Health Risk Assessment of BTEXS Exposure in Photocopy Centers

Aungsiri Tipayarom*

Abstract

Photocopier is a machine generally used in most office. In making a copy, volatile organic compounds (VOCs) especially benzene, toluene, ethylbenzene, xylenes, and styrene (BTEXS) are released. Inhalation of these VOCs could cause health effects to the workers. The objective of this study was to determine the concentrations of BTEXS that the workers exposed in the working area and assess their health risks. The study had employed three different photocopy centers and monitored the concentrations of BTEXS obtained from the breathing zone of the workers. Samples were taken the first two weeks of the semester and throughout the semester. The results showed that the concentrations of BTEXS depended on the numbers of the photocopier, ventilation system and space in the photocopy centers. For all the centers, the highest concentrations of each compound found at the breathing zone of the workers were 2.26, 11.47, 1.52, 4.31 and 0.46 $\mu g.m^{-3}$, respectively. The concentrations of BTEXS were used to determine the health risk. For non-cancer risk assessment, the HQ less than $88.84x10^{-4}$ indicated that no health effect could be caused by BTEXS. For cancer risk, only benzene was assessed and the result showed its risk of less than 0.5 per 1,000,000 people.

Keywords : Photocopier, BTEXS, Occupational health, Health risk assessment

Department of Environmental Science, Faculty of Science Silpakorn University.

* Corresponding author, E-mail: aungsiri@gmail.com Received 22 September 2014, Accepted 8 December 2014

1. Introduction

A Photocopier is common office equipment generally used to make cheap and quick copies of documents and other visual images. In the process of making a copy, the toner which contained BTEXS has released considerable amount of compounds that may affect workers' health. In earlier studies, experiments on photocopier BTEXS emissions were conducted with the environmental test chamber and the measurements at the photocopy center. Leovic et al. [1], Brown [2] and Hsu et al. [3] reported VOCs emissions from dry-process photocopiers in an environmental test chamber while Lee et al. [4] quantitatively characterized the emission rates of total and individual VOCs from the photocopiers. Lee and Hsu [5] measured BTEXS (benzene, toluene, ethylbenzene, xylenes and styrene) emissions at 12 photocopy centers in Taiwan and found that toluene and styrene were the most abundant compounds among those VOCs and BTEXS. However, only few studies had been done to determine the effect of BTEXS on human exposure [6-8] and none reported the risk assessment on their health.

Emissions from photocopier can cause several adverse health effects, especially when prevention measures are not concerned. Son et al. [9] suggested that VOCs present at low concentrations may not have acute effect but a long-term exposure could result in mutagenic and life-time cancer risks to people. Workers in the photocopy center are the high risk group that could be affected by VOCs, particularly BTEXS. In this study, three different sizes and characteristics (ventilation system, number of copiers) of the photocopy centers at Silpakorn University were employed as the case study. The sizes and characteristics of these three photocopy centers are similar to those normally found in the office where the copying is performed. Therefore, the concentrations found from this study may be comparable to those found in similar offices and the risk assessment may be used to evaluate their personnel health risks.

The objective of this study was to determine the concentrations of benzene, toluene, ethyl benzene, xylenes and styrene that the workers exposed from the photocopy working area and assess the risks on their health.

2. Materials and Methods

2.1 Sampling site and study group

Three photocopy centers at Silpakorn University Thailand (denoted as center A, B and C) were chosen to represent the different sizes of photocopy working areas. Besides, these centers were also different in their physical characteristics (wide-opened/push-and-pull door, window) as well as the activity within the centers, the numbers of the photocopier and ventilation system (electric fan, air condition). These characteristics were recorded and compared. The ventilation conditions were determined by measuring air velocity and air flow. The Compu Flow Thermo Anemometer, ALNOR, Model 8585 was used to determine air movement and air change within the room.

Preliminary survey found that the orders of photocopy were higher during first two weeks of the semester than later periods during semester. Therefore, the study was done by taking the samples at two periods of time: during first two weeks of the semester to represent high service period and the rest of the semester after the first two weeks to represent normal service period.

All workers in center A (1 people), B (2 people) and C (2 people) were subjects in this study. The workers in center A and B worked 8 $hr.d^{-1}$ and 5 $d.w^{-1}$ while the workers in center C worked 10 $hr.d^{-1}$ and 5 $d.w^{-1}$.

