

Effects of airtightness and ventilation on the humidity environment of non-residential spaces in detached houses

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Abstract. In recent years, outdoor air humidity has significantly increased, especially during the hot and humid summer season in Japan. In this regard, if a room is overcooled for a long period of time, then there is the risk of condensation in areas where humid outdoor air enters interior rooms through gaps. Thus, the purpose of this research is to understand the effects of airtightness and ventilation on the humidity environment of non-residential spaces (e.g., inside partition walls) in detached houses. Based on the findings, in airtight non-residential spaces, no effects of high humidity were observed, due to outdoor air infiltration. However, if there were small holes at the top/bottom of the partition walls, then the humidity in the non-residential spaces increased. In the case of exhaust ventilation, the humidity in the non-residential spaces increased, which promoted the entry of outdoor air into such spaces. This is because the inside of the building had negative pressure. As for the case of balanced ventilation, the effect was smaller. Overall, these results provide important information for considering effective methods for suppressing summer condensation.

Keywords: Condensation, humidity environment, summer, airtightness, ventilation, non-residential spaces, experiments.

1 Introduction

During the hot and humid summer, air-conditioning is essential for maintaining a suitable thermal environment in a detached house. However, extended overcooling, as shown in Fig. 1, poses a risk of summer condensation in non-residential spaces, such as within partition walls and behind ceilings. This occurs when humid outdoor air infiltrates close to the interior surface of the room through gaps. Figure 2 shows the average outdoor air temperature and dew point in August in Tokyo [1], [2]. Historically (1990–2010), the dew point was approximately 21°C, but in recent years (around 2020), it has risen to around 23°C–24°C and is projected to exceed 24°C in the future (2077–2099). Consequently, the likelihood of summer condensation is expected to increase. This study aims to understand the factors influencing temperature and humidity formation in non-residential spaces and propose measures to prevent summer condensation. This research presents experimental results clarifying the effects of

airtightness, ventilation, and wallpaper moisture permeability resistance on the humidity environment within non-residential spaces, including partition walls.

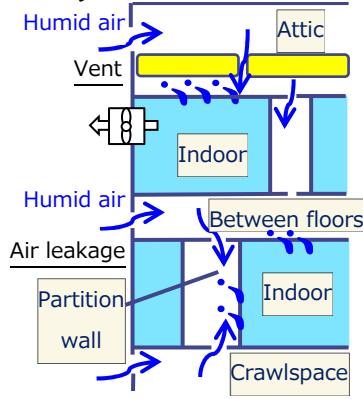


Fig. 1. Image of condensation

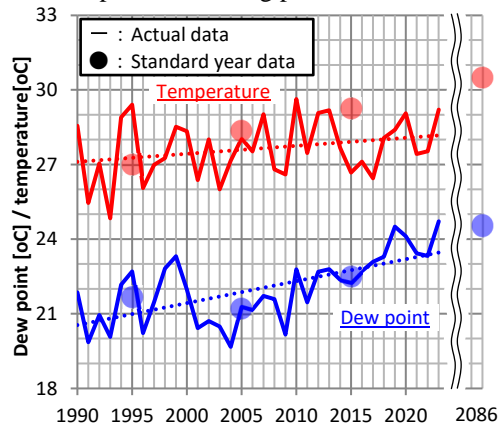


Fig. 2. Temp., dew point (August, Tokyo) [1],[2]

2 Experimental methods

2.1 Experimental building

In this study, measurements were taken in a one-story wooden hut (floor area 9.9 m²) built in a constant temperature and humidity laboratory. Figure 3 presents the floor plan, while Fig. 4 shows the cross-section and insulation specifications. It has non-residential spaces such as spaces under ceiling insulation and partition walls. The insulation performance was equivalent to the Japanese energy conservation standard, with the total equivalent clearance area of 51.2 cm² and a clearance value of 1.69. In this case, ventilation could be switched between balanced ventilation and exhaust ventilation.

