Asian Journal of Atmospheric Environment
Vol. 8-1, pp. 35-47, March 2014
doi: http://dx.doi.org/10.5572/ajae.2014.8.1.035

Indoor Exposure and Health Risk of Polycyclic Aromatic Hydrocarbons (PAHs) via Public Facilities $PM_{2.5}$, Korea (II)

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ABSTRACT

The purpose of the study is to evaluate the pollution level (gaseous and particle phase) in the public facilities for the PAHs, non-regulated materials, forecast the risk level by the health risk assessment (HRA) and propose the guideline level. PAH assessments through sampling of particulate matter of diameter $<2.5\ \mu m$ ($PM_{2.5}$). The user and worker exposure scenario for the PAHs consists of 24-hour exposure scenario (WIES) assuming the worst case and the normal exposure scenario (MIES) based on the survey. This study investigated 20 PAH substances selected out of 32 substances known to be carcinogenic or potentially carcinogenic. The risk assessment applies major toxic equivalency factor (TEF) proposed from existing studies and estaimates individual Excess Cancer Risk (ECR). The study assesses the fine dusts ($PM_{2.5}$) and the exposure levels of the gaseous and particle PAH materials for 6 spots in each 8 facility, e.g. underground subway stations, child-care facilities, elderly care facilities, super market, indoor parking lot, terminal waiting room, internet café (PC-rooms), movie theater. For internet café (PC-rooms) in particular, that marks the highest $PM_{2.5}$ concentration and the average concentration of 10 spots (2 spots for each cafe) is $73.3\ \mu g/m^3$ (range: 6.8-185.2 $\mu g/m^3$). The high level of $PM_{2.5}$ seen in internet cafes was likely due to indoor smoking in most cases. For the gaseous PAHs, the detection frequency for 4-5 rings shows high and the elements with 6 rings shows low frequency. For the particle PAHs, the detection frequency for 2-3 rings shows low and the elements with 6 rings show high frequency. As a result, it is investigated that the most important PAHs are the naphthalene, acenaphthene and phenanthrene from the study of Kim *et al.* (2013) and this annual study. The health risk assessment demonstrates that each facility shows the level of 10^{-6}-10^{-4}. Considering standards and local source of pollution levels, it is judged that the management standard of the benzo (a)pyrene, one of the PAHs, shall be managed with the range of 0.5-1.2 ng/m^3. Smoking and ventilation were considered as the most important PAHs exposure associated with public facility $PM_{2.5}$. This study only estimated for inhalation health risk of PAHs and focused on the associated cancer risk, while multiple measurements would be necessary for public health and policy.

Key words: Polycyclic aromatic hydrocarbons, Indoor, Public facilities, $PM_{2.5}$, Health risk, Guideline

1. INTRODUCTION

The polycyclic aromatic hydrocarbons (PAHs) is the most representing hazardous material among the polycyclic organic matter (US EPA, 2007, 1993; NIEHS, 1998). The fine particles ($PM_{2.5}$) account for 44-56% of the total suspended particles and more than 80% of the PAHs are highly related to the $PM_{2.5}$ (Ohura *et al.*, 2004). PAHs in air are partitioned in a vapor and a particulate phase (Zhu *et al.*, 2009). The materials are classified as the semi-volatile organic compounds and the incomplete combustion crystal of the organic matter (Zhou and Zhao, 2012; Harrison and Smith, 1996).

Generally, it was reported that the sources of pollution of the PAHs under the outdoor environment were vehicle combustion (Shah *et al.*, 2005), civil and industrial coal combustion and petroleum asphalt (Zhu *et al.*, 2012). Meanwhile, the information on the source of pollution for indoor air is insufficient and it is known that the indoor sources of the PAHs are smoking (Mitra and Ray, 1995) and heating. However, it is generally reported that the indoor PAH concentration with insufficient information on the source of pollution is higher than the outdoor air with well-known source of pollu-

Table 1. General characteristics of study facilities.

	Internet cafes	Indoor parking lots	Underground subway stations	Terminal waiting rooms	Super markets	Movie theaters	Child care facilities	Elderly care facilities
Smoking status	Yes	No	No	No	No	No	No	No
Traffic of automobile	Heavy or some	Heavy	Heavy	Heavy of some	Heavy	Heavy	Some	Some or light
Location of facilities	Urban (aboveground)	Urban (underground)	Urban (underground)	Urban (aboveground)	Urban (aboveground)	Urban (aboveground)	Rural (aboveground)	Rural (aboveground)
Age of facilities	6.8 (4-14)	13.8 (9-22)	15.6 (3-29)	19.8 (8-41)	12.8 (9-22)	10 (9-11)	8.5 (8-9)	7.5 (7-8)
The use of a heat source	No	Petroleum gas	Petroleum gas	Petroleum gas	Town gas	Petroleum gas	Petroleum gas	Petroleum gas
Number of people using (person/day)	128 (60-200)	1,125 (350-3,000)	27,296 (4,239-79,062)	4,875 (300-15,000)	2,010 (500-3,500)	1,000	260 (120-400)	70 (60-80)

tion (Zhang *et al*., 2009; Menichini *et al*., 2007; Li *et al*., 2005; Li and Ro, 2000).

A recent study indicated that PAHs in gas and particulate phase of indoor environments influenced by tobacco smoke, traffic and cooking at home (Wang *et al*., 2013; Lee *et al*., 2003). The relevant studies mostly focused on the assessment of PAHs associated with particles (Slezakova *et al*., 2009a; Mannino and Orechio, 2008). There are some studies reporting the details about the $PM_{2.5}$ concentrations in Guangzhou 12.8-371 μg/m^3 were higher than in Hongkong 11.1-31.4 μg/m^3 (Wang *et al*., 2013).

The benzo(a)pyrene (BaP), known as a representing hazardous material of the PAHs, is a carcinogenic indicator of the PAHs (EU, 2004), classified as a potential carcinogen on the human body (IARC, 2010) and other PAHs include the possible human carcinogens (IARC, 1987, 2002). Recently, the WHO evaluates the benzo(a)pyrene, a representing carcinogen among the PAHs, as 1/10,000 (1×10^{-4}) of 1.2 ng/m^3, 1/100,000 (1×10^{-5}) of 0.1 ng/m^3 and 1/1,000,000 (1×10^{-6}) of 0.01 ng/m^3. It is raised that the potential cancer potency of the dibenzo(a,l)pyrene or dibenzo(a)anthracene is much higher than the BaP (Okana-Mensah *et al*., 2005) and there are new attempts to evaluate the potential risks of the PAHs.

The US EPA (2002) variously proposes the estimates of human risks reflecting the compound features of the PAHs and there are two main methods. First, the surrogate approach method approaches based on the unknown PAHs compounds. Second, the relative potency factor approach method is an approach to the components and estimates the initial carcinogenic level by adding degrees from each material from the PAHs compounds including the benzo(a)pyrene. The recent provisional guidance for assessing PHA risks of the EPA implements this approach, previously evaluated by Kim *et al*. (2013) and the study contains the result as an annual study.

Therefore, the study compares and evaluates the indoor PAHs distribution (gas and particle) from representing public under the regulation on the local public facilities and the purpose of the study is to propose the local PAHs standard level by performing the risk assessment on the exposure scenarios for the users and the workers in the public facilities.

2. EXPERIMENTS AND METHODS

2.1 Select the Public Facilities for the Survey

The study investigates fine dusts ($PM_{2.5}$) and distribution features of gaseous and particle PAHs from 6 spots in each 8 facilities (underground subway stations, child-care facilities, elderly care facilities, super market, indoor parking lot, terminal waiting room, internet café, movie theater). The descriptions of public facilities are shown in Table 1. The site survey of the study covered a total of 32 facilities in 4-5 groups for 4 months from July to November, 2012. In addition, the outdoor air is measured from 18 places. The cities under the survey include 3 large cities (Pusan, Incheon, Daegu) and 5 medium and small cities (Suncheon, Gwangyang, Yeosu, Jinju, Changwon).

