Asian Journal of Atmospheric Environment
Vol. 5-2, pp.121-133, June 2011
doi: 10.5572/ajae.2011.5.2.121

Risk Assessment of Volatile Organic Compounds (VOCs) and Formaldehyde in Korean Public Facilities: Derivation of Health Protection Criteria Levels

Ho-Hyun Kim, Young-Wook Lim, Dong-Chun Shin[1], Jong Ryeul Sohn[2] and Ji-Yeon Yang*

The Institute for Environmental Research, Yonsei University College of Medicine, 250 Seongsan-no, Seoul 120-749, Korea
[1]Department of Preventive Medicine, Yonsei University College of Medicine, 250 Seongsan-no, Seoul 120-749, Korea
[2]Department of Environmental Health, College of Health Science, Korea University, Seoul 136-701, Korea

*Corresponding author. Tel: +82-2-2228-1896, E-mail: jyyang67@yuhs.ac

ABSTRACT

This study suggests criteria to conduct a risk assessment of VOCs and formaldehyde in uncontrolled public facilities. Pollutants and facilities were selected based on two years of monitoring data and exposure scenarios in 573 uncontrolled public facilities, composed of 10 types of public institutions. With the exception of social welfare facilities, lifetime ECRs of formaldehyde and benzene in each facility were higher in employees than in users, except in social welfare facilities. In social welfare facilities, the risk of benzene for users (1×10^{-5}) was higher than that of workers (1×10^{-6}) because facility users live in the facility 24 hours per day, compared to workers who spend an average of 8 hours per day in the facility. The risk of benzene to workers in restaurants, academies, performance halls, internet café and pubs were estimated as high as 1×10^{-4} and the risk to workers in the theaters and karaoke bars were recorded as 1×10^{-5}. Because lifetime ECRs of carcinogens exceeded 1×10^{-4} for workers and users in most facilities, risk management of formaldehyde and benzene in these facilities is necessary. Although HQs of toluene and xylenes did not exceed 1.0, their HQs did exceed 0.1 in some facilities, so they were evaluated as potentially harmful materials. Additionally, criteria for health protection in IAQ by facility are suggested at 60-100 $\mu g/m^3$ for formaldehyde, 400-500 $\mu g/m^3$ for TVOCs, 10-20 $\mu g/m^3$ for benzene, 150-170 $\mu g/m^3$ for toluene and 100 $\mu g/m^3$ for xylenes, based on the survey on IAQ and HRA methodology. The excess rates of IAQ to health protection criteria in all facilities were 16% for formaldehyde, 8% for TVOCs and benzene, 9% for toulene, and 5% for xylenes.

Key words: Risk assessment, Health protection criteria, Public facility, VOCs, HCHO

1. INTRODUCTION

Individuals use various indoor spaces or public facilities for their lifetime and inhalation of polluted indoor air increases human health risks (Gioda and Aquino Neto, 2003). Indoor air quality (IAQ) is critical in maintaining a healthy life but proper management of IAQ can be very difficult. Pollutants may be present in public facilities that are utilized by all ages, such as restaurants, exhibition halls and performance halls. Therefore, in terms of public health, it is very important to consider all age groups when determining IAQ criteria for public facilities (Jones, 1999).

Hazardous indoor agents include respiratory particulates, bioaerosols, and toxic chemicals such as lead, asbestos, aldehydes and total volatile organic compounds (TVOCs) (Yoon *et al.*, 2010). In particular, TVOCs can be released to indoor spaces through construction finishing materials, so there is an emphasis on TVOC risk assessment in new buildings (Rehwagen *et al.*, 2003). An increase in VOCs appears to cause respiratory health problems (Diez *et al.*, 2000; Wieslander *et al.*, 1996). According to IARC (IARC, 2004b), the indoor air pollutant formaldehyde (HCHO) is currently classified as Group 1 or carcinogenic, and is found in glue, carpets, detergents, furniture and construction materials (Wolkoff *et al.*, 1998).

Health risk assessment (HRA) methodology and previous applications of criteria for substances and media such as ambient air, drinking water and soil, included various exposure scenarios based on actual survey data (US EPA, 1985). The inhalation exposure of individuals depends on personal time allocated to daily activities in different microenvironments (Bruinen de Bruin *et al.*, 2008). A more complete picture of human inhalation exposure and factors determining this exposure can be obtained by combining the daily activity and microenvironment monitoring data (Sexton *et al.*, 2007). Although this study performed a survey on actual conditions with representative samples obtained around the whole nation, complete enumeration in all facilities was not feasible.

The health risk to users (customers) or workers was calculated using HRA methodology. The methodology used to determine health protection criteria is also used in the U.S., the E.U. and in the World Health Organization (WHO) (Michael and Christin, 2005; WHO, 2000; US EPA, 1985). The carcinogen standard is essentially zero, based on HRA targeting as low as reasonably achievable (ALARA) level. However, zero is an ideal level which can be difficult, if not impossible, to reach in reality. Therefore the U.S. EPA, after considering technical, social and economic factors, established guidelines of 1×10^{-6}-1×10^{-4} (US EPA, 1985). The WHO recommends reference doses based on levels corresponding to health risk of 1×10^{-5} (WHO, 2000). For non-cancer pollutants, the criteria is defined as a level which does not produce harmful effects even after lifetime exposure, and is calculated by considering safety levels based on non-cancer reference dose.

The Korean Ministry of Environment started managing IAQ in 1989, by creating recommended environmental standards and guidelines of some underground spaces including underground shopping centers and underground parking lots. The 'Air Quality Control in Underground Locations Act' was enacted in 1996, and supplements the aforementioned guidelines. In 2003, the 'Air Quality Control in Underground Locations Act' was revised to include more facilities, and was renamed the 'Indoor Air Quality Control in Public Use Facilities, etc. Act.' While the 'Air Quality Control in Underground Locations Act' managed only underground facilities such as subway stations and underground shopping centers, the newly revised act also regulates libraries, museums, medical service buildings, indoor parking lots, airport terminal waiting areas, funeral halls and child care facilities. The revised act not only includes additional controlled facilities, but also increases the effectiveness of managing IAQ in these facilities by consolidating indoor spaces by within one act. However, due to user sensitivity and length of exposure, IAQs for schools and workplaces are still controlled separately by the 'School Health Act' or 'Occupational Safety and Health Act', respectively. As the importance of IAQ has become more apparent, so has the necessity to expand the list of controlled facilities.

This study aims to assess the risk of indoor air pollutants such as formaldehyde and VOCs in various uncontrolled public facilities using HRA methodology. This study will also suggest health protection criteria for risk management of uncontrolled public facilities, based on a nationwide survey that describes the actual conditions in ten different types of uncontrolled public facilities.

Table 1. Description of types and number to survey facilities in this study.

