

An Analysis of Natural Ventilation and Ventilation load in relation to Occupants' window opening Behaviour in residential Building

Jihyun Yoo¹, Soonchan Kim², Liu Qi², Seungwoo Choi², Jaeyun Bae², and Junseok Park^{3*}

¹Ph.D. Candidate, Hanyang University, Department of Architectural Engineering, Seoul, Korea

²Master's Course, Hanyang University, Department of Architectural Engineering, Seoul, Korea

³Professor, Hanyang University, Department of Architectural Engineering, Seoul, Korea

Abstract. For reducing the energy consumption in buildings, each country strengthened the standard of insulation without the standard of ventilation. However, because of it, sick building syndrome has occurred. Accordingly, the importance of ventilation in building has been increased to reduce the polluted indoor air and promote the better Indoor Air Quality. The previous study has only focused on the window opening behaviour and developed the machine learning algorithm of window opening. However, it is the ventilation rates that affects Indoor Air Quality. Therefore, in this study, the ventilation rates was derived from carbon dioxide decay method. From this ventilation behaviour, occupants are not only controlling their indoor environment, but also making the ventilation load in their building.

1 Introduction

From International Energy Agency research, building energy consumption was 40% of the total energy consumption. The energy consumption in building is affected by their occupants. Among this occupant behaviours, ventilation (window opening and mechanical ventilation) is widely used to provide thermal comfort in indoor environment [1]. Focusing on window opening behaviour, window opening algorithms has been developed [2-3]. Window opening not only makes better indoor air quality, but also affects the energy consumption due to ventilation load [4]. However, research on physical performance has progressed, but research on energy that affected by their occupants is relatively unnoticed [5]. Therefore, if these occupant behaviours are noticed and embedding in energy simulation program, it will contribute to predicting precise energy consumption. Therefore, in this study, the ventilation rates using carbon dioxide decay method was analysed. From this ventilation behaviour, the ventilation load was also analysed.

2 Methods

2.1 Samples

Thirty occupied housing unit was selected from four complexes. Complex A,B,D were located on Suwon City, which is suburban area of Seoul, and Complex C is located on Seoul City. The samples of complex A,B,C were measured 2014-12-01 to 2015-09-30, and the samples of Complex D were measured 2017-12-01 to

2017-03-15. The characteristics of samples are shown in Table 1.

Table 1. characteristics of samples

Complex	The number of samples	Floor Area [m ²]	Measurement period
A	6	109-172	2014-12-01
B	9	137-163	- 2015-09-30
C	8	72-163	2017-12-01
D	7	72-163	- 2017-03-15

2.2 Measurement

The parameter and each device are shown in Table 2. The temperature, RH, and CO₂ were measured from TR-72UI and its interval was 10minutes. Measurement point was the center of the living room and, the device was placed 1.2 meter away from the floor for preventing the radiation effect. Window opening was measured from UX90-001 and its interval was also 10minutes. Ventilation rates was measured from carbon dioxide decay method. From this ventilation rates, Air change rate per day(ACD) was analysed. Air change rate per day is the indicator showing how much ventilation was performed in proportion to the volume.

* Corresponding author: junpark@hanyang.ac.kr

Table 2. measurement parameter and the specification of devices

Parameter	Device	Interval	Measurement point
Temperature			
RH	TR-76UI	10 min	Living room
CO ₂			
Window opening	UX90-001	10 min	
Ventilation rates (or ACD)	Carbon Dioxide Decay method	By an event	

2.3 Equation

The equation used in this study are shown in (1), (2), (3). Equation (1) and (2) are the Carbon dioxide decay method for calculating ventilation rates. The ventilation load was derived from Equation (3)

$$C = Co + (Cs - Co) * e^{-\frac{(Q\Delta t)}{V}} + \frac{M}{Q} (1 - e^{-\frac{(Q\Delta t)}{V}}) \quad (1)$$

$$Q = \frac{V}{\Delta t} [\ln(Cs - Co) - \ln(C - Co)] \quad (2)$$

$$q = 0.33 * n * V * \Delta t \quad (3)$$

3 Result and Discussion

3.1 Outdoor environment

For proving that these measurement period could represent the typical weather, the outdoor temperature was analysed. Fig 1. and Fig 2. shows the daily average outdoor temperature of each complex, comparing with the daily average outdoor temperature of Typical Meteorological Year (TMY) data. From those figures. As a result, the outdoor temperature of measurement period could be considered representative of the Korea temperature.

