HEALTH RISK ASSESSMENTS OF MICROENVIRONMENT EXPOSURES AND URINARY BIOMARKERS OF INDOOR-OFFICE WORKERS: A PRELIMINARY STUDY

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ABSTRACT: Volatile organic compounds (VOCs) are major source of pollutants in the ambient air, especially along the congested roadsides where the air qualities are generally below the standard. Whereas, for the indoor-office workers who spend most of their times inside, the indoor air pollution is an important environmental concern. In this study, the health risk assessments of benzene, toluene, ethylbenzene, xylene, formaldehyde and acetaldehyde ambient air were conducted at two office buildings in central Bangkok, Thailand during the summer of 2011. The average ambient air benzene, toluene, ethyl-benzene, *m-*, *p*-xylene, *o*-xylene, formaldehyde and acetaldehyde were 134.34, 239.28, 73.73, 48.46, 22.24, 21.16 and 7.42 μg/m^3, while the average personal air benzene, toluene, ethylbenzene, *m-*, *p*-xylene, *o*-xylene, formaldehyde and acetaldehyde exposures were 165.70, 580.50, 84.45, 62.86, 24.52, 14.11 and 1.35 μg/m^3 respectively. Most of each microenvironments of ambient and personal air exposures were not significantly differences except for the acetaldehyde (Independent t-test, $p<0.05$). Total concentration of personal air exposures was significantly higher than ambient air concentration *(*Independent t-test, $p<0.05$*).* All microenvironments of ambient air concentration in this study showed strongly and positively correlated to personal air exposures (Spearman's rho correlation, r=1.000). Averages of life time cancer risk range of benzene, ethylbenzene, formaldehyde and acetaldehyde in official workers were 1.584E-04 - 2.05E-04, 8.26E-06 - 2.01E-05, 2.54E-05 – 7.08E-05 and 2.63E-06 – 3.08E-06, respectively. Of which cancer risk calculation of benzene, ethylbenzene and formaldehyde were higher than acceptable limit of 1.00E-06. But hazard quotients (HQs) of all microenvironments were varied from 0.001 to 0.003 which less than one. Each of microenvironments and total concentration of exposures (TVOCs) had positive relationship to urinary formic acid (Linear regression analysis, $p<0.05$). We concluded that the indoor office workers have higher cancer risk of microenvironments in ambient air exposures and urinary formic acid should be an appropriate biomarker for these exposures.

Keywords: Risk assessment, Microenvironment, Exposure, Biomarker, Indoor, Office worker

INTRODUCTION

Volatile organic compounds (VOCs) are organic chemicals that have - high vapor pressures at normal, room-temperature conditions**.** They are divided into 2 types of non-chlorinated VOCs or non-halogenated hydrocarbons (aliphatic and aromatic hydrocarbons, alcohols, aldehyde and ketone) and chlorinated VOCs or halogenated hydrocarbons (halogenated VOCs). The VOCs are numerous, diverse, and ubiquitous. Many VOCs are dangerous to human health and can cause harm to the environment. VOCs are an important group of air pollutants to be investigated, as they contribute to the most serious air pollution problems [1-6]. Benzene, toluene, ethylbenzene and xylene are known as major components of both indoor and outdoor air contaminants [7] as well as aldehydes of formaldehyde and acetaldehyde [8, 9]. They have been demonstrated to be active in the formation of photochemical smog and ground-level ozone production. Several VOCs found in urban air are classified as carcinogenic compounds (e.g., benzene and ethylbenzene). Some of them may cause short- and long-term adverse health effects, even at very low concentrations. Important signs or symptoms associated with exposure to VOCs include eye irritation, nose and throat discomfort, headache, allergic skin reaction, nausea, fatigue, or dizziness [10] which has led to the phenomenon of

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sick building syndrome and related complaints of workers [11, 12]. VOCs are regulated by law, especially indoors, where their concentrations are the highest. The United States Environmental Protection Agency [13] has found concentrations of VOCs in indoor air to be 2 to 5 times greater than in outdoor air and sometimes much higher. During certain activities, indoor levels of VOCs may reach 1,000 times that of the outside air. Jones [14] reported that individual VOC emissions are not that high in an indoor environment, but the indoor total VOCs (TVOCs) concentrations can be up to five times higher than the VOCs outdoor levels. Therefore, it is important to measure VOCs in indoor environment, where most people in developed countries spend up to 90% of their time indoors [11, 15], in order to assess their possible risk and to determine the source strengths of VOCs [16, 17].