Study years	Types of facility	Number of facility
1st survey ('05-'06)	Movie theater	70
	Restaurant	86
	Academy	70
	Performance hall	22
	Internet café	30
	Karaoke	30
	Pub	30
2nd survey ('06-'07)	Wedding hall	32
	Gymnasium	17
	Exhibition hall	20
	Social welfare (facility)	166

2. MATERIALS AND METHODS

2.1 Survey Period and Selection of Uncontrolled Facilities

We investigated a total of 573 facilities, composed of 10 types of public institutions that are not currently subject to legal management by the "Indoor Air Quality Control in Public Use Facilities, etc. Act." The first survey was conducted from March to October of 2005 and involved 338 facilities including movie theaters, restaurants, academies, performance halls, internet cafés, karaoke bars, and pubs. The second survey was conducted from June 2006 to August 2007 and involved 235 facilities including wedding halls, gymnasiums, exhibition halls and social welfare facilities such as handicapped care facilities, child welfare facilities, elderly welfare facilities and female care facilities (Table 1).

2.2 Target Pollutants and Classification of Carcinogenicity

This study examined HCHO and five representative VOCs: benzene, toluene, ethyl benzene, xylenes and styrene. Target pollutants were classified into carcinogen and non-carcinogenic chemicals according to classification of carcinogenicity by the US EPA (1997). In this study, the carcinogens include formaldehyde (B1: Probable human carcinogen) and benzene (A: Human carcinogen) and the non-carcinogens include toluene, ethyl benzene, xylenes and styrene. All of the non-carcinogens are classified as D (not considered a human carcinogen) by US EPA.

Table 2. RRT[1)] program results by unknown sample for QA/QC of involved laboratories.

Chemicals	Measured concentration by laboratories (μg/m^3)			Average concentration (μg/m^3)	Standard deviation (μg/m^3)	Relative standard deviation by laboratories (%)
	A Lab.	B Lab.	C Lab.			
Formaldehyde	93.3	85.6	92.6	90.5	0.49	−0.4-8.0
TVOC	118.2	106.4	122.2	115.6	8.21	−2.2-8.0

[1)]RRT: Round robin test for QA/QC of measured data by different laboratories

2. 3 Sampling and Analysis

Indoor air samples of target pollutants were collected during business hours at each facility, and the collection location within each facility was chosen based on ventilation, interior structures, and emission sources in each facility.

Samples of 5 VOCs were collected by personal air sampler (Sibata, Japan) with a Tenax sorbent tube (1/4″ × 20 cm stainless steel, Supelco, USA). Samples were collected over a period of 30 minutes and sampler flow was 0.2 L/minute. After the sample was collected, the sorbent tube was put into Swagelok, sealed with Teflon caps on both ends and refrigerated at less than −75°C until analysis. VOCs were measured within a week of sampling, using GC/MSD (gas chromatography/mass selected detector, USA) connected to a thermal desorber within.

Indoor samples of HCHO were collected with a personal air sampler by installing an ozone scrubber cartridge to remove the interference of ozone in front of DNPH-silica cartridge (Waters Corp, USA) charging 350 mg DNPH (2,4-dinitrophenylhydrazone)-silica (1.0 mg DNPH) or 1.0 cm (i.d.) × 2.0 cm (o.d.) × 4.3 cm (total length) cartridge. HCHO samples were collected at the same sampling location as VOCs, from a height of 1.0-1.5 m at a flow rate of 0.5 L/min for 30 minutes. After sampling, the DNPH cartridge was sealed with plastic caps on the both ends and stored at −70°C until analysis. The absorbed formaldehyde was derived and analyzed with HPLC (high performance liquid chromatography, USA).

2. 4 Quality Assurance/Quality Control (QA/QC)

This study involved a nationwide survey with three different institutions in charge of sampling and analysis in different regions of Korea. In order to QA/QC the results from several different institutions, the following measures were each performed twice: adjustment of the personal air pump, cleaning check of TVOC and HCHO sorbent tube and DNPH cartridge, tube-use history management of TVOC sorbent tube, and a RRT (Round Robin Test). An RRT is an inter-laboratory test and a reciprocal comparative test of a sample at a certain level. Samples for the first and the second RRT were collected from the same spot at the same time and were quantitatively analyzed for QA/QC of measurement and analysis at each of the institutions. Calibration curves were drawn of each substance, by institution, and the coefficient of determination of all substances was over 0.997 (r^2). The first RRT showed that deviation of the range of TVOC and HCHO levels according to institution was less than 10% (Table 2).

2. 5 Classification of Facilities for Risk Assessment

In uncontrolled public facilities there was no statistically significant difference in variables such as region, allowance of smoking, location above-ground or underground, business hours, occurrence of construction, or use of air freshener and ventilation. Smoking did not significantly increase the IAQ because only 30% of the facilities allow smoking inside. Therefore the risk assessments did not take into account whether or not a facility allowed smoking indoors.

2. 6 Assessment of Human Exposure and Uncertainty Analysis

Human exposure from polluted indoor air should be calculated by considering contamination levels, daily inhalation rates, body weight, exposure frequency, exposure duration and life expectancy (Table 3). Daily inhalation rate was applied according to the characteristics of workers and users of each facility. Daily inhalation rates of users are cited in Korea Exposure Factors Handbook (Jang *et al.*, 2007). The average daily inhalation rate for adults (13.4 m^3/day) was based on a lifetime chronic exposure assessment of adults from Korea Exposure Factors Handbook (Jang *et al.*, 2007). For short-term exposure, the total volume of rest, sedentary exercise, light exercise, middle-intensity activity and vigorous exercise for men and women were estimated at 0.45 m^3/hr, 0.5 m^3/hr, 1.1 m^3/hr, 1.4 m^3/hr and 3.2 m^3/hr, respectively (Jang *et al.*, 2007). In addition, the characteristics of each facility were considered when calculating inhalation rates. There are no data on inhalation rates of workers in South Korea, so the 'Exposure Factors Handbook' of US

Table 3. Exposure factors for worker and user in the survey facilities.

