LEVELS OF SELECTED INDOOR AIR POLLUTANTS IN THREE HA NOI OFFICES

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ABSTRACT

A study on the levels of indoor air pollutants in Ha Noi was conducted. Three offices in Ha Noi were selected for this purpose. Selected indoor air pollutants including SO_2, NO_2 and respirable particulate matter (PM_{10}) were monitored in the wet and dry seasons of 2015. Air conditioners were turned on for the whole time, while air purifiers were turned on for haft of the time in each sampling site. An hourly measurement of outdoor levels was also conducted before indoor measurement. Levels of outdoor PM_{10} varied in the range of 13.4-106.0 $\mu g/m^3$. The level of indoor PM_{10} varied in the range of 3.5-25.1 $\mu g/m^3$. The average levels of indoor PM_{10} were lower than that of outdoor one in all cases. High time resolution data showed that indoor PM_{10} levels temporarily increased sharply by activities (walking and room sweeping) and high frequency of opening the doors. Concentrations of outdoor/indoor SO_2 varied in the range of < 0.4-34.5 /< 0.4-47.1 ppb. Concentrations of outdoor/indoor NO_2 varied in the range of 4.3-33.4/3.3-27.8 ppb.

Keywords: indoor air pollution, PM_{10}, SO_2, NO_2, air purifier, offices.

1. INTRODUCTION

Nowadays, people tend to spend more time of their daily life in closed spaces thus resulting in an increasing rate of healthy problems due to the indoor air pollution. WHO (2018) has released a news saying that indoor air pollution leads to earlier death of 4 million people each year worldwide [1]. Skolnick [2] reported that a population living in the tight energy efficient buildings contracted upper respiratory diseases at rates 46 to 50 % higher than a compared group living in better ventilated houses.

Researches on indoor air quality in Ha Noi as well as in Viet Nam are scarce. Recently, Quang *et al.* conducted a study on the number concentration of ultrafine particles in indoor and outdoor air in Ha Noi [3]. Occurrence of phthalate diesters in indoor air in northern Viet Nam was investigated by Tran *et al.* [4]. Tran *et al.* studied about cyclic and linear siloxanes in indoor air in northern cities in Viet Nam [5]. The levels of indoor airborne black carbon in Ha Noi was assessed by Tran *et al.* [6]. Indoor PM_{10}, SO_2 and NO_2 have not yet been investigated in Viet Nam as far as we know. This study is designed to determine the levels of those pollutants in Ha Noi offices.

2. MATERIALS AND METHODS

2.1. Monitoring design

Monitoring sites were selected to represent for three levels of air quality: good, average and bad. Map of the sites is presented in Figure 1. The sites were chosen provided that no specific pollutant source such as cooking, incense burning, *etc.* can directly affect indoor air quality. Both indoor and outdoor air quality were monitored in each site. Details of indoor sites and sampling positions are presented in Figure 2. Outdoor sampling positions were selected in a manner representing for ambient air quality meaning that they were not directly affected by local sources and not so close to any obstructed objects such as wall. The inlets of indoor and outdoor samplers were at 1.5-meter height. Schedule for the monitoring of indoor and outdoor air quality is presented in Table 1. The monitoring was conducted in two periods, the dry and wet seasons. For the wet season, the monitoring campaign was conducted from 15th July to the beginning of August 2015. In the dry season, the monitoring campaign was conducted from 10th Nov. 2015 to 25th Nov. 2015. All sampling days were in the weekdays without raining. Air conditioners were turned on at least 30 minutes before measurement in all sites. Air purifiers were turned on in 2/4 invested days in each site. All activities in the room during the sampling period were also recorded.

Table 1. Schedule for monitoring of indoor and outdoor air at the office sites.