2.2 BTEXS sampling and analysis

Total 120 air samples were taken from three photocopy centers during first two weeks of the semester and during the period after the first two weeks (November 2012 – February 2013). The air sample was collected by passive Carbopack B sorbent tubes (Sigma-Aldrich Co. LLC., St.Louis, MO, USA) that was attached to the workers' breathing zone for 8 to 10 hrs depending on their working shifts.

Determination of the sampling rate for passive Carbopack B sorbent tube was obtained from Environmental Research and Training Center. To determine the sampling rate, the canister together with Carbopack B tubes were placed for the same periods of time during sampling. The results of BTEXS concentration obtained from canister and Carbopack B tube were related. The plotted of the relationship was used to determine the sampling rate as followed the in house method of Environmental Research and Training Center [10].

The analysis of BTEXS was performed by GC-MS (SHIMADZU, QP 5000, Columbia, Maryland, USA) equipped with Thermal Desorption Unit (MARKES International Ltd., Rhondda Cynon Taff, United Kingdom) as follow the US EPA Method TO-17 [11]. The Carbopack B sorbent tubes were purged by nitrogen gas (99.9999%) for 10 minutes to remove humidity and oxygen, then, desorbed to a charcoal trap by pure helium gas (99.9999%) at flow rate 1.3 $mL.min^{-1}$ and temperature of 300^{o}C for 10 minutes. BTEXS were trapped to -30^{o}C GC column (Agilent J&W GC column; 60 m length with internal diameter of 0.32 mm, Santa Clara, CA, USA) with liquid nitrogen and quantified each of the concentrations by external standard and their calibration curves. Breakthrough checking and blank analysis were also conducted for quality control and assurance. Detection limits of benzene, toluene, ethylbenzene, xylenes and styrene were 0.15, 0.14, 0.45, 1.88 and 0.04 $\mu g.m^{-3}$, respectively.

The statistical analysis with paired sample t-test at $p < 0.05$ was employed to determine the differences of BTEXS concentrations obtained from different photocopy centers and to determine the differences between two sampling periods: during first two weeks of the semester and the period after the first two weeks.

2.3 Risk assessment

From the concentrations of BTEXS found in the breathing zone of the workers, the intake of BTEXS exposure (I) is determined by using Eq. (1) [12].

$$\text{Intake } (mg.m^{-3}.d^{-1}) = (CA \times IR \times ET \times EF \times ED) / (BW \times AT) \quad (1)$$

where the concentration in BTEXS is expressed in $mg.m^{-3}$, IR the inhalation rate, ET the exposure time, EF the exposure frequency, ED the duration of exposure, BW the body weight, and AT the time period over which exposure is averaged.

The risk for non-carcinogen is assessed from hazard quotient (HQ) which is derived from the ratio of the intake rate (I) to the reference dose (R_fD) or

$$HQ = I/R_fD \quad (2)$$

Reference dose of BTEXS shown in Table 1 was retrieved from EPA's Integrated Risk Information System. In case of several compounds with the same toxic effect, Risk is calculated from Eq. (3) [13].

$$Risk = \sum HQ = I_1/R_fD_1 + I_2/R_fD_2 + \ldots\ldots I_n/R_fD_n \quad (3)$$

Where I_1, I_2, I_3,… I_n was intake of compound 1, 2, 3…..n and R_fD_1, R_fD_2, ,… R_fD_n was reference dose of compound 1, 2,…..n.

A ratio of 1.0 or above for the hazard quotient indicates a toxic effect is likely while conversely a ratio of < 0.5 indicates a low risk. For benzene, the slope factor of 0.029 $mg.kg^{-1}$ [13] was used to calculated cancer risk by multiplying intake with the slope factor (Risk = intake x slope factor).