2.2 Sampling and Analysis

Indoor and outdoor sampling was performed in agreement with the usual recommended practices (US EPA, 1990). Sample were collected approximately in the centre of the public facilities, for collecting particulate phase simultaneously at a human breathing height (1.5-1.8 m), distant from corners and as fas as possible, from obstruction (Masih *et al*., 2010). The outdoor level samples were collected at 4-5 m above the road to protect samplers against vandalism (Menichini *et* *al*., 2007). 24-h samples were simultaneously collected, respectively.

The method of sampling indoor and outdoor air, pretreatment and analysis is based on the US EPA Compendium Method TO-13A (U.S. EPA, 1999) and the prior study (Kim *et al*., 2013; Wang *et al*., 2013) performed the PAHs evaluation through the sampling with the diameter < 2.5 μm ($PM_{2.5}$).

The preliminary study was performed to check the indoor PAH detection rate. The survey shows that the PAHs detection rate (higher than 80%) is proper within the flow range of 4-5 L/min and the sampling time is configured at least 24 hours to minimize the error in the weight concentration of the $PM_{2.5}$ considering the PAHs features in high loss rates during the pre-treatment process. In addition, the PAHs surveyed in the study are analyzed by the PAHs standard (Quebec Ministry of Env. PAHs 24 Mix) provided by AccuStandard (AccuStandard Inc., U.S.A). The PAHs standard materials used in the preliminary survey uses the product of Supelco (EPA 610 mix, U.S.A).

The $PM_{2.5}$ and PAHs samples are taken by the Minivol portable sampler (PAS-201, Air Metrics, U.S.A) by connecting the PTFE filter (Teflon 47 mm, 1.0 μm, PALL Life sciences., U.S.A) and the PUF glass cartridge (polyurethane foam installed) to the small-sized sampler for 24 hours with the amount of 5 L/min. The PTFE filter to take samples of the $PM_{2.5}$ and particle PAHs is used after depositing into the acetone : methanol (7 : 3, v/v) solution, cleaning with the microwave for 2 hours and drying with the high purity nitrogen (N2) to remove organic impurities before use. The pretreated filter weighs after measuring the moisture for 24 hours in the desiccator to measure the mass concentration of the $PM_{2.5}$. The filter is sealed into the petri dish (50Φ) made with the polystyrene for storage and carriage. The PTFE filter for sampling is stored in the thermo-hygrostat for 24 hours before and after the sampling, weighed by the analysis scale with more than 0.001 mg of sensitivity (AT261, Mettler toledo, Switzerland) for 3 times and the arithmetic average is taken. The weight is measured by the same method with the filter taken by the control filter before and after the sampling to minimize the error in the weight measurement due to temperature and humidity to calculate the weight concentration of the $PM_{2.5}$ and the weight difference before and after the measurement is applied to each sampling filter. The absorbent to sample the gaseous PAHs (polyurethane foam, PUF) is rinsed in the soxhlet extractor for 16 hours (6 cycles/hour) with the order of methylene chloride-acetone, dried, wrapped in the aluminium foil and sealed in a glass jar before sampling. The PAHs analysis uses the Agilent GC/MS (HP-6890/HP-5973N) and applies the analysis procedure for the EPA TO-13A Method and the local air pollution process test standard (ES 01552.1) as mentioned before. The GC column is the HP-5 with the dimensions of 30 m length, 0.32 mm external diameter and 0.25 μm internal diameter and the sample is analyzed by injecting 1-2 μL each.

2. 3 Assessment of PAHs

This study investigated 20 PAH substances selected out of 32 substances known to be carcinogenic or potentially carcinogenic by the International Agency for Research on Cancer (IARC) and the US EPA (Table 1). Table 1 shows the average RPFs based on tumor bioassay data with their associated range and relative confidence ratings, and an overview of the tumor bioassay database for this compound. Risk assessments and potency assessments of various individual PAHs and complex mixtures of PAHs have been attempted. BaP is the only PAH for which a database is available, allowing a quantitative risk assessment.

2. 4 Quality Control

The study performs the degree management using PAHs standard, proxy standard and internal standard materials to raise the reliability for the analyzed materials. The degree management performs the linearity and dwelling times reproduction assessment of the calibration curves, detection limit, recovery factor assessment of pre-treated samples, recovery factor assessment of pre-treatment devices using standard materials and blank test assessment. The linearity assessment of the calibration curve shows proper linearity with higher than 0.98 of the correlation efficient (R^2) for most materials and the reproduction of the dwelling time (RSD %) is less than 0.1%. The reproduction assessment of the instrument detection limit (IDL) shows that the reproduction based on the benzo (a)pyrene is proper with 2.06% of the RSD and the method detection limit (MDL) is 0.02 ng/μL based on the benzo(a)pyrene. In addition, the detection limit after conversion to the air concentration by applying the sampling flow (7,200 L) is 0.003 ng/m^3 and the data below the figure are treated as N.D (Not Detected).

The PAHs extraction recovery rate (%) is assessed by injecting 80-100 μL of the substitute standard (SS: 10 μg/mL) and 30-50 μL of the internal standard (IS: 10 μg/mL) to calibrate the losses during the pre-treatment process for the all samples (particles and gases). The study uses 5 SS (Naphthalene-d8, Acenaphthene-d10, Phenanthrene-d10, Chrysene-d12 and Perylene-d12) and 2 IS (Benzo(a)pyrene-D12, Pyrene-D10) materials to assess the recovery and the average recovery of the gaseous collection material (PUF) satisfy the recovery rate (60-120%) recommended by the US

Table 2. Molecular weight and toxic equivalency factor about Compound of PAHs used in this study.

Compound	Molecular weight ($g\ mol^{-1}$)	TEF1[a]	TEF2[b]	TEF3[c]
Naphthalene (Nap)	128			
Acenaphthylene (AcPy)	152		0.001	
Acenaphthene (AcP)	154		0.001	
Flourene (Flu)	165		0.001	
Phenanthrene (PA)	178		0.001	
Anthracene (Ant)	178		0.01	
Fluoranthene (FL)	202		0.001	0.08
Pyrene (Pyr)	202		0.001	
Benzo(a)anthracene (BaA)	228	0.1	0.1	0.2
Chrysene (CHR)	228	0.001	0.01	0.1
Benzo(b)fluoranthene (BbF)	252	0.1	0.1	0.8
Benzo(j)fluoranthene (BjF)			0.1	0.3
Benzo(k)fluoranthene (BkF)	252	0.1	0.1	0.03
Benzo(e)pyrene (BeP)	252		0.01	
Benzo(a)pyrene (BaP)	252	1	1	1
Indeno(1,2,3-c,d)pyrene (IND)	276	0.1	0.1	0.07
Dibenzo(a,h)anthrancene (DBA)	278	1	1	10
Benzo(g,h,i)perylene (BghiP)	276		0.01	0.009
Benzo(a,i)perylene (BaiP)				0.6
Benzo(a,l)perylene (BalP)				30

[a]value adopted from US EPA (1993)
[b]value adopted from Malcom and Dobson (1994)
[c]value adopted from US EPA (2010)

EPA Method 8100 for 4 materials except the Acenaphthene-d10 including 65.4% for Naphthalene-d8, 127.2% for Acenaphthene-d10, 112.5% for Phenanthrene-d10, 78.1% for Chrysene-d12 and 60.7% for Perylene-d12.

In addition, the average recovery of the particle sampling media (filter) satisfies the recovery rates (60-120%) recommended by the US EPA Method 8100 for Naphthalene-d8 and Chrysene-d12 including 77.6% for Naphthalene-d8, 132.5% for Acenaphthene-d10, 127.6% for Phenanthrene-d10, 73.1% for Chrysene-d12 and 57.7% for Perylene-d12. The average recovery through the extraction and concentration without the filter or the PUF using the PAH standard material (24 mix, 10 μg/mL) to understand the PAHs extraction recovery (%) for the pre-treated equipment (soxhlet extractor) is 88.8%. The recoveries of each PAH from the PUF and filters ranged between 60.7% to 127.2% and 57.7% to 127.6% respectively and its relative standard deviation (RSD) ranged from 0% to 11.1%.

2. 5 Risk Assessment

The risk assessment in the study estimates the excess cancer risk (ECR) by applying various toxic equivalency factor (TEF) like the prior study of Kim *et al.* (2013). Therefore, the study first performs the Surrogate method of the PAHs, the assessment by applying the relative potency factors (RPF) method calculated by the concentration and the carcinogenic potency as the benzo(a)pyrene indicator and second, the assessment by applying the EPA (1993) TEF for 7 of 24 carcinogenic PAHs. Third, the Malcolm and Dobson (1994) method providing the TEF values for 24 types and last, the TEF values of the EPA (2010) are used to calculate the final PAHs risk degrees with 4 categories.