		1st day	2nd day	3rd day	4th day
Indoor	PM_{10} measurement	10 ↔ 18	10 ↔ 18	10 ↔ 18	10 ↔ 18
	NO_2, SO_2 sampling	10 ↔ 11 17 ↔ 18	10 ↔ 11 17 ↔ 18	10 ↔ 11 17 ↔ 18	10 ↔ 11 17 ↔ 18
Outdoor	PM_{10} measurement	9 ↔ 10	9 ↔ 10	9 ↔ 10	9 ↔ 10
	NO_2, SO_2 sampling	9 ↔ 10	9 ↔ 10	9 ↔ 10	9 ↔ 10

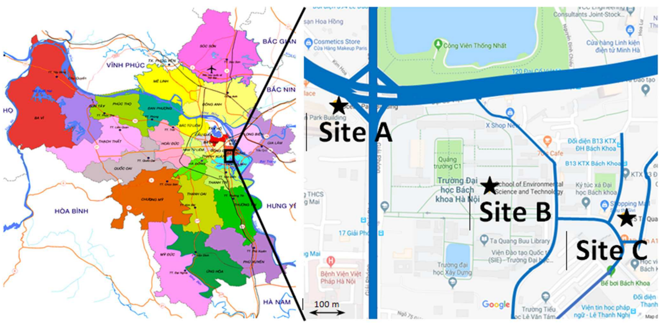


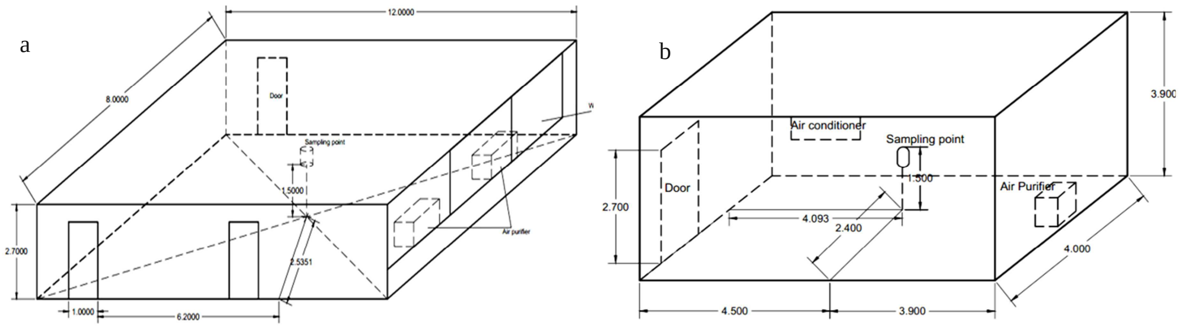
Figure 1. Map of monitoring sites.

2.2. The methodology of measurement

PM_{10} concentrations were directly measured onsite by AEROCET 531S (Met One) based on the principle of light scattering method with measuring range from 0 to 1,000 µg/m^3. The collection of SO_2 and NO_2 samples were done using absorption method with Kimoto pump at a flow rate of 0.5 L/min in 60 minutes. SO_2 from air was absorbed by the solution of potassium tetrachloromercurate (TCM) and NO_2 was absorbed by the solution of sodium hydroxide and sodium arsenite. The amount of SO_2 collected during sampling was determined colorimetrically accordance with MASA 704A method and the amount of NO_2 was determined by reacting the nitrite ion with phosphoric acid, sulfanilamide, and N-(1-naphthyl)-ethylenediamine dihydrochloride (NEDA) and measuring the absorbance of the highly colored azodye at 540 nm (MASA 406 method).

2.3. Data analysis

Statistical analysis (t-test) was carried by R software version 3.4.1.



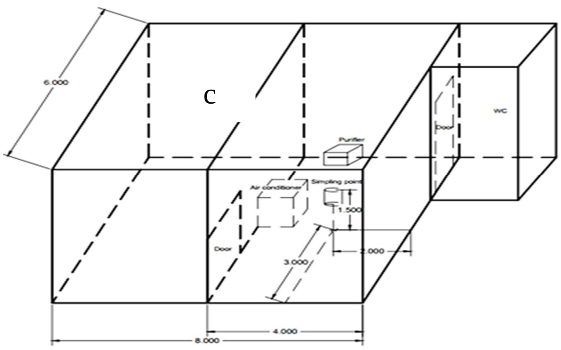


Figure 2. Description of sites: a) A site, air conditioner is a Cassette type; the indoor site is a meeting room located at the 13nd floor, the outdoor site is located at the 19th floor, b) B site, a working room located at 3rd floor in a university building adjacent with 2 main roads and a small road but more than 100 m away from each road. People coming in and out at high frequency; c) C site is at 1st floor, near a mechanical pilot laboratory.