2.2 Experimental condition

The outdoor temperature was a constant 30°C, while the indoor temperature was 24°C, with the air conditioner set on the “light breeze” mode. In order to determine the difference in humidity in the non-residential spaces under each condition, the outdoor condition was changed from low humidity (30% RH, dew point 10.5°C) to high humidity (60% RH, dew point 21.4°C) after approximately one hour. The experiments were conducted under the conditions shown in Table 1. For the condition with poor airtightness (Nos. 1–3), holes with a diameter of 25 mm were drilled through the top and bottom plates (see Fig. 6–8) in the compartment located at the center of Fig. 4 (assuming a through-hole for wiring). Regarding the condition with good airtightness (No. 4), the through-hole at the top and bottom of the partition wall were taped shut. In both conditions, a through-hole with a diameter of 25 mm was provided at a height of 1 m above the floor on the vertical side of the partition wall facing the room (entrance

side), assuming clearance of a switch. Overall, three ventilation systems were used: balanced ventilation (No. 1); supply and exhaust ventilation with a large air supply (No. 2) to create positive pressure in the room; and exhaust ventilation (Nos. 3 and 4) to create negative pressure in the room. To compare the moisture permeability resistance of the wallpaper, the experiments were conducted for all conditions with and without wallpaper (P.E. 100 μ , 0.21 m²sPa/ng) on the indoor surface of the plasterboard. Since general vinyl wallpaper includes a moisture permeability resistance of 0.016 m²s Pa/ng [3], the wallpaper used in these experiments had relatively high moisture permeability resistance (e.g., dust-proof wallpaper applied in clean rooms).

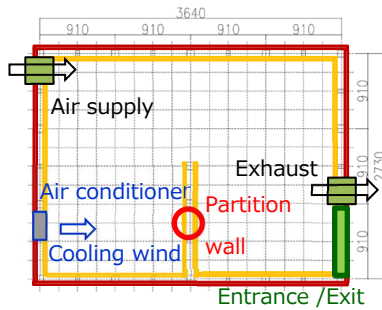


Fig. 3. Floor plan

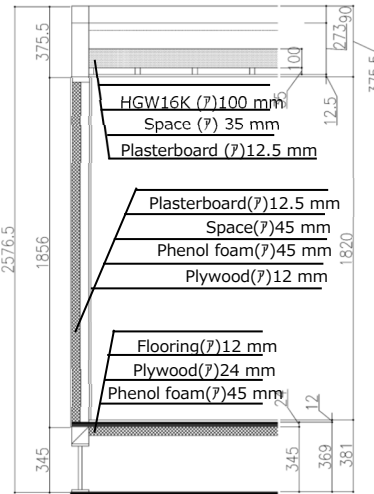


Fig. 4. Cross-section and insulation spec.

Table 1. Experimental condition

Condition	Airtightness	Ventilation method
No. 1		Balanced ventilation (OA: 30 m ³ /h, EA: 30 m ³ /h)
No. 2	Holes exist (non-airtightness)	Supply and exhaust ventilation with a large air supply (OA: 45 m ³ /h, EA: 30 m ³ /h)
No. 3		Exhaust ventilation (EA: 30 m ³ /h)
No. 4	No holes (airtightness)	

2.3 Experimental and measurement instruments

A window air conditioner was used for cooling, while a fan was used to adjust the ventilation air volume with a voltage regulator. The temperature and humidity in the outdoor, indoor, and non-residential spaces (e.g., partition walls and crawlspace) were measured at 1-minute intervals using T-type thermocouples and a CHS-UPS humidity sensor (made by TDK). As for the differential pressure in these spaces, it was measured at 1-second intervals using a SDP800 pressure sensor (made by Sensirion) until 18 hours after the experiment began.