The study configures average users for each facility depending on the features of the public facilities, ages and gender features of the average users and determines the representing exposure factors (weight, breathing rate, dwelling time, visiting times, etc.) which form the WIES and the MIES. The survey covers the average number of visitors, ages, gender and dwelling time for the facilities. The number of subjects is 144 users (visitors) and workers and the exposure factors are finally figured based on the survey results. The body exposure may be calculated by considering the contamination concentration, inhalation rate, body weight, exposure frequency, exposure duration and lifetime. Here, the daily inhalation rate is applied by assuming the average exposure time and the exposure for 24 hours in the facilities based on the survey. The inhalation rate is 13.3 m^3/day, daily average inhalation rate by referring to the recommended value of the US EPA. The body weight is 60 kg, average weight of Korean adults proposed by the Ministry of Health and Welfare, selected and applied as the representing value. The average life is 70 years, the life expectancy of Koreans surveyed by the National Statistics Office. The study

Table 3. Relative human exposure variable in various public facilities.

	Inhalation rate (m^3/day)[a]	Exposure time (hr/day)[b]			Exposure frequency (day/yr)[c]			Exposure duration (yr)[d]			Body weight (kg)[e]	Average life span (yr)[f]
		Mean±S.D	Min	Max	Mean±S.D	Min	Max	Mean±S.D	Min	Max		
Internet cafe (n=26)	13.3	3.6±1.3	1.5	6.0	103.0±34.1	52.0	200.0	35.0±7.0	20.0	45.0	60	70
Indoor parking lots (n=18)	13.3	1.0±0.4	0.5	1.5	27.0±30.0	6.0	118.0	50.0±16.0	20.0	70.0	60	70
Underground subway stations (n=17)	13.3	1.0±0.5	0.5	2.0	124.8±45.1	46.0	185.0	50.0±19.0	20.0	75.0	60	70
Terminal waiting rooms (n=23)	13.3	1.0±0.4	0.5	1.5	15.0±9.6	5.0	40.0	50.0±13.7	20.0	70.0	60	70
Super markets (n=12)	13.3	1.4±0.6	0.5	2.0	29.0±23.1	5.0	75.0	50.0±13.7	30.0	70.0	60	70
Movie theaters (n=24)	13.3	3.5±1.0	1.5	5.0	18.0±10.9	3.0	50.0	50.0±8.2	30.0	60.0	60	70
Child care Facilities (n=13)	13.3	9.0±1.9	6.0	12.0	252.0±96.0	125.0	365.0	5.0±0.6	4.0	6.0	60	70
Elderly care facilities (n=11)	13.3	24.0±0.0	24.0	24.0	360.0±11.8	325.0	365.0	10.0±3.7	5.0	15.0	70	70

[a]value adopted from US EPA (1997)
[b c d]value adopted from questionnaire Survey
[e]value adopted from Korea Research Institute of Standards and Science (2004)
[f]value adopted from Korea National Statistical Office

finds out the medical facilities for the senior people is the highest (24 hours/day), followed by Childcare facilities (9.0 hours/day), internet cafe (3.6 hours/day), movie theater (3.5 hours/day), super market (1.4 hours/day), underground subway station and terminal waiting room (1.0 hour/day) and indoor parking lot (0.5 hour/day). The medical facilities for the senior shows the highest visiting frequency (360 times/month), followed by daycare centers (252 times/month), underground subway station (125 times/month), Internet cafe (103 times/month), super market (29 times/month), indoor parking lot (27 times/month), movie theaters (18 times/month) and terminal waiting room (15 times/month) (Table 3).

The study determines various toxic indicators of the PAHs carcinogens (carcinogenic potency, unit risk, exposure reference, POD) and applies safety coefficients from collected toxic data to evaluate the non-carcinogenic PAHs and to calculate the RfC. The carcinogenic potency evaluation or inhalation unit risk is calculated from the collected human carcinogenic data to evaluate the non-carcinogenic features of the PAHs.

As assessed by Kim *et al.* (2013), the study finally calculates the risk degree with (1) the method which expresses the relative cancer potency for individual PAH for the Benzo(a)pyrene (Yang *et al.*, 2007) and (2) the method which applies the toxic equivalent quotient (TEQ) of the PAHs mixture using the TEFs of individual PAH (Chen and Liao, 2006).

3. RESULTS AND DISCUSSION

3. 1 $PM_{2.5}$ Concentration Distribution

The $PM_{2.5}$ concentrations measured from 32 facilities in 8 groups show that the internet cafe marks the highest value, followed by underground subway station, medical and child-care facilities, elderly care facilities, waiting room, indoor parking lot, super market and movie theater.

In particular, it is the internet café (PC-room) that marks the highest $PM_{2.5}$ concentration and the average concentration of 10 spots (2 spots for each cafe) is 73.3 μg/m^3 (range: 6.8-185.2 μg/m^3) ($p<0.01$) (Table 4). Castro *et al.* (2011) has investigated the indoor $PM_{2.5}$ ranged, from 37 to 82 μg/m^3 (mean of 57.2 μg/m^3) at the home influenced by tobacco smoke. The non-smoking home exhibited lower $PM_{2.5}$ revels, 8.3 to 22.5 μg/m^3 (mean of 14.5 μg/m^3). The prior study of Kim *et al.* (2013) shows that the $PM_{2.5}$ concentration of the internet cafe reaches 110.0 μg/m^3 on average, much higher than that of the study (range: 83.5-138.5 μg/m^3). Comparing such values to the $PM_{2.5}$ guideline of the WHO (average 25 μg/m^3 for 24 hours, 10 μg/m^3 on

Table 4. Comparison of $PM_{2.5}$ and PAHs in various public facilities.

	$PM_{2.5}$			PAHs		
	Mean±S.D	Min	Max	Mean±S.D	Min	Max
Internet café (n=20)	73.3±49.6	6.8	185.2	70.9±29.0	33.4	128.9
Indoorparking lots (n=8)	20.7±2.3	17.4	23.3	52.5±29.3	21.3	99.5
Undergroundsubway stations (n=10)	47.4±18.6	26.8	79.8	80.0±30.7	29.4	129.4
Terminalwaiting rooms (n=10)	22.0±6.0	12.6	30.3	44.5±28.6	4.4	88.9
Super markets (n=10)	12.8±7.2	6.1	23.1	52.9±14.4	33.7	72.5
Movie theaters (n=8)	9.5±4.4	3.0	14.9	24.1±10.7	12.5	45.8
Child care facilities (n=4)	22.4±7.5	12.6	30.9	21.0±19.3	6.7	48.0
Elderly care facilities (n=4)	23.3±7.4	12.8	30.0	20.1±10.5	11.3	35.3
p-value		<0.01			<0.01	

the annual average), the Internet cafe and the underground subway station are far beyond the standards and the concentrations in the elderly care facilities, terminal waiting room and indoor parking lots are similar to the standard values.

The indoor/outdoor concentration ratio (I/O ratio) of the $PM_{2.5}$ for 8 facilities in the study shows that the internet cafe is the highest (9.7), followed by the indoor parking lot (2.0), underground subway station (1.6), super market (1.5), child-care facilities (1,4), elderly care facilities (1.1), movie theater (1.0) and terminal waiting room (0.8), meaning that the indoor values are higher than those of the outdoor except the terminal waiting room. The internet cafe shows the lowest outdoor concentration (7.5 $\mu g/m^3$) but the highest indoor concentration of 73.3 $\mu g/m^3$.