3. RESULTS AND DISCUSSION

3.1. PM_{10} concentrations

The levels of PM_{10} during the sampling time are presented in Table 2. As shown in Table 2, the PM_{10} levels varied with the monitoring sites and the seasons. The outdoor PM_{10} concentrations of the 3 sites were from 10.8 to 67.8 (mean = 38.2) µg/m^3 in the wet season and from 13.4 to 106.0 (mean = 42.5) µg/m^3 in the dry season. The PM_{10} concentration in this study is lower but comparable with previous research of Thuy *et al.* in which PM_{10} concentration was of 106.47 ± 63.95 µg m^{-3} [7]. Outdoor PM_{10} concentrations on some monitoring days were higher than WHO guideline of 50 µg/m^3 for daily average [8]. On the contrary, the indoor PM_{10}

concentrations of these sites in the wet season and dry season were lower than the level of WHO guideline: the range were 3.5-25.1 (mean = 13.3) µg/m^3 and 3.7-24.7 (mean = 11.2) µg/m^3, respectively. Research of Oh *et al.* showed that the levels of indoor PM_{10} reached the range of 66.7 µg/m^3-101.0 µg/m^3 for 10 different childcare centers in Korea, which were much higher than those in this study although air conditioners and air purifiers were installed and fully operated in almost all of those centers (7 of 10 sites having air purifiers turned on during sampling time and the remaining sites having only air conditioners turned on) [9].

It is documented that indoor to outdoor (I/O) ratios of PM_{10} are close to 1 when no smokers are presented [10]. The I/O ratios are normally calculated based on simulated data. In this research, outdoor levels were measured in the period of 1 hour and earlier than indoor measurement (Figure 3). Those I/O ratios of PM_{10} concentrations in this study were significantly lower than 1 in all tests (data were not shown). Those low I/O ratios implied the good effect of air conditioners on the reduction of PM_{10} level. I/O ratio is the lowest in site A. The reason is that site A is a meeting room at elevated height and air was mainly exchanged though central air conditioner, and there was almost no activity in the room. Whereas, site C is located near a mechanical pilot experiment room and site B had a high frequency of opening the doors. To determine the effect of air purifier on PM_{10} removal, we conducted t-test analysis between groups of indoor PM_{10} concentrations when air purifiers were turned on and off. The t-test analysis showed that the difference of indoor PM_{10} between the two conditions were not statistical significant with p value > 0.05.

Table 2. Average level of PM_{10} (µg/m^3).

Site	Air purifier	Wet season			Dry season		
		Date	Outdoor (*µg/m^3*)	Indoor (*µg/m^3*)	Date	Outdoor (*µg/m^3*)	Indoor (*µg/m^3*)
A	OFF	23-Jul	57.9 ± 7.3	3.5 ± 2.4	10-Nov	31.6 ± 12.3	5.7 ± 4.0
		24-Jul	61.7 ± 10.8	10.8 ± 11.4	11-Nov	25.2 ± 6.0	5.8 ± 3.0
	ON	27-Jul	47.2 ± 7.6	7.7 ± 5.9	12-Nov	30.4 ± 1.6	4.3 ± 3.3
		06-Aug	10.8 ± 2.0	4.0 ± 2.6	16-Nov	42.8 ± 7.7	3.7 ± 3.5
B	OFF	29-Jul	12.9 ± 3.4	11.5 ± 5.9	10-Nov	13.4 ± 3.5	8.5 ± 5.6
		31-Jul	38.8 ± 10.0	24.1 ± 10.0	11-Nov	26.8 ± 6.9	15.2 ± 6.7
	ON	04-Aug	23.5 ± 2.7	16.0 ± 32.6	12-Nov	14.5 ± 1.8	5.0 ± 2.6
		05-Aug	43.1 ± 5.8	10.9 ± 6.7	13-Nov	27.7 ± 3.7	6.1 ± 4.5
C	OFF	21-Jul	27.4 ± 8.6	25.1 ± 15.2	17-Nov	55.5 ± 22.9	17.2 ± 8.4
		23-Jul	67.8 ± 41.3	13.8 ± 6.5	18-Nov	106.0 ± 26.9	24.7 ± 13.7
	ON	24-Jul	44.5 ± 8.7	15.1 ± 13.0	19-Nov	64.0 ± 14.3	16.9 ± 15.0
		25-Jul	22.5 ± 13.3	17.3 ± 7.4	20-Nov	71.6 ± 19.0	21.6 ± 15.1

