

# A 신축아파트 및 B 백화점에서 기계환기에 의한 실내공기질의 개선 효과

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## Effect of Mechanical Ventilation System on Improvement of Indoor Air Quality in A Newly Built Apartment and B Department Store

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### ABSTRACT

본 연구에서는 기계환기에 의한 실내공기질 개선효과를 현장실험을 통해 파악하기 위해 환기설비를 갖춘 A 신축아파트와 다중이용시설인 B 백화점을 연구 대상으로 하였다.

A 신축아파트에서는 새집증후군 등 주요 실내공기오염의 원인물질인 VOCs 및 HCHO를 측정 대상으로 선정하고 미환기 상태에서 16가구에서 전반적인 신축아파트의 실내공기오염 특성을 파악하였으며, 이중 상대적으로 TVOC 농도가 높은 2가구를 대상으로 환기전후의 농도 특성을 파악하였다. B 백화점에서는 CO<sub>2</sub> 및 HCHO를 대상으로 선정하고 1~7층별로 미환기시와 기계환기 1시간 이후의 농도 특성을 통해 환기에 의한 저감율을 파악하였으며, 이후 환기시설 정상가동 상태에서 3년간 실내공기오염물질의 농도 특성을 파악하였다.

미환기 상태에서 A 신축아파트의 VOCs 및 HCHO 농도는 일부 지점에서는 에틸벤젠, 자일렌 등의 농도가 실내환경기준을 초과하고 있었다. 특히 환기전후의 TVOC 농도 특성은 A-1 지점의 경우 미환기시 3,547  $\mu\text{g}/\text{m}^3$ 에서 환기시 961  $\mu\text{g}/\text{m}^3$  그리고 A-2 지점의 경우 미환기시 3,117  $\mu\text{g}/\text{m}^3$ 에서 환기시 594  $\mu\text{g}/\text{m}^3$ 으로 환기에 의해 각각 73%, 81% 저감율이 나타났다. 또한 개별 VOCs 및 HCHO물질별 환기에 의한 저감율은 31.4~96.7%로 나타났으며, 환기이후 모든 물질이 실내기준보다 훨씬 낮은 수준으로 나타났다. B 백화점에서는 평균 CO<sub>2</sub> 농도는 미환기시 855 ppm에서 기계환기 1시간 이후 580 ppm으로 약 32% 저감되었으며, HCHO의 평균농도도 251  $\mu\text{g}/\text{m}^3$ 에서 70.3  $\mu\text{g}/\text{m}^3$ 으로 약 72%의 저감되는 것으로 나타났다. 이후 환기시설 정상가동 상태에서 3년간 실내공기질의 측정결과 지속적으로 실내환경 기준을 만족하였다.

최근 실내공기질 개선을 위해 다양한 개선 방법이 소개되고 있으나, 이중 기계환기는 신축아파트 및 다중이용시설 등에서 실내공기질을 실내환경기준 이하로 지속적이고 쾌적하게 유지할 수 효과적 방법으로 고려된다.

**Key words** : department store, indoor air quality, newly built apartment, ventilation

### 1. Introduction

Since the early 1970s, the energy crisis has brought unexpected problems associated with indoor air. Newly constructed buildings are better insulated and sealed tightly to conserve heat. However, those of structural

conditions have led to inadequate ventilation, thus resulting in poor indoor air quality(IAQ), which will also damage the health of people working and living in the building(Editorial, 2012).

The ventilation is a determinant of indoor air quality in the building, as it serves as the primary

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mechanism for removal of gaseous contaminants generated. So, high concentration of the contaminants accumulated inside is expected at lower ventilation rates with constant emission rates(Hodgson et al., 2000). Therefore, the ventilation for fresh air exchange is essential for occupant health(Drivas et al., 1972; Hodgson et al., 2000; Zhang et al., 2012).

Recently in Korea, it has been emphasized that maintaining high quality of indoor environment is important for health and safety of occupants in the building. Many studies have also reported the importance of IAQ management and ventilation(Shin et al., 2005; Hwang et al., 2006; Ryu et al., 2009; Park, 2010; Lee et al., 2012).