Exposure factors		Movie theater	Restaurant	Academy	Performance hall	Internet café	Karaoke	Pub	Wedding hall	Gymnasium	Exhibition hall	Social welfare
Inhalation[1] (μg/hr)	Worker	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.5	0.5	0.5	0.5
	User	0.5 (sedentary)	1.0 (light)	0.5 (sedentary)	1.6 (moderate)	0.5 (sedentary)	3.2 (heavy)	1.6 (moderate)	1.0 (light)	3.2 (heavy)	1.0 (light)	0.5 (sedentary)
Exposure time[2] (hr/day)	Worker	8	8	8	8	8	8	8	8	8	8	8
	User-Mean	2.3	1.5	3.0	2.8	2.5	2.2	2.5	1.7	2	1.8	13.1
	User-Max	3.0	3.0	6.0	4.0	6.0	3.0	4.0	4.0	3	3	24
Exposure frequency[2] (days/yr)	Worker	300	300	300	300	300	300	300	300	264	300	288
	User-Mean	30	100	240	40	100	50	100	15.6	90	43	252
	User-Max	60	240	300	60	300	180	240	24	240	240	360
Exposure duration[2] (years)	Worker	40	40	40	40	40	40	40	40	40	40	40
	User (User age)	60 (5-65)	69 (1-70)	60 (5-65)	60 (5-65)	50 (5-55)	60 (5-65)	45 (20-65)	60 (1-60)	45 (14-60)	45 (14-60)	65 (1-65)
Body weight[3] (kg)	Worker	60	60	60	60	60	60	60	60	60	60	60
	User											
	Age 1-4 years	–	10	–	–	–	–	–	10	–	–	10
	Age 5-13 years	30	30	30	30	30	30	–	30	30	30	30
	Age > 13 years	60	60	60	60	60	60	60	60	60	60	60

[1]US EPA (1997)

[2]Survey data by a questionnaire for facility users (customers) and workers during the indoor air sampling periods in this study

[3]KATS (2004): Average body weight of 1-4 years old: 12.1 kg, Average body weight of 5-13 years old: 32.3 kg, Average body weight of 14-19 years old: 58.6 kg, Average body weight of > 20 years old: 62.8 kg

EPA was used to estimate occupational inhalation rates (US EPA, 1997). Workers risks were calculated based on the inhalation rate of a chronic exposure via single route, 20 m^3/day (90th upper confidence limit value) by the precautionary principle (US EPA, 1997).

Body weight was estimated using the average body weight by age as provided by the Korean Agency for Technology and Standards (KATS, 2004). Age distribution at each facility was determined by questionnaire. Average life span was estimated to be 70 years which is the average life expectancy in Korea. Exposure time and duration were based on survey data collected from a questionnaire completed by facility users (customers) and workers during the sampling periods.

Exposure frequency was divided into three groups according to exposure scenario. Group 1 was composed of workers with the highest exposure frequency (Worker Exposure Scenario; WES), group 2 was composed of frequent users (User Worst Exposure Scenario; UWES) and group 3 was composed of average users whose exposure was expected to be low (User Average Exposure Scenario; UAES).

Human exposure based on exposure scenario in each facility was calculated by modifying the formula slightly to reflect exposure conditions according to exposure time (1).

$$\text{LADD (mg/kg/day)} = \sum C_{IA} \times \frac{IR_{kj} \times ET_{kj} \times EF_{kj} \times ED_{kj}}{BW_i \times AT} \quad (1)$$

Where LADD: Lifetime average daily dose (mg/kg/day)
C_{IA} : Concentration of chemicals in indoor air at facility (mg/m^3)
IR_{kj} : Inhalation rate for exposure scenario, k and facility, j (m^3/hr)
ET_{kj} : Exposure time for exposure scenario, k and facility, j (hrs/day)
EF_{kj} : Exposure frequency for exposure scenario, k and facility, j (days/yr)
ED_{kj} : Exposure durations for exposure scenario, k and facility, j (yrs)
BW_i : Body weight at age, I (kg)
AT : Average time for lifetime (days)

2.7 Dose-response Data for Pollutants

Cancer potency (q_1*) is the probability of cancer calculated by unit body weight and per dose as a 95% upper limit of linear coefficient in a dose-response curve. Unit risk is an excess cancer risk which can be estimated when a healthy adult is exposed to air contaminated by a unit concentration (1 μg/m^3) of a pollutant.

Formaldehyde was analyzed using a cancer potency of 4.6×10^{-2} (mg/kg/day)$^{-1}$ in a linearized multistage model based on dose-response data from Kerns *et al.* (1983). The cancer potency of benzene (WHO, 2000) was 3.6×10^{-2} (mg/kg/day)$^{-1}$ (Table 4).

The risk of non-cancer pollutants was assessed with reference concentration (RfC), which is defined as an exposure reference level that does not result in toxic effects after lifetime exposure to the substance. RfC of toluene was determined to be 46 mg/m^3 as No Observed Adverse Effect Level (NOAEL), which means that 46 mg/m^3 is the lowest concentration that does have a toxic effect on humans following inhalation exposure to toluene (Neubert *et al.*, 2001; Cavalleri *et al.*, 2000). The inhalation exposure reference level or RfC of toluene was calculated to be 5 mg/m^3 when taking into account uncertainties associated with toxicity levels. Inhalation exposure references of non-cancer pollutants were determined by following this same proce-

Table 4. Dose-response assessment of carcinogenicity for subject's pollutants in indoor air.

Carcinogens	Critical effect	Dose-response model	Cancer potency ((mg/kg/day)$^{-1}$)	Unit risk ((μg/m^3)$^{-1}$)
Formaldehyde	Squamous cell carcinoma	Linearized miltistage model	4.60×10^{-2}	1.30×10^{-5}
Benzene	Leukaemia	Linearized miltistage model	3.60×10^{-2}	6.00×10^{-6}

Table 5. Dose-response assessment of non-carcinogenic effect for subject's pollutants in indoor air.

Chemicals	Critical effect	Critical dose (mg/m^3)	RfC[a] (mg/m^3)
Toluene	Neurological effects	LOAEL[b]=46	5
Ethyl benzene	Developmental toxicity	NOAEL[c]=434	1.0
Xylenes	Impaired motor coordination	NOAEL=39	0.1
Styrene	CNS effects	NOAEL=34	1.0

[a]Lowest Observed Adverse Effect Level Reference Concentration via inhalation by the IRIS, US EPA
[b]Lowest Observed Adverse Effect Level
[c]No Observed Adverse Effect Level

dure. RfC values for (Korsak *et al*., 1994; Mutti *et al*., 1984; Hardin *et al*., 1981) each substance are presented in Table 5.

2. 8 Risk Characterization of Target Pollutants via Indoor Air

Assumption of risk is a process that combines the results of dose-response assessment and exposure assessment in risk assessment and then determines lifetime Excess Cancer Risk (ECR) and carcinogens hazard quotient (HQ) of non-cancer pollutants after an actual exposure to a pollutant (US EPA, 1987). Lifetime ECR and HQ for various exposure scenarios in the facilities were calculated using the following US EPA formula (US EPA, 1997):

$$ECR = LADD\ (mg/kg/day) \times Slope\ factor\ ((mg/kg/day)^{-1}) \quad (2)$$

$$HQ = \frac{LADD\ (mg/kg/day)}{RfC\ (mg/m^3) \times 20\ (m^3/day)/70\ (kg)} \quad (3)$$

When calculating the HQ of non-cancer pollutants, the reference concentration (RfC, mg/m^3) should be converted to reference dose (mg/kg/day) to reflect human exposure units. RfC is calculated based on an average adult in the U.S.; therefore, RfC was converted based on average body weight (70 kg) and daily inhalation rate (20 m^3/day) for the U.S. (US EPA, 1987).

