Development of an automatic sliding window system to control adequate ventilation rate

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Abstract. Under the influence of COVID-19, it is recommended to ventilate to reduce the risk of infection in the room. In an air-conditioned room, window open can increased the ventilation rate that caused by indoor and outdoor temperature difference. However, there is a concern that opening the window in the air-conditioned room will increase the heating and cooling loads due to air leakage. In addition, it is difficult to maintain the appropriate ventilation rate, because the outdoor air temperature changes from time to time. To solve this problem, we have developed an automatic window opening system to control the natural ventilation rate. This system can be controlling the appropriate ventilation rate for the room by adjusting the opening area of window automatically. In this study, actual measurements were conducted to understand the operating performance of the system, and its effect on the indoor thermal environment. The measurements were conducted in summer and winter season, and the results were compared between the developed window opening system and 95 mm width opened ordinary window. As a result, it was confirmed that the ventilation rate could be controlled by this system. In addition, in the case of the developed window opening system, the system controlled the ventilation rate when there was a large difference in indoor and outdoor temperatures, which prevented the deterioration of the indoor thermal environment and reduced the heating load compared to the ordinary window.

Keywords. Natural ventilation, Window, Ventilation measurement, Temperature.
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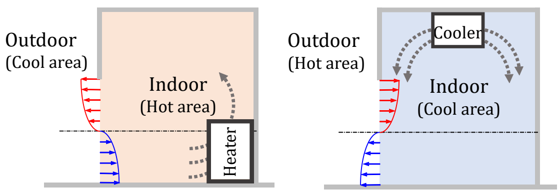
1. Introduction

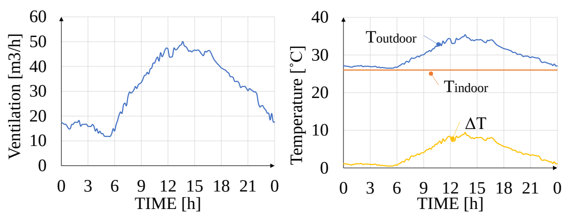
It has been reported by ASHRAE[1)] and others that securing adequate ventilation is effective to reduce the risk of infection such as COVID-19 in the room. Natural ventilation by opening windows and doors (see **Fig. 1**) is the simplest method to increase the ventilation rate when there is an indoor and outdoor temperature difference. However, there are concerns that opening the window in the air-conditioned room may be affected by the outdoor air temperature, resulting in poor heating and cooling efficiency and deterioration of the indoor thermal environment. Also, excessive ventilation may increase the heating and cooling load and power consumption. In addition, it is difficult to maintain the appropriate ventilation rate, because the outdoor air temperature changes from time to time. As a preliminary study, CONTAM was used to analyse the natural ventilation rate at a single opening. The opening conditions were as shown in **Table 1**, the outdoor condition was August 3, 2021, Nagano, and the indoor temperature was 26 °C. **Fig. 2** shows the results of the calculation using CONTAM. The ventilation rate exceeds 30 m³/h during the daytime when the outdoor air temperature is high, but it does not meet the required ventilation rate during the hours when



a) During cooling b) During heating
Fig. 1 - Natural convection in a single aperture.

Tab. 1 - Aperture conditions in CONTAM.

Model Summary	
Type	Two-way flow
Formula	One-opening
Model Parameters	
Height	2 m
Width	40 mm
Discharge coefficient	0.6



a) Ventilation rate b) Temperature
Fig. 2 - Calculation of ventilation rate by CONTAM.

there is little indoor and outdoor temperature difference. This indicates that it is not easy to maintain the proper ventilation rate by manually opening and closing the windows.

The purpose of this study was to develop an automatic window opening system to control the natural ventilation rate according. This system (see **Fig. 3**) can be controlling the appropriate ventilation rate for the room by adjusting the opening area of the window automatically. From the equation of Brown[2] (**Equation (1)**), we calculated the opening width when the required ventilation rate per person is 30 m^3/h[3) 4) 5)].

2. Methods

In this study, actual measurements were conducted to understand the operating performance of the system. To confirm the indoor thermal environment, measurements were taken in summer and winter. Results were compared between the automatic window opened by this system and the ordinary window opened at 95 mm in width. The width of the automatic window opened by this system was adjusted every 30 seconds. Also, there are two types of window openings: constant opening and intermittent opening. In the case of intermittent opening, the concentration of pollutants in the room increases while the window is closed. So, the actual measurements were conducted with the window constantly open.