Another issue regarding IAQ is indoor sources. Particularly, the sources environmentally issued are volatile organic compounds(VOCs) and formaldehyde (HCHO) since both sources highly associate with materials used in construction and finishing the interiors of the buildings. Continuous emission of VOCs results in substantial contamination of the indoor air, and such contamination would eventually have negative impacts on the health effects and well-beings of the occupants(Andersson et al., 1997). Offermann(2009) reported that new homes in California that are built with relatively higher air tightness can have lower outdoor air exchange rates, and can often exceed the limit suggested by a guideline for air contaminants with indoor sources, HCHO and VOCs. Thus, mechanical ventilation systems are needed to provide dependable and continuous supply of outdoor air to new homes as well as to reduce various indoor HCHO sources.

However, the IAQ problems are not limited to new homes. Many commercial buildings such as department store have also struggled with the IAQ due to inappropriate ventilation. For example, the mechanical ventilation systems are not considered when designing some of the buildings(US EPA, 2013).

The main objective of this study is to characterize the IAQ and to compare the IAQ before and after the mechanical ventilation system is applied. Based on the

objective, the study will identify current sources of indoor air contaminants, assess exposure to measured air contaminants, and suggest effective strategies that will enhance the indoor air quality in the building.

## II. Materials and Methods

### 1. Sampling site and air sampling

The study was performed at A newly built apartment(A site) in Pusan and B department store(B site) in Gyeongnam, which a mechanical ventilator is equipped with. The characteristics of the two sites are presented in Table 1.

The A site has pre-heater ventilator with 120 m<sup>3</sup>/h of air capacity and parameters used for chemical analysis are the concentrations of VOCs and HCHO estimated.

Samples of the indoor air were collected from 16 households under non-operation of the mechanical ventilation system. Of them, two households with relatively high TVOC concentration were selected to compare the IAQ concentrations before and after operating the ventilator.

The B site is equipped with total heat recovery ventilator with 15,000 m<sup>3</sup>/h of air capacity at 1~3 floor and 10,300 m<sup>3</sup>/h of air capacity at 4~7 floor separately. CO<sub>2</sub> and HCHO were selected for chemical analysis. Since these compounds are commonly found in indoor environment of the building. Indoor air samples for pre and post ventilation were also collected, respectively for comparison.

The samples for pre ventilation were collected during non-operation of mechanical ventilation system and the samples of post ventilation were collected 1 hour after operating the ventilator.

According to BUILDING ACT in Korea, the recommended ventilation rate “by volume” is 0.7 of air change per hour(ACH) on minimum in apartment house and building(MOLIT, 2013). The ventilation rate calculated for the A site was 0.7 ACH and 1.3 ACH for the B site, respectively.

Methods used for collecting and analyzing the samples followed the general method for indoor air measurement by Ministry of Environment of Korea(MOE, 2010). With this method, VOCs were collected twice on sorbent samplers containing Tenax-TA. The flow rate and volume of the samples were 0.1 L/min and 3 L, respectively. For HCHO, the samples were collected twice in parallel on silica cartridges impregnated with 2,4-DNPH at the flow rate of 1 L/min. Volumes sampled was 30 L. The CO<sub>2</sub> concentrations were measured for one hour using NDIR monitors(Model 8762, TSI, USA). The samplers were placed in the middle of the sampled sites with a height of 1.2~1.5 m above the floor. After sampling, the collected VOCs and HCHO samples were delivered to the laboratory for analysis.

## 2. VOCs and HCHO Analysis

The analysis methods for VOCs and HCHO are described in Table 2. VOCs were quantitatively analyzed by automatic thermal desorption(ATD 400, Perkin Elmer, USA) coupled with gas chromatography/mass spectrometry(Clarus 500, Perkin Elmer, USA), which follow Korean Indoor Air Quality Standard Method.

Target analytes were benzene, toluene, ethylbenzene, xylene, and styrene HCHO extracted with 5 mL of acetonitrile(HPLC grade) from the 2,4-DNPH cartridge was analyzed by high-performance liquid chromatography (Series 200, Perkin Elmer, USA) equipped with an UV diode array detector. The UV spectra of formaldehyde were compared with the respective spectra of standards.

## III. Results

### 1. VOCs and HCHO in the A newly built apartment

The descriptive statistics of VOCs and HCHO concentrations in the 16 households of A newly built apartment is shown in Table 3. The samples were collected from the living room of the sampled in the absence of mechanical ventilation system. Besides, to minimize the impact of outdoor air, windows and doors were required to be closed as much as possible during the measurement time.

