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Measurement of air change behaviour at Finnish apartment rooms

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Abstract. While the expectation for natural ventilation is increasing under the context of COVID-19, fresh air at residential houses in Finland is basically guaranteed by mechanical ventilation systems. It means that natural ventilation is not considered as an available potential of ventilation in Finnish building regulation. Even if the mechanical ventilation system handles the air quality, the natural ventilation by window opening is expected to be a supportive measure. However, there is not enough measured data about how much air change is fulfilled by window opening. The article describes the evaluation of fresh air accessibility by window openings at six Finnish apartments. To understand the behaviour of air change, CO_2 mass balance equation model was applied. The results of summer season clarified that the actual number of air changes are 085 to 1.54 times per hour with one-side opening. The CO_2 mass balance model for apartments, which is a kind of tracer gas decay method, is an effective way to estimate the actual number of air changes without preventing occupants' daily living. Since some buildings, such as residential, school, churches, are affected by the moisture problems, the management of moisture behaviour by both natural and mechanical ventilation is essential.

1. Introduction

1.1. Importance of ventilation

Currently, the residential built environment faces two big risks; one is related to the heat waves and cold waves threat caused by the climate crisis, and another is indoor infection risk under the context of COVID-19 crisis. Therefore, enhancing ventilation is one of the key measures for coping with these risks. REHVA, ASHRAE or SAGE-EMG publish the guidelines for epidemic [1, 2, 3]. These guidelines show the acceptable limitation of CO_2 concentration rate for managing safe indoor air quality, such as under 1000 ppm in ASHRAE or 1500 ppm in REHVA. CO_2 concentration rate can be the appropriate key indicator to monitor indoor air quality. However, these guidelines don't show the air change rate as an indicator. In case of Japanese guideline for COVID-19 based on SHASE (the Society of Heating, Air-Conditioning, and Sanitary Engineers of Japan) [4], the air change rate is also shown as one of indicators. In addition, enhancing natural ventilation is strongly recommended. Natural ventilation cannot guarantee the appropriate amount of air change, because it is unstable and the efficiency is affected by local situation such as window layout, surrounding of building, wind profile or occupants' behavior. In case of Finland, fresh air at residential houses in Finland is basically guaranteed by mechanical ventilation systems and the natural ventilation is not considered as an available ventilation

solution in the Finnish building regulation. That's why a centralized ventilation system controls the indoor air quality of rooms in apartment building. Especially in the context of infection control under the COVID-19, ventilation is getting more important than ever. Even if the mechanical ventilation system handles the air quality, natural ventilation by window opening is expected to be a supportive measure. However, there is not enough measured data about how much air change is fulfilled by window opening.

1.2. Objectives

To clarify the potential of natural ventilation for air change under Finnish climate condition, the article describes the evaluation of fresh air accessibility by window openings at rooms of Finnish apartments.

2. Methodology

2.1. Investigated apartment rooms

The authors measured the indoor environment factors (air temperature, relative humidity, and CO_2 concentration rate) in both summer and winter in 2022. The article reports the evaluation results of summer investigation. The number of air changes was estimated with several patterns of opening window combination, closed condition, one-side opening condition, and cross-opening condition. The details of investigated cases is summarized in Table 1.

Table 1. Detail of investigated cases

		Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**
Number of Rooms		4	3	5	5	4	4
Number of Adults		4	4	4	2	3	4
Number of Child		2	2	3	0	0	2
Volume	m^3	119.6	120.2	123.6	209.4	130.8	125.0

2.2. Layout of openings

Fig 1 shows the pictures of openings a living room. The opening consists of three parts, door for accessing balcony, small window for ventilation, and large window. The large window is usually closed and only open when cleaning the glass. In summer season, the occupants of investigated room manage the door for accessing balcony for ventilation because it is large and easy to open. Fig 2 shows the layout of openings of the apartment rooms. Every living room connects to the balcony and kitchen and bedroom are located the opposite side. When the occupants handle cross ventilation by opening kitchen or bedroom together with openings at living room.

