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Pattern Classification of Volatile Organic Compounds in Various Indoor Environments

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Abstract The purpose of this study was to survey the distribution patterns of volatile organic compounds (VOCs) and formaldehyde in the various indoor environments using cluster analysis. We investigated VOCs and formaldehyde in subway stations, underground shopping areas, medical centers, maternity recuperation centers, public childcare centers, large stores, funeral homes, and indoor parking lots from June 2005 to May 2006 (9 p.m. to 6 a.m.). The concentration of total volatile compounds (TVOCs) in maternity recuperations was 2,605.7 μg/m^3, which was higher than that stated in the guideline and other chosen facilities. TVOCs in public childcare centers were 1,951.6 μg/m^3, which also exceeded the guideline. Moreover, the concentration of TVOCs in every facility exceeded the guideline of the Ministry of Environment, Korea. In the case of formaldehyde, the mean concentration of 336.5 μg/m^3 found only in public childcare centers exceeded the 120 μg/m^3 stated in the guideline. Finally, by applying cluster analysis, three patterns of the indoor air pollutions were distinguished. In the results of the analysis, concentrations of TVOCs and formaldehyde of cluster 3 were higher than clusters 1 and 2, which were 2,561.4 and 184.9 μg/m^3, respectively.

Keywords VOCs · Formaldehyde · Cluster analysis · Receptor method · Public facility

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1 Introduction

When you look at the background of the advent of the indoor air quality problems, even though the indoor air quality problems gradually increased in residential areas and non-industrial areas before the 1970s, the level of interest in the problems was very low (Stolwijk 1992). Since 1970s, however, as an effort to improve energy-saving efficiency in many industries, an increasing number of buildings implemented air tightness for higher heat efficiency and installed energy-saving equipment. As a result, the indoor air quality of these buildings became aggravated, people's interest increased in the management of indoor air quality, and its potential for health risks increased (NAS 1993). It is known that a health-threatening material affecting indoor air quality consists of various chemicals including volatile organic compounds (VOCs), formaldehyde, and heavy metals (Shim and Kim 2006). Indoor air pollution refers to the state of polluted air in various indoor spaces such as houses, schools, offices, public buildings, hospitals, underground facilities, and means of transportation. It has very complex causes, and although it may not threaten the life of indoor residents, it certainly has long-term negative effects on health (Lee and Chang 2000). Indoor air can contain many kinds of pollutants that differ physically, chemically, and biologically. The sources of these pollutants include external air, tobacco smoke, heaters, ovens, cooking devices, cement, detergents, construction materials, and paints. It is also known that the emission volumes also vary widely depending on the pollutant (James 1991; Tichenor et al. 1990).

In developed countries, there has been active research on indoor air quality, from studies on the current status to studies on indoor air quality prediction models and health risk assessment for residents. In Korea, after the enactment and enforcement of the "Act on internal air quality management in public facilities" by the Ministry of Environment in 2003 and 2004, studies on indoor air quality in a variety of indoor spaces have been actively conducted, in order to increase the number of major facilities for indoor air quality management and to introduce various management techniques based on this Act. Furthermore, to increase the number of controlled pollutants, many studies are being conducted to identify the level of concentration of VOCs that are known to pose high health risk in various indoor environments in addition to the legally restricted pollutants. However, the level of studies on reasonable measures for implementing VOCs and indoor air quality management methods are still very low.

To prepare reasonable countermeasures and management methods for controlling indoor air pollution, we need to conduct studies on indoor air pollution, which can be done using receptor methods (Nam et al. 2002). This study investigated the concentrations of VOCs in the air of different indoor environments and used cluster analysis to classify VOCs into specific clusters or public facilities with similar concentration patterns of VOCs. Furthermore, this study identified the characteristics of the derived clusters and the pollution patterns of VOCs in the indoor air of different environments. Dong-Sul and Hyeong-Seok (1990) and Nam et al. (2002) applied the method used in this study to manage PM_{10} in underground facilities and various indoor spaces. Among the variety of receptor methods, particularly when information on pollution sources is insufficient, factor analysis, multiple regression analysis, cluster analysis, and other multivariate analyses are generally used (Hwang et al. 2001; Yoo and Kim 1997; Son et al. 2003; Hopke 1985). These applied statistical methods classify data into specific clusters of similar properties when information on pollution sources is insufficient and quantitatively examine whether or not the classification has been properly performed. In Korea, Dong-Sul and Hyeong-Seok (1990) have used them to analyze the concentrations of various pollutants in the indoor environment from new angles and also to analyze pollution patterns. The purpose of this study is to understand the shapes of VOCs in various indoor environments so as to provide the basic data required for making selections of VOCs, definitions of standards, and classifications of regulated facilities in the future.