The range of TVOC concentration was from 1171.6 to 3546.8  $\mu\text{g}/\text{m}^3$  with 2396.1  $\mu\text{g}/\text{m}^3$  on average. However, maximum concentrations in 4 households exceeded 3,000  $\mu\text{g}/\text{m}^3$ . For comparison, the mean concentration of 733 households by National Institute

**Table 1.** Specifications for the newly built apartment and the department store

|   | Site  | Ventilation equipment  | Measurements           |
|---|---|--|------------------------|
| A | Newly Built Apartment<br>(Area 76 m <sup>2</sup> , Volume: 175 m <sup>3</sup> , User: - )                             | Pre-heater ventilator<br>(Air capacity : 120 m <sup>3</sup> /h)  | VOCs, HCHO             |
| B | Department Store<br>(Business area : 27,372 m <sup>2</sup> ,<br>Volume: 114,962 m <sup>3</sup> , User: 4,500 persons) | Total heat recovery ventilator<br>(Air capacity : 1~3F 15,000 m <sup>3</sup> /h × 3ea,<br>4~7F 10,300 m <sup>3</sup> /h × 4ea) | CO <sub>2</sub> , HCHO |

**Table 2.** Analysis conditions of VOCs and HCHO

| Compounds | Sampling method    | Analysis system  |
|-----------|--------------------|--|
| VOCs      | Tenax TA Tube      | Thermal desorption apparatus (ATD 400, Perkin Elmer)<br>Oven temp. 320°C / Desorb flow 30 mL/min, 10 min /<br>Trap high temp. 320°C / Trap low temp. -30°C<br>GC/MS system (Clarus 500, Perkin Elmer)<br>Column Elite-1(60m, 0.32mm, 1 $\mu\text{m}$ ) / Carrier gas Helium /<br>Flow 1.0 mL/min / Final temp. 40°C→ 8°C→ 200°C /<br>MS ion source temp. 230°C |
| HCHO      | 2,4-DNPH Cartridge | HPLC (Series 200, Perkin Elmer)<br>Detector UV/vis. 360 nm / Column C18 reverses<br>Mobile phase Acetonitrile / Flow 1.0 mL/min  |

**Table 3.** Concentrations of VOCs and HCHO in the 16 households of A newly built apartment

| Compounds    | MOE standard ( $\mu\text{g}/\text{m}^3$ ) | Concentration ( $\mu\text{g}/\text{m}^3$ ) in NIER(2005) |                    | Concentration ( $\mu\text{g}/\text{m}^3$ ) in this study |        |
|--------------|---|--|--------------------|--|--------|
|              |   | Mean $\pm$ SD  | Mean $\pm$ SD      | Min~Max  | Median |
| TVOC         | -   | 2646.2 $\pm$ 1992.4                                      | 2396.1 $\pm$ 723.5 | 1171.6~3546.8  | 2404.3 |
| Benzene      | 30  | 8.4 $\pm$ 88.0   | 0.9 $\pm$ 1.1      | 0.0~4.5  | 0.5    |
| Toluene      | 1,000                                     | 1003.0 $\pm$ 746.3                                       | 334.6 $\pm$ 80.6   | 208.6~516.4  | 316.7  |
| Ethylbenzene | 360                                       | 120.0 $\pm$ 129.9  | 204.6 $\pm$ 88.4   | 68.3~411.9   | 183.0  |
| Xylene       | 700                                       | 286.9 $\pm$ 363.2  | 141.5 $\pm$ 181.2  | 30.8~804.7   | 101.5  |
| Styrene      | 300                                       | 63.2 $\pm$ 71.8  | 66.7 $\pm$ 17.1    | 33.3~101.4   | 64.8   |
| HCHO         | 210                                       | 293.1 $\pm$ 238.3  | 31.0 $\pm$ 14.4    | 4.9~58.6   | 27.9   |

of Environmental Research(NIER) in 2005 was 2646.2  $\mu\text{g}/\text{m}^3$ (NIER, 2005).