2. 9 Determination of Heath Protection Criteria

Health protection criteria for uncontrolled public facilities were determined in three steps. In the first step, the reasonable maximum toxicity reference dose that does not result in harmful effects on humans was determined. After reviewing several toxicity information databases such as US EPA IRIS and WHO, the highest reference or guidance value was selected. The purpose of this first step is to establish the upper limit of toxicity for each substance for health protection.

In the second step, the indoor air target level was calculated as part of establishing the target risk goal. This step is similar tithe concept of preliminary remediation goals as described in the US EPA risk assessment guidelines for Superfund, human health evaluation manual (RAGS/HHEM), part B (US EPA, 1991). The target level is derived from risk-based calculations that consider exposure patterns for users and workers of subject facilities. The target level was calculated using the following US EPA formula (US EPA, 1991):

$$Target\ Level\ (\mu g/m^3) = Target\ Risk \times \left(\frac{BW_i \times AT}{IR_{kj} \times ET_{kj} \times EF_{kj} \times ED_{kj}}\right) \quad (4)$$

Target risk is the acceptable or achievable risk goal, described as a function of the acceptable individual lifetime excess cancer risk for carcinogens and acceptable hazard quotient for non-carcinogens. Target excess cancer risks for workers and users are 1×10^{-4} and 1×10^{-5} respectively, and target HQs (Hazard Quotients) for non-carcinogens are 1.0 and 0.1 for workers and users, respectively. The US EPA suggests that is the target HQ be used to calculate a risk-based goal at a pre-specified HI (Hazard Index) of 1.0 for multimedia and multiroutes. If the HI for multimedia and multiroutes is not available, target HQ can be calculated using the relative risk contribution (RRC) by single medium and route to total HI. The default value of target HQ is 0.1 (considering 10% RRC to total HI) for a single exposure medium and pathway (US EPA, 2001). We used 0.1 as the default value of single exposure media target HQ for a facility's user.

In the third and final step, the lowest levels between the reasonable maximum toxicity reference dose (calculated in the first step) and the risk-based target level (calculated in the second step) are selected according to substance and use patterns in the facility. Finally, health protection criteria are determined by rounding down to the lowest level of each substance.

3. RESULTS AND DISCUSSION

3. 1 Monitoring of Formaldehyde and VOCs

Table 6 shows the concentration of target pollutants in the facilities. The average level of formaldehyde in each facility ranged from 23.4 μg/m^3 to 141 μg/m^3. The highest average value of formaldehyde was in performance halls (141 μg/m^3), with levels in exhibition halls (112 μg/m^3) and pubs (84.5 μg/m^3) slightly lower. The high levels of formaldehyde in indoor air are probably caused by indoor materials and human activities (Weng *et al*., 2009). The high levels in performance and exhibition halls is likely caused by stage and display exhibit remodeling, which involves the use of wood, glue, paint and new products. High levels of carbonyls shortly after refurbishment might be due to emissions from décor and construction materials (Weng *et al*., 2009). Cooking food for customers (Zhang and Smith, 1999) and smoking in bars also increased the levels of HCHO (Jones, 1999; Godish, 1991). In academies, tables, chairs, school supplies, electronics and books contributed to higher levels of formaldehyde (Fantuzzi *et al*., 1996).

When indoor HCHO levels were examined according to country, the levels of HCHO in Brazil (at a workplace in a university) and China (in a hotel) were 22.5-161.5 μg/m^3 and 26.3-63.0 μg/m^3 respectively (Caval-

Table 6. Concentrations of formaldehyde and VOCs in indoor air by the survey facilities.

Study years	Facilities	Mean ± S.D[a] (μg/m³)						
		Form-aldehyde	TVOC	Benzene	Toluene	Ethyl-benzene	Xylenes	Styrene
'05-'06	Movie theater (n=70)	54.0±55.6	373±377	12.8±11.9	146±156	14.8±14.7	34.6±37.4	6.6±6.9
	Restaurant (n=86)	39.0±42.9	313±306	8.4±7.6	82.5±102	9.2±8.0	13.7±13.1	4.6±4.9
	Academy (n=70)	74.8±58.6	366±357	8.2±9.1	127±192	8.4±7.6	20.0±21.1	5.9±7.1
	Performance hall (n=22)	141±157	368±250	12.2±12.8	136.9±145	10.0±10.8	38.6±45.7	4.3±3.8
	Internet café (n=30)	63.2±53.7	337±293	29.9±19.0	186.8±128	20.3±24.8	47.2±45.4	10.0±9.0
	Karaoke (n=30)	51.4±44.4	273±168	26.0±20.2	143.4±109	14.4±13.2	31.4±24.3	7.6±7.1
	Pub (n=30)	84.5±81.6	368±259	29.4±19.6	177.9±116	18.2±16.8	36.3±28.8	7.0±6.8
'06-'07	Wedding hall (n=32)	51.1±48.5	408±409	2.5±1.56	69.9±100	7.5±6.4	20.2±20.7	2.4±2.2
	Gymnasium (n=17)	23.4±23.6	515±383	2.5±1.6	113±121	7.7±5.5	17.4±10.5	2.7±4.0
	Exhibition hall (n=20)	113±87.3	360±571	2.1±0.8	96.7±109	19.1±40.7	58.8±149.3	4.0±4.2
	Social welfare (n=166)	30.4±30.6	227±586	1.6±1.9	42.0±123	9.03±40.5	9.55±36.6	4.1±13.0

[a]standard deviation

Table 7. Comparison of formaldehyde and benzene concentrations in indoor air by other studies.

Chemicals	Facilities	Mean (μg/m³)	References
Formaldehyde	Work place at university (n=8)	22.5-161.5	Cavalcante *et al.* (2005)
	Hotel ballroom (n=28)	26.3-63.0	Feng *et al.* (2004)
	Cinema (n=6)	65.2-114.6	Weng *et al.* (2009)
Benzene	Public building (n=150)	1.0-21.3	Bruinen *et al.* (2008)
	Shopping mall (n=6)	1.18	Guo *et al.* (2004)
	Restaurant (n=4)	1.10	Guo *et al.* (2004)

cante *et al.,* 2005; Feng *et al.*, 2004). Weng *et al.* (2009) found that HCHO levels in theaters (65.2-114.6 μg/m³) tend to be slightly higher than levels observed in this study (54 μg/m³). Conversely, indoor HCHO concentrations in cinemas were much higher in this study than compared with Weng *et al.*'s work in China (2009) (Table 7).

The occurrence and concentrations of HCHO and VOCs in homes can be affected by indoor sources, human activities, ventilation rates, and seasonal factors such as temperature changes and humidity (Van der wall *et al.*, 1997). HCHO and VOC levels in this study were higher than those reported in previous studies, although the facilities, seasons and places of the studies were not same.