As surveyed by Kim *et al.* (2013), most internet cafes are placed underground and not equipped with indoor ventilation and the sampling process seems to be affected by some smokers (Castro *et al.*, 2011; Mitra and Ray, 1995). In addition, the indoor parking lot is a facility mostly with large malls and features insufficient ventilation, as well as shows high concentration due to the emission by cars with frequently visit and scattering dusts on the floor. In contrast, the terminal waiting room shows that the outdoor $PM_{2.5}$ is observed higher than the indoor environment and it is because the outdoor air is highly polluted due to vehicles and other transportation, as well as the emitted gas due to idling in the terminal. It is judged that the cinema shows low concentration because it is located in a large-sized multiplex building with mechanical ventilation compared to the internet cafe. The highest $PM_{2.5}$ pollution was found at site internet cafes (PC-rooms) area which might be influenced by human activity, such as smoking and cooking. Dust particles could be resuspened via human activities, recontributing to the indoor $PM_{2.5}$ (Wang *et al.*, 2013). Exposure to PM and associated PAHs are of particular concern for both children and adults (Ohura *et al.*, 2005).

The $PM_{2.5}$ exposure is related to deteriorating lung functions, increasing lung infection, respiratory system symptoms, deteriorating the cardiovascular system and causing chronic obstructive pulmonary diseases. Even worse, it may be a cause of oxidation stress in the human DNA, the important phase of forming certain cancers (Novotna *et al.*, 2007).

3.2 Distribution of PAH Compounds in Gaseous and Particulate Phase

The materials with 2-4 rings show high detection frequency in the gaseous phase out of 24 PAHs from the facilities and 7 materials like naphthalene, acenaphthylene, fluorene, phenanthrene, anthracene, fluoranthene and pyrene show 100% detection rates and benzo(a)pyrene marks 68% detection rate. The study finds out that 13 of 24 materials show the detection rates higher than 80% and 5 materials are not detected, meaning that the materials with 5-6 rings show low detection rates. The PAHs are categorized into 3 groups including 2-3 rings, 4 rings and 5-6 rings (Schauer *et al.*, 2003).

The acenaphthene shows the highest concentration of 30.87 ng/m^3, followed by the phenanthrene of 18.93 ng/m^3, naphthalene of 19.08 ng/m^3 and these materials show relatively high concentrations (Table 5). Therefore, it may be said that the PAHs with 2-3 rings show high concentrations as a whole.

The PAHs with 2-3 rings are detected in the gaseous phase much and known that they mark relatively high concentrations and their emission sources are placed indoor (Castro *et al.*, 2011; Slezakova *et al.*, 2010; Lizhong Zhu, 2009; Fanf *et al.*, 2004). The study also shows that the acenaphthene, phenanthrene, naphthalene and fluorene, PAHs with 2-3 benzene rings, mark high concentrations. The prior study of Kim *et al.* (2013) indicates that the internet cafe and the underground subway station show the high concentrations and both facilities commonly show high concentrations of the acenaphthene (38.37 and 28.17 ng/m^3)

Table 5. Results of PAHs concentration measured in various public facilities.

PAHs	PC rooms		Indoor parking lots		Underground subway stations		Terminal waiting rooms		Super markets		Movie theaters		Child care facilities		Elderly care facilities	
	Vapor (n=20)	Particle (n=20)	Vapor (n=8)	Particle (n=8)	Vapor (n=10)	Particle (n=10)	Vapor (n=10)	Particle (n=10)	Vapor (n=10)	Particle (n=10)	Vapor (n=8)	Particle (n=8)	Vapor (n=4)	Particle (n=4)	Vapor (n=4)	Particle (n=4)
Naphthalene	12.55±10.69 (96.6%)	0.44±0.53 (3.4%)	3.82±2.01 (91.0%)	0.38±0.38 (9.0%)	19.08±10.59 (95.2%)	0.97±1.16 (4.8%)	8.13±5.13 (94.3%)	0.49±0.49 (5.7%)	9.70±5.19 (91.3%)	0.93±0.90 (8.7%)	3.59±2.57 (97.0%)	0.11±0.15 (3.0%)	6.32±9.20 (98.9%)	0.07±0.09 (1.1%)	3.82±3.80 (87.6%)	0.54±0.58 (12.4%)
Acenaphthylene	4.74±4.87 (93.9%)	0.31±0.52 (6.1%)	0.80±0.80 (95.2%)	0.04±0.02 (4.8%)	1.32±0.50 (86.3%)	0.21±0.13 (13.7%)	1.32±0.98 (77.6%)	0.38±0.46 (22.4%)	0.53±0.31 (84.1%)	0.10±0.12 (15.9%)	0.46±0.47 (85.2%)	0.08±0.09 (14.8%)	1.30±1.56 (94.9%)	0.07±0.07 (5.1%)	1.42±0.58 (96.6%)	0.05±0.05 (3.4%)
Acenaphthene	0.36±0.27 (4.4%)	7.83±18.96 (95.6%)	30.87±27.08 (99.0%)	0.32±0.51 (1.0%)	25.31±18.54 (97.9%)	0.55±0.76 (2.1%)	16.29±18.14 (96.0%)	0.68±1.33 (4.0%)	16.76±10.08 (98.6%)	0.24±0.50 (1.4%)	0.01±0.04 (8.3%)	0.11±0.21 (91.7%)	0.05±0.06 (100%)	N.D	0.51±0.37 (79.7%)	0.13±0.26 (20.3%)
Fluorene	4.26±1.33 (94.7%)	0.24±0.28 (5.3%)	2.14±0.70 (98.6%)	0.03±0.03 (1.4%)	5.30±3.39 (94.1%)	0.33±0.29 (5.9%)	1.98±1.51 (88.0%)	0.27±0.26 (12.0%)	6.99±4.09 (98.2%)	0.13±0.13 (1.8%)	2.88±1.71 (97.0%)	0.09±0.05 (3.0%)	2.72±2.61 (97.5%)	0.07±0.09 (2.5%)	2.26±2.03 (79.3%)	0.59±0.41 (20.7%)
Phenanthrene	18.93±7.42 (96.2%)	0.74±0.88 (3.8%)	6.97±3.17 (96.3%)	0.27±0.27 (3.7%)	14.17±7.29 (88.2%)	1.89±4.42 (11.8%)	5.91±3.18 (91.9%)	0.52±0.92 (8.1%)	11.01±7.09 (99.1%)	0.10±0.17 (0.9%)	6.71±5.99 (99.0%)	0.07±0.06 (1.0%)	4.25±4.54 (95.9%)	0.18±0.16 (4.1%)	5.73±4.50 (87.9%)	0.79±0.53 (12.1%)
Anthracene	2.57±1.41 (92.8%)	0.20±0.27 (7.2%)	0.60±0.34 (95.2%)	0.03±0.04 (4.8%)	1.09±0.59 (76.2%)	0.34±0.79 (23.8%)	0.65±0.36 (82.3%)	0.14±0.14 (17.7%)	1.07±0.71 (89.9%)	0.12±0.18 (10.1%)	1.39±1.41 (96.5%)	0.05±0.11 (3.5%)	0.58±0.57 (85.3%)	0.10±0.12 (14.7%)	0.79±0.43 (87.8%)	0.11±0.13 (12.2%)
Fluoranthene	2.36±0.87 (81.4%)	0.54±0.71 (18.6%)	1.17±0.65 (68.4%)	0.54±0.24 (31.6%)	2.38±1.05 (73.0%)	0.88±1.26 (27.0%)	0.89±0.43 (61.4%)	0.56±0.43 (38.6%)	1.20±0.67 (80.0%)	0.30±0.43 (20.0%)	1.67±1.62 (90.3%)	0.18±0.20 (9.7%)	1.11±1.03 (93.3%)	0.08±0.03 (6.7%)	0.97±0.38 (90.7%)	0.10±0.17 (9.3%)
Pyrene	2.41±1.18 (75.8%)	0.77±0.81 (24.2%)	1.49±0.93 (73.4%)	0.54±0.29 (26.6%)	2.08±0.69 (69.6%)	0.91±1.23 (30.4%)	0.93±0.45 (66.4%)	0.47±0.34 (33.6%)	1.32±0.78 (81.5%)	0.30±0.53 (18.5%)	1.97±1.46 (91.2%)	0.19±0.19 (8.8%)	1.64±1.75 (95.9%)	0.07±0.02 (4.1%)	1.06±0.40 (93.0%)	0.08±0.14 (7.0%)
Benzo[c]phenanthrene	0.05±0.08 (20.0%)	0.20±0.30 (80.0%)	0.03±0.04 (50.0%)	0.03±0.03 (50.0%)	0.01±0.03 (33.3%)	0.02±0.04 (66.7%)	0.04±0.05 (44.4%)	0.05±0.07 (55.6%)	0.01±0.03 (25.0%)	0.03±0.03 (75.0%)	0.06±0.09 (54.5%)	0.05±0.09 (45.5%)	N.D	0.01±0.02 (100%)	N.D	N.D
Benz[a]anthracene	0.11±0.18 (14.3%)	0.66±0.85 (85.7%)	0.08±0.12 (53.3%)	0.07±0.12 (46.7%)	0.09±0.06 (47.4%)	0.10±0.10 (52.6%)	0.09±0.07 (39.1%)	0.14±0.12 (60.9%)	0.04±0.04 (44.4%)	0.05±0.03 (55.6%)	0.08±0.14 (27.6%)	0.21±0.27 (72.4%)	0.01±0.01 (7.7%)	0.12±0.09 (92.3%)	0.02±0.02 (25.0%)	0.06±0.11 (75.0%)
Chrysene	0.47±0.62 (29.7%)	1.11±0.84 (70.3%)	0.10±0.10 (22.2%)	0.35±0.21 (77.8%)	0.17±0.09 (29.8%)	0.40±0.37 (70.2%)	0.21±0.28 (29.6%)	0.50±0.36 (70.4%)	0.09±0.17 (47.4%)	0.10±0.13 (52.6%)	0.32±0.46 (42.1%)	0.44±0.53 (57.9%)	0.12±0.19 (48.0%)	0.13±0.08 (52.0%)	0.16±0.21 (53.3%)	0.14±0.16 (46.7%)
Benzo(b+j)fluoranthene	0.17±0.34 (10.7%)	1.42±0.81 (89.3%)	0.07±0.05 (20.0%)	0.28±0.16 (80.0%)	0.21±0.18 (31.3%)	0.46±0.47 (68.7%)	0.24±0.22 (30.4%)	0.55±0.36 (69.6%)	0.10±0.16 (21.3%)	0.37±0.22 (78.7%)	0.09±0.09 (12.2%)	0.65±0.68 (87.8%)	0.22±0.18 (48.9%)	0.23±0.25 (51.1%)	0.04±0.04 (16.7%)	0.20±0.25 (83.3%)
Benzo(k)fluoranthene	0.07±0.09 (6.7%)	0.98±0.79 (93.3%)	0.05±0.05 (14.7%)	0.29±0.21 (85.3%)	0.15±0.11 (30.0%)	0.35±0.31 (70.0%)	0.18±0.15 (36.0%)	0.32±0.25 (64.0%)	0.05±0.05 (18.5%)	0.22±0.12 (81.5%)	0.08±0.08 (16.3%)	0.41±0.30 (83.7%)	0.17±0.18 (50.0%)	0.17±0.13 (50.0%)	0.07±0.08 (33.3%)	0.14±0.21 (66.7%)
DMBA	N.D	0.29±0.57 (100%)	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	0.10±0.30 (100%)	N.D	N.D	N.D	N.D
Benzo(e)pyrene	0.16±0.18 (10.3%)	1.40±1.48 (89.7%)	0.08±0.12 (19.5%)	0.33±0.45 (80.5%)	0.17±0.14 (36.2%)	0.30±0.25 (63.8%)	0.24±0.19 (27.0%)	0.65±0.56 (73.0%)	0.15±0.15 (36.6%)	0.26±0.26 (63.4%)	0.15±0.20 (22.4%)	0.52±0.69 (77.6%)	0.08±0.07 (19.5%)	0.33±0.31 (80.5%)	0.15±0.20 (55.6%)	0.12±0.17 (44.4%)
Benzo(a)pyrene	0.25±0.28 (18.9%)	1.07±0.92 (81.1%)	0.07±0.08 (21.2%)	0.26±0.39 (78.8%)	0.15±0.13 (48.4%)	0.16±0.23 (51.6%)	0.13±0.16 (31.7%)	0.28±0.31 (68.3%)	0.17±0.17 (47.2%)	0.19±0.19 (52.8%)	0.05±0.05 (19.2%)	0.21±0.29 (80.8%)	0.17±0.35 (37.8%)	0.28±0.55 (62.2%)	N.D	0.01±0.03 (100%)
3-Methylcholanthrene	N.D	N.D	N.D	N.D	N.D	N.D	N.D	0.06±0.13 (100%)	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
I123P	N.D	1.02±0.84 (100%)	N.D	0.10±0.12 (100%)	0.01±0.04 (4.2%)	0.23±0.32 (95.8%)	0.10±0.14 (32.3%)	0.21±0.49 (67.7%)	N.D	0.06±0.11 (100%)	N.D	0.37±0.56 (100%)	N.D	0.05±0.04 (100%)	N.D	N.D