Table 1 Inhalation slope factor and reference dose for BTEXS

Compound	Slope factor $(mg.kg^{-1}.d^{-1})^{-1}$	Reference dose* $(mg.kg^{-1}.d^{-1})$
Benzene	0.029 [15]	0.00855 [15]
Toluene	—	1.4 [16]
Ethylbenzene	—	0.286 [17]
Xylenes	—	0.029 [19]
Styrene	—	0.285 [19]

Note: Inhalation R_fDs are based on the R_fD_i $(mg.kg^{-1}.d^{-1})$ = R_fC $(mg.m^{-3})$ x 20 $m^3.d^{-1}$ x 1/64.73 kg where 20 $m^3.d^{-1}$ is assumed adult inhalation rate and 64.73 kg is adult body weight [14]

3. Results and Discussion

3.1 Sampling site characteristics

The photocopy centers used in this study differed in terms of the numbers of the photocopier (Table 2) but similar in their activities. From the preliminary survey, it was found that all centers had higher photocopy orders during first two weeks of the semester than during the period after the first two weeks. In term of room sizes and numbers of the photocopier, center B had the biggest room volume (90 m^{-3}) while the numbers of the photocopier was the lowest (3 photocopier). The differences in room volume and number of photocopier may result in the concentrations of BTEXS in the centers. In evaluation of these factors, center A and C could accumulate more BTEXS from the photocopiers than center B.

For ventilation, the ventilation in center C seemed to be better than those in center A and B because of its wide opened door and two exhausted fans that drive higher air movement within the center. This was consistent with the air velocity measurement in center C (151.2 $m.min^{-1}$) that was higher than those found at center A and B (58.8 and 31.4 $m.min^{-1}$ for center A and B, respectively) (Table 2). In addition, there was no air confined area in center C since all air velocity measurements were more than 0.85 – 1.42 $m.min^{-1}$.

Table 2 Characteristics of photocopy centers

	Center A	Center B	Center C
Room volume (m^3)	42	90	45
Number of copiers	4	3	5
Type of entrance[a]	A	B	A
Type of ventilation[b]	w, f	a	a, d, e
No. of exhaust fans	—[c]	—	2
Average air velocity ($m.min^{-1}$)[d]	58.8	31.4	151.2
Temperature (^oC)[e]	28.2	28.1	27.6
Air confined points[f]	—[g]	3	—
Working hours/week	40	40	70

[a] A: wide-opened; B: push-and-pull door, [b] a: air conditioner on; w: window open; d: door open; e: exhaust fan; f: floor fan, [c] no exhaust fan, [d] one-time measurement, [e] 8-hour average, [f] The positions having air velocity less than 0.85 – 1.42 $m.min^{-1}$, [g] no air confined point

For center B, the photocopier was set up in an air conditioned room without exhausted fan. The door was push-and pull type but normally closed. This obstructed the air flow into the center. In comparison of the ventilation of center A and center B, the air movement in center A was better than center B because center A had wide opened door.

In conclusion, the characteristics of the photocopy center probably have the effects on BTEXS accumulation. As the ventilation resulted from air circulation from a wide opened door and electric/exhaust fan, the room space (volume) and the number of the photocopier were considered as mentioned above, the concentrations of BTEXS in center A may be > center B > center C.

3.2 BTEXS concentrations in photocopy centers

For all photocopy centers, the concentrations of BTEXS obtained from the workers' breathing zone were found to be in the same way. The results showed the concentrations of BTEXS in the order of toluene > xylenes > benzene > ethylbenzene > styrene (Fig. 1). This sequence was the same in both sampling periods: during first two weeks of the semester and the period after the first two weeks. The highest concentration of toluene among other BEXS was also reported in earlier studies [6, 8, 20]. However, the concentrations found in this study was comparable to that found in Sarkhosh et al. [8], although it was a little lower to that reported in Lee et al. [20]. The concentration of BTEXS found in this study at all photocopy centers was much lower than permissible exposure limits suggested (Table 3) by OSHA and ACGIH [21].

Table 3 Permissible exposure limits in ($\mu g.m^{-3}$)

	OSHA		ACGIH	
	8-h TWA	10-h TWA[a]	8-h TWA	10-h TWA[a]
Benzene	$3.19x10^3$	$2.23x10^3$	$3.19x10^3$	$2.23x10^3$
Toluene	$7.54x10^5$	$5.29x10^5$	-[b]	-[b]
Ethylbenzene	$4.34x10^5$	$3.04x10^5$	$4.34x10^5$	$3.04x10^5$
Xylenes	$4.34x10^5$	$3.04x10^5$	$4.34x10^5$	$3.04x10^5$
Styrene	$4.26x10^5$	$2.98x10^5$	$2.13x10^5$	$1.49x10^5$