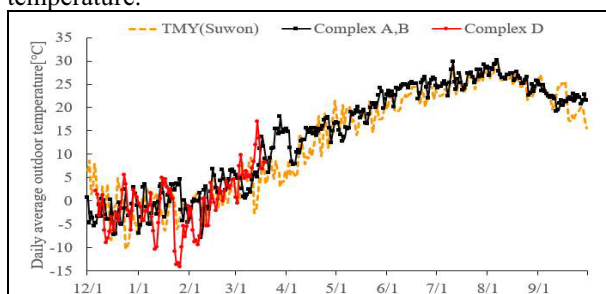


Fig. 1. The outdoor temperature of Complex A,B,D and TMY.

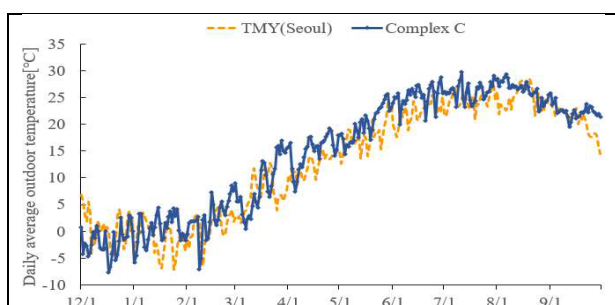


Fig. 2. The outdoor temperature of Complex C and TMY.

3.2 Indoor environment

The results of analyzing the indoor temperature and carbon dioxide distribution of all households are shown in Figures 3 and 4. Fig 3 shows the indoor temperature distribution of all households. The black dot represents the average of all 30 samples, and the pink range represents the maximum and minimum values at that point in time. As for the heating period (January-March), the average household temperature was 21°C, but the indoor temperature variation by household was found to be large. Figure 4 shows the distribution of carbon dioxide, a representative material of indoor pollutants. The indoor carbon dioxide concentration showed that the heating period was higher than the intermediate period and the cooling period, and this is due to the ventilation behavior of the occupants.

Through this, it was found that even under similar outdoor conditions, occupant maintained different indoor temperatures and indoor pollutants through the environmental control by each occupant.

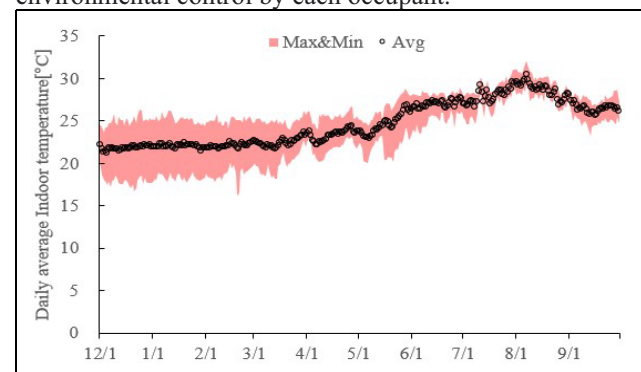


Fig. 3. Distribution of daily average indoor temperature

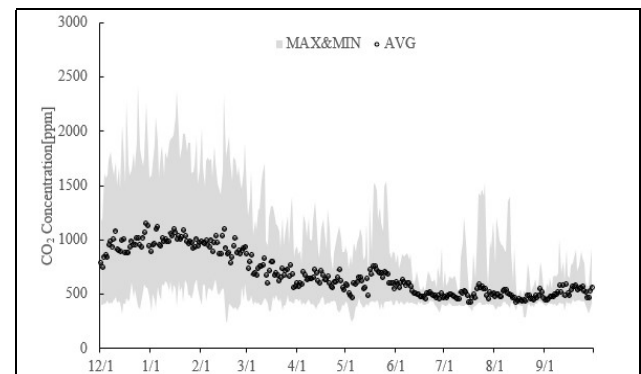


Fig. 4. Distribution of CO₂ concentration of all samples

3.3 Window opening behaviour

The average of air change per day (ACD) and window opening hours in relation to daily average outdoor temperature are shown in Fig. 5. It shows that the window opening and ACD have the similar trend. In heating period, it was found that the standard deviation of each sample was small, however, after 18°C, ACD and window opening hours increased significantly and standard deviation of ACD was also increased. From those result, despite it was the similar outdoor environment, the window opening behaviour of occupants was different, especially in cooling period.

