Experimental Evaluation of the Moisture Buffering Effect of Hygrothermal Material

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Abstract
Residential buildings newly constructed in Japan are well insulated and airtight for energy conservation. However, the indoor environment of these houses can suffer from high humidity in the summer and low humidity in the winter. In order to mitigate this problem, hygrothermal materials are installed in some Japanese houses. The test method for small samples of hygrothermal material is prescribed in the Japanese Industrial Standards (JIS). However, the moisture buffering effect of the hygrothermal materials adopted in actual houses is unclear. The purpose of this study was to clarify the effect of hygrothermal material on indoor moisture control. A series of experiments was carried out in two identical rooms. In the room installed with hygrothermal material, variations in relative humidity were controlled and compared with the room without hygrothermal material. This material demonstrated good performance for moisture buffering effect in an actual-scale room.

Keywords: Hygrothermal Materials, Moisture Buffering Effect, Moisture Variation, Moisture Distribution, Experimental House, Loading Ratio

Introduction

Residential buildings newly constructed in Japan are well insulated and airtight for energy conservation. However, the relative humidity (RH) of the indoor environment can be too high in the summer and too low in the winter. Indoor humidity is an important factor for air quality and occupant health. For this reason, it is necessary to ensure the long life of houses and healthy life of occupants by keeping the indoor humidity within an appropriate range. To control variations in indoor RH, hygrothermal materials with moisture adsorption/desorption properties are installed as finishing materials in some Japanese houses.

The test method for small samples of hygrothermal material is prescribed in the JIS [1, 2]. However, little research has been done on the moisture buffering effect of hygrothermal materials adopted in actual houses. In addition, the indoor humidity environment depends on the combination of many factors, such as moisture sources (occupants, moisture-emitting equipment, plants), ventilation and air infiltration, moisture adsorption and desorption from surrounding surfaces (interior walls, floors, etc.), air flow and temperature distribution, as well as the humidity ratio of the outdoor air. Previous studies have evaluated the moisture buffering effect in a climate chamber [3, 4], but this is different from the actual outdoor climate.

The aim of this study was to clarify the moisture buffering effect and moisture distribution in the full-scale rooms of a test house.

Outline of Experiment

Experimental House

A series of experiments was carried out in an experimental house located on the campus of Akita Prefectural University, Japan, from October to November 2009. **Figure 1** shows a schematic view and the location of measurement points in the house. The experimental house is composed of two wooden stories. The test rooms are situated on both sides of the entrance hall. This experiment was performed in the test rooms on the second floor. Northern rooms were not used. The western room is named “Room A”, and the eastern room is “Room B”. Each room is 4.2 m in width, 4.6 m in depth and 2.9 m in height and the floor area is 19.2 m^2. The internal volume is 55.6 m^3. Each room was equipped with ten sensors (THT-B121, Shinyei Technology Co., Ltd.) for measuring the temperature and RH at 1-min intervals. The outdoor temperature and humidity were measured by psychrometers. At the center of the rooms, temperature and RH sensors were set at 0.05 and 1.5 m high from the floor and at 0.05 m below the ceiling in order to measure the vertical temperature and RH distribution. At the surface of the walls, sensors were set at 1.5 m high from the floor. Each sensor is covered by a cylinder 8 mm in diameter. Therefore, the measured point is 4 mm away from the surface. At the corner between walls a sensor was set at 0.05 m high from the floor level. The other sensors were set at 1.5 m high from the floor level.

Experimental Cases

The interior surfaces of Room A were covered with polyethylene sheets in all experimental cases in order to prevent moisture adsorption and desorption with the building envelope. In Room B, interior surface walls were installed with hygrothermal materials of 12-mm-thick vermiculite board made from unfired vermiculite, calcium hydroxide, silica and pulp by autoclaving at 180℃ [5]. The ceiling and floor were covered with polyethylene sheets. As shown in **Table 1**, experiments were carried out for four cases, each with a different loading ratio of hygrothermal materials. The loading ratio means the ratio of the material surface area to the experimental room volume. The surfaces of Room A were covered with polyethylene sheets in all experimental cases. The polyethylene sheets were used to change the area of hygrothermal materials according to the different cases. The loading ratio was different between experiments for Room B.

Moisture was provided by evaporation from a tray (size: 265W×170D×225H mm) with water, which was electrically heated. An electric balance was used for measuring the quantity of humidification. A mechanical fan was installed in the air inlet formed temporarily in the wall between the experimental room and the adjustment northern room. The air change rate was measured by an air volume flow meter (SwemaFlow 65, Kona Sapporo Co., Ltd.). The target air change rate is 0.5 1/h and the target humidification rate is 150 g/h. **Figure 2** shows the schedule for each experimental case. Each experiment consisted of a preconditioning period for 24 h and a constant humidification period of 12 h followed by no humidification for 24 h or more.

