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# A Study on the Discharge of Volatile Organic Compounds in Indoor Air of Newly-constructed Apartment Houses

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## Abstract

Because of the building is made airtight, Indoor Air Quality(IAQ) is go from bad to worse. There are many source of indoor pollution in any home. These include irritation of the eyes, nose, and throat, headaches, dizziness, and fatigue. Such immediate effects are usually short-term and treatable. In this study was measured and analyzed VOCs exposure levels and characteristic of Indoor air pollutant from new apartments in Korea. VOCs were measured indoor pre-residential and residential in new apartment and analyzed GC/MS. The concentration levels of indoor respirable TVOC were found to be higher than those of outdoor TVOC for new apartments. Before occupation, the average indoor and outdoor concentrations were 1498.61 ug/m$^3$ and 468.38 ug/m$^3$, respectively. After being occupied, the average indoor and outdoor concentration were 847.04 ug/m$^3$ and 102.84, respectively. The concentrations of TVOC in new apartments before occupation were shown in the order of Toluene(328.12 ug/m$^3$) > *m,p*-Xylene(163.67 ug/m$^3$) > Ethylbenzene(80.70 ug/m$^3$)>*o*-XYlene (67.04ug/m$^3$). In addition, the TVOCs concentrations after occupation were also found in the order of Toluene (272.28 ug/m$^3$) > m.p-Xylene(121.79 ug/m$^3$) > Ethylbenzene(53.92 ug/m$^3$)>O-Xylene(24.94 ug/m$^3$). As a result, the concentrations of VOCs in new apartment houses were shown to be affected by indoor environment according activity patterns. So new apartments need to be controled in indoor air quality so that the residents can have more comfortable and healthier living environment.

**Key Words :** Indoor Air, New apartment, VOCs

## 1. Introduction

Contemporary society needs more attentions to health and pleasant environments. The people who have to stay indoor for more than 80% of a day have paid more attention to indoor environment, and need higher quality of residential environment and upgraded life, which is considered as an important task to be carefully taken care of in modern architecture[1].

Present architecture has developed various manufacturing and processing technologies for improved design, durability, safety, execution, and economy, and used a great number of chemical matters. However, closed buildings and constructional materials and furniture made of chemical matters have caused worsened indoor air environment.

Indoor air pollutants are generated from activities of residents, smoking and combustion tools as well as constructional materials, and if they are not controlled by proper methods, they may cause unpleasant stimulation. In particular, if people stay in a place with high polluting concentration for a long time, their health may be harmfully affected. Especially, there was a report that as volatile organic compounds have strong toxicity to

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nervous system as well as breathing and circulation systems, give harm to sensibility of peripheral nervous systems and involve cancer and genetic toxicity, they should be strictly controlled as indoor pollutants[2].

So, Korea has implemented the Act of Indoor Air Quality in Multi-use Facilities since May 30, 2004 with a purpose of health promotion and maintenance through reasonable management of indoor air quality[3], and provided how to test indoor air quality of apartment houses of 「Indoor Air Quality Process Test」 to measure indoor air pollutants in reasonable and unified manner.

Many countries including Korea have studied VOCS (Volatile Organic Compounds: VOCs) and Formaldehyde (HCHO) that are known to cause cancer and harm due to indoor air pollutants and harmful sources such as indoor constructional materials, furniture, and living utensils[4]. However, most of our studies on them are confined to small area. So, as the limited studies have a possibility to generate vague anxiety against indoor air environment of apartment houses where most of the people reside, it is suggested that scientific and valid data should be prepared.

Therefore, this study identifies the VOCs of newly-constructed apartment houses for 120 families and discharge characteristics of pollutants discharged from various utensils to maintain healthful and safe indoor air quality of apartment houses, and the results will be used as basic data on indoor air quality of apartment houses for improved indoor air environment.

## 2. Research and Methods

### 2.1. Research Period and Subject Selection

This study measured and analysed the distribution of discharge concentration of pollutants in indoor air, targeting apartment houses for 120 families in Seoul, Incheon, Goyang, Kimhae, Mokpo, and Yeosu (Table 1) from February to August 2005. It targeted newly-constructed apartment houses which have not been occupied yet and where no moving is expected during this research. And to identify whether higher section has more sunshine and chemical reaction that discharges pollutants occurs more actively, this study divided the apartment into lower, middle and higher sections. (lower-below 6 floor, middle- below 7 floor ~13 floor, and higher- above 14 floor)

### 2.2. Research Method

#### 2.2.1. How to Collect specimens

This study examined the current status of VOCs based on "How to Test Indoor Air Quality Processing" developed by the Ministry of Environment. It examined the period of residence, time to collect specimens, floors and areas, directions of living rooms, temperature and humidity in collecting specimens.