Several studies have identified some organic compounds which can be used as markers for the particulate matter emitted air pollution sources [18-22]. For example, the carbonyls, which are the major species of organic compounds involved in photochemical air pollution, since the aldehydes and ketenes are the key products of photo-oxidation of gas-phase hydrocarbons [23, 24]. The ability of organic chemicals that cause health effects varies greatly from those that are highly toxic, to those with no known health effects. As with other pollutants, the extent and nature of the health effects will depend on many factors including level of exposure and length of exposure times. Up to now, there is not much known about what health effects caused by the levels of organics usually found in office. There are limited numbers of studies on the indoor microenvironment in Thailand. This study aimed to evaluate microenvironments of VOCs including benzene, toluene, ethyl-benzene, xylene (BTEX) and aldehydes of formaldehyde and acetaldehyde in ambient air and personal exposures in indoor-office workers, as well as assess their health risks and the relationship between ambient air concentrations and urinary biomarkers in the office workers.

MATERIALS AND METHODS

Study areas & Study subjects

Thirty-two indoor-office workers of 2 office buildings located in Pathumwan district, central Bangkok, Thailand were selected for this study. All indoor-office workers were healthy and had worked for more than six months. They were provided with a consent form before the study was begun. Permission to conduct cancer risk assessment from human subjects in this study was approved by the Ethical Review Committee for Research Involving Human Research Subjects, Health Science Group, Chulalongkorn University. The study was conducted in the summer of 2011.

Sample collections

Indoor ambient air and personal air samples were collected –using the active sampling method (8 hours during work time: 8.00 A.M.-16.00 P.M.). The sampling train system consisted of a 2,4 DNPH cartridge (for formaldehyde and acetaldehyde) and activated charcoal tube (for benzene, toluene, ethyl-benzene and xylene) connected to a low flow personal air pump. Both cartridge and charcoal tube were kept at 4^{o}C during transportation to the laboratory and stored in a refrigerator until their analysis.

Urine samples were collected from 32 office workers in glass containers and stored at -20^{o}C for the t, t-MA, formaldehyde, acetaldehyde and formic acid analyses.

Air sample analysis

The 2, 4-DNPH cartridge was extracted immediately after sampling collection, and was eluted with acetonitrile (ACN) and analyzed for the presence of formaldehyde, acetaldehyde and formic acid by the method of Morknoy [25]. For the detection of benzene, toluene, ethylbenzene and xylene, the activated charcoal was extracted with carbon disulfide (CS_2), and the sample solution was then analyzed by the Gas Chromatography/Flame Ionized Detector (GC/FID).

Urine samples analysis

All urinary samples were analyzed by GC/FID, as described by De Graff et al. [26]. All measured values were divided by urinary creatinine (Cr) concentration for clinical chemistry analysis [27]. The World Health Organization (WHO) has adopted guidelines for the acceptable limits of urinary creatinine concentrations to be between 0.3 and 3.0 g/L [28].

Cancer and non-cancer risk calculation

The inhalation exposures were estimated in terms of Chronic Daily Intake (CDI) for cancer and Exposure Concentration (EC) for non-cancer. The calculations of CDI and EC were done according to Risk Assessment Guidance for Superfund (RAGS) Part A and Part F approaches, respectively. They can be expressed as followed:

$$CDI = CA \times IR \times ET \times EF \times ED / (BW \times AT)$$

$$EC = CA \times ET \times EF \times ED/AT$$

Table 1 The reference values for carcinogenic and non-carcinogenic substances

Substances	Reference value			
	IUR $(\mu g/m^3)^{-1}$		SFI $(mg/kg/day)^{-1}$	
Carcinogenic substances				
Benzene	$7.8 \times 10\text{-}6^{a,b}$	$2.9 \times 10\text{-}5^{c}$	$2.73 \times 10\text{-}2^{b}$	0.1^{c}
Ethylbenzene	$1.1 \times 10\text{-}3^{b}$	$2.5 \times 10\text{-}6^{c}$	$3.85 \times 10\text{-}3^{b}$	0.0087^{c}
Formaldehyde	$1.3 \times 10\text{-}5^{a,b}$	$6 \times 10\text{-}6^{c}$	-	0.021^{c}
Acetaldehyde	$2.2 \times 10\text{-}6^{a,b}$	$2.7 \times 10\text{-}6^{c}$	-	0.01^{c}
Non-carcinogenic substances	RfC (mg/m^3)			
Toluene	$5.0^{a,b}$			
Xylenes	$0.1^{a,b}$			

[a] Integrated Risk Information System (IRIS), 2010
[b] The Risk Assessment Information System (RAIS), 2009
[c] Office of Environmental Health Hazard Assessment (OEHHA), 2003

Where; CDI (mg/kg/d) = Chronic Daily Intake
= Average Daily Dose (ADD) for non-cancer

EC ($\mu g/m^3$) = Exposure Concentration
CA (mg/m^3) = Contaminant concentration in Air
IR (m^3/h) = Inhalation Rate (0.875 m^3/h assumed for adult)
BW (kg) = Body Weight (60 kg, average body weight of workers)
ET (h/d) = Exposure Time (8 h/d for workers)
EF (d/y) = Exposure Frequency (350 d/y assumed for workers)
ED (y) = Exposure Duration (30 y for workers)
AT (d) = Averaging Time (70 y × 365 for cancer or ED × 365 for non-cancer)

Cancer risk was evaluated by multiplying CDI by inhalation cancer slope factor (CSF_i).
Hazard quotient (HQ) for non-cancer can be calculated by dividing EC by the reference concentration for inhalation (RfC), as following equations.

Cancer risk = CDI × CSF_i

Risk = IUR × EC
IUR = Inhalation Unit Risk $[(\mu g/m^3)^{-1}]$

Where; Cancer risk > 1.00E-6 means Carcinogenic effects of concern
Cancer risk ≤ 1.00E-6 means Acceptable level

HQ = ADD/RfD

RfD = Reference dose for inhalation
HQ = EC/(RfC × 1000 μg/mg)

Where; HQ > 1 means Adverse non-carcinogenic effects of concern
HQ ≤ 1 means Acceptable level

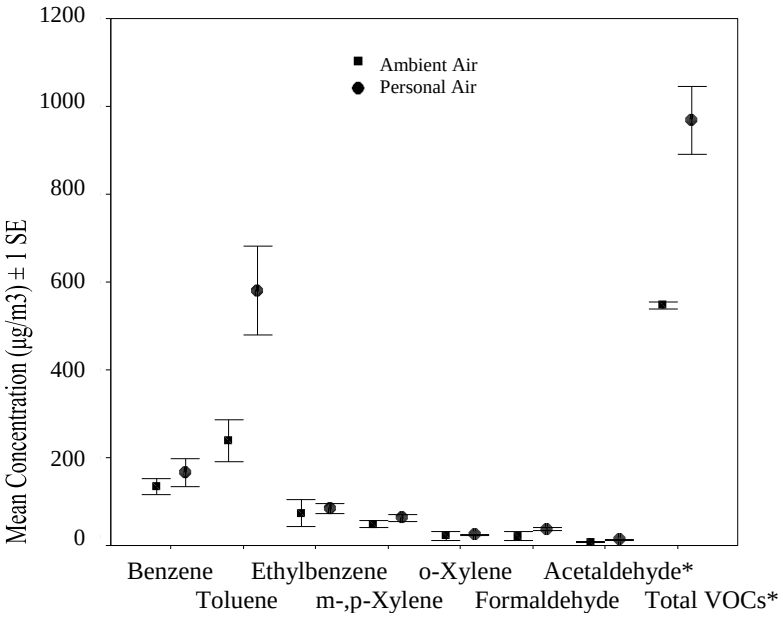
The reference values for carcinogenic and non-carcinogenic substances were shown in Table 1**.**

Statistical analysis
All analytical measurements were performed in duplication to give value with standard error. All analyses were carried out with SPSS 17.0 for Windows statistical software package. Descriptive statistical analysis was evaluated on concentrations of parameters. Independent t-test was computed to compare between ambient and personal air concentrations and Spearman's rho correlation was done for correlation between them. Linear regression was estimated association between the ambient air concentrations and urinary biomarker parameters.

