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Variation of Indoor Air Quality in a New Apartment Building by Bake-Out

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ABSTRACT: Bake-out was executed against the newly constructed apartment buildings using two methods to find out the effect of improvement on the indoor air quality and identify the concentration changes in the indoor air by the bake-out method for 3 months after occupancy. From two methods of bake-out executed before occupying, we did not find any reduction effect on the hazardous substances in the indoor air. The concentration of the hazardous substances in the indoor air tended to increase due to the sink effect, but it turned to decrease due to enough ventilation by desorption. The extent of adsorption depends on hazardous substances, building materials and furniture. The longer the period of bake-out is noticed when the formaldehyde concentration was higher than that from the total volatile organic compounds (TVOCs) because of sink effect. Therefore TVOCs had more reducing effect on the concentration of indoor air hazardous substances than the formaldehyde. The concentration level of indoor air contamination materials could be reduced from the re-desorption of hazardous materials through a sufficient duration of ventilation although bake-out has raised the concentration level of indoor air contamination materials by the adsorption effect for a short period of time.

Key words: Bake-out, Indoor air quality, Sink effect, TVOC, Formaldehydes, BTEX

INTRODUCTION

Since newly constructed apartments have tens of times more the concentration of hazardous substances like the volatile organic compounds (VOCs) that are discharged from building materials, the indoor air contamination of newly constructed apartments has been a serious social problem. Therefore, studies on the materials of causing indoor air contamination and appropriate measures are actively made for the newly constructed apartments as the problems of sick house syndrome and multiple chemical sensitivity are intensively dealt by the press (Jang *et al.*, 2004; Jang *et al.*, 2007; Lee, 2004; Lee *et al.*, 2004; Sim, 2006).As for the effective method of removing VOCs and formaldehyde that are discharged from the building materials and furniture of newly constructed apartments, a procedure known as a "bake-out" has been commonly used (Etkin, 1996; Girman, 1989; Wieslander *et al.*, 1997; Hodgson *et al.*, 1994). The principle of this procedure is to drive VOCs out of materials into indoor air by raising the temperature in the building up to a level of 32~ 40°C, while increasing outdoor air exchange so that emissions are removed from the building. The procedure generally takes several days to 2 weeks and is performed before the occupancy (Kim and Kim, 2005).

The existing studies related to "bake-out" can be classified into the studies through chamber and

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modeling and the studies through the spot survey. According to the results of those, a decrease of 60<"94% in the total volatile organic compounds (TVOCs) levels was achieved with the bake-out, though contradictory results have also been reported (Bayer, 1990; Borazzo and Girman, 1993; Offerman *et al.*, 1993). The effect of bake-out has not been established in the domestic as well as in the overseas since control of environmental conditions is difficult. The details for the bake-out temperature, bake-out period, and appropriate number of ventilation for removing hazardous substances have not been decided. This study, in order to see the bake-out effect in newly constructed apartments, has measured and analyzed indoor air contamination materials and checked the concentration changes of contamination materials for three months before and after move-in.

MATERIALS & METHODS

This study has been conducted for an apartment with areas of 112.40 3, 159.03 3 and 196.12 3 from a total of 352 households among newly constructed apartment in the area of Gyeonggi province for the period from October of 2006 to February of 2007. Of these, the apartment subjected for the survey prior to move-in were 30 households and those of having performed the partial bake-out work were 4 households, coming to a total of 34 households. Two households among 30 target households prior to move-in was excluded from the survey because of the re-building work after the bake-out and the survey has been finally done on a total of 28 households. Some households after move-in were excluded as the move-in process gets delayed. Then, 8 households that have become difficult to continue surveying due to the re-construction works from a defect and individual circumstances were excluded. Hence, it has been made on a total of 20 households.

Partial bake-out targets, as the households excluded from the survey target prior to move-in, were 5 places of study room, children's room and multi-purpose rooms from four households that have appealed severely for the bad smell within their apartment rooms. Heating system is individual heating method, the temperature of Korean under floor heating system can be set up to a maximum of 85°C and the indoor temperature can be set to a maximum of 35°C, which method allows adjusting temperature by each room.