The specimens were collected at the center of living rooms of apartment houses in lower, middle and higher sections before and 2 months after movement. 30 minutes after ventilation, windows, doors and openings where residents are exposed to outdoor air were closed for 60 minutes and specimens were collected once a hour. The measurement was carried from the floor at least 1m away from the wall and 1.2~1.5 m high, Carbotrap 300 (20/40 mesh, Perkin-Elmer Ltd., UK) was connected to a portable pump (SIBATA Co, Japan), and the specimens were collected for 30 minutes with flux of 100 mL/min. At each point, Field blank, Duplicate, and outdoor specimens were prepared and every of them were sealed up with light closed with foil and stored in a chill and dark place at below

**Table 1.** Number and location of subjects

| N | Seoul | Kyonggi | Incheon | Gimhae | Yeosu | Mokpo |
|---|---|---|---|---|---|---|
| Low floor | 12 | 4 | 12 | 4 | 4 | 4 |
| Middle floor | 12 | 4 | 12 | 4 | 4 | 4 |
| High floor | 12 | 4 | 12 | 4 | 4 | 4 |
| Total | 36 | 12 | 36 | 12 | 12 | 12 |

**Table 2.** Conditioning of ATD and analysis conditions of GC/MS

| STD 1000(DANI, Italy) | | GC/MS(Shimadzu GC-2010, Japan) | |
|---|---|---|---|
| Purge Temp. and time | 40℃, 0.5 min | GC column | VB-1(0.25 mm, 60 m, 1.0 μm) |
| Desorb time and flow | 15 min, 50 mL/min | Initial Temp. | 40℃(6 min) |
| Desorb Temp. | 250℃ | Oven Ramp Rate 1 | 4℃/min(40~180℃) |
| Cold Trap holding time | 15 min | Oven Ramp Rate 2 | 20℃/min(180~250℃) |
| Cold Trap high temp. | 300℃ | Final Temp. | 250℃(10min) |
| Cold Trap low temp. | -10℃ | Column flow | 1.5 mL/.min |
| Cold Trap packimg | Tenax-TA | Ms Source Temp. | 200℃ |
| Split | No | Detector Type | EI(Quadropole) |
| Valve Temp. | 200℃ | Mass Range | 35~300 amu |
| Transfer lime Temp. | 200℃ | Electron Energy | 70eV |

4℃ before analysis.

### 2.2.2. How to Analyse

This study GS/MS analysis method to analyse concentration of VOCs. For the calibration curve of VOCs, standard gas was diluted, two or three standard matters were made between 0.1 ~ 1 ppm, the concentration of each standard matter was set to include the concentration of unknown specimens. The absorption tube where specimens was collected was desorbed with a use of heat desorption equipment, and the specimens were reconcentrated in a low-temperature concentration tube and injected to GC/MS for analysis. The analysis conditions of GC/MS are presented in Table 2.

## 2.3. Degree Management of Measuring Tools

### 2.3.1. Evaluation of Reproductibility of Analysing Tools

This study evaluated reproductibility of the analytical method using GC/MS with response factor and relative standard deviation(RSD), and the results are summarized in Table 3.

The standard matters with different concentration levels (5ng, 10ng, 20ng, 50ng, 100ng) were injected to Tenax and they were analysed with specimens every experiment. The reproductibility of detention time of 6 main pollutants was 0.1%, and response factor was ±10%, which indicates that reproductibility is good.

### 2.3.2 Evaluation of Detection Limit

This study used Method Detection Limits(MDL). It conducted 7 repetitive analyses, targeting fluid standard matters with low concentration that was 3 and 5 times as much as the value estimated by considering the value of Simal vs Noise applied for detection of peak area. And then, standard deviation of measured concentration was applied for the equation. (Table 4)

**Table 3.** Linearity of thermal desorption with GC/MS analysis for 6 target VOCs

| | RSD | | | Linearity |
|---|---|---|---|---|
| | N | Retention Time | Area | ($R^2$) |
| Benzene | 13 | 0.10% | 12.70% | 0.999 |
| Toluene | 13 | 0.10% | 12.50% | 0.999 |
| Ethylbenzene | 13 | 0.10% | 13.60% | 0.999 |
| m,p-Xylene | 13 | 0.10% | 18.10% | 0.999 |
| Styrene | 13 | 0.10% | 7.20% | 0.999 |
| o-Xylene | 13 | 0.10% | 19.80% | 0.999 |

### 2.3.3 Evaluation of Duplicate Precision

This study collected and analysed specimens under the same conditions and at the same points. At this time, it evaluated Mean Duplicate Precision (MDP).

### 2.3.4. Blank specimens

This study prepared the field blank at the same time

**Table 4.** MDL(Method detection limits) of 6 target VOCs

| Compounds | MDL | |
|---|---|---|
| | ng | μg/m$^3$ |
| Benzene | 0.64 | 0.11 |
| Toluene | 1.72 | 0.29 |
| Ethylbenzene | 2.18 | 0.36 |
| *m,p*-Xylene | 3.21 | 0.54 |
| Styrene | 0.59 | 0.10 |
| *o*-Xylene | 3.36 | 0.56 |

when specimens was collected at measuring points to measure pollution that may occur in handling of the absorption tube. As no pollutants were found in the Field blank, it was analysed that no pollution occurs in handling and storage of the specimens.