Table 5. Continued.

PAHs	PC rooms		Indoor parking lots		Underground subway stations		Terminal waiting rooms		Super markets		Movie theaters		Child care facilities		Elderly care facilities	
	Vapor (n=20)	Particle (n=20)	Vapor (n=8)	Particle (n=8)	Vapor (n=10)	Particle (n=10)	Vapor (n=10)	Particle (n=10)	Vapor (n=10)	Particle (n=10)	Vapor (n=8)	Particle (n=8)	Vapor (n=4)	Particle (n=4)	Vapor (n=4)	Particle (n=4)
Dibenz(a,h)anthracene	0.03±0.08 (6.8%)	0.41±0.28 (93.2%)	N.D	0.02±0.03 (100%)	0.01±0.02 (20.0%)	0.04±0.04 (80.0%)	0.01±0.02 (6.7%)	0.14±0.23 (93.3%)	N.D	0.03±0.02 (100%)	N.D	0.12±0.22 (100%)	N.D	N.D	N.D	N.D
Benzo(g,h,i)perylene	N.D	1.11±0.62 (100%)	N.D	0.14±0.08 (100%)	0.02±0.06 (14.3%)	0.12±0.16 (85.7%)	0.12±0.24 (40.0%)	0.18±0.26 (60.0%)	N.D	0.09±0.10 (100%)	0.05±0.15 (10.2%)	0.44±0.60 (89.8%)	N.D	0.07±0.13 (100%)	0.03±0.07 (100%)	N.D
Dibenzo(a,h)pyrene	N.D	0.50±0.79 (100%)	N.D	0.03±0.03 (100%)	N.D	0.01±0.03 (100%)	N.D	0.20±0.25 (100%)	N.D	0.05±0.12 (100%)	N.D	0.06±0.10 (100%)	N.D	0.07±0.09 (100%)	N.D	N.D
Dibenzo(a,i)pyrene	N.D	0.13±0.24 (100%)	N.D	0.06±0.11 (100%)	N.D	0.03±0.05 (100%)	N.D	0.20±0.24 (100%)	N.D	0.08±0.12 (100%)	N.D	0.09±0.20 (100%)	N.D	0.14±0.16 (100%)	N.D	N.D
Dibenzo(a,l)pyrene	N.D	0.09±0.23 (100%)	N.D	0.01±0.02 (100%)	N.D	N.D	N.D	0.08±0.11 (100%)	N.D	0.05±0.14 (100%)	N.D	0.03±0.04 (100%)	N.D	N.D	N.D	N.D
∑PAHs	49.49	21.45	48.34	4.13	71.71	8.28	37.45	7.07	49.16	3.79	19.57	4.58	18.75	2.22	17.03	3.08

(ND: Not detected, less than 0.02 ng/m^3)
*DMBA: 7,12-Dimethylbenz(a)anthracene
I123P: Indeno[1,2,3-cd]pyrene

and naphthalene (15.72 and 5.17 ng/m^3). The prior study of Wang (2013) shows that the PAHs with 2-4 rings (Phe > Nap > Flu and Pyr) show high concentrations and reports that it is mainly due to the coal and wood combustion. The research facilities covered by the study do not perform the direct coal and wood combustion and it is judged that the internal and external sources of pollution from gas utilities, cooking (frying and oil combustion), smoking and incense burning (Masih *et al.*, 2010) jointly contribute to the pollution.