For VOCs, benzene and toluene levels were highest in internet cafés (29.9 μg/m³ and 186.8 μg/m³, respectively) and pubs (29.4 μg/m³ and 177.9 μg/m³, respectively). Benzene levels ranged from 1-30 μg/m³ and toluene ranged from 40-180 μg/m³. The internet cafés and pubs that were sampled are located underground, allowed smoking, and had a lack of ventilation. Furniture, electronics, carpeting, air fresheners and cooking were additional sources of VOCs (Chao and Chan, 2001; Wolkoff and Nielsen, 2001). Many other toxic VOCs such as xylenes have been identified in ETS (Environmental Toxic Substance) (Xie *et al.*, 2003). It is also regarded as an important source of indoor pollution: smoking has been identified as the major indoor source of benzene, contributing an average of 2-3 μg/m³ to total indoor air concentrations (Ilgen *et al.*, 2001a). The ranges of benzene (1-30 μg/m³) reported in this study were similar to those reported by Bruinen de Bruin *et al.* (2008), but higher than those measured by Guo *et al.* (2003) (Table 7).

3. 2 Risk Assessment

Tables 8 and 9 show the lifetime health risks of carcinogens and non-cancer pollutants.

Lifetime ECRs of HCHO (Table 8) and benzene (Table 9) according to exposure scenario in each facility were higher in workers (who spend more time in a facility) than in users (who are typically exposed for less time) except in the case of social welfare facilities. In a social welfare facility, the risks of carcinogens were higher for users than for workers because the users are living in the facility 24 hours per day, compared to workers who only spend 8 hours/day in the facility.

When looking at lifetime ECR of HCHO according to exposure group, the risk to workers was higher in performance halls (1×10^{-3}) than in movie theaters,

Table 8. Excess cancer risks of formaldehyde in indoor air for the subject's facilities.

Survey years	Facilities	Exposure scenarios		
		WES[a]	UWES[b]	UAES[c]
'05-'06	Movie theater	1.20E-04	9.34E-06	3.58E-06
	Restaurant	4.48E-04	3.13E-04	6.66E-05
	Academy	2.64E-04	1.46E-04	5.75E-05
	Performance hall	1.01E-03	3.34E-04	1.53E-04
	Internet café	2.66E-04	1.20E-04	1.68E-05
	Karaoke	1.52E-04	1.64E-04	3.26E-05
	Pub	2.90E-04	2.45E-04	6.43E-05
'06-'07	Wedding hall	5.22E-05	7.20E-06	1.99E-06
	Gymnasium	1.48E-05	5.57E-05	1.39E-05
	Exhibition hall	1.17E-04	1.21E-04	1.30E-05
	Social welfare	5.21E-06	4.35E-05	1.66E-05

[a]Worker Exposure Scenario
[b]User Worst Exposure Scenario
[c]User Average Exposure Scenario

Table 9. Excess cancer risks of benzene in indoor air for the subject's facilities.

Survey years	Facilities	Exposure scenarios		
		WES[a]	UWES[b]	UAES[c]
'05-'06	Movie theater	5.33E-05	4.13E-06	1.58E-06
	Restaurant	1.34E-04	9.34E-05	1.99E-05
	Academy	1.05E-04	5.76E-05	2.27E-05
	Performance hall	1.40E-04	4.63E-05	2.12E-05
	Internet café	1.23E-04	5.53E-05	7.74E-06
	Karaoke	6.81E-05	7.36E-05	1.47E-05
	Pub	1.22E-04	1.03E-04	2.69E-05
'06-'07	Wedding hall	2.36E-06	3.25E-07	8.98E-08
	Gymnasium	2.03E-06	7.65E-06	1.91E-06
	Exhibition hall	2.23E-06	2.31E-06	2.48E-07
	Social welfare	3.78E-06	3.15E-05	1.20E-05

[a]Worker Exposure Scenario
[b]User Worst Exposure Scenario
[c]User Average Exposure Scenario

restaurants, academies, internet café, karaoke bars and pubs (1×10^{-4}) and in wedding halls and gymnasium (1×10^{-5}). In restaurants, academies, performance halls, internet café, karaoke bars, pubs, gymnasiums, exhibition halls and social welfare facilities, the risks of frequent users and average users were calculated to be 1×10^{-4} to 1×10^{-5} respectively (Table 8). Only users of movie theaters and workers in social welfare facilities were below government standards, with a risk of one per million (1×10^{-6}). Weng *et al.* (2009) reported risk of 1×10^{-3} to both workers and users, illustrating that the risk to low-frequency users was as high as the risk to workers. In movie theaters, the risk to workers and frequent users was 1.20×10^{-4} and 9.34×10^{-6}, respectively. The risk of HCHO exposure for users in movie theaters reported by Weng *et al.* (2009) (average risk 4.4×10^{-4}) was higher than that of this study (average risk 3.58×10^{-6}). This difference was likely caused by frequency of use patterns and background levels in the facilities.

The lifetime ECRs of HCHO of workers and frequent users in restaurants, academies, performance halls, karaoke bars and pubs was found to be 1×10^{-4} and 1×10^{-5}, respectively. The highest HQ of toluene for frequent users was found in restaurants, which was likely caused by cooking and smoking in these facilities. In addition, the lifetime ECR may have been influenced by an increase in the number of individuals eating in restaurants.

The high risk of HCHO exposure in academies and performance halls was likely caused by various sources of pollution such as tables, chairs and construction materials in academies and equipment in performance halls. In addition, repeated exposure for 20-25 days per month led to higher risk in academies. In karaoke bars and pubs, the underground location, lack of ventilation, and presence of smoking in a small space contributed to the high risk, rather than exposure time or frequency. In exhibition halls, both workers and frequent users had high risks, averaging 1.17×10^{-4} and 1.21×10^{-4}, respectively. This was caused by various new products, stage refurbishment and exhibition equipment. Lifetime ECRs of formaldehyde for frequent and average users in the social welfare facilities were 1×10^{-5} and 1×10^{-6}, respectively, and were higher than the values reported for workers in the same facilities.

The risk of benzene exposure for workers in the restaurants, academies, performance halls, internet café and pubs were estimated at 1×10^{-4} and the risk to workers in theaters and karaoke bars were 1×10^{-5} (Table 9). Risk to users in wedding halls, gymnasiums, exhibition halls and social welfare facilities were within safe limits (1×10^{-6}) due to low frequency of use. However, the risks of formaldehyde exposure to frequent and average users in the social welfare facilities were higher (1×10^{-5}) than that of workers. As said before, this is because users spend more time in the facility than workers. Previous risk assessments in the same facilities included in this study are lacking, so the results of this study were compared with risks assessments of similar public facilities. According to Weng *et al.* (2009), the risk of formaldehyde exposure was high to workers and users of shopping centers (1×10^{-3}) and workers and users of supermarkets (1×10^{-4}). These high exposure risks in public places may contribute to increased risk of cancer in the general population (Weng *et al.*, 2009).