### 2.4. Statistical Analysis

For an analysis of the results of the experiment and questionnaire, this study used SPSS 12.0 for Windows and identified general things such as concentration of pollutants of the newly-constructed apartment houses, socio-demographical characteristics of residents through technical statistical analysis of frequency, percentage and mean. And to analyse the relations between indoor air pollutants and factors that may affect concentration of pollutants, this study used correlation analysis, Kruskal-Wallis test and ANOVA test and t-test to analyse the relations between living utensils and activity and practice.

## 3. Results and Discussion

### 3.1. Distribution of Temperature and Humidity

This study measured indoor temperature and humidity, and outside temperature in measuring indoor pollutants. The results are presented in Table 6 and 7. The mean humidity in indoor air in the apartment house before moving-in was 35.7% and 60.7% after moving-in. The mean temperatures in indoor air in the apartment house before moving-in were 20.3℃ and 11.7℃ and 26.4℃ and 26.9℃ after moving-in. The difference in temperature before and after moving-in was due to season. It was winter to early spring before

**Table 5.** Precision of thermal desorption with GC/MS analysis for 6 target VOCs

| | N | Sample 1 | Sample 2 | MPD |
|---|---|---|---|---|
| TVOC | 5 | 22,336 | 22,402 | 3.39 |
| Benzene | 5 | 9.46 | 9.37 | 10.02 |
| Toluene | 5 | 234 | 231 | 11.23 |
| Ethylbenzene | 3 | 72 | 106 | 16.34 |
| m,p-Xylene | 3 | 126 | 136 | 22.21 |
| Styrene | 3 | 27 | 33 | 13.37 |
| o-Xylene | 4 | 78 | 130 | 2.59 |

**Table 6.** Temperature in apartments (unit : ℃)

| Status | | N | Mean | S.D | Min. | Max. |
|---|---|---|---|---|---|---|
| Before resident | Indoor | 120 | 20.3 | 4.33 | 5.8 | 26.0 |
| | outdoor | 120 | 11.7 | 3.93 | -1.5 | 18 |
| After resident | Indoor | 120 | 26.4 | 1.72 | 23.0 | 31.0 |
| | outdoor | 120 | 26.9 | 2.79 | 21.0 | 34.0 |

**Table 7.** Humidity in apartments(unit : %)

| Status | N | Mean | S.D | Min. | Max. |
|---|---|---|---|---|---|
| Before resident | 120 | 35.7 | 6.83 | 22.5 | 64.0 |
| After resident | 120 | 60.7 | 11.0 | 41.0 | 81.0 |

moving-in, and it was June and July during 2 months after moving-in. According to the study by Jeon et al.[5] that presented results similar to the temperature before moving-in in this study, indoor and outdoor temperatures of newly0built apartment house were 20℃ and 7.5℃ from November 2004 to December 2005. And the study by National Institute of Environmental Research[6] measured temperature of 1-year old apartment house on February and April and the results were 21~25℃, which is similar to the results of this study.

### 3.2. Comparison of Concentrations Before and After Moving-in and Indoor and Outdoor Concentrations

Table 8 presents the results of VOCs measurement before and 2 month after moving-in.

The concentrations of VOCs of newly-built apartment house before and after moving-in were presented as follows: Toluene > m,p-Xylene > Ethylbenzene > o-Xylene. When concentrations before and after moving-in were compared, the concentration of Aldehydes after moving-in was higher than that before moving-in while the concentration of Toluene was 328.12 $\mu g/m^3$ before moving-in and 272.28 $\mu g/m^3$, after moving-in. The concentrations of m,p-Xylene before moving-in were 163.66 $\mu g/m^3$ and 121.79 $\mu g/m^3$. Most of the concentrations of VOCs were higher before moving-in than after moving-in. According to the study by Uchiyama et al.[7] the concentrations of Toluene and Ethylbenzene decreased after moving-in, which is sim-

