of propionaldehyde followed by motorcycle taxi drivers, indoor workers, traffic policemen and security guards, correspondingly.

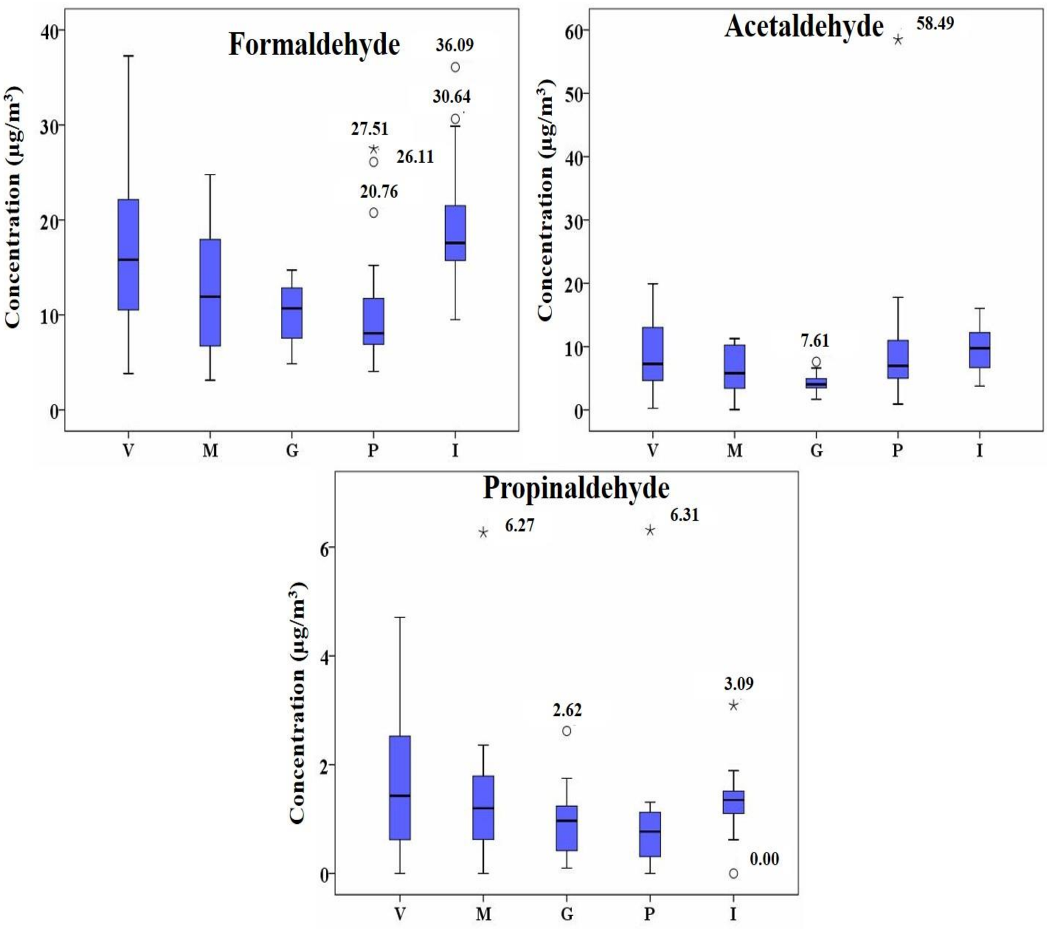


Figure 6.9 Personal exposure of all workers to CCs at all sampling sites

Focusing on the ambient and indoor air samples, indoor workers still showed the highest level followed by traffic policemen, motorcycle drivers, street vendors and security guards, respectively. For acetaldehyde, policemen had the greatest level followed by indoor workers, street vendors, motorcycle taxi drivers and security guards, respectively. Traffic policemen expressed the greatest propionaldehyde concentration followed by indoor workers, motorcycle taxi drivers, street vendors and security guards, correspondingly. (Fig. 6.10)

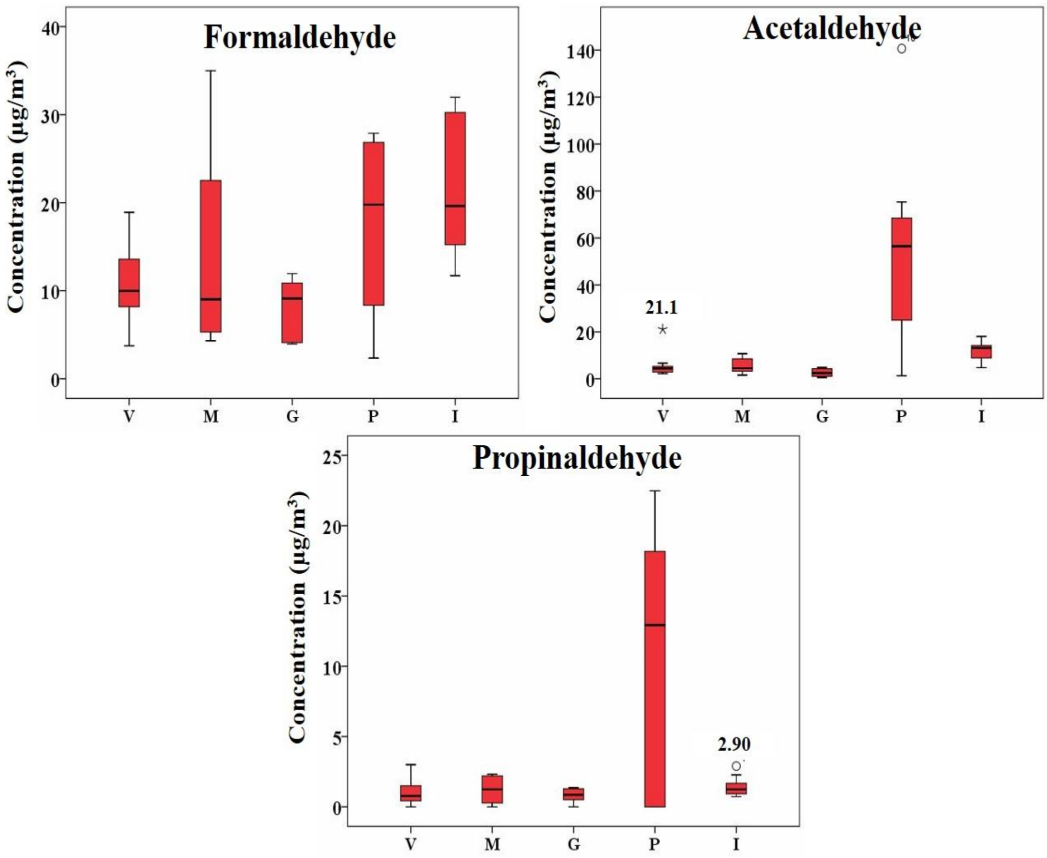


Figure 6.10 Ambient and indoor air concentration of CCs at all sampling sites of all workers

The results of CCs concentrations of all worker groups were shown in Table 6.10. For formaldehyde, the greatest values were found for both ambient and personal exposure samples of the indoor workers and this might be caused by formaldehyde was majorly generated from the indoor sources (indoor materials) such as furniture, wood products, carpet, painting and curtain, etc. Normally, formaldehyde level was higher in the indoor than that measured in the outdoor air (64). Therefore, the officer who worked in the office was shown greater concentration comparing to the others. For acetaldehyde, the traffic police had the greatest levels for both personal and ambient air samples. These results might be caused by the type of fuel and gasohol, which contained both gasoline and ethanol, was increasingly used in recent year. Morknoy (2008)(17) reported that the percentage of acetaldehyde emission in Thailand was increase 127.7

from vehicles using gasohol, and this might be the reason that explained why traffic police showed the greatest acetaldehyde level.

Table 6.11 CCs concentrations of all worker groups

Sample	Compound	Average conc. (μg/m³)					Concentration Ranking (High to Low)[3]
		Street vendor (V)	Motor-cycle taxi driver (M)	Security guard (G)	Traffic police men (P)	Indoor worker (I)	
Personal exposure[1]	Formaldehyde	17.14 ±9.43	12.84± 7.05	10.01± 3.11	9.39± 5.33	23.31± 12.41	$I^a>V^b>M^{bc}>G^c>P^c$
	Acetaldehyde	8.46± 5.68	6.41±3 .54	3.76± 1.65	11.06± 11.00	9.41± 1.59	$P^a>I^a>V^{ab}>M^{ab}>G^b$
	Propionaldehyde	1.70± 1.31	1.44±1 .38	0.77± 0.69	1.23± 1.38	1.25± 0.84	$V^a>M^{ab}>I^{ab}>P^{ab}>G^b$
Ambient/ indoor air[2]	Formaldehyde	10.65 ±4.77	14.19± 10.72	8.25± 3.30	17.44± 8.20	26.48± 14.18	$I^a>P^b>M^b>V^b>G^c$
	Acetaldehyde	5.81± 5.54	5.70±3 .21	2.49± 1.54	43.13± 35.06	8.73± 4.91	$P^a>I^b>V^b>M^b>G^b$
	Propionaldehyde	0.98± 0.88	1.20±0 .94	0.71± 0.55	8.40± 7.16	1.39± 1.22	$P^a>I^b>M^b>V^b>G^b$

[1]Data were reported as the mean ± 1SD which obtained from 19, 20, 23, 48 and 48 of street vendor, motorcycle taxi driver, guard, traffic police and indoor worker, respectively.

[2]Data were reported as the mean ± 1SD which obtained from 10, 10, 11, 48 and 48 of street vendor, motorcycle taxi driver, guard, traffic police and indoor worker, respectively.

[3]Worker codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, and c) having significant different ($p < .05$) mean levels.

From overall results, traffic policemen showed the highest concentrations of BTEX and acetaldehyde for both personal exposure and ambient air samples according to the location of this worker was situated at road intersection. The levels of these traffic pollutants were depended on the activities of their jobs and the location of their workplace. It was found that the workers who performed their job closed to the main road had the tendency to expose to these pollutants than those of other workers. For the association between two types of samples, the workers who always stay at their workplace (such as indoor workers) during their working time were shown the relationship of all pollutants. In view of seasonal variation, BTEX and carbonyls in wet season were higher than those of dry season due to the photolysis under solar radiation in summer.

CHAPTER VII

Health risk assessment of outdoor and indoor workers and their risk perception and risk communication

7.1 Health risk assessment of outdoor and indoor workers

7.1.1 General information of all workers

Four steps of risk assessment were used to calculate cancer and non-cancer risk of all workers which included the moderate exposure group (street vendors, motorcycle taxi drivers and security guards, high exposure group (traffic policemen) and low exposure group (indoor workers or officers). For cancer risk, CDI was estimated using Risk Assessment Guidance for Superfund (RAGS) Part A approach (US. EPA, 1989), while non-cancer risk was calculated using the RAG part F guideline (US. EPA, 2009). The personal exposure samples were only considered for risk evaluation and benzene, ethylbenzene, formaldehyde and acetaldehyde were concerned, whereas toluene, m,p-Xylene, o-Xylene and propionaldehyde were considered for non-cancer risk. For BTEX, Total samples of street vendors, motorcycle taxi drivers, security guards, traffic policemen and indoor workers were 19, 20, 24, 48 and 48, respectively. For CCs, total risk values of street vendors, motorcycle taxi drivers, security guards, traffic policemen and indoor workers were 20, 20, 24, 48 and 48, respectively. The questionnaires were conducted at the same time of sampling and the data was showed in Table 7.1.

Table 7.1 Questionnaire data of all worker groups

Exposure group	Worker	Gender		Average	
		Male	Female	Body weight (kg)	Exposure time (y)
Moderate	Street vendor	12	8	64.53±8.26	10.60±8.17
	Motorcycle taxi driver	20	-	70.25±11.86	7.63±9.56
	Security guard	24	-	66.33±11.10	9.56±7.98
High	Traffic policemen	48	-	77.96±0.56	21.65±0.48
Low	Indoor worker	32	16	65.31±2.32	12.51±0.28

7.1.2 Health risk assessment of outdoor workers at roadside area

The lifetime cancer and non-cancer risk of outdoor workers at roadside area were calculated and the 95% CI with box plot graphs were shown in Table 7.2, 7.3 and Fig 7.1. For cancer risk, benzene, ethylbenzene, formaldehyde and acetaldehyde were considered, while toluene, m,p- Xylene, o- Xylene and propionaldehyde were investigated for non-cancer risk. Firstly, the highest cancer risk of street vendors was benzene, followed by formaldehyde, acetaldehyde and ethylbenzene, respectively. On the other hands, propionaldehyde was determined the highest non-cancer risk followed by o-Xylene, m,p-Xylene and toluene, correspondingly. For motorcycle taxi drivers, benzene posed the greatest level, followed by formaldehyde, acetaldehyde and ethylbenzene, respectively. Propionaldehyde posed the greatest risk value, followed by o-Xylene, m,p-Xylene and toluene, respectively. For security guards, the highest cancer risk value was benzene, followed by formaldehyde, acetaldehyde and ethylbenzene, correspondingly. However, the highest non-cancer risk level was o-Xylene, followed by propionaldehyde, m,p-Xylene and toluene, respectively.

According to the sampling sites for street vendors, SCB (SCB Bank) showed the greatest cancer risk value for benzene, followed by SCI (Faculty of Science), OS (Osot Sala), BBL (BBL Bank) and KTB (KTB Bank), respectively. For ethylbenzene, SCB had significantly higher risk value than SCI, OS, KTB and BBL, correspondingly. In view of formaldehyde, SCB still contained highest risk level followed by OS, BBL, SCI and KTB, respectively. Formaldehyde level of SCB was significantly higher than KTB. SCB showed the greatest risk value of acetaldehyde followed by OS, SCI, BBL and KTB, respectively. For total cancer risk, the highest value was shown at SCB, SCI, OS, BBL and KTB, respectively. There was a significance difference between SCB and KTB.

Considering of non-cancer risk of toluene, SCB had the highest risk level than BBL, SCI, OS and KTB, correspondingly. For m,p-Xylene, the statistical analysis showed SCB demonstrated highest risk level followed by SCI, KTB, BBL and OS, correspondingly. The greatest risk value for o-Xylene was found at SCB, KTB, OS, SCI and BBL, respectively. SCB showed the greatest risk level of propionaldehyde was greater than those found at OS, SCI, BBL and KTB, respectively. The greatest total non-cancer risk level of street vendors was found at SCB, OS, SCI, BBL and KTB, correspondingly. Furthermore, toluene, propionaldehyde and total non-cancer risk showed the significance difference between SCB and KTB. The highest cancer and non-cancer risk values of all pollutants were found at SCB, while the lowest levels were tended to appeared at KTB.

In view of motorcycle taxi driver, the highest risk level of benzene was found at SCI which significantly greater than followed by OS, BBL, SCB and KTB, respectively. Nevertheless, SCI showed the greatest risk value of ethylbenzene followed by BBL, OS, SCB and KTB, correspondingly. However, OS demonstrated the highest risk level of formaldehyde followed by SCI, BBL, SCB and KTB, respectively. Similarly, the greatest risk value of acetaldehyde was found at OS followed by SCI, BBL, SCB and KTB, correspondingly. For total cancer risk level, SCI represented the highest value followed by OS, BBL, SCB, and KTB, respectively. For non-cancer risk level of toluene, SCI revealed the highest value followed by OS, BBL, KTB and SCB, correspondingly. SCI contained the greatest risk level of m,p-Xylene which followed by OS, BBL, KTB and SCB. The greatest risk level of o-Xylene was presented at SCI followed by SCB, OS, KTB and BBL, correspondingly. Nonetheless, OS presented the highest risk level of propionaldehyde while SCI was the lowest. SCI still contained the greatest non-cancer risk value followed by OS, BBL, SCB and SCI, respectively. Although, there were no significant difference in all substances among the sampling sites. SCI sites showed the highest cancer and non-cancer risk levels of most pollutants, whereas the lowest cancer and non-cancer risk values were varied in all sites. As well as security guards, the risk levels of motorcycle taxi drivers were relied on the concentrations of pollutant in each site along with all factors of risk equation.

Consideration of cancer risk levels of security guards, the greatest risk level of benzene was expressed at SCI, followed by ARC, ART, GRA, MBA and POL, severally. The statistical analysis showed that SCI significantly higher than GRA, MBA and POL. For cancer risk causing by ethylbenzene, POL expressed the highest value which greater than that in MBA and it followed by ART, SCI, ARC and GRA, severally. MBA provided the greatest risk level of formaldehyde followed by ART, GRA, ARC, SCI and POL, severally. However, the greatest risk level causing by acetaldehyde was presented at MBA followed by ARC, ART, GRA, POL and SCI, respectively. The greatest value of total cancer risk was given at SCI followed by ART, ARC, GRA, MBA and POL, severally (the significance difference were found between SCI and MBA and POL). In view of non-cancer risk, the highest risk value due to toluene was expressed at ARC followed MBA, ART, GRA, SCI and POL, severally. For the greatest risk value of m,p-Xylene, SCI was considered followed by GRA, ART, POL, MBA and ARC, correspondingly. Nevertheless, ARC represented the greatest risk level of o-Xylene followed by GRA, ART, SCI, POL and MBA, severally. ARC provided the highest risk causing by propionaldehyde which followed by GRA, MBA, ART, POL and SCI, respectively. From overall of non-cancer risk, the highest of total risk level was expressed at ARC, GRA, SCI, ART, MBA and POL, severally. It seemed like the highest cancer risk values of the substances were varied in sampling sites and this was depended on the pollutant concentrations of the sampling sites and also the exposure time, body weight and exposure duration of individual persons.

