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Evaluation of Anti-condensation Performance of External Walls with Fibrous Insulation

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Abstract. In recent years, there has been a tendency to focus on high airtightness and the thermal insulation performance of houses for the purpose of the improvement of the indoor heat environment and reduction in the heating and cooling loads. However, the high airtightness and insulation performance increase the risk of intrusion into the inside of the wall, which causes interstitial condensation because the water vapor generated in the room cannot be discharged to the outside. In this study, we evaluate the anti-condensation performance of the walls using cellulose-fiber-based heat insulation (CF), which has a large moisture capacity and excellent moisture adsorption and desorption performance. The usefulness of CF is confirmed by clarifying the occurrence of internal condensation through measurement data analysis of a demonstration house, as well as numerical simulations.

1. Introduction

In recent years, housing has tended to be highly insulated and airtight for the purpose of saving energy by improving the indoor thermal environment and reducing the cooling and heating loads. The criteria in the energy conservation standards, which represent the heat insulation performance of the building, have been revised from the heat loss coefficient to the outer skin heat transmission coefficient, and the building skin performance is regarded as more important. However, accompanying this, the water vapor generated indoors is not discharged to the outside; instead, it invades the inside of the wall and causes internal condensation, raising the risk of impairing the heat insulation performance and durability of the building.

Therefore, in this study, we evaluate the anti-condensation performance on walls with cellulose fiber insulation (CF) with a high moisture capacity and excellent moisture adsorption and desorption performance. Here, we investigate the performance of CF and its usefulness by clarifying the presence or absence of internal dew condensation by measurement data analysis of the wall temperature and humidity, and numerical simulation.

2. Overview of demonstration house

Figure 1 and Table 1 show the appearance and specifications, respectively, of the real house used for the measurement, and Fig. 2 shows the plan. This demonstration house is a wooden house in Yufuin, Oita Prefecture in Japan. The temperature and humidity were measured indoors and on the surface of the insulation material in the external wall. Fig. 3 shows the basic configuration and measurement points of the external wall used for the measurement, and Table 2 shows the change points from the basic configuration of each wall. Walls 1 and 2, which are the northern walls, can be compared by the presence or absence of a ventilation layer in the wall; Walls 3 and 4 on the south side can be compared by the finishing of the indoor side surface. The indoor condition is central air-conditioning system operating for 24 hours, and there is no internal moisture generation because the house was unoccupied.

Figure 1. Exterior of demonstration house.

Table 1. Specifications of the demonstration house

Total floor area	235.61 m^2
Area classification	Area 5
Annual insolation area classification	A3
Insolation area classification	H2
Mean heat transmission coefficient of external wall	$0.34/(m^2 \cdot K)$