**Table 8.** Concentrations of VOCs in new apartments(unit : $\mu g/m^3$)

| Compound | Before Resident | | | | | After Resident | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | S.D | Min. | Max. | I/O | Mean | S.D | Min. | Max. | I/O |
| TVOC | 1498.61 | 1190.57 | 24.14 | 5635.68 | 3.2 | 847.04 | 459.28 | 167.72 | 2307.34 | 8.2 |
| Toluene | 328.12 | 240.45 | 16.11 | 1591.05 | 2.8 | 272.28 | 137.48 | 99.23 | 859.11 | 4.9 |
| *m,p*-Xylene | 163.66 | 227.59 | 0.50 | 1038.21 | 4.3 | 121.79 | 115.76 | 2.93 | 582.97 | 19.1 |
| Ethylbenzene | 80.70 | 115.36 | <MDL | 628.88 | 3.2 | 53.92 | 50.53 | 2.47 | 243.87 | 14.3 |
| *o*-Xylene | 67.04 | 98.95 | <MDL | 421.35 | 4.8 | 24.94 | 24.99 | 0.71 | 123.78 | 21.9 |
| $\beta$-Pinene | 22.98 | 26.60 | <MDL | 108.64 | - | 22.36 | 23.53 | <MDL | 109.02 | - |
| Butyl acetate | 23.15 | 28.26 | <MDL | 100.86 | 2.0 | 15.30 | 19.40 | <MDL | 97.62 | 11.0 |
| $\alpha$-Pinene | 18.40 | 27.38 | <MDL | 178.55 | - | 17.72 | 17.37 | 0.97 | 77.52 | - |
| Styrene | 14.20 | 17.43 | <MDL | 102.05 | 56.9 | 20.67 | 20.94 | <MDL | 108.80 | - |
| *n*-Butanol | 14.76 | 17.63 | <MDL | 116.10 | 5.5 | 18.98 | 18.75 | 2.68 | 120.58 | 58.2 |
| Methyl Isobutyl Ketone | 11.97 | 20.76 | <MDL | 142.20 | 2.2 | 5.85 | 7.42 | <MDL | 65.47 | 12.3 |
| Nonanal | 5.85 | 5.17 | <MDL | 39.35 | 5.2 | 11.00 | 4.92 | 1.42 | 25.89 | 15.4 |
| *D*-Limonene | 5.41 | 25.60 | <MDL | 193.86 | - | 10.68 | 15.35 | <MDL | 89.12 | - |
| *n*-Decane | 8.28 | 18.97 | <MDL | 146.10 | 12.2 | 4.91 | 5.55 | <MDL | 35.22 | 35.4 |
| *n*-Undecane | 8.10 | 12.03 | <MDL | 78.69 | 2.7 | 4.42 | 4.93 | <MDL | 32.87 | 348.1 |
| *n*-Nonane | 7.19 | 7.08 | <MDL | 41.94 | 1.9 | 5.19 | 6.84 | <MDL | 49.20 | 12.9 |
| Benzene | 2.98 | 1.71 | <MDL | 7.88 | 0.4 | 3.20 | 8.14 | <MDL | 67.80 | 4.2 |
| 1,2-Dichloroethane | 0.19 | 1.54 | <MDL | 14.97 | - | 0.22 | 1.45 | <MDL | 12.90 | - |
| Chloroform | 0.40 | 0.04 | <MDL | 4.23 | - | - | - | <MDL | <MDL | - |
| Carbon tetrachloride | 1.39 | 14.73 | <MDL | 155.87 | - | - | - | <MDL | <MDL | - |

ilar to the results of this study.

The indoor and outdoor concentration (I/O) of TVOCs in newly-built apartment house before moving-in were 1498.61/4683.38($\mu g/m^3$) and 847.04/102.84($\mu g/m^3$) after moving-in. The I/O ratio of benzene which is a carcinogen was 0.4 before moving-in, and 4.2 after moving-in. The I/O ratio of Toluene was 2.8 before moving-in and 4.9 after moving-in. The I/O ration of m,p-Xylene was 4.3 before moving-in and 19.1 after moving-in, and the I/O ratio after moving-in was higher that before moving-in. It is thought that the general I/O ratio was higher because a great amount of indoor pollutants were discharged from furniture or utensils after moving-in.

According to the study by Kim et al.[8] which is similar to this study, I/O ratio of Benzene in the newly-built apartment house was 1.20 and the 65.7% had higher concentration of Benezene in indoor air. The indoor concentrations of Benzene, Toluene, Ethylbenzene, o-Xylene, and m,p-Xylene in this study were 4.2 times, 4.9 times, 14.3 times, 21.9 times, and 19.1 times higher that those of outdoor air. They were higher than the I/O ratios presented in the study on VOCs in houses and offices in Seoul (2004): 1.4 times, 1.2 times, 1.3 times, 2.4 times, and 1.8 times, which indicates serious indoor pollution in apartment house. Therefore, this study suggests that we should identify and control various sources of pollution that affects indoor air pollution.