Table 7.2 Cancer risks of outdoor workers exposed to BTEX and CCs

Worker	Compound	Average CDI (mg kg^{-1} d^{-1})	Chemical-specific risk (95%CI)			Cancer risk level Ranking (High to Low)*
			Lower	Upper	Average	
Street vendor	Benzene	3.24E-04	4.54E-06	1.49E-05	9.71E-06	SCB[a]>SCI[a]>OS[a]>BBL[a]>KTB[a]
	Ethylbenzene	6.24E-05	1.17E-07	3.94E-07	2.55E-07	SCB[a]>SCI[b]>OS[b]>KTB[b]>BBL[b]
	Formaldehyde	1.58E-04	2.93E-06	8.56E-06	5.74E-06	SCB[a]>OS[ab]>BBL[ab]>SCI[ab]>KTB[b]
	Acetaldehyde	6.69E-05	5.67E-07	2.00E-06	1.28E-06	SCB[a]>OS[a]>SCI[a]>BBL[a]>KTB[a]
	Total cancer risk	6.11E-04	8.77E-06	2.52E-05	1.70E-05	SCB[a]>SCI[ab]>OS[ab]>BBL[ab]>KTB[b]
Motor-cycle taxi driver	Benzene	3.60E-04	3.52E-06	1.44E-05	8.94E-06	SCI[a]>OS[a]>BBL[a]>SCB[a]>KTB[a]
	Ethylbenzene	6.68E-05	5.43E-08	4.26E-07	2.40E-07	SCI[a]>BBL[a]>OS[a]>SCB[a]>KTB[a]
	Formaldehyde	2.63E-04	9.73E-07	5.70E-06	3.32E-06	OS[a]>SCI[a]>BBL[a]>SCB[a]>KTB[a]
	Acetaldehyde	1.26E-04	2.28E-07	1.11E-06	6.69E-07	OS[a]>SCI[a]>BBL[a]>SCB[a]>KTB[a]
	Total cancer risk	8.16E-04	5.00E-06	2.13E-05	1.32E-05	SCI[a]>OS[a]>BBL[a]>SCB[a]>KTB[a]
Security guard	Benzene	8.23E-04	1.15E-05	3.34E-05	2.25E-05	SCI[a]>ARC[ab]>ART[ab]>GRA[b]>MBA[b]>POL[b]
	Ethylbenzene	4.69E-05	7.44E-08	2.87E-07	1.80E-07	POL[a]>MBA[a]>ART[a]>SCI[a]>ARC[a]>GRA[a]
	Formaldehyde	1.28E-04	1.61E-06	3.75E-06	2.68E-06	MBA[a]>ART[a]>GRA[a]>ARC[a]>SCI[a]>POL[a]
	Acetaldehyde	4.89E-05	2.93E-07	6.85E-07	4.89E-07	MBA[a]>ARC[a]>ART[a]>GRA[a]>POL[a]>SCI[a]
	Total cancer risk	1.05E-03	1.44E-05	3.72E-05	2.58E-05	SCI[a]>ART[ab]>ARC[ab]>GRA[ab]>MBA[b]>POL[b]

*Sampling site codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, and c) having significant different ($p < .05$) mean levels.

Table 7.3 Non-cancer risks of outdoor workers exposed to BTEX and CCs

Worker	Compound	Average EC	Chemical-specific risk (95%CI)			Cancer risk level Ranking (High to Low)*
			Lower	Upper	Average	
Street vendor	Toluene	4.13E+00	6.16E-04	1.82E-03	1.22E-03	SCB[a]>BBL[b]>SCI[b]>OS[b]>KTB[b]
	m,p-Xylene	4.00E-01	1.87E-03	9.57E-03	5.73E-03	SCB[a]>OS[a]>KTB[a]>BBL[a]>SCI[a]
	o-Xylene	9.86E-01	4.39E-03	2.36E-02	1.40E-02	SCB[a]>KTB[a]>OS[a]>SCI[a]>BBL[a]
	Propionaldehyde	1.45E-01	1.18E-02	4.24E-02	2.71E-02	SCB[a]>OS[b]>SCI[b]>BBL[b]>KTB[b]
	HI	5.66E+00	2.30E-02	7.30E-02	4.80E-02	SCB[a]>OS[b]>SCI[b]>BBL[b]>KTB[b]
Motor-cycle taxi driver	Toluene	6.17E+00	2.68E-04	1.38E-03	8.26E-04	SCI[a]>OS[a]>BBL[a]>KTB[a]>SCB[a]
	m,p-Xylene	5.57E-01	1.39E-03	6.62E-03	4.00E-03	SCI[a]>OS[a]>BBL[a]>KTB[a]>SCB[a]
	o-Xylene	1.35E+00	1.56E-04	1.96E-02	9.86E-03	SCI[a]>SCB[a]>OS[a]>KTB[a]>BBL[a]
	Propionaldehyde	2.07E-01	8.60E-04	3.72E-02	1.82E-02	OS[a]>BBL[a]>KTB[a]>SCB[a]>SCI[a]
	HI	8.28E+00	6.27E-03	5.95E-02	3.29E-02	OS[a]>SCI[a]>BBL[a]>SCB[a]>KTB[a]
Security guard	Toluene	2.91E+00	2.70E-04	8.95E-04	5.82E-04	ARC[a]>MBA[a]>ART[a]>GRA[a]>SCI[a]>POL[a]
	m,p-Xylene	5.93E-01	1.14E-03	1.07E-02	5.93E-03	SCI[a]>GRA[a]>ART[a]>POL[a]>MBA[a]>ARC[a]
	o-Xylene	2.32E+00	1.04E-03	4.53E-02	2.32E-02	ARC[a]>GRA[a]>ART[a]>SCI[a]>POL[a]>MBA[a]
	Propionaldehyde	9.74E-02	2.14E-03	2.22E-02	1.22E-02	ARC[a]>GRA[a]>MBA[a]>ART[a]>POL[a]>SCI[a]
	HI	5.92E+00	8.66E-03	7.50E-02	4.18E-02	ARC[a]>GRA[a]>SCI[a]>ART[a]>MBA[a]>POL[a]

*Sampling site codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, and c) having significant different ($p < .05$) mean levels.

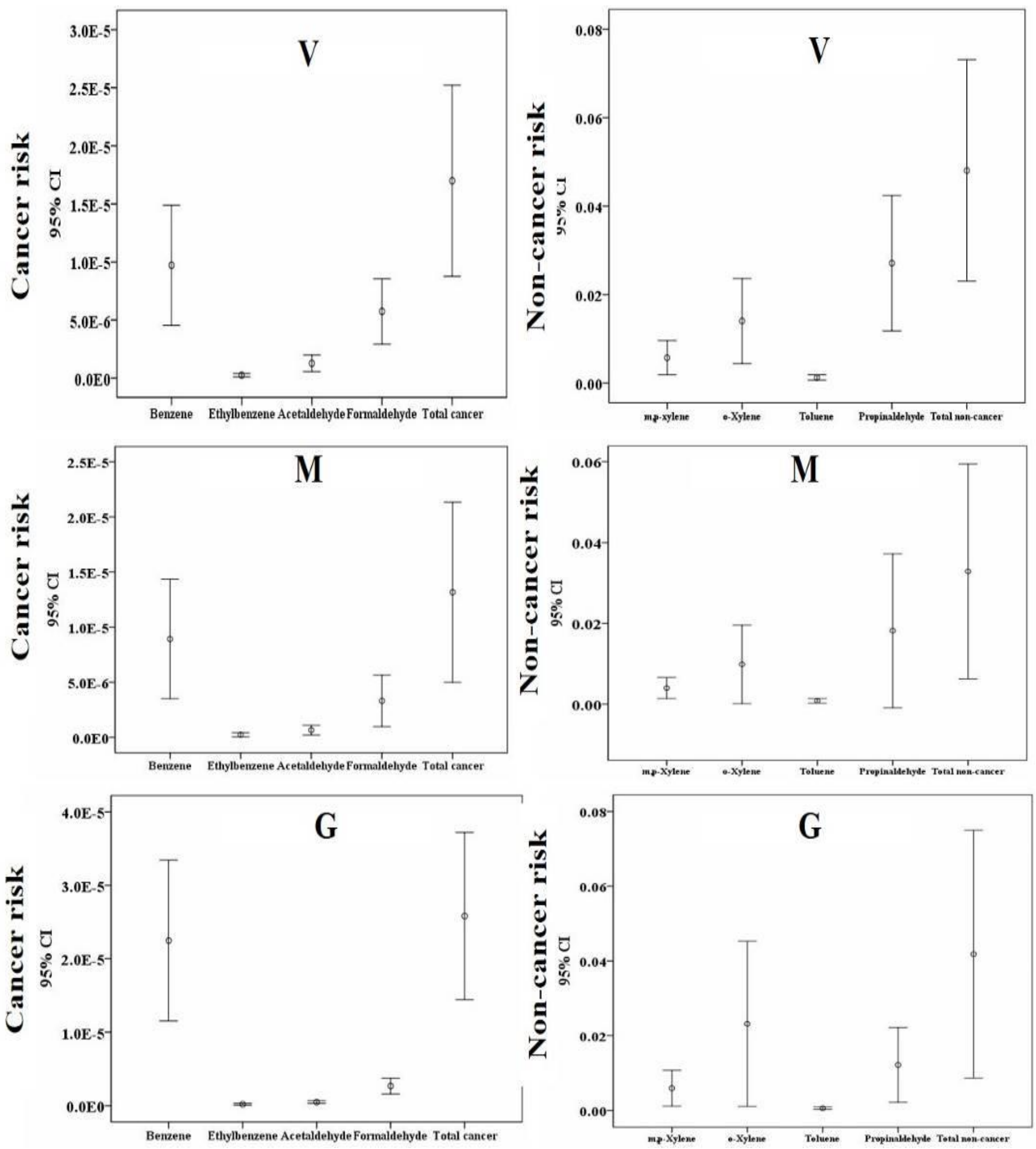


Figure 7.1 95%CI cancer and non-cancer risk of outdoor workers at roadside area

Comparing among the outdoor workers (Table 7.4), security guards had the highest cancer risk level exposed to benzene, followed by street vendors and motorcycle taxi drivers, respectively. For ethylbenzene, street vendors showed the greatest risk level, followed by motorcycle taxi drivers and security guards, respectively. For acetaldehyde, street vendors had the highest risk level, followed by motorcycle taxi drivers and security guards, correspondingly. For formaldehyde, street vendors also had the highest risk level, followed by motorcycle taxi drivers and security guards, respectively. Security guards had the highest total cancer risk value followed by street vendors and motorcycle taxi drivers, respectively. In view of non-cancer risk level, there was no significant difference of all substances in all workers. For total cancer-risk level, the highest risk level was found for street vendors followed by security guards and motorcycle taxi drivers, correspondingly. Motorcycle taxi drivers had the lowest both cancer and non-cancer risk values might be caused by this occupation was travelled all the time depending on customer request, while street vendors and security guards tended to stayed at the working area throughout their working time. Therefore, both street vendors and security guards who worked closed to the roadside, were exposed to the pollutants for 8 hours a day.

Table 7.4 Cancer and non-cancer risks of outdoor workers exposed to BTEX and CCs

Risk	Compound	Chemical-specific risk (95%CI)			Cancer risk level Ranking (High to Low)*
		Lower	Upper	Average	
Cancer	Benzene	9.51E-06	1.91E-05	1.43E-05	$G^a>V^b>M^b$
	Ethylbenzene	1.44E-07	3.00E-07	2.22E-07	$V^a>M^a>G^a$
	Formaldehyde	2.63E-06	4.98E-06	3.81E-06	$V^a>M^{ab}>G^b$
	Acetaldehyde	5.21E-07	1.05E-06	7.86E-07	$V^a>M^{ab}>G^b$
	HI	1.36E-05	2.46E-5	1.91E-05	$G^a>V^a>M^a$
Non-cancer	Toluene	5.08E-04	1.12E-03	8.52E-04	$V^a>M^a>G^a$
	m,p-Xylene	3.05E-03	7.56E-03	5.25E-03	$G^a>V^a>M^a$
	o-Xylene	7.10E-03	2.53E-02	1.62E-02	$G^a>V^a>M^a$
	Propionaldehyde	1.04E-02	2.67E-02	1.86E-02	$V^a>M^a>G^a$
	HI	2.47E-02	5.70E-02	4.09E-02	$V^a>G^a>M^a$

*Sampling site codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, and c) having significant different ($p < .05$) mean levels.

*V, M, G, P and I stand for street vendor, motorcycle taxi driver, security guard, traffic policemen and indoor worker, respectively.

7.1.3 Health risk assessment of traffic policemen at road intersection

Personal exposure samples of 48 traffic policemen were investigated and then the cancer and non-cancer risk levels were calculated. The sequence order of cancer risk level was benzene, ethylbenzene, formaldehyde and acetaldehyde, respectively. For non-cancer risk value, m,p-Xylene posed to highest risk level to traffic policemen, followed by o-Xylene, toluene and propionaldehyde, correspondingly.

For cancer risk (see Table 7.5), the highest average cancer risk for benzene was found at HD (Henry Dunant Intersection), followed by SY (Samyan Intersection), PT (Pathumwan Intersection) and CP (Chaloem Phao Intersection), respectively. Likewise, HD intersection had the greatest cancer risk value of benzene, followed by SY, PT and CP, correspondingly. Similarly, HD intersection had the highest risk value, followed by SY, PT and CP, respectively. However, the highest average cancer risk for acetaldehyde was found at SY followed by HD, CP and PT, respectively. HD expressed the greatest cancer risk value of all pollutants with the exception of acetaldehyde, however, it showed an insignificant difference of acetaldehyde among the sites. The concentrations of toxic air substances were extremely high at HD site, and the long exposure duration of traffic police that were caused HD showing the highest cancer risk level.

Table 7.5 Cancer risks of traffic policemen exposed to BTEX and CCs

Worker	Compound	Average CDI (mg kg^{-1} d^{-1})	Chemical-specific risk (95%CI)			Cancer risk level Ranking (High to Low)*
			Lower	Upper	Average	
Traffic policemen	Benzene	1.15E-02	2.40E-04	3.88E-04	3.14E-04	$HD^{a}>SY^{b}>PT^{b}>CP^{b}$
	Ethylbenzene	5.14E-03	1.49E-05	2.47E-05	1.98E-05	$HD^{a}>SY^{b}>PT^{b}>CP^{b}$
	Formaldehyde	2.52E-04	3.85E-06	6.74E-06	5.30E-06	$HD^{a}>SY^{a}>PT^{ab}>CP^{b}$
	Acetaldehyde	2.84E-04	1.89E-06	3.78E-06	2.84E-06	$SY^{a}>HD^{a}>CP^{a}>PT^{a}$
	Total cancer risk	1.69E-02	2.64E-04	4.21E-04	3.42E-04	$HD^{a}>SY^{b}>PT^{b}>CP^{b}$

*Sampling site codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, and c) having significant different ($p < .05$) mean levels.

For non-cancer risk value (see Table 7.6), HQ was calculated for toluene, m,p-Xylene, o-Xylene and propionaldehyde. In case of m,p-Xylene, HD also had the greatest HQ, followed by SY, PT and CP, respectively. In contrast to m,p-Xylene, SY showed the highest HQ of o-Xylene, followed by HD, PT and CP, correspondingly. The same as m,p-Xylene, HD had the greatest HQ of toluene, followed by SY, PT and CP, respectively. Similarly, the HQ of propionaldehyde was illustrated at HD followed by SY, PT and CP, correspondingly. HD still expressed the greatest non-cancer risk levels of all pollutants with the exception of o-Xylene, and reason of this fact was the same as cancer risk. The error bar of both cancer and non-cancer risk of traffic policemen were presented in Fig. 7.2.

Table 7.6 Non-cancer risks of traffic policemen exposed to BTEX and CCs

Worker	Compound	Average EC	Chemical-specific risk (95%CI)			Cancer risk level Ranking (High to Low)*
			Lower	Upper	Average	
Traffic policemen	Toluene	2.21E+02	3.86E-02	5.35E-02	4.61E-02	$HD^{a}>SY^{ab}>PT^{b}>CP^{b}$
	m,p-Xylene	4.56E+01	3.82E-01	5.68E-01	4.75E-01	$HD^{a}>SY^{b}>PT^{b}>CP^{b}$
	o-Xylene	3.78E+01	3.06E-01	4.81E-01	3.94E-01	$SY^{a}>HD^{a}>PT^{a}>CP^{b}$
	Propionaldehyde	6.66E-02	2.18E-02	4.83E-02	3.50E-02	$HD^{a}>SY^{ab}>PT^{ab}>CP^{b}$
	HI	3.04E+02	7.68E-01	1.13E+00	9.50E-01	$HD^{a}>SY^{a}>PT^{b}>CP^{b}$

*Sampling site codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, and c) having significant different ($p < .05$) mean levels.