The mean concentrations of VOCs and HCHO were toluene 334.6  $\mu\text{g}/\text{m}^3$ , ethylbenzene 204.6  $\mu\text{g}/\text{m}^3$ , xylene 141.5  $\mu\text{g}/\text{m}^3$ , styrene 66.7  $\mu\text{g}/\text{m}^3$ , benzene 0.9  $\mu\text{g}/\text{m}^3$  and HCHO 31.0  $\mu\text{g}/\text{m}^3$ , respectively. From these results, it can be considered indoor pollutants are dominated by toluene, followed by ethylbenzene, xylene, styrene, HCHO and benzene.

The mean concentration ratio to MOE standard of benzene, toluene, ethylbenzene, xylene, styrene, and HCHO were 0.03, 0.33, 0.57, 0.20, 0.22, and 0.15, respectively, which means the mean concentrations of VOCs and HCHO measured were lower than the standards. Only one household showed the higher indoor concentration of ethylbenzene and xylene than the standard.

In this study, two sites (A-1, A-2 household) relatively high in TVOC concentration ( $>3,000 \mu\text{g}/\text{m}^3$ ) were selected to find decreasing rate of VOCs and HCHO concentration before(ventilator off) and after(ventilator on) operating the ventilator. The results of the monitored sites are presented in Table 4.

The concentrations of TVOC were decreased from 3,546.8  $\mu\text{g}/\text{m}^3$  to 961.0  $\mu\text{g}/\text{m}^3$  in A-1 site, and from 3117.2  $\mu\text{g}/\text{m}^3$  to 593.7  $\mu\text{g}/\text{m}^3$  in A-2 site by mechanical ventilation. Reduction rates of TVOC by ventilation were 72.9 and 81.0%, respectively.

Before operating the ventilator, ethylbenzene and styrene concentration in A-1 site exceeded the standards; however, concentrations of all VOCs and HCHO after operating the ventilator decreased below the standards and the reduction rates of 5 VOCs and HCHO were from 31.4 to 96.7%. Through the ventilation, the concentrations

**Table 4.** Variations of VOCs and HCHO concentration by ventilation in A-1 and A-2 households of A newly built apartment

| Compounds    | A-1 household                              |                |               | A-2 household                              |                |               |
|--------------|--|----------------|---------------|--|----------------|---------------|
|              | Concentration ( $\mu\text{g}/\text{m}^3$ ) |                | Reduction (%) | Concentration ( $\mu\text{g}/\text{m}^3$ ) |                | Reduction (%) |
|              | Ventilation off                            | Ventilation on |               | Ventilation off                            | Ventilation on |               |
| TVOC         | 3546.8                                     | 961.0          | 72.9          | 3117.2                                     | 593.7          | 81.0          |
| Benzene      | 1.72                                       | 1.18           | 31.4          | 4.47                                       | 1.22           | 72.7          |
| Toluene      | 486.0                                      | 167.2          | 65.6          | 316.7                                      | 138.4          | 56.3          |
| Ethylbenzene | 411.9                                      | 58.8           | 85.7          | 298.4                                      | 42.8           | 85.7          |
| Xylene       | 804.7                                      | 26.6           | 96.7          | 189.7                                      | 14.1           | 92.5          |
| Styrene      | 57.6                                       | 37.9           | 34.2          | 89.4                                       | 44.3           | 50.5          |
| HCHO         | 34.5                                       | 14.7           | 57.4          | 22.7                                       | 13.5           | 40.5          |

of xylene in A-1 and A-2 greatly decreased by 96.7% and 92.5% with the reduction of the concentration of HCHO by more than 40%.

2. CO<sub>2</sub> and HCHO in the B department store

This study was performed at B department store built in 2006. The B department store located in downtown have a business area of 27,372 m<sup>2</sup> and 8 stories high, and often exceeded the IAQ guideline limit in accordance with IAQ Act.

The variation in CO<sub>2</sub> and HCHO concentrations before and after operating the ventilator on every floor(1~7th) is shown in Fig. 1.

The CO<sub>2</sub> concentration under the ventilator off was average 855 ppm with 578~1,131 ppm range. In particular, on 7th floor, the concentration was estimated 1,131 ppm, which exceeds the MOE standard by 1,000 ppm. This may be because the 7th floor is the food court where many people are crowded. After 1 hour of mechanical ventilation, the average reduction of CO<sub>2</sub> concentration was 580 ppm with the range of 516~714 ppm. All floors satisfied the MOE standard for the CO<sub>2</sub> concentration under the ventilation, resulting in the reduction rate of 32.2% on average.