### 3.3. Comparative Analysis of Pollution According to Floors

Table 9 and 10 presents the concentration distribution of volatile organic compounds in indoor air. According to different solar conditions found in higher floors of apartment houses, temperature and humidity of upper floors tend to be relatively higher. However, in this study, the concentration of Toluene was 329.44 $\mu g/m^3$ at lower floors, 282.44 $\mu g/m^3$ at middle floors and 373.66 $\mu g/m^3$ at higher floors, which increased from lower to higher, and from middle to higher, but rather its concentration decreased from lower to middle

**Table 9.** VOCs concentrations before resident in new apartments floor (unit : $\mu g/m^3$)

| Compound | Low floor | Middle floor | High floor | p-value |
|---|---|---|---|---|
| TVOC | 1587.72±1269.07 | 1279.71±936.88 | 1633.56±1335.22 | 0.652 |
| Toluene | 329.44±239.43 | 282.44±171.23 | 373.66±294.10 | 0.528 |
| *m,p*-Xylene | 165.14±221.69 | 136.10±189.98 | 190.43±268.22 | 0.632 |
| Ethylbenzene | 73.69±99.28 | 68.57±94.85 | 100.04±146.15 | 0.680 |
| *o*-Xylene | 66.65±92.54 | 56.40±89.61 | 78.29 ±114.58 | 0.661 |
| Styrene | 13.72±17.18 | 13.56±14.52 | 15.33±20.57 | 0.886 |
| Benzene | 2.85±1.56 | 3.10±1.80 | 3.00±1.80 | 0.908 |
| 1,2-Dichloroethane | 0.40±2.46 | 0.17±1.06 | <MDL | 0.607 |
| Chloroform | <MDL | 0.11±0.69 | <MDL | 0.378 |
| Carbon tetrachloride | <MDL | 4.10±25.29 | <MDL | 0.378 |

**Table 10.** VOCs concentrations after resident in new apartments floor (unit : $\mu g/m^3$)

| Compound | Low floor | Middle floor | High floor | p-value |
|---|---|---|---|---|
| TVOC | 860.41±451.49 | 864.04±485.95 | 815.07±450.78 | 0.881 |
| Toluene | 255.33±106.94 | 275.88±131.40 | 286.93±170.92 | 0.603 |
| *m,p*-Xylene | 119.57±90.27 | 118.90±122.65 | 127.18±134.65 | 0.945 |
| Ethylbenzene | 50.96±39.89 | 55.21±54.28 | 55.82±57.67 | 0.902 |
| *o*-Xylene | 24.61±20.19 | 24.81±27.01 | 25.44±28.06 | 0.989 |
| Styrene | 18.67±16.28 | 20.56±23.50 | 22.96±22.90 | 0.676 |
| Benzene | 2.23±2.48 | 3.32±11.05 | 4.12±8.70 | 0.601 |
| 1,2-Dichloroethane | 0.17±1.03 | 0.15±0.91 | 0.36±2.15 | 0.794 |
| Chloroform | <MDL | <MDL | <MDL | - |
| Carbon tetrachloride | <MDL | <MDL | <MDL | - |

floors. The concentrations of Benzene 2.85 $\mu g/m^3$ for lower floors 3.10 $\mu g/m^3$ for middle floors and 3.00 $\mu g/m^3$ for higher floors. The concentrations according to floors were almost same. This study did not find any change in concentration of VOCs from lower to higher.($p>0.05$) The studies by National Institute of Environmental Research[6] and Jeon et al.[5] did not find any change in concentration of VOCs in newly-built apartment house according to floors. Therefore, it is suggested that higher concentration in higher floors depends on dimension, constructional materials(finishing and heat insulating materials), and indoor environment (remodelling and furniture), and further studies on it is needed.

### 3.4. Comparative Analysis of Pollution according to Areas

This study examined indoor air quality of newly-built apartment houses in Seoul, Incheon, Gyeonggi, Gyeongsando(Kimhae) and Jeollado(Yeosu and Mokpo), and Table 11 presents the concentrations of VOCs in four areas.

The concentration of VOCs in Seoul was higher after moving-in than that before moving-in, and the concentration before moving-in in Incheon, Gyeonggi, Gyeongsando and Jeollado was higher than that after moving-in. The concentrations of TVOCs before moving-in were presented as follows: Incheon and Gyeonggid: 1764.70 $\mu g/m^3$ > Jeollado: 1596.69 $\mu g/m^3$ > Gyeongsangdo : 1339.06 $\mu g/m^3$ > Seoul : 998.94 $\mu g/m^3$. The concentrations after moving-in were presented as follows: Seoul :1157.09 $\mu g/m^3$ > Gyeongsangdo :1141.75 $\mu g/m^3$ > Incheon and Gyeonggido :740.03 $\mu g/m^3$ > Jeollado :463.80 $\mu g/m^3$.