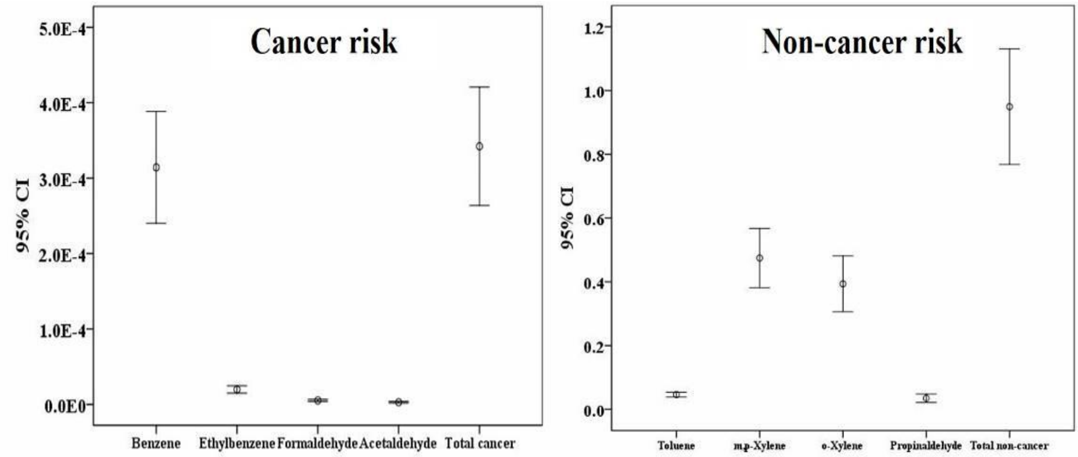


Figure 7.2 95%CI cancer and non-cancer risk of traffic police at road intersection

7.1.4 Health risk assessment of indoor workers

Forty-eight personal exposure samples of indoor workers were applied to analyze cancer and non-cancer risk values and the box plots were demonstrated in, Table 7.7, 7.8 and Fig.7.3. In view of carcinogenic chemicals, CC (Communication Center) had the greatest risk value than those in EG (Faculty of Engineering), ED (Faculty of Education), EC (Faculty of Economic), respectively. As well as benzene, SS had the greatest risk value of ethylbenzene than those in EG, ED, EC, respectively. For risk value of formaldehyde, EG had the highest value, followed by CC, ED and EC, correspondingly. However, the highest risk value of acetaldehyde was found at CC followed by EG, ED and EC, correspondingly.

Table 7.7 Cancer risks of indoor workers exposed to BTEX and CCs

Worker	Compound	Average CDI (mg kg^{-1} d^{-1})	Chemical-specific risk (95%CI)			Cancer risk level Ranking (High to Low)*
			Lower	Upper	Average	
Indoor worker	Benzene	1.50E-04	2.66E-06	5.53E-06	4.10E-06	$CC^{a}>EG^{b}>ED^{bc}>EC^{c}$
	Ethylbenzene	3.45E-04	7.96E-07	1.86E-06	1.33E-06	$CC^{a}>EG^{b}>ED^{c}>EC^{c}$
	Formaldehyde	2.78E-04	3.91E-06	7.76E-06	5.84E-06	$CC^{a}>EG^{b}>ED^{c}>EC^{c}$
	Acetaldehyde	9.05E-05	6.34E-07	1.17E-06	9.04E-07	$CC^{a}>EG^{b}>ED^{b}>EC^{c}$
	Total cancer risk	7.73E-04	8.49E-06	1.58E-05	1.22E-05	$CC^{a}>EG^{b}>ED^{c}>EC^{c}$

*Sampling site codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, and c) having significant different ($p < .05$) mean levels.

In view of non-carcinogenic substances, CC provided the highest HQ for toluene, followed by EG, ED and EC, respectively. For m,p-Xylene, the highest HQ value was found at CC followed by EG, ED and EC, correspondingly. SS showed the highest HQ for o-Xylene, followed by EG, ED and EC, correspondingly. For propionaldehyde, SS presented the highest HQ, followed by EG, ED and EC, respectively. Both cancer and non-cancer risk values of indoor workers were illustrated the same trend for all pollutants and CC revealed the greatest risk level followed by EG, ED and EC, respectively. Focusing on the BTEX concentrations, the highest pollutant levels were mostly found at CC site which contrast to the concentrations of CCs. Carbonyl levels were found to be varied in all sampling sites but the highest risk levels were showed at CC site. Of the results, the exposure duration and body weight of the worker who worked at CC site were greater comparing to those from other sites. Consequently, the risk levels of most toxic substances were supposed to be highest at this site.

Table 7.8 Non-cancer risks of indoor workers exposed to BTEX and CCs

Worker	Compound	Average EC	Chemical-specific risk (95%CI)			Cancer risk level Ranking (High to Low)*
			Lower	Upper	Average	
Indoor worker	Toluene	2.93E+01	2.33E-02	6.05E-02	4.19E-02	CC[a]>EG[b]>ED[b]>EC[b]
	m,p-Xylene	3.93E+00	2.58E-02	5.61E-02	4.10E-02	CC[a]>EG[b]>ED[b]>EC[b]
	o-Xylene	4.02E+00	3.53E-03	8.68E-03	6.10E-03	CC[a]>EG[b]>ED[b]>EC[b]
	Propionaldehyde	2.69E-01	8.58E-03	2.43E-02	1.65E-02	CC[a]>EG[b]>ED[b]>EC[b]
	HI	3.75E+01	6.46E-02	1.46E-01	1.05E-01	CC[a]>EG[b]>ED[b]>EC[b]

*Sampling site codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, and c) having significant different ($p < .05$) mean levels.

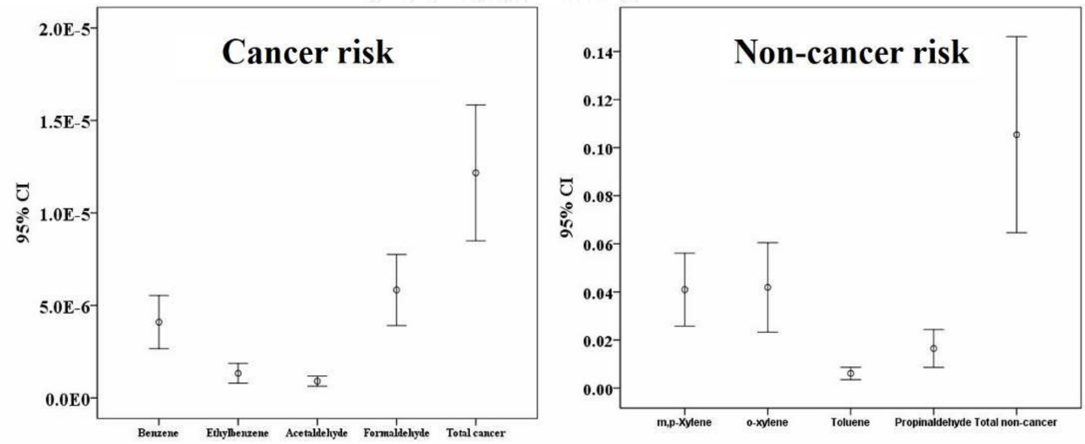


Figure 7.3 95%CI cancer and non-cancer risk of indoor workers

7.1.5 Comparison on health risk assessment among workers

Total samples of street vendors, motorcycle drivers, security guards, traffic policemen and indoor workers were 19, 20, 24, 48 and 48, respectively. Total cancer risk and total non-cancer risk of all worker groups were considered and compared using one-way ANOVA and the results were shown in Table 7.9. Considering on benzene risk level, the traffic policemen had the highest value, followed by security guards, motorcycle taxi driver, street vendors and indoor workers, correspondingly. For ethylbenzene, traffic policemen had the highest risk value followed by officer, motorcycle taxi drivers, street vendors and security guards, respectively. In contrast to benzene and ethylbenzene, the officer had the greatest risk level of formaldehyde, followed by traffic police, street vendors, security guards and motorcycle taxi drivers, respectively. There was a significant difference between indoor workers and security guards. Traffic policemen exposed to the highest risk level of acetaldehyde followed by street vendors, indoor workers, security guards and motorcycle taxi drivers, correspondingly. Thus, the workers who had the greatest total cancer risk value was traffic policemen followed by security guards, street vendors, motorcycle taxi drivers and indoor workers, respectively. Risk values of benzene, ethylbenzene, acetaldehyde and total cancer showed the significant difference between traffic policemen and the other worker groups.

Considering of non-cancer risk, the sequence order of toluene were policemen, officer, street vendors, motorcycle taxi drivers and security guards, respectively. The same as toluene, policemen had the greatest risk level followed by officer, security guards, motorcycle taxi drivers and street vendors, respectively. For risk value of o-Xylene, traffic officer still exposed to the highest risk followed by indoor workers, security guards, street vendors and motorcycle taxi drivers, correspondingly. Propionaldehyde was posed the highest risk level for traffic policemen followed by street vendors, indoor workers, security guards and motorcycle taxi drivers, respectively. Comparing the mean difference of non-cancer risk, there were significance difference between traffic policemen and others for toluene, m,p-Xylene and o-Xylene, while propionaldehyde showed significance differences between policemen and security guards; policemen and indoor workers. The sequence order of total non-cancer risk were policemen, officers, street vendors, security guards and motorcycle taxi drivers, respectively. Total non-cancer risk showed the significance difference between traffic policemen and the other worker groups.

Not surprisingly, traffic policemen had the greatest risk values of all substances with the exception of formaldehyde because this worker worked at the office (police's booth) which located at the major intersection in Pathumwan district. Furthermore, traffic police performed their jobs at the road in order to control the traffic; hence, this occupation was absolutely exposed to the traffic air pollutants at the highest levels. For formaldehyde, the major sources of this substance was from the household product and furniture materials and thus the indoor worker were exposed to formaldehyde comparing to the others.

Table 7.9 Cancer and non-cancer risks of all workers exposed to BTEX and CCs

Risk	Compound	Chemical-specific risk (95%CI)			Cancer risk level Ranking (High to Low)*
		Lower	Upper	Average	
Cancer	Benzene	7.08E-05	1.33E-04	1.02E-04	$P^a>G^b>V^b>M^b>I^b$
	Ethylbenzene	4.46E-06	8.46E-06	6.46E-06	$P^a>I^b>V^b>M^b>G^b$
	Formaldehyde	4.01E-06	5.72E-06	4.87E-06	$I^a>V^{ab}>P^{ab}>M^{ab}>G^b$
	Acetaldehyde	1.10E-06	1.78E-06	2.17E-06	$P^a>V^b>I^b>M^b>G^b$
	Total cancer risk	8.15E-05	1.48E-04	1.15E-04	$P^a>G^b>V^b>M^b>I^b$
Non-cancer	Toluene	1.22E-02	2.00E-02	1.61E-02	$P^a>I^b>V^b>M^b>G^b$
	m,p-Xylene	1.15E-01	2.01E-01	1.58E-01	$P^a>I^b>G^b>V^b>M^b$
	o-Xylene	1.00E-01	1.75E-01	1.38E-01	$P^a>I^b>G^b>V^b>M^b$
	Propionaldehyde	1.72E-02	2.86E-02	2.29E-02	$P^a>V^{ab}>M^{ab}>I^b>G^b$
	HI	2.50E-01	4.19E-01	3.35E-01	$P^a>I^b>V^b>G^b>M^b$

*Sampling site codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, and c) having significant different ($p < .05$) mean levels.

*V, M, G, P and I stand for street vendor, motorcycle taxi driver, security guard, traffic policemen and indoor worker, respectively.

Comparing the personal exposure levels of workers with other studies were shown in Table 7.10 (8, 104-108). The results showed that traffic police workers (in this study) had the highest cancer risk value and this might be caused by this worker group directly exposed to the exhaust gas and the evaporation of gasoline. Furthermore, policemen contained a high cancer risk level due to their performance at the roadside during their working time. Not only the concentrations of these VOCs were impacted the health risk level, but the exposure duration, exposure time of their work were also taken in to account. From overall data, it can be concluded that the workers who worked most of their working time closed to the roadside area or at the intensive traffic area, were exposed to BTEX and CCs at high levels comparing to the others. These personal exposure concentrations were affected to the health risk value in order to increase risk level of the air pollutants.

Table 7.10 Comparison on cancer and non-cancer risk of all workers with another studies

Subject	Location	Pollutant	Cancer risk x 10E-6	Non-cancer risk x 10E-3	Reference
Street vendor*	Bangkok, Thailand	Benzene Ethylbenzene Formaldehyde Acetaldehyde Toluene m,p-Xylene o-Xylene Propionaldehyde	9.71 0.26 5.74 1.28	 1.22 5.73 14.0 27.1	This study
Motorcycle taxi driver*		Benzene Ethylbenzene Formaldehyde Acetaldehyde Toluene m,p-Xylene o-Xylene Propionaldehyde	8.94 0.24 3.32 6.69	 0.83 4.00 9.86 18.2	This study
Security guard*		Benzene Ethylbenzene Formaldehyde Acetaldehyde Toluene	22.50 0.18 2.68 0.49	 0.58	This study

		m,p-Xylene		5.93	
		o-Xylene		23.20	
		Propionaldehyde		12.20	
Traffic policemen*		Benzene	314		
		Ethylbenzene	19.8		
		Formaldehyde	5.30		
		Acetaldehyde	2.84		
		Toluene		46.10	
		m,p-Xylene		475.00	
		o-Xylene		394.00	
		Propionaldehyde		35.00	
Indoor worker*		Benzene			
		Ethylbenzene	1.33		
		Formaldehyde	5.84		
		Acetaldehyde	0.90		
		Toluene		41.90	
		m,p-Xylene		41.00	
		o-Xylene		6.10	
		Propionaldehyde		16.50	
Policemen	Ioannina, Greece	Benzene	62.6		Pilidis et al., 2009
		Formaldehyde	201		
Laboratory technicians		Benzene	50.1		
		Formaldehyde	267		
Petrol pump workers	Kolkata, India	Benzene	96.6		Majumdar et al., 2008
		Formaldehyde	35.2		
		Acetaldehyde	4.03		
		Toluene		21.7	
Gas service station workers	Chonburi, Thailand	Benzene	200		Yimrungruang et al., 2008
		Toluene		34.0	
	Bangkok, Thailand	Benzene	175		Tunsaringkarn et al., 2012
		Ethylbenzene	0.955		
		Toluene		8.00	
		Xylene		2.00	

	Bangkok, Thailand	Benzene	182–250		Kitwattanavong et al., 2011
		Ethylbenzene	4.11–5.52		
		Formaldehyde	7.81–10.4		
		Acetaldehyde	1.39–2.45		
		Toluene		12.0–15.0	
		m,p-Xylene		157–215	
		o-Xylene		56.0–73.0	
		Propionaldehyde		26.0–47.0	
Worship place workers	Bangkok, Thailand 1.Kanlayanamit Temple	Benzene	21.8–43.2		Maspat and Prueksasit, 2013
		Ethylbenzene	0.574–1.12		
		Toluene		3.10–4.90	
		m,p-Xylene		21.0–35.0	
		o-Xylene		11.0–21.0	
	2. Tao Maha Brama Temple	Benzene	51–106		
		Ethylbenzene	2.24–7.43		
		Toluene		7.10–11.0	
		m,p-Xylene		80.0–130.0	
		o-Xylene		31.0–54.0	

*The data were obtained from this study
Source:(Kanjanasiranont et al., 2016)(93)

7.2 Scenario of cancer risk reduction for all workers

The strategies for cancer risk reduction were investigated because all worker groups had risk levels which greater than an acceptable value (1 x 10^{-6}) and the percentage of unacceptable risk of each worker were demonstrated in Table 7.11. Focused on the percentage of cancer risk level, if the value was greater than 30%, it should be concerned and find the way to reduce risk. Cancer risk values, which lower than 30% were marked as "not considerate" or NC as expressed in the Table 7.11 below. From the data, cancer risk values of traffic police exposure to benzene, ethylbenzene, formaldehyde and acetaldehyde, were showed the highest comparing to other workers. For street vendors, the scenarios of risk reduction were studied for cancer risk values of benzene, formaldehyde and acetaldehyde, while benzene, ethylbenzene, formaldehyde risk levels were found for motorcycle taxi drivers. For security guards, cancer risk levels of benzene, formaldehyde and acetaldehyde were focused. As well as traffic police, all risk levels exposure to cancer substances were studied too.

Table 7.11 The percentage of unacceptable risk

Worker	% Unacceptable risk*			
	Benzene	Ethylbenzene	Formaldehyde	Acetaldehyde
Street vendor	79.0	5.0	75.0	45.0
Motorcycle taxi driver	80.0	25.0	45.0	25.0
Security guard	79.2	0.0	79.2	12.5
Traffic policemen	100.0	100.0	95.8	83.4
Indoor worker	68.8	39.6	56.3	35.4

*Data were obtained from 19, 20, 24, 48 and 48 of street vendor, motorcycle taxi driver, guard, traffic police and indoor worker, respectively.