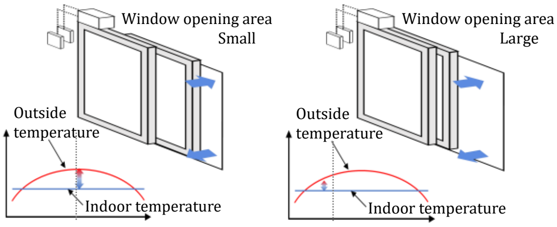
Fig. 4 shows the target experimental building in Takaoka city, Toyama, and **Fig. 5** shows the temperature measurement points. Both rooms have a floor area of 6.25 m^2, a room volume of 15 m^3, and a window height of 2 m. The ventilation rate using the constant concentration method, indoor temperature distribution, and power consumption were measured. In addition, to understand the external environment, the outdoor temperature, wind direction and speed, and solar radiation were measured.

3. Results of the study in summer

The measurement was conducted on September 11, 2021, and all air conditioners in both rooms and the corridor were set at 22 °C.

3.1 ventilation rate

Fig. 6 shows the measured ventilation rate. **Fig. 7** shows the results of the temperature changes, and the opening width of the window using this system. According to the results, in the case of the automatic window opened by this system, the ventilation rate was generally maintained at 30 m^3/h throughout the day. The daily average ventilation rate was measured to be about 28.9 m^3/h. On the other hand, in the case of the ordinary window opened at 95 mm in width, the ventilation rate increased during high outdoor temperatures. The average ventilation rate during the daytime (9:00 to 18:00) was measured to be



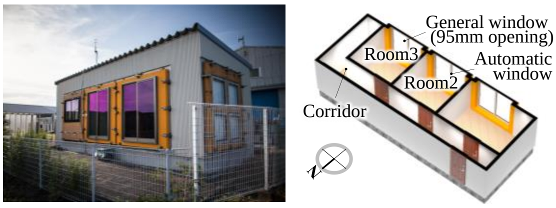
a) ΔTemperature large b) ΔTemperature small

Fig. 3 – The automatic window opening system.

Eq. 1 - The equation of Brown[2].

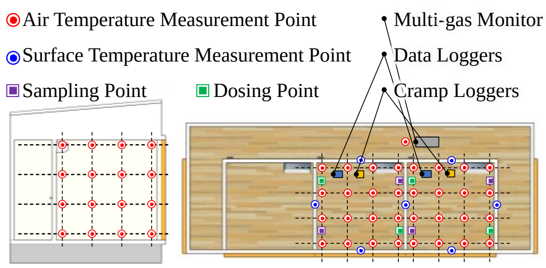
$$Q = \frac{\alpha A}{3}\sqrt{\frac{2\Delta P}{\rho}} \qquad (1)$$

where Q is the ventilation rate [m^3/s], α is the flow coefficient [-], A is the window opening area [m^2], ρ is the fluid density of air [kg/m^3], and ΔP is the pressure difference between indoor and outdoor [Pa].



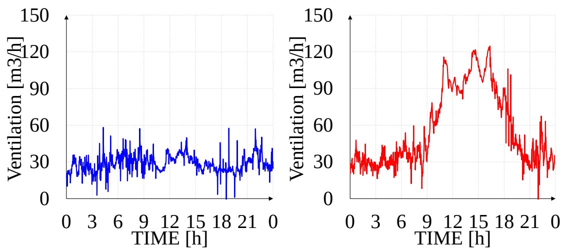
a) External view b) Interior view

Fig. 4 - Overview of the experimental building.



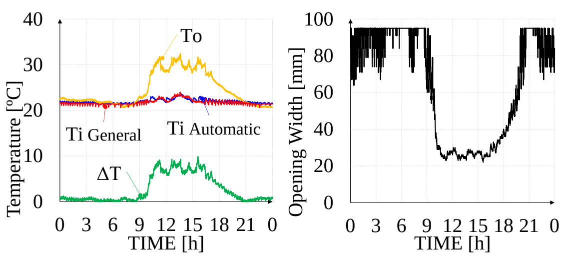
Vertical section Horizontal section temperature

Fig. 5 - Temperature measurement points.



a) Automatic window b) Ordinary window

Fig. 6 - Ventilation rate.



a) Temperature b) Opening width

Fig. 7 - Temperature changes and opening width.

about 65.6 m³/h. The system adjusted the opening width according to the indoor and outdoor temperature difference. It was confirmed that the ventilation rate could be controlled by using this system.

3.2 indoor thermal environment

Fig. 8 shows the horizontal temperature distribution in the room at 10:00 and 13:00, and **Fig 9** shows the vertical temperature distribution in the cross-section of the opening at 13:00. In both rooms, the indoor temperature was generally maintained at the set temperature of 22 °C. However, in the case of the ordinary window opened at 95 mm in width, the indoor temperature increased slightly due to the high outdoor temperature and increased air leakage. The maximum indoor and outdoor temperature difference was measured at 9.9 °C in the room with the automatic window opened by this system.

