CFD analysis of the optimal installation location of adsorption material in two ventilation conditions in residential buildings: natural convection and mechanical ventilation

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ABSTRACT

Recently, many studies have focused on the adsorption of pollutants as a method for improving indoor air quality. In Korea, the Health-Friendly Housing Construction Standards specify requirements for the installation of pollutant-absorbing materials. It is recommended that at least 10% of the total area of the living room and bedroom walls be covered. However, current guidelines regarding the installation locations of the adsorption material are unclear.

The purpose of this study is to analyse (using CFD simulation) the optimal installation location of adsorption material under two ventilation conditions: natural convection and mechanical ventilation in residential buildings. A dressing room and bedroom were set up as representative spaces for the two conditions. In each space, the adsorptive effect was quantitatively analyzed by comparing the case in which the adsorption material was not installed with the case where in which adsorption material was installed on either the wall or the ceiling. The pollutant to be absorbed was set to toluene according to the Korean standard, and the adsorptive effect was evaluated by the reduction of toluene concentration per installation area. Our results showed that the dressing room showed the best adsorptive effect when the adsorption material was installed on the ceiling, which reduced the breathing zone toluene concentration by about 47%. We surmise that adsorption increased due to the pollutant's tendency to rise in response to the buoyancy caused by the heat load generated by the occupant. On the other hand, in the bedroom, the adsorptive effect was the best when the adsorption material was installed on the inlet side wall, which reduced the breathing zone toluene concentration by 21% and the room average toluene concentration by 25%. This result is likely due to the close proximity between the occupant and the adsorption material and the fast air velocity of the inlet side wall. Therefore, under both natural convection and mechanical ventilation conditions, it is most effective to install the adsorption material where airflow is formed and air circulation is good.

KEYWORDS

Adsorption materials, Installation location, Toluene, Adsorptive Phenomenon, CFD

1 INTRODUCTION

As people's interest in health has increased, indoor air quality management has received greater emphasis. Indoor air quality has to be carefully managed because poor air quality can adversely affect the health of occupants, potentially causing such conditions as Sick Building Syndrome (SBS) and Multi-chemical Sensitivity (MCS) (Meggs, 1997). Recently, the use of pollutant adsorption materials has attracted attention as a potential strategy to help control and manage indoor air quality. In Korea, the use of adsoprtion materials is included as a recommended standard in the 2013 "Health-Friendly Housing Construction Standards," and related materials are being actively developed (S. Kim, 2015). However, while the development of adsorption materials is ongoing, the research and construction criteria pertaining to the application of these materials remain inadequate. In Korea, only the Health-Friendly Housing Construction Standards propose construction criteria for the application of adsorption materials, suggesting, for example, a minimum installation area of 10% of the living room and bedroom walls. However, they do not provide clear guidelines as to the optimal installation location. Actual architectural spaces can be wide and complicated, so even if the same material is applied to the same area, performance can vary greatly depending on the installation location. Therefore, in order to realize the efficient and uniform performance of these materials, it is necessary to investigate adsorptive performance according to installation location and to determine which installation locations are optimal. To that ends, this study aims to examine the proper installation location of pollutant adsorption materials in an apartment building using Computational Fluid Dynamics (CFD) simulation.

2 METHODS

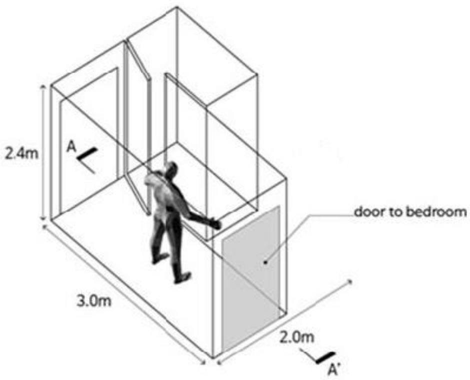
Typical ventilation conditions in residential apartment buildings can be divided into two categories: natural convection conditions and mechanical ventilation conditions.

In natural convection conditions, only buoyancy is ventilated, and there are no additional ventilation systems. In an apartment building, dressing room is typically ventilated using natural convection. Under mechanical ventilation conditions, a mechanical ventilation facility exists through which a certain amount of mechanical ventilation is accomplished. In Korea, it is obligatory to install ventilation facilities so that new apartment buildings can be ventilated 0.5 times per hour. Therefore, most spaces such as living rooms and bedrooms are under mechanical ventilation conditions.