Concerning on the risk equation, the ways to decrease risk were consisted of the exposure and the hazard of substances, however, the applicable factor of risk reduction was only the exposure route. Consequently, the factors of risk equation due to the exposure factor, were involved chemical concentration (CA), exposure time (ET) and exposure duration (ED). In this study, the inhalation route was the major exposure route, hence, the CA value could be declined by using the standard mask with VOCs filter that can be blocked VOCs for 95%. For ET and ED factors, the exposure time (working time) was changed from 8 to 4 hours and the exposure duration was set at 5 years for all workers. These two factors were applied in order to reduce the time which the workers were received these toxic air pollutants. Four scenarios of risk reduction and risk levels were illustrated in Table 7.12 and 7.13. These scenarios were the optional ways for all workers in order to showed and compare the values of cancer risk between the real risk levels and the reducing risk value that obtained from these strategies. In contrast to cancer risk levels, the reduction of non-cancer risk levels did not focus for this study because the risk values of all workers were in an acceptable level.

From overall results, the best way to reduce cancer risk values of all worker groups was the reduction of CA by using the specific mask to protect them from BTEX and CCs during their working time. Notwithstanding, the concentration of benzene of the high exposure group (traffic police) was still greater than an acceptable level but these value much lower than the original ones.

Table 7.12 The reduction of contact rate

Factor	Input value	Workers	Chemical-specific risk (Mean (95%CI))			
			Benzene	Ethylbenzene	Formaldehyde	Acetaldehyde
CA_R	0.05 x CA	Street vendor	(4.85E-07) 2.27E-07-7.44E-07	NC	(2.76E-07) 1.41E-07-4.11E-07	(6.28E-08) 2.85E-08-9.71E-08
		Motorcycle taxi driver	(4.47E-07) 1.76E-07-7.18E-07	NC	(1.66E-08) 4.87E-08-2.83E-07	(3.35E-08) 1.14E-08-5.55E-08
		Security guard	(1.12E-06) 5.76E-07-1.67E-06	NC	(1.34E-07) 8.06E-08-1.87E-07	(2.44E-08) 1.46E-08-3.42E-08
		Traffic policemen	(1.57E-05) 1.20E-05-1.94E-05	(9.89E-07) 7.44E-07-1.23E-06	(2.65E-07) 1.92E-07-3.37E-07	(1.42E-07) 9.46E-8-1.89E-07
		Indoor worker	(2.05E-07) 1.33E-07-2.77E-06	(6.64E-08) 3.98E-09.30E-08	(2.92E-07) 1.96E-07-3.88E-07	(4.52E-08) 3.17E-08-5.87E-08

*NC = Not considerate

*Data were obtained from 19, 20, 24, 48 and 48 of street vendor, motorcycle taxi driver, guard, traffic police and indoor worker, respectively.

Table 7.13 The reduction of exposure time and exposure duration

Factor	Input value	Worker	Chemical-specific risk (Mean (95%CI))			
			Benzene	Ethylbenzene	Formaldehyde	Acetaldehyde
ET[1]	4 hr	Street vendor	(4.86E-06) 2.27E-06-7.44E-06	NC	(2.76E-06) 1.41E-06-4.11E-06	(6.82E-07) 2.85E-07-9.71E-07
		Motorcycle taxi driver	(4.47E-06) 1.76E-06-7.18E-06	NC	(1.66E-06) 4.87E-07-2.83E-06	(3.35E-07) 1.14E-07-5.55E-07
		Security guard	(1.12E-05) 5.76E-06-1.67E-05	NC	(1.34E-06) 8.06E-07-1.87E-06	(2.44E-07) 1.46E-07-3.42E-07
		Traffic policemen	(1.57E-04) 1.20E-04-1.94E-04	(9.895E-06) 7.44E-06-1.23E-05	(2.65E-06) 1.92E-06-3.37E-06	(1.42E-06) 9.46E-07-1.89E-06
		Indoor worker	(3.60E-06) 2.47E-06-4.73E-06	(1.23E-06) 7.92E-07-1.66E-05	(5.12E-06) 3.67E-06-6.56E-06	(6.77E-07) 4.99E-07-8.56E-07
ED[2]	5 y	Street vendor	(5.00E-06) 3.10E-06-6.89E-06	NC	(2.64E-06) 1.94E-06-3.33E-06	(6.57E-07) 4.30E-07-8.83E-07
		Motorcycle taxi driver	(5.76E-06) 4.22E-06-7.30E-06	NC	(2.26E-06) 9.77E-07-3.55E-06	NC
		Security guard	(7.57E-06) 5.78E-06-9.36E-06	NC	(1.43E-06) 1.07E-06-1.78E-06	NC
		Traffic policemen	(6.95E-05) 5.86E-05-8.05E-05	(4.43E-06) 3.69E-06-5.18E-06	(1.24E-06) 1.02E-06-1.46E-06	(6.78E-07) 3.63E-07-9.94E-07
		Indoor worker	(1.62E-06) 1.24E-06-1.99E-06	(3.17E-07) 2.55E-07-3.79E-07	(1.29E-06) 8.96E-07-1.68E-06	(3.81E-07) 2.62E-07-5.00E-07
ET & ED[2]	4 hr & 5 y	Street vendor	(3.51E-06) 2.33E-06-4.70E-06	NC	(1.32E-06) 9.70E-07-1.67E-06	(3.29E-07) 2.15E-07-4.42E-07
		Motorcycle taxi driver	(4.86E-06) 2.56E-06-7.17E-06	NC	(1.13E-06) 4.88E-07-1.77E-06	NC
		Security guard	(6.46E-06) 4.26E-06-8.66E-06	NC	(7.14E-07) 5.35E-07-8.92E-07	NC
		Traffic policemen	(3.48E-05) 2.93E-05-4.02E-05	(2.22E-06) 1.85E-06-2.59E-06	(6.20E-07) 5.10E-07-7.30E-07	(3.39E-07) 1.82E-07-4.97E-07
		Indoor worker	(8.08E-07) 6.22E-07-9.95E-07	(2.56E-07) 1.87E-07-3.25E-07	(1.29E-06) 8.96E-07-1.68E-06	(1.91E-07) 1.31E-07-2.50E-07

[*]NC = Not considerate

[1]Data were obtained from 19, 20, 24, 48 and 48 of street vendor, motorcycle taxi driver, guard, traffic police and indoor worker, respectively.

[2]Data were obtained from 14, 6, 16, 24 and 24 of street vendor, motorcycle taxi driver, guard, traffic police and indoor worker, respectively.

7.3 Risk perception and risk communication of all workers

As discussed in previous topic, BTEX and CCs generating from the vehicles were affected to the workers who spend their time working at Pathumwan district. There is no doubt that these workers (street vendors, motorcycle taxi drivers, security guards, traffic police and indoor workers) were exposed to BTEX and CCs at high level and causing in their health effects. The several ways to reduce risk were described in the topic of 7.2, even though this study was concerned the real situation of these workers by conducting the questionnaire to understand their knowledge and attitude to these toxic compound.

KA questionnaire was taken for pre-test and post-test to evaluate the changing of knowledge and attitude. After conducting the pre-test questionnaire, the knowledge of CCs and BTEX, risk assessment and practice were given to the workers. Moreover, the CCs and BTEX concentrations and risk values were shown to them in order to make them aware and realize about the situation that they faced every day. The post-test questionnaire was taken after giving the overall information by using the same questions as the pre-test questionnaire. The study subjects of each worker were 30. The decode of KA questionnaire, the statistical analysis of KA questionnaire and media of risk communication was expressed in Appendix F. The statistical data using SPSS were provided in Appendix G.

7.3.1 Characteristic of all workers

The samples of street vendors, motorcycle taxi drivers, security guards, traffic police and indoor workers were 30, 30, 30, 30 and 30, respectively. The general data of workers were showed in Table 7.14, Fig. 7.4 and 7.5.

Table 7.14 The average age of all workers

Worker	Average of age (yrs)	Min.	Max.
Street vendor	40 ± 11	21	65
Motorcycle taxi driver	39 ± 9	26	60
Security guard	39 ± 8	20	53
Traffic policemen	47 ± 8	28	58
Indoor worker	41 ±11	24	65

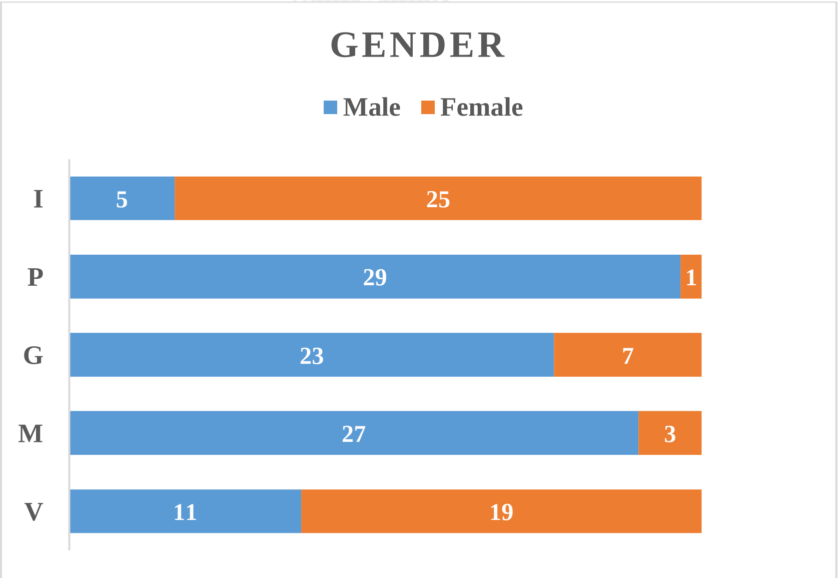


Figure 7.4 Gender of all workers

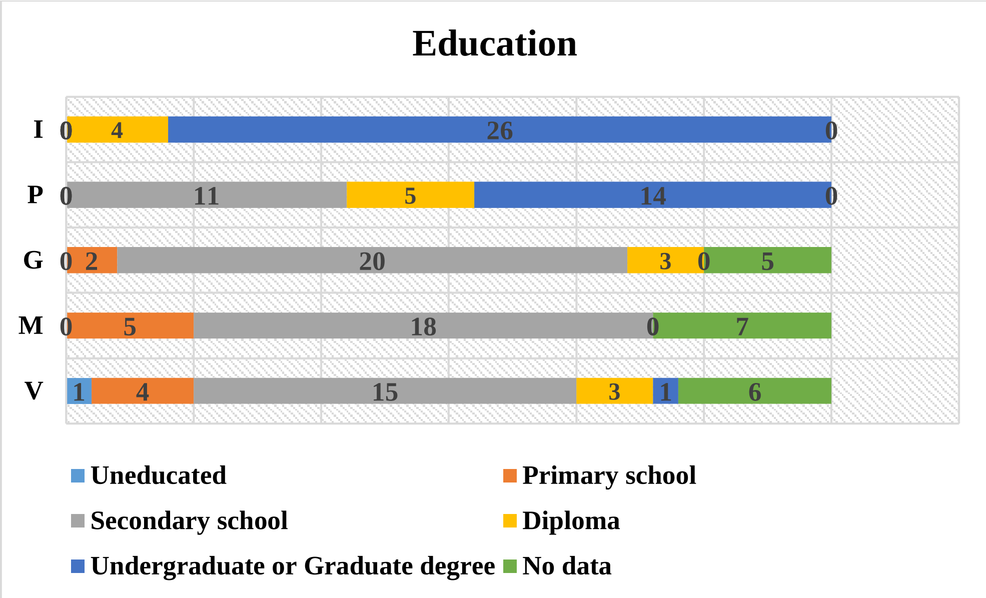


Figure 7.5 The educational status of all workers

7.3.2 The comparison of pre-test and post-test questionnaire of all workers

T-Test was applied to compare the mean difference between pre and post-testing. Knowledge was separated into three parts which included the knowledge of air pollution (K_A), knowledge of health risk assessment (K_H) and knowledge of practice (K_P). Likewise, the attitude was separated into three parts which consisted of the attitude of air pollution (A_A), attitude of health risk assessment (A_H) and attitude of practice (A_P). For results of post-test, the correlation between knowledge and attitude was observed by using Pearson's correlation which included K_A&A_A, K_H&A_H and K_{All}&A_P. For the correlation between knowledge and attitude of the practice part, the knowledge of all parts (K_{All}) which consisted of K_A, K_H and K_P were selected to investigate due to the limitation of the question in this part. However, the part of practice was not observed in this study because it takes time to approve their practices.

For pre-test and post-test of knowledge and attitude of all worker groups were presented in Table 7.15, Fig. 7.6 and 7.7, correspondingly. The results of the association between knowledge and attitude were shown in Table 7.16, Fig. 7.8. In view of street vendors, there were significant differences between pre and post-testing for K_A, K_H and K_P. The same way as the knowledge, A_A, A_H, and A_P were also showed significantly different between pre-test and post-test. From the statistical analysis, it was found that risk communication was successfully elevated their knowledge and attitude of air pollution, health risk assessment and practice. The relationship between K_A&A_A was revealed a direct relationship, while K_H&A_H, and K_{All}&A_P were no correlations. Thus, increasing of the knowledge of air pollution can change their attitude on air pollution. These results can be explained by the income of these occupation was more important than their health risk and thus they did not concern on the attitude of prevention practice. Even though, they knew the health risk problems, they still decided to work in this area.

For motorcycle taxi drivers, K_A and K_P of pre and post-test were significantly different whereas K_H was not. In view of attitude, there were significant differences of A_H and A_P between pre and post-test while A_A was not. T-test analysis was showed that risk communication had the potential to increase their knowledge of air pollution and practice, and attitude on health risk assessment and practice. For the knowledge of health risk, most motorcycle drivers already known because they often feel sick during the rush hour traffic time. Moreover, they knew that their working area had the intensive traffic, hence the statistical analysis of A_A was insignificant difference. The correlation between knowledge and attitude were found for both K_H&A_H, and K_{All}&A_P. It meant that the knowledge of health risk made them realized their attitude on health risk, and the knowledge of all parts was shown the changing in their attitude on their practice.

For security guards, the overall K_A, K_H, K_P, A_A, A_H and A_P were found significant differences between pre and post-test questions. Giving the knowledge to security guards can elevate their knowledge and attitude of air pollution, health risk assessment and practice. The association between knowledge and attitude were found that only K_{All}&A_P was correlated while K_A&A_A, and K_H&A_H were found insignificant differences. It showed that the knowledge that they gained from the risk communication can attribute to their practice.

For traffic policemen, K_A, K_H of pre and post-test were observed the significant differences with the exception of K_P. In view of attitude, there were the significant differences of A_A, A_H and A_P between pre and post-test. Increasing in knowledge can made the traffic policemen more understand on air pollution and health risk assessment. However, the traffic police have already known the way to protect themselves from BTEX and CCs so the statistical analysis was showed an insignificant difference between pre and post-test. Due to the relationship between knowledge and attitude, the results showed that there were the correlations for K_H&A_H, and K_{All}&A_P. The knowledge of health risk assessment can change their attitude on their health risk and the received knowledge of all parts was made them more concerned on their prevention practice.

For indoor workers, the comparison of pre and post-test were showed significant differences for K_A, K_H, K_P, A_A, A_H and A_P. The risk communication was successfully elevated their knowledge and attitude of air pollution, health risk assessment and practice. The association using Pearson's correlation between knowledge and attitude revealed that the knowledge was not related to the attitude for K_A&A_A, K_H&A_H, and K_{All}&A_P. Even through, their knowledge has increased, however, it cannot change their attitude on all parts. These results can be explained by the indoor workers thought that working in the office can expose to theses pollutants at a very low level, thus their attitude in all parts were still the same. In addition, the level of education of this worker group was higher than another so it was hard to change their attitude comparing to other workers.

From overall results, risk communication in this study was effectiveness in order to increase their knowledge and attitude on the toxic air pollutants with the exception of some workers who have already known about this information and thus the changing in knowledge or attitude of these workers still the same. The association between knowledge and attitude was more complicated because of several impacted factors such as benefit, education, experience and income. Even though, they realized that the effect of their health risk, they did not change their practice because they thought that their benefit (income) was more important than their health. However, the risk communication of this study was successful in order to make them realized on their health risk for the workers who always exposed to these pollutants (motorcycle taxi drivers and traffic police).