3.2. Dynamic nature of indoor PM_{10}

The dynamic nature of indoor PM_{10} was clearly observed in this study. Different factors including number of people and their activities in the room clearly affected the levels of PM_{10}. Examples of the variation in the concentration of PM_{10} in different cases are presented in Figure 3. When there was no activity in the room, PM_{10} was stably low as in Figure 3a. PM_{10} increased about three times comparing with normal conditions when there were activities such as performance as presented in Figure 3b. Similarly, room sweeping activity could make the level of PM_{10} increasing abruptly from a level lower than 20 μg/m^3 to 10 folds higher (as shown in Figure 3c). The peak existed in a very short time. This phenomenon happened because such activities made the settled PM_{10} to resuspend. Figure 3d presents the large variations of PM_{10} in a room in which door was opened at frequency of about 1 time every 3 minute. The reasons for high levels of indoor PM_{10} can be explained as following. When the door was opened more frequently, more PM_{10} from outside entering the room. Besides that, the actions of opening the doors and moving of the people doing that can also make settled particles to resuspend.

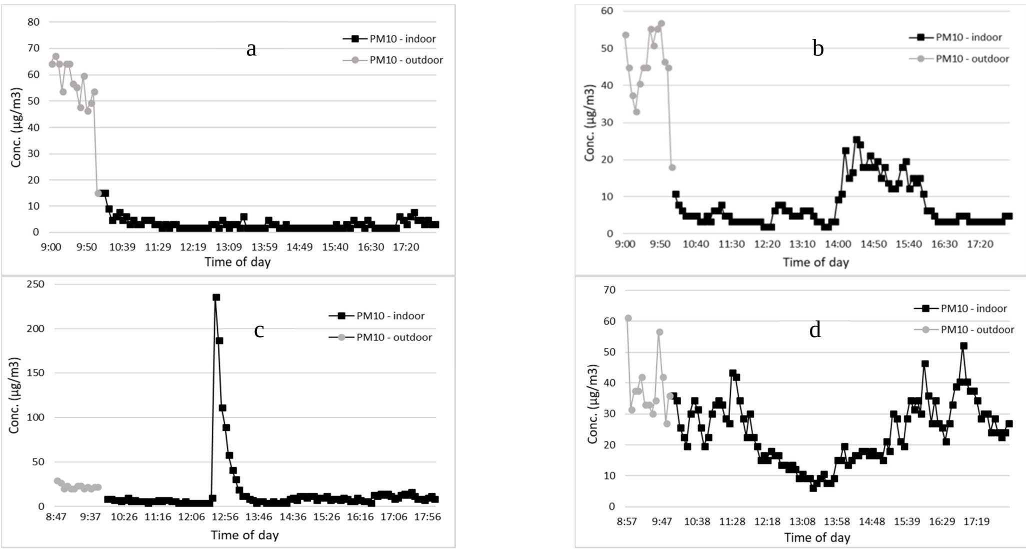


Figure 3. Variations in PM_{10} levels a) when there was no activity in a new, clean room; b) performance practice of dozen people in the room from 14 to 16 h; c) the room was swept from 12:36; d) when the door was opened at high frequency (about 1 time every 3 minute).

3.3. SO_2 and NO_2 concentrations

Table 3 and Table 4 show the concentrations of SO_2 and NO_2 at the 3 sites in the wet and dry season, respectively. In the wet season, the outdoor and indoor NO_2 concentrations ranged from 7.8 to 33.4 (mean = 13.3) ppb and from 3.3 to 27.8 (mean = 9.3) ppb, respectively. In the dry season, outdoor and indoor NO_2 concentrations were in the range of 4.3-27.7 (mean = 12.3) ppb and 4.7-19.4 (mean = 10.2) ppb, respectively. The level of outdoor NO_2 was comparable with monthly average of NO_2 from February to December 2016 of 14.5-34.8 ppb in the research of Sakamoto *et al.* [10]. The range of outdoor NO_2 in dry season were slightly lower than that in the wet season. Indoor and outdoor levels of NO_2 cannot be compared because they were taken at different time. All of the measured NO_2 concentrations are below the recommended value of WHO for hourly average of 106.5 ppb (200 μg/m^3) [8]. Baek *et. al.* [11] reported that the level of indoor NO_2 in Korean urban offices ranged from 9 to 58 ppb, while the outdoor level ranged from 10 to 73 ppb. The levels of NO_2 in this research were lower than those in Baek's research.

Table 3. SO_2 and NO_2 concentrations in offices in the wet season (ppb).