The concentration of benzene before moving-in was 1.07~3.81 $\mu g/m^3$, and that after moving-in was 0.60~7.00 $\mu g/m^3$. The concentrations of all the four areas

**Table 11.** VOCs concentration in new apartments by area (Kruskal-Wallis test, unit : $\mu g/m^3$)

| | Region | N | Benzene | Toluene | Ethylbenzene | *m,p*-Xylene | Styrene | *o*-Xylene | TVOC |
|---|---|---|---|---|---|---|---|---|---|
| Before resident | Seoul | 31 | 2.38 | 228.50 | 53.74 | 99.83 | 11.60 | 37.40 | 998.94 |
| | Incheon & KyungKiDo | 47 | 3.81 | 377.44 | 108.27 | 232.68 | 20.41 | 97.56 | 1764.70 |
| | KyungSangDo | 10 | 1.07 | 224.09 | 81.33 | 203.86 | 3.42 | 80.65 | 1339.06 |
| | JeonRaDo | 21 | 3.01 | 418.12 | 29.34 | 43.12 | 8.83 | 21.30 | 1596.69 |
| | p-value | | 0.000 | 0.000 | 0.066 | 0.003 | 0.001 | 0.031 | 0.013 |
| After resident | Seoul | 35 | 7.00 | 971.04 | 92.80 | 202.27 | 34.04 | 41.38 | 1157.09 |
| | Incheon & KyungKiDo | 43 | 2.08 | 253.28 | 42.71 | 102.25 | 19.68 | 19.33 | 740.03 |
| | KyungSangDo | 10 | 0.90 | 199.05 | 70.15 | 172.66 | 6.90 | 38.72 | 1141.75 |
| | JeonRaDo | 24 | 0.60 | 192.81 | 10.57 | 18.26 | 8.67 | 5.27 | 463.80 |
| | p-value | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

were not more than the recommended standard(30 $\mu g/m^3$). Risto[9] measured VOCs in normal houses and houses with sick house syndrome and the concentrations of benzene in each house were 3.11 $\mu g/m^3$ and 10.73 $g/m^3$ respectively, which was similar to the results of this study. The concentration of benzene in newly-built apartment houses of Seoul which was reported by Jeon et al. was 6.90 $\mu g/m^3$. Both of the results were not more than the recommended standard.

The concentrations of Toluene before moving-in were 377.44 $\mu g/m^3$ in Incheon and Gyeonggido, and 418.12 $\mu g/m^3$ in Jeollado, which were not more than Korean recommended standard (1000 $\mu g/m^3$), but they were more than the Japanese recommended standard(260 $\mu g/m^3$). That after moving-in was 971.04 $\mu g/m^3$ in Seoul. According to the research by National Institute of Environmental Research[6], the mean concentration of Toluene was 18.99~682.77 $\mu g/m^3$ and those of Gyeongsangdo and Gyeonggido were more than the Japanese recommended standard(260 $\mu g/m^3$), which was about 13.8%.

This study found that indoor pollution of metropolitan cities such as Seoul and the places with higher air pollution was higher, and that the concentration of VOCs in densely populated places was higher, which was the same as the result of other study ( National Institute of Environmental Research[6]).

### 3.5. Comparative Analysis of Pollution according to Living Environments

Table 12 and 13 present the results of the comparative analysis of many factors in living environment

**Table 12.** VOCs concentrations by repairs (unit : $\mu g/m^3$)

| | | n | Benzene Mean | Benzene S.D | Benzene p | Toluene Mean | Toluene S.D | Toluene p | Ethylbenzene Mean | Ethylbenzene S.D | Ethylbenzene p | 1,2-Dichloroethane Mean | 1,2-Dichloroethane S.D | 1,2-Dichloroethane p |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Floor change | Yes | 14 | 9.88 | 18.54 | 0.006 | 348.08 | 123.93 | 0.004 | 97.41 | 57.63 | 0.001 | 0.46 | 1.73 | 0.275 |
| | No | 97 | 2.27 | 4.74 | | 263.08 | 136.22 | | 48.15 | 46.58 | | 0.19 | 1.42 | |
| Wallpaper change | Yes | 14 | 9.23 | 18.57 | 0.031 | 375.07 | 165.47 | 0.001 | 71.48 | 44.65 | 0.033 | 0.92 | 3.45 | 0.262 |
| | No | 97 | 2.36 | 4.87 | | 259.18 | 127.13 | | 51.89 | 51.08 | | 0.12 | 0.86 | |
| Veranda change | Yes | 31 | 3.66 | 6.06 | 0.194 | 368.08 | 167.53 | 0.000 | 78.16 | 56.46 | 0.001 | 0.42 | 2.32 | 0.815 |
| | No | 80 | 3.06 | 8.88 | | 237.26 | 103.42 | | 45.14 | 45.16 | | 0.15 | 0.95 | |
| New furniture | Yes | 92 | 3.26 | 8.44 | 0.762 | 281.17 | 144.55 | 0.275 | 57.73 | 51.07 | 0.050 | 0.27 | 1.60 | 0.427 |
| | No | 19 | 3.07 | 6.86 | | 238.12 | 87.81 | | 38.02 | 45.72 | | 0.00 | 0.00 | |
| Remodeling | Yes | 43 | 4.73 | 11.14 | 0.051 | 336.84 | 157.27 | 0.000 | 73.51 | 51.81 | 0.000 | 0.45 | 2.18 | 0.306 |
| | No | 68 | 2.27 | 5.42 | | 233.94 | 105.91 | | 42.25 | 46.14 | | 0.08 | 0.67 | |
| Paint | Yes | 13 | 4.37 | 8.23 | 0.499 | 300.23 | 113.55 | 0.166 | 60.01 | 43.15 | 0.354 | 0.50 | 1.79 | 0.240 |
| | No | 98 | 3.07 | 8.19 | | 270.29 | 140.11 | | 53.61 | 51.60 | | 0.19 | 1.41 | |
| Smoking | Yes | 4 | 0.98 | 1.14 | 0.425 | 226.38 | 121.37 | 0.500 | 25.15 | 21.43 | 0.252 | 0.00 | 0.00 | 0.737 |
| | No | 108 | 3.28 | 8.27 | | 273.98 | 138.25 | | 54.99 | 51.03 | | 0.23 | 1.48 | |