Table 7.15 Comparison of knowledge and attitude between pre-test and post-test of all workers

Worker	*p*-value of T-test					
	Knowledge			Attitude		
	K_A	K_H	K_P	A_A	A_H	A_P
Street vendor	0.000**	0.000**	0.043*	0.014*	0.000**	0.017*
Motorcycle taxi driver	0.003**	0.083	0.000**	0.118	0.000**	0.000**
Security guard	0.000**	0.000**	0.006**	0.012*	0.001**	0.010**
Traffic policemen	0.000**	0.000**	0.161	0.001**	0.000**	0.018*
Indoor worker	0.000**	0.000**	0.001**	0.000**	0.000**	0.000**

* mean significantly different ($p < .05$) mean levels

** mean significantly different ($p < .01$) mean levels

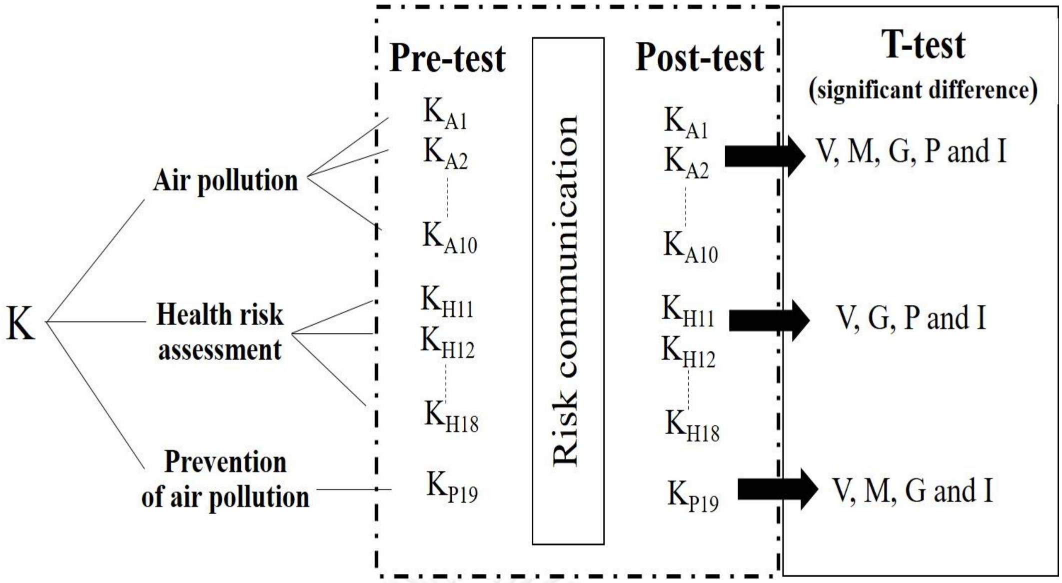


Figure 7.6 Comparison of knowledge between pre and post-test of all workers

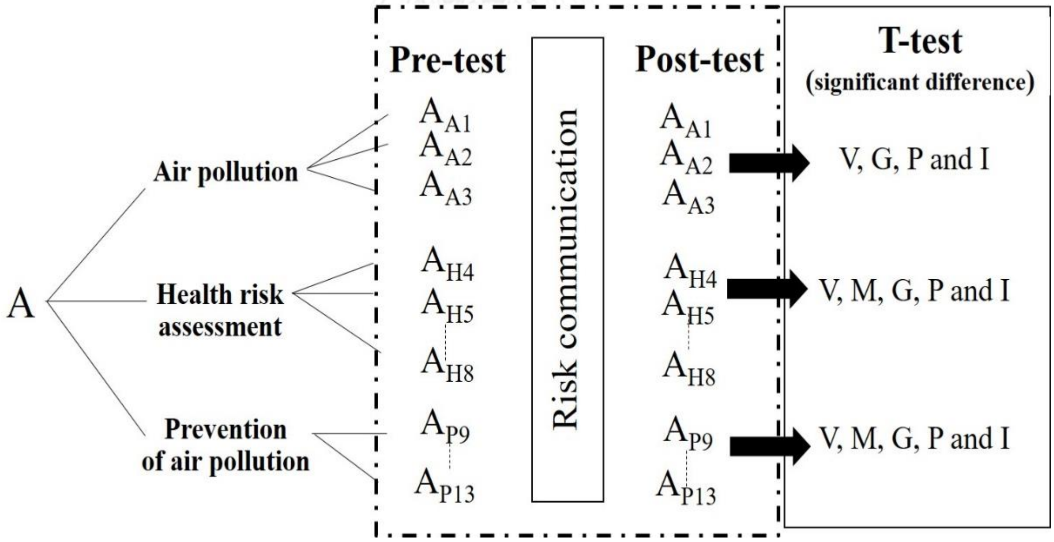


Figure 7.7 Comparison of attitude between pre and post-test of all workers

Table 7.16 Correlation of knowledge and attitude of all workers

Variable	Pearson's correlation (*r*)				
	Street vendor	Motorcycle taxi driver	Security guard	Traffic policemen	Indoor worker
K_A&A_A	0.402*	0.076	0.151	0.247	-0.296
K_H&A_H	0.149	0.357*	0.111	0.358*	0.113
K_{All}&A_P	0.175	0.357*	0.334*	0.368*	-0.161

* mean significantly different ($p < .05$) mean levels

** mean significantly different ($p < .01$) mean levels

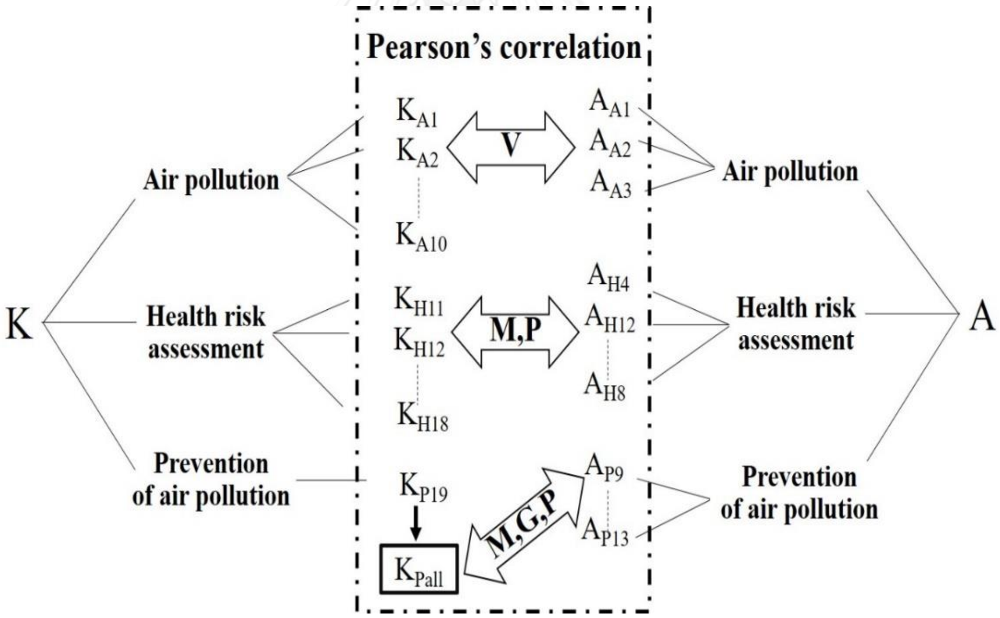


Figure 7.8 Correlation between knowledge and attitude of all workers

From overall results, Traffic policemen had the greatest value of total cancer risk because this worker group worked at intersection and they performed their jobs 7 days a week. For total non-cancer risk, the values of all workers were found in an acceptable level. The best way to reduce cancer risk of all workers was wearing the standard mask that can redudce the levels of BTEX and carbonyls for 95%. However, total cancer risk levels of traffic policemen and security guards still greater than an acceptable value. For risk perception and communication, the residual scores of post-test questionnaires were significantly higher than those of pre-test and it meant that risk communication in this study was very effective in order to increase their knowledge and attitude on air pollution, helath risk assessment and prevention practice. The correlation between knowledge and attitude on air pollution was found for street vendors, whereas the knowledge and attitude on health risk assessment was found for motorcycle taxi drivers and traffic policemen. For the knowledge of all parts, this was affected to attitude on prevention practice for motorcycle taxi drivers, security guards and traffic policemen. These correlations were depended on the educational statuse of each worker group.

CHAPTER VIII
CONCLUSION AND RECOMMENDATIONS

8.1 Conclusions

The ambient air and personal exposure air samples of three worker groups who worked in Pathumwan district were collected along their working time (8hr). First, the outdoor workers at roadside area consisted of street vendor, motorcycle taxi driver and security guard. Second, traffic policemen were assigned to represent the outdoor workers at road intersection. The third group was the indoor workers. These workers were spent their working time at their workplace that located closed to the roadside area. The overall results were concluded as

1) Comparing among the outdoor workers at roadside area, street vendors (117.87±43.45 µg/m^3) had the greatest BTEX concentration followed by motorcycle taxi drivers (114.87±65.60 µg/m^3) and security guards (99.41±47.81 µg/m^3), respectively. On the contrary, BTEX ambient air concentrations of the street vendors (213.95±200.17 µg/m^3) were showed the highest BTEX concentration followed by motorcycle taxi drivers (172.42±188.26 µg/m^3) and security guards (118.34±92.23 µg/m^3), respectively.

2) Comparison of all worker groups, traffic police had the greatest BTEX value of ambient air and personal exposure samples followed by officers, motorcycle drivers, vendors and guards, correspondingly.

3) For personal exposure of formaldehyde, indoor workers received the highest concentration followed by street vendors, motorcycle taxi drivers, security guards and traffic policemen. However, the workplace of indoor workers still contained the highest value followed by traffic policemen, motorcycle taxi drivers, street vendors and security guards. For acetaldehyde, the greatest levels of personal and ambient samples were

found for traffic policemen, office workers, street vendors, motorcycle taxi drivers and security guards.

4) The association between ambient air and personal exposure samples of BTEX were obtained for street vendors, traffic policemen and office workers. Motorcycle taxi drivers, security guards and indoor workers, showed the relationship between two types of samples of formaldehyde, whereas, acetaldehyde level was detected only in the indoor workers. Three occupations of moderate-exposure group found the correlation between the samples of propionaldehyde.

5) The statistical analysis showed there was no significant difference of the ambient air of BTEX between summer and rainy seasons for outdoor workers at roadside area, while there were significant differences between two seasons for traffic police and indoor workers.

6) The same as BTEX, the CCs in ambient air of outdoor workers at roadside area, traffic police and office workers were found insignificant differences with the exception of acetaldehyde of security guards.

7) Traffic policemen had the greatest total cancer risk value (2.64E-06 to 4.21E-04) followed by security guards (1.44E-05 to 3.72E-05), street vendors (8.77 E-06 to 2.52E-05), motorcycle taxi drivers (5.00E-06 to 2.13E-05) and indoor workers (8.49E-06 to 1.58E-05), respectively. For total non-cancer risk, there was no non-cancer risk of concern.

8) For scenario of cancer risk reduction, the best way to decrease the concentrations of BTEX and CCs was wearing the mask during their working time, followed by the reduction of exposure time&exposure duration, exposure time and exposure duration, correspondingly.

9) Both risk perception and communication in this study were found the effectiveness of all workers according to the difference between pre- and post-test of KA questionnaire, while the association between knowledge and attitude of air pollution was shown in street vendors. For the relationship between knowledge and

attitude of health risk assessment was shown in motorcycle taxi drivers and traffic policemen, while all part of knowledge (air pollution, health risk assessment and practice) and attitude of practice was found for motorcycle taxi drivers, security guards and traffic policemen.

8.2 Recommendation and suggestions

1) According to the uncertainty factors of risk estimation, the inhalation rate (IR) may result in the over- or under-estimate for calculation of risk assessment, therefore, the inhalation rate of male and female should be applied in this study for more accuracy estimation of risk calculation.

2) In order to get more explicit discussion on ambient air concentration of the pollutants, the number of vehicles should be observed during the sampling. In view of indoor workers, the ventilation system should be investigated in order to support the results of indoor air for each sampling site.

3) For the health risk assessment, traffic policemen had the highest cancer risk levels which extremely greater than an acceptable value, hence, the information of risk values of traffic policemen should be given to The Royal Thai Police in order to apply this data for further study on prevention practice of traffic policemen.

4) For the appropriate prevention practices of all worker groups, the practices part of KA questionnaire should be further investigated for the effectiveness of risk management and risk reduction for all workers in this study.

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APPENDIX

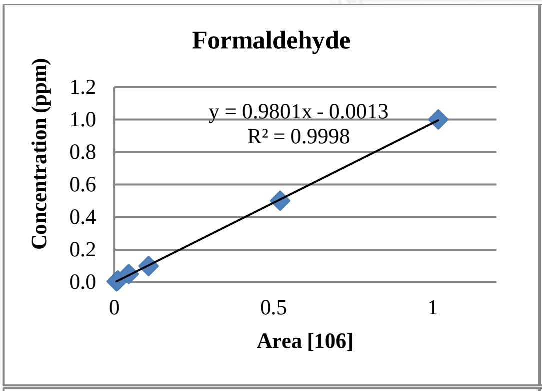
APPENDIX A: Quality control techniques of carbonyl compounds and BTEX

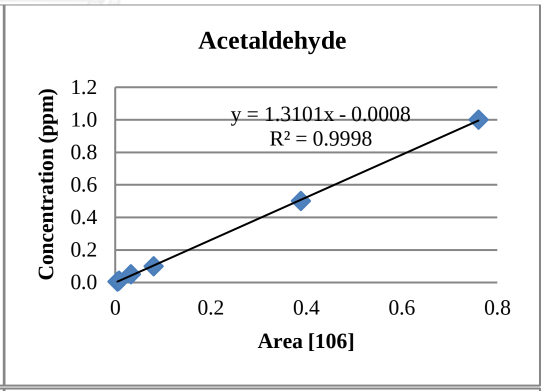
A.1 Quality control techniques of carbonyl compounds

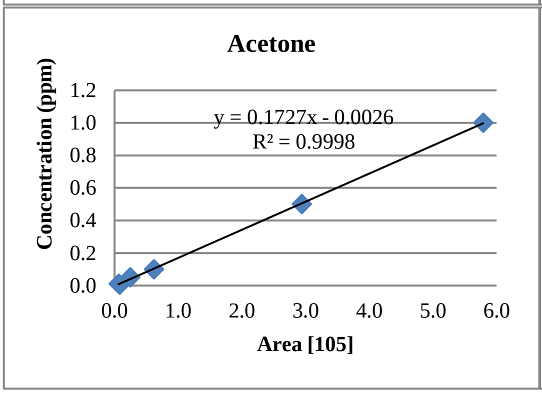
A.1.1 Standard curves of carbonyl compounds

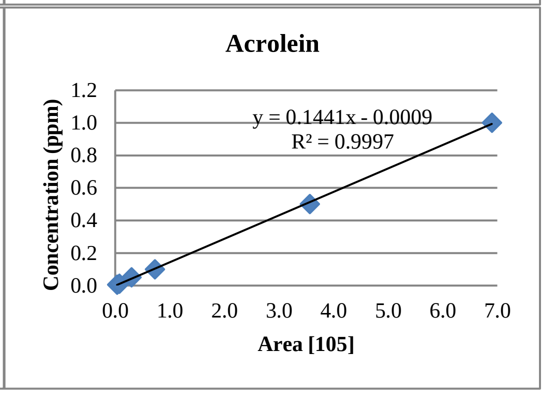
Table A.1 Peak areas of each carbonyl compounds for standard curves

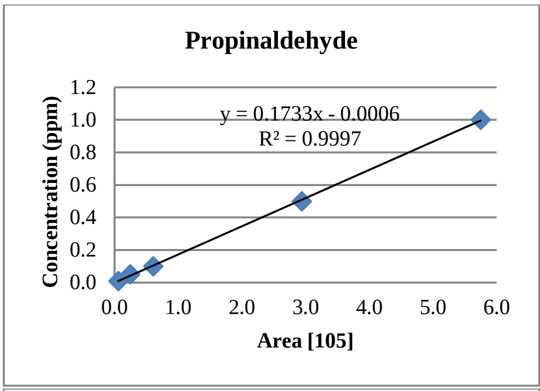
Compound	Peak area					
	0.005 ppm	0.010 ppm	0.050 ppm	0.100 ppm	0.500 ppm	1.000 ppm
Formaldehyde	4582	9430	45751	92552	467712	997247
Acetaldehyde	2675	6593	33879	68565	347486	642887
Acetone	2586	5241	25730	51398	259371	520068
Acrolein	3136	6622	33178	65420	332227	666023
Propionaldehyde	2340	5141	24521	48938	249703	499239
Crotonaldehyde	1987	4838	23120	46022	231274	461608
Butyraldehyde	1915	3909	19382	38564	197244	396273
Benzaldehyde	1467	3022	17380	34073	171403	349937
Isovaleraldehyde	1662	3355	18057	36449	182999	368613
Valeraldehyde	1708	3249	16160	31766	161643	323299
o-Tolualdehyde	1349	2528	12663	25364	127075	254385
m-,p-Tolualdehyde	2620	5253	25292	51827	260684	517586
Hexanaldehyde	1256	2398	14114	27270	137640	279730
2,5-Dimethylbenzaldehyde	532	2111	11002	22193	111632	225387