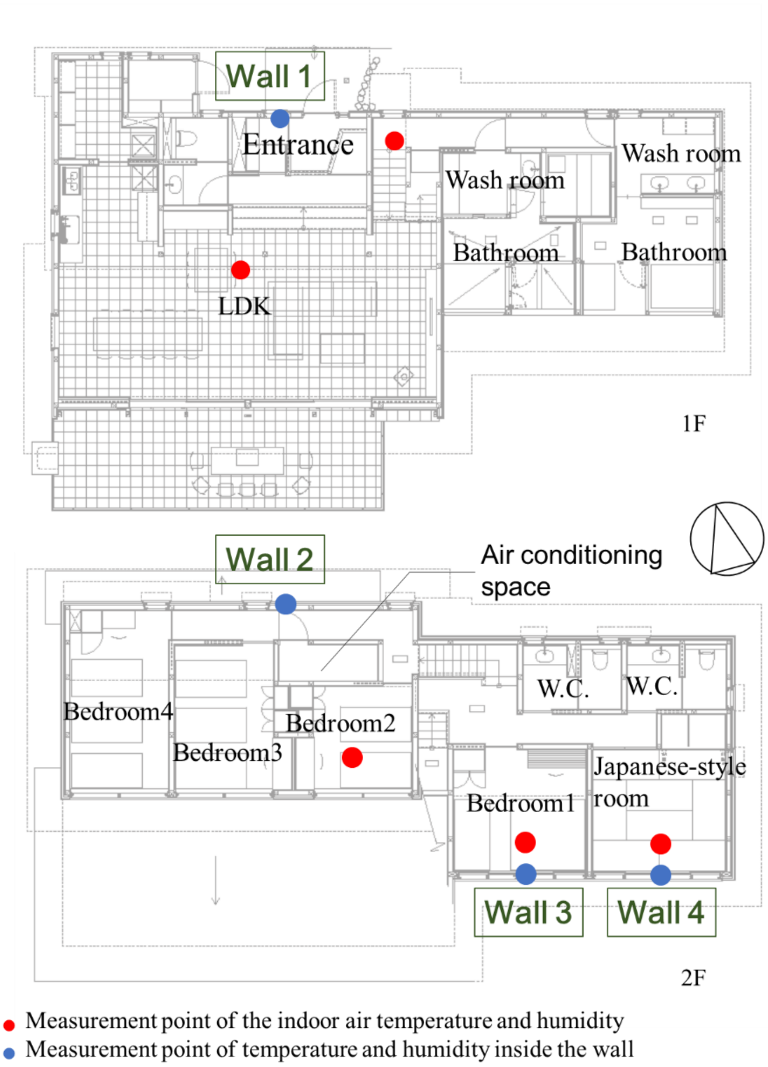


Figure 2. Plan and measurement points

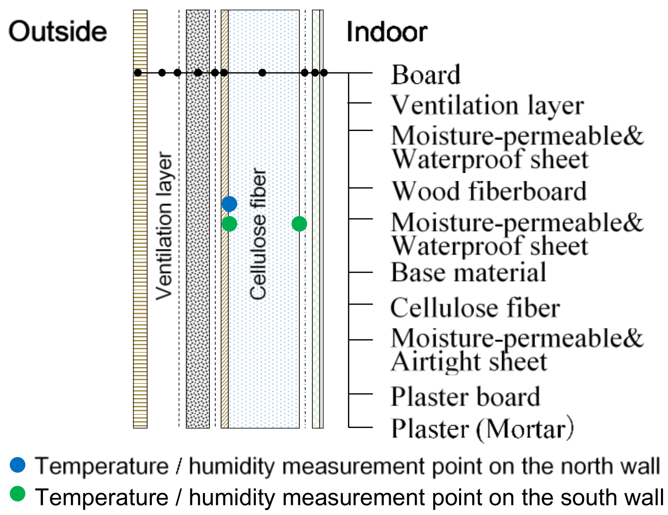


Figure 3. Standard composition of external wall (Wall 2) and temperature and humidity measurement points inside wall

Table 2. Type of wall

North side	Wall 1	Without ventilation layer
	Wall 2	Standard composition
South side	Wall 3	Vinyl cloth finish
	Wall 4	Earth wall finish

3. Comparison of measured and calculated results

Figure 4 shows the actual measurement and calculation results of Walls 1 to 4 from March 4 to March 17, 2017. Hygrabe [1], which is an unsteady heat transfer calculation tool for the building envelope, was used for the calculation. The indoor/outside air conditions used for calculation are as shown in Table 3. Regarding the measured values, the relative humidity is stable with respect to the change in temperature in Walls 1 to 4; however, the absolute humidity fluctuates greatly. Therefore, the adsorption and desorption of moisture of CF is confirmed. In Wall 2 with a ventilation layer, the absolute humidity fluctuation is slightly larger than in Wall 1 without a ventilation layer, and the exchange of moisture between the outside air and ventilation layer is increased. For Walls 3 and 4 on the south side, the temperature and humidity on the outside air side exhibit almost the same behavior; however, on the indoor side, the relative humidity is higher at Wall 4 with the earth wall finish. From this, it is confirmed that CF, which is used as a heat insulating material, also adsorbs and desorbs moisture from the interior side when there is no vapor barrier, such as vinyl cloth, on the interior side. In these walls, the relative humidity on the CF surface is sufficiently low, and internal dew condensation does not occur under conditions without internal moisture generation. In addition, the calculation results are in agreement with the measurement results for both temperature and humidity, and the validity of the simulation is confirmed.

