COMPARISON OF VENTILATION STRATEGIES DURING BAKE-OUT IN WINTER AT NEWLY BUILT APARTMENT BUILDINGS

E. Y. Park[1], D. H. Kang[1], D. H. Choi[1], S. M. Lee[2], Y. S. Min[2], J. H. An[2], M. S. Yeo[3], and K. W. Kim[3†]

[1]*Department of Architecture, Graduate School of Seoul National University, Korea*
[2]*Institute of Construction Technology, Samsung Engineering &Construction, Korea*
[3]*Department of Architecture, College of Eng., Seoul National University, Korea*

ABSTRACT

To reduce the concentration of volatile organic compounds (VOCs) and formaldehyde emitted from building materials and furnishings, it has been suggested that new buildings undergo a bake-out. According to the existing studies [3, 4], ventilation during a bake-out is believed to be essential for reducing the concentration of indoor air pollutants. For a practical use of bake-out, several ventilation strategies such as natural and mechanical ventilation can be considered. The aim of this study is to compare the effect of decreasing the concentration of indoor air pollutants according to ventilation strategies during a bake-out. For this purpose, four experimental cases were tested under different ventilation and heating conditions in a newly built apartment building using a radiant floor heating system in Korea. Among four experimental cases, unit 1 was reference, unit 2 was baked out without ventilation, unit 3 was baked out with natural and mechanical ventilation (opening windows and operating exhaust fans in kitchen and bathrooms), and unit 4 was baked out with natural ventilation (opening windows). The experimental results show that reduction rate of the concentration of indoor air pollutants in unit 3 baked out with natural and mechanical ventilation is the highest among the test units.

KEYWORDS

Indoor air quality, Bake-out, Ventilation, Newly built apartment buildings, Volatile organic compounds (VOCs), Formaldehyde

INTRODUCTION

Recently, the problem of indoor air quality in newly built apartment buildings has become a major concern in Korea. To resolve this problem, the Indoor Air Quality Management Act [1], a regulation concerning the permissible concentration of formaldehyde and 5 volatile organic compounds (VOC) in newly built apartment buildings have been enforced by the Ministry of Environment of Korea since May 30, 2004. According to this act, apartment building construction companies must measure the concentration levels of 6 toxic substances and provide public notification before residents move in. To meet the requirements of the government regulations, using source control strategies, such as using low-emission building materials, is widely practiced. After using low emission materials, most of the apartments have satisfied the regulation. However, the concentration of indoor air pollutants is often higher than the regulation allows because of high outdoor temperature as occur in summer. Therefore, employing a building bake-out by one of the follow-up measures is required to meet the regulations after the construction of the apartment buildings.

Of course, in winter outdoor and indoor temperature are lower, and the concentration of indoor air

† Corresponding Author: *Tel: + 82-2-880-7066, Fax: + 82-2-885-8057*
E-mail address: snukkw@snu.ac.kr

pollutants is lower than the regulated limit. However, after moving into the new buildings, the occupants start using the heating system, so the concentration of indoor air pollutants increases and a building bake-out is also required for the sake of the occupants' health.

Studies on bake-out effect that reduces emission rate of building materials' pollutants or concentration of indoor air pollutants have been ongoing. Girman et al. (1989) conducted a bake-out experiment at temperature between 29~32℃ for 24 hours in an office building. In their results, different reduction rates were found for each VOC after the bake-out. Thus, they noted that firm conclusions of the bake-out effect for decreasing concentrations of indoor air pollutants cannot be drawn clearly and further bake-out studies of several buildings must be conducted under varying temperature conditions and ventilation rates [2]. J Li et al. (2005) successfully decreased the concentration of formaldehyde and VOCs after a bake-out with intermittent ventilation in a chamber test [3]. Kang et al. (2006) conducted a bake-out of a residential building to evaluate the appropriate point of time to ventilate and the effect of ventilation on bake-out. It was found that ventilation during bake-out is essential to ensuring that bake-out effectively decreases levels of VOCs and formaldehyde [4]. When the preceding studies were considered, Based on these previous studies, it can be assumed that ventilation must be conducted during the bake-out to maximize the decrease of indoor air pollutants. Also, it is necessary to ventilate consistently when the bake-out is conducted.

Most of the apartment buildings in Korea mainly use natural ventilation with opening windows and also are installed exhaust fans in kitchens and bathrooms. So, in the present study the room temperature of the test units was lower than the designated temperature for the bake-out during the bake-out with ventilation, because of low outdoor temperature in winter. Thus, it is questionable whether ventilating while the designated temperature is falling is adequate for effective bake-out or whether maintaining the temperature without ventilation is sufficient. On the other hand, the rate of airflow fluctuates during natural ventilation. Thus, it is necessary to draw up plans for consistent ventilation and follow them during the bake-out.