3.3 power consumption

Fig. 10 shows the power consumption of the air conditioner in each room. There was no significant difference between the two rooms, and the air conditioner operated at about 0.1 kW to 0.15 kW during the daytime when power consumption was high. However, in the case of the ordinary window opened at 95 mm in width, it operated at about 0.18 kW from 13:00 to 14:00. Due to increased air leakage, the cooling load temporarily increased.

4. Results of the study in winter

The measurement was conducted on December 5, 2021. The air conditioner was set at 28°C to provide indoor and outdoor temperature difference.

4.1 ventilation rate

Fig. 11 shows the measured results of the ventilation rate. **Fig. 12** shows the results of the temperature changes, and the opening width of the window using this system. According to the results, in the case of the automatic window opened by this system, the ventilation rate was controlled throughout the day. Although the daily average ventilation rate was measured to be about 46.3 m³/h, which was about 16 m³/h higher than the controlled rate of 30 m³/h. Based on the results of the opening width, the ventilation rate was calculated to be about 28.4 m³/h by the theoretical formula. It was confirmed that this system was working properly. In winter, when the indoor and outdoor temperature difference is large, the opening width becomes very small, so errors are likely to occur. Also, the ventilation rate may have increased due to the influence of the window frame. On the other hand, in the case of the ordinary window opened at 95 mm in width, the daily average ventilation rate was measured to be about 184.5 m³/h. It was because the difference in indoor and outdoor temperatures was large that the ordinary window was always had excessive ventilation. During the daytime, the outdoor temperature rise,

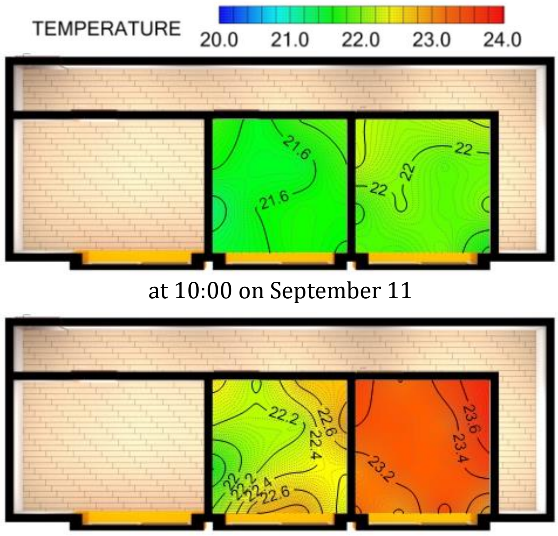
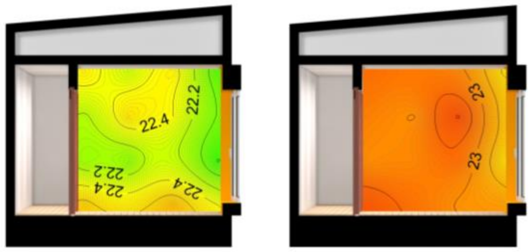
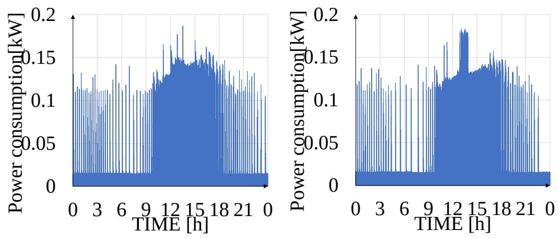
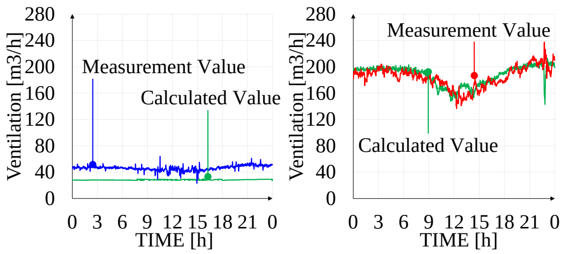


Fig. 8 - Horizontal temperature distribution.