Table 3. Calculation conditions

Calculated wall	Indoor condition	Outdoor condition
Wall 1 (Entrance)	Stair hall	Outdoor measurement
Wall 2 (Hallway on the second floor)	Room 2	
Wall 3 (Room 2)	Room 1	
Wall 4 (Japanese style room)	Japanese style room	

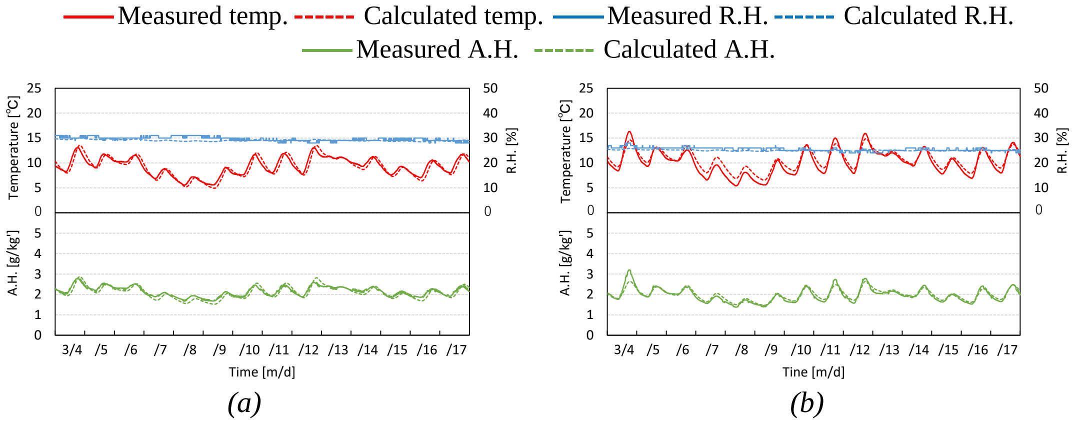
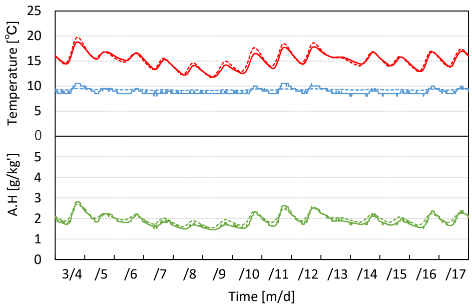


Figure 4-(a). Wall 1 (Entrance, without ventilation layer), outside of CF
Figure 4-(b). Wall 2 (second hallway, standard wall composition), outside of CF



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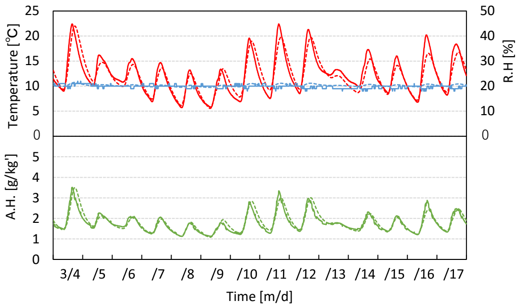
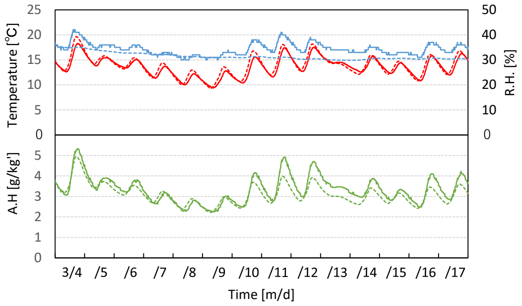
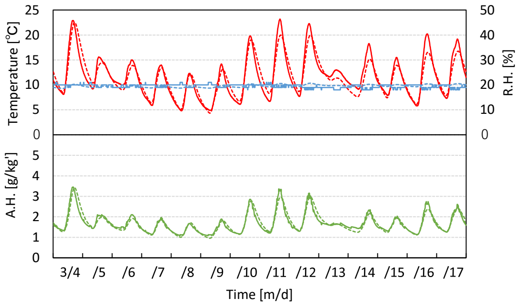