The survey result of the materials detected with the highest concentration from all the studied facilities based on the particle PAHs concentration shows that the acenaphthene marks the highest concentration of 7.83 ng/m^3 (Table 5). As the same with the study of Kim *et al.* (2013), the study shows that the acenaphthene marks the highest concentration among gaseous and particle PAHs. It is reported that the particle PAHs are detected from materials with 5-7 rings (Slezakova *et al.*, 2010; Lizhong Zhu, 2009; Li *et al.*, 2006) and the heavy-weight PAHs are mainly related to the particle materials (Pan *et al.*, 2012). The study shows that the concentration distribution of the particle materials with more than 5 rings increases compared to the gaseous ones and the acenaphthene with 3 rings shows the highest concentration from all the facilities. The acenaphthene shows the highest concentration of 7.83 ng/m^3 in the internet cafe and other substances show the concentrations with less than 1 ng/m^3.

In conclusion, the study of Kim *et al.* (2013) and the annual study show that the naphthalene, acenaphthene and phenanthrene are the most crucial PAHs and in particular, Kim *et al.* (2013) shows that the acenaphthene records the high concentration among the particle PAHs, meaning that the gaseous PAH concentration distribution ranges 34.5-55.9%, lower gaseous concentration distribution compared to the study. As shown in the previous study, the study demonstrates that the particle materials take higher proportion due to much affected by physical environment like the temperature and humidity (Lu *et al.*, 2008; Tsapakis and Stephanou, 2005).

Kim *et al.* (2013) shows that remaining 7 facilities other than the underground subway station exceed the benzo(a)pyrene concentration recommended by the WHO, 1.0 ng/m^3 but the study evaluates it as an improved environment because the facility shows the level below the recommended value. It is expected to implement local situations and regulation on non-smoking movement in the indoor environment including the internet cafe or large restaurants. It is reported that the tobacco smoking is the most important source of pollution of the PAHs and recently shows that 549 individual PAHs are caused by the tobacco smoking

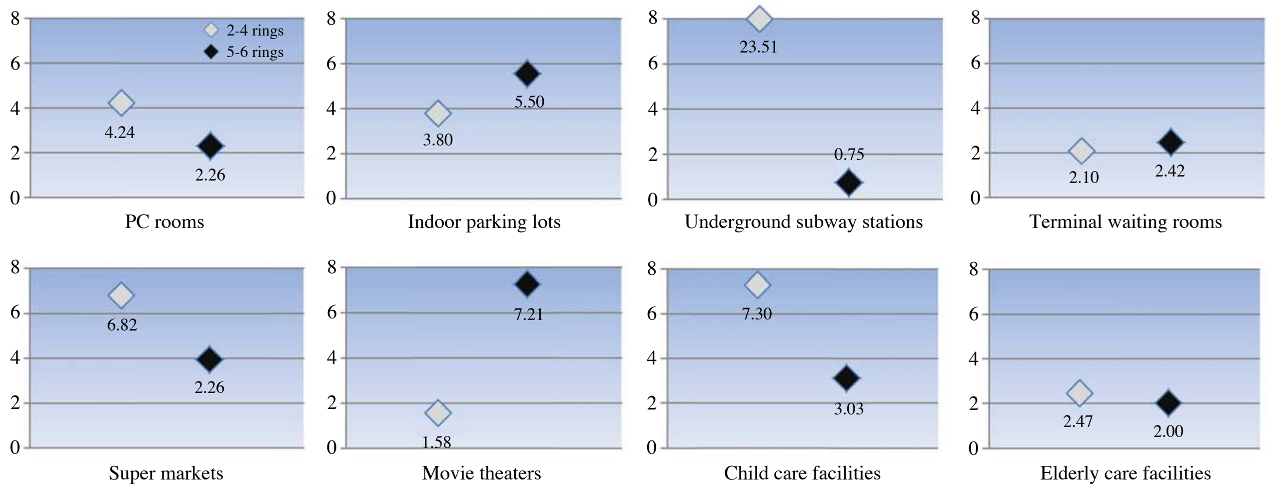

Fig. 1. I/O (indoor/outdoor) Ratio of PAHs concentrations in various public facilities.

(Thielen *et al.*, 2008).

The comparison of the indoor and outdoor ratio (I/O ratio) of the average naphthalene for 7 facilities shows that the child-care facilities marks the highest level, followed by the underground subway station and the internet cafe and the phenanthrene shows high level in the cinema and the underground subway station (Fig. 1). The annual prior study of Kim *et al.* (2013) shows the tendency in exceeding 1 in the underground subway station, followed by the child-care facilities and the internet cafe, demonstrating the clear existence of the indoor source of pollution. As similar to the study, Kim *et al.* (2013) contains the measurement for once (24 hours) per facility not in winter, but from June to October and the result does not measure the outdoor air quality. Therefore, it is estimated that the indoor sources of pollution and indoor in the public facilities affect more than the seasonal effect (Zhang and Tao, 2008) (Menichini *et al.*, 2007). The distribution of PAHs between both phases predominantly depends on the physical characteristics of the compounds and physical conditions such as temperature and humidity (Lu *et al.*, 2008). The seasonal variation of energy consumption in the residential sector that are mainly generated from combustion sources (Zhang and Tao, 2008).

The comparison of Kim *et al.* (2013) and the study on the distributions of gaseous and particles PAHs for the facilities shows that the gaseous PAHs accounts for 69.8% of the total PAHs concentration and the distribution in other 5 facilities ranges from 84.1 to 92.8%. The reason why the gaseous concentration distribution in the internet cafe is low compared to other facility groups is that the $PM_{2.5}$ concentration is high, as well as the particle PAHs.

3.3 Health Risk Assessment

The result of the risk assessment based on the exposure scenario in the public facilities due to the PAHs proposed by the 4 TEF-adjusted methods is in Table 6.

The risk estimate shows that the excessive carcinogenic risk of the surrogate approach ranges 10^{-8}-10^{-6} for each facility within the safe category and the internet cafe shows higher than 10^{-6}. Assuming the worst exposure of 24 hours/lifetime estimates that the surrogate approach shows the range of 10^{-6}-10^{-4} for each facility. The excessive carcinogenic risk of the 7 carcinogens in the RPFs assessment ranges 10^{-8}-10^{-6} and the internet cafe and the health and welfare centers for the senior show higher than 10^{-6}. Assuming the exposure of 24 hours/lifetime estimates the range of 10^{-6}-10^{-4} for each facility.

The excessive carcinogenic risk of the Malcolm and Dobson (1994) RPFs assessment shows the range of 10^{-8}-10^{-6} for each facility and the internet cafe (smoking/non-smoking) and elderly care facilities show higher than 10^{-6}. Assuming the exposure of 24 hours/lifetime estimates the range of 10^{-5}-10^{-4} for each facility. The excessive carcinogenic risk of the EPA (2010) RPFs assessment shows higher than 10^{-6} for each facility except the terminal waiting room and the super market. Assuming the exposure of 24 hours/lifetime estimates the level of 10^{-5}-10^{-4} for each facility. The RPFs of 11 PAHs proposed by the US EPA (2010) shows 1 for the benzo(a)pyrene, 10 for the dibenzo(a,h)anthracene and 30 for the dibenzo(a,l)pyrene, meaning that the risk assessment is different depending on the concentration of each material. Kim *et al.* (2013) substitutes the TEFs values of the US EPA and estimates 1.78E-04 assuming the exposure in the basic scenario and in the worst case scenario (24 hours), the internet

Table 6. Relative risk comparison in various public facilities by applying different relative potency factor (RPF).