3. 3 Health Protection Criteria for Uncontrolled Public Facilities Based on Risk Assessment

Facilities were divided according to the age of their users (adults, adolescents, all age groups and sensitive groups) based on information collected from a two-year survey of user ages. VSDs (Virtually Safety Doses) of each substance were then determined (Table 10). By comparing the levels with health protection upper limits considering toxicity, stricter levels were selected as health protection criteria. Additionally, feasibility of the Act including the criteria was also considered. In the results of each facility according to exposure scenario, a level of over 1,000 μg/m^3 followed low average concentration, low exposure frequency and short exposure period and difference in exposed subjects by facility in making exposure scenario for risk assessment, so it poorly reflected the reality. To supplement these, health protection guidelines are suggested by considering health protection upper limits considering toxicity, health protection upper limits considering exposure and feasibility. VSDs of offices and bars (the only facilities used by adults only) are presented in the following table according to facility and substance. Facilities were classified by user age as follows: those used only by adults (offices and bars), those used by adolescents (academies, internet café and karaoke bars) and those used by sensitive groups (so-

Table 10. Health protection criteria for indoor air quality of uncontrolled public facilities.

Process to the health protection criteria	Concentrations in indoor air (μg/m^3)						
	Formaldehyde	TVOCs	Benzene	Toluene	Ethyl benzene	Xylenes	Styrene
1st step:							
Upper tolerant value[a]	100	1000	30	260	1000	100	260
2nd step:							
Target levels in indoor air[b]							
Adults facilities	100	500	20	170	500	250	170
Adolescents facilities	100	400	20	150	500	120	150
Sensitive groups facilities	60	400	10	150	400	100	130
3rd step:							
Health protection levels in indoor air[c]							
Adults facilities	100	500	20	170	500	100	170
Adolescents facilities	100	400	20	150	500	100	150
Sensitive groups facilities	60	400	10	150	400	100	130

[a]It is the upper limits considering toxicity of each substance for health protection and which is chosen a higher value in reference or guidance values in indoor air at several toxicity information database such as US EPA IRIS and WHO.

[b]It is derived from risk-based calculation considering exposure patterns for user and worker of subject facilities to target risk. Target excess cancer risks for worker and user are 1×10^{-4} and 1×10^{-5}, respectively, and target HQs (Hazard Quotients) of non-carcinogen are 1.0 and 0.1 for worker and user, respectively.

[c]It is the lowest level of data by 1st step and data by 2nd step in the subject's facilities.

Table 11. Excess rates of indoor air quality to the health protection criteria by uncontrolled public facilities.

Chemicals	Health Protection criteria for indoor air quality ($\mu g/m^3$)	Excess rate of indoor air quality (%)			
		Total facilities	Adults facilities	Adolescents facilities	Sensitive groups facilities
Formaldehyde	60-100	16	21	30	9
TVOCs	400-500	8	11	24	0
Benzene	10-20	8	17	21	1
Toluene	150-170	9	11	19	5
Ethyl benzene	400-500	1	0	0	1
Xylenes	100	5	5	6	1
Styrene	130-170	0.3	0	1	0

cial welfare facilities). The health management criteria of the facilities for sensitive groups (social welfare facilities) were the most conservatively.

The most conservative value for each pollutant is selected for the health protection criteria as follows. The guidelines for health protection in indoor air are suggested to be 60 (max 100) $\mu g/m^3$ for formaldehyde, 400 (max 500) $\mu g/m^3$ for TVOCs, 10 (max 20) $\mu g/m^3$ for benzene, 150 (max 170) $\mu g/m^3$ for toluene, 400 (max 500) $\mu g/m^3$ for ethyl benzene, 100 $\mu g/m^3$ for xylenes, and 130 (max 170) $\mu g/m^3$ for styrene. Indoor air concentrations in excess of the health protection criteria are shown in Table 11.

Formaldehyde is classified as a legally controlled substance with a standard of 100 $\mu g/m^3$. There are no guidelines for each VOC in Korea, and the recommended guidelines for TVOCs are less than 400 $\mu g/m^3$ in sensitive facilities such as medical institutions, 500 $\mu g/m^3$ in subway stations and 1,000 $\mu g/m^3$ in indoor parking lots. As the risk assessment conducted for this study shows that the risk of formaldehyde exposure is high, guidelines for formaldehyde exposure are suggested to be 60 (for facilities used by sensitive groups and adolescents)-100 (for facilities done only by adults) $\mu g/m^3$. For VOCs, the current criteria for TVOCs (400 $\mu g/m^3$) can be used for all facilities, including sensitive facilities such as medical institutions. In addition, this study shows that risk of exposure to benzene is also high and needs to be managed. The suggested exposure limit is less than 10 $\mu g/m^3$.

In Germany the guidelines are presented as ranges rather than specific values. The German Ministry of Environment, Nature Conservation and Nuclear Safety suggests a range of 200-300 $\mu g/m^3$, assuming long-term exposure. Guidelines are not provided for formaldehyde and benzene. Poland's Ministry of Health and Social Welfare has no guidelines for TVOC and suggests less than 10 $\mu g/m^3$ for benzene category A (24 h exposure), 20 $\mu g/m^3$ for benzene category A (8 h exposure), 50 $\mu g/m^3$ for formaldehyde category A (24 h exposure), and 100 $\mu g/m^3$ for formaldehyde category A (8 h exposure). In Japan, there are no guidelines for benzene and the guidelines for formaldehyde and TVOC are less than 100 $\mu g/m^3$ and 400 $\mu g/m^3$, respectively (KEI, 2004). Finland's Ministry of Environment does not provide guidelines for TVOCs. For VOCs, benzene, and formaldehyde the guidelines are set at less than 50 $\mu g/m^3$ (Bruinen de Bruin *et al.*, 2008).

However, unlike other countries, Japan presented references of each VOC as follows: less than 260 $\mu g/m^3$ for toulene (compared to 150 $\mu g/m^3$ in this study), 870 $\mu g/m^3$ for xylenes (compared to 100 $\mu g/m^3$ in this study), 3,800 $\mu g/m^3$ for ethyl benzene (compared to 500 $\mu g/m^3$ in this study) and 220 $\mu g/m^3$ for styrene (compared to 150 $\mu g/m^3$ in this study) (WHO, 2005). When these levels were compared with those suggested by this study, the levels of TVOC, toluene and styrene were similar while the levels of xylenes and ethyl benzene were different. This difference was caused by a difference in VOC concentrations in facilities, as well as a different approach to management and HRAs. However, in most countries the suggested guidelines for formaldehyde are 50-100 $\mu g/m^3$, and guidelines for TVOCs either are not recommended or are 200-400 $\mu g/m^3$. As a result, the levels suggested as guidelines are similar to reference levels suggested by this study, which were calculated from the risk assessment and based on survey results describing the actual conditions of public facilities.