[a] Adjusted by reduction factor [22]

[b] Not available

For benzene, ethylbenzene and xylenes, the range of these concentrations found during semester sampling were between 1.06-1.80, 0.91-1.33 and 1.95-2.64 $\mu g.m^{-3}$, respectively. Compared to the range of these compounds obtained during first two weeks of the semester (1.55-2.26, 1.42-1.69 and 2.31-4.31 $\mu g.m^{-3}$ for benzene, ethylbenzene and xylenes respectively), the concentrations obtained during first two week of the semester were higher than those found during the period after the first two weeks more than half. For styrene, the concentrations obtained from all photocopy centers for both sampling periods were low and similar (Fig. 1). The toner probably composed of the low concentration of styrene.

3.3 Comparison of BTEXS concentrations between two sampling periods

BTEXS concentrations obtained from all photocopy centers during semester and during first two weeks of the semester were compared. Comparison for each of the compounds, the statistical analysis showed that the concentrations of each BTEXS obtained during the first two weeks of the semester were significantly higher than those obtained during the period after the first two weeks of the semester at $p<0.05$. For center A, the BTEXS concentrations obtained during first two weeks of the semester were 1.2.-1.6 times higher than those obtained during the period after the first two weeks. For center B, BTEXS concentrations during first two weeks of semester were 1-1.6 times higher while it was 1.2-2.2 times higher for center C. This result showed that BTEXS concentrations were depended upon their services. At the beginning of the semester, the orders of photocopy were higher due to students' hand out preparation.

3.4 Comparison of BTEXS among photocopy centers

Comparison of each of the compounds by center, the result showed that each BTEXS concentrations obtained from center C were lower than those found from center A and center B. This was probably due to the ventilation and the number of the photocopiers in each center. As mentioned earlier that the ventilation of center C was the best due to the wide opened door that allowed freely air movement. This is consistent with the lowest BTEXS concentrations found in both sampling periods. For center B, the air conditioning room with usually closed door obstructed the air to move into the room. This resulted in poor ventilation.

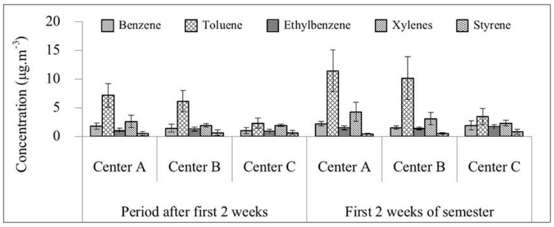

Fig. 1. Concentrations of BTEXS in photocopy centersNote : Center A and B were 8-h TWA, Center C were 10-h TWA

For center A, the air was higher ventilated than it was in center B. This was because the door of center A was wide opened and should, therefore, lower the BTEXS concentration. However, the smaller room space and more numbers of photocopiers had caused the higher BTEXS found in center A. In conclusion, BTEXS obtained from center C was statistically different from center A and B at $p<0.05$. Furthermore, the comparison between center A and B showed no significantly difference at $p<0.05$.

3.5 Health risk assessment

Using the BTEXS concentrations in each photocopy center, the intake rate of BTEXS ($mg.m^{-3}.d^{-1}$) is determined using Eq. (1) [12-13] where IR = 0.6 $m^{-3}.h$ [12], ET = 8 $h.d^{-1}$ for Center A and B and 10 $h.d^{-1}$ for Center C, EF = 140 $d.y^{-1}$ for during semester and 20 $d.y^{-1}$ for first two weeks of the semester, ED the duration of exposure = 25 y [23], BW = 64.73 kg [14], and, AT = ED x 365 $d.y^{-1}$ for non-carcinogen and 70 y x 365 $d.y^{-1}$ for carcinogen. On this basis, the intake rate of benzene, toluene, ethylbenzene, xylenes and styrene during the first two weeks of the semester were illustrated in Table 4 and Table 5).