2 Materials and Methods (This Protocol Adopted from the Ministry of Environment, Korea)

2.1 Subjects and Methods

For the collection of VOCs, we used a stainless absorption tube (0.25 in.×9 cm, PerkinElmer, UK) which was filled with 200 mg or more of Tenax-TA (60/80 mesh, Supelco, USA). Before collection, we conducted thermal desorption preprocessing at 300°C for over 3 h using a thermal desorption machine (TC20, Markes, USA). For the pump for the collection of VOCs, we used the Personal Air Sampler (Gilian, USA), which had little variation of flow before and after collection, and collected VOCs at 0.2 L/min for 30 min. Also, we used Digital Flowmeter (Alltech, USA) to measure the total flow absorption before and after collection. We found that the change of flow after collection was within 5% compared to the flow before collection in almost all collections. After sample collection was complete, the two ends of the absorption tubes were blocked with storage caps and stored in a refrigerator at 4°C until analysis, and the analyses were conducted within 1 week after collection. The VOCs were analyzed using the thermal desorption machine Turbomatrix ATD (Perkinelmer, UK) and gas chromatography (GC-MSD, HP-6890, Agilent 5973 inert, USA).

For the collection of formaldehyde, we used the 2,4-DNPH derivatization method which forms stable derivatives by reacting with ketone as well as aldehyde during sample collection to facilitate analysis of DNPH derivatives which are generated by the reaction of carbonyl compounds with 2,4-DNPH. For the collection pump, we used a Personal Air Sampler (Gilian, USA) that has relatively little change of flow after collection at a flow rate of 0.5 L/min, and the collection time was 30 min. For the collection medium, we used a 2,4-DNPH cartridge (Supelco, USA) which is a 4-cm polypropylene tube coated with highly pure 2,4-DNPH. During the aldehyde measurement, ozone acts as an obstruction by decreasing 2,4-DNPH derivatives or reacting with 2,4-DNPH to form artificial impurities. Thus, to remove such effects of ozone, we installed an ozone scrubber (Supelco, USA) which is a 2,4-DNPH cartridge filled with KI at its front part. Furthermore, because sunlight can form artifacts, we prevented exposure to sunlight by using aluminum foil during measurement. When the measurements were completed, the samples were individually stored in containers, which were coated inside with aluminum and stored at 4°C or lower until solvent extraction. All the experimental apparatuses used for the extraction and analysis of samples were washed with HPLC-grade acetonitrile (J.T. Baker, USA) which was the extraction solvent, dried in a drying machine at 60°C for at least 30 min, and purged with highly pure N2 (99.999%). For sample extraction, the 2,4-DNPH cartridge was fixed inside of a vacuum elution rack (Supelco, USA) which is a solvent extraction device. The samples were extracted at a very low speed (1 ml/min) using 5 ml of acetonitrile, which had been filtered three times or more with a fat soluble filter (47 mm, 0.45μm, PTFE), and analyzed with HPLC (Younglin Korea).

2.2 Data Analysis Method

In this study, clusters of similar indoor environments were formed using cluster analysis for various indoor environments. Among the cluster analysis methods, this study employed an agglomerative hierarchical cluster analysis, which is widely used because the algorithm is simple and thus making the calculations easy. Moreover, a Euclidian distance was used to determine the dissimilarity criterion, and the Ward's method was used as a clustering method to represent the distance between classified groups or cases.

Before conducting the cluster analysis, this study converted the raw data. Because the variate distribution is not symmetrical but biased to one side, the result of the statistical analysis can be exaggerated or flawed; therefore, this study first conducted a frequency analysis for the raw data to determine the variate distribution of each variable of the data. This analysis found that the raw data were biased and needed normalization of distribution by data transformation before a cluster analysis could be conducted. Thus, we conducted a logarithmic transformation of the raw data. In addition, we used a *z*-score to standardize the data so that the variables will have the same weights of average 0 and dispersion 1.

3 Results

3.1 Concentration Distribution of VOCs in Various Indoor Environments

The average concentrations of VOCs in various indoor environments are listed in Table 1. The Act on indoor air quality of public facilities by the Ministry of Environment regulates formaldehyde and total VOCs (TVOCs) in the indoor air of various public facilities but does not regulate individual VOCs. This study compared the average concentration of formaldehyde and TVOCs in indoor air of various surveyed public facilities with the regulations of the Act and found that only public childcare facilities exceeded the criterion for formaldehyde. In the case of TVOCs, the average concentrations of all the surveyed public facilities exceeded the criterion.