2.3. CO_2 mass balance equation

The methodology for measuring ventilation rate Mass balance equation model regarding CO_2 concentration was applied to estimate the behavior of air change.

$$V_o C_o dt + mGdt = V_r dC_r + V_o C_r dt \quad \text{(Eq 1)}$$

V_o Ventilation rate [m^3/s]

V_r Room volume [m^3]

C_r CO_2 concentration rate, indoor [mg/m^3]

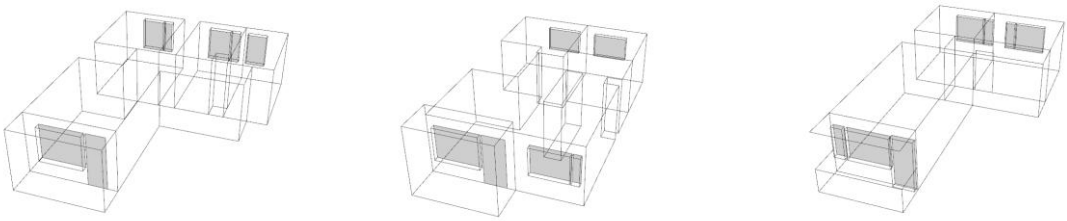
G CO_2 generation rate from body [mg/s/person]

m Number of people [person]

C_o CO_2 concentration rate, outdoor [mg/m^3]

a) Case1 b) Case2 c) Case5

Fig 1. Openings at the living room



a) Case1 b) Case2 c) Case5

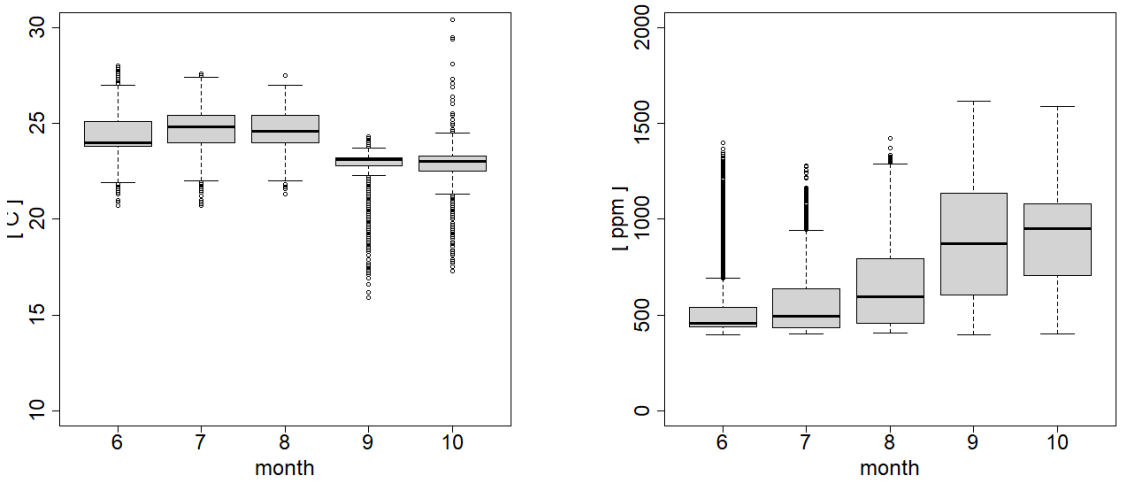
Fig 2. Openings at the living room

3. Results and Discussions

3.1. Trend of indoor environment

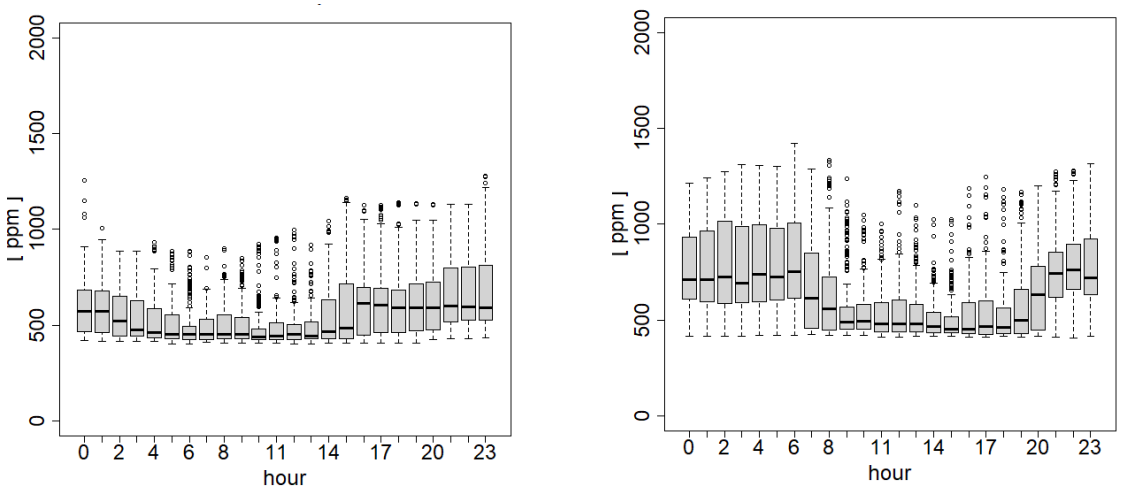
Fig 3 shows the monthly boxplots of indoor air temperature and CO_2 concentration in Case 1. The range between the first and third quartiles is 2 to 3°C and the range of monthly indoor air temperature are quite small. The monthly average indoor air temperature dropped approximately 1°C from August to September while the average outdoor air temperature decreased around 9°C. Through the months, the level of CO_2 concentration gradually increased from summer to autumn. It is because that the opportunity of window openings gets decreased through outdoor air temperature dropping down. In other word, window opening for natural ventilation worked well in summer season to keep CO_2 concentration level low.