		Actual service hours		24 hours	
		Risk values (per persons)	LADD (ng/kg-day)	Risk values (per persons)	LADD (ng/kg-day)
PC rooms	Surrogate approach	1.72E-06	5.66E-03	8.12E-05	2.67E-01
	RPF 1[a]	3.18E-06	1.04E-02	1.50E-04	4.92E-01
	RPF 2[b]	3.49E-06	1.15E-02	1.65E-04	5.40E-01
	RPF 3[c]	1.06E-05	3.47E-02	4.98E-04	1.63E+00
Indoor parking lots	Surrogate approach	4.95E-08	1.63E-04	2.25E-05	7.38E-02
	RPF 1	7.18E-08	2.36E-04	3.26E-05	1.07E-01
	RPF 2	8.60E-08	2.82E-04	3.91E-05	1.28E-01
	RPF 3	1.01E-06	3.30E-03	4.57E-04	1.50E+00
Underground subway stations	Surrogate approach	2.33E-07	7.64E-04	2.29E-05	7.51E-02
	RPF 1	4.08E-07	1.34E-03	4.01E-05	1.32E-01
	RPF 2	4.97E-07	1.63E-03	4.89E-05	1.60E-01
	RPF 3	1.16E-06	3.81E-03	1.14E-04	3.74E-01
Terminal waiting rooms	Surrogate approach	3.36E-08	1.10E-04	2.75E-05	9.03E-02
	RPF 1	6.53E-08	2.15E-04	5.34E-05	1.75E-01
	RPF 2	7.51E-08	2.47E-04	6.14E-05	2.02E-01
	RPF 3	3.99E-08	1.31E-04	3.26E-05	1.07E-01
Super markets	Surrogate approach	7.95E-08	2.61E-04	2.42E-05	7.94E-02
	RPF 1	1.08E-07	3.55E-04	3.29E-05	1.08E-01
	RPF 2	1.27E-07	4.17E-04	3.86E-05	1.27E-01
	RPF 3	2.66E-08	8.72E-05	8.08E-06	2.65E-02
Movie theaters	Surrogate approach	8.99E-08	2.95E-04	1.75E-05	5.75E-02
	RPF 1	2.67E-07	8.76E-04	5.19E-05	1.71E-01
	RPF 2	3.01E-07	9.88E-04	5.86E-05	1.92E-01
	RPF 3	4.35E-05	1.43E-01	8.46E-03	2.78E+01
Child care facilities	Surrogate approach	7.53E-07	2.47E-03	4.07E-05	1.34E-01
	RPF 1	8.75E-07	2.88E-03	4.73E-05	1.55E-01
	RPF 2	9.51E-07	3.12E-03	5.14E-05	1.69E-01
	RPF 3	1.54E-04	5.05E-01	8.32E-03	2.73E+01
Elderly care facilities	Surrogate approach	5.05E-07	1.66E-03	3.58E-06	1.18E-02
	RPF 1	1.04E-06	3.40E-03	7.35E-06	2.41E-02
	RPF 2	1.54E-06	5.06E-03	1.09E-05	3.59E-02
	RPF 3	8.96E-03	2.94E+00	6.36E-03	2.09E+01

[a]value adopted from US EPA (1993)
[b]value adopted from Malcom and Dobson (1994)
[c]value adopted from US EPA (2010)

cafe and the indoor parking lot show the risk level of 10^{-3} and other facilities mark the level of 10^{-4}.

The recent study of Castro *et al.* (2011) reports that the lifetime lung cancer risk exceeds the risk of 4.1×10^{-3} for a smoking family, 1.7×10^{-3} for a non-smoking family and 8.7×10^{-5} $(ng/m^3)^{-1}$ (Ohura *et al.*, 2004), the health-based guideline level and Wang *et al.* (2013) states that the general household has the risk of 10^{-6}-10^{-5} due to the PAHs exposure of the $PM_{2.5}$. Therefore, the risk level shows difference depending on the features in the studies including the characteristics of the source of pollution in the indoor environment, smoking and external air (Wang *et al.*, 2013; Zhou and Zhao, 2012; Zhang *et al.*, 2009; Menichini *et al.*, 2007; Ohura *et al.*, 2004; Zhu *et al.*, 2002). The limitation in the study is that the number of total samples is not enough and the risk assessment assumes the exposure for 24 hours in the facilities. The important uncertainties in our exposure scenario of potential exposures and health risks remain (Kim *et al.*, 2012). In addition, we investigated 32 public facilities, the selected facilities and could not be to represent.

4. CONCLUSIONS

It is the internet cafe that marks the highest $PM_{2.5}$ concentration and the average concentration of 10 spots (2 spots for each cafe) is 73.3 μg/m^3 (range: 6.8-185.2 μg/m^3). Such level is lower than 100 μg/m^3, the PM_{10} standard for indoor air in the sensitive facilities defined in "The Act of Managing Indoor Air in the Public Facilities", etc. However, the internet cafe and the underground subway station exceed the standard levels compared to the $PM_{2.5}$ guideline of the WHO (25 μg/m^3 average for 24 hours, 10 μg/m^3 for annual average) and the elderly care facilities, terminal waiting room and indoor parking lots show similar levels. Kim *et al.* (2013) and the study show that the naphthalene, acenaphthene and phenanthrene are the most crucial PAHs and in particular, Kim *et al.* (2013) shows that the acenaphthene records the high concentration among the particle PAHs, meaning that the gaseous PAH concentration distribution ranges 34.5-55.9%, lower gaseous concentration distribution compared to the study. The result following the risk assessment method shows that the excessive carcinogenic risk by the RPF EPA (2010), excessive carcinogen benzo(a) pyrene indicator, 7 carcinogens and RPF (1994) mark the level of 10^{-6}-10^{-4} in the internet cafe (smoking/non-smoking), indoor parking lot, underground subway station, terminal waiting room, super market, movie theater, child-care facilities and elderly care facilities. It is desirable to propose the risk level concentration of 1×10^{-5} when local standard is configured considering the possibility for observation based on the toxic level of the benzo(a)pyrene with PAHs guideline of the risk assessment by the WHO (2000). Therefore, considering foreign standards and local source of pollution levels, it is judged that the management standard of the benzo(a)pyrene shall be managed with the range of 0.5-1.2 ng/m^3.

ACKNOWLEDGEMENT

This study is a part of the results of and was funded by the "Establishment of Management for Non-regulated Indoor Pollutants (2012)" study from the National Institute of Environmental Research (Indoor Environment Division). We would like to express our appreciation for their support.

REFERENCES

Castro, D., Slezakova, K., Delerue-Matos, C., da Conceição Alvim-Ferraz, M., Morais, S., do Carmo Pereia, M. (2011) Polycyclic aromatic hydrocarbons in gas and particulate phases of indoor environments influenced by tobacco smoke: Levels, phase distributions, and health risks. Atmospheric Environment 45, 1799-1808.

Chen, S.C., Liao, C.M. (2006) Health risk assessment on human exposed to environmental polycyclic aromatic hydrocarbons pollution sources. Science of the Total Environment 366(1), 112-123.

Eu (European Union) (2004) Directive 2004/107/EC of the European Parliament and the Council relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air. Official Journal of European Uion L23, 3-16.

Fang, G.C., Chang, K.F., Lu, C., Bai, H. (2004) Estimation of PAHs dry deposition and BaP toxic equivalency factors (REFs) study at Urban, Industry Park and rural sampling sites in central Taiwan, Taichung. Chemosphere 55, 787-796.

Harrison, R.M., Smith, D.J.T. (1996) Source apportionment of atmospheric polycyclic aromatic. Environmental Science & Technology 30, 825.

IARC Monograph of carcinogenic risk to humans, Supplement 7 (1987) Overall evaluation of carcinogenicity. An updating of IARC Monograph 142, 321-324.

IARC Monographs on the Evaluation of Carcinogenic Risks to Humans (2002) Some traditional herbal medicines, some mycotoxins, naphthalene and styrene. IARC Summary of Data Reported and Evaluation 82, 367.

IARC Monographs on the Evaluation of Carcinogenic Risks to Humans (2010) Some non-heterocyclic polycyclic aromatic hydrocarbons and some related exposures. IARC Monograph 92, 773.

Kim, H.H., Lim, Y.W., Jeon, J.M., Kim, T.H., Lee, G.W., Lee, W.S., Lim, J.Y., Shin, D.C., Yang, J.Y. (2013) Indoor Exposure and Health Risk of Polycyclic Aromatic Hydrocarbons (PAHs) in Public Facilities, Korea. Asian Journal of Atmospheric Environment 7(2): 72-84.

Lee, P.K., Brook, J.R., Dabek-Zlotorzynska, E., Mabury, S. (2003) Identification of the major soirces contributing to $PM_{2.5}$ observed in Toronto. Environmental Science and Technology 37, 4831-4840.

Li, A., Schoonover, T.M., Zou, Q., Norlock, F., Conroy, L.M., Scheff, P.A., Wadden, R.A. (2005) Polycyclic aromatic hydrocarbons in residential air of ten Chicago area homes: concentrations and influencing factors. Atmospheric Environment 39, 3491-3501.