The average concentration of formaldehyde in the indoor air of public childcare facilities was 336.5 $\mu g/m^3$, which was approximately 2.8 times as high as the criterion for formaldehyde in the indoor air of public facilities as stipulated by the Act, which is 120 $\mu g/m^3$. In the case of TVOCs, the Act applies different criteria such as 500, 400, and 1,000 $\mu g/m^3$ in consideration of the sensitivity of residents to

Table 1 Average concentration of volatile organic compounds in the various indoor environments (unit, μg/m^3)

Pollutant	Sauna (*n*=5)		Library (*n*=3)		Subway station (*n*=3)		Maternity recuperation center (*n*=2)		Public childcare center (*n*=8)		Medical center (*n*=6)		Large store (*n*=8)		Underground shopping area (*n*=8)		Funeral house (*n*=3)		Indoor parking lot (*n*=9)	
Formaldehyde	105.0	±106.9	34.8	±13.8	33.0	±8.0	28.9	±28.8	336.5	±306.8	24.1	±17.0	98.1	±66.3	35.8	±17.1	8.6	±8.0	49.5	±38.3
TVOCs	1621.8	±633.1	1268.2	±1238.5	1073.6	±253.9	2604.7	±133.7	1951.6	±1267.2	931.1	±673.1	1954.4	±1420.0	2267.1	±1378.7	1542.5	±616.4	1412.1	±847.1
Methylchloroform	0.2	±0.2	0.0	±0.0	0.1	±0.0	0.3	±0.0	0.1	±0.1	0.1	±0.1	0.1	±0.2	0.1	±0.1	0.3	±0.1	0.3	±0.2
Benzene	48.6	±50.3	4.7	±1.9	5.2	±1.1	7.8	±1.0	7.5	±3.6	5.1	±0.8	6.8	±4.4	10.8	±7.0	7.8	±1.6	16.6	±9.5
Carbon tetrachloride	0.3	±0.0	0.3	±0.0	0.4	±0.0	0.8	±0.4	0.8	±1.1	0.3	±0.0	0.4	±0.2	0.6	±0.5	0.5	±0.0	0.4	±0.1
Trichloroethylene	4.6	±2.6	1.8	±0.4	2.9	±0.6	21.3	±5.1	3.0	±1.3	2.0	±0.1	2.8	±0.8	4.2	±1.3	2.4	±0.1	3.5	±1.3
Toluene	89.2	±22.1	32.4	±8.1	65.4	±29.0	151.3	±3.7	90.6	±64.8	61.5	±45.2	83.0	±34.7	158.0	±50.7	122.6	±3.6	91.1	±40.5
Tetrachloroethylene	2.2	±0.2	1.8	±0.1	2.6	±0.2	2.3	±0.1	2.2	±0.6	2.1	±0.2	2.0	±0.2	2.6	±0.5	2.0	±0.1	2.3	±0.7
Ethylbenzene	6.3	±2.3	6.3	±7.2	13.1	±9.5	9.0	±2.2	23.9	±30.0	12.1	±15.5	4.8	±4.3	10.6	±7.5	6.7	±0.9	11.4	±7.1
m,p-Xylene	10.8	±7.0	6.3	±7.2	15.1	±8.3	7.6	±2.0	37.5	±46.3	21.7	±30.1	4.2	±4.4	10.1	±7.8	6.3	±1.7	13.7	±8.0
Styrene	5.8	±1.4	2.1	±0.8	2.6	±0.3	5.3	±0.8	6.6	±3.7	3.4	±1.7	4.5	±2.1	11.2	±15.0	5.6	±1.2	4.4	±1.7
1,1,2,2,-Tetrachloroethane	3.3	±0.7	4.7	±3.7	3.0	±0.2	3.0	±0.9	2.9	±0.8	2.8	±0.5	2.7	±0.3	4.3	±1.2	2.4	±0.0	2.7	±0.7
o-Xylene	6.9	±3.5	8.0	±7.1	8.8	±3.1	8.4	±1.6	27.1	±32.8	14.9	±18.4	5.5	±3.9	12.8	±6.2	6.5	±0.7	12.4	±8.9
1-Ethyl-4-methylbenzene	3.9	±0.8	3.6	±2.8	4.0	±0.8	10.2	±1.3	7.7	±7.8	2.9	±0.6	3.2	±0.9	5.7	±4.9	3.3	±1.7	6.7	±2.7
1,3,5-Trimethylbenzene	3.2	±0.9	6.1	±4.0	4.1	±0.9	9.1	±1.0	5.5	±5.2	2.8	±0.7	3.6	±1.0	8.4	±4.0	5.7	±2.1	6.8	±4.2
1,2,4-Trimethylbenzene	6.5	±1.3	12.7	±12.2	9.5	±3.6	25.3	±4.0	11.9	±11.5	5.2	±1.6	6.5	±2.0	19.1	±13.2	11.5	±6.6	29.4	±33.4
1,3-Dichlorobenzene	3.3	±0.6	3.3	±0.1	3.5	±0.2	3.9	±0.1	2.8	±0.5	6.6	±8.0	3.9	±0.4	4.6	±1.1	3.2	±0.1	3.9	±0.7
1,4-Dichlorobenzene	3.4	±0.6	3.4	±0.0	3.6	±0.1	4.1	±0.1	2.9	±0.5	8.3	±12.1	4.0	±0.5	4.8	±1.1	3.3	±0.1	4.2	±0.9
1,2-Dichlorobenzene	2.6	±0.2	2.2	±0.1	2.8	±0.1	3.1	±0.1	2.9	±0.2	2.6	±0.4	3.6	±1.1	3.4	0.7	2.4	±0.3	4.1	±2.0