This study was conducted by dividing the bake-out execution households prior to move-in into the "method recommended by the Ministry of Environment" and "method carried out by the Korea National Housing Corporation" and the detailed methods are the same as in the following.The bake-out method recommended by the Ministry of Environment

1- All drawers and doors shall be kept open.
2- All the doors and windows facing with the out side shall be kept closed.
3- After maintaining for 5~6 hours by setting the heating temperature to 30~40°C, ventilate the households by opening all the doors.
4- Perform 3 or more times of the steps above.

The bake-out guidelines of Korea National Housing Corporation (Korea National Housing Corporation, Bake-Out Guidelines 2005)

1- The first day temperature of boiler shall be kept in the range of 23~25°C and the temperature shall be maintained in the range of 28~30°C from the second day and on.
1- Open 5cm of the balcony window.
2- Open all doors of rooms and furniture within the apartments
3- Perform this job 15~30 days prior to move-in (running boiler for 5 days in case of the apart ments for the general public and for 3 days in case of the national rental houses).

Since both of the methods do not indicate the execution time in detail for ventilation, natural ventilation was made immediately after the bake-out work by opening all doors and windows until the indoor temperature drops to the indoor temperature prior to bake-out.After ventilating for at least 30 minutes by opening all windows and doors of target households' rooms and furniture, we have measured it for 30 minutes after keeping airtight and closing the windows and doors that were in contact with the outside air.

We have performed the t-test by using SAS a statistic package in order to verify the difference according to whether bake-out or not after move-in and whether expansion or not prior to move-in. Also, we have carried out the distribution analysis in order to analyze the data by the floor and area of the apartment of bake-out method prior to

move-in and conducted the paired t-test to see difference by the bake-out method with the difference in concentration prior to move-in. The results were statistically significant for $p<0.05$.

RESULTS & DISCUSSION

The setup temperatures and indoor temperatures, for the households of having performed the bake-out by the "method of Korea National Housing Corporation" and households of having performed by the "method of the Ministry of Environment", are shown on the Table 1.The indoor temperatures conducted by the "method of Korea National Housing Corporation" were 1~3°C higher than the "method of the Ministry of Environment" and the bake-out was performed with the temperature 3~6°C lower than the target temperature.

As the concentration of the indoor air quality of the apartment prior to move-in, it has shown a concentration of 127.8 3/3 as for formaldehyde and the VOCs such as toluene, ethyl benzene, xylene and styrene have shown the respective densities of 210.5 3/3, 19.0 3/3, 18.8 3/3 and 36.0 3/3. The concentration of TVOCs was relatively high with a concentration of 2864.7 3/3. The hazardous substance densities of indoor air prior to move-in are the same as shown on the following Table 2. We have obtained the VOCs concentration ratio of indoor to outdoor by measuring the outdoor concentration prior to move-in. In the outdoor, the substances such as benzene, toluene, ethyl benzene and styrene were detected in a very small sum.

The result of bake-out from the "method of Korea National Housing Corporation" and "method recommended by the Ministry of Environment" has not shown any reduction effect in the hazardous substances of indoor air. In case of the 5 day method of Korea National Housing Corporation that was expected to show the effect of bake-out most apparently,the concentration of formaldehyde has shown the result of increasing the concentration level of indoor air contamination substances. However in the cases for the bake-out methods performed by the method of Korea National Housing Corporation and the 3 day method recommended by the Ministry of

Table 1. Target temperature of bake-out and indoor temperature

	Ministry of environment(ME)			Korea national housing corporation (JuGong)		
1st	T. ONDOL[+]	T. indoor[++]	Indoor[+++]	T. ONDOL	T. indoor	Indoor
2nd	75	30	26~27	75	28	26.5~28
3rd	85	35	28~30	85	35	28~31
4-5th[†]	85	35	29~30	85	35	29~32
	-	-	-	85	35	30~32

[+] Target ONDOL temperature, [++] target indoor temperature, [+++] indoor temperature