Results and Discussion

Quantity of Humidification and Air Change Rate

The measured values for water temperature, moisture production rate and total moisture production are shown in **Table 2**. In order to prevent surface condensation, the water temperature was controlled to below 65℃. There was a slight difference in water temperature, moisture production rate and total moisture production between experimental cases. The water temperature changed in the range of 64.1 to 66.3℃. The moisture production rate changed in the range of 142.2 to 164.4 g/h. The total moisture production changed in the range of 1725 to 1968 g. The values for the air change rate measured by three methods are shown in **Table 3**. The three methods were measurement using an air volume flow meter, calculation by the constant concentration method using water vapor emission rate and calculation by the decay method using absolute humidity (AH) change. The value for the air change rate measured by the air volume flow meter was close to the target value of 0.5 1/h, but the values obtained using the constant concentration method and decay method were slightly different from the target value. The reason is that the ventilation rate was influenced by high-velocity outdoor wind during the experiment.

Humidity Variations and Distribution

(1) Results for Cases 1 and 4

The change in temperature, AH and RH for Case 1 and Case 4 is shown in **Fig. 3** to **Fig. 8**. In the case with hygrothermal materials installed on the four side walls (Case 1), during the preconditioning period in Room A, the RH changed by about 10% due to the influence of the outdoor air RH change over the course of 6 h. The RH in Room B was very stable compared with Room A. During the humidification period in Room A, the RH increased by about 20% over the course of 12 h. In Room B, the RH increased by about 15%. During the following period in Room A, the RH rapidly decreased by 30% after the 12 h. In Room B, the RH gradually decreased by 15%. The same tendency was found for the change in AH.

In the case of hygrothermal materials installed on one side of the walls (Case 4), the moisture buffering effect in Room B was small. It was found that humidity variation was suppressed by the use of hygrothermal materials.

The AH at the center point was higher than that at other points. However, the temperature at the center point was higher than that at other points in the test room. The RH at the center point was lower than that at other points in the test room. The AH of the surface of walls installed with hygrothermal materials in Room B was lower than that at the center point. When hygrothermal materials were installed on the interior surface of the walls, the moisture distribution of AH at the surface of the wall became lower than that at other measured points during the humidification period. However, the moisture distribution of absolute humidity at the corner point was lowest in the experimental room in almost all cases.

(2) Comparison of humidity change between Room A and Room B

A comparison of the average humidity change between Room A and Room B in each case is shown in **Figs. 9** to **12**. These figures show the average of the 10 measurement points for the humidity change, which is shown by the difference from the values at the beginning or the end of humidification. In all cases, AH and RH in Room A were higher than that in Room B during the humidification period and were lower than in Room B during the following period. This means that Room B installed with hygrothermal materials adsorbed and desorbed moisture during the humidification period and during the following period, respectively.

The humidity controlling effect depends on the loading ratio of hygrothermal materials. However, the effect was not directly proportional to the loading ratio.

Evaluation of Moisture Buffering Effect

In order to evaluate the moisture buffering effect, the following index is used.

Index of moisture adsorption effect: $$K_1 = 1 - \frac{S_1'}{S_1}$$ (Eq. 1)

Index of moisture desorption effect: $$K_2 = 1 - \frac{S_2'}{S_2}$$ (Eq. 2)

S_1 is the accumulated area of increased humidity ratio in the experiments in Room A for 12 h after humidification started and S_1' is the same area of increased humidity ratio in the experiments in Room B (**Fig. 13**). S_2 is the accumulated area of decreased humidity ratio in the experiments in Room A for 12 h after humidification ended and S_2' is the same area of decreased humidity ratio in the experiments in Room B (**Fig. 13**). Therefore, K_1 and K_2 mean the ratio of the amount of humidity variation in the case with hygrothermal materials to the case without moisture absorption and desorption.

Relationship between Moisture Buffering Effect and Loading Ratio

The relationship between the moisture buffering effect determined in the previous section and the loading ratio is shown in **Fig. 14**. Except for Case 2, the K_1 and K_2 values increase as the loading ratio increases. These results are reasonable. The values of K_1 are higher than K_2 because the speed of adsorption is higher than that of desorption. However, the result for Case 2 is far from this tendency. One reason is the effect of strong outdoor wind, resulting in a high ventilation rate. The measured results for the ventilation rate shown in Table 3 indicate that the value in Case 2 was higher than that in the other cases. With the high ventilation rate, the decreasing and increasing rate of AH becomes smaller.

Conclusions

Experiments were conducted to investigate the moisture buffering effect and moisture distribution in relation to the use of hygrothermal materials. The results were as follows. Changes in humidity during the humidification period and following period in Room A were suppressed by 9%, and 7%, respectively, compared with Room B without hygrothermal materials. The humidity gradient existed between the central point and the surface of the walls, with hygrothermal materials. As the loading ratio increased, the moisture buffering effect increased. However, the moisture buffering effect in Case 2 was lower than the value expected, due to an increase in the air change rate.