The objective of this study is to compare the effect of reducing concentration of the indoor air pollutants according to ventilation strategies during bake-out. Toward this end, a field study was conducted in a newly built apartment building using the radiant floor heating system without ventilation, which is standard for residential apartments in Korea. The bake-out study was conducted with ventilation and without ventilation on various test units, and the results in each unit were compared. Also, the units with significant airflow fluctuations due to natural ventilation were compared with the units with relatively consistent airflows due to either natural ventilation or exhaust fans.

MEATHOD OF EXPERIMENT

Description of test housing units

A field study was conducted on a residential building under different ventilation and heating conditions to compare the reduction effect of the indoor air pollutants. Units comprising an area of 135m^2 finished with the same materials were selected from the newly built apartment buildings located in Seoul, Korea. A radiant floor heating system was installed and a mechanical ventilation system was not used, but exhaust fans were installed in the kitchen and bathrooms. As shown in the floor plan of the unit in Figure 1, all of the rooms could be ventilated by natural means, i.e. by opening windows and doors.

To keep uniform and consistent ventilation during the bake-out, the air was supplied by opening windows into the test units and was exhausted outside by mechanical fans. At this point, windows opened slightly (about 5 cm) and in the opposite direction; if balcony windows were opened on the left,

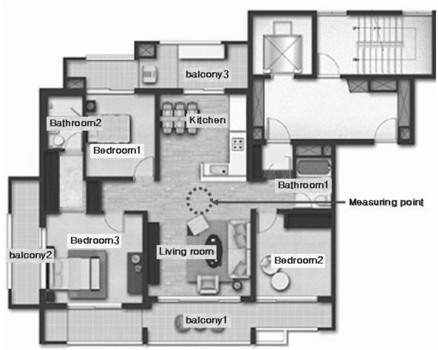


Figure 1 Floor plan of the unit & measuring point

a) b) c)

Figure 2 Preparations for experiment a) opening doors of the furniture, b) shade on the balcony windows c) preparations for the sampling

living room windows facing the balcony windows were opened on the right to prevent from influencing the ventilation rate due to fluctuating wind pressure. During the test, doors of the furniture were always opened (Figure 2(a)). Shade sheets were installed in the south balcony windows to remove differences of indoor temperature among the test units from solar radiation (Figure. 2(b)). The shade sheets were made of aluminum and the aluminum sheets did not emit pollutants, which did not affect the results of the test. The measuring point was centered horizontally and vertically in the test unit, in other words; the concentrations were measured in the middle of the living room (Figure 2(c)).

Test schedule

The measurements were taken according to official testing method enforced in the Indoor Air Quality Management Act (hereafter referred to as the "IAQ Act") [1] released by the Korea Ministry of Environment (Jan.12～Feb.7, 2007). The test conditions were divided into 4 cases as shown in Figure 2 and Table 1. Unit 1 was the reference unit, and bake-out and ventilation were not conducted. Units 2, 3, and 4 were baked out for 10 days at 30℃. There was no ventilation during the bake-out in unit 2. Unit 3 was ventilated by opening windows and operating fans simultaneously, and unit 4 was ventilated only by opening windows. Right after the bake-out, all the test units were ventilated with entirely opening windows for one day to cool structures of the test units and remove indoor air pollutants that were emitted from building materials. Then, the room temperature of all the test units was controlled at 22℃ because the room temperature should be maintained above 20℃ during measurements according to official testing method and further ventilation was not conducted. Measurements of the concentration of

Table 1 Bake-out and ventilation procedure and environment conditions

Test unit	Test condition	Room temperature and air change rate conditions	
		During bake-out	After bake-out
Unit 1	No bake-out without ventilation	Room temperature: 15℃	Room temperature: 22℃
		Shut tightly	
Unit 2	Bake-out, no ventilation	Room temperature: 30℃	
		Shut tightly	
Unit 3	Bake-out, ventilation	Room temperature: 30℃	
		Opening windows and operating exhaust fans in kitchen and bathroom	
Unit 4	Bake-out, ventilation	Room temperature: 30℃	
		Opening windows	

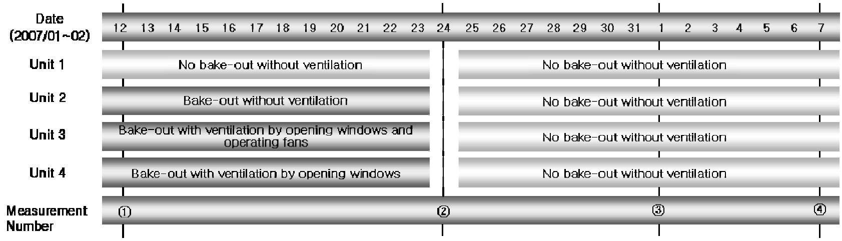


Figure 3 Measurements schedule according to bake-out conditions

VOCs and formaldehyde were taken four times under nearly identical temperature and ventilation conditions: a measurement before bake-out and three times after bake-out.