pollutants and the residential characteristics of the public facilities. When we compare the average concentrations of TVOCs in the various indoor environments of the public facilities with the criteria set by the Act, the average concentration in maternity recuperation centers was the highest at 2,605.7 μg/m^3, which was approximately 6.5 times as high as the criterion 400 μg/m^3 for maternity recuperation centers set by the Act. The average concentration in public childcare centers also exceeded the criterion: it was 1,951.6 μg/m^3, which was approximately 4.9 times as high as the criterion of 400 μg/m^3.

Among the individual VOCs, toluene showed the highest average concentration in all of the public facilities that were surveyed in this study. The individual VOC that showed the highest concentration next to toluene was benzene for saunas and large stores (48.6 and 6.8 μg/m^3, respectively); m,p-xylene for subway stations, public childcare facilities, and medical centers (15.1, 37.5, and 21.7 μg/m^3, respectively); and 1,2,4-trimethylbenzene for libraries, maternity recuperation centers, underground shopping centers, and funeral houses (12.7, 25.3, 19.1, 11.5, and 29.4 μg/m^3, respectively).

Samples were collected from subway stations (three), underground shopping centers (eight), medical centers (six), public childcare facilities (eight), libraries (three), large stores (eight), funeral houses (three), jjimjilbangs (five), maternity recuperation centers (three), and indoor parking lots among the 17 public facilities in Seoul, Daegu, and Asan.

3.2 Cluster Classification

To classify clusters of public facilities with similar indoor environments based on the concentration data for VOCs in the indoor air of public facilities with various indoor environments, we used the diagram in Fig. 1 and classified clusters at a relatively low dissimilarity level and temporarily classified the public facilities into three clusters. Cluster 1 included 18 public facilities (medical center C, medical center D, medical center E, medical center F, library A, library B, large store A, large store B, large store C, large store D, large store E, large store F, large store G, indoor parking lot G, jjimjilbang B, subway station B, public childcare facility A, and underground shopping center D), cluster 2 included 23 public facilities (underground shopping center A, underground shopping center B, underground shopping