Acknowledgments

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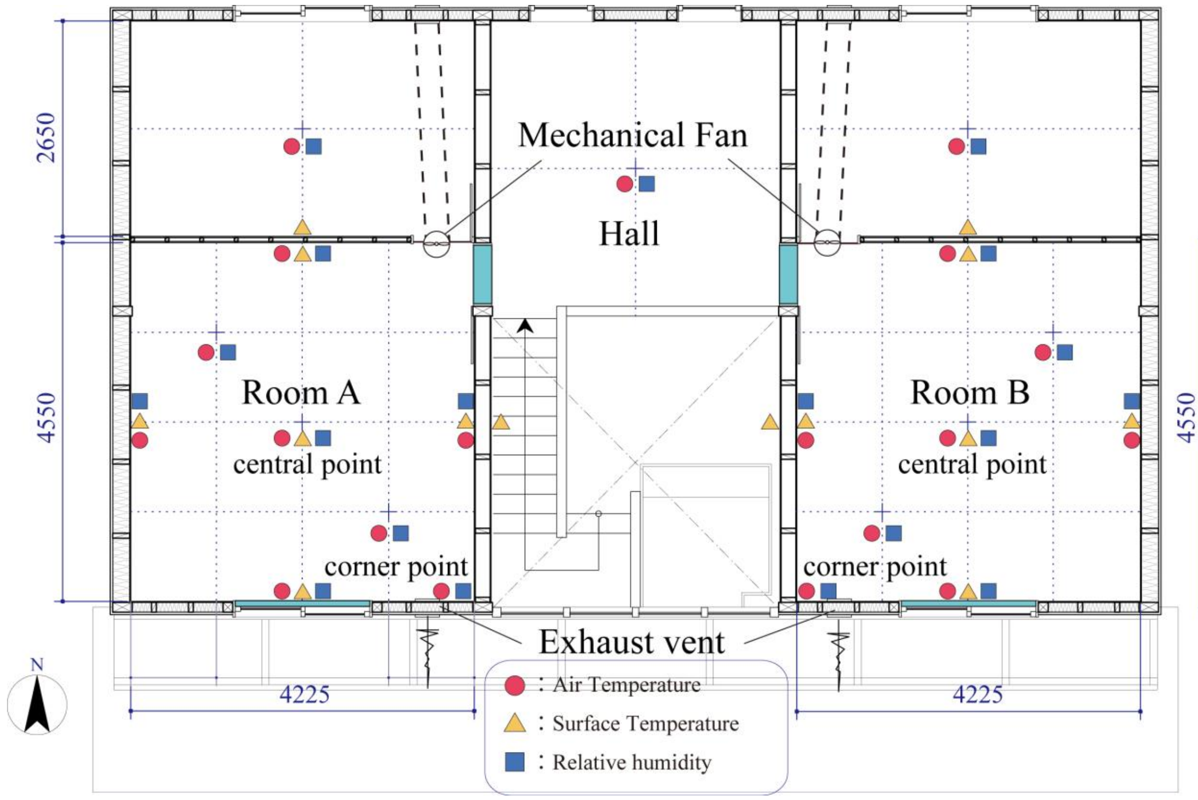

Fig. 1 Schematic view and location of measurement points in the experimental house