The intake of each BTEXS was then used to calculate the hazard quotient (HQ) by Eq. (2). Table 4 showed that the hazard quotients of all BTEXS in both sampling periods were less than 1. These hazard quotients (between $0.07x10^{-4}$ to $88.84x10^{-4}$) suggest no direct detrimental effects from inhalation of BTEXS. However, BTEXS was the group of compounds that normally emitted from photocopier at the same time. As a result, risk of BTEXS exposure was recalculated from Eq. (3). Hence, the non-cancer risk of BTEXS to the exposed workers during semester was less than $88.84x10^{-4}$ and was less than $17.38x10^{-4}$ for the risk they obtained during first two weeks of the semester. As a result, the non-cancer risks for BTEXS exposure in all centers were relatively low and posed no adverse effect to the workers.

Table 4 Non-cancer risk for BTEXS for workers in center A, B and C

Compound	Intake ($mg.m^{-3}.d^{-1}$)		Risk	
	Period after the first two weeks	First two weeks of the semester	Period after the first two weeks	First two weeks of the semester
Center A				
Benzene	$5.12x10^{-5}$	$0.92x10^{-5}$	$59.88x10^{-4}$	$10.72x10^{-4}$
Toluene	$20.5x10^{-5}$	$4.66x10^{-5}$	$1.46x10^{-4}$	$0.33x10^{-4}$
Ethylbenzene	$3.01x10^{-5}$	$0.62x10^{-5}$	$1.05x10^{-4}$	$0.22x10^{-4}$
Xylenes	$7.51x10^{-5}$	$1.75x10^{-5}$	$25.89x10^{-4}$	$6.04x10^{-4}$
Styrene	$1.56x10^{-5}$	$0.19x10^{-5}$	$0.55x10^{-4}$	$0.07x10^{-4}$
Non-cancer risk for BTEXS			$88.84x10^{-4}$	$17.38x10^{-4}$
*Non-cancer risk for BTEXS in worst scenario**				$139.01x10^{-4}$
Center B				
Benzene	$4.21x10^{-5}$	$0.63x10^{-5}$	$49.23x10^{-4}$	$7.39x10^{-4}$
Toluene	$17.63x10^{-5}$	$4.14x10^{-5}$	$1.26x10^{-4}$	$0.30x10^{-4}$
Ethylbenzene	$3.78x10^{-5}$	$0.58x10^{-5}$	$1.32x10^{-4}$	$0.20x10^{-4}$
Xylenes	$5.57x10^{-5}$	$1.27x10^{-5}$	$19.22x10^{-4}$	$4.39x10^{-4}$
Styrene	$1.91x10^{-5}$	$0.22x10^{-5}$	$0.67x10^{-4}$	$0.08x10^{-4}$
Non-cancer risk for BTEXS			$71.71x10^{-4}$	$12.35x10^{-4}$
*Non-cancer risk for BTEXS in worst scenario**				$98.79x10^{-4}$
Center C				
Benzene	$3.77x10^{-5}$	$0.98x10^{-5}$	$44.08x10^{-4}$	$11.52x10^{-4}$
Toluene	$8.25x10^{-5}$	$2.55x10^{-5}$	$0.59x10^{-4}$	$0.18x10^{-4}$
Ethylbenzene	$3.24x10^{-5}$	$0.86x10^{-5}$	$1.13x10^{-4}$	$0.30x10^{-4}$
Xylenes	$6.93x10^{-5}$	$1.17x10^{-5}$	$23.91x10^{-4}$	$4.04x10^{-4}$
Styrene	$2.49x10^{-5}$	$0.44x10^{-5}$	$0.87x10^{-4}$	$0.15x10^{-4}$
Non-cancer risk for BTEXS			$70.58x10^{-4}$	$16.20x10^{-4}$
*Non-cancer risk for BTEXS in worst scenario**				$129.56x10^{-4}$

* In worst case scenario, the calculation was based on the high concentrations of each compound during first two weeks of the semester and exposure frequency = (140+20) = 160 $d.y^{-1}$

It was noticed that the non-cancer risks for BTEXS exposure for each centers were similar regardless the differences in their exposed concentrations (Table 4). This was true for both of the sampling periods. This result suggested that the differences among the center characteristics (the ventilation, the room space and the number of the photocopier) may be sensitive to show the differences in the exposed concentrations but they are not sensitive enough to detect the differences of the risk due to those concentrations.

In addition, for the worst scenario, the risk was calculated in term of the high concentrations found during first two weeks of the semester, the $\sum$HQ became less than 139.01×10^{-4} and it was suggested that BTEXS risk still low even with elevated ambient concentrations.