In regard to HCHO, building materials, clothing, furniture stores as well as inefficient ventilation can generate HCHO in the department store(Kim, 2010). Before the ventilator was on, the HCHO concentrations were from 153 to 339.2 µg/m<sup>3</sup>. However, the level of HCHO for post ventilation decreased to 33.3~139.7 ppm,

which met the standards in all sites except the ground-floor. The reduction rate of HCHO was average 72.0%(251.0→70.3 µg/m<sup>3</sup>) by ventilation.

Table 5 illustrates how effective the ventilation applied to the department is in maintaining the satisfied level of IAQ for 3 years. The mean values of 4 compounds(PM10, CO<sub>2</sub>, HCHO and CO) all satisfied the standard. The concentrations of HCHO were 47.0~84.7 µg/m<sup>3</sup> range, which were all acceptable.

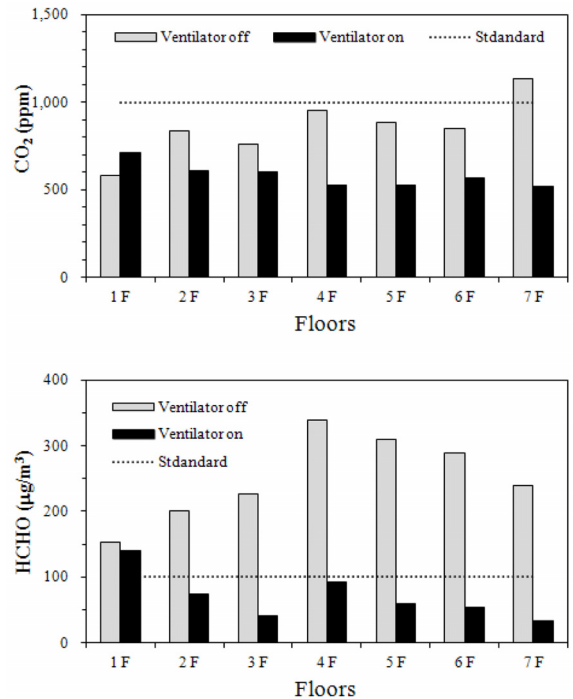


Figure 1. Variations of CO<sub>2</sub> and HCHO concentration by ventilation in B department store

Table 5. IAQ concentration for the last 3 years in B department store

| Compounds                 | Standard | 2010. 6. 15 |      |      | 2011. 6. 3 |      |      | 2012. 6. 29 |      |      | Ave.      |
|---------------------------|----------|-------------|------|------|------------|------|------|-------------|------|------|-----------|
|                           |          | 3F          | 4F   | 6F   | 3F         | 4F   | 6F   | 3F          | 4F   | 6F   |           |
| PM10 (µg/m <sup>3</sup> ) | 150      | 46.0        | 40.5 | 47.9 | 29.2       | 40.7 | 37.5 | 36.0        | 36.5 | 39.8 | 39.3±5.5  |
| CO <sub>2</sub> (ppm)     | 1,000    | 407         | 529  | 473  | 410        | 370  | 476  | 374         | 358  | 351  | 416±63    |
| HCHO (µg/m <sup>3</sup> ) | 100      | 47.0        | 61.8 | 51.6 | 62.8       | 70.8 | 59.0 | 61.1        | 84.7 | 44.8 | 60.4±12.3 |
| CO (ppm)                  | 10       | 0.9         | 0.8  | 0.8  | 1.4        | 1.4  | 1.0  | 1.1         | 1.2  | 1.2  | 1.1±0.2   |

#### IV. Discussion

A majority of materials used in construction of the building generates VOCs and HCHO and emissions of VOCs and HCHO will contaminate indoor air and even possibly threaten the health and well-being of the occupants (Andersson et al., 1997).

In the 16 households in A newly built apartment, the mean concentrations of VOCs and HCHO were measured lower than the MOE standards, whereas the highest concentration of ethylbenzene and styrene were  $411.9 \mu\text{g}/\text{m}^3$  and  $804.7 \mu\text{g}/\text{m}^3$ , which were higher than the standards. In other words, the mean concentrations of VOCs and HCHO acceptable according to IAQ Act(NIER, 2005; Kwak et al., 2006; Lim et al., 2006; Kwon et al., 2009).