Table 2. Concentrations of indoor air pollutants before move-in

Compounds	N	GM	GSD	Range	I/O[++]
Formaldehyde	28	127.8	1.84	25.6-384.6	17.1
Benzene	28	1.9[+]	-	-	trace
Toluene	28	210.5	4.77	1.3-4156.5	trace
Ethylbenzene	28	19.0	2.77	0.9-362.1	trace
Xylene	28	18.8	2.68	9.0-2164.0	2.1
Styrene	28	36.0	5.41	1.4-244.0	trace
TVOCs	28	2864.7	2.15	524.4-12139.3	12.8

[+] Trace, LOD of benzene, [++] I /O : VOCs concentration ratio of indoor to outdoor

Environment, the concentration level of formaldehyde has slightly decreased. The formaldehyde concentration level of bake-out methods has not shown a significant difference from the analysis result.

While the result of TVOCs has shown a different result as compared to that of formaldehyde, the bake-out work performed by the 5 day method of Korea National Housing Corporation has shown a reduction of 56%, we could see almost no effect from the bake-out case performed in the same way for 3 days and performed by the method recommended by the Ministry of Environment. However, the results by each method were not statistically significant and the result of paired t-test for the concentration difference before and after the bake-out has not shown a significant difference as well (Table 3).We have averaged the differences between the concentrations before bake-out and the concentration after one month of move-in by dividing into the households of having performed bake-out prior to move-in and households of not having performed bake-out prior to move-in. We could see the reduction ratios of 55% and 15% respectively from formaldehyde and TVOCs (Table 4).

In the concentration of indoor air contamination materials after one month of move-in, the concentrations of formaldehyde and VOCs have greatly decreased as compared to those prior to move-in. As compared to those of the first month, the concentration of indoor air contamination materials on the 2nd month after move-in has shown a slight increase in the concentration of formaldehyde, toluene and TVOCs and the concentration of ethyl benzene and styrene has shown almost the same concentration level (Table 5). The households that have shown an increase in the level of formaldehyde as compared to that of the first month were 5 households of having performed

Table 3. Concentrations of compounds by bake-out method in indoor air before move-in

Compounds	Method	N	Before bake-out	After bake-out	After bake-out	F-value
			GM(GSD)	GM(GSD)	GM(GSD)	
HCHO	JuGong +	4	127.5(1.83)	123.7(1.46)		
	JuGong ++	9	72.3(2.54)	125.1(1.75)	149.3(1.29)	1.29
	ME+++	5	149.2(1.70)	83.1(2.86)		
	No Bake-out	10	145.8(1.45)			
TVOCs	JuGong +	4	2707.7(2.50)	2771.7(2.67)		
	JuGong ++	9	4068.7(1.25)	2401.9(1.77)	1774.3(1.94)	0.51
	ME+++	5	3360.8(1.78)	2818.3(2.80)		
	No Bake-out	10	2418.1(2.35)			

+ Korea National Housing Corporation method by bake-out (3days), ++ Korea National Housing Corporation method by bake-out (5days),
+++ Ministry of Environment,

Table 4. Concentrations of compounds by bake-out

Compounds	Bake-out+	N	Before - After++	Decrement (%)+++
HCHO	Yes	11	53.7	55
	No	9	24.1	
TVOC	Yes	11	3012.1	15
	No	9	2545.3	

+ Bake-out before move-in, ++ "Initial concentration before move-in" - "concentration of 1 month after move-in", +++ Decrement(%) whether bake-out or not

Table 5. Concentrations of indoor air pollutants after move-in

Compounds	N	After 1 month GM(GSD)	After 2 month GM(GSD)	After 3 month GM(GSD)
Formaldehyde	20	106.4(1.27)	125.7(1.43)	127.5(1.66)
Benzene	20	1.9[+]	-	-
Toluene	20	5.6(8.35)	8.3(9.55)	11.16(8.56)
Ethylbenzene	20	7.7(2.57)	7.4(2.55)	5.9(2.54)
Xylene	20	9.6(1.22)	9.2(1.16)	9.1(1.27)
Styrene	20	3.7(4.86)	1.41[++]	-
TVOCs	20	934.7(2.53)	1168.8(1.52)	1226.3(1.89)

[+] Trace, LOD of benzene, [++] trace, LOD of styrene

bake-out after move-in and 5 households of having not performed bake-out. However in case of TVOCs, the concentration level has shown increase in 2 households of having performed bake-out and in 10 households of having not performed bake-out.