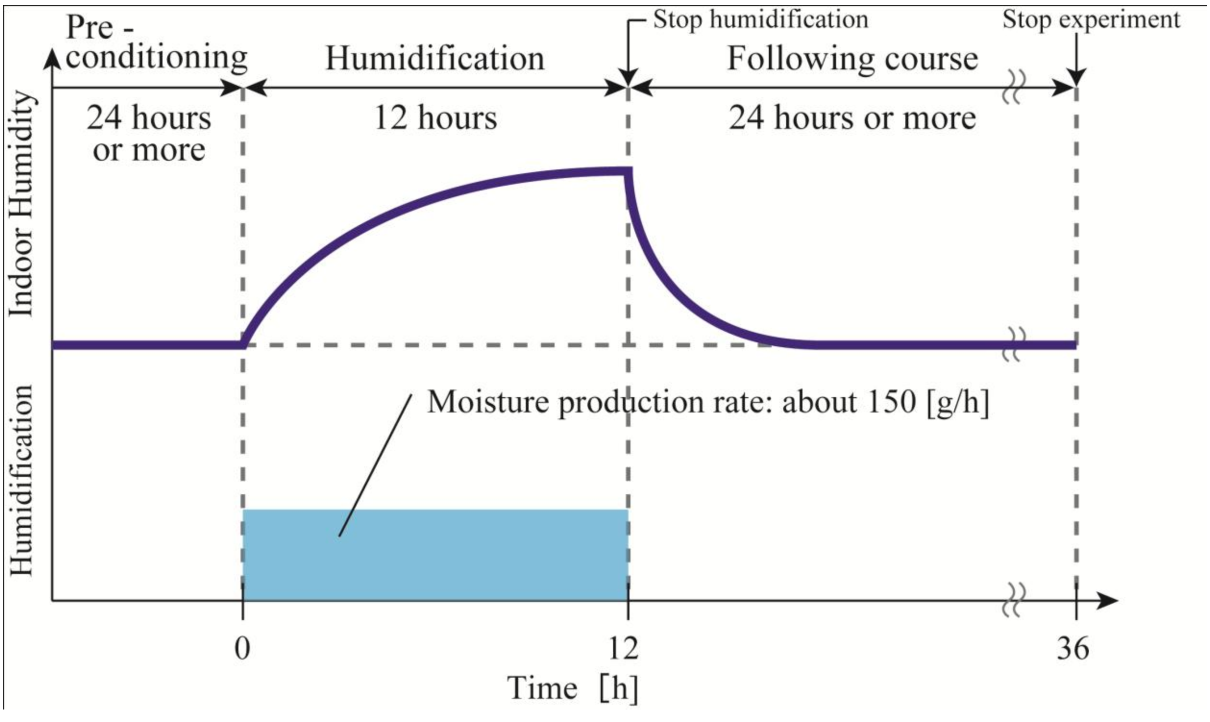

Fig. 2 Schedule for each experimental case

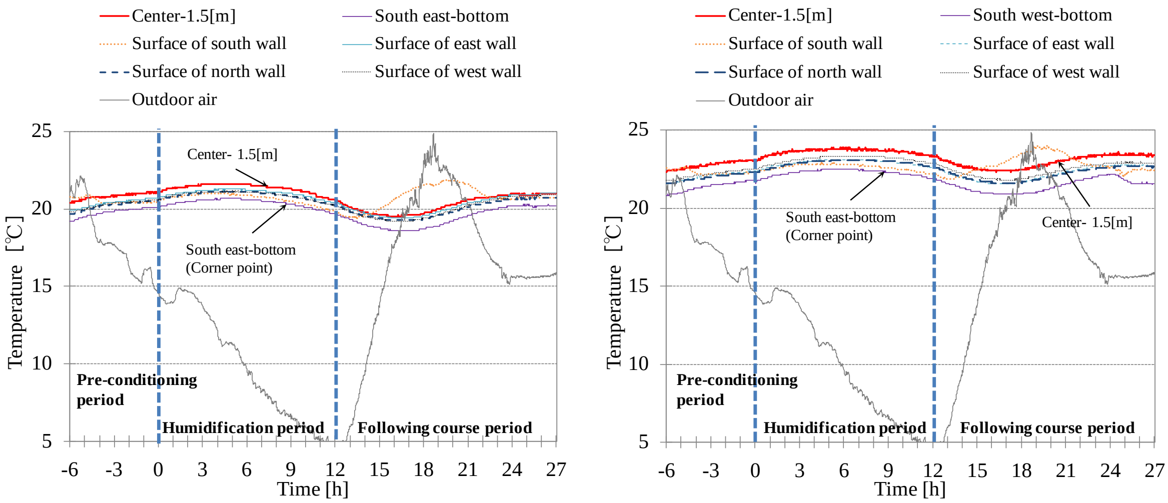

Fig. 3 Temperature variations in Case 1

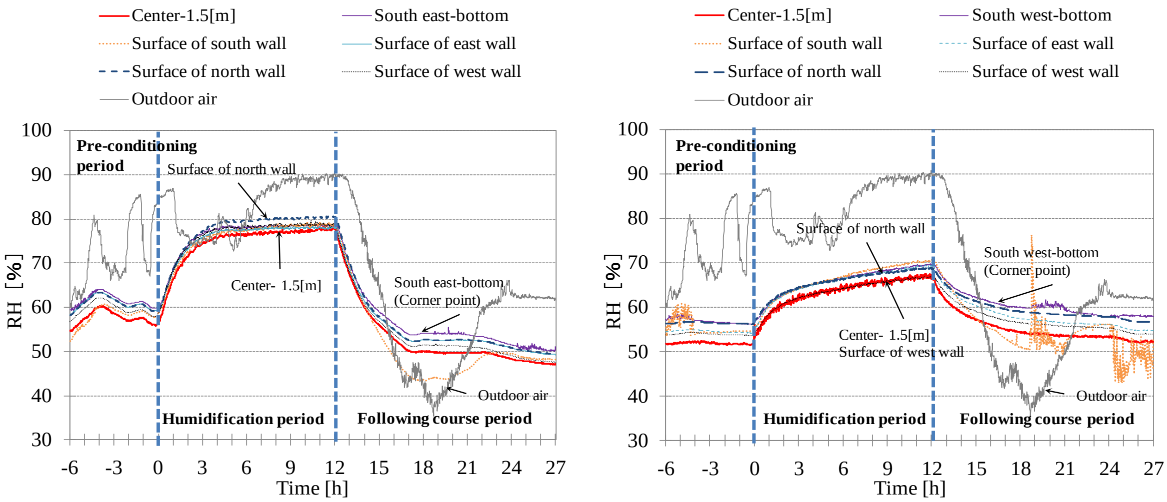

Fig. 4 RH variations in Case 1

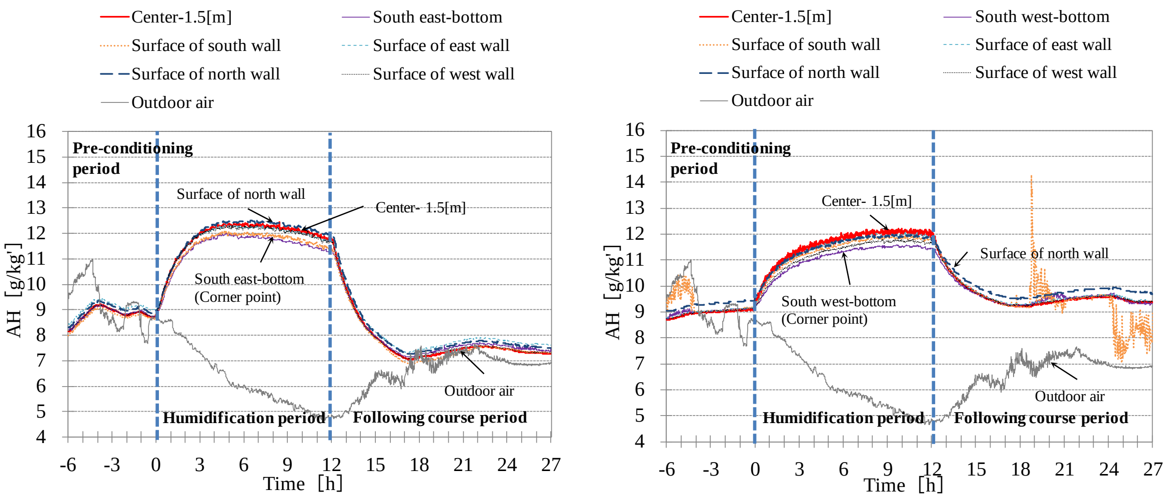

Fig. 5 AH variations in Case 1

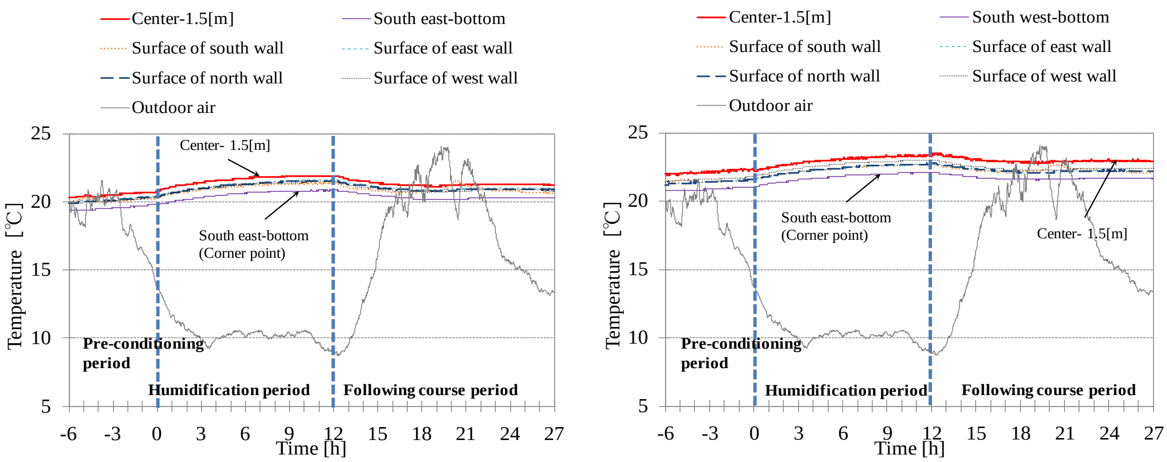

Fig. 6 Temperature variations in Case 4

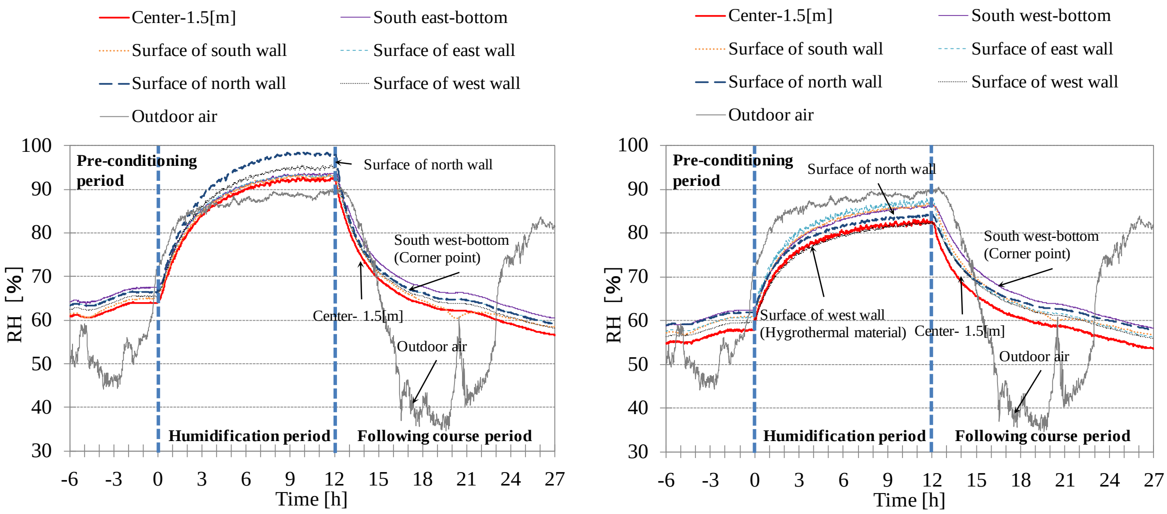

Fig. 7 RH variations in Case 4

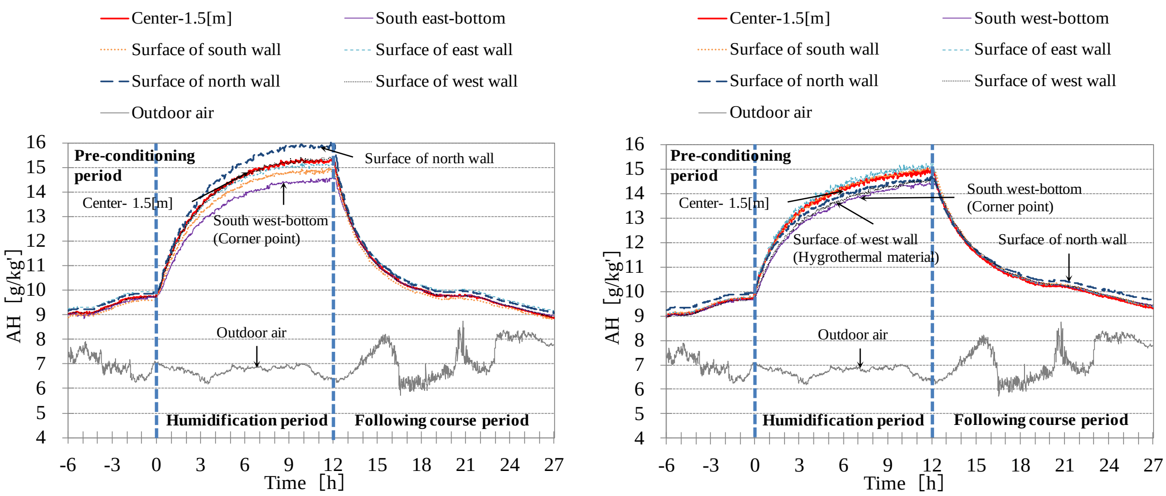

Fig. 8 AH variations in Case 4