RESULTS

Exposure assessment
Mean age of indoor-official workers was 35.79 years. The average ambient air benzene, toluene, ethyl-benzene, *m-*,*p*-xylene, *o*-xylene, formaldehyde and acetaldehyde were 134.34, 239.28, 73.73, 48.46, 22.24, 21.16 and 7.42 $\mu g/m^3$ while the average personal air benzene, toluene, ethylbenzene, *m-*, *p*-xylene, *o*-xylene, formaldehyde and acetaldehyde were 165.70, 580.50, 84.45, 62.86, 24.52, 14.11 and 1.35 $\mu g/m^3$ respectively (Figure 1). Each of ambient air was not significantly difference compared to personal air exposures except acetaldehyde. But total ambient air concentration was significantly lower than personal air exposure (Independent t-test, $p<0.05$).

Correlation between ambient air and personal air exposures
The Spearman's rho-correlation analysis showed that all ambient air concentrations were strongly



*Significant difference between ambient air and personal air exposures at $p<0.05$

Figure 1 Ambient air and personal exposures of office workers

Table 2 The Spearman's rho-correlation[a] between ambient and personal air exposures of workers

Parameter	Personal Benzene	Personal Toluene	Personal Ethylbenzene	Personal m-, p-Xylene	Personal o-Xylene	Personal TXylene	Personal BTEX	Personal Formaldehyde	Personal Acetaldehyde
Ambient	**1.000**	-0.903	-0.001	0.858	0.449	0.813	-0.656	0.314	0.008
Benzene	**(*0.000*)**	(*0.097*)	(*0.999*)	(*0.142*)	(*0.551*)	(*0.187*)	(*0.344*)	(*0.686*)	(*0.992*)
Ambient		**1.000**	0.413	-0.586	-0.156	-0.532	0.917	-0.532	0.214
Toluene		**(*0.000*)**	(*0.587*)	(*0.414*)	(*0.844*)	(*0.468*)	(*0.0830*)	(*0.468*)	(*0.786*)
Ambient			**1.000**	0.339	0.355	0.350	0.724	-0.335	0.740
Ethylbenzene			**(*0.000*)**	(*0.661*)	(*0.645*)	(*0.650*)	(*0.2760*)	(*0.665*)	(*0.260*)
Ambient m-,				**1.000**	0.822	0.996	-0.223	-0.187	-0.001
p-Xylene				**(*0.000*)**	(*0.178*)	(*0.004*)	(*0.767*)	(*0.813*)	(*0.999*)
Ambient					**1.000**	0.870	0.140	-0.706	-0.285
o-Xylene					**(*0.000*)**	(*0.130*)	(*0.860*)	(*0.294*)	(*0.715*)
Ambient						**1.000**	-0.179	-0.274	-0.047
TXylene						**(*0.000*)**	(0.821)	(*0.726*)	(*0.953*)
Ambient							**1.000**	-0.640	0.385
BTEX							**(*0.000*)**	(*0.360*)	(*0.615*)
Ambient								**1.000**	0.353
Formaldehyde								**(*0.000*)**	(*0.698*)
Ambient									**1.000**
Acetaldehyde									**(*0.000*)**

[a]Spearman's rho-correlation r (*p-value*)
TXylene = Total Xylene
BTEX = Benzene + Xylene + Ethylbenzene + Xylene

and positively correlated to personal concentration exposures (r=1.000, $p<0.001$) (Table 2)

