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The Hygric Performances of Moisture Adsorbing/Desorbing Building Materials

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ABSTRACT

Controlling indoor relative humidity is of great importance in the evaluation of thermal comfort and perceived air quality. This study aimed to develop a new mineral fiber board as an interior surface material with high capacity of moisture adsorption and desorption. A series of experiments were carried out in this study using an accurately controlled chamber, mock-up rooms, and real-scale test houses. The chamber test was conducted to measure the moisture adsorption and desorption content of the materials. In the mock-up rooms, the effects of the new mineral fiber board on indoor humidity were investigated under three different conditions. The three different conditions include: 1) a mock-up room with an electric humidifier, 2) a mock-up room with an open water basin, and 3) a mock-up room without artificial humidifying measures. In the real-scale test houses, the efficiency of the new mineral fiber board was also investigated under two different conditions of low-humidity and very high-humidity. Through the chamber test, it was found that the moisture adsorption content of the new mineral fiber board was three times more than that of the ordinary mineral fiber board. The moisture desorption content of the new board was also two and half times more than that of the ordinary mineral fiber board. In the mock-up test, the newly developed mineral fiber board could also control indoor humidity levels effectively by desorbing moisture under low humidity conditions. However, through the real-scale test, it was found that the new mineral fiber board could not absorb or desorb indoor moisture effectively if extremely dry or humid conditions last for a long time. Overall, the new mineral fiber board was proven to be effective in controlling indoor moisture except under extremely dry or humid conditions.

Keywords*:* Moisture adsorption/Desorption property; Interior surface materials; Mineral fiber board; Chamber test; Mock-up room test; Relative humidity.

INTRODUCTION

Relative humidity levels influence indoor environmental quality and occupants' thermal comfort. At a very low humidity level, there may be complaints of dry noses, mouths, eyes, and skin, and increases of respiratory illnesses (Lechner, 1989). When excessive moisture accumulates in buildings or on building materials, some building occupants, particularly those with allergies or respiratory problems, may be exposed to adverse health risks due to the problem of mold growth. Humidifiers and dehumidifiers are the most common and conventional ways to control indoor relative humidity in buildings. Another effective way of controlling relative humidity fluctuations without consuming electric energy is to use porous materials that have the ability of absorbing and releasing moisture from and to the adjacent environment (Abadie and Mendoncav, 2009). In particular, various types of porous building materials with moisture adsorption/desorption properties have been introduced to the market in countries which have a hot and humid climate. Previous studies have been conducted to evaluate the hygric buffering capability of various types of building materials as follows:

Abadie and Mendonca (2009) have evaluated the moisture performance of building materials commonly found in buildings, including concrete and cement, plasterboard, brick, particle, fiberboards and wood. Pavilk and Cerny (2008), Pavilk and Cerny (2009) and Toman *et*

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al. (2009) evaluated the hygrothermal performance of interior thermal insulation systems including hydrophilic mineral wool. In addition, experimental protocols have been suggested to evaluate the hygrothermal performance of building materials. In the NORDTEST project (Rode, 2005) an experimental protocol has been proposed that specifies a moisture buffer value that includes in its definition the surrounding air vapor concentration variation (Rode *et al.,* 2006; Abadie and Mendoncav, 2009; Janssen and Roels, 2009) Other experimental methodologies to evaluate the hygrothermal performance of building materials have been proposed in the Japanese Industrial Standard (JIS) (JIS A 1470-1, 2002) and the International Standards Organization (ISO) (ISO 24353, 2008).

The purpose of this study is to evaluate and compare the moisture adsorption/desorption performances of an interior building material through chamber test, mock-up test and real scale test. The hygrothermal performance of the material was measured by the chamber in accordance with the ISO 24353 standard. In the mock-up test and the real-scale test, the moisture adsorption/desorption properties were examined, by comparing the changes in indoor relative humidity variations of mock-up rooms and real-scale houses obtained by other conditions.

METHODS

Tested Building Materials

In this study, moisture adsorption/desorption properties of interior building materials including an ordinary mineral fiber board, a new mineral fiber board developed in this study, and an ordinary gypsum board were compared using chamber tests, mock-up room tests and real-scale tests. Table 1 shows the physical properties of the tested materials.

The ordinary mineral fiber board was manufactured as a ceiling tile and it was made of mineral fibrous wool as its base material together with some chemical additives. It was manufactured through mixing, molding, drying, cutting, carving, surface finishing and spraying procedures. The mineral fiber board was evaluated as a good fire resistant, sound absorbing, and thermal insulation material (Thompson *et al*., 2002).

The new mineral fiber board was also made of mineral fibrous wool, but activated china clay was used as an additive. Due to its high degree of micro-porosity, the activated china clay has a high moisture adsorption/ desorption capacity within the normal indoor temperature and relative humidity ranges. Previous researches (Haneed, 2007; Eloussaief and Benzina, 2010) have shown that china clay can control the indoor relative humidity level by adsorbing moisture when the indoor moisture level is high and by desorbing moisture when it is low. Since both of the mineral boards have very similar sand patterns on the surfaces, it is not easy to distinguish the new mineral fiber board from the ordinary board.

The gypsum board is widely used as surface materials for interior walls and ceilings in the construction industry. It is usually manufactured through the processes of calcination of gypsum into plaster, producing slurry from the plaster, and passing the slurry through machines for shaping, setting, and cutting into a board. Fig. 1 shows the surface shapes of the tested materials.

Measurements in Chamber

The moisture control performances of three different materials were evaluated in a test chamber in accordance with the ISO 24353:2008. Fig. 2 shows the structure of the test chamber suggested in the ISO standard. It consists of an electronic balance, a moisture-proof box with a thermostat, a temperature sensor, a humidity gauge, and a humidifier. The size of each a specimen was 250 mm × 250 mm and the thickness is 12 mm. The side and rear surfaces of the specimens were isolated from the surrounding air by attaching with aluminum tape and foil so that only the front surface could adsorb or desorb moisture.

Before conducting moisture adsorption and desorption tests, the specimen was preconditioned inside the chamber with the ambient temperature of 23 ± 0.5°C and the relative humidity of 50% until the specimen reached a constant mass. The specimen was considered to have reached a constant mass when the rate of mass increase was less than 0.01 g in 24 hours.

Moisture adsorption/desorption tests were then performed by maintaining the relative humidity levels inside the chamber. First, a moisture adsorption test was carried out at 75% RH for 12 hours. A desorption test was then performed at 50% RH for an additional 12 hours.

During the 24 hour moisture adsorption/desorption tests, the mass change of the test specimen was measured at a 10 minute interval to the nearest 0.01g. The mass was then recorded at the end of the first 12 hour period as the result of the moisture adsorption process, and at the end of the second 12 hour period as the result of the desorption process.

Measurements in Mock-up rooms

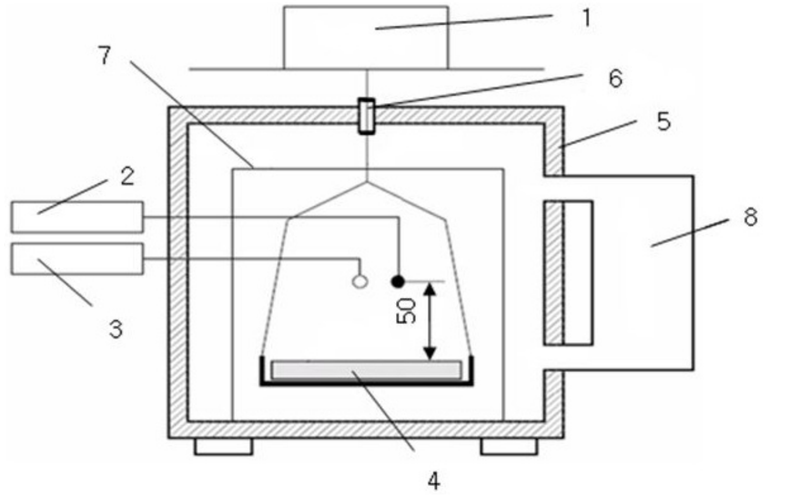
The hygric performances of the interior building materials were also tested in mock-up rooms. The mock-up tests were carried out in four test room of a 2 story mock-up building located in the Korea Institute of Construction Technology. The floor area of each room is 14.19 m^2, and the volume is 32.64 m^3. The air change rate of the mock-up room is 3.8 1/h at 50 pa.

Table 1. Physical properties of tested materials.

Product	Material	Thickness (m)	Density (kg/m^3)	Moisture content (%)
Mineral fiber board	Mineral fibrous wool	0.012	300	1.3
New mineral fiber board	Mineral fibrous wool + Activated China clay	0.012	340	2.3
Gypsum board	Gypsum	0.0095	610	0.2

(a) Mineral fiber board (b) New mineral fiber board (c) Gypsum board

Fig. 1. Surface shape of tested materials.



1: Electronic balance; 2: Hygrometer; 3: Thermometer; 4: Specimen; 5: Moisture-proof boc; 6: Rubber plug; 7: Windscreen; 8: Programmable air conditioner.

Fig. 2. Test apparatus suggested by ISO 24353.

Fig. 3 shows the floor plan of the mock-up building. The ceilings of the rooms 1 and 3 were finished with the ordinary mineral fiber boards, while the ceilings of the rooms 2 and 4 were finished with the new mineral fiber boards. The walls and floors of the four mock-up rooms were finished with the gypsum boards.

The measurement cases of the mock-up test are summarized in Table 2. Electric humidifiers and open water basins were used in order to simulate higher humidity conditions.

In Case 1, electric humidifiers were operated in rooms 1 and 2. Case 2 was also conducted in rooms 1 and 2 after the Case 1 was finished, but open water basins were used as a humidifying measure. In Case 3, rooms 3 and 4 were maintained in natural condition without humidifier or open water basin in order to simulate lower humidity conditions.

Fig. 4 shows the features of three different humidifying conditions in the mock-up test. The indoor humidity levels and temperatures of each room were measured using a temperature/humidity logger (Sato, SK-L200TH-II).

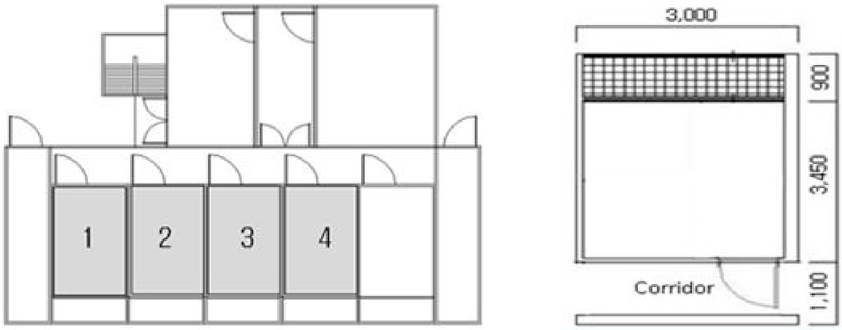
In Case 1 with electric humidifiers, the measurement was conducted for 6 days. The room temperatures in both rooms were maintained at 21°C to 24°C by radiant floor heating. The electric humidifier in each room was operated for two days and the average humidification rate was 0.125 ℓ/h. In Case 2 with open water basins, the measurement was conducted for 28 days. The rooms were also maintained to be at the same temperatures as in Case 1. In each room, about three liters of water were naturally vaporized from the open water basin over 28 days at an average vaporization rate of 0.0045 ℓ/h.

In Case 3, the measurement lasted for 62 days, and the room temperature ranged from 21°C to 26°C. The room temperature was a little higher than that of rooms 1 and 2 because no sensible heat was transformed into latent heat.

Measurements in Real-scale Test Houses

The hygrothermal performance of the interior building materials was also investigated and compared in two real-scale test houses. The test houses are also located in the Korea Institute of Construction Technology. Each test house consists of 3 bedrooms, 2 bathrooms, a living room, and a kitchen. The volume of each test house is 169.65 m^3, and the air change rate of is 8.3 1/h at 50 pa.

The new mineral fiber boards were installed on the ceiling the of test house A and the ordinary mineral fiber



(a) floor plan (b) floor plan detail

Fig. 3. Floor plan of the mock-up building.

Table 2. Measurement cases of the mock-up test.

Section	Case 1		Case 2		Case 3	
No.	Room 1	Room 2	Room 1	Room 2	Room 3	Room 4
Test period	Feb. 28–Mar. 5		Mar. 10–Apr. 6		Feb. 28–Apr. 30	
Humidification Method	E.H	E.H	O.B	O.B	N	N
Ceiling	M	N.M	M	N.M	M	N.M
Floor	G	G	G	G	G	G
Wall	G	G	G	G	G	G

E.H: Electric humidifier; O.B: Open water basin; M: Mineral fiber board; N.M: New mineral fiber board; G: Gypsum board; N: Natural condition without humidifier(none).

(a) electric humidifier (rooms 1 and 2) (b) open water basin (rooms 1 and 2) (c) none (rooms 3 and 4)

Fig. 4. Humidifying conditions in the mock-up rooms.

boards were installed on the ceiling of test house B. The walls and floors of the both house were equally finished with the gypsum boards and wall papers equally. The measurement cases of the real-scale test are summarized in Table 3.

The indoor relative humidity levels of the two real-scale test houses were measured during two different periods. The Case 4 was conducted in test house A for 24 days from December 1 to December 24 to investigate the absorption/ desorption performance of the materials under middle levels of outdoor relative humidity condition. The indoor temperatures in both houses were maintained at around 10°C by radiant floor heating. The Case 5 was conducted in test house B for 32 days from Jun 15 to July 17, 2009 investigate the performance of the materials under higher outdoor relative humidity condition. In this case, the two test houses were not air-conditioned.

RESULTS AND DISCUSSION

Chamber Test Results

The moisture contents, the moisture content differences, and moisture adsorption/desorption rates were calculated with the measured data using Eq. (1)–(4) according to the ISO 24353:2008 standard.

Moisture adsorption content

$$\rho_{A,a} = \frac{m_a - m_o}{A} \quad [kg/m^2] \tag{1}$$

Table 3. Measurement cases of the real-scale test.

Section	Case 4		Case 5	
Test house No.	A–test house	B–test house	A–test house	B–test house
Test period	Dec. 1–Dec. 24		Jun. 15–Jul. 17	
Wall	G + W.P	G + W.P	G + W.P	G + W.P
Ceiling	N.M	M	N.M	M
Floor	P.F	P.F	P.F	P.F

M: Mineral fiber board; N.M: New mineral fiber board; G: Gypsum board; W.P: Wall Paper; P.F: Plywood Flooring.

Moisture desorption content

$$\rho_{A,d} = \frac{m_a - m_d}{A} \quad [kg/m^2] \tag{2}$$

Moisture content difference between adsorption and desorption

$$\rho_{A,s} = \rho_{A,a} - \rho_{A,d} \quad [kg/m^2] \tag{3}$$

Moisture adsorption/desorption rates at time *n*

$$G_n = \frac{m_n - m_{n-1}}{\Delta t} \quad [kg/m^2 \cdot h] \tag{4}$$

Among the three specimens, the new mineral fiber board showed a dramatic mass change throughout the adsorption and desorption processes.

The moisture adsorption and desorption performances of the materials are clearly explained in Table 4 including the measured masses and calculated moisture contents from the chamber tests.

The moisture adsorption content of the new mineral fiber board was three times more than that of the ordinary mineral fiber board, and five times more than that of the gypsum board. The moisture desorption content of the new board was also two and half times more than that of the ordinary mineral fiber board, and four times more than that of the gypsum board.

Fig. 5 shows the moisture adsorption/desorption rates calculated by equation 4 based on the measured moisture adsorption/desorption contents during the 24 hour test period. As clearly indicated in the graphs, most of the moisture was adsorbed and desorbed during the first three hours of each process.

Table 4. Measurement results of the chamber test.

Category	New mineral fiber board	Mineral fiber board	Gypsum board
A(m^2)	0.0625	0.0625	0.0625
m_o (10^{-3}kg)	0.00	0.00	0.00
m_a (10^{-3}kg)	2.47	0.83	0.47
m_d (10^{-3}kg)	0.48	0.02	0.00
$\rho_{A,a}$ (g/m^2)	39.5	13.3	7.5
$\rho_{A,d}$ (g/m^2)	31.8	13.0	7.5
$\rho_{A,s}$ (g/m^2)	7.7	0.3	0.0

Mock-up Room Test Results

In Case 1, the ceilings of rooms 1 and 2 were finished with the ordinary mineral fiber board and the new mineral fiber board respectively and an electric humidifier was operated in each room. Fig. 6 shows the relative humidity profiles of Case 1, and Table 5 shows the temperatures and relative humidity values of each room. The humidity values of room 2 were always lower than those of room 1. The average relative humidity of room 2 with the new mineral fiber board was about 13.9% points lower than that of room 1. Fig. 7 shows the relative humidity profiles of Case 2 where open water basins were placed in the middle of rooms 1 and 2. The humidity values of room 2 were maintained lower than those of room 1 in common with Case 1. The average relative humidity of room 2 was also 11.9% points lower than that of room 1.

From the measurement results of Cases 1 and 2 where the artificial humidifying means were used it was proven that the new mineral fiber board could control indoor humidity levels effectively by absorbing moisture under high humidity conditions.

Figs. 8 and 9 show the relative humidity and absolute humidity profiles of Case 3. In this case, the ceilings of rooms 3 and 4 were finished with the ordinary mineral fiber board and the new mineral fiber board, respectively. The rooms were maintained in natural conditions without any humidifier.

As shown in Table 5, the average absolute humidity of room 4 with new mineral fiber board was higher than the average outdoor humidity, even though there was no intentional moisture source inside. According to Fig. 9 showing the absolute humidity profiles, the absolute humidity levels in room 4 were higher than outdoor absolute humidity during the early periods of the measurement, but after a certain period of time the absolute humidity levels in room 4 were distributed in the middle ranges of outdoor absolute humidity levels. For example, during the period between February 28 and March 15, the average absolute humidity of room 4 was 0.0052 kg/kg′, which is higher than average outdoor absolute humidity, 0.0035 kg/kg′. During the period between April 15 and April 30, however, there was no significant difference between the average absolute humidity of room 4, 0.0051 kg/kg′, and the average outdoor absolute humidity, 0.0050 kg/kg′. The higher humidity levels of room 4 in the early stages might be due to the moisture absorbed by the boards during transport, storage, and curing process. It seemed that the boards absorbed and desorbed indoor moistures

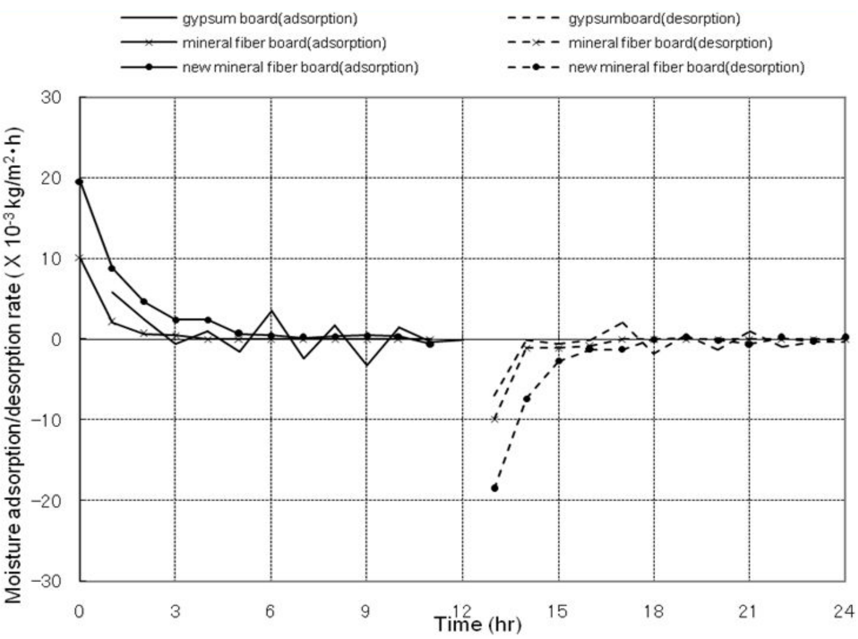


Fig. 5 Moisture adsorption/desorption rates of tested materials.

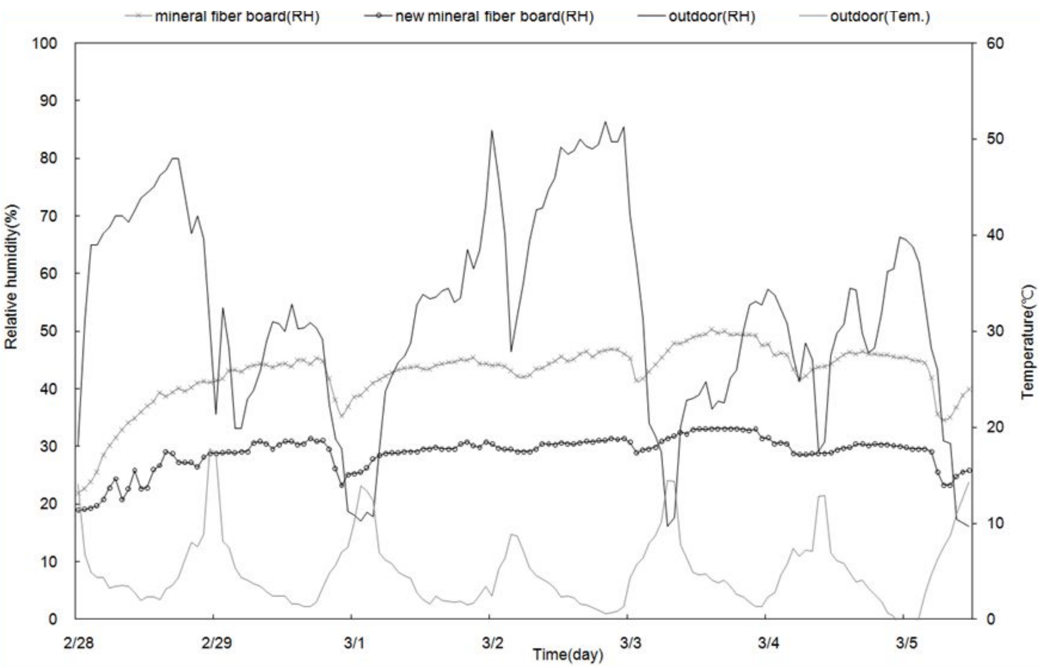


Fig. 6. Relative humidity profiles of Case 1(with electric humidifier).

Table 5. Measurement results of the mock-up test.

		Temperature (°C)	Relative humidity (%)	Absolute humidity (kg/kg′)
Case 1	Mineral fiber board	22.9 ± 1.1	42.8 ± 5.2	0.0074 ± 0.0008
	New mineral fiber board	22.8 ± 1.1	28.9 ± 3.0	0.0049 ± 0.0005
	Outdoor	4.9 ± 3.7	53.0 ± 17.9	0.0027 ± 0.0008
Case 2	Mineral fiber board	21.9 ± 1.2	45.0 ± 4.2	0.0073 ± 0.0005
	New mineral fiber board	22.1 ± 1.1	33.1 ± 3.5	0.0054 ± 0.0005
	Outdoor	10.6 ± 4.3	55.6 ± 21.6	0.0041 ± 0.0012
Case 3	Mineral fiber board	23.8 ± 1.9	21.3 ± 1.4	0.0038 ± 0.0003
	New mineral fiber board	23.1 ± 1.7	28.9 ± 2.4	0.0051 ± 0.0004
	Outdoor	11.6 ± 5.6	54.1 ± 20.1	0.0042 ± 0.0013

effectively after fully desorbing the absorbed moisture for a few days.

From these measurements, it was proven that the newly developed mineral fiber board could also control indoor humidity levels effectively by desorbing moisture under low humidity conditions.

For example, the new mineral fiber board can effectively adsorb indoor moisture generated from daily activities such as cooking, dish washing and clothes drying, and then can desorb the moisture back into the space when the humidity level decreases.

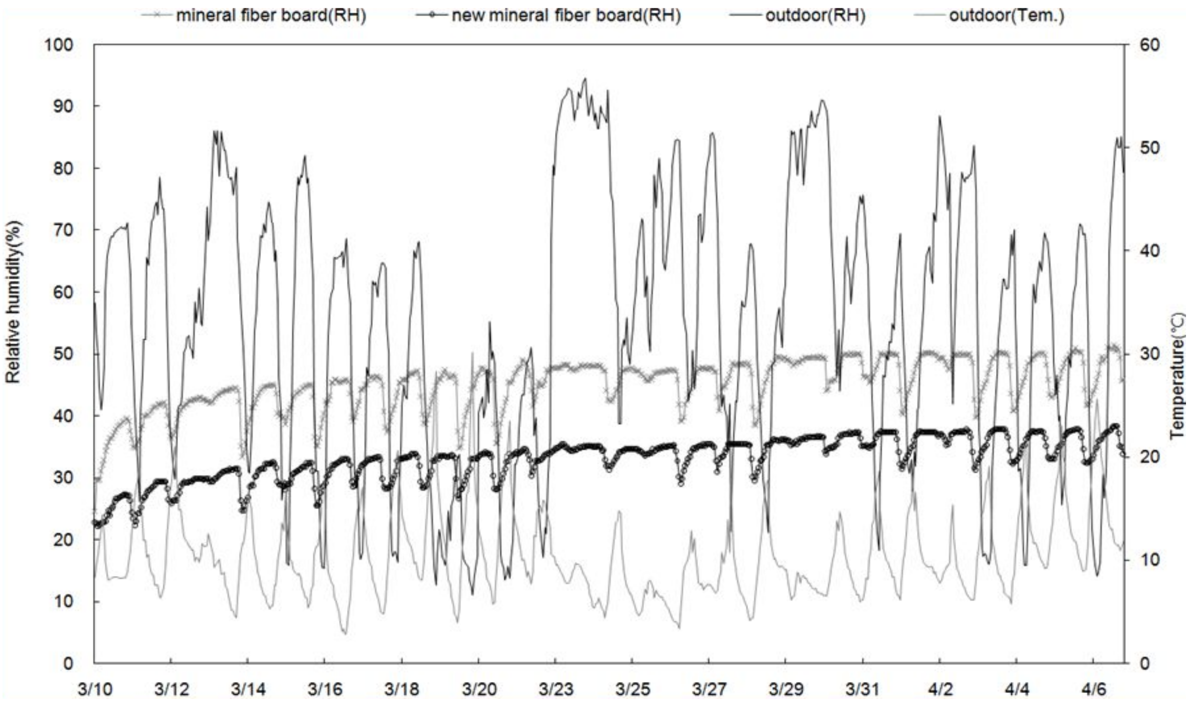


Fig. 7. Relative humidity profiles of Case 2 (with open water basin).

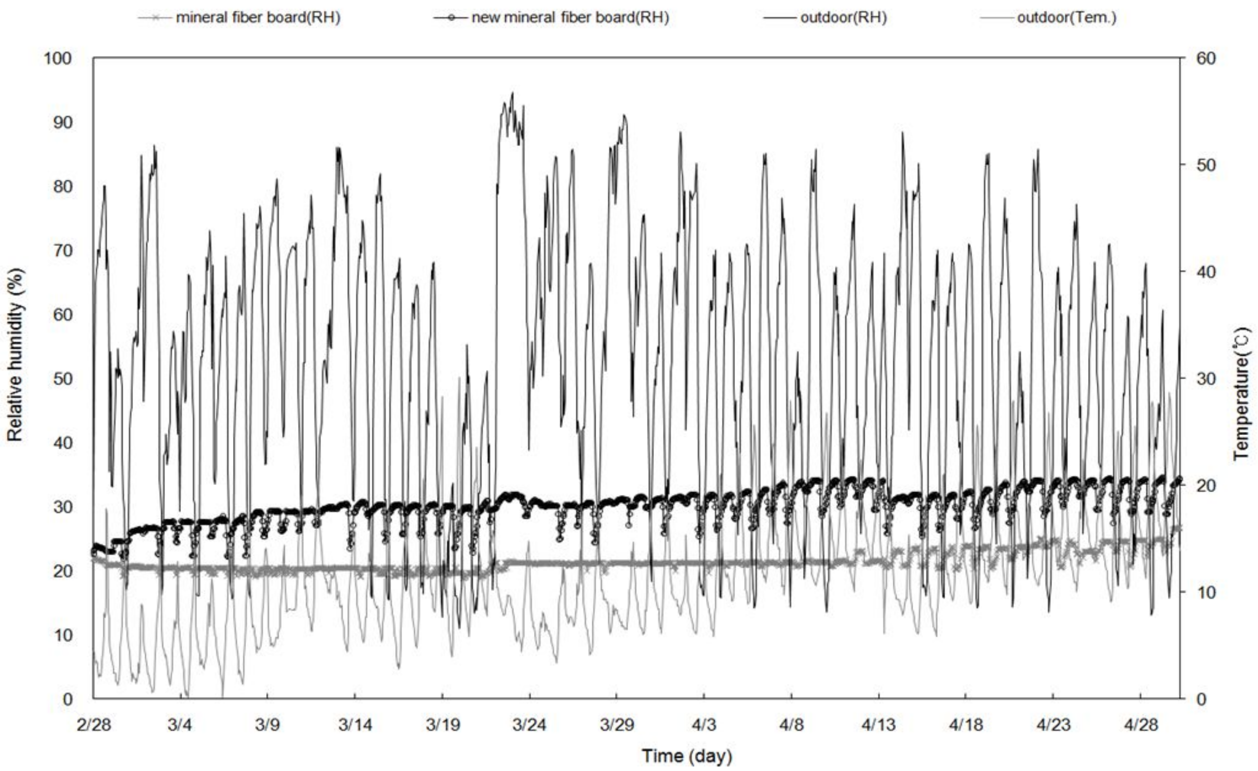


Fig. 8. Relative humidity profiles of Case 3 (natural condition).

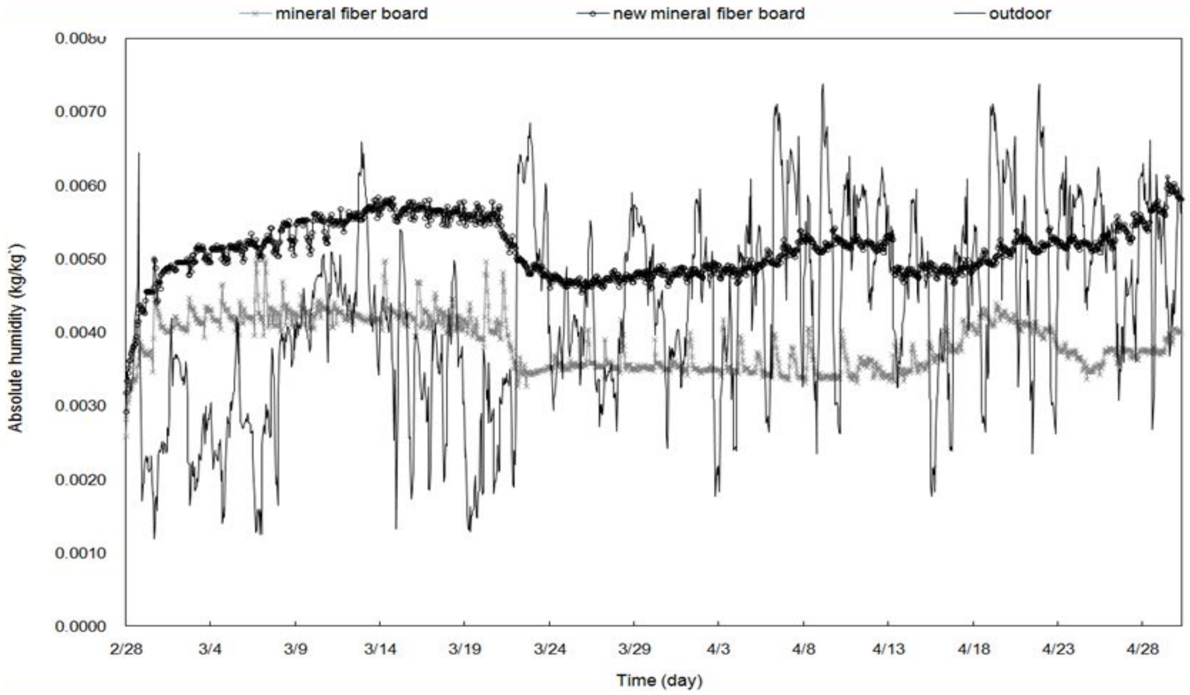


Fig. 9. Absolute humidity profiles of Case 3 (natural condition).

Real-scale Test Results

Fig. 10 shows the relative humidity profiles of Case 4. The ceilings of test house A and B were finished with the new mineral fiber board and the ordinary mineral fiber board, respectively. According to Table 6, the average outdoor absolute humidity as well as the average absolute humidity levels of two test houses were very low. The average absolute humidity of test house A was even lower than the average outdoor relative humidity, while that of test house B was equal to the average outdoor relative humidity. The new mineral fiber board might to absorb indoor moisture since the amount of moisture inside the material was too low. If extremely dry conditions last for a long time, it may not be possible to effectively control indoor humidity by using the mineral fiber board. However, since plenty of moisture-emitting activities occur inside a building, it is expected that the new mineral fiber board adsorbs indoor moisture and then desorbs when the humidity level decreases.

Fig. 11 shows the relative humidity profiles of Case 5. The average outdoor absolute humidity, 0.0150 kg/kg′, was much higher than that of Case 4. There was no significant difference in the absolute humidity between test houses A and B. It seemed that the new mineral fiber board could not absorb indoor moisture since it must be fully saturated due to very humid ambient air. Therefore, if extremely humid conditions last for a long time, it may not be possible to effectively control indoor humidity by using the mineral fiber board.

CONCLUSION

Mechanical humidification and dehumidification are the most common and conventional ways to control indoor relative humidity in buildings. However, the mechanical control of indoor humidity causes a great deal of energy consumption. The experimental assessment of the hygrothermal performance of the new mineral fiber board was carried out using the chamber test, mock-up tests and real-scale test houses.

The chamber test revealed that the moisture adsorption content of the new mineral fiber board was three times more than that of the ordinary mineral fiber board, and five times more than that of the gypsum board. The moisture desorption content of the new board was also two and half times more than that of the ordinary mineral fiber board, and four times more than that of the gypsum board.

The hygric performances of the interior building materials were also tested in mock-up rooms. From the mock-up measurements, it was proven that the newly developed mineral fiber board could also control indoor humidity levels effectively by desorbing moisture under low humidity conditions. However, from the real-scale test houses, it was found that the new mineral fiber board could not absorb or desorb indoor moisture effectively when extremely dry or extremely humid conditions last for a long time.

All these results from the mock-up tests and the real-scale test show that the new mineral fiber board was proven to be effective in controlling indoor moisture, except under extremely dry or humid conditions lasting for a long time.

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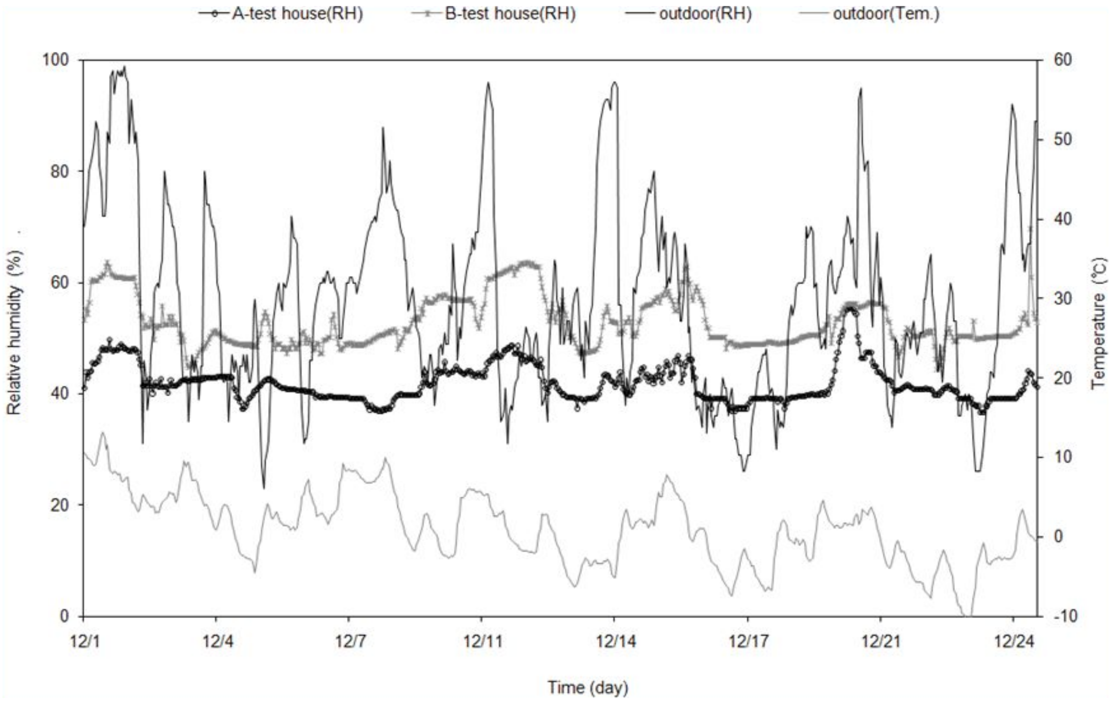

Fig. 10. Relative humidity profiles of Case 4.

Table 6. Measurement results of the real-scale test.

		Temperature (°C)	Relative humidity (%)	Absolute humidity (kg/kg′)
Case 4	A-test house	10.3 ± 2.5	41.8 ± 3.7	0.0020 ± 0.0008
	B-test house	11.4 ± 3.4	52.7 ± 4.9	0.0026 ± 0.0008
	Outdoor	1.1 ± 4.5	56.9 ± 16.9	0.0026 ± 0.0014
Case 5	A-test house	27.8 ± 2.0	49.9 ± 8.0	0.0134 ± 0.0025
	B-test house	28.0 ± 3.2	50.1 ± 8.8	0.0133 ± 0.0027
	Outdoor	26.3 ± 2.6	78.8 ± 12.6	0.0150 ± 0.0014