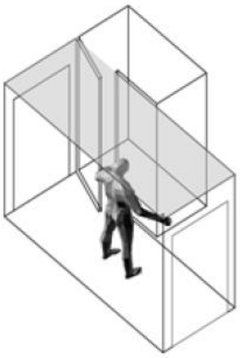
In this study, the dressing room was set as the representative space for natural convection conditions, while the bedroom was set as the representative space for mechanical ventilation conditions. Each case was then classified according to the location of the adsorption material in the representative space, and the adsorptive effect was calculated for each case using CFD. Finally, based on this, we worked to determine the optimal location of adsorption materials according to the ventilation conditions in apartment buildings.

2.1 Natural convection conditions

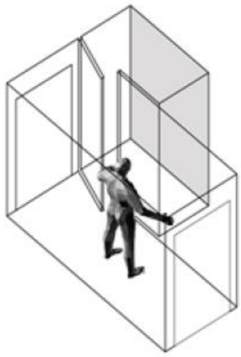
The dressing room set as the target space is the most common flat type (J. H. Kim, 2011), one of which is connected to the bedroom and the other of which is connected to the bathroom. As shown in Figure 1, we examined three potential installation locations for the adsorption material: the ceiling, the outside of the built-in cabinet, and the inside cabinet. Therefore, the toluene concentration in the breathing region was calculated when the baseline model (Case 1 - 0) without the adsorption material was installed at each location and compared with the current Korean standard. In addition, the reduction of the toluene concentration in the breathing zone per installed area was evaluated.



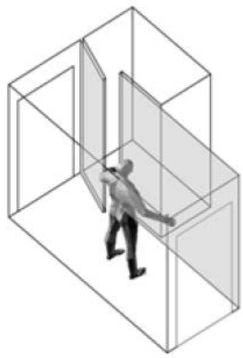
(a) Case 1-0 (Baseline model)



(b) Case 1-1



(c) Case 1-2



(d) Case 1-3

Figure 1: Simulation cases according to location of adsorption materials in dressing room

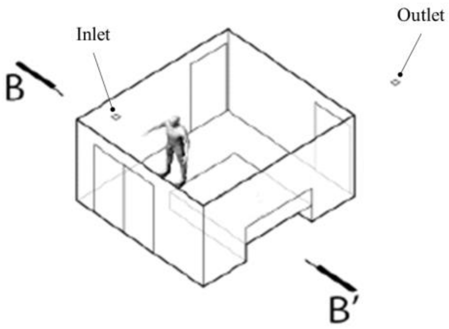
The pollutant in the target space was set as toluene according to the Korean standards. Toluene is a typical volatile organic compound (VOC) released from interior finishing materials (Missia, Demetriou, Michael, Tolis, & Bartzis, 2010). The amount of toluene generated was set to four times the current Korean Healthy Building (HB) material certification standards, based on previous research (Jang et al., 2005). The initial concentration was the concentration of toluene from the adjacent bedroom, which was determined using the average of experimental data from fifteen previous studies (D. Kim, Kim, Kim, Lee, & Kim, 2015). For the CFD simulation, toluene was assumed to be a passive scalar, and the adsorption surface was analyzed under the condition of a surface concentration of 0 (Seo, 2008) (Park, Seo, & Kim, 2015). In addition, we assumed that human body which is a kind of heat source is placed in the center of the dressing room. Table 1 shows the analysis conditions.

Table 1: CFD boundary conditions for the dressing room

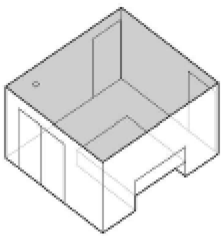
	Values
Toluene emission rate	0.32 ㎎/㎡ h
Initial toluene concentration	185.53 ㎍/㎥
Heat source	55.0W (Human, Sensible heat)
Wall temperature	24℃
Turbulence model	Realizable k-ε turbulence model

2.2 Mechanical ventilation conditions

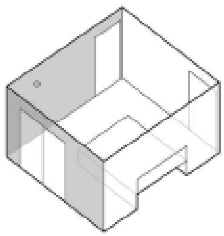
There is an inlet and an outlet in the bedroom, and one full unit of mechanical ventilation is performed every two hours. In addition, we assume that the human body is standing next to the bed. As shown in Figure. 2, there are four cases under investigation; a case without adsorption material, a case in which the material is installed on the ceiling, a case in which the material is installed on the inlet side wall, and case in which the material is installed on the outlet side wall. The reduction of toluene concentration in the breathing zone and the reduction of the average toluene concentration per installation area were evaluated in relation to the baseline model (Case 2-0). The installation area of the adsorption material was set at 10% of the wall area of the bedroom in accordance with the recommended standards in Korea.