Cancer risk and non-cancer assessments

Risk assessment of indoor-official workers was calculated by using Chronic Daily Intake (CDI) for cancer and Exposure Concentration (EC) for non cancer. Our results showed that the CDI for benzene, ethylbenzene, formaldehyde and acetaldehyde were 5.84E-03 – 7.58E-03, 2.14E-03 – 5.23E-03, 0.56E-03 – 1.56E-03, 3.42E-04 – 3.99E-04 mg/kg/d respectively. While the exposure concentrations (EC) of these compounds were found to be in the range of 13.65 – 17.70, 5.01 – 12.20, 1.30 – 3.63, 0.80 – 0.93 µg/m^3 (Table 3). The averages life time cancer risk range of benzene, ethylbenzene, formaldehyde and acetaldehyde in indoor-official workers were 1.58E-04 – 2.05E-04, 8.26E-06 - 2.01E-05, 2.54E-05 – 7.08E-05 and 2.63E-06 – 3.08E-06, respectively, which the cancer risks of benzene, ethylbenzene and

Table 3 Average life time cancer risk and hazard quotients (HQ) assessments of indoor-official workers

Parameter	CDI (mg/kg/d)	Average Life Time Cancer Risk	EC (µg/m^3)	Average HQ
Benzene	5.84E-03 – 7.58E-03	1.58E-04 – 2.05E-04	13.65 – 17.70	0.001 – 0.002
Ethylbenzene	2.14E-03 – 5.23E-02	8.26E-06 - 2.01E-05	5.01 – 12.20	0.000 – 0.000
Formaldehyde	0.56E-03 – 1.56E-03	2.54E-05 – 7.08E-05	1.30 – 3.63	0.000 – 0.001
Acetaldehyde	3.42E-04 – 3.99E-04	2.63E-06 – 3.08E-06	0.80 – 0.93	0.000 – 0.000
Toluene	9.60E-03 – 1.43E-02	-	22.39 – 33.44	0.000 – 0.000
m-, p-Xylene	2.02E-03 – 2.82E-03	-	8.29 – 5.70	0.000 – 0.000
o-Xylene	6.09E-04 – 1.62E-03	-	1.78 – 4.71	0.000 – 0.000
Sum of risk	-	9.0E-03 – 2.18E-02	-	0.001 – 0.003

Table 4 Association of exposures and urinary biomarkers of official workers

Ambient Air Exposures (µg/m^3) and Urinary Biomarkers (µg/g Cr)	Mean Concentration	Linear regression model results*		
		Standardized Coefficient	95% CI	*p-value*
Benzene (Exposure)	134.34			
t, t-MA	0.24	-8.374E-5	-0.019 to 0.018	0.993
Formaldehyde	50.13	0.362	-1.614 to 2.338	0.711
Acetaldehyde	90.92	-0.481	-2.987 to 2.025	0.698
Formic Acid	20.91	-0.685	-1.231 to 0.139	0.016
Toluene (Exposure)	239.28			
t, t-MA	0.24	3.074E-05	-0.007 to 0.007	0.993
Formaldehyde	50.13	-0.133	-0.858 to 0.592	0.711
Acetaldehyde	90.92	0.177	-0.743 to 1,096	0.698
Formic Acid	20.91	0.259	0.051 to 0.452	0.016
Ethylbenzene (Exposure)	73.73			
t, t-MA	0.24	-4.722E-05	-0.010 to 0.010	0.993
Formaldehyde	50.13	0.204	-0.910 to 1.318	0.711
Acetaldehyde	90.92	-0.271	-1.684 to 1.142	0.698
Formic Acid	20.91	-0.386	-0.694 to 0.078	0.016
m-,p-Xylene (Exposure)	48.46			
t, t-MA	0.24	0.000	-0.040 to 0.040	0.993
Formaldehyde	50.13	0.789	-3.519 to 5.097	0.711
Acetaldehyde	90.92	-1.049	-6.512 to 4.414	0.698
Formic Acid	20.91	-1.493	-2.683 to -0.303	0.016
o-Xylene (Exposure)	22.24			
t, t-MA	0.24	0.000	-0.032 to 0.032	0.993
Formaldehyde	50.13	0.625	-2.788 to 4.038	0.711
Acetaldehyde	90.92	-0.831	-5.159 to 3.497	0.698
Formic Acid	20.91	-1.183	-2.125 to -2.400	0.016
Formaldehyde (Exposure)	21.16 µg/m^3			
t, t-MA	0.24	-0.000	-0.032 to 0.032	0.993
Formaldehyde	50.13	-0.630	-4.070 to 2.810	0.711
Acetaldehyde	90.92	0.838	-3.525 to 5.201	0.698
Formic Acid	20.91	1.192	0.242 to 2.142	0.016
Acetaldehyde (Exposure)	7.42 µg/m^3			
t, t-MA	0.24	0.003	-0.550 to 0.555	0.993
Formaldehyde	50.13	-10.841	-7.036 to 48.353	0.711
Acetaldehyde	90.92	14.416	-60.657 to 89.488	0.698
Formic Acid	20.91	20.512	4.461 to 38.862	0.016
TVOCs (Exposures)	**546.62** µg/m^3			
t, t-MA	0.24	2.492E-03	-0.012 to 0.017	0.727
Formaldehyde	50.13	-0.201	-1.750 to 1.348	0.793
Acetaldehyde	90.92	0.317	-1.644 to 2.280	0.744
Formic Acid	20.91	-0.514	-0.945 to -0.083	0.021