3 Experimental Results

3.1 Temperature, humidity, and differential pressure in the non-residential spaces

Figure 5 presents the temperature and humidity measurements under Condition No. 1 (without the wallpaper), while Fig. 6 shows the differential pressure measurements. After the constant temperature and humidity laboratory became humid, the indoor temperature and humidity were 24°C–25°C and 55% RH (absolute humidity: 10–11 g/kg'), respectively, due to the effect of air conditioning. Meanwhile, the temperature and humidity of the outdoor and attic spaces were approximately 30°C and 60% RH (15 g/kg'), respectively. The temperature of the crawlspace was lower than that of the outdoor space (due to the effect of the ground), at approximately 29°C. The temperature in the partition wall was about the same as that of the room because both vertical sides of this wall faced the room and the humidity was about 65% RH (13 g/kg') in Condition No. 1. The temperature and humidity under the ceiling insulation was about 27°C,

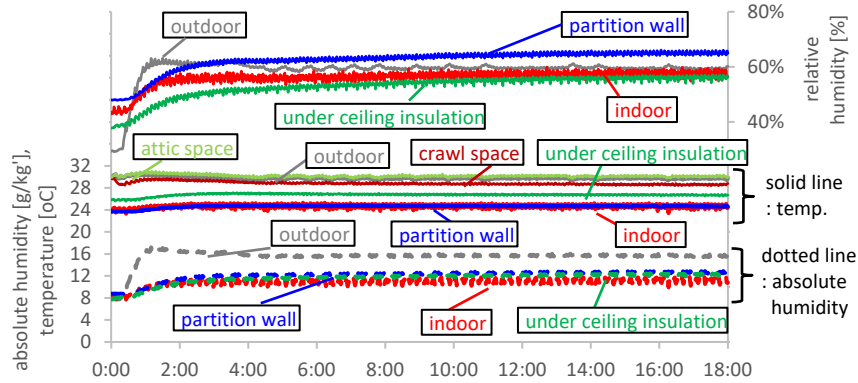


Fig. 5. Measurement of temperature and humidity (Cond. No. 1 (without wallpaper))

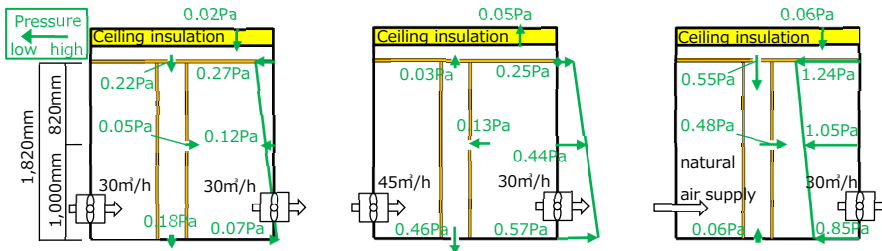


Fig. 6. Condition No. 1

Fig. 7. Condition No. 2

Fig. 8. Condition No. 3

Notes: These figures show the measurements of differential pressure. As for the window air conditioner used in the experiment, when the compressor was started, the room was depressurized by approximately 2.5 Pa because air was exhausted from the room through the air conditioner. Meanwhile, the compressor was operated for and stopped for roughly 2 and 4 minutes, respectively. The differential pressures shown in Figs. 6–8 are the average values when the compressor was not running.

55%RH (12 g/kg'), respectively. When the horizontal differential pressure was evaluated at FL+1000 mm, along with the vertical differential pressure at the boundary (e.g., the ceiling and floor surfaces), the differential pressure between the inside and outside was close to 0 Pa, since the air supply and exhaust by the mechanical ventilation were equal. Meanwhile, the partition wall was 0.22 Pa lower than under the ceiling insulation, 0.18 Pa higher than the crawlspace, and 0.05 Pa higher than in the room. Therefore, air flow from the attic to the crawlspace and room was via under the ceiling insulation. Conversely, under Condition No. 2 (Fig. 7), in which a large amount of air was supplied and the room was under positive pressure, the air flow was from the room to the partition wall and under the ceiling insulation. Under Condition No. 3 (Fig. 8), in which the room was under negative pressure, the direction of the differential pressure between the non-residential spaces and the room was the same as in Condition No. 1. However, the differential pressure was larger.