The contamination level of indoor air by the bake-out work after move-in has not yielded a statistically significant result. However, the concentrations of formaldehyde after one month of move-in have appeared higher in the households of having performed bake-out (112.3 3/3) than in the households of having not performed bake-out (102.7 3/3), but have appeared lower after 3 months of move-in (99.4 3/3). The concentrations in the households of having not performed bake-out have steadily increased (120.7 3/3, 155.4 3/3) after move-in (Table 6). The concentration of TVOCs after one month of move-in has appeared higher in the households of having performed bake-out (1412.1 3/3) than in the households of having not performed bake-out (724.1 3/3). However, the concentration increase between 1 month after move-in (724.1 3/3) and 2 months after move-in (1212.1 3/3) has shown a significant difference in the households of having not performed bake-out (Table 6). While the concentration levels of TVOCs before and after move-in are generally high, the respective VOCs have considerably decreased after move-in.

The apartment subjected for this study had the structure of showing living room after passing through a small passageway on the entrance in a plane structure (3 bay, 4 bay) that is popular among newly built apartments with the areas of 112.40 m^2, 159.03 m^2 and 196.12 m^2. The concentration of formaldehyde, prior to move-in from the result of actual survey, has shown the concentration level higher than the concentration level (Jang *et al.*, 2007; Lee, 2004) of existing newly built apartments and the concentration of TVOCs has also shown a level higher than other newly built apartments. Since the actual survey was made after balcony extensions and other interior works (in-

Table 6. Concentrations of indoor air pollutants by bake-out after move-in

Compounds	Yes (N=8)	No (N=12)	t-value
HCHO 1st[+]	112.3(1.34)	102.7(1.22)	0.66
2nd[++]	132.2(1.32)	120.7(1.52)	0.27
3rd[+++]	99.4(1.86)	155.5(1.34)	4.06
TVOC 1st	1412.1(2.09)	724.1(2.63)	2.79
2nd	1101.7(1.60)	1212.1(1.50)	0.24[*]
3rd	1262.2(2.45)	1201.8(1.57)	0.03

[+] GM(GSD) of 1 month after move-in, [++] GM(GSD) of 2 month after move-in, [+++] GM(GSD) of 3 month after move-in
[*] $p<0.05$ difference GM of 2 month to 1 month after move-in

door renovation) that are commonly executed prior to move-in, it might have made some influence on the result.

According to the survey, it was much more time taken for ventilation and cleaning in the case of first month after move-in than that of second or third month after move-in. In order to remove the irritating smell in newly built apartments, they were usually using the items such as charcoal, flowerpots and air-cleaner. Also for 2~3 months after move-in, they were indifferent of ventilation due to the external conditions of cold temperature and were running boiler by setting the indoor temperature higher than one month after move-in. Also by replacing door or furniture with new one during the period of free defect-repair, it was judged that the concentration level of indoor contamination materials was raised.

The substances, which have increased the concentration level of TVOCs from the result of this study, included the hazardous substances generated from interior work, finishing materials, partitioned wall and ceiling materials that are common construction materials and the substances of surfactants that are used for cleanser, emulsifying agent, forming agent for cement, lubricating additive, sterilizer and paint dispersing agent. Especially, the substances used for the cleaning or cleansing materials and substances of incense making materials used for aromatic or deodorant were detected high although there were some differences by each household. According to these results, the cleaning and managing works on new apartments after move-in were predicted to raise the concentration level of TVOCs.

In the preceding study about bake-out, while there are various studies (Etkin, 1996; Girman, 1989; Hodgson *et al.*, 1994) of insisting that indoor air contamination could be reduced by discharging VOCs immediately, there are other studies that it could cause discharging other chemical materials that might have been remained without being exposed.