**Table 13.** VOCs concentrations by repairs (unit : μg/m$^3$)

| | | N | m,p-Xylene | | | o-Xylene | | | Styrene | | | TVOCs | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | S.D | p | Mean | S.D | p | Mean | S.D | p | Mean | S.D | p |
| Floor change | Yes | 14 | 223.54 | 131.84 | 0.001 | 43.63 | 30.23 | 0.001 | 26.82 | 22.76 | 0.148 | 1154.81 | 456.31 | 0.006 |
| | No | 97 | 108.26 | 106.37 | | 22.48 | 23.15 | | 26.82 | 22.76 | | 808.96 | 443.25 | |
| Wallpaper change | Yes | 14 | 165.71 | 116.60 | 0.032 | 30.62 | 21.42 | 0.083 | 31.76 | 24.44 | 0.013 | 1069.68 | 342.58 | 0.015 |
| | No | 97 | 116.61 | 116.15 | | 24.35 | 25.49 | | 19.43 | 20.13 | | 821.25 | 464.92 | |
| Veranda change | Yes | 31 | 186.89 | 135.60 | 0.000 | 37.76 | 29.72 | 0.001 | 32.97 | 25.79 | 0.000 | 1106.37 | 482.39 | 0.000 |
| | No | 80 | 97.96 | 97.21 | | 20.26 | 21.19 | | 16.16 | 16.67 | | 754.24 | 410.00 | |
| New furniture | Yes | 92 | 131.34 | 116.63 | 0.022 | 26.82 | 25.19 | 0.031 | 21.54 | 21.91 | 0.592 | 881.32 | 479.93 | 0.253 |
| | No | 19 | 81.42 | 104.79 | | 17.00 | 23.02 | | 17.53 | 15.43 | | 713.44 | 300.65 | |
| Remodeling | Yes | 43 | 172.69 | 123.48 | 0.000 | 34.55 | 26.92 | 0.000 | 28.51 | 24.15 | 0.001 | 1071.34 | 459.09 | 0.000 |
| | No | 68 | 91.25 | 99.22 | | 19.19 | 21.91 | | 16.02 | 17.11 | | 714.25 | 401.87 | |
| Paint | Yes | 13 | 133.22 | 88.05 | 0.296 | 24.30 | 15.90 | 0.384 | 26.02 | 23.65 | 0.271 | 988.98 | 356.92 | 0.093 |
| | No | 98 | 121.41 | 119.28 | | 25.25 | 26.04 | | 20.17 | 20.59 | | 834.49 | 467.82 | |
| Smoking | Yes | 4 | 48.10 | 38.71 | 0.193 | 9.31 | 6.17 | 0.163 | 23.42 | 25.51 | 0.163 | 689.40 | 430.47 | 0.520 |
| | No | 108 | 124.52 | 116.82 | | 25.52 | 25.24 | | 20.57 | 20.88 | | 852.87 | 461.15 | |

and VOCs concentrations. Most of the VOCs concentrations were higher in case that floorings and wall papers were replaced, verandas and interior were replaced, or new paint was applied.

The concentration of benzene when floorings was replaced in moving-in was 9.88 μg/m$^3$ while its concentration when no replacement occurred was 2.27 μg/m$^3$. Its concentration when new floorings is applied was higher ($p<0.01$). The concentrations of Toluene, Ethylbenzene, m,p-Xylene, and o-Xylene were 2 times higher when floorings were replaced ($p<0.01$). The VOCs concentrations were higher in case of changed indoor environments such as replacement of wall papers, remodelling of verandas, new interior decoration, new furniture and new paint. ($p<0.05$)

Michael[10] studied the practice of residents' activities, and pollutants to find that the VOCs concentrations of smoking houses were higher than those of non-smoking houses, which indicates that indoor pollution of the houses where smokers reside was higher. However, this study there was no difference in concentration in case of indoor smoking. The study by Lee et al.[11] which dealt with relations between the living status of residents and concentration of indoor pollutants detected assumed that the concentrations of VOCs detected were higher when there were smokers inside the houses but, the TVOC concentration of the houses with smokers in winter was 150.43 μg/m$^3$, and that of the houses without smokers was 154.83 μg/m$^3$, which was similar. The TVOCs concentration of the houses with smokers in this study was 689.40 μg/m$^3$ while that of the houses without smokers was 852.87 μg/m$^3$. Rather, the concentration of TVOCs concentration of the houses without smokers was higher.