Site	Air purifier	Date	Outdoor			Indoor		
			Start sampling time (hour)	SO_2 (ppb)	NO_2 (ppb)	Start sampling time (hour)	SO_2 (ppb)	NO_2 (ppb)
A	OFF	27-Jul	9	9.2	8.9	10	7.3	4.5
						17	11.9	5
		06-Aug	9	10.7	8.4	10	8.8	3.3
						17	10.3	6.7
	ON	23-Jul	9	20.7	25.6	10	19.1	22.8
						17	47.1	23.9
		24-Jul	9	12.3	11.1	10	20.3	5
						17	13.4	5
B	OFF	29-Jul	9	34.5	10	10	3.8	6.7
						17	5	7.8
		31-Jul	9	16.8	7.8	10	14.2	5.6
						17	10.7	6.1
	ON	04-Aug	9	14.9	10.6	10	13.8	8.9
						17	7.7	8.4
		05-Aug	9	11.1	12.8	10	11.1	7.8
						17	8.4	7.2
C	OFF	21-Jul	9	33.7	33.4	10	47.1	27.8
						17	5	7.8
		25-Jul	9	12.6	7.8	10	9.6	12.3
						17	8.4	5.6
	ON	23-Jul	9	34.5	11.7	10	44	10.6
						17	34.5	7.2
		24-Jul	9	8.8	11.7	10	17.2	10.6
						17	11.9	7.2

In the wet season, the ranges of outdoor and indoor SO_2 concentrations were 8.8-34.5 (mean = 18.3) ppb and 3.8-47.1 (mean = 16.3), respectively. In the dry season, the ranges of outdoor and indoor SO_2 concentrations were < 0.4-15.7 (mean = 9.3) ppb and < 0.4-20.7 (mean = 9.5) ppb, respectively. The outdoor SO_2 concentrations in this study were higher but comparable with the annual average SO_2 concentration of 4-18 ppb in inner districts of Ha Noi [12]. The range of outdoor SO_2 in dry season were lower than in the wet season. Indoor and outdoor levels of SO_2 cannot be compared because they were taken at different time. WHO does not recommend hourly average level of SO_2. Therefore, directly comparing of hourly SO_2 level with WHO guideline is impossible. However, it is still meaningful to mention that some SO_2 concentrations were about some fold higher than the limit recommended by WHO guidelines for daily average of 10.6 ppb (20 µg/m^3) [8]. Klinmalee *et al*. measured SO_2 concentration in Thailand's public buildings and revealed the results being between 1.3 and 5 ppb [13]. The sites were two universities classrooms and a shopping mall, which had some resemblances to the sites in this study. Those results indicated that indoor SO_2 levels in Thailand were much lower than those in Viet Nam.

Table 4. SO_2 and NO_2 concentrations in offices in dry season (ppb).

Site	Air purifier	Date	Outdoor			Indoor		
			Start sampling time (hour)	SO_2 (ppb)	NO_2 (ppb)	Start sampling time (hour)	SO_2 (ppb)	NO_2 (ppb)
A	OFF	10-Nov	9	15.3	7.2	9	8.8	4.7
						10	14.2	5.9
			16	15.7	7.8	16	10.3	6.3
						17	10.7	10.7
		11-Nov	9	12.3	10.2	10	7.7	6.7
			16	9.2	18.3	17	20.7	5.7
	ON	12-Nov	9	<0.4	8.1	10	20.3	8.7
			16	6.1	8.1	17	7.3	10.2
		16-Nov	9	11.5	4.3	10	10.3	8.2
			16	6.1	11.8	17	6.5	14.1
B	OFF	10-Nov	9	14.6	10.4	10	5.7	8.3
			16	6.5	8.4	17	7.3	9.1
		11-Nov	9	7.7	27.7	10	6.9	12.3
			16	8.8	9.3	17	6.5	9
	ON	12-Nov	9	8.8	22.6	10	6.5	9
			16	6.1	20.1	17	6.5	8.1
		13-Nov	9	13.8	10.3	10	16.1	12.3
			16	6.1	9.1	17	20	19.4
C	OFF	17-Nov	9	10.4	20.6	10	8.4	6.8
			16	<0.4	6.5	17	5.4	11
		18-Nov	9	5.4	19.9	10	3.5	17.1
			16	7.7	9.3	17	3.8	11
	ON	19-Nov	9	12.3	11.1	10	8.4	14.2
			16	14.1	6.1	17	11.1	14.3
		20-Nov	9	12.3	15.9	10	13.8	13.1
			16	11.5	10.9	17	<0.4	9.8