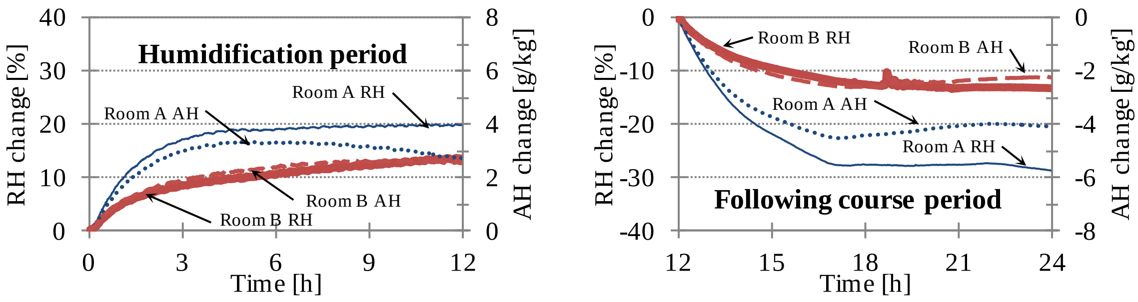

Fig. 9 Comparison of average humidity changes in Case 1

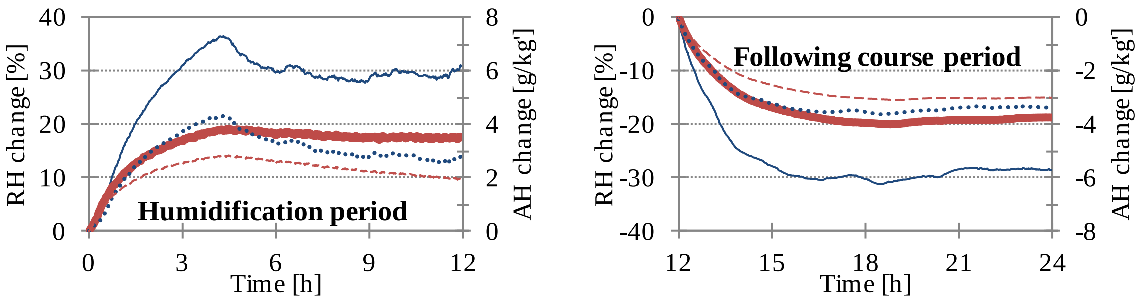

Fig. 10 Comparison of average humidity changes in Case 2

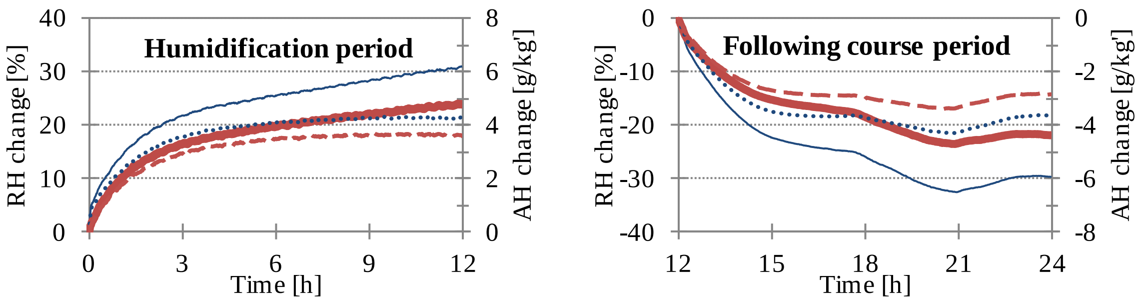

Fig. 11 Comparison of average humidity changes in Case 3

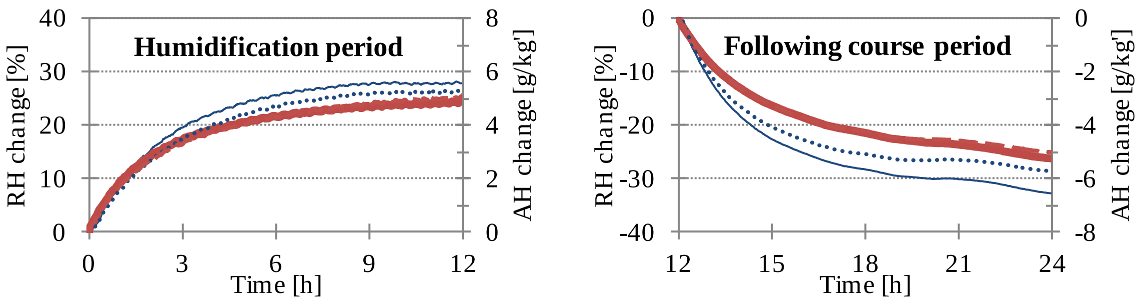

Fig. 12 Comparison of average humidity changes in Case 4

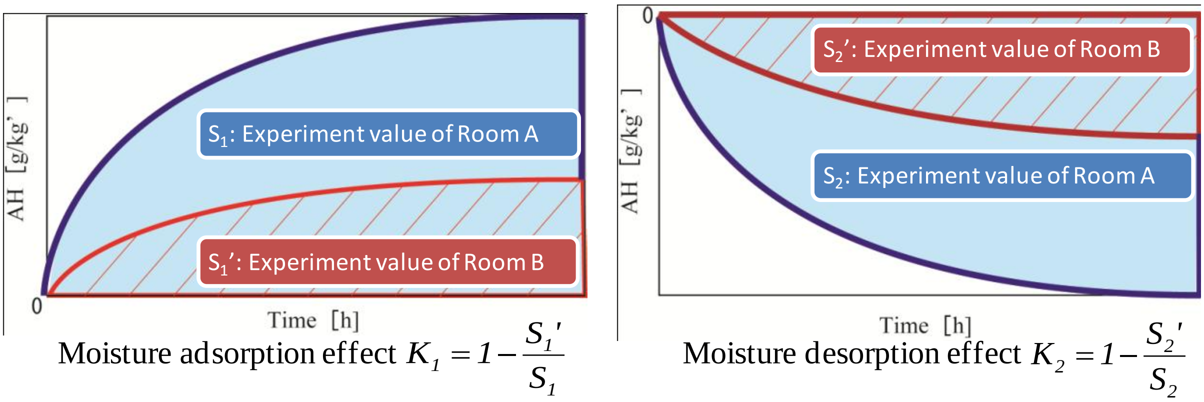

Fig. 13 Schematic of moisture adsorption effect and desorption effect