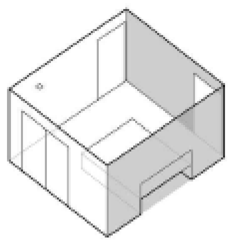
(a) Case 2-0(Baseline model)



(b) Case 2-1



(c) Case 2-2



(d) Case 2-3

Figure 2: Simulation cases according to location of adsorption material in bedroom

Toluene was assumed to be emitted from the ceiling, walls, floor, and furniture. The toluene emission rate was set at 0.08 mg / m^2 h, which is equivalent to the standard of a newly built apartment house according to HB certification standards. Other techniques for analyzing the generation and adsorption of toluene were the same as those used for the dressing room case. Table 2 shows the analysis conditions.

Table 2: CFD boundary conditions for the bedroom

	Values
Toluene emission rate (Ceiling, wallpaper, flooring, furniture)	0.08 mg/m^2 h
Heat source	55.0W (human, sensible heat)
Supply air temperature	20℃
Ventilation rate	0.5 ACH

Turbulence model	Realizable k-ε turbulence model

3 RESULTS

3.1 Natural convection conditions

Figure 3 shows case-by-case results of our analysis of toluene concentration distribution according to the installation location of the adsorption material (section A-A '). We can confirm that the toluene concentration in the region adjacent to the adsorption material is low. Figure 4 (a) shows the breathing zone toluene concentration by case. The baseline model exhibited a toluene concentration of 1,111 $\mu g/m^3$. was is more than the 1,000 $\mu g/m^3$ limit set by the indoor air quality (IAQ) standards in Korea. On the other hand, when the adsorption material was installed, the concentration toluene concentration was reduced to relative to the reference concentration. Figure 4 (b) shows that the reduction in toluene concentration per area was the largest in Case 1-1. In this case, the toluene concentration in the breathing zone was reduced by about 47%. We infer that that this is due to air flow being directed upward due to the presence of human body heat and thus promoting the performance of the adsorption material installed on the ceiling.

We therefore conclude that, under natural convection conditions such as those found in a dressing room, it most effective to install adsorption material in the ceiling given the heat generated from the human body.

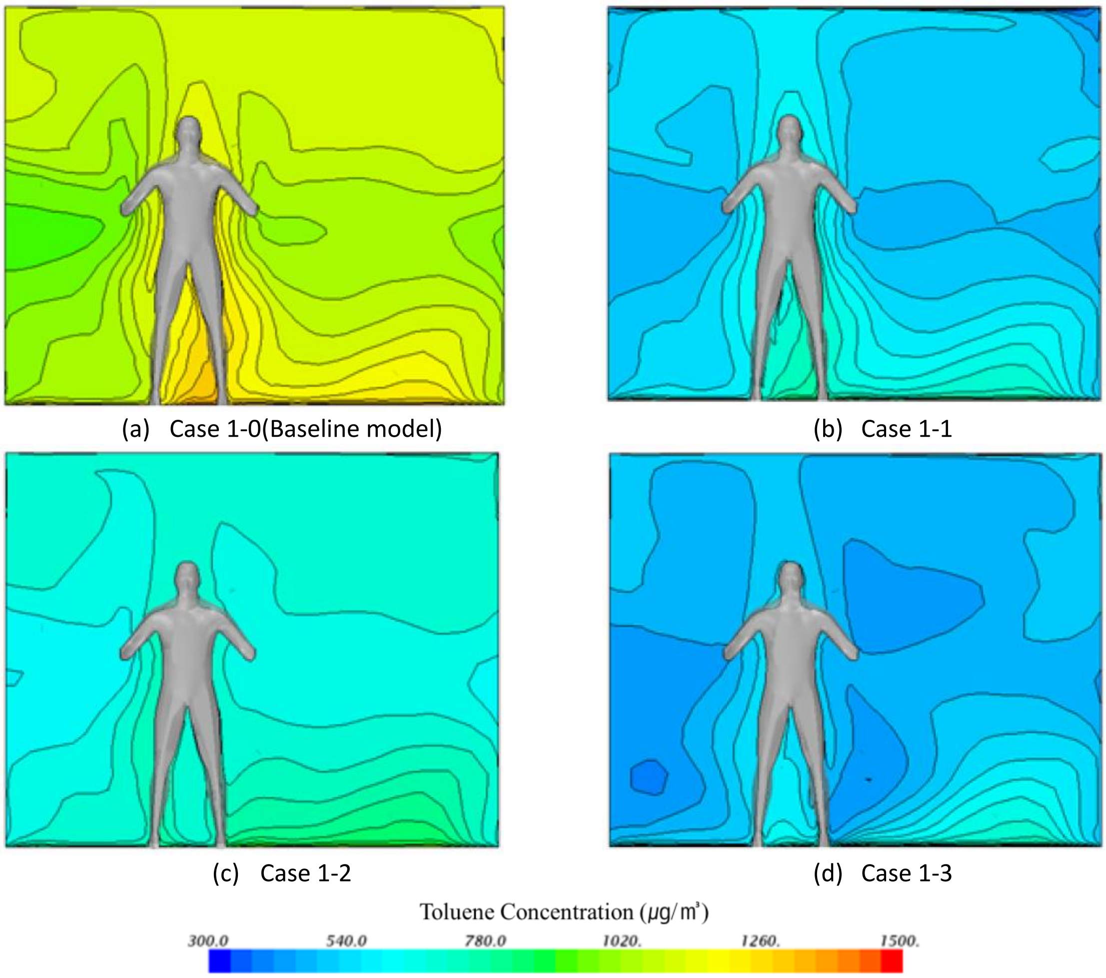
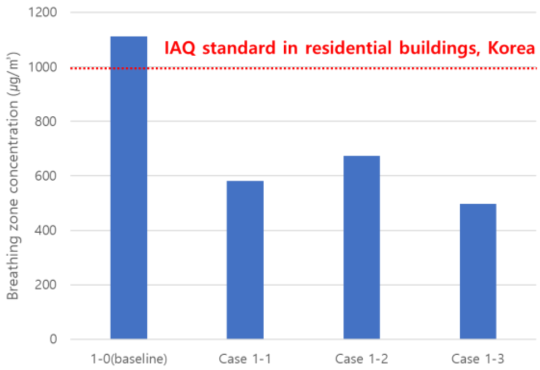
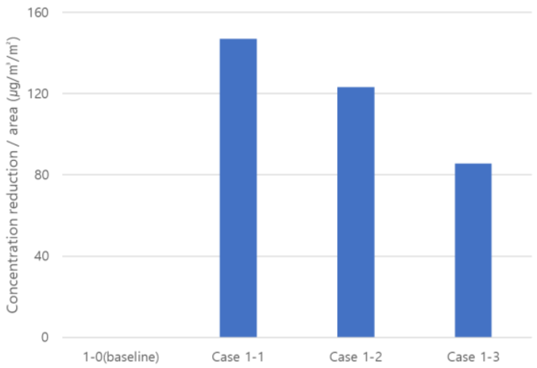