Fig 4 shows the series of hourly CO_2 concentration trends in each month from July to October. In summer season, the CO_2 concentration was low through the day, it means that the occupants managed the level of CO_2 concentration by window opening. By shifting to the autumn season, the level of CO_2 concentration increased especially in night-time. The CO_2 generation from occupants' body was higher than exhausting CO_2 by ventilation system. The results shows that window opening as occupant behaviour has potential to manage CO2 concentration level.



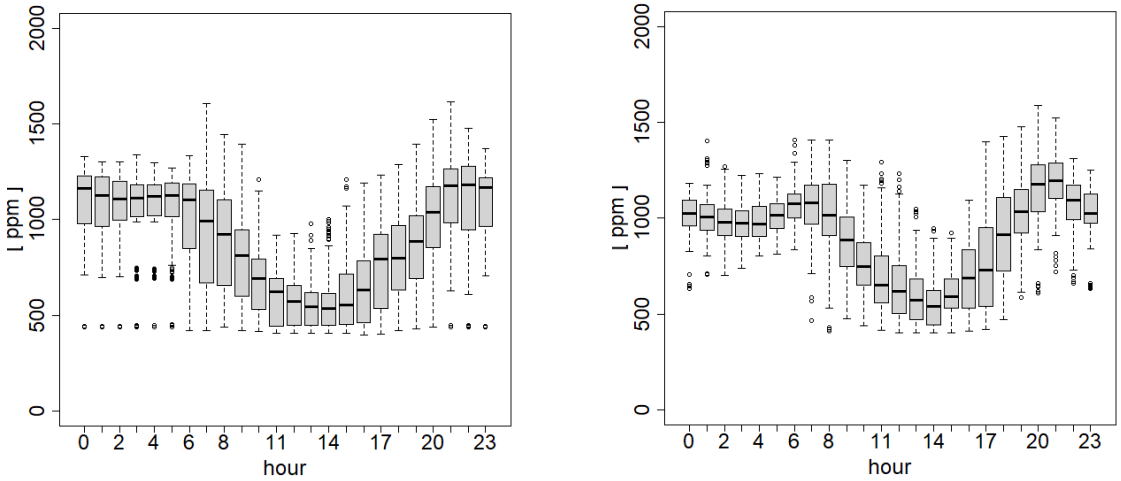
Indoor air temperature CO_2 concentration