(d)

Figure 4-(c). Wall 3 (Bedroom 1, vinyl cloth), inside of CF
Figure 4-(d). Wall 3 (Bedroom 1, vinyl cloth), outside of CF



(e)



(f)

Figure 4-(e). Wall 4 (Japanese style room, earth wall), inside of CF
Figure 4-(f). Wall 4 (Japanese style room, earth wall), outside of CF
Figure 4. Measurement and calculation results (March 4th - March 17th, 2017)

4. Evaluation of anti-condensation performance

4.1. Calculation condition

The anti-condensation performance of the external wall was evaluated by Hygrabe. For the calculation conditions, the confirmation method of the dew condensation performance [2] according to the energy saving standard in Japan was used. Equation 1 is the calculation formula for the indoor temperature and humidity conditions. For the outside air condition, the temperature and relative humidity of the Expanded AMeDAS weather data (EA weather data, standard year) were used. Table 4 shows the wall structure used for the calculation. Walls 1 and 2, which differ according to the presence or absence of the ventilation layer in the demonstration house, are based, and a vapor barrier is present on the interior side of all walls because the conditions change depending on the presence or absence of wooden fiberboard and the kind of heat insulation material. Table 5 shows the physical properties of CF and glass fiber heat insulation (GW) used as thermal insulation materials. In addition, as shown in Table 6, the calculation target areas were Areas 1 to 6, among which 1 to 8 areas classified according to the energy conservation standards, the solar radiation amount is expected to be equivalent. The minimum thickness of thermal insulation material specified by the energy saving standard in each region is used. The calculation period based on the confirmation method of the anti-condensation performance is three years, starting from July 1, of which the period used to confirm the performance is from December 1 to April 30. In addition, when the relative humidity inside the wall remains a maximum 98%, internal dew condensation does not occur, and the anti-condensation performance is evaluated. Because the performance criterion in this study is winter, the outside air-side surface of the thermal insulation material, which is likely to cause winter dew condensation, was used as the performance confirmation site.

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$$T = 7.0\cos\frac{2\pi(D-212)}{365} + 20.0 \quad (1)$$

T: Temperature, D: Total number of days starting from January 1st
Relative humidity: 70% (constant)

Table 4. Wall pattern

Thermal insulation	Without ventilation layer		With ventilation layer	
	Without wood fiber board	With wood fiber board	Without wood fiber board	With wood fiber board
CF	Wall 1-CF	Wall 1-CF/W	Wall 2-CF/V	Wall 2-CF /V/W
GW	Wall 1-GW	Wall 1-GW/W	Wall 2-GW/V	Wall 2-GW/V/W

Table 5. Physical properties of thermal insulation

Thermal insulation	Thermal conductivity [W/m·K]	Specific heat [J/kg·K]	Specific weight [kg/m^3]	Moisture conductivity [kg/m·s·Pa]	Moisture capacity [m^3/m^3(kJ/kg)]
CF	0.039	1880.0	35.0	8.550E-12	8.013E-05
GW	0.039	840.0	56.0	1.200E-10	7.248E-07