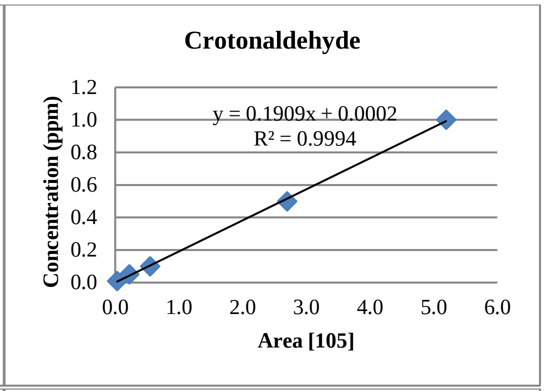


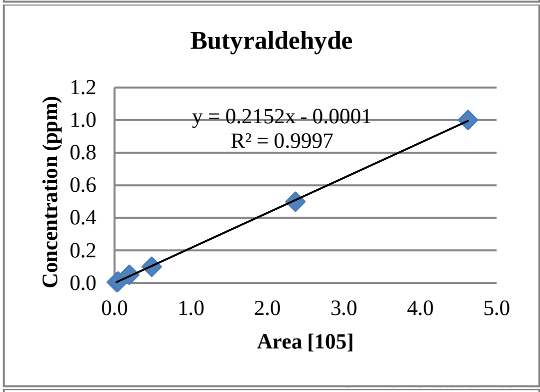


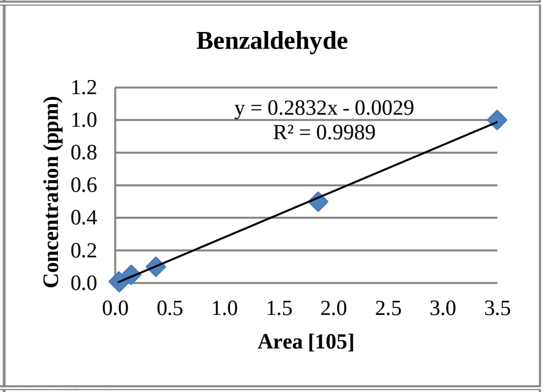


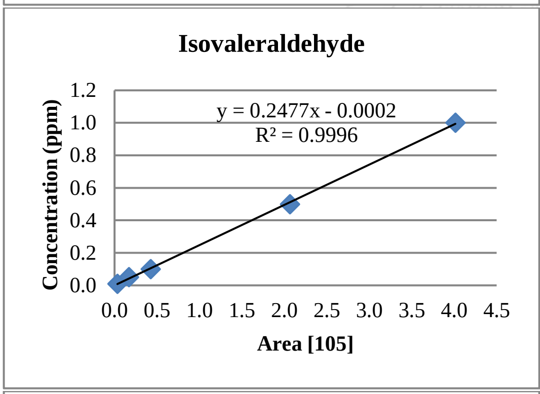


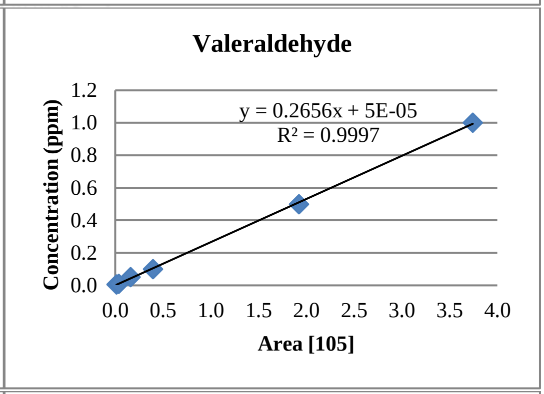

Propinaldehyde
Concentration (ppm)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
y = 0.1733x - 0.0006
R² = 0.9997
0.0 1.0 2.0 3.0 4.0 5.0 6.0
Area [105]

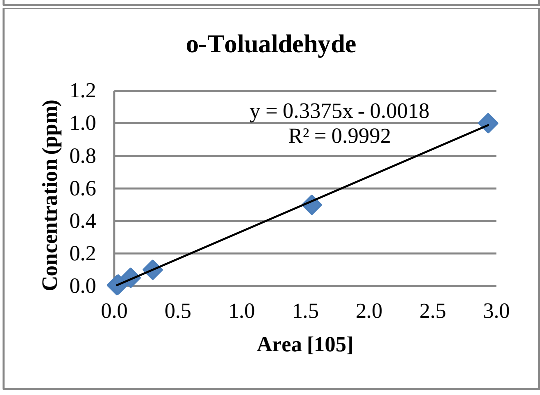

Crotonaldehyde
Concentration (ppm)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
y = 0.1909x + 0.0002
R² = 0.9994
0.0 1.0 2.0 3.0 4.0 5.0 6.0
Area [105]

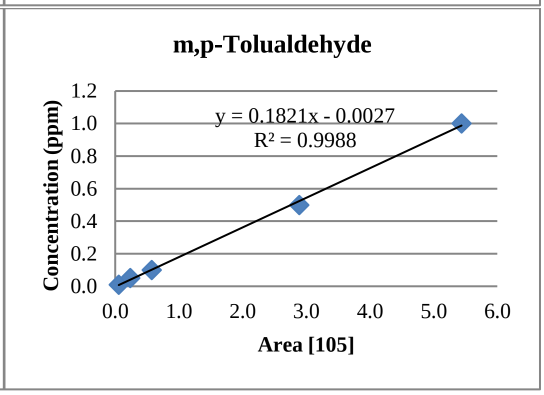

Butyraldehyde
Concentration (ppm)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
y = 0.2152x - 0.0001
R² = 0.9997
0.0 1.0 2.0 3.0 4.0 5.0
Area [105]


Benzaldehyde
Concentration (ppm)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
y = 0.2832x - 0.0029
R² = 0.9989
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
Area [105]


Isovaleraldehyde
Concentration (ppm)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
y = 0.2477x - 0.0002
R² = 0.9996
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5
Area [105]


Valeraldehyde
Concentration (ppm)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
y = 0.2656x + 5E-05
R² = 0.9997
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
Area [105]


o-Tolualdehyde
Concentration (ppm)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
y = 0.3375x - 0.0018
R² = 0.9992
0.0 0.5 1.0 1.5 2.0 2.5 3.0
Area [105]


m,p-Tolualdehyde
Concentration (ppm)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
y = 0.1821x - 0.0027
R² = 0.9988
0.0 1.0 2.0 3.0 4.0 5.0 6.0
Area [105]

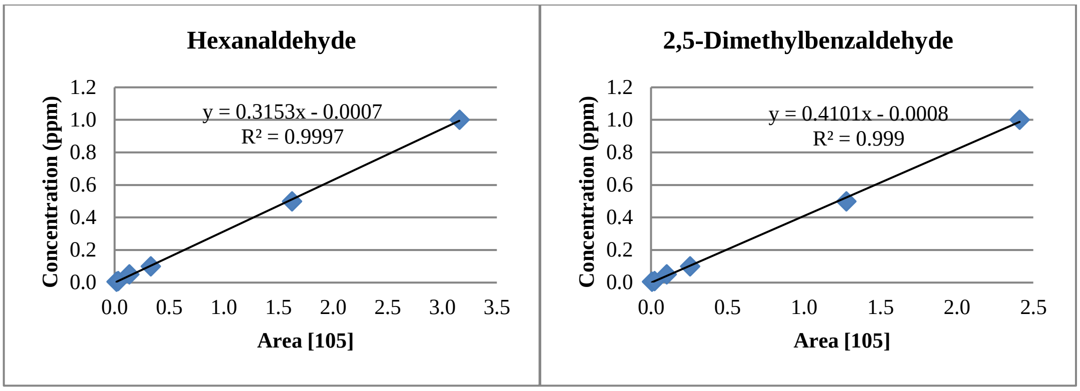


Figure A.1 Standard curve of 13 carbonyl compounds for dry season

A.1.2 % RSD, IDL and IQL of carbonyl compounds

Table A.1.2 % RSD, IDL, and IQL of carbonyl compounds

Aldehyde	For	Ace	Acet	Acro	Pro	Cro	But	Iso	Val	o-Tol	m,p	Hex	2,5
Std. 0.05 ppm/1	0.042	0.041	0.041	0.04	0.041	0.04	0.042	0.04	0.041	0.041	0.04	0.041	0.039
Std. 0.05 ppm/2	0.041	0.041	0.042	0.041	0.041	0.039	0.042	0.041	0.041	0.04	0.041	0.041	0.039
Std. 0.05 ppm/3	0.041	0.041	0.042	0.041	0.042	0.043	0.04	0.04	0.041	0.04	0.04	0.043	0.039
Std. 0..05 ppm/4	0.042	0.042	0.042	0.041	0.041	0.04	0.043	0.041	0.041	0.039	0.041	0.041	0.04
Std. 0.05 ppm/5	0.042	0.042	0.043	0.042	0.043	0.039	0.04	0.042	0.042	0.043	0.042	0.042	0.039
Std. 0.05 ppm/6	0.042	0.042	0.043	0.042	0.042	0.04	0.037	0.042	0.042	0.041	0.041	0.041	0.04
Std. 0.05 ppm/7	0.043	0.043	0.043	0.042	0.042	0.041	0.04	0.042	0.042	0.041	0.041	0.041	0.041
Std. 0.05 ppm/8	0.043	0.043	0.043	0.042	0.042	0.043	0.042	0.041	0.042	0.043	0.042	0.04	0.039
Std. 0.05 ppm/9	0.043	0.042	0.043	0.042	0.042	0.043	0.042	0.042	0.042	0.04	0.04	0.042	0.04
Std. 0.05 ppm/10	0.043	0.043	0.043	0.042	0.042	0.044	0.041	0.04	0.041	0.043	0.041	0.043	0.041
Average	0.042	0.042	0.043	0.042	0.042	0.041	0.041	0.041	0.042	0.041	0.041	0.042	0.040
SD	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001
%RSD	1.869	1.944	1.664	1.704	1.513	4.548	4.227	2.130	1.270	3.526	1.804	2.342	2.074
LOD	0.002	0.002	0.002	0.002	0.002	0.006	0.005	0.003	0.002	0.004	0.002	0.003	0.002
LOQ	0.008	0.008	0.007	0.007	0.006	0.019	0.017	0.009	0.005	0.014	0.007	0.010	0.008

A.2 Quality control techniques of BTEX

A.2.1 Standard curves of BTEX

Table A.2.1 Peak area ratios of benzene, toluene, ethylbenzene, m-, p-xylene, and o-xylene at different concentration of mix standard BTEX

Compound	Peak area						
	125 ng/mL	250 ng/mL	500 ng/mL	1000 ng/mL	2000 ng/mL	4000 ng/mL	8000 ng/mL
Benzene	1.14	1.45	1.95	2.70	4.58	8.43	16.48
Toluene	2.06	3.05	4.42	6.71	11.19	19.34	35.96
Ethylbenzene	0.67	0.80	1.35	3.76	7.71	16.39	33.66
m,p-xylene	0.82	1.37	2.29	4.26	8.46	15.17	31.58
o-Xylene	0.99	1.18	2.88	4.55	8.92	17.08	35.18

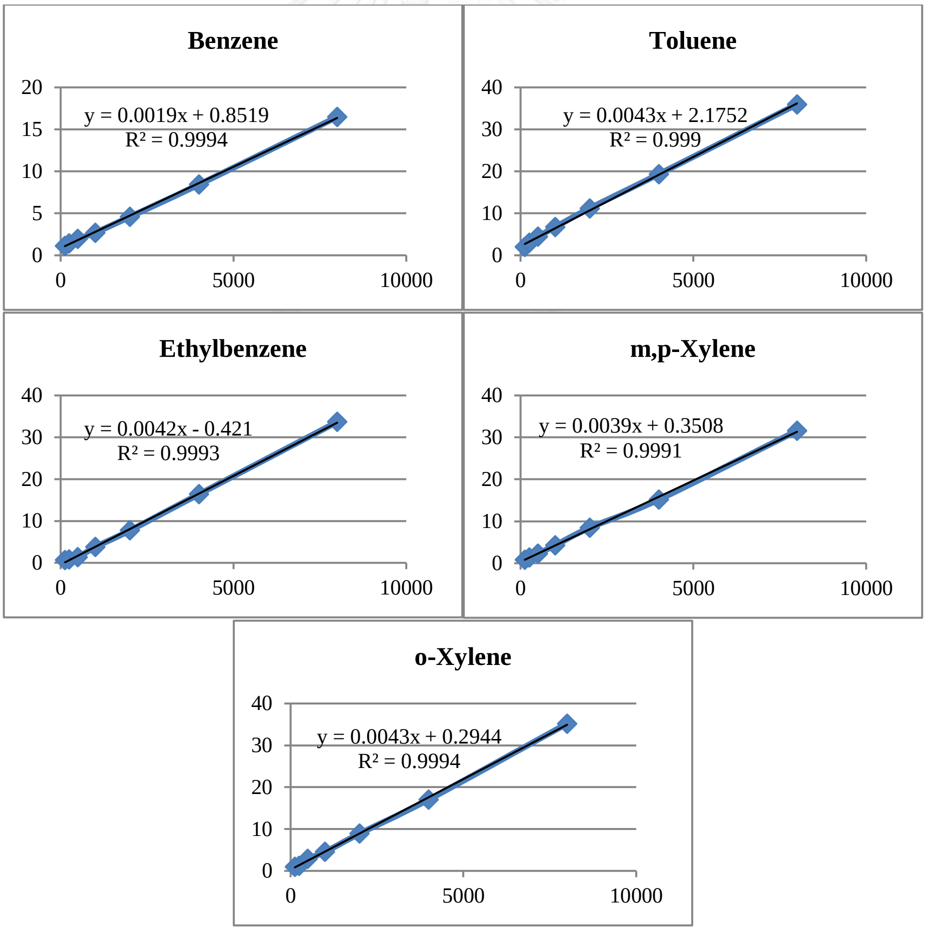


Figure A.2 Standard curves of BTEX for wet season

A.2.2 LOD, LOQ and %RSD of BTEX

Table A.2.2 The peak areas of BTEX for LOD, LOQ and %RSD calculation

Compounds	Peak area (25 ng/ml)					Average	SD	LOD (ng/ml)	LOQ (ng/ml)	RSD	% Recovery
	1.00	2.00	3.00	4.00	5.00						
Benzene	0.57	0.53	0.56	0.51	0.58	0.55	0.02	3.98	13.27	4.22	99.33
Toluene	0.36	0.37	0.38	0.34	0.41	0.37	0.01	5.22	17.41	4.33	100.12
Ethylbenzene	0.27	0.30	0.28	0.29	0.28	0.28	0.02	3.01	10.04	3.85	103.39
m,p-Xylene	0.33	0.29	0.31	0.32	0.36	0.31	0.03	6.03	20.11	2.81	99.71
o-Xylene	0.68	0.72	0.63	0.69	0.69	0.68	0.03	3.60	11.99	6.84	100.56

APPENDIX B Concentrations of carbonyl compounds and BTEX of outdoor workers at all sampling sites

B.1 BTEX concentrations of outdoor workers at roadside area

Table B.1 BTEX concentrations of street vendors

Sample	Site	Rain					Summer				
		Ben	Toluene	Ethyl	m,p	o	Ben	Toluene	Ethyl	m,p	o
Personal	OS	20.59	37.05	2.50	6.68	13.71	13.37	37.35	3.20	2.02	2.64
	KTB	15.27	25.51	4.56	12.48	31.65	15.35	23.42	1.72	0.51	1.56
	SCI	34.53	63.15	5.46	5.29	26.46	49.66	82.24	3.59	2.31	2.97
	SCB	11.34	67.06	5.04	9.16	26.55	46.22	81.40	9.90	4.20	4.95
	BBL	29.88	18.39	3.20	6.14	14.30	17.15	203.40	2.43	2.22	2.80
Ambient air	OS	36.61	118.01	4.44	2.71	19.96	18.45	48.18	2.71	2.81	2.30
	KTB	15.12	18.00	3.41	9.90	36.71	13.05	95.98	0.75	ND	1.18
	SCI	43.56	252.23	5.34	3.01	3.70	54.79	140.41	3.37	2.26	3.10
	SCB	24.65	51.26	6.12	30.70	41.68	22.67	58.33	7.86	4.36	4.51
	BBL	31.43	72.50	10.26	18.73	44.53	22.07	716.32	2.56	2.61	4.32

Table B.2 BTEX concentrations of motorcycle taxi drivers

Sample	Site	Rain					Summer				
		Ben	Toluene	Ethyl	m,p	o	Ben	Toluene	Ethyl	m,p	o
Personal	OS	25.64	28.81	3.39	3.08	5.10	28.80	38.14	3.48	2.98	3.65
	KTB	42.84	85.22	8.93	11.29	13.88	31.85	104.50	6.80	8.84	7.22
	SCI	28.80	71.23	6.74	3.83	47.62	32.18	38.74	2.57	2.45	3.37
	SCB	27.13	38.64	3.67	3.74	31.71	29.12	57.79	9.05	6.51	6.83
	BBL	35.51	51.42	6.69	6.81	16.50	26.93	97.73	7.13	6.92	6.94
Ambient air	OS	20.91	34.79	4.57	4.46	8.59	28.26	9.64	0.58	0.88	0.67
	KTB	38.30	54.21	4.81	1.41	11.40	29.19	85.78	5.43	6.01	4.84
	SCI	61.80	462.71	7.73	14.28	136.91	21.74	52.50	3.41	3.41	3.59
	SCB	21.99	109.61	4.13	3.20	102.13	19.56	42.40	5.75	2.60	3.61
	BBL	35.45	49.53	7.26	6.92	20.62	25.20	114.96	8.67	8.02	9.86