Figure 3: Comparison of toluene concentration distribution by cases in dressing room



(a) Breathing zone toluene concentration



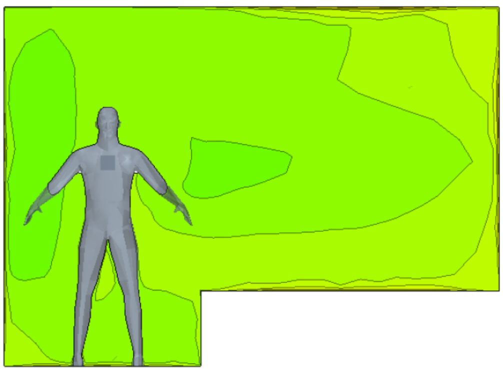
(b) Concentration reduction / installation area

Figure 4: Toluene concentration and concentration reduction by installation area in dressing room

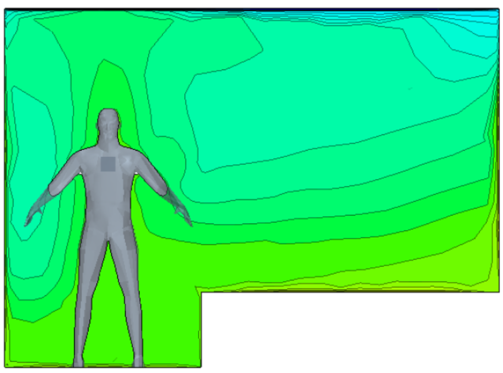
3.2 Mechanical ventilation conditions

Figure 5 shows the toluene concentration distribution for each bedroom case (section CC '). It can be seen that in all cases the toluene concentration is reduced near where the adsorption material is installed. Figure 6 shows the reduction in toluene concentration per installation area. Case 2-2 showed the most marked decrease in toluene concentration in the breathing zone, with a reduction of 21% compared with the baseline model. Case 2-2 also showed the best effect with regard to the average room concentration, showing a reduction of 25% compared with the baseline model. Adsorptive performance as measured by breathing zone concentration was therefore best when the adsorption material was installed close to the breathing zone. On the other hand, with regard to average concentration, it is most effective to install the adsorption material where the air velocity on the surface is fast. We infer that the adsorption rate is largely influenced by the convective mass transfer coefficient of the adsoprtion material surface.

