

A Study on the Improvement of Indoor Air Quality of Newly-Built Apartment Houses Using Low Emission Building Materials

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Abstract

This study aims to improve the indoor air quality of newly-built apartment houses in Korea through the measurement and evaluation of formaldehyde (HCHO) and volatile organic compounds (VOCs) generated from building finishing materials at each construction stage. Small chamber tests were carried out for 12 kinds of low emission building finishing materials and 10 site measurements were conducted according to the construction stage. The study showed that the concentration of HCHO and VOCs could be controlled by the use of low emission building materials.

Keywords: indoor air quality; newly-built apartment houses; low emission building materials; formaldehyde (HCHO); volatile organic compounds (VOCs)

1. Introduction

Low emission building materials have been widely used in Korean construction since 2004 when the indoor air quality management law became effective, but as a whole, indoor air quality still needs to be improved. Previous studies indicated that the indoor air quality of newly-built apartment houses could not satisfy the recommended guidelines of HCHO and VOCs (Yee (2006), Park (2007))¹.

Such results are attributable to the lack of environmental data on the emission rate of pollutants from various building materials. The generation of pollutants at each construction stage during which architectural finishing materials for walls, floors, and ceilings are used is not well documented for complex constructions.²

In order to evaluate air quality factors, the emission rates of HCHO and VOCs from representative building finishing materials were measured. From the results of the emission rate measurements, low emission building finishing materials were selected using the Healthy Building Material certification grades established by the Korea Air Cleaning Association.

Finally, the concentrations of HCHO and VOCs generated at each construction stage for a real apartment house using selected low emission building finishing materials were measured and evaluated to

ascertain the main polluting material or construction stage.

2. The Standard, Measurement and Analysis of Indoor Air Quality

2.1 The standard of indoor air quality

An internationally unified standard for indoor air quality is not yet available, particularly for measurements and analysis. However, the EPA and ISO have established measurement methods, which tend to be acknowledged. The standards are not significantly different.

The recommended guidelines for HCHO and VOCs (benzene, toluene, ethyl benzene, xylene, 1,4-dichloro benzene, styrene), which are the main cause of the Sick House Syndrome in apartment buildings recommended in 2004 are shown in Table 1.³

Table 1. Recommended Limits for HCHO and VOCs

	Korea ($\mu\text{g}/\text{m}^3$)	Japan ($\mu\text{g}/\text{m}^3$)	WHO ($\mu\text{g}/\text{m}^3$)
HCHO	Under 210	Under 100	Under 100
VOCs	Benzene	Under 30	-
	Toluene	Under 1000	Under 260
	Ethylbenzene	Under 360	Under 3800
	Xylene	Under 700	Under 870
	Styrene	Under 300	Under 220

2.2 Measurement and analysis of indoor air quality

Samples were taken in the middle of living rooms in test units. The basic measurement point was 1m away from the wall and 1.2~1.5m above the floor. Samples were taken after ventilation for 30 minutes and establishment of airtight condition for 5 hours.

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HCHO and VOCs concentrations were measured using the indoor air quality test method that uses HPLC, GC/MSD, and TDS equipment (see Table 2., Table 3.)⁴.

Table 2. GC/MS Analysis Conditions

Cryogenic focusing	Split mode 25: 1 -50°C → 12°C/s → 280°C (5min)
Thermal Desorption	Splitless mode, Flow: 50 ml/min 30°C → 60°C/min → 240°C (5min)
Detector	Agilent 5973 inert MSD
Column	HP-VOC 60m, I.D 0.2mm, Film 1.12 μm
MS	Temp. Program 40°C → 4°C/min → 200°C (10min) → 6°C/min → 250°C
	Final Temp. 250°C (3min)

Table 3. HPLC Conditions

Detector	UV/VIS 360 nm (0.002 AUFS)
Column	Waters Symmetry TM C18 (4.6×250mm, USA)
Column Temp.	25°C (Room Temp.)
Flow Rate	1.3 ml/min

3. Measurement of Emission Rates of HCHO and TVOC from Building Finishing Materials Using a Small Chamber

3.1 Measurement outline

The measurement was carried out to find low emission building finishing materials using a small chamber. Twelve finishing materials including four kinds of wallpaper, two kinds of flooring, three kinds of furniture, and three kinds of adhesive were included in the study. In addition, functional building materials such as diatomite, charcoal paint and charcoal tile were included. The operating conditions and air sampling methods are summarized in Tables 4. and 5.

Table 4. Operating Conditions of the Small Chamber

Items	Specification	
	HCHO	TVOC
Sampling Capacity (V)	4.5 l	4.5 l
Sampling Time (T)	30 min	30 min
Air Rate for Sampling (Q)	150 ml/min	150 ml/min
Chamber Capacity (v)	20 l	
Ventilation Rate (N)	0.5 n/h	
Specimen Load Rate (L)	2.0 m ² /m ³	
Specimen Size (A)	0.165m×0.165m, 2ea	
Temperature (T)	25±1°C	
Humidity (RH)	50 ± 5%	
Sampling Cartridge	Ozone Scrubber + LP-DNPH (SUPELCO 21014)	Tenax TX

Table 5. Air Sampling Methods

Sampling Device	HCHO	2, 4-DNPH Silica Cartridge (Supelo, S10, USA) Ozone Screwber (Waters, USA)
	TVOC	Tenax-TA (60/80mesh, Supelo, USA)
Sampling	HCHO	Digital Pump (Sibata MP-Σ300) 150 ml/min× 30min = 4.5l
	TVOC	Digital Pump (Sibata MP-Σ300) 150 ml/min× 30min = 4.5l
Storage	Store in refrigerator below 4°C	

Low emission building finishing materials were selected on the basis of the Healthy Building Material certification grades established by the Korea Air Cleaning Association. Table 6. shows HB Certification Grades of Building Materials⁴.

Table 6. HB* Certification Grades of Building Materials (Revised on 23 March 2006)

(Unit: mg/m ² h)				
Grade		General Materials	Paints	Adhesives
Very Excellent *****	TVOC	Under 0.10	Under 0.10	Under 0.25
	HCHO	Under 0.005	Under 0.005	Under 0.01
Excellent ****	TVOC	Over 0.10 Under 0.20	Over 0.10 Under 0.20	Over 0.25 Under 0.50
	HCHO	Over 0.005 Under 0.02	Over 0.005 Under 0.02	Over 0.01 Under 0.12
Good ***	TVOC	Over 0.20 Under 0.40	Over 0.20 Under 0.40	Over 0.50 Under 1.50
	HCHO	Over 0.02 Under 0.12	Over 0.02 Under 0.12	Over 0.12 Under 0.40
General I **	TVOC	Over 0.40 Under 2.00	Over 0.40 Under 2.00	Over 1.50 Under 5.00
	HCHO	Over 0.12 Under 0.60	Over 0.12 Under 0.60	Over 0.40 Under 2.00
General II *	TVOC	Over 2.00 Under 4.00	Over 2.00 Under 4.00	Over 5.00 Under 10.00
	HCHO	Over 0.60 Under 1.25	Over 0.60 Under 1.25	Over 2.00 Under 4.00

*HB stands for Healthy Building

3.2 Measurement results

The measurement results for HCHO and TVOC from building finishing materials and functional building materials are shown in Table 7.

Table 7. Measurement Results of HCHO and TVOC from Building Materials (Unit: mg/m²h)

Building Materials	HCHO	TVOC
Wallpaper	D1*	0.021 (Excellent)
	D2*	0.022 (Excellent)
	D3*	0.014 (Excellent)
	S*	0.012 (Excellent)
Flooring	H*	0.001 (Very Excellent)
	G*	0.005 (Very Excellent)
Furniture	FH*	0.339 (General I)
	FL*	0.061 (Good)
	R*	0.164 (General I)
Adhesive	G*	0.017 (Excellent)
	O*	0.008 (Excellent)
	S*	0.008 (Excellent)
Diatomite	0.012 (Excellent)	0.062 (Very Excellent)
Charcoal Paint	0.004 (Very Excellent)	0.137 (Excellent)
Charcoal Tile	0.008 (Excellent)	0.168 (Excellent)

*Products of specific companies

As shown in Table 7., the measurement results can be summarized as follows.

Wallpapers were usually evaluated as "Very Excellent" regarding HCHO and TVOC emission rates. The floorings received the "Very Excellent" grade for the HCHO test, but in the TVOC test, one belonged to

the "Excellent" grade and the other received a "Good" grade.

Three kinds of furniture were evaluated as "Good" and "General I" regarding both HCHO and TVOC. Three kinds of adhesives showed the results of "Excellent" grade concerning HCHO emission rate and "Good" to "Very Excellent" grade concerning TVOC emission rate.

Diatomite showed the results of "Excellent" and "Very Excellent" grades regarding HCHO and TVOC emission rate.

Charcoal paint was evaluated as "Excellent" in terms of TVOC and "Very Excellent" in terms of HCHO emission rate. Charcoal tile showed the result of "Excellent" concerning both HCHO and TVOC emission rates.

4. Measurement of HCHO and VOCs Generated from each Construction Stage of an Apartment House

4.1 Measurement outline

A test to measure the pollutants from each construction stage at a test house with an area of 115m² was carried out. Measuring was made on 10 occasions from August to December 2007.

The floor plan and details of the test house are described in Fig.1. and Table 8.

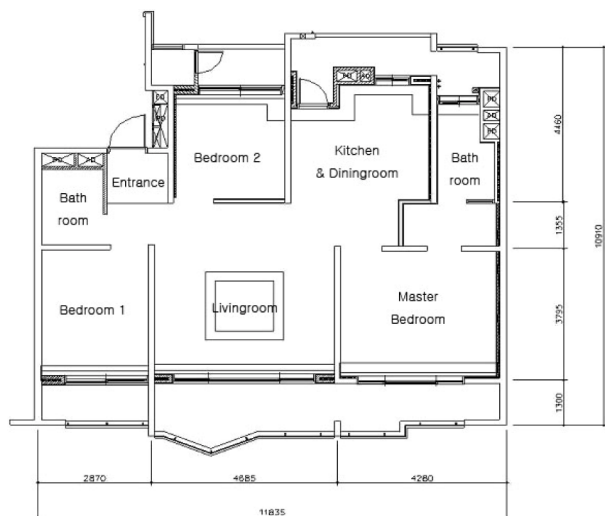


Fig.1. Test House Floor Plan

Table 8. Test House Details

Structure	RC
Area	115m ²
Window	1. All windows are installed 2. Before installation of Ondol flooring: Daytime-open, night-time-closed After installation of Ondol flooring: Daytime-open intermittently, night-time-closed
Interior finishing	The test house was ventilated for 50 days after existing finishing materials were removed.
Heating	Floor radiative heating using hot water piping (Ondol)
Infiltration	Natural ventilation: 0.15 - 0.2 n/h

The low emission finishing materials, which were evaluated through the small chamber test, were applied to the test house. The details of the location and area of finishing materials are described in Table 9.⁵

Table 9. Outlines of Interior Finishing Materials Used in the Test House

Finishing Materials	Applied position	Area (m ²)	
Low emission materials	Wallpaper (wall)	All rooms	70.58
	Wallpaper (ceiling)	All rooms	62.3
	Upper kitchen furniture	Kitchen (Highly glossy)	27.56
	Lower kitchen furniture	Kitchen (PVC film)	17.85
	Shoe chest	Porch	25.02
	Living room furniture	Living room	6.72
	Door frame	4 rooms	6.65
	Art wall	Main wall of living room	8.55
	Ondol flooring	Master bedroom	16.34
	Wooden flooring	Living and kitchen	35.61
	Monorium	Small room	8.24
	Magnasium board	Kitchen wall	4.85
	Diatomite	Kitchen wall	8.44
		Ceiling of living room and kitchen	35.61
	Charcoal tile	Wall of living room	4.95

Measurement and air sampling photographs at each construction stage and the state of finishing materials applied to the test house are shown in Table 10.

4.2 Measurement results

1) Indoor temperature and humidity

Fig.2. shows the temperature and relative humidity during the measurements. Since the measurements were carried out over a period from summer through the winter, it shows a wide range of temperatures from 18°C to 29°C and relative humidity from 25% to 70%.

2) Formaldehyde (HCHO)

Fig.3. shows the distribution of the emission rate of HCHO. The concentration before installation of finishing materials was zero. After the installation of doorframe - Art wall - wallpaper - flooring - living room furniture - kitchen furniture - diatomite - charcoal tile, the emission rates were measured. Though there were some variations in the concentration at each construction stage, the air quality remained far below the recommended guideline for new apartment buildings (210 μg/m³). As shown in Fig.3., the concentrations appeared to have increased after Art wall and furniture were installed. Particularly after flooring work, it increased continuously even after two weeks, and the concentration of HCHO increased after flooring and kitchen furniture were completed, indicating that more HCHO was discharged during the flooring and furniture installation.

Table 10. Measurement Steps and Dates and the State of Finishing Materials and Measurement Pictures

Step	Date	Construction Stage	State of Finishing Materials and Measurement Photographs
1st	8.10	Before installation	
2nd	8.16	Doorframe	
3rd	8.23	Art wall	
4th	9.10	Wallpaper	
5th	9.20	Flooring	
6th	10.4	Before setting the furniture	
7th	10.18	Living room furniture and shoe chest	
8th	10.29	Kitchen furniture	
9th	12.3	Diatomite	
10th	12.14	Charcoal tile	

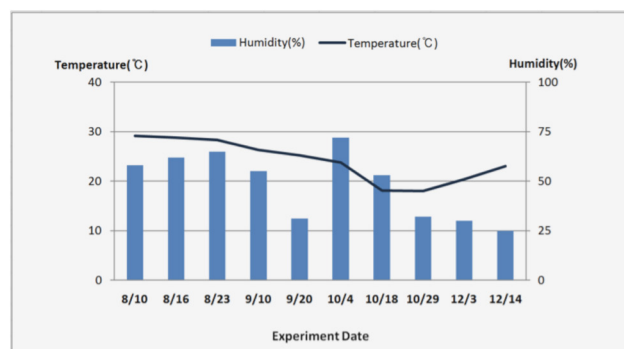


Fig.2. Temperature and Relative Humidity During the Measurement Period

However, HCHO was significantly reduced after diatomite and charcoal tile were applied. Diatomite, among others, showed the lowest concentrations.

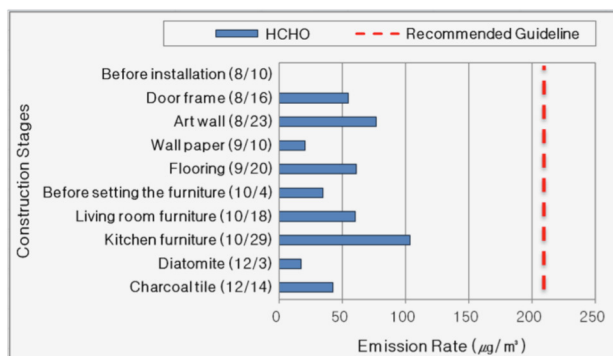


Fig.3. HCHO Concentration

3) VOCs

Table 11. indicates the concentration of five VOCs at each construction stage.

Table 11. Concentration of VOCs

(Unit: µg/m³)

Construction stages	Ben-zene	Tol-uene	Ethyl benzene	Xylene	Styene
Before installation	0.00	15.71	2.79	9.61	1.64
Doorframe	0.38	119.95	10.06	25.15	4.07
Art wall	0.41	49.58	5.52	12.57	1.93
Wallpaper	0.92	53.15	6.03	17.29	2.38
Flooring	0.29	84.35	2.09	5.26	1.08
Before setting the furniture	0.63	28.41	1.69	3.62	4.67
Living room furniture and shoe chest	1.80	599.11	11.66	21.88	13.62
Kitchen furniture	2.77	780.94	56.72	63.55	24.86
Diatomite	2.38	150.99	13.86	18.87	7.49
Charcoal tile	2.07	142.89	10.98	12.93	6.83

As a result of measuring VOCs (benzene, toluene, ethyl benzene, xylene, styrene) during the five construction stages in order of doorframe - Art wall - wallpaper - flooring - furniture (living room and kitchen), very low levels of VOCs (four components except toluene), 10% less than the recommended guideline, were detected over the entire process of finishing work⁶.

Fig.4. shows the concentration of benzene at each construction stage.

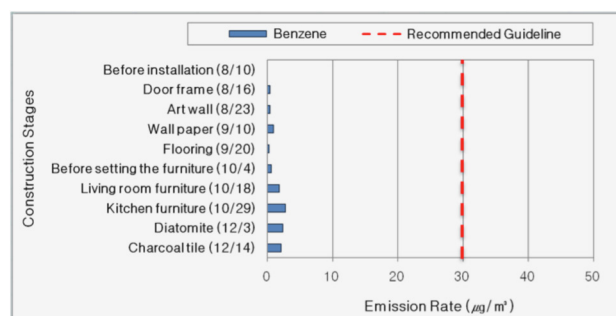


Fig.4. Concentration of Benzene

As shown in Fig.4., the concentration of benzene is very low at all construction stages.

The concentration of toluene at each construction stage is shown in Fig.5.

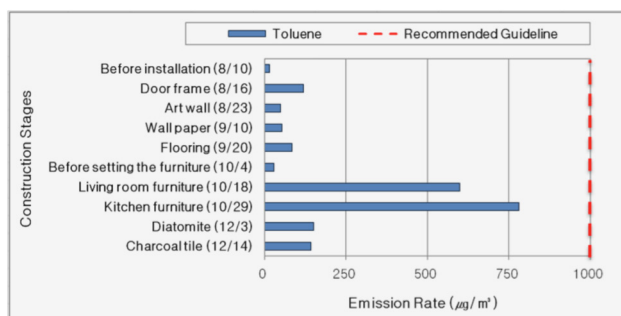


Fig.5. Concentration of Toluene

Toluene drastically increased after setting the floor and kitchen furniture, but also drastically decreased after diatomite and charcoal tile were applied⁷.

Fig.6. shows the concentration of xylene at each construction stage.

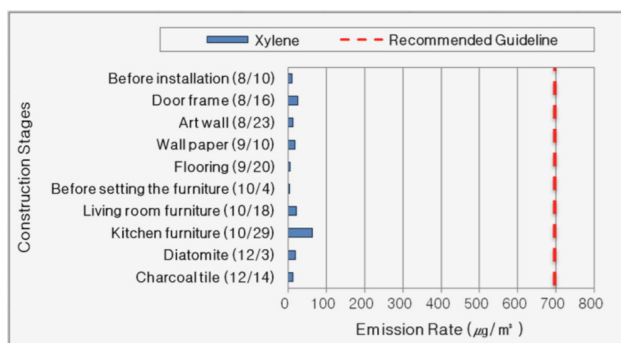


Fig.6. Concentration of Xylene

The concentration of xylene at each construction stage was also very low in comparison with the recommended guideline. The concentration of toluene at each construction stage is shown in Fig.7.

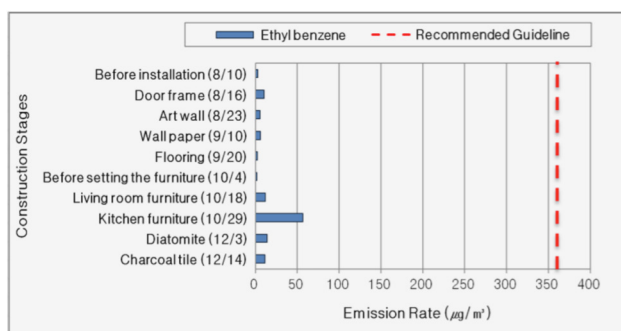


Fig.7. Concentration of Ethyl Benzene

The concentration of ethyl benzene after installation of kitchen furniture was increased a little, but was still far lower than the recommended guideline. Fig.8. shows the concentration of styrene at each construction stage.

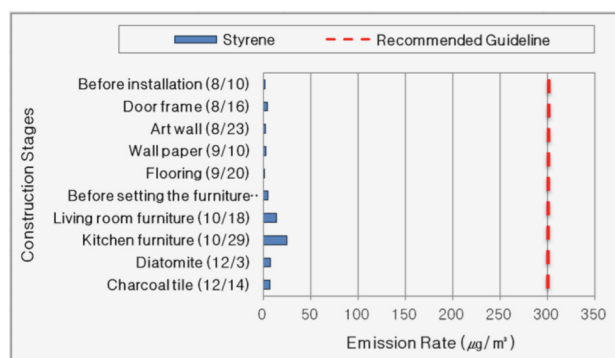


Fig.8. Concentration of Styrene

As shown in Fig.8., the concentration of styrene is very low at each construction stage.

5. Conclusions

From the measurement results for HCHO and TVOC from 12 kinds of low emission building finishing materials and functional building materials using the small chamber method, wallpapers and floorings turned out to belong to the "Very Excellent" or "Excellent" grades.

In the case of adhesives, the grade was "Excellent" or "Good". As furniture showed "Good" and "General I" grade, it needs to be improved in respect to air quality. All the functional building materials such as diatomite, charcoal paint and charcoal tile received the grade of "Very Excellent" or "Excellent".

The results of the measurement and evaluation of HCHO and VOCs discharged from building finishing materials at each construction stage can be summarized as follows.

- 1) As a result of measuring the emission rates of HCHO and VOCs from the low emission building materials at each construction stage (10 stages) in order of before installation - doorframe - Art wall - wallpaper - flooring - before setting the furniture - living room furniture and shoe chest - kitchen furniture - diatomite - charcoal tile, the concentration of HCHO and VOCs appeared to be much lower than the recommended guidelines.
- 2) The concentration before installation was measured after removing existing materials and ventilating for three months. No HCHO was detected, but very slight VOCs were detected.
- 3) After doorframe installation there was some increase in the concentration of HCHO and VOCs, but both of them were below the recommended guidelines.
- 4) Five components of VOCs after installation of kitchen furniture appeared to have remained within the allowable limit, but the overall concentration increased because of the furniture.
- 5) After applying diatomite, HCHO and the toluene of VOCs were reduced by 83% and 81%, respectively. These results show that diatomite can be used as a functional finishing material that removes HCHO and TVOC.

Though it is necessary to use the proved low emission and functional building materials, more importantly, thorough construction management may also be required to improve the indoor air quality of newly-built apartment houses.

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