Measurement and analysis method

Formaldehyde was collected using DNPH cartridges. Thirty (30) liters of air samples were taken for 30 minutes, and the samples were analyzed using HPLC. VOCs were collected using Tenax TA tubes. Three (3) liters of air samples were taken for 30 minutes, and the samples were analyzed using thermal desorber and GC-MS. Various VOCs were identified—toluene, ethylbenzene, xylene, and styrene—and total volatile organic compound (TVOC) levels were analyzed along with measuring the relative humidity and temperature in each unit.

RESULTS AND DISCUSSION

Environmental condition

Each of the room temperatures and the relative humidity during all measurement periods were plotted in Figure 4. The temperature of unit 1 remained at 18℃, during the bake-out in the other units. The temperature in unit 2, baked out without ventilation, reached 30℃. The room temperature of unit 3 ranged between 22℃ and 24℃ with relative humidity as low as 35% because of opening windows for ventilation due to low outdoor air temperature. The temperature in unit 4 remained between 22℃ and 26℃. After the bake-out, the temperature of all of the test units was controlled at 22℃, and the temperature was maintained at 22℃ with a relative humidity of 32%.

In comparing the temperatures of units 3 and 4 prior to and during the bake-out, it was noted that the temperature in unit 4 changed frequently. Therefore, it was concluded that opening windows for

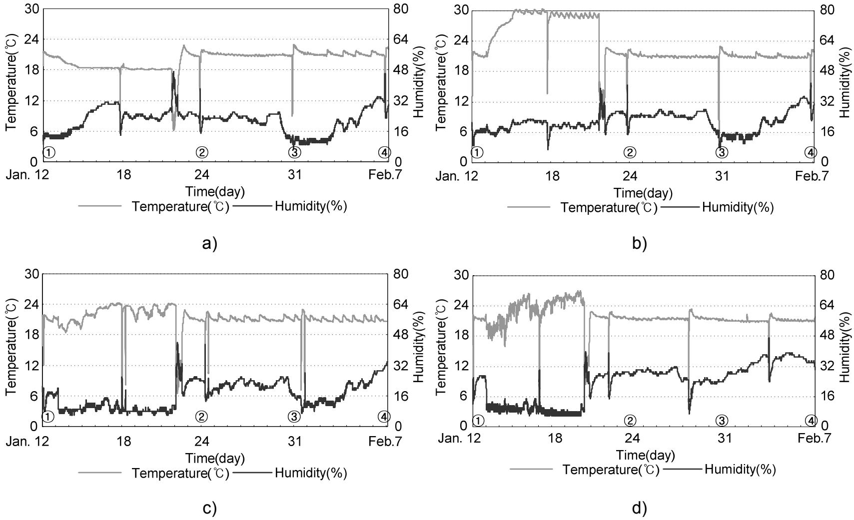


Figure 4 Indoor air temperature and humidity profile a) unit 1, b) unit 2, c) unit 3, d) unit 4

ventilation can frequently change the ventilation rate.

Variation of pollutants concentration

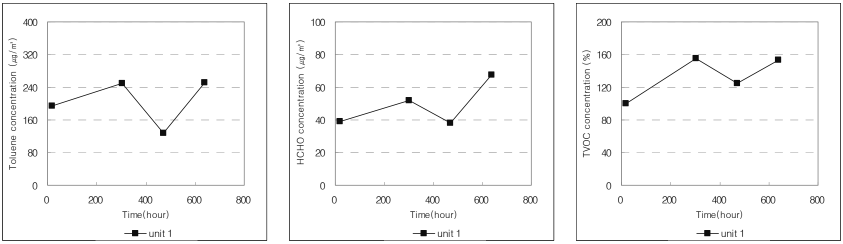
Concentration variances for unit 1 (no bake-out, no ventilation) did not show normal aging and subsequent decay. For example, the concentrations of formaldehyde and TVOC, except for that of toluene, increased during all measurement periods. It was concluded that the concentrations were only affected by environmental conditions, such as infiltration, humidity, and temperature, during each measurement period (Figure. 5).