As a result, under mechanical ventilation conditions, we conclude that it is most effective to install the adsorption material on the surface near the area in which the occupant spends the most time or in an area where air circulation is good and the contact between the pollutant and the adsorption material is active.



(a) Case 2-0 (Baseline model)



(b) Case 2-1

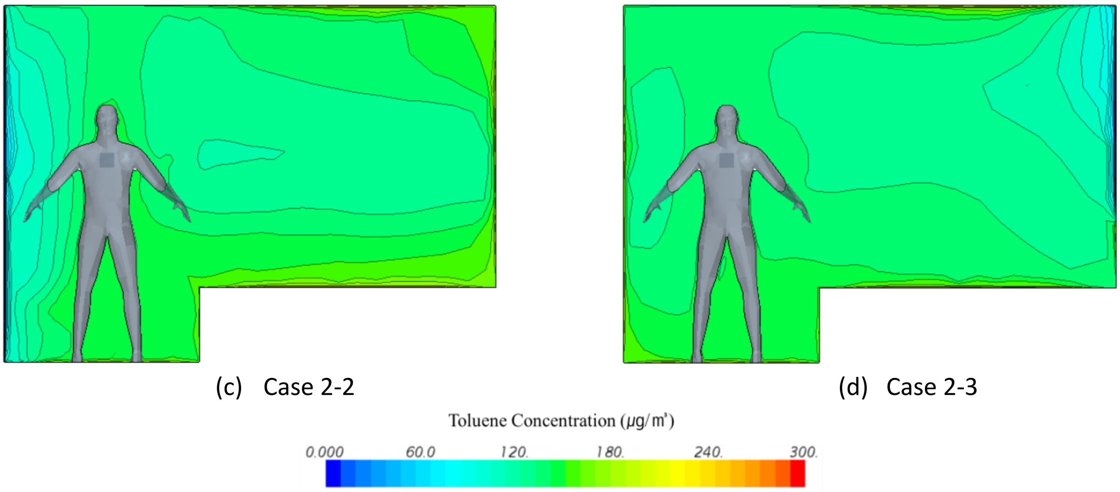
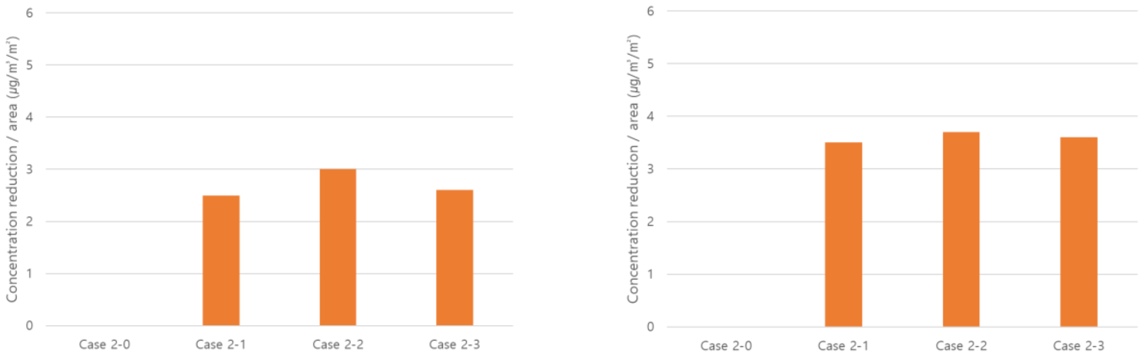


Figure 5: Comparison of toluene concentration distribution by cases in bedroom



(a) Breathing zone toluene concentration reduction / installation area

(b) Room average toluene concentration reduction / installation area

Figure 6: Concentration reduction by installation area in bedroom

4 CONCLUSION

The installation of adsorption material is one strategy to improve indoor air quality. However, clear guidelines on the optimal installation location for adsorption material in architectural space have been lacking, and few studies have broached the topic. In this study, the ventilation conditions in the apartment house were divided into natural convection conditions and mechanical ventilation conditions, and an architectural space representing each condition was selected. Then, various cases were classified according to the location of the adsoprtion material installed in each space, and adsorptive performance was calculated for each case using CFD.

According to our results, it is most effective to install adsorption material in the area of air circulation where the airflow is formed under both natural convection and mechanical ventilation. In addition, it has been shown that adsorption materials placed near where occupants tend to spend the most time are effective in reducing the concentration of toluene in the breathing zone.

In order to realize uniform and efficient performance of adsorption materials, related studies should be actively carried out in the future. Ultimately, clear construction guidelines related to the installation location of adsorption materials are required.

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