4. CONCLUSIONS

Levels of indoor PM_{10} in several offices in Ha Noi were observed with the concentrations in the wet season and dry season being 3.5-25.1 (mean = 13.3) µg/m^3 and 3.7-24.7 (mean = 11.2) µg/m^3, respectively. The indoor PM_{10} concentrations were lower than daily level of WHO guidelines of 50 µg/m^3. Variations of PM_{10} concentration with different factors including the number of people in the room and their activities, the frequency of opening the doors were also observed reconfirming the dynamic nature of indoor PM_{10}.

Levels of hourly indoor NO_2 were of 3.3-27.8 (mean = 9.3) ppb and 4.7-19.4 (mean = 10.2) ppb in wet season and dry season, respectively. The levels of NO_2 were well met the recommendation of WHO of 106.5 ppb (200 µg/m^3). The levels of indoor SO_2 were 3.8-47.1 (mean = 16.3) ppb and < 0.4-20.7 (mean = 9.5) ppb in the wet season and dry season, respectively.

REFERENCES

1. World Health Organization - Household air pollution and health, World Health Organization (2018) Retrieved from http://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health.
2. Skolnick A. - Even air in the home is not entirely free of potential pollutants, Journal of the American Medical Association **262** (1989) 3102–3103.
3. Quang T. N., Hue N. T., Thai P., Mazaheri M., Morawska, L. - Exploratory assessment of indoor and outdoor particle number concentrations in Ha Noi households, Science of The Total Environment **599–600** (2017) 284–290.
4. Tran T. M., Le H. T., Minh T. B., Kannan K. - Occurrence of phthalate diesters in indoor air from several Northern cities in Viet Nam, and its implication for human exposure, Science of The Total Environment **601–602** (2017) 1695–1701.
5. Tran T. M., Le H. T., Vu N. D., Minh Dang G. H., Minh T. B., Kannan K. - Cyclic and linear siloxanes in indoor air from several northern cities in Viet Nam: Levels, spatial distribution and human exposure, Chemosphere **184** (2017) 1117–1124.
6. Tran L. K., Quang T. N., Hue N. T., Van Dat M., Morawska L., Nieuwenhuijsen M., Thai P. K. - Exploratory assessment of outdoor and indoor airborne black carbon in different locations of Ha Noi, Viet Nam, Science of The Total Environment **642** (2018) 1233–1241.
7. Thuy N. T. T., Dung N. T., Sekiguchi K., Thuy L. B., Hien N. T. T., Yamaguchi R. - Mass Concentrations and Carbonaceous Compositions of $PM_{0.1}$, $PM_{2.5}$, and PM_{10} at Urban Locations in Ha Noi, Viet Nam. Aerosol and Air Quality Research **18** (2018) 1591–1605.
8. WHO, Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide, Global update 2005, World Health Organization, Copenhagen (2005) pp. 9, 16, 18.
9. Oh H. J., Nam I. S., Yun H., Kim J., Yang J. and Sohn J. R. - Characterization of indoor air quality and efficiency of air purifier in childcare centers, Korea, Building and Environment **82** (2014) 203-214.
10. Sakamoto Y., Shoji K., Bui M.T., Pham T. H., Vu T. A., Ly B. T. and Kajii Y. - Air quality characteristics in Ha Noi, Viet Nam in 2015-2016 based on one-year observation

of NOx, O_3, CO and one-week observation of VOCs, Atmos, Pollution Res. **9** (2018) 544-551.

11. Baek S. O. K., Kim Y. S., and Perry R. - Indoor air quality in homes, offices and restaurants in Korean urban areas-indoor/outdoor relationships, Atmospheric Environment **31** (4) (1997) 529-544.
12. Hien P. D., Hangartner M., Fabian S., Tan P. M. - Concentrations of NO_2, SO_2, and benzene across Ha Noi measured by passive diffusion samplers, Atmos. Environ. **88** (2014) 66-73.
13. Klinmalee A., Srimongkol K., and Kim Oanh N. T. - Indoor air pollution levels in public buildings in Thailand and exposure assessment, Environ Monit Assess **156** (2009) 581-594.