Table B.3 BTEX concentrations of security guards

Sample	Site	Rain					Summer				
		Ben	Toluene	Ethyl	m,p	o	Ben	Toluene	Ethyl	m,p	o
Personal	MBA	55.11	45.61	5.65	1.75	5.22	25.89	70.56	7.75	6.80	6.12
	POL	39.10	38.07	0.97	1.18	58.41	10.12	43.64	16.10	7.80	6.43
	ARC	47.11	42.60	2.23	0.62	36.43	38.46	15.11	1.94	1.78	0.97
	ART	52.44	31.72	0.99	5.19	34.09	39.19	17.68	1.70	0.14	1.01
	SCI	66.50	19.10	2.54	18.82	43.99	22.08	22.66	2.97	2.67	2.68
	GRA	64.37	17.39	1.93	10.39	29.73	21.16	16.43	1.18	1.40	1.25
Ambient air	MBA	38.78	34.42	3.37	0.98	13.81	26.89	28.32	5.59	3.60	2.69
	POL	154.72	54.57	1.01	1.21	110.97	21.21	48.15	20.78	9.30	7.97
	ARC	43.59	28.79	0.06	0.20	57.07	43.79	10.19	0.98	0.85	0.37
	ART	26.48	2.65	ND	2.05	9.50	25.37	94.74	1.56	0.08	1.26
	SCI	69.01	10.76	2.05	18.45	21.08	23.31	12.29	1.88	1.28	1.43
	GRA	102.04	41.16	5.82	9.27	121.86	20.85	14.73	2.05	1.27	1.44

B.2 CCs concentrations of outdoor workers at roadside area

Table B.4 CCs concentrations of street vendors

Sample	Site	Rain			Summer		
		For	Ace	Pro	For	Ace	Pro
Personal	OS	22.91	7.74	1.04	21.92	11.58	1.57
	KTB	8.93	2.79	0.69	6.92	7.38	0.36
	SCI	16.37	10.87	1.73	22.91	11.51	3.39
	SCB	13.37	2.31	1.86	28.40	17.29	3.43
	BBL	13.24	5.13	2.00	15.81	7.45	0.47
Ambient air	OS	10.23	4.77	0.79	9.56	2.61	0.10
	KTB	3.76	2.87	0.43	4.40	2.24	ND
	SCI	8.19	3.44	0.58	13.57	4.07	3.00
	SCB	11.88	21.10	0.75	9.71	6.65	1.57
	BBL	16.31	5.28	1.10	18.91	5.07	1.50

Table B.5 CCs concentrations of motorcycle taxi drivers

Sample	Site	Rain			Summer		
		For	Ace	Pro	For	Ace	Pro
Personal	OS	17.56	8.71	3.74	13.96	5.16	1.40
	KTB	14.00	6.80	1.41	9.30	7.22	1.13
	SCI	8.20	4.93	1.19	10.02	3.21	ND
	SCB	4.09	2.83	0.60	15.16	11.12	2.06
	BBL	20.99	7.37	1.93	15.11	6.74	1.66
Ambient air	OS	22.51	10.72	2.32	11.13	3.28	1.02
	KTB	34.99	10.02	2.20	6.92	4.26	0.07
	SCI	4.32	2.43	0.27	5.31	1.59	ND
	SCB	4.86	4.19	0.07	6.49	4.76	1.47
	BBL	24.02	8.53	ND	21.31	7.20	2.26

Table B.6 CCs concentrations of security guards

Sample	Site	Rain			Summer		
		For	Ace	Pro	For	Ace	Pro
Personal	MBA	14.21	5.61	1.14	12.72	4.51	0.43
	POL	12.82	5.48	1.38	11.70	5.92	1.30
	ARC	7.89	3.98	1.79	5.62	1.76	0.27
	ART	9.24	3.61	0.94	10.02	2.76	0.10
	SCI	5.58	4.39	0.40	10.91	1.59	ND
	GRA	11.13	3.44	1.48	9.21	2.03	0.05
Ambient air	MBA	10.87	4.69	0.99	8.84	1.10	1.12
	POL	11.95	4.82	1.36	9.38	2.46	1.29
	ARC	3.96	2.50	0.51	4.12	2.34	0.72
	ART	ND	ND	ND	5.04	0.54	ND
	SCI	4.01	2.57	0.51	9.76	0.59	ND
	GRA	11.89	4.28	1.33	10.96	1.52	ND

APPENDIX C Concentrations of carbonyl compounds and BTEX of traffic policemen at all sampling sites

C.1 BTEX concentrations of traffic policemen at road intersection

Table C.1 BTEX concentrations of traffic policemen

Sample	Site	Rain					Summer				
		Ben	Toluene	Ethyl	m,p	o	Ben	Toluene	Ethyl	m,p	o
Personal	PT	551.28	1444.08	223.77	245.65	253.40	226.33	713.36	111.29	150.85	130.68
	SY	459.11	1101.71	241.90	217.90	222.14	199.26	542.43	67.23	118.79	127.74
	HD	607.93	1372.84	275.24	291.41	240.18	364.83	842.12	167.67	226.57	74.91
	CP	691.02	1401.56	177.91	227.11	188.23	310.55	710.34	163.14	145.07	97.20
Ambient air	PT	692.20	1729.26	366.88	355.52	354.32	401.31	1242.17	208.07	185.87	144.41
	SY	552.54	1116.10	250.50	288.82	255.02	312.05	712.67	167.99	152.41	120.93
	HD	733.61	2016.41	333.84	327.53	356.74	504.56	1137.24	155.05	232.44	140.47
	CP	637.56	1448.65	282.65	339.33	312.35	405.30	941.03	310.88	168.89	111.89

C.2 CCs concentrations of traffic policemen at road intersection

Table C.2 CCs concentrations of traffic policemen

Sample	Site	Rain			Summer		
		For	Ace	Pro	For	Ace	Pro
Personal	PT	11.02	8.74	0.95	7.49	7.24	1.84
	SY	7.83	6.96	2.58	13.38	17.23	0.89
	HD	8.51	7.92	2.07	8.07	8.35	1.85
	CP	9.58	25.19	2.77	9.23	6.87	1.13
Ambient air	PT	23.68	74.85	18.83	13.72	41.75	14.44
	SY	14.11	48.56	9.90	16.34	30.46	5.51
	HD	17.80	65.42	13.55	25.20	64.21	13.31
	CP	18.93	14.95	1.15	9.75	4.83	0.83

APPENDIX D Concentrations of carbonyl compounds and BTEX of indoor workers at all sampling sites

D.1 BTEX concentrations of indoor workers

Table D.1 BTEX concentrations of indoor workers

Sample	Site	Rain					Summer				
		Ben	Toluene	Ethyl	m,p	o	Ben	Toluene	Ethyl	m,p	o
Personal	CC	16.70	509.32	47.80	56.05	65.88	11.19	230.62	8.41	30.15	28.97
	ED	15.75	329.48	32.60	64.36	38.32	13.69	153.26	11.16	33.71	27.66
	EG	8.58	338.10	31.49	59.93	52.24	7.07	176.78	14.54	34.22	32.78
	EC	7.03	362.43	32.40	51.75	43.03	2.25	209.54	10.89	30.38	23.09
Ambient air	CC	17.02	523.83	44.82	65.03	64.04	12.69	241.44	13.68	31.44	25.99
	ED	17.60	318.47	31.68	58.66	61.22	11.83	175.68	13.47	33.04	26.72
	EG	8.82	421.11	30.26	64.88	60.45	6.48	208.98	11.78	32.49	29.80
	EC	5.26	384.61	32.60	50.79	40.90	2.00	258.54	15.14	31.71	29.74

D.2 CCs concentrations of indoor workers

Table D.2 CCs concentrations of indoor workers

Site	Rain			Summer		
	For	Ace	Pro	For	Ace	Pro
CC	24.11	4.25	1.84	17.52	7.48	1.57
ED	25.83	23.36	1.78	14.82	11.37	1.42
EG	27.79	4.78	0.97	16.53	8.84	1.27
EC	30.74	5.85	1.17	29.18	9.37	1.19
CC	20.86	6.53	1.02	19.09	6.60	1.31
ED	23.56	10.05	1.28	17.40	11.83	1.53
EG	40.01	6.66	3.29	18.82	10.08	1.47
EC	36.40	6.24	1.16	35.69	11.82	1.69

APPENDIX E Statistical analysis

E.1 ANOVA analysis

Table E.1 ANOVA analysis of personal exposure of traffic policemen

Dependent Variable	(I) Sites	(J) Sites	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Formaldehyde	PT	SY	-1.35417	2.22104	.545	-5.8304	3.1220
		HD	.96583	2.22104	.666	-3.5104	5.4420
		CP	-.14917	2.22104	.947	-4.6254	4.3270
	SY	PT	1.35417	2.22104	.545	-3.1220	5.8304
		HD	2.32000	2.22104	.302	-2.1562	6.7962
		CP	1.20500	2.22104	.590	-3.2712	5.6812
	HD	PT	-.96583	2.22104	.666	-5.4420	3.5104
		SY	-2.32000	2.22104	.302	-6.7962	2.1562
		CP	-1.11500	2.22104	.618	-5.5912	3.3612
	CP	PT	.14917	2.22104	.947	-4.3270	4.6254
		SY	-1.20500	2.22104	.590	-5.6812	3.2712
		HD	1.11500	2.22104	.618	-3.3612	5.5912
Acetaldehyde	PT	SY	-4.10000	4.42380	.359	-13.0156	4.8156
		HD	-.14667	4.42380	.974	-9.0622	8.7689
		CP	-8.04083	4.42380	.076	-16.9564	.8747
	SY	PT	4.10000	4.42380	.359	-4.8156	13.0156
		HD	3.95333	4.42380	.376	-4.9622	12.8689
		CP	-3.94083	4.42380	.378	-12.8564	4.9747
	HD	PT	.14667	4.42380	.974	-8.7689	9.0622
		SY	-3.95333	4.42380	.376	-12.8689	4.9622
		CP	-7.89417	4.42380	.081	-16.8097	1.0214
	CP	PT	8.04083	4.42380	.076	-.8747	16.9564
		SY	3.94083	4.42380	.378	-4.9747	12.8564
		HD	7.89417	4.42380	.081	-1.0214	16.8097

E.2 Pearson's analysis of traffic policemen

Table E.2 Pearson's analysis of traffic policemen

Correlations

		Personal ace	Ambient ace
P.ace	Pearson Correlation	1	.048
	Sig. (2-tailed)		.743
	N	48	48
A.ace	Pearson Correlation	.048	1
	Sig. (2-tailed)	.743	
	N	48	48

E.3 T-test analysis of traffic policemen

Table E.3 T-test analysis of traffic policemen

Paired Samples Test

		Paired Differences					t	df	Sig.
		Mean	Std. Deviation	Std. Error Mean	95% CI Lower	95% CI Upper			
Pair 1	ForDry - Forwet	.30708	7.74883	1.58172	-2.96496	3.57913	.194	23	.848
Pair 2	AmFordry - AmForwet	-2.37792	12.24334	2.49916	-7.54783	2.79199	-.951	23	.351

E.4 Descriptive analysis of traffic policemen

Table E.4 95% CI of risk of traffic policemen

Descriptives

			Statistic	Std. Error
Formaldehyde	Mean		.000005295	.0000007189
	95% Confidence Interval for Mean	Lower Bound	.000003849	
		Upper Bound	.000006741	
	5% Trimmed Mean		.000004525	
	Median		.000004082	
	Variance		.000	
	Std. Deviation		.0000049806	
	Minimum		.0000008	
	Maximum		.0000300	
	Range		.0000291	
	Interquartile Range		.0000025	
	Skewness		3.598	.343
	Kurtosis		15.032	.674
Acetaldehyde	Mean		.000002837	.0000004696
	95% Confidence Interval for Mean	Lower Bound	.000001892	
		Upper Bound	.000003782	
	5% Trimmed Mean		.000002348	
	Median		.000001782	
	Variance		.000	
	Std. Deviation		.0000032538	
	Minimum		.0000003	
	Maximum		.0000194	
	Range		.0000192	
	Interquartile Range		.0000023	
	Skewness		3.470	.343
	Kurtosis		15.088	.674

APPENDIX F

F.1 Decode of KA questionnaire

Table F.1 Decode of KA questionnaire

Pre-test of Knowledge part				
k1	1	1	1	1
k2	1	1	1	1
k3	1	1	1	1
k4	1	1	1	1
k5	1	0	0	0
k6	0	0	0	0
k7	0	1	0	0
k8	0	0	0	0
k9	0	0	0	0
k10	1	1	1	1
Post-test of Knowledge part				
kp1	1	1	1	1
kp2	1	1	1	1
kp3	1	1	1	1
kp4	1	1	1	0
kp5	1	0	1	1
kp6	0	0	1	0
kp7	1	1	1	1
kp8	1	0	1	1
kp9	1	1	1	1
kp10	1	1	1	1
(Pre-test)-(Post-test)				
minus1	0	0	0	0
minus2	0	0	0	0
minus3	0	0	0	0
minus4	0	0	0	-1
minus5	0	0	1	1
minus6	0	0	1	0
minus7	1	0	1	1
minus8	1	0	1	1
minus9	1	1	1	1
minus10	0	0	0	0
Decode of Knowledge part				
Decode1	1	1	1	1
Decode2	1	1	1	1
Decode3	1	1	1	1

Decode4	1	1	1	0.5
Decode5	1	1	2	2
Decode6	1	1	2	1
Decode7	2	1	2	2
Decode8	2	1	2	2
Decode9	2	2	2	2
Decode10	1	1	1	1
Summation	13	11	15	13.5

F.2 KA questionnaire

F.2.1 KA questionnaire (Thai version)

แบบสำรวจความรู้ ความคิดเห็น และการปฏิบัติตนเรื่องมลพิษอากาศ

Part 1 General information

คำชี้แจง: โปรดทำเครื่องหมาย ✓ ลงในช่อง ☐ ที่ตรงกับข้อมูลของท่าน

1. Gender ☐ Male ☐ Female

2. Age ....years Body weight..........................kg

3. การศึกษาสูงสุด

☐ไม่ได้เรียน ☐ประถมศึกษา ☐มัธยมศึกษา/ปวช

☐อนุปริญญา/ปวส. ☐ ปริญญาตรีหรือสูงกว่า

4. อาชีพ

☐แม่ค้า พ่อค้า ☐ มอเตอร์ไซด์รับจ้าง ☐ยามรักษาความปลอดภัย

☐ตำรวจจราจร ☐พนักงานออฟฟิศ

ส่วนที่ 2 ความรู้เกี่ยวกับความเสี่ยงจากการปฏิบัติงานบริเวณริมถนน

คำชี้แจง: โปรดทำเครื่องหมาย ✓ ลงในช่อง ☐ ที่ตรงกับความคิดของท่านมากที่สุด

คำถาม	ถูก/ใช่	ผิด/ไม่ใช่
1. การจราจรบนท้องถนนเป็นแหล่งกำเนิดสารอินทรีย์ระเหยง่าย		
2. การ**เผาไหม้**น้ำมันเชื้อเพลิงจากยานพาหนะ ทำให้เกิดสารอินทรีย์ระเหยง่าย		
3. การ**ระเหย**ของน้ำมันเชื้อเพลิงจากยานพาหนะเป็นแหล่งกำเนิดสารอินทรีย์ระเหยง่าย		