The designated temperature of unit 2 (bake-out, no ventilation) was maintained at 30℃, as there was no ventilation to allow for permeation of the low outdoor temperatures of winter. Unit 2 maintained the highest room temperature among the test units, but the concentration of toluene and formaldehyde increased after the bake-out (Figure 6). It was concluded that since the concentration of indoor air pollutants was increasing during the bake-out, high concentrations of indoor air pollutants could prevent emissions of VOCs and formaldehyde from building materials if ventilation is not conducted during the bake-out. Further, it was also concluded that when the room temperature falls after the bake-out, pollutants could be emitted from the building materials rapidly, and the concentration of indoor air pollutants could increase.

The temperature in unit 3 (bake-out, natural and mechanical ventilation) was maintained at 25℃, lower than the designated bake-out temperature of 30℃ because of ventilation. As shown in Figure. 7, in unit 3 the reduction rate of the formaldehyde, toluene, and TVOC concentrations was much higher compared to the initial concentration. Most significantly, the concentration of toluene decreased to 69% of the former concentration within 7 days after the bake-out ended. It was concluded that the decrease in concentration occurred because ventilation plays a role in decreasing the concentration of indoor air pollutants and promoting VOCs and formaldehyde emissions of building materials, even if the designated temperature for bake-out is not maintained.

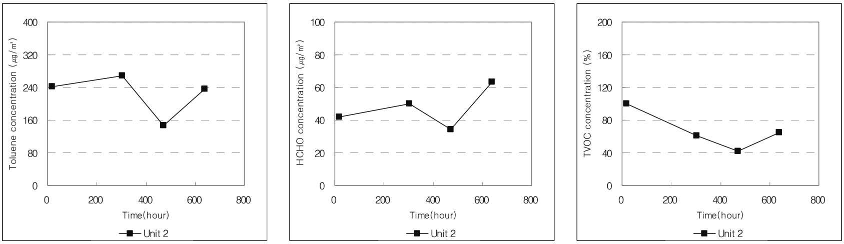
The results from unit 4 (bake-out, natural ventilation) differ from those of units 2 and 3 as the concentration level of formaldehyde and toluene, except for TVOC, did not decline significantly. In addition, the concentration of formaldehyde after the bake-out was notably higher than it was originally.

For example, the toluene concentration of unit 4 decreased to 21%, 11% of the initial concentration at 7



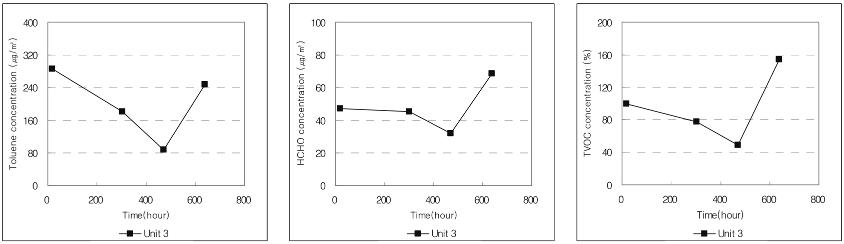
a) b) c)

Figure 5 Concentrations of unit 1 a) toluene b) formaldehyde c) TVOC



a) b) c)

Figure 6 Concentrations of unit 2 a) toluene b) formaldehyde c) TVOC



a) b) c)

Figure 7 Concentrations of unit 3 a) toluene b) formaldehyde c) TVOC

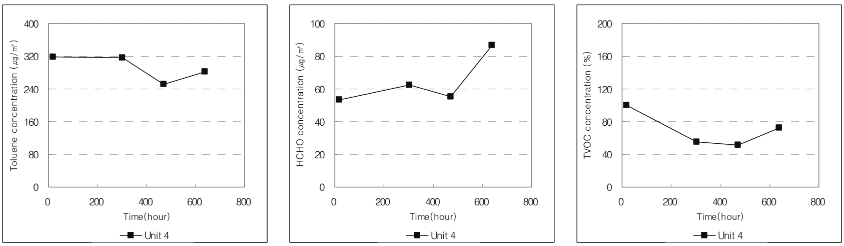
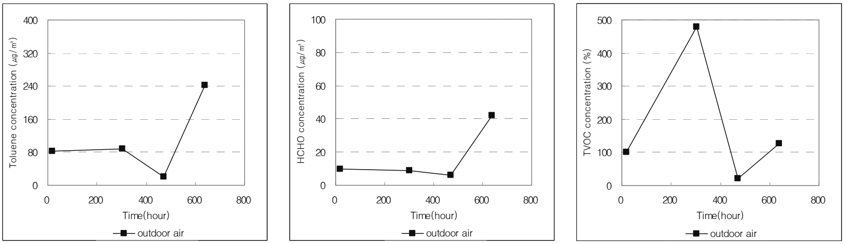


Figure 8 Concentrations of unit 4 a) toluene b) formaldehyde c) TVOC



a) b) c)

Figure 9 Concentrations of outdoor air a) toluene b) formaldehyde c) TVOC

days, 14 days after the bake-out ended, but formaldehyde concentration, at 14 days after the bake-out ended, increased to 63% of the initial concentration (Figure 8). This shows that indoor air pollutants were not exhausted outside enough because of changing ventilation rate.