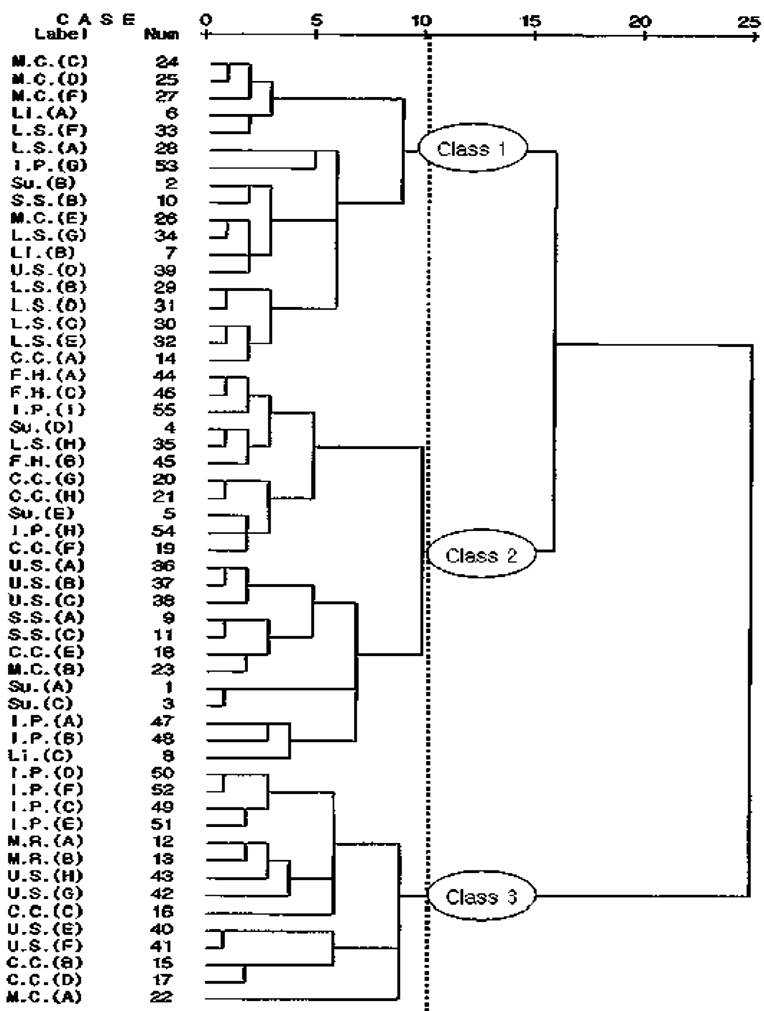

Fig. 1 A dendrogram using the Euclidean distance after logarithmic transformation: *M.C.* Medical center, *Li.* Library, *L.S.* Large store, *I.P.* Indoor parking lot, *S.S.* Subway station, *F.H.* Funeral house, *C.C.* Childcare center, Su. Sauna, *M.R.* Maternity recuperation centers

center C, jjimjilbang A, jjimjilbang B, jjimjilbang C, jjimjilbang D, jjimjilbang E, funeral home A, funeral home B, funeral home C, library C, indoor parking lot A, indoor parking lot B, indoor parking lot H, indoor parking lot I, public childcare facility E, public childcare facility F, public childcare facility G, public childcare facility H, subway station A, subway station C, medical center B, and large store H), and cluster 3 included 14 public facilities (indoor parking lot C, indoor parking lot D, indoor parking lot E, indoor parking lot F, maternity recuperation center A, maternity recuperation center B, underground parking lot E, underground parking lot F, underground parking lot G, underground parking lot H, public childcare facility B, public childcare facility C, public childcare facility D, and medical center A). The facilities that did not belong to any cluster were not classified.

3.3 Pollution Patterns of VOCs by Cluster

With regard to the similarity of indoor environments of the classified public facilities, cluster 1 has 11 large stores and medical centers, which account for over 60% of all the facilities in cluster 1. These facilities are characterized by a large volume of interior space compared to other facilities. Cluster 2 has 18 saunas, indoor parking lots, public childcare facilities, funeral homes, and underground shopping centers, which account for over 80% of all facilities in cluster 2. These facilities are characterized by combustion activities and the existence of various sources of VOCs. Cluster 3 has eight underground parking lots and underground shopping centers, which account for over 57% of all the facilities in cluster 3. These facilities are characterized by the existence of many sources of VOCs and poor ventilation conditions (Table 2).

A comparison of the concentrations of VOCs by cluster found that those in cluster 3 showed the highest concentrations of the surveyed VOCs excluding carbon tetrachloride compared to those in clusters 1 and 2. In contrast, cluster 2 showed the lowest concentrations of TVOCs, benzene, carbon tetrachloride, trichloroethylene, ethylbenzene, m,p-xylene, styrene, 1,1,2,2-tetrachloroethane, o-xylene, 1-ethyl-4-methylbenzene, 1,3,5-trimethylbenzne, and 1,2,4-trimethylbenzene, while cluster 1 showed the lowest concentrations of formaldehyde, toluene, tetrachloroethylene, 1,3-dichlorobenzene, 1,4-dichlorobenzene, and 1,2-dichlorobenzene. However, when we verified the differences in concentration distribution of VOCs in various indoor environments by cluster, there was no statistically significant difference in the concentrations of VOCs in indoor environments between the public facilities in cluster 1 and cluster 2 except for methyl chloroform, toluene, and 1.3.5-trimethylbenzene (Table 3).