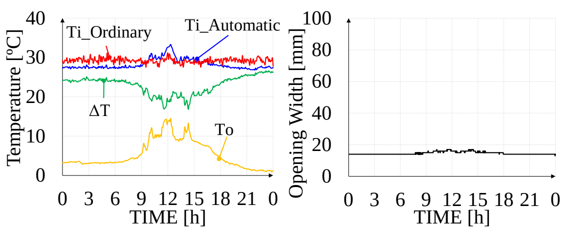

a) Automatic window b) Ordinary window
Fig. 9 - Vertical temperature distribution.



a) Automatic window b) Ordinary window
Fig. 10 - Power consumption of the air conditioner.



a) Automatic window b) Ordinary window
Fig. 11 - Ventilation rate.



a) Temperature b) Opening width
Fig. 12 - Temperature changes and opening width.

and the indoor and outdoor temperature difference became smaller, so the ventilation rate decreased.

4.2 indoor thermal environment

Fig. 13 shows the horizontal temperature distribution in the room at 13:00 and 22:00. In both rooms, during the daytime when the outdoor temperature was high, the indoor temperature was around 28 °C, which is the set temperature. However, as the outdoor temperature decreased, the indoor temperature near the openings also decreased. Especially in the case of the ordinary window opened at 95 mm in width, the indoor temperature was affected by the outdoor temperature due to increased air leakage. The temperature difference in the room was large, and the indoor temperature near the opening was lower by about 6 ˚C or more. **Fig. 14** shows the vertical temperature distribution in the cross-section of the opening at 22:00. In the case of the ordinary window opened at 95 mm in width, cold drafts occur due to large air leakage. In winter, the occurrence of cold drafts was reduced by using this system.

4.3 Power consumption

Fig. 15 shows the power consumption of the air conditioner in each room. In the case of the automatic window opened by this system, the air conditioner operated at about 0.2-0.4 kW. On the other hand, in the case of the ordinary window opened at 95 mm in width, the air conditioner operated at about 0.5-1.1 kW during other the hours when the indoor and outdoor temperature difference was large. It indicated that using this system prevented the increase of heating load due to excessive ventilation, and saved energy compared to the ordinary window opened at 95 mm in width.

5. Conclusion

In this study, we developed an automatic window opening system to control the natural ventilation rate. The following findings were obtained from the study.

(1) This system was able to control the ventilation rate, and the daily average ventilation rate was about 28.9 m^3/h throughout the day in summer. However, in winter, the daily average ventilation rate was controlled at about 46.3 m^3/h.

(2) The ventilation rate controlled by this system prevented the deterioration of the indoor thermal environment and the occurrence of cold drafts, in winter.

(3) By controlling the ventilation rate to prevent excessive air leakage, the heating load was reduced, and power consumption was reduced.

6. Acknowledgement

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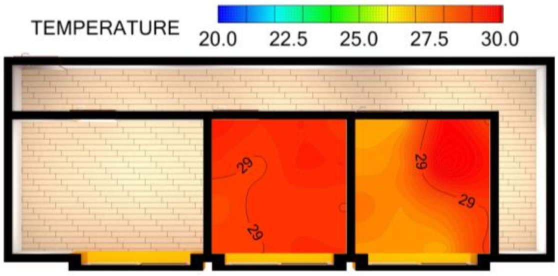
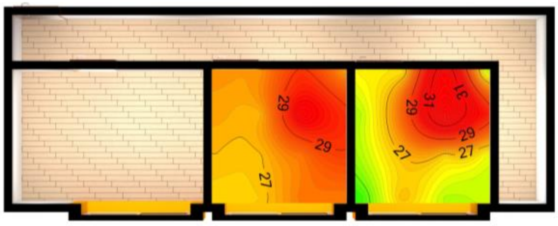
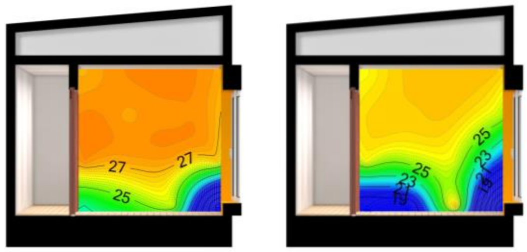


at 13:00 on December 5



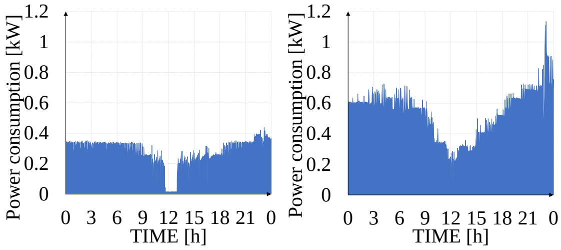
at 22:00 on December 5

Fig. 13 - Horizontal temperature distribution.



a) Automatic window b) Ordinary window

Fig. 14 - Vertical temperature distribution.



a) Automatic window b) Ordinary window

Fig. 15 - Power consumption of the air conditioner.

7. References

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