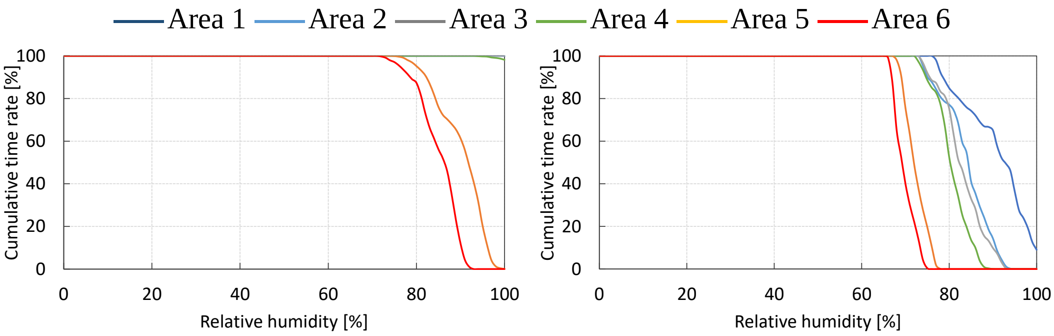
Table 6. Object area for calculation

Area classification	Location	Insolation area classification
1) Area 1	Kushiro, Hokkaido	A3, H3
2) Area 2	Hakodate, Hokkaido	
3) Area 3	Hakuba, Nagano	
4) Area 4	Kesennuma, Miyagi	
5) Area 5	Sagamihara, Kanagawa	
6) Area 6	Tokyo	

4.2. Calculation results

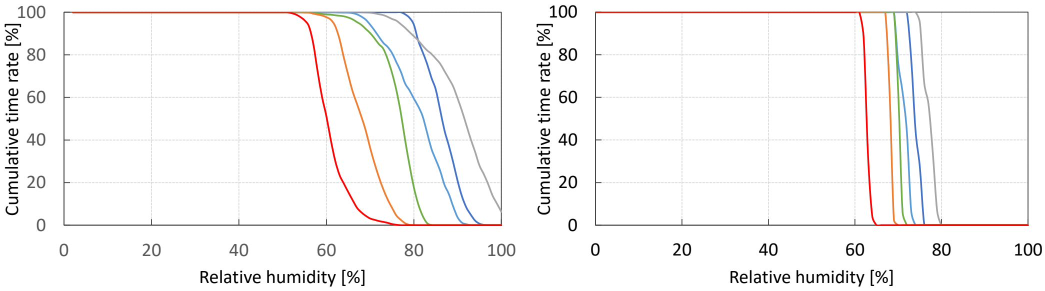
4.2.1. Thermal insulation CF

Figure 5 shows the calculation results for the CF heat insulation material. In all walls, the relative humidity inside the wall tends to increase in colder areas. For Wall 1-CF, which does not have both a ventilation layer and a wood fiberboard, slight condensation is confirmed in Area 5 and it is confirmed that condensation is prevented in Area 6. Regarding Wall 1-CF/W with only the wood fiber board and Wall 2-CF/V with only the ventilation layer, the relative humidity tends to decrease in the case of Wall 2-CF/V in areas excluding Area 3. In Hakuba, Nagano Prefecture, which is the area to be calculated as Area 3, because a large amount of snowfall is expected in the winter, the tendency is different when there is a ventilation layer. With regard to the anti-condensation performance, dew condensation occurred only in Area 1 for Wall 1-CF/W, and only in Area 3 for Wall 2-CF/V, and these have a similar performance. In addition, it was confirmed that Wall 2 with both a ventilation layer and a wood fiber board prevented internal condensation in all areas.



(a) (b)

Figure 5-(a) Wall 1-CF (without ventilation layer and wood fiber board)
Figure 5-(b) Wall 1-CF/W (without ventilation layer, with wood fiber board)