Fig 3. Monthly boxplots of measured values, Case 1



July

August



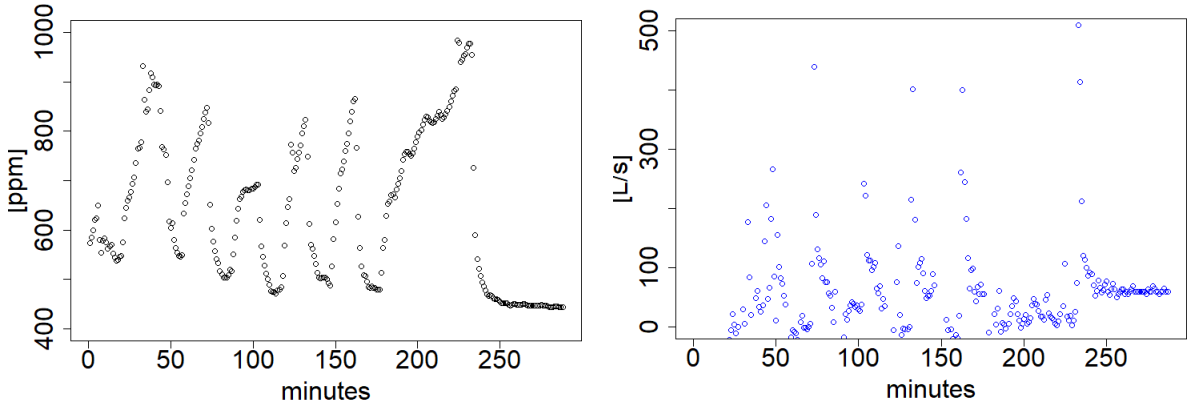
September

October

Fig4. Hourly trends of CO_2 concentration at Case 1

3.2. Ventilation rate at one-side opening

Fig. 5 shows the trend of CO_2 concentration rate during the measurement of Case 1. The CO_2 concentration rate changed between 500 and 900 ppm by reputation of window open and close. By closing windows, CO_2 concentration increased from 500 ppm to 850 ppm in 15 minutes in the apartment room with three adults. By opening one window, the CO_2 concentration decreased from 850 ppm to 480 ppm in 15 minutes. The maximum level did not exceed the limitation suggested by the guideline as 1000 ppm. The window opening can be a supportive measure to control indoor air quality under the limitation suggested by the guidelines. Fig. 6 shows the air change volume rate during the measurement and the dark grey bars indicate a one-side opening case. Case 1 has potential to change the amount of air 104 L/s on average, which is equivalent to 3.13 times per hour when the opening at balcony opened as the occupants usually do in summer. In the case of the apartment flat of Case 2, it has air exchange of 81.6 L/s on average, which is equivalent to 2.44 times per hour when the opening at balcony opened. And the case of apartment flat of Case 5, the air of 28.4 L/s in average, which is equivalent to 0.85 times per hour, is changed when the opening at bedroom opened.



CO_2 concentration Air change rate

Fig 5. Trends of value during the measurement at Case 1

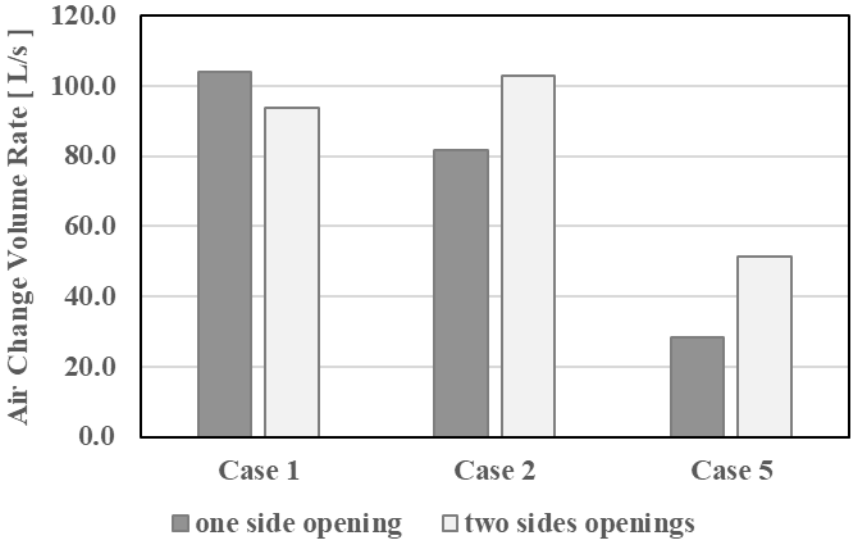


Fig 6. Air change volume rate

3.3. Ventilation rate at cross ventilation

Light grey bars in Fig 6 indicate the air change volume rate in two-side openings which means cross ventilation was implemented. In addition to the opening opened at one-sided study, which is mentioned in 3.2, the result of cross-ventilation was 93.9 L/s in average, which is equivalent to 2.82 times per hour in Case1. The result of Case 2 was 103 L/s on average, which is equivalent to 3.10 times per hour, at cross ventilation. And 51.4 L/s, which is equivalent to 1.54 times per hour in Case 5. Compared with one-side opening, cross ventilation increased the air change volume 26% in Case 2 and 81% improvement in Case 5. On the other hand, the amount of air change in Case 1 decreased by 10%. The performance of ventilation is affected by not only occupant behavior but also wind profile. Therefore, it is needed to investigate more long-term and reputation of measurement in different wind situations in order to get more accurate result.

4. Conclusions

The results of summer season clarified that the actual number of air changes are 0.85 to 1.54 times per hour with one-side opening and it reaches up to 3.12 when cross ventilation. The measured apartment rooms are all available to apply cross-ventilation across living room to bedroom. Since some buildings, such as residential, school, churches, are affected by the moisture problems, the management of moisture behavior by both natural and mechanical ventilation is essential. The observation of air change with the CO_2 mass balance model can be an effective method also for the problem. The CO_2 mass balance model for apartments, which is a kind of tracer gas decay method, is an effective way to estimate the ventilation rate without preventing occupants' daily living.

Acknowledgement

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