*Adjust for age

formaldehyde were higher than the acceptable limit of 1.00E-06. Only the cancer risk of acetaldehyde was in the acceptable limit. Sum of cancer risk of workers was 9.0E-03 – 2.18E-02. For non-cancer risk, the hazard quotients (HQs) ranges of benzene, ethylbenzene, m-, p-xylene, o-xylene, formaldehyde and acetaldehyde in this study were 0.001- 0.002, 0.000 - 0.000, 0.000 – 0.000, 0.000 – 0.000, 0.000 – 0.001 and 0.000 – 0.000 respectively, while, the hazard index (sum of HQs, HI) was less than one (0.001 – 0.003).

Association between ambient air exposures and urinary biomarkers

The average concentrations of urinary t, t-MA, formaldehyde, acetaldehyde and formic acid were 0.24, 50.13, 90.92, 20.91 μg/g Cr, respectively (Table 4). The benzene, ethylbenzene, *m*-, *p*-xylene, *o*-xylene, formaldehyde and acetaldehyde exposures were not associated with urinary t, t-MA, formaldehyde, acetaldehyde but they were significantly and positively associated with formic acid (Linear regression analysis, $p<0.05$). The TVOCs was 546.62 μg/m^3, which was significantly and positively associated with formic acid (Linear regression analysis, $p<0.05$)

DISCUSSION

The occurrence and concentrations of VOCs in indoor environments can be affected by several factors such as outdoor atmospheric conditions, indoor sources, indoor volume, human activities, chemical reactions, ventilation rates, and seasonal factors [29-31]. These indoor sources of VOCs may have been originated from the adhesives and painting materials, which are generally used by the manufactures of these products. The previous study by Afshari et al. [32] found that water-based paints emitted significant amounts of toluene, xylenes, *n*-butanol and high molecular weight aliphatic hydrocarbons, depending upon the thickness of the paint layer. Their studies found that the ambient air concentration was the primary factor in determining indoor air quality, while infiltration of outdoor air could be substantially increased the indoor pollutants and thereby influenced the indoor air quality [33, 34]. In fact, some components in these emissions are highly reactive and may be contribute to the health damage such as benzene, ethylbenzene, formaldehyde and acetaldehyde as carcinogens [8].

The results of this study showed high exposures of benzene**,** ethylbenzene and formaldehyde concentrations higher than the acceptable limit. Among this VOCs, benzene was the highest caused of cancer, followed by formaldehyde, ethylbenzene and acetaldehyde. Since humans spend most of their lives indoors, it is necessary to minimize any exposure to VOCs. These indoor sources of VOCs may have been originated from the adhesives and painting materials, which are generally used by the manufactures of these products. The previous study by Afshari et al. [32] found that water-based paints emitted significant amounts of toluene, xylenes, *n*-butanol and high molecular weight aliphatic hydrocarbons, depending upon the thickness of the paint layer. Some other studies found that the ambient air concentration was the primary factor in determining indoor air quality, while infiltration of outdoor air could be substantially increased the indoor pollutants and thereby influenced the indoor air quality [34]. In fact, some components in these emissions are highly reactive and may be contribute to the health damage such as benzene, ethyl benzene, formaldehyde and acetaldehyde as carcinogens [8, 35].