Li, C.S., Ro, Y.S. (2000) Indoor charcateristics of polycyclic aromatic hydrocarbons in the urban atmosphere of Taipei. Atmospheric Environment 34, 611-620.

Li, J., Zhang, G., Li, X.D., Qi, S.H., Liu, G.Q., Peng, X.Z. (2006) Source seasonality of polycyclic aromatic hydorcarbons (PAHs) in a subtropical city, Guangzhou, South China. Science of the Total Environment 355, 145-155.

Lu, H., Zhu, L., Chen, S. (2008) Pollution level, phase distribution and health risk of polycyclic aromatic hydrocarbons in indoor air at public places of Hangzhou, China. Environmental Pollution 152, 569-575.

Malcolm, H.M., Dobson, S. (1994) The calculation of an environmental assessment level (EAL) for atmospheric PAHs using relative potencies. London, UK, Depart-

ment of the Environment.
Mannino, M.R., Orechio, S. (2008) Polycyclic aromatic hydrocarbons (PAHs) in indoor dust matter of Palermo (Italy): Extraction, GC-MS analysis, distribution and sources. Atmospheric Environment 42, 1801-1817.
Masih, J., Masih, A., Kulshrestha, A., Singhvi, R., Taneja, A. (2010) Charcateristics of polycyclic aromatic hydrocarbons in indoor and outdoor atmosphere in the North central part of India. Journal of Hazardous Materials 177, 190-198.
Menichini, E., Iacovella, N., Monfredini, F., Turrio-Baldassarri, L. (2007) Relationships between indoor and outdoor air pollution by carcinogenic PAHs and PCBs. Atmospheric Environment 41, 9518-9529.
Mitra, S., Ray, B. (1995) Patterns and sources of polycyclic aromatic hydrocarbons and their derivatives in indoor air. Atmospheric Environment 29, 3345-3356.
NIEHS (National Institute of Environmental Health Sciences) (1998) 8th report on carcinogens 1998 summary. U.S. Department of Health and Human Services Public health Service.
Novotna, B., Topinka, J., Solansky, I., Chvatalova, I., Lnenickova, Z., Sram, R.J. (2007) Impact of air pollution and genotype variability on DNA damage in Prague policemen. Toxicology Letters 172, 37-47.
Ohura, T., Amagai, T., Fusaya, M., Matsushita, H. (2004) Polycyclic aromatic hydrocarbons in indoor and outdoor environments and factors affecting their concentrations. Environmental Science and Technology 38, 77-83.
Ohura, T., Noda, T., Amagai, T., Fusaya, M. (2005) Prediction of personal exposure to $PM_{2.5}$ and carcinogenic polycyclic aromatic hydrocarbons by their concentrations in residential microenvironments. Environmental Science and Technology 39, 5592-5599.
Okona-Mensah, K.B., Battershill, J., Boobis, A., Fielder, R. (2005) An approach to in bestigating the importance of high potency polycyclic aromatic hydrocarbons(PAHs) in the induction of lung cancer by air pollution. Food and Chemical Toxicology 43, 1103-1116.
Pan, S.H., Li, J., Lin, T., Ahang, G., Li, X.D., Yin, H. (2012) Polycyclic aromatic hydrocarbons on indoor/outdoor glass window surfaces in Guangzhou and Hong Kong, south China. Environmental Pollution 169, 190-195.
Schauer, C., Niessner, R., Poschl, U. (2003) Polycyclic aromatic hydrocarbons in urban air particulate matter: decadal and seasonal trends, chemical degradation, and sampling artifacts. Environmental Science and Technology 37, 2861-2868.
Shah, S.D., Ogunyoku, T.A., Miller, J.W., Cocker, D.R. (2005) On-road emission rates of PAH and n-alkane compounds from heavy-duty diesel vehicles. Environmental Science & Technology 39, 5276-5284.
Slezakova, K., Castro, D., Pereira, M.C., Morais, S., Delerue-Matos, C., Alvim-Ferraz, M.C. (2009a) Influence of tobacco smoke on carcinogenic PAH composition in indoor PM_{10} and $PM_{2.5}$. Atmospheric Environment 43, 6376-6382.
Slezakova, K., Castro, D., Pereira, M.C., Morais, S., Delerue-Matos, C., Alvim-Ferraz, M.C. (2010) Influence of traffic emissions on the carcinogenic polycyclic aromatic hydrocarbons in outdoor breathable particles. Journal of the Air and Waste Management Association 60, 393-401.
Thielen, A., Klus, H., Müller, L. (2008) Tobacco smoke: unraveling a controversial subject. Experimental and Toxicologic Pathology 60, 141-156.
Tsapakis, M., Stephanou, E.G. (2005) Occurrence of gaseous and particulate polycyclic aromatic hydrocarbons in the urban atmosphere: study of sources and ambient temperature effect on the gas/particle concentration and distribution. Environmental Pollution 133, 147-156.
U.S. EPA (U.S. Environmental Protection Agency) (1993) Provisional guidance for quantitative risk assessment of polycyclic aromatic hydrocarbons: EPA/600/R-93/089; Office of research and development, U.S. Environmental Protection Agency: Washington, DC.
U.S. EPA (U.S. Environmental Protection Agency) (1999) Determination of Polycyclic Aromatic Hydrocarbons (PAHs) in Ambient Air Using Gas Chromatography/Mass Spectrometry (GC/MS): EPA/625/R-96/010b; U.S. Environmental Protection Agency: Cincinnati, OH 45268.
U.S. EPA (U.S. Environmental Protection Agency) (2002) Peer Consultation Workshop on Approaches to Polycyclic Aromatic Hydro carbon (PAH) Health Assessment EPA/635/R-02/005; National Center for Environmental Assessment Office of Research and Development U.S. Environmental Protection Agency: Washington, DC.
U.S. EPA (U.S. Environmental Protection Agency) (2007) Polycyclic organic matter (POM). Washington, DC.
U.S. EPA (U.S. Environmental Protection Agency) (2010) Development of a relative potency factor (RPF) approach for polycyclic aromatic hydrocarbon (PAH) mixtures: EPA/635/R-08/012A; U.S. Environmental Protection Agency: Washington, DC.
Wang, W., Huang, M.J., Chan, C.Y., Cheung, K.C. (2013) Risk assessment of non-dietary exposure to polycyclic aromatic hydrocarbons form human hair. Atmospheric Environment 73, 204-213.
WHO (World Health Organization) (1987) Polynuclear aromatic hydrocarbons (PAHs). In: Air quality guidelines for Europe. World Health Organization Regional Office for Europe, Copenhagen, 105-117.
WHO (World Health Organization) (2000) Air Quality Guidelines, second ed. WHO Regional Publications, European Series 91, Copenhagen, 186-194.
WHO (World Health Organization). (2000) Guideline for Air Quality. WHO Geneva.
Yang, C.R., Lin, T.C., Chang, F.H. (2007) Particle size distribution and PAH concentrations of incense smoke in a combustion chamber. Environmental Pollution 145(2), 606-615.
Zhang, L., Bai, Z., You, Y., Wu, J., Feng, Y., Zhu, T.

(2009) Chemical and stable carbon isotopic characterization for PAHs in aerosol emitted from two indoor sources. Chemosphere 75, 453-461.

Zhang, Y., Tao, S. (2008) Seasonal Variation of polycyclic aromatic hydrocarbons (PAHs) emissions in China. Environmental Pollution 156, 657-663.

Zhou, B., Zhao, B. (2012) Population inhalation exposure to polycyclic aromatic hydrocarbons and associated lung cancer risk in Beijing region: Contributions of indoor and outdoor sources and exposures. Atmospheric Environment 62, 472-480.

Zhu, L., Lu, H., Chen, S., Amagai, T. (2009) Pollution level, phase distribution and source analysis of polycyclic aromatic hydrocarbons in residential air in Hangzhou, China. Journal of Hazardous Materials 162, 1165-1170.

Zhu, X.L., Liu, W.L., Lu, Y.Y., Zhu, T. (2002) A comparison of PAHs source profiles of domestic coal combustion, coke plant and petroleum asphalt industry. Acta Scientiae Circumstantiae (In Chinese) 22, 199-203.

(Received 23 October 2013, revised 5 March 2014, accepted 18 March 2014)