When it comes to indoor air quality in newly built apartments, improvement of airtightness and use of the building materials containing harmful chemical substances are the main issues discussed(Choi et al., 2006). Thus, the ventilation that assists air exchange to remove VOCs and HCHO generated is so important(Hodgson et al., 2000).

In comparison to the IAQ concentration that the ventilation was not applied(A-1, A-2 household), the concentration of VOCs and HCHO with the ventilation dropped by 34.2~96.7% and were even less than MOE standard with 1 hour ventilation.

In other words, the mechanical ventilation had remarkable impact on reducing the concentration of VOCs and HCHO. Recently, bake-out in newly built apartments has become a promising strategy that enhances indoor air quality. Lee et al.(2011) reported that the reduction rate of TVOC was approximately 66% by application of bake-out process the newly-built apartments for seven days. However, contradictory evidence has also been arisen, reporting that the bake-out strategy did not work, but rather increased the concentration of TVOC to more than the original one(Girman et al., 1989). Hence, the efficiency of bake-out has yet to be proven domestically and

internationally(Kang et al., 2010; Kim et al., 2010).

In addition, the department store also needs to focus on maintaining the indoor air quality to the levels recommended by MOE, because many people are gathered spending considerable time in this closed environment. So control in indoor quality in the department store should be considered. For instance, some of the department stores are being managed for indoor air quality by a central automated system and IAQ certification system(Good Indoor Air Quality Certification, 2013).

In fact, great amount of the air pollution sources exists in the department store, because such a closed environment is inappropriately ventilated or mechanical ventilation systems in the building do not operate properly enough to bring the fresh air in. Most of all, the concentration of CO<sub>2</sub> that is highly correlated with the quality of the indoor air was chosen as one of parameters determining the indoor air quality in this study.

In B department store, in the condition of ventilator switched off, the concentration on average was estimated above the standard, which was 855 ppm, and on 7th floor, in particular, about 1,000 ppm was more gone over the limit.

This phenomenon can be explained by two possible concepts. One comes from common sense that blockage of gas exchange, CO<sub>2</sub> in this case, due to inadequate ventilation leads to the accumulation of the CO<sub>2</sub> level inside, thus resulting in elevated concentration of CO<sub>2</sub> compared to the outdoor. The other reason could be that a large number of people staying in the department store exhale the CO<sub>2</sub> by breathing and the amount of the CO<sub>2</sub> breathed out from all customers could not be neglected(Persily, 1997).

The level of CO<sub>2</sub> in outdoor is normally not above 350~400 ppm. In other words, insufficient ventilation as well as considerably high numbers of the customers in B department store should be taken into account as major causes to lower the indoor air quality. However, 1 hour operation of the ventilator showed the great reduction of CO<sub>2</sub> level by 32.2% on average as stated in the result.

The concentrations of all floors went to the normal level, which was 1,000 ppm, suggested by MOE by only allowance of the ventilation for 1 hour.

For HCHO, which was also considered as the parameter, MOE set 100  $\mu\text{g}/\text{m}^3$  as the cut off level(MOE,2007). If the concentration is above this level, it can cause serious irritation on eye, nose, and throat as well as lowered airway and pulmonary dysfunction(Sametetal.,1988). With the same condition as used for CO<sub>2</sub> level comparison, the levels of HCHO were compared with. Before the ventilator operated, the concentrations on all floors were reported 1.5 to 3.4 times higher than the standard. However, the ventilation system created the same effect of reduction on HCHO, lowering the level by 72.0% on average.

## V. Conclusions

In this study, the effect of the ventilation on IAQ in two sites was clearly proven. In A newly built apartment, by comparing with 0.7 ACH as the initial result without the ventilation, the TVOC with the ventilation was dropped by 70%. And the reduction rates of VOCs and HCHO were 31.4~96.7% range. In B department store with 1.3 ACH at the initial point, the reduction rates of CO<sub>2</sub> and HCHO by ventilation were 32.2% and 72.0% on average, respectively. From those results, importance of operating the ventilation for enhancing the IAQ was remarkably emphasized.

Limit in using the building materials that induce decrease in IAQ can be the most efficient and effective ways, however application of this into the reality can sometimes hardly be possible, if they are already built on with those materials. Rather, equipment of the mechanical ventilation system to the newly constructed buildings should be emphasized and recommended to improve IAQ.

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