As a result of this study, it was suggested that there was a difference in the VOCs concentrations according to factors of living environments, and replacement of floorings and wall papers, and interior remodelling affected the VOCs concentration. However, as these factors were not decided with other factors excluded, this study suggests that further studies on estimation of sources are needed. Therefore, for improvement of indoor air quality in middle-term and long-term, indoor air pollutants should be identified and controlled effectively.

## 4. Conclusions

This study measured the concentrations of Aldehydes and VOCs in indoor environment and assumed sources of indoor air pollutants, targeting 120 newly-built apartment houses in six areas (Seoul, Incheon, Gyeonggi, Mokpo and Kimhae ) from February to July 2005. And it examined subjective symptoms of residents and evaluated the carcinogenic influence on human bodies, and the results are presented as follows:

1. This study measured temperatures and humidities of apartment houses, and the mean humidity was 35.7% before moving-in and 60.7% after moving-in. The mean indoor and outdoor temperature were 20.3℃ and 11.7℃ before moving-in and 26.4℃ and 26.9℃ after moving-in.

2. The indoor and outdoor concentrations of TVOCs were 1498.61 $\mu g/m^3$ and 468.376 $\mu g/m^3$ before moving-in and 847.04 $\mu g/m^3$ and 102.844 $\mu g/m^3$ after moving-in. The indoor concentration was higher than the outdoor concentration.

3. The VOCs concentrations of newly-built apartment houses before moving-in were as follows: Toluene (328.12 $\mu g/m^3$) > m,p-Xylene (163.668 $\mu g/m^3$)> Ethylbenzene(80.70 $\mu g/m^3$) > o-Xylene(67.04 $\mu g/m^3$). However, the VOCs concentrations after moving-in were as follows: Toluene(272.28 $\mu g/m^3$) > m,p-Xylene (121.79 $\mu g/m^3$)> Ethylbenzene(53.92 $\mu g/m^3$) > o-Xylene(24.94 $\mu g/m^3$).

4. According to activity practice of residents two months after moving in newly-built apartment houses, the TVOCs concentration from living utensils are presented as follows: 1154.81 $\mu g/m^3$ for the houses whose floorings are replaced; 1106.37 $\mu g/m^3$ for the houses whose verandas were remodelled; and 1071.34 $\mu g/m^3$ for the houses whose interior decoration was remodelled. They were higher than those of the houses without remodelling or replacement (808.96 $\mu g/m^3$, 754.24 $\mu g/m^3$, and 714.25), which indicates that their activities affected indoor air pollution.

## References

1) Park J. C., 2005, A measurement of Formaldehyde and Volatile Organic Compounds in newly-constructed apartment house, M.S, Department of Architecture, The Graduate School of Chung-Ang University, Seoul.
2) Kim S. D., Kim T. S., Lee H. K., Lee J. J., 1993, The spatial characteristics of ventilation efficiency, Journal of Korea Air Pollution Research Association, 9(3), 236-241.
3) Ministry of Environment, 2004, Indoor Air Quality Process Test Methods.
4) Jo J. J., 2004, Surveys of the concentration of VOCs at measurement sites in new apartment, Proceeding of the 37th Meeting of Korean Society for Atomospheric Environment, 201-202.
5) Jeon H. J., A source identification and characteristics of Volatile Organic Compounds(VOCs) and Formaldehyde in apartment housing, M.S, Department of Environmental Engineering, The Graduate School of Engineering, Hanyang University, Seoul.
6) National Institute of Environmental Research, 2004, A survey of the indoor air quality in new apartments in Korea.
7) Uchiyama S. etc 2, 2001, A source identification of Volatile Organic Compounds in new apartment, Japan Construction Academic Society thesis, 547.
8) Kim J. C., 2005, An application of risk assessment for establishment of the standard of HAPs in new/old apartment, M.S, Department of Envireonmental Engineering(Air Pollution Control), The Graduate School of Engineering, Hanyang University, Seoul.
9) Risko K., 1995, Volatile organic compounds in the indoor air of normal and sick house, Atmospheric environment, 29(6), 693-702.
10) Michael R. etc, 2001, Volatile Organic Compound, Poly cyclic Aromatic Hydrocarbons and Elements in the Air of Ten Urban Homes, Indoor Air, 11, 49-64.
11) Lee S. M., Kang D. S., Kang S. J., Sohn J. Y., 1998, Air exchange rates and Indoor Air Quality levels of hugh-rise apartments in winter, Journal of the Society of Living Environment System, 5(2), 9-14.