4 Discussion

It is generally known that indoor environments are affected by various environmental factors such as the use of the building, the behavioral characteristics of residents, construction materials, household merchandise, and building location. The Ministry of Environment classifies 17 types of public facilities into three categories according to the use and characteristics of the building and regulates air pollutants that are believed to have harmful effect on residents. Furthermore, the Ministry of Environment is conducting many studies to increase the number of types of regulated pollutants and the number of controlled facilities and is planning to reinforce or ease the regulations after reviewing the validity of regulations about the present restricted pollutants.

In order to demonstrate that indoor air quality is affected greatly by other environmental factors as well

Table 2 Classified public facilities after cluster analysis

Class	*n*	Public facilities
1	18	Large store (7), medical center (4), library (2), indoor parking lot (1), sauna (1), subway station (1), childcare center (1), underground shopping area (1)
2	23	Sauna (4), indoor parking lot (4), childcare center (4), funeral house (3), underground shopping area (3), subway station (2), library (1), medical center (1), large store (1)
3	14	Indoor parking lot (4), underground shopping area (4), childcare centers (3), maternity recuperation centers (2), medical center (1)

Table 3 The concentrations of volatile organic compounds in each class after cluster analysis

Pollutants	Class	Concentration (μg/m^3)			p value
		n	Mean	SD	
HCHO	1a	23	62.1	95.4	<0.05
	2a	18	63.8	65.3	
	3b	14	184.9	266.2	
TVOCs	1a	23	1476.3	610.8	<0.01
	2a	18	1268.8	1141.9	
	3b	14	2561.4	1188.1	
Methylchloroform	1a	23	0.2	0.2	<0.01
	2b	18	0.1	0.1	
	3a	14	0.2	0.1	
Benzene	1	23	17.7	28.0	>0.05
	2	18	5.9	4.3	
	3	14	12.8	5.6	
Carbon tetrachloride	1a	23	0.4	0.1	<0.01
	2a	18	0.3	0.1	
	3b	14	0.8	0.8	
Trichloroethylene	1a	23	3.2	1.7	<0.01
	2a	18	2.5	0.9	
	3b	14	6.5	6.5	
Toluene	1a	23	95.4	30.3	<0.01
	2b	18	57.1	32.6	
	3c	14	145.1	60.0	
Tetrachloroethylene	1a	23	2.2	0.5	<0.01
	2a	18	2.0	0.2	
	3b	14	2.5	0.5	
Ethylbenzene	1a	23	10.3	6.5	<0.01
	2a	18	2.9	1.3	
	3b	14	23.4	22.1	
m,p-Xylene	1a	23	14.8	12.1	<0.01
	2a	18	2.9	1.5	
	3b	14	30.5	37.1	
Styrene	1a	23	4.5	1.9	<0.01
	2a	18	3.0	1.3	
	3b	14	10.8	10.7	
1,1,2,2-Tetrachloroethane	1	23	3.2	1.4	>0.05
	2	18	2.8	0.5	
	3	14	3.5	1.3	
o-Xylene	1a	23	11.9	8.6	<0.01
	2a	18	4.0	1.2	
	3b	14	24.2	24.9	
1-Ethyl-4-methylbenzene	1a	23	4.1	1.6	<0.01
	2a	18	3.0	0.9	
	3b	14	9.7	5.8	

Table 3 (continued)

Pollutants	Class	Concentration (μg/m³)			*p* value
		n	Mean	SD	
1,3,5-Trimethylbenzene	1a	23	5.3	3.3	<0.01
	2b	18	3.2	0.7	
	3c	14	8.6	4.2	
1,2,4-Trimethylbenzene	1a	23	12.2	11.1	<0.01
	2a	18	5.6	1.5	
	3b	14	28.4	25.6	
1,3-Dichlorobenzene	1	23	3.4	0.7	>0.05
	2	18	3.6	0.4	
	3	14	5.5	5.1	
1,4-Dichlorobenzene	1a	23	3.5	0.8	<0.05
	2a	18	3.8	0.5	
	3b	14	6.4	7.7	
1,2-Dichlorobenzene	1a	23	2.7	0.3	<0.01
	2a,b	18	3.3	1.5	
	3b	14	3.7	0.9	

a Group 1

b Group 2

c Group 3

as the use of the building, this study classified indoor environments according to the concentration patterns of VOCs and presents their characteristics so as to provide the basic data for the establishment of more systematic and flexible management plans and for the revision of the Indoor Air Quality Management Act in the future. It was found that most concentrations of TVOCs in various indoor environments exceeded the guidelines defined in the present Indoor Air Quality Management Act. VOCs are known to be the primary pollutants causing sick house syndrome, and multiple chemical sensitivity can have significant negative effects on residents' health. However, this study found that they exist in high concentrations in the indoor air of most indoor environments. In contrast, although formaldehyde is also known to be a cause of sick house syndrome and to have negative effects on health, it did not exceed the guidelines in most indoor environments excluding public childcare facilities. Nevertheless, public childcare facilities are where children with weak immunity against environmental pollutants stay for a long period of time; therefore, thorough investigations must be conducted, and appropriate management plans must be established as soon as possible.