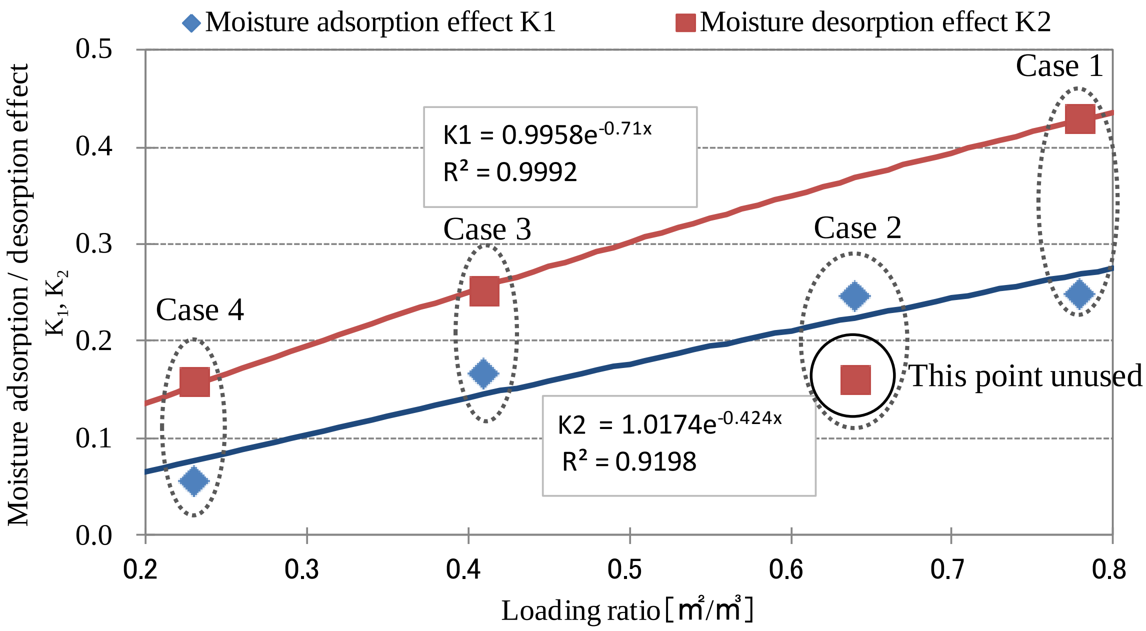

Fig. 14 Relationship between moisture buffering effect and loading ratio

Table 1 Experiments on hygrothermal material location and loading ratio

Experimental cases (Dane day)		Hygrothermal materials	Loading ratio [m²/m³]	Target of ventilation rate [1/h]
Case1 (Oct 30th - Nov 1st)	Room C	none	0	0.5
	Room D	4 sides of walls	0.78	
Case2 (Nov 2nd - 4th)	Room C	none	0	
	Room D	3 sides of walls	0.64	
Case3 (Nov 5th - 8th)	Room C	none	0	
	Room D	2 sides of walls	0.41	
Case4 (Nov 9th - 11th)	Room C	none	0	