For benzene, the slope factor of 0.029 $mg.kg^{-1}.d^{-1}$ [13] was used to calculate cancer risk. The cancer risks from exposure to benzene during the semester for centers A, B, and C were 0.5, 0.4 and 0.4 per 1,000,000 people, respectively. The benzene cancer risks for all photocopy centers were the same as that was 0.1 per 1,000,000 people during first two weeks of the semester (Table 5).

In the worst case scenario, the cancer risk for benzene in all photocopy centers was less than 0.8 per 1,000,000 people (0.8×10^{-6}). This cancer risk was compared to the US EPA baseline value for cancer risk (1×10^{-6}), the cancer risk for benzene exposure was low.

Table 5 Benzene cancer risk for workers in center A, B and C

Compound	Intake ($mg.m^{-3}.d^{-1}$)		Risk (person per 1,000,000 people)	
	Period after the first two weeks	First two weeks of the semester	Period after the first two weeks	First two weeks of the semester
Center A				
Cancer risk[a]	1.83×10^{-5}	0.33×10^{-5}	0.5	0.1
Cancer risk for benzene in worst scenario[a]				0.8
Center B				
Cancer risk[a]	1.50×10^{-5}	0.23×10^{-5}	0.4	0.1
Cancer risk for benzene in worst scenario[a]				0.5
Center C				
Cancer risk[a]	1.35×10^{-5}	0.35×10^{-5}	0.4	0.1
Cancer risk for benzene in worst scenario[a]				0.8

[a] In worst case scenario, the calculation was based on the high concentrations of each compound during first two weeks of the semester and exposure frequency =(140+20)=160 $d.y^{-1}$

4. Conclusion

The study was conducted in three photocopy centers with differences in their physical, e.g. room space, door type, air conditioning, natural air, etc., and the numbers of photocopier. Consideration of these factors, the accumulation of BTEXS from photocopiers may be higher in center A > center B > center C.

The results of air sampling at the breathing zone of the workers showed that the concentrations of BTEXS were in the order of toluene > xylenes > benzene > ethylbenzene > styrene for all the photocopy centers. This sequence was the same in both sampling periods: during first two weeks of the semester and the period after the first two weeks. However, the concentrations of each BTEXS obtained during the first two weeks of the semester were significantly higher than those obtained during the period after the first two weeks at $p<0.05$.

Comparison of each of the compounds by center, BTEXS concentrations obtained from center A>center B> center C with statistically difference ($p<0.05$) between center A and B but no significant difference ($p<0.05$) between center A and center C and between center B and center C.

Adopted the concentrations of BTEXS found in all three photocopy center, the HQ for individual BTEXS were between 0.07×10^{-4} to 88.84×10^{-4} suggest no direct detrimental effects. When the non-cancer risk for all BTEXS was summarized, the risk on the exposed workers during semester was less than 88.84×10^{-4} and less than 17.38×10^{-4} during first two weeks of the semester. The risks were still low in both sampling periods and suggested that BTEXS concentrations in those three photocopy centers had no adverse effect on their workers.

For cancer risk, only benzene was assessed. The result showed that the cancer risks for the workers in these three photocopy centers were similar. During the semester, the cancer risk was less than 0.5 per 1,000,000 people and less than 0.1 per 1,000,000 people for the workers to expose to benzene during first two weeks of the semester.

Although this study had shown relatively low risk on non-cancer BTEXS and the cancer risk from benzene exposure, it was noticed that these risk could be higher when the exposure concentrations were higher. This study also showed the effects of the photocopier's activities on the exposed concentrations by comparing the concentration found during the first two weeks of the semester to the concentration found during the period after the first two weeks. As a result, the mitigation measures on this situation might start with having local exhaust ventilation, improvement of work place environment and increase workers' awareness of health risks.

5. Acknowledgement

The authors would thank the Environmental Research and Training Center (ERTC) for their assistance and cooperation in sampling and samples analysis. Faculty of Science, Silpakorn University is acknowledged for the partial financial support.

6. References

[1] K. Leovic, D. Whitaker, C. Northeim and L. Sheldon, "Evaluation of a Test Method for Measuring Indoor Air Emissions from Dry-process Photocopiers", Journal of Air & Waste Management Association 48, 1998, pp. 915-923.