Although the domestic Indoor Air Quality Management Act does not regulate individual VOCs in the 17 public facilities excluding new apartment houses, this study classified and presented the distribution patterns of individual VOCs in various indoor environments according to the characteristics of these pollutants. The classification method used in this study was cluster analysis, which is an applied statistical analysis method that is widely used in the natural sciences to classify specific groups that share similar properties in a given data group. Cluster analysis is a statistical analysis of which the main purpose is to analyze the characteristics and relationships of clusters on the basis of the distance or dissimilarity between objects under the condition that the numbers, contents, and the structures of clusters are not completely known. The basic principle is to measure the dissimilarity on the basis of the distance between two objects so as to classify those objects that share the same pattern. Two objects that have a short distance or small dissimilarity between them belong to the same cluster (Hopke 1991). In general, cluster analysis is largely classified into a hierarchical cluster analysis and non-hierarchical cluster analysis.

Non-hierarchical cluster analysis is used to optimally distribute objects into specific predefined clusters when the number of clusters is already known or can be estimated. On the other hand, hierarchical cluster analysis is used in conjunction with the pedigree-type dendrogram when one cluster is included in another cluster but no duplication between clusters is allowed and the number of clusters is unknown. Hierarchical cluster analysis has such advantages as simpler algorithms and shorter calculation times when compared to non-hierarchical cluster analysis and the possibility of simple expression of the structural relationships between the clusters on a two-dimensional space called a dendrogram.

After conducting a cluster analysis for subway stations, underground shopping centers, medical centers, public childcare facilities, libraries, large stores, funeral homes, and indoor parking lots, this study classified them into three clusters. It was found that the concentrations of VOCs in the indoor air of the public facilities in cluster 3 were higher than those in the other two clusters. For clusters 1 and 2, the differences of concentrations between most of the surveyed facilities were not statistically significant. Therefore, it seems that there are no great differences in the indoor environments of the public facilities in these two clusters. Among the public facilities that belong to cluster 3, which showed the highest concentrations, indoor parking lots and underground shopping centers accounted for 57% of all the public facilities in cluster 3. These facilities are characterized by the existence of many sources of VOCs such as automobiles and household merchandise displayed on various display windows. Furthermore, ventilation is not as smooth as in the aboveground floors. As a result, the indoor concentrations of VOCs were higher than they were for other indoor environments. Furthermore, the most common condition of the public facilities that belong to cluster 3 was found to be the poor air ventilation at the time of survey, and this must have influenced the high concentration of VOCs. Maternity recuperation centers are the place where newborn babies and their mothers who are very sensitive to indoor air quality stay, but all of them belonged to cluster 3 which showed the highest concentration of VOCs in this study. Therefore, high interest and preparation of improvement measures for these facilities are urgently needed.

The VOCs that did not show a difference in concentration among the three clusters were benzene, 1,1,2,2-tetrachloroethane, and 1,3-dichlorobenzene. These compounds did not show big differences in concentration according to the use of the building. Furthermore, aside from cluster 3, the concentrations of VOCs between clusters 1 and 2 did not show any significant difference. To sum up the above results, the concentrations of VOCs in public facilities with various indoor environments do not show big differences according to the use of the building, but other environmental factors such as efforts to improve indoor air quality contributes greatly to the improvement of concentration of VOCs in indoor air. Moreover, because some chemicals in indoor air can have different characteristics depending on residential forms and living environments (Moon et al. 2006), it is important to understand the sources of pollutants such as VOCs before anything else.

With regard to the directions of indoor environment policies in Korea which classify and manage the indoor air quality of public facilities according to the use of the building under the present Indoor Air Quality Management Act, the findings from this study ask for more studies on the factors that influence indoor air quality including the size of facilities, air conditioning status, and other physical conditions. Based on the data acquired through these studies, we need to reinforce indoor environmental health laws and establish more efficient indoor environment and health policies based on consideration of other complex factors.