	Room D	1 side of walls	0.23	

Table 2 Measured values for water temperature, moisture production rate and total moisture production

Experimental cases		Water temperature [℃]	Moisture production rate [g/h]	Quantities of total moisture production [g]
Case1	Room C	64.2	142.2	1732
	Room D	65.5	150.1	1839
Case2	Room C	64.1	154.6	1833
	Room D	66.3	164.4	1968
Case3	Room C	64.4	143.8	1725
	Room D	66.1	154.6	1855
Case4	Room C	64.1	153.8	1846
	Room D	66.2	158.1	1898

Table 3 Values for air change rate

Experimental cases		Air volume flow mater [1/h]	Constant Consentration Method [1/h]	Concentration Dencay Method [1/h]	Outside wind speed [m/s] (Humidificatio period)	Outside wind speed [m/s] (After the stop of humidification)
Case1	Room C	0.48	0.38	0.38	0.5	1
	Room D	0.49	0.44	(0.22)		
Case2	Room C	0.48	0.59	0.66	2.2	2.7
	Room D	0.49	0.51	(0.31)		
Case3	Room C	0.48	0.37	0.48	0.3	0.7
	Room D	0.49	0.43	(0.35)		
Case4	Room C	0.48	0.28	0.27	0.2	1
	Room D	0.49	0.32	(0.20)		

( ) was installed with hygrothermal materials, therefore, it is only reference value.