[2] S.K. Brown, "Assessment of Pollutant Emissions from Dry-process Photocopiers", Indoor Air 9, 1999, pp. 259-267.

[3] D.J. Hsu, H.L. Huang, C.H. Chien and T.S. Lin, "Potential Exposure to VOCs Caused by Dry Process Photocopiers: Results from a Chamber Study", Bulletin of Environmental Contamination and Toxicology 75, 2005, pp. 1150-1155.

[4] S.C. Lee, S. Lam and H.K Fai, "Characterization of VOCs, Ozone, and PM10 Emissions from Office Equipment in an Environmental Chamber", Building and Environment 36, 2001, pp. 837-842.

[5] C.W. Lee and D.J. Hsu, "Measurements of Fine and Ultrafine Particles Formation in Photocopy Centers in Taiwan", Atmospheric Environment 41, 2007, pp. 6598-6609.

[6] A.B. Stefaniak, P.N. Breysse, M.P.M. Murray, B.C. Rooney and J. Schaefer, "An evaluation of Employee Exposure to Volatile Organic Compounds in Three Photocopy Centers", Environmental Research Section A 83, 2000, pp. 162-173.

[7] J.E.C. Lerner, E.Y. Sanchez, J.E. Sambeth and A.A. Porta, "Characterization and Health Risk Assessment of VOCs in Occupational Environments in Buenos Aires, Argentina", Atmospheric Environment 55, 2012, pp. 440-447.

[8] M. Sarkhosh, A.H. Mahvi, M.R. Zare, Y. Fakhri and H.R. Shamsolahi, "Indoor Contaminants from Hardcopy Devices: Characteristics of VOCs in Photocopy Centers", Atmospheric Environment 63, 2012, pp. 307-312.

[9] B. Son, P. Breysse and W. Yang, "Volatile Organic Compounds Concentrations in Residential Indoor and Outdoor and Its Personal Exposure in Korea", Environment International 29, 2003, pp. 79-85.

[10] Environmental Research and Training Center, "Technical Report: Establishment of Appropriate Methodology for Ambient VOCs Monitoring in Thailand", Environmental Research and Training Center, 2008.

[11] US EPA, "Compendium Method TO-17: Determination of Volatile Organic Compounds in Ambient Air Using Active Sampling onto Sorbent Tubes (2nd ed.)", US EPA, 1999.

[12] US EPA, "Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A)", US EPA, 1989.

[13] F.M. Dunnivant and E. Anders, "A Basic Introduction to Pollutant Fate and Transport", John Wiley & Sons, Inc., 2005.

[14] NSTDA, "SizeThailand", Available: http://www .sizethailand.org/sizechart.html, 22 August 2014.

[15] US EPA. "Integrated Risk Information System: Benzene (CASRN 71-43-2)", Available: http:// www.epa.gov/iris/subst/0276.htm, 21 August 2014.

[16] US EPA "Integrated Risk Information System: Toluene (CASRN 108-88-3)", Available: http:// www.epa.gov/iris/subst/0118.htm, 21 August 2014.

[17] US EPA. "Integrated Risk Information System: Ethylbenzene (CASRN 100-41-4)", Available: http://www.epa.gov/iris/subst/0051 .htm, 21 August 2014.

[18] US EPA, "Integrated Risk Information System: Xylenes (CASRN 1330-20-7)", Available: http: //www.epa.gov/iris/subst/0051.htm, 21 August 2014.

[19] US EPA, "Integrated risk information system: Styrene (CASRN 100-42-5)", Available: http:// www. epa.gov/iris/subst/0104.htm, 21 August 2014.

[20] C.W. Lee, Y.T. Dai, C.H. Chein and D.J. Hsu, "Characteristics and Health Impacts of Volatile Organic Compounds in Photocopy Centers", Environmental Research 100, 2006, pp. 139-149.

[21] NIOSH, "NIOSH Method 1501: Aromatic Hydrocarbons", Available: http://www.cdc.gov/ niosh/docs/2003-154/pdfs/1501.pdf, 22 August 2014.

[22] M. Kindley, "Adjusting Occupational Exposure Limits for Extended Work Shifts", Workplace Hygiene Corporate Office, 2014.

[23] US EPA, "Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Supplemental Guidance)", US EPA, 1991.