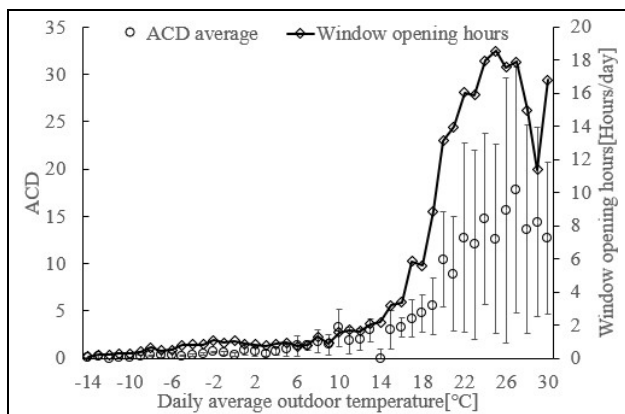


Fig. 5. Air Change per Day (ACD) and window opening hours in relation to Daily average outdoor temperature

3.4 Ventilation load

The figure of ACD and heat loss and gain of all samples in measurement period are shown in Fig.6 and Fig.7. Fig.6 is the heat loss of all samples in heating period. It was found that the heat loss in heating period is very low. It means that the occupants do not often ventilate in cold weather. In contrast, in Fig.7, occupants do often ventilate in mid and cooling period. The Heat loss and gain of all samples in cooling period were greater than that of all samples in heating period. However, some samples showed heat gain and samples showed heat loss despite the same period. This means that, depending on the ventilation operation plan, not only can the cooling load be reduced, but also better indoor air quality can be maintained.

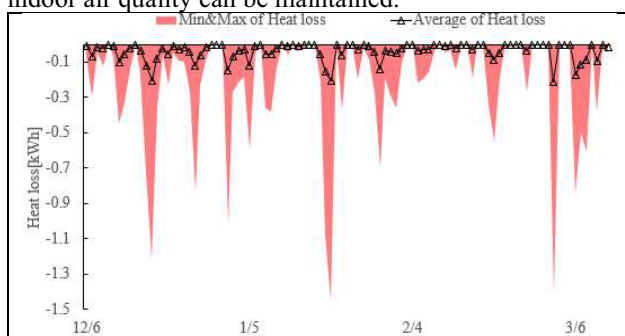


Fig. 6. Heat loss of all samples in heating period

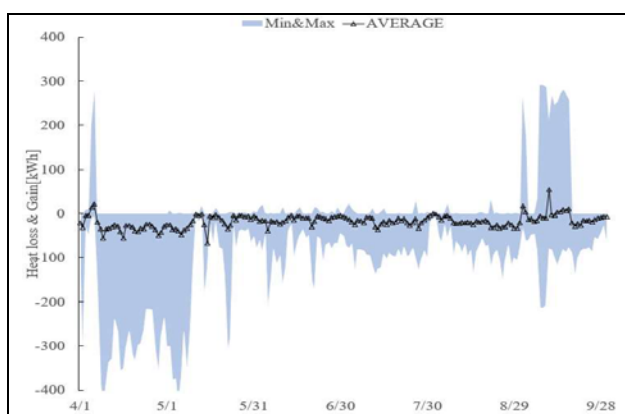


Fig. 7. Heat loss and gain of all samples in mid and cooling period.

4 Conclusion

In this study, the air change rate per day (ACD) was analyzed and the following conclusions were drawn. The outdoor temperature in measurement period could represent typical temperature comparing with the data of Typical Meteorological Year (TMY). Despite measurement period was the similar outdoor environment, the indoor temperature, carbon dioxide was different by each sample. The window opening behavior, which is a representative behavior of occupants, behaved in relation to the outside temperature as in previous studies, and it was confirmed that there was a large variation by each household as the cooling period approached. Also, ACD was found to move in the same pattern as the window opening time. It was found that heat loss in relation to natural ventilation was small in heating period, which means that occupants do not open windows during the cold weather. On the other hand, the window opening behavior in cooling period was more frequent compared to that of the heater, and despite the same period, one household lost heat and gained heat. It is considered that the air quality can be maintained. In a future study, for narrowing the gap of building performance between the design phase and implementation phase, the ventilation rate (ACD) and window algorithm would be embedded in the Energy plus program.

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