3.2 Dimensionless absolute humidity ratio in the non-residential spaces

Since the absolute humidity of the non-residential spaces depended on the outdoor and indoor values, both effects were considered by the dimensionless absolute humidity ratio χ shown in Equation (1) [4]. In the equation, X is the absolute humidity, the subscript a is the attic, i is the indoor, and o is the outdoor. When χ was close to 0, the absolute humidity of the non-residential spaces was close to the indoor value. However, when χ was close to 1, then it was close to the outdoor value.

$$\chi_a = (X_a - X_i)/(X_o - X_i) \quad (1)$$

Figure 9 presents the χ (30-minute moving average) for each condition of the partition wall. Based on the findings, the humidity in the partition wall did not increase under

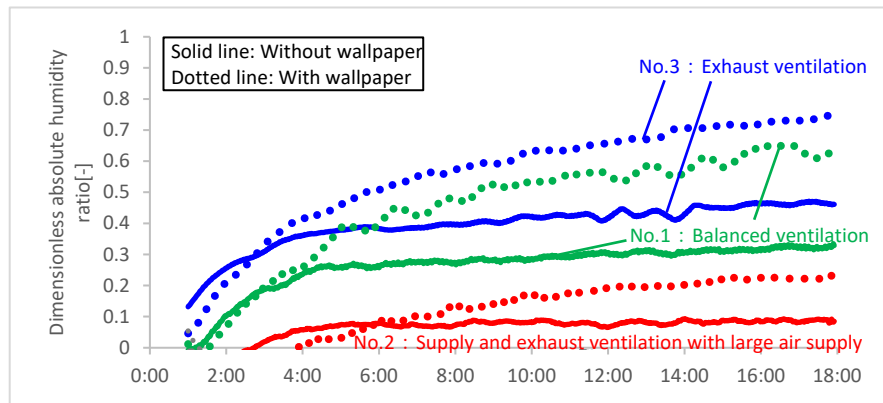


Fig. 9. Dimensionless absolute humidity ratio

Note: In this study, the method of Hens et al [4] was used to evaluate the humidity increase in non-residential spaces, given that the indoor/outdoor absolute humidity was somewhat different for each experimental condition. As the conditions were based on summer, the high and low humidity outdoor areas were set to 1 and 0, respectively, with respect to the dimensionless absolute humidity ratio.

Condition No. 4 (in which there was no through-hole), indicating that air tightening is important to control the humidity increase in the partition wall. In addition, the χ for the partition wall without the wallpaper after 18 hours was 0.08 for Condition No. 2 (supply and exhaust ventilation with a large air supply), 0.33 for Condition No. 1 (balanced ventilation), and 0.46 for Condition No. 3 (exhaust ventilation), with the smaller values shown on the left. This is because the positive pressure in the room suppressed the flow of moisture from the outside to the partition wall, indicating that the ventilation method had a significant effect on the humidity of the partition wall. Moreover, the χ for the partition wall after 18 hours was generally higher under the condition with the wallpaper. For example, in Condition No. 1 (balanced ventilation), the χ was 0.63 with the wallpaper and 0.33 without the wallpaper. This was because the moisture permeability resistance from the partition wall to the room was suppressed, indicating that such resistance of the wallpaper had a significant influence on the humidity environment in the partition wall.

4 Conclusion

In this study, several experiments were conducted to understand the effects of airtightness, ventilation, and moisture permeability resistance of wallpaper on the humidity environment in non-residential spaces. The results are as follows. First, in airtight non-residential spaces, no effects of high humidity (due to outdoor air infiltration) were observed. However, even if there were small holes at the top or bottom of the partition wall, the humidity in the non-residential spaces still increased. Second, in the case of exhaust ventilation, the humidity in the non-residential spaces increased, which promoted the entry of outdoor air. This was because the structure had negative pressure. Conversely, in the case of balanced ventilation, the effect was smaller. Finally, when the moisture permeability resistance of the wallpaper was large, moisture permeation from the non-residential spaces to the indoor spaces was suppressed, while the humidity in the spaces increased. These results suggest that building airtightness, a ventilation plan that prevents negative pressure inside the building, and a design that reduces moisture permeability on the interior side wall surfaces are important to suppress summer condensation.

Disclosure of Interests. Author 1 is currently an employee of Sekisui House, Ltd., but was enrolled in a doctoral course at Kyoto University at the time this study was conducted and declares no conflict of interest. Author 2 declares no conflict of interest.

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