One of the limitations of this study was that although indoor smoking was an important variable when considering exposure to benzene and other substances, it was not measured during business hours due to opposition from some business owners who believed that the measurements and results could hinder business. This means that the risk of exposure to pollutants in smoking facilities was almost certainly assessed at a lower level than actual conditions, which explains why the risks were lower than expected in some smoking facilities. In addition, human risk was assessed based on the assumption that an individual would be exposed to a level for all one's life (70 years) (worst condition),

Table 12. Summary of indoor air quality guideline at the several countries.

Chemicals ($\mu g/m^3$)	Nation													
	Korea					Finland			Germany				Poland	
	Medical institution	Subway station	Underground parking lot	America	Canada	S1	S2	S3	GV II	GV I	Japan	Norway	Category A (24 hr exposure)	Category B (8 hr exposure)
Formaldehyde		100		100	120	30	50	100	–	120	100	100 (30 min)	50	100
TVOCs	400	500	1,000	–	–	200	300	600	1,000-3,000		400	–	–	
Benzene		–		0.63 ppm	–		–		–		–	–	10	20
Toluene		–		–	–		–		3,000	300	260	–	200	250
Ethyl benzene		–		–	–		–		–		3,800	–	100	150
Xylenes		–		–	–		–		–		870	–	100	150
Styrene		–		–	–		–		300	30	220	–	20	30

and there are some uncertainties about this assumption (Guo *et al*., 2003). One of the limitations when deriving health protection criteria for the general population is that the relative risk contribution (RRC) is assumed to be 0.1, because low frequency and exposure time were conservatively estimated to be approximately 2 hours for the general user.

Indoor pollutants vary from chemical substances to microorganisms and mineral fibers. The current 'Indoor Air Quality Control in Public Use Facilities, etc. Act' describes legal regulations and recommended guidelines for indoor air quality and contaminants. The five pollutants that are the subject of legal regulations include PM_{10}, CO_2, HCHO, TBC and CO. The five pollutants for which there are recommended guidelines include NO_2, Rn, TVOC, asbestos and ozone. Guidelines and management differ according to country (WHO, 2000) (Table 12). While formaldehyde, radon, PM_{10} and VOCs are commonly controlled as major pollutants, the control of other substances varies greatly according to country (WHO, 2005). Guidelines are provided for biological pollutants such as mold and mites, which are known to provoke asthma and allergy in children, although actual references are presented in only a few cases. In addition, cigarette smoke is a pollutant that requires management, but most countries do not suggest guidelines.

In addition to the indoor pollutants and facilities described in this study, health protection criteria for various indoor pollutants related to environmental disease should be established through health risk assessment methodology for various indoor facilities.

4. CONCLUSIONS

This study performed an HRA based on exposure scenarios from survey results on IAQ in movie theaters, restaurants, academies, performance halls, internet cafés, karaoke bars, pubs, wedding halls, gymnasiums, exhibition halls and social welfare facilities.

Because lifetime ECRs of carcinogens were calculated as high as 1×10^{-4} for workers and 1×10^{-4} for users of most facilities, risk management of formaldehyde and benzene in these facilities is necessary. The HQs of toluene and xylenes exceeded 0.1 but did not exceed 1.0 in some facilities including restaurants, so they were evaluated to be potentially harmful materials to human health. When risks are assessed by facility, the risk of exposure in performance halls, restaurants, academies, pubs, internet cafés, karaoke bars and exhibition halls were higher than those of others, risk management in these facilities is needed. With the exception of academies and performance halls, most of the facilities allowed smoking. The underground location of pubs and internet cafés, as well as the lack of ventilation, could also increase risk. In social welfare facilities, unlike other facilities, the risk of users was higher than that of workers because the users were exposed longer due to the fact that they live in the facilities. As the social welfare facilities showed a high usage rate of sensitive groups, strict IAQ guidelines should be determined to prevent occurrence of disease caused by poor IAQ.

Additionally, criteria for health protection by the facility are suggested to be 60-100 $\mu g/m^3$ for formaldehyde, 400-500 $\mu g/m^3$ for TVOCs, 10-20 $\mu g/m^3$ for benzene, 150-170 $\mu g/m^3$ for toulene, 400-500 $\mu g/m^3$ for ethyl benzene, 100 $\mu g/m^3$ for xylenes and 130-170 $\mu g/m^3$ for styrene, based on the IAQ survey using HRA methodology. The excess rates of indoor pollutant concentration compared to health protection criteria in all facilities were 16% for formaldehyde, 8% for TVOCs and benzene, 9% for toulene, 1% for ethyl benzene, 5% for xylenes and 0.3% for styrene.

Finally, when assuming lifetime exposure to a background level in each public facility, the risk in less frequently used facilities may decline. However, use of these public facilities can vary greatly throughout the population and long-term exposure can produce harmful effects, especially to the health of children, the elderly and pregnant women, so strict guidelines and removal of pollution sources is strongly recommended.

ACKNOWLEDGEMENTS

This work was supported in part by the Korean Ministry of Environment, of "Survey of Indoor Air Quality in Public Facilities I (2006), II (2007)" and we appreciate the support.

REFERENCES

Bruinen de Bruin, Y., Koistinen, K., Kephalopoulos, S., Geiss, O., Tirendi, S., Kotzias, D. (2008) Characterisation of urban inhalation exposures to benzene, formaldehyde and acetaldehyde in the European Union. Environtal Science and Pollution Research 15, 417-430.

Cavalcante, R.M., Seyffert, B.H., Montes D'Oca, M.G., Nascimento, R.F., Campelo, C.S., Pinto, I.S., Anjos, F.B., Costa, A.H.R. (2005) Exposure assessment to formaldehydes and acetaldehydes in workplace. Indoor Built Environment 14, 165-172.

Cavalleri, A., Gobba, F., Nicali, E., Fiocchi, V. (2000) Dose-related color vision impairment in toluene-exposed workers. Archives of Environmental Health 55, 399-404.

Chao, C.Y., Chan, G.Y. (2001) Quantification of indoor VOCs in twenty mechanically ventilated buildings in Hong Kong. Atmospheric Environment 35, 5895-5913.

Diez, U., Kroeβner, T., Rehwagen, M., Richter, M., Wetzig, H., Schulz, R., Borte, M., Metzner, G., Krumbiegel, P., Herbarth, O. (2000) Effects of indoor painting and smoking on airway symptoms in atopy risk children in the first year of life results of the LARS-study. International Journal of Hygiene and Environmental Health 203, 23-28.

Fantuzzi, G., Aggazzotti, G., Righi, E., Cavazzuti, L., Predieri, G., Franceschelli, A. (1996) Indoor air quality in the university libraries of Modena (Italy). The Science of the Total Environment 193, 49-56.