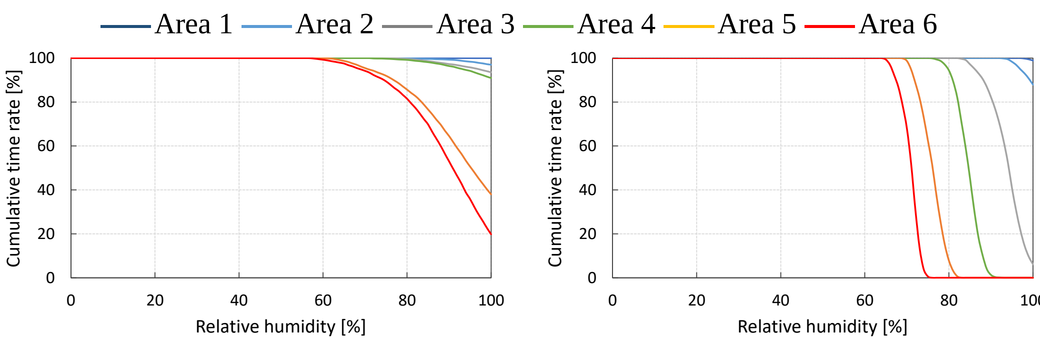


(c) (d)

Figure 5-(c) Wall 2-CF/V (with ventilation layer, without wood fiber board)
Figure 5-(d) Wall 2- CF/V/W (with ventilation layer and wood fiber board)
Figure 5. Calculation result (thermal insulation material CF)

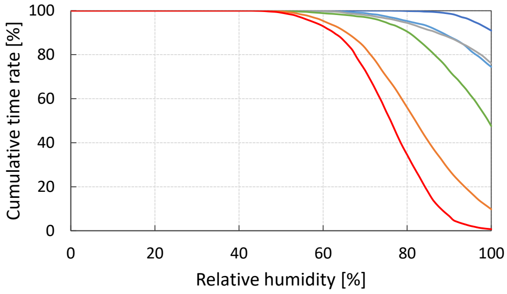
4.2.2. Thermal insulation GW

Figure 6 shows the results for the GW thermal insulation material. Walls 1-GW and 2-GW/V without wood fiber board confirmed the occurrence of condensation in all areas. For Walls 1- GW/W and 2-GW/V/W with wood fiber board, although it is possible to confirm the anti-condensation performance in the relatively warm Areas 4 to 6, condensation is not prevented for cold Areas 1 to 3. In addition, the tendency that the relative humidity in the wall increases in colder areas is the same as that for the CF case. However, in the case of GW, the time during which the relative humidity in the wall is generally high increases, thereby increasing the risk of internal condensation.



(a) (b)

Figure 6-(a) Wall 1-GW (without ventilation layer and wood fiber board)
Figure 6-(b) Wall 1-GW/W (without ventilation layer, with wood fiber board)



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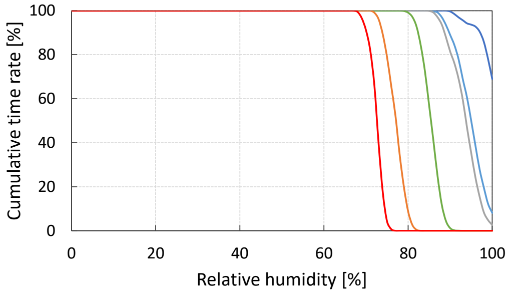

(d)

Figure 6-(c) Wall 2-GW/V (with ventilation layer, without wood fiber board)
Figure 6-(d) Wall 2- GW/V/W (with ventilation layer and wood fiber board)
Figure 6. Calculation result (thermal insulation material GW)

5. Conclusion

In this study, we investigated the anti-condensation performance of walls containing cellulose fiber insulation, which is a hygroscopic building material. The cellulose fiber thermal insulation used in the wall adsorbs and desorbs moisture; thus, the relative humidity inside the wall maintains a constant value regardless of temperature change. In a wall containing a cellulose fiber heat insulation material, even when there is no vapor barrier on the interior side, the dew condensation performance is ensured by installing a ventilation layer and wood fiber board, and condensation can be prevented in all areas.

6. References

[1] Ozaki A and Tsujimaru T 2005 Prediction of hygrothermal environment of buildings based upon combined simulation of heat and moisture transfer and airflow *Proceedings of 9th International IBPSA Conference* pp 899–906.
[2] Housing Performance Assessment and Labeling Association 2015 *Test guideline on thermal environment (Measures to prevent the occurrence of condensation) based on calculation result [Japanese]*.