Figure 9 shows the concentration of outdoor air pollutants. At the end of the test, the concentration of outdoor air pollutants increased sharply. It is believed that the concentration of each test unit must have been affected, and the concentration of all test units would have increased sharply at the end of the test (Figure 9).

In comparing unit 2 (bake-out, no ventilation) and unit 3 (bake-out, ventilation), it can be deduced that if ventilation is not conducted during the bake-out, there is little reduction effect on the levels of indoor air pollutants despite maintaining the bake-out temperature. On the other hand, if ventilation is provided during the bake-out, though the room temperature is lower than the bake-out temperature, there is a reduction on the level of indoor air pollutants. Therefore, during the bake-out, ventilation is essential for improving indoor air quality because ventilation plays a role in decreasing the concentration of indoor air pollutants, thus allowing the emission rate from building materials to be accelerated.

In comparing unit 3 (bake-out, natural and mechanical ventilation) and unit 4 (bake-out, natural ventilation), it can be observed that the concentration of indoor air pollutants decreased generally in unit 3, while a reduction of indoor air pollutants was not evident in unit 4. These results show that during bake-out, natural ventilation is inadequate in sustaining the required ventilation rate due to frequent changes in air exchange rate. Therefore, it is necessary to provide a uniform and consistent airflow path when ventilation is conducted during bake-out.

CONCLUSIONS

In this study, we measured volatile organic compounds (VOCs) and the formaldehyde concentration of indoor air to compare the effect of decreasing the concentration of indoor air pollutants during bake-out according to ventilation strategies in a newly built apartment building one month prior to occupation.

Unit 2 (bake-out, no ventilation) was maintained the designated temperature for bake-out due to no ventilation, but after the bake-out, the concentration of indoor air pollutants increased. It was concluded that because high concentrations of indoor air pollutants prevent emissions of VOCs and formaldehyde from building materials, pollutants could be emitted from the building materials rapidly when the room temperature falls after the bake-out, and the concentration of indoor air pollutants could increase.

Temperature of unit 3 (bake-out, natural and mechanical ventilation) was lower than the designated bake-out temperature because of the ventilation. However, reduction rate of the concentration of indoor air pollutants was higher compared to reduction rate of unit 2 (bake-out, no ventilation). Thus, it is believed that if consistent and uniform ventilation was conducted during bake out, the concentration of indoor air pollutants could decrease, and emission rate of pollutants from building materials could be more accelerated. For these reason, after the bake-out, the concentration of indoor air pollutants could decrease.

Temperature of unit 4 (bake-out, natural ventilation) was similar to unit 3. However, pattern reducing the concentration of indoor air pollutants differed from unit 3. In spite of ventilating during the bake-out, the concentration of indoor air pollutants in unit 4 increased. This shows that indoor air pollutants were not exhausted outside enough because of changing ventilation rate frequently. Therefore, it is believed that bake-out should be conducted with uniform and consistent ventilation.

In Comparing four cases, reduction rate of the concentration of indoor air pollutants in unit 3 baked out with opening windows and operating exhaust fans was the highest among the unit 1, 2 and 4. Therefore, to maximize reduction rate of concentration of indoor air pollutants after the bake-out, it is necessary that ventilation should be conducted and provide a uniform and consistent airflow path when ventilation is conducted during bake-out.

REFERENCES

1. Korea Ministry of Environment, Indoor air quality management act: revision. 2005.
2. John R. Girman, 1989, The Bake-out of the Office Building : A Case Study, Environment International vol. 15, pp.449~453
3. J. Li, J. Liu, Y. Lu, B. Xie and S. Deng, 2005, Improve of IAQ by a New Bake-out Method Based on Chamber Tests, The 6th Int, Conf. on Indoor Air Quality and Climate, Beijing, China, Indoor Air 2005, pp.3075~3079
4. D. H. Kang, D. H. Choi, S. S. Kim, M. Y. Park, M. S. Yeo and K. W. Kim, 2006, Ventilation Strategies for Effective Bake-out in New Apartment Buildings, Healthy Building 2006, pp. 321~324