Feng, Y., Wen, S., Wang, X., Sheng, G., He, Q., Tang, J., Fu, J. (2004) Indoor and outdoor carbonyl compounds in the hotel ballrooms in Guangzhou, China. Atmospheric Environment 38, 103-112.

Gioda, A., Aquino Neto, F.R. (2003) Poluic-ão quí mica relacionada ao ar de interior no Brasil (Chemical pollution related to the indoor air in Brazil). Quí mica Nova 26(3), 359.

Godish, T. (1991) Air Quality. Lewis Publishers, Michigan, USA.

Guo, H., Lee, S.C., Chan, L.Y., Li, W.M. (2003) Risk assessment of exposure to volatile organic compounds in different indoor environments. Environmental Research 94, 57-66.

Hardin, B.D., Bond, G.P., Sikov, M.R., Andrew, F.D., Beliles, R.P., Niemeier, R.W. (1981) Testing of selected workplace chemicals for teratogenic potential. Scandinavian Journal of Work, Environment & Health 7, 66-75.

Ilgen, E., Karfich, N., Levsen, K., Angerer, J., Schneider, P., Heinrich, J., Wichmann, H.E., Dunemann, L., Begerow, J. (2001a) Aromatic hydrocarbons in the atmospheric environment: part I. Indoor versus outdoor sources, the influence of traffic. Atmospheric Environment 35, 1235-1252.

International Agency for Research on Cancer (IARC) (2004b) The IARC Monographs Series. Overall Evaluations of Carcinogenicity to Humans, http://monographs.iarc.fr/monoeval/ grlist.html (accessed on 28 November 2004).

Jang, J.Y., Jo, S.N., Kim, S., Kim, S.J., Cheong, H.K. (2007) Korean Exposure Factors Handbook. Korea Ministry of Environment, Seoul, pp. 24-51.

Jones, A.P. (1999) Indoor air quality and health. Atmospheric Environment 33, 4535-4564.

KATS (Korean Agency for Technology and Standards) (2004) Size Korea, Seoul, p. 268.

KEI (Korea Environment Institute) (2004) Research on improvement measures for indoor air quality management, Seoul, pp. 33-82.

Kerns, W.D., Pavkov, K.L., Donofrio, D.J. (1983) Carcinogenicity of formaldehyde in rats and mice after long-term inhalation exposure. Cancer Research 43, 4382-4392.

Korsak, Z., Wisniewska-Knypl, J., Swiercz, R. (1994) Toxic effects of subchronic combined exposure to n-butyl alcohol and m-xylene in rats. International Journal of Occupational Medicine and Environmental Health 7, 155-166.

Michael, K., Christin, V. (2005) Health determinants in Europe for indoor and outdoor pollutions from a public health and social medicine view. Experimental and Toxicological Pathology 57, 9-17.

Mutti, A., Mazzucchi, A., Rustichelli, P., Frigeri, G., Arfini, G., Franchini, I. (1984) Exposure-effect and exposure-response relationships between occupational exposure to styrene and neuropsychological functions. American Journal of Industrial Medicine 5, 275-286.

Neubert, D., Gericke, C., Hanke, B., Beckmann, G., Baltes, M.M., Kühl, K.P., Bochert, G., Hartmann, J. (2001) Multicenter field trial on possible health effects of toluene. II. Cross-sectional evaluation of acute low-level exposure. Toxicology 168, 139-183.

Rehwagen, M., Schlink, U., Herbarth, O. (2003) Seasonal cycle of VOCs in apartments. Indoor Air 13, 283-291.

Sexton, K., Mongin, S.J., Adgate, J.L., Prattc, G.C., Ramachandran, G., Stock, T.H., Morandi, M.T. (2007) Estimating volatile organic compound concentrations in selected microenvironments using time-activity and personal exposure data. Journal of Toxicology and Environmental Health, Part A 70(5), 465-476.

US EPA (1985) Principles of risk assessment: a non-technical review. Preparedfor a risk assessment workshop. Easton, MD, March 17-18.

US EPA (1987) Assessment of Health Risk to Garment Workers and Certain Home Residents from Exposure to Formaldehyde, Office of Toxic Substances, Washington, DC.

US EPA (1989) Risk assessment guidance for superfund: volume I, Human health evaluation manual, Office of emergency and remedial response, EPA/540/1-89/002.

US EPA (1991) Risk assessment guidance for superfund: volume I, Human health evaluation manual - Part B, Development of risk-based preliminary remediation goals, Office of emergency and remedial response, EPA/540/R-92/003.

US EPA (1997) NCEA (National Center For Environmental Assessment), Exposure Factors Handbook. 5-1-5-27.

US EPA (2001) Risk assessment guidance for superfund: volume I, Human health evaluation manual - Part D, Standardized planning, reporting and review of Superfund risk assessments, Office of emergency and remedial response, EPA/9285, 7-47.

Van der wal, J.F., Hoogeveen, A.W., Wouda, P. (1997) The influence of temperature on the emission of volatile organic compounds from PVC flooring, carpet, and paint. Indoor Air 7, 215-221.

Weng, M., Zhu, L., Yang, K., Chen, S. (2009) Levels and health risks of carbonyl compounds in selected public places in Hangzhou. China Journal of Hazardous Materials 164, 700-706.

WHO (2000) Regional Office for Europe, Copenhagen, Denmark Air Quality Guidelines-Second Edition. pp. 12-30.

WHO (2005) Regional Office for Europe. Copenhagen, Denmark. Air Quality Guidelines Global Update. pp. 189-207.

Wieslander, G., Norbäck, G., Björnsson, E., Janson, C., Boman, G. (1996) Asthma and the indoor environment: the significance of emission of formaldehyde and volatile organic compounds from newly painted surfaces. International Archives of Occupational and Environmental Health 69, 115-124.

Wolkoff, P., Schneider, T., Kildesf, D.R., Jaroszewski, M., Schunk, H. (1998) Risk in cleaning: chemical and physical exposure. Science of Total Environment 215, 135-156.

Wolkoff, P., Nielsen, G.D. (2001) Organic compounds in indoor air - their relevance for perceived indoor air quality? Atmospheric Environment 35, 4407-4417.

Xie, J., Wang, X., Sheng, G., Bi, X., Fu, J. (2003) Determination of tobacco smoking influence on volatile organic compounds constituent by indoor tobacco smoking simulation experiment. Atmospheric Environment 37, 3365-3374.

Yoon, C.Y., Lee, K.L., Park, D.G. (2010) Indoor air quality differences between urban and rural preschools in KOREA. Environmental Science and Pollution Research international.

Zhang, J.F., Smith, K.R. (1999) Emissions of carbonyl compounds from various Cookstoves in China. Environmental Science & Technology 33, 2311-2320.

(Received 28 September 2010, accepted 6 May 2011)