However, exposure to the combinations of air pollutants is inevitable. Data dealing with the effects of co-exposure to air pollutants are very limited. In most cases, it is not possible to recommend guidelines for such combinations. World Health Organization (WHO) recommended the indoor concentrations of airborne benzene associated with an excess lifetime risk of 1.00E-04, 1.00E-05 and 1.00E-06 are 17.00, 1.70 and 0.17 μg/m^3 respectively, and these concentrations are not difference from outdoor concentrations [36]. Our results demonstrated that the indoor ambient air benzene was 134.34 μg/m^3, or 7.95 folds higher than the limited level (17.00 μg/m^3 as recommended by WHO).

Many studies carried out in other Asian's cities have found higher indoor benzene concentrations than those reported from cities in the developed world [37-40]. Formaldehyde and acetaldehyde are the most abundance of indoor office building than outdoor [41, 42] but results from our study exhibited lower level than the study by Ongwandee et al. [43]. Furthermore, we found that indoor ambient air VOC levels strongly correlated with personal exposures. But the personal exposure was higher than ambient air concentrations, which supported the previous studies that conducted in other countries such as USA [44], Turkey [45] and UK [17, 46].

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emitted significant amounts of toluene, xylenes, *n*-butanol and high molecular weight aliphatic hydrocarbons, depending upon the thickness of the paint layer. Leong et al. [34] found that the ambient air concentration was the primary factor in determining indoor air quality, while infiltration of outdoor air could be substantially increased the indoor pollutants and thereby influenced the indoor air quality. In fact, some components in these emissions are highly reactive and may be contribute to the health damage such as benzene, ethylbenzene, formaldehyde and acetaldehyde as carcinogens [8].

The Hazard Quotients (HQs) of benzene and formaldehyde were 0.001 – 0.002 and 0.000 – 0.001 but the HQs of the other VOCs were zero, and all were less than one. These sources of VOCs can be reduced by increasing outdoor air ventilation. However, this entails increased costs in building construction, operation, and energy [47]. Low VOC-emitting materials are being developed and are used more widely in buildings to help achieve healthier and more productive indoor environments. Leong et al. [34] in their preliminary study of relationship between outdoor and indoor air pollutant concentrations at Bangkok's major streets found that the pollutant levels inside the building were due to inadequate ventilation and air infiltration of outdoor air pollutants emitted from vehicular emissions with little or no contribution from indoor sources.

Higher doses of the exposures may overwhelm the metabolic capacities and led to the presence of un-metabolites which may be remained in urine. Therefore, the urinary t, t-MA, formaldehyde, acetaldehyde and formic acid could be used as biomarkers of these exposures [48-51]. Each of VOCs and TVOCs reported in this study were associated with urinary formic acid ($p<0.05$).

Sufficient assessment of the hazards, risks of indoor environments and the regulation of indoor air pollutants such as benzene, ethylbenzene, formaldehyde and acetaldehyde are necessary to protect human health, especially children and people who are sensitive to these chemicals. Therefore, from a practical standpoint, it is an expedient to reduce indoor exposure levels to as low as possible. This will require reducing or eliminating human activities that released these VOCs, such as smoking tobacco, using solvents for hobbies or cleaning, or using building materials that off-gas VOCs.

CONCLUSIONS

Our results demonstrated that indoor-office workers had higher exposures of VOCs and led to higher risk of cancer. We found good correlations between ambient air VOCs and personal exposures in summer sampling periods. There were also strong associations of each ambient gas-phase organic compounds and urinary formic acid. Urinary formic acid could be considered as a good biomarker for monitoring of VOCs exposures. Increasing awareness of consequences indoor air quality and a health promotion program for maintaining a healthy and comfortable working environment must be exercised.

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