5 Conclusions

To provide the basic data for the selection of VOCs with regard to public facilities, definition of guidelines, and classification of regulated facilities, all of which are required for consideration in drafting the Indoor Air Quality Management Act, and to identify the forms of VOCs in various indoor environments, this study investigated VOCs and formaldehyde in some subway stations, underground shopping centers, medical centers, public childcare facilities, libraries, large stores, funeral homes, and indoor parking lots among the public facilities specified in the Act on indoor air quality of public facilities, by the Ministry of Environment, which were located in Seoul, Daegu, and Asan from June 2005 to May 2006.

The findings from this study are summarized as follows: Firstly, the average concentration of TVOCs in maternity recuperation centers was 2,605.7 μg/m^3, which is approximately 6.5 times as high as the guideline (400 μg/m^3) provided by the Ministry of Environment, and the average concentration in public childcare facilities was 1,951.6 μg/m^3, which is approximately 4.9 times as high as the guideline. Furthermore, all the surveyed facilities exceeded the guideline for the concentration of TVOCs.

Secondly, only the public childcare facilities exceeded the guidelines of the Ministry of Environment for formaldehyde. The average concentration of formaldehyde in the indoor air of public childcare facilities was 336.5 μg/m^3, which was approximately 2.8 times as high as the 120 μg/m^3 stated in the guideline.

Thirdly, after conducting a cluster analysis for subway stations, underground shopping centers, medical centers, public childcare facilities, libraries, large stores, funeral homes, and indoor parking lots, they were classified into three clusters. In the indoor air of public facilities in cluster 3, the concentrations of TVOCs and formaldehyde were 2,561.4 and 184.9 μg/m^3, which were higher than those of clusters 1 and 2 and exceeded the guidelines of the Ministry of Environment.

This study classified some of the public facilities specified in the Act on indoor air quality of public facilities of the Ministry of Environment into clusters and identified the distribution patterns of harmful pollutants of indoor air for each facility. However, this study did not examine the sizes of the facilities, air conditioning status, and all of the types of facilities. In the future studies, these limitations must be overcome, and more efficient management measures for indoor environmental health and citizen's welfare are required on the basis of the data acquired from these studies.

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References

Dong-Sul, K., & Hyeong-Seok, K. (1990). Pattern recognition using concentration of air pollutants in the under ground mall. *Korean Society for Atmospheric Environment, 6*(1), 1–1.

Hopke, P. K. (1985). *Receptor modeling in environmental chemistry*. New York: Wiley Interscience.

Hopke, P. K. (1991). *Receptor modeling for air quality management*. New York: Elsevier Science Publishing Company Inc.

Hwang, I. J., Kim, T. O., & Kim, D. S. (2001). Source identification of PM-10 in Suwon using the method of positive matrix factorization. *Korean Society for Atmospheric Environment, 17*(2), 133–145.

James, E. (1991). An engineering approach to controlling indoor air quality. *Environmental Health Perspectives, 95*, 15–21.

Lee, S. C., & Chang, M. (2000). Indoor and outdoor air quality investigation at school in Hong Kong. *Chemosphere, 40*, 109–112.

Moon, K. H., Byeon, S. H., Choi, D. W., Lee, E. I., Oh, E. H., & Kim, Y. W. (2006). Risk assessment of aldehydes in some residential indoor air included atopy patient's homes. *Korean Society of Environmental Health, 32*(1), 19–26.

Nam, B. H., Hwang, I. J., & Kim, D. S. (2002). Pattern classification of PM-10 in the indoor environment using disjoint principal component analysis. *Korean Society for Atmospheric Environment, 18*(1), 25–37.

National Academy of Sciences (NAS). (1993). *Human exposure assessment for airborne pollutants*. Washington: National Academy Press.

Shim, S. H., & Kim, Y. S. (2006). Characteristics and evaluation of indoor air quality in new apartment houses—with a focus on volatile organic compounds and formaldehyde. *Korean Society of Environmental Health, 32*(4), 275–281.

Son, B., Breysse, P., & Yang, W. (2003). Volatile organic compounds concentration in residential indoor and outdoor and its personal exposure in Korea. *Environment International, 29*(2), 79–85.

Stolwijk, J. A. (1992). Risk assessment of acute health and comfort effects of indoor air pollution. *Annals of the New York Academy of Sciences, 641*, 56–62.

Tichenor, B. A., Sparks, L. A., White, J. B., & Jackson, M. D. (1990). Evaluating sources of indoor air pollution. *Journal of the Air & Waste Management Association, 40*, 487–492.

Yoo, S. J., & Kim, D. S. (1997). Classification of ambient particulate matters using cluster analysis and disjoint principal component analysis. *Korean Society for Atmospheric Preservation, 13*(1), 51–63.