4. การ**เผาไหม้น้ำมันเชื้อเพลิง**จากยานพาหนะทำให้เกิดกลุ่มสารเบนซิน โทลูอีน เอทิลเบนซิน และไซลีน (BTEX), และสารฟอร์มัลดีไฮด์ และอะซิทัลดีไฮด์		
5. การ**ระเหย**ของน้ำมันเชื้อเพลิง**ไม่ใช่**แหล่งกำเนิด**สารประกอบ BTEX**		
6. การ**เผาไหม้**น้ำมันเชื้อเพลิง ทำให้เกิด**สารเฉพาะกลุ่ม BTEX**		
7. การ**เผาไหม้**น้ำมันเชื้อเพลิง**ต่างชนิด** ทำให้เกิดสารอินทรีย์ระเหยง่าย**ชนิดเดียวกัน**		
8. การ**เผาไหม้น้ำมันเชื้อเพลิง**ประเภท**เบนซินและดีเซล** ทำให้เกิดสาร**ฟอร์มัลดีไฮด์**และ**อะซิทัลดีไฮด์**		
9. การเผาไหม้น้ำมันน้ำมันเชื้อเพลิง**แก๊สโซฮอล์** ทำให้เกิดสารประกอบ BTEX		
10. พื้นที่ที่มีการ**จราจรหนาแน่น** จะมีปริมาณสารอินทรีย์ระเหยง่ายกลุ่มนี้**ในระดับที่ไม่สูง**		
11. สารอินทรีย์ระเหยง่ายสามารถ**แพร่ผ่าน**จากภายนอกอาคารไปภายในตัวอาคารได้		
12. **ภายในอาคารไม่มี**แหล่งกำเนิดสารอินทรีย์ระเหยง่าย		
13. แหล่งกำเนิดสาร**ฟอร์มัลดีไฮด์** ได้แก่ เครื่องถ่ายเอกสารและเครื่องปริ้นเตอร์		
14. แหล่งกำเนิดสารประกอบ BTEX ได้แก่ ผ้าม่าน, พรมปูพื้น, สีทาอาคาร, น้ำยาทำความสะอาด, สารเคลือบผิวเฟอร์นิเจอร์และโต๊ะตู้ต่างๆ รวมทั้งพื้นผนังที่ทำด้วยไม้		
15. อาคารที่ติดตั้งเครื่องระบายอากาศและฟอกอากาศ จะส่งผลให้มีสารอินทรีย์ระเหยง่าย**มากกว่า** อาคารที่ไม่ได้ติดตั้ง		
16. อาคารที่ตั้งอยู่ใกล้ถนนที่มีการจราจรหนาแน่นจะมีปริมาณสารอินทรีย์ระเหยง่าย**สูงเท่ากับ**อาคารที่ตั้งบริเวณอื่นๆ		
17. สารอินทรีย์ระเหย จากควันยานพาหนะจะ**เข้าสู่ร่างกาย**ผ่านทางการ**หายใจ**และการ**สัมผัส**		
18. อาการ**เบื้องต้น**จากการสูดดมควันจากการเผาไหม้ของสารอินทรีย์ระเหยในยานยนต์ได้แก่ ปวดศีรษะ มึนงง คลื่นไส้ อาเจียน อ่อนเพลีย		
19. การสูดดมควันจากการเผาไหม้ของสารอินทรีย์ระเหยจากยานยนต์เป็น**ระยะเวลานาน**ทำให้เกิดโรคร้ายแรง ได้แก่ **โรคหัวใจ และปอดบวม**		
20. **นอกเหนือจากโรคในข้อ13** แล้ว การสูดดมควันจากการเผาไหม้ของสารอินทรีย์ระเหยเป็นระยะเวลานานสามารถทำให้เกิด**โรคมะเร็งเม็ดเลือดขาว มะเร็งโพรงจมูก มะเร็งคอหอยส่วนจมูก และมะเร็งในท่อไต**		
21. ถ้าโอกาส (ความเสี่ยง) ของการเกิดโรคมะเร็งที่ได้กล่าวในข้อ14 อยู่ในอัตราส่วน**ที่ ไม่เกิน 1 คน ต่อ 10,000 คน** ถือว่า **ยอมรับได้**		
22. **ความเสี่ยง**ต่อสุขภาพของประชาชนทีทำงาน ณ บริเวณพื้นที่ที่มี**การจราจรหนาแน่น** จะ**สูงกว่า**บริเวณพื้นที่มี**การจราจรเบาบาง**		
23. การทำงานบริเวณที่มีการจราจรหนาแน่น ใน**ชั่วโมงเร่งด่วน**จะส่งผลเสียต่อสุขภาพ**เท่าๆกับ**การทำงานใน**ช่วงเวลาอื่นๆ**		

24. การทำงานในบริเวณพื้นที่ที่มี**การจราจรเบาบาง**ไม่สามารถช่วย**ลดความเสี่ยง**จากการรับสัมผัสสารอินทรีย์ระเหยได้		
25. การสวมใส่หน้ากากป้องกันแบบ**มีตัวกรอง** จะสามารถป้องกันได้ดี**เท่ากับ**หน้ากาก**ผ้าทั่วไป**		

ส่วนที่ 3 ความคิดเห็นเกี่ยวกับความเสี่ยงจากการปฏิบัติงานบริเวณริมถนน

คำชี้แจง: โปรดทำเครื่องหมาย ✓ ลงในช่อง □ ที่ตรงกับความคิดเห็น/ความรู้สึกของท่านมากที่สุด

ข้อความ	**ไม่เห็นด้วยอย่างยิ่ง**	**ไม่เห็นด้วย**	**เห็นด้วย**	**เห็นด้วยอย่างยิ่ง**
1. ท่านคิดว่าท่านปฏิบัติงานในบริเวณพื้นที่ที่มีการ**จราจรหนาแน่น**				
2. ท่านคิดว่าบริเวณพื้นที่ที่ท่านปฏิบัติงาน มีปริมาณสารอินทรีย์ระเหยง่าย จากควันยานพาหนะใน**ปริมาณสูง**				
3. ท่านคิดว่าท่านสูดดมสารอินทรีย์ระเหยง่ายจากการเผาไหม้ของยานยนต์ และการระเหยจากเชื้อเพลิงขณะปฏิบัติงานงาน**ในระดับสูง**				
4. ท่านคิดว่าการสูดดมสารอินทรีย์ระเหยง่าย เป็นระยะเวลา**น้อยกว่า 10 ปี** จะ**ไม่ส่งผลกระทบต่อสุขภาพ**ของท่าน				
5. ท่านคิดว่าการสูดดมสารอินทรีย์ระเหยง่าย เป็นระยะเวลา **10-20 ปี จะมีโอกาส**ส่งผลกระทบต่อสุขภาพของท่าน				
6. ท่านคิดว่าการสูดดมสารอินทรีย์ระเหยง่าย เป็นระยะเวลา 30 **ปี** จะส่ง**ผลกระทบต่อสุขภาพ**ของท่าน**แน่นอน**				
7. ท่านกังวลหรือไม่ ถ้าโอกาสที่ทำให้เกิด**โรคมะเร็ง**จากสารอินทรีย์ระเหยง่าย มี**สัดส่วนเกิน 1 ในล้านคน**				
8. ท่านคิดว่าการให้ความรู้เรื่องมลพิษอากาศจากการจราจร และ**โอกาส(ความเสี่ยง)** จากการทำงานบริเวณที่มีการจราจรหนาแน่น **มีประโยชน์กับท่าน**				
9. ท่านคิดว่าการสวม**หน้ากากที่มีตัวกรอง** เป็นวิธีป้องกันอันตรายจากการสูดดมมลพิษทางอากาศที่**ท่านสามารถทำได้**				
10. ท่านคิดว่าการสวม**หน้ากากที่มีตัวกรอง** ระหว่างปฏิบัติงาน**เป็นอุปสรรค**ต่อท่าน				

11. ท่านคิดว่าหน้ากากแบบ**มีตัวกรอง**ราคาอันละ บาท มีราคา**แพงเกินไป**สำหรับท่าน				
12. ท่านคิดว่าเครื่อง**กรองอากาศ**, เครื่อง**ระบายอากาศหรือเครื่องฟอกอากาศ** สามารถช่วย**ลดปริมาณสารอินทรีย์ระเหยง่ายภายในอาคาร**ได้				
13. ท่านคิดว่าท่านจะ**ลดการรับสัมผัส**สารอินทรีย์ระเหยง่ายโดยการ**นำเครื่องถ่ายเอกสารและเคื่องปริ้นเตอร์ ไปไว้บริเวณภายนอกอาคาร**				
14. ท่านรู้สึกอยากเปลี่ยนสถานที่ปฏิบัติงาน /หรือเปลี่ยนงานเมื่อทราบถึงผลกระทบของการสูดดมสารดังกล่าวจากการเผาไหม้ยานยนต์ที่เกิดกับร่างกายท่าน (**<u>กรณีที่รายได้ยังคงเท่าเดิม</u>**)				
15. ท่านรู้สึกอยาก**ลดระยะเวลาปฏิบัติงาน** เพื่อลดการสูดดมสารดังกล่าว				

F.2.2 KA questionnaire (English version)

Part I General information

Please check the appropriate box or, where relevant, specify your answer

1. Gender ☐ Male ☐ Female

2. Age ....year Body weight..........................kg.

3. Educational status

☐ Uneducated ☐ Primary school ☐ Secondary school

☐ Diploma ☐ Under graduate or Graduate degree

4. Occupational

☐ Street vendor ☐ Motorcycle taxi driver ☐ security guard

☐ Traffic police ☐ Indoor worker

Part 2 The knowledge part

Please check the appropriate box or, where relevant, specify your answer

Question	**Yes/ Correct**	**No/ Incorrect**
26. Volatile organic compounds (VOCs) is generated from the traffic		
27. Combustion of fuels produces VOCs		
28. VOCs come from the evaporation of fuel		
29. Combustion of fuels also produces benzene, toluene, ethylbenzene and xylenes (BTEX), formaldehyde and acetaldehyde		
30. BTEX is not originated from the evaporation of fuel		
31. The fuel combustion produces only BTEX		
32. Combustion of different types of fuels generates the same type of VOCs		
33. Combustion of fuel such as benzene and diesel fuel produces formaldehyde and acetaldehyde		
34. The combustion of gasohol generates BTEX		
35. High traffic density area shows low level of VOCs		
36. VOCs can penetrate from outdoor into indoor environment		
37. There is no source of VOCs in the indoor		
38. Office printers and copy machine are sources of formaldehyde		
39. The sources of BTEX are from curtain, carpet. paints, cleaner, furniture coating and wood products		
40. Ventilation system in building show higher VOCs level than that measuring in the building with no ventilation system		
41. The building located close to high traffic area will have the same level of VOCs comparing to other areas		
42. The routes of exposure for VOCs are dermal and inhalation		
43. The basic health problems of VOCs exhaust gas are headache, dizziness, nausea, vomiting and weakness		
44. Long-term adverse health effect of VOCs exhaust gas exposure are a heart disease and pneumonia		
45. Other health concerns (except for No.13) caused by VOCs (long time exposure) are **leukemia, nasopharyngeal carcinoma**		
46. The chance or risk of getting cancer (in No.14).is occurred 1 in10,000 is an acceptable risk		
47. Workers who work near the high traffic area have higher risk level than those in the low traffic area		
48. Working at areas of high automobile traffic during the rush hour traffic will affect to health problems as well as other durations		
49. The workers who work at the low traffic volume cannot reduce risk from VOCs exposure		

50. Wearing the filter mask can be blocked VOCs greater than the protective mask		

Part 3 The opinion of risk at traffic road

Please check the appropriate box or, where relevant, specify your answer

Question	Strongly Disagree	Disagree	Agree	Strongly Agree
16. Your workplace is located at a high traffic area				
17. Your workplace was contained high levels of VOCs exhaust gases				
18. You exposed to high level of VOCs during your working time				
19. The exposure of VOCs exhaust gases less than 10 years will not affect to the health problems				
20. The exposure of VOCs exhaust gases for 10-20 years may affect to the health problems				
21. The exposure of VOCs exhaust gases for 30 years will affect to the health problems				
22. You are concerned if the cancer risk level is greater than an acceptable value (10^{-6})				
23. Giving knowledge and risk causing from the traffic air pollution is useful				
24. You are willing to wear the filter mask to protect yourself from the traffic air pollutants				
25. The filter mask is uncomfortable				
26. The price of filter mask is too expensive (85 baht)				
27. Air ventilation system and air purifier can reduce VOCs level				
28. Place the copy machine and printer outside of the office room can decrease the exposure level of VOCS				
29. You want to change your workplace or job when you know the health effects of VOCs exposure (the same amount of income)				
30. You want to reduce your working time for decreasing of VOCs exposure				

F.3 The media of risk communication

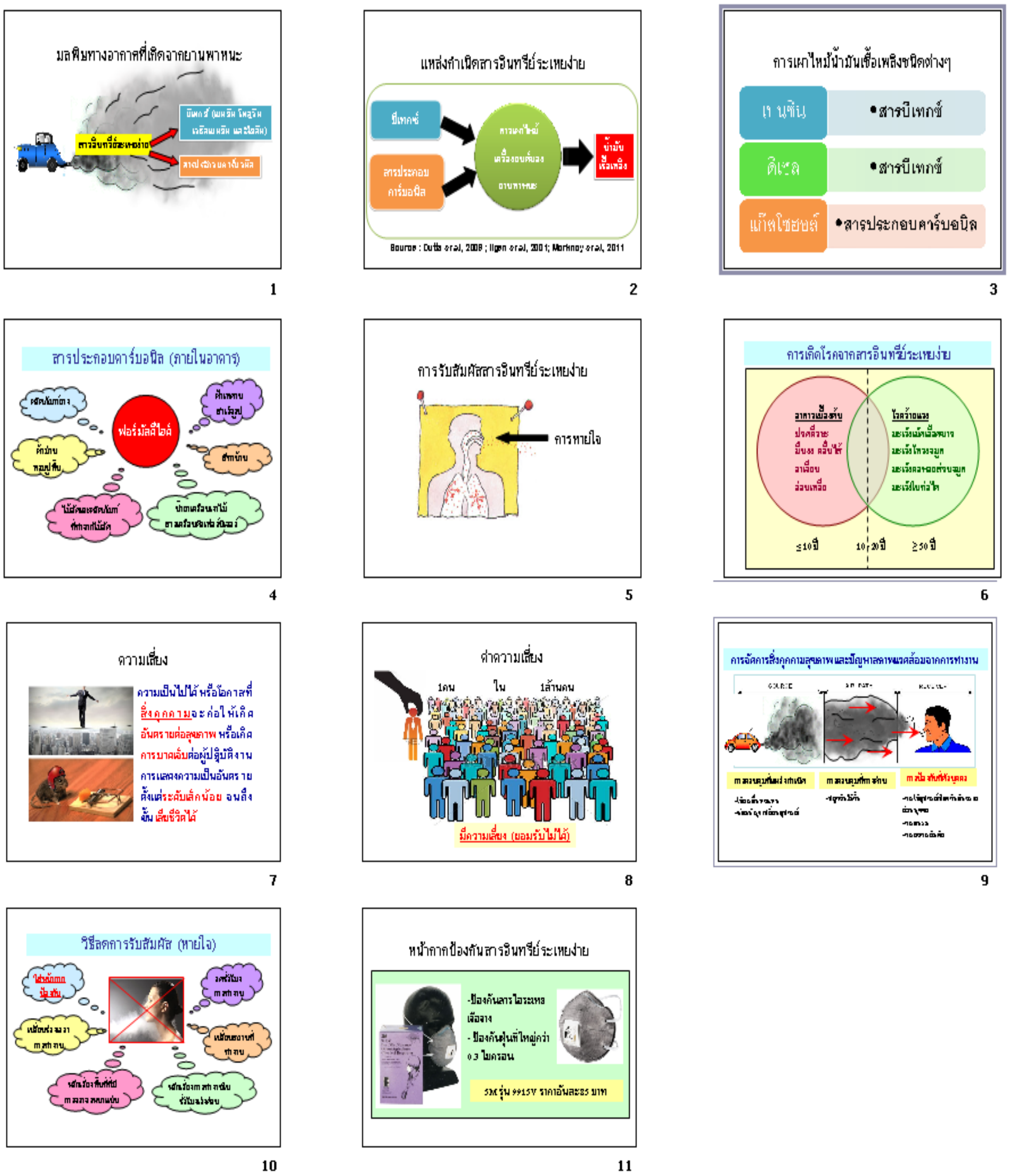


Fig F.1 The media of risk communication

APPENDIX G The statistical analysis of KA questionnaire

G.1 Comparison on the difference between pre-test and post-test questionnaire

Table G.1 T-test analysis of pre- and post-test questionnaires

Part	Section	Sig. (2-tailed)				
		Street vendor	Motorcycle taxi driver	Security guard	Traffic policemen	Indoor worker
Knowledge	Air pollutant	0.000*	0.003*	0.000*	0.000*	0.000*
	Health risk assessment	0.000*	0.083	0.000*	0.000*	0.000*
	Practice	0.043*	0.000*	0.006*	0.161	0.001*
Attitude	Air pollutant	0.000*	0.118	0.012*	0.001*	0.000*
	Health risk assessment	0.014*	0.000*	0.001*	0.000*	0.000*
	Practice	0.017*	0.000*	0.010*	0.018*	0.000*

* mean significantly different ($p < .05$) mean levels
** mean significantly different ($p < .01$) mean levels

G.2 Correlation between knowledge and attitude

Table G.2 Pearson's correlation of KA questionnaire

Correlation	Part	Pearson's coefficient (r)				
		Street vendor	Motorcycle taxi driver	Security guard	Traffic policemen	Indoor worker
Knowledge and Attitude	Air pollutant	0.402*	0.076	0.151	0.247	-0.296
	Health risk assessment	0.149	0.357*	0.111	0.358*	0.113
	Practice	0.175	0.357*	0.334*	0.368*	-0.189

* mean significantly different ($p < .05$) mean levels
** mean significantly different ($p < .01$) mean levels

G.3 T-test analysis of KA questionnaire of the traffic policemen

Table G.3 Comparison of pre and post-test of traffic police

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	Upper			
Pair 1	KpAir - KAir	2.43333	1.65432	.30204	1.81560	3.05107	8.056	29	.000
Pair 2	Kp2Risk - K2Risk	2.20000	1.62735	.29711	1.59234	2.80766	7.405	29	.000
Pair 3	Kp2Practice - K2Practice	.20000	.76112	.13896	-.08421	.48421	1.439	29	.161
Pair 4	Ap2Air - A2Air	1.93333	2.94704	.53805	.83289	3.03378	3.593	29	.001
Pair 5	Ap2Risk - A2Risk	1.90000	2.20266	.40215	1.07751	2.72249	4.725	29	.000
Pair 6	Ap2Practice - A2Practice	.76667	1.67504	.30582	.14120	1.39214	2.507	29	.018

G.4 Pearson's correlation of KAP questionnaire of the traffic policemen

Table G.4 Correlation between knowledge and attitude of traffic police

Correlations

		DKAir	DAair
DKAir	Pearson Correlation	1	.247
	Sig. (1-tailed)		.094
	N	30	30
DAair	Pearson Correlation	.247	1
	Sig. (1-tailed)	.094	
	N	30	30

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