According to the result of this study, while the "method of Korea National Housing Corporation (method of Korea National Housing Corporation for 5 days)" as compared to the "method recommended by the Ministry of Environment" has shown a low reduction ratio of indoor air contamination due to the high adsorption effect in case of formaldehyde in the bake-out method prior to move-in, the "method of Korea National Housing Corporation" had higher reduction ratio of air contamination materials than the "method recommended by the Ministry of Environment" in case of TVOCs. Formaldehyde level has increased the adsorption ratio and TVOCs level has decreased as the period of performing bake-out gets longer. From this result, we could see that formaldehyde has higher adsorption ability than TVOCs. According to the result of having averaged the concentration differences prior to move-in and after one month of move-in by dividing households into two groups of having performed and having not performed bake-out prior to move-in, we could see the reduction ratios of 55% and 15% in the respective concentration levels of formaldehyde and TVOCs, showing significant effect on the result of bake out.

As for the influential factors on the effect of bake-out, there are the external factors such as bake-out time, bake-out temperature, ventilation (Borazzo and Girman, 1993) and adsorption/desorption effect (Won *et al.*, 2001) and internal factor like the temperature dependency for the chemical material discharge of materials (Wigluzs, 2002). According to a number of studies, the increase in the discharge speed of chemical materials could have a large difference (Kim and Kim, 2005) according to the formation of materials although they are identical types of materials" and the chemical substances within the material could be greatly reduced as the temperature of bake-out gets higher and the bake-out period gets longer (Girman, 1989; Bayer, 1990; Kang, 2005). However as the bake-out temperature gets higher and the period gets longer, there are high possibilities of damaging materials and high costs (Levin, 1989) and these can increase the indoor concentration of chemical materials due to the adsorption/desorption effect from the ventilation conditions that need to be relatively suppressed in order to accomplish the target temperature of materials when performing bake-out (Won *et al.*, 2001). The adsorption/desorption effect, which is the greatest factor that impedes the effect of bake-out, occurs from almost all materials and is recognized as an important factor of determining indoor air contamination level (Sparks, 1991). Ac-

cording to the preceding study, the contamination level of indoor air is raised in the process of desorption after hazardous substances are absorbed into various indoor living articles and this can explain that the high concentration level of these materials may be exposed although much ventilation is made after performing the bake-out work. Therefore, the bake-out work after move-in shall be performed with caution in the state of securing sufficient ventilation time.

In the summertime when the outdoor temperature is high, the reduction effect of indoor air contamination materials could be large since it is less influenced by the adsorption effect if the bake-out work can be performed together with ventilation (Kang, 2005). However in the wintertime when the outdoor temperature is low, the amount of ventilation should be reduced to securing the indoor temperature, this lack of ventilation can result in the rise of indoor air contamination level. When move-in without performing the bake-out work in the winter and operating boiler, much of hazardous materials can be discharged into the indoor environment as the temperature gets higher than that prior to move-in and this can cause the adsorption effect due to the insufficient ventilation. Since the heating method in Korea uses the "Ondol (Korean underfloor heating system)" unlike other countries, some effect can be obtained if ventilation is made by opening windows even in the wintertime when the outdoor temperature is low. If future studies can be performed for the relationships between the adsorption/desorption effect and ventilation during the time of bake-out as well as for the discharges of hazardous substances from building materials, finishing materials and furniture, it is judged that the efficient measures of bake-out can be established.

CONCLUSION

The concentration level of formaldehyde has appeared exceeding the recommended level of newly built apartments and the concentration level of TVOCs has exceeded the recommended level of the administration law for the indoor air quality of crowded facilities. The concentration level of indoor air contamination materials could be reduced from the re-desorption of hazardous materials through a sufficient duration of ventilation although bake-out has raised the concentration level of indoor air contamination materials by the adsorption effect for a short period of time. The bake-out work accompanied with ventilation for the control of indoor air quality when move-in during the wintertime could reduce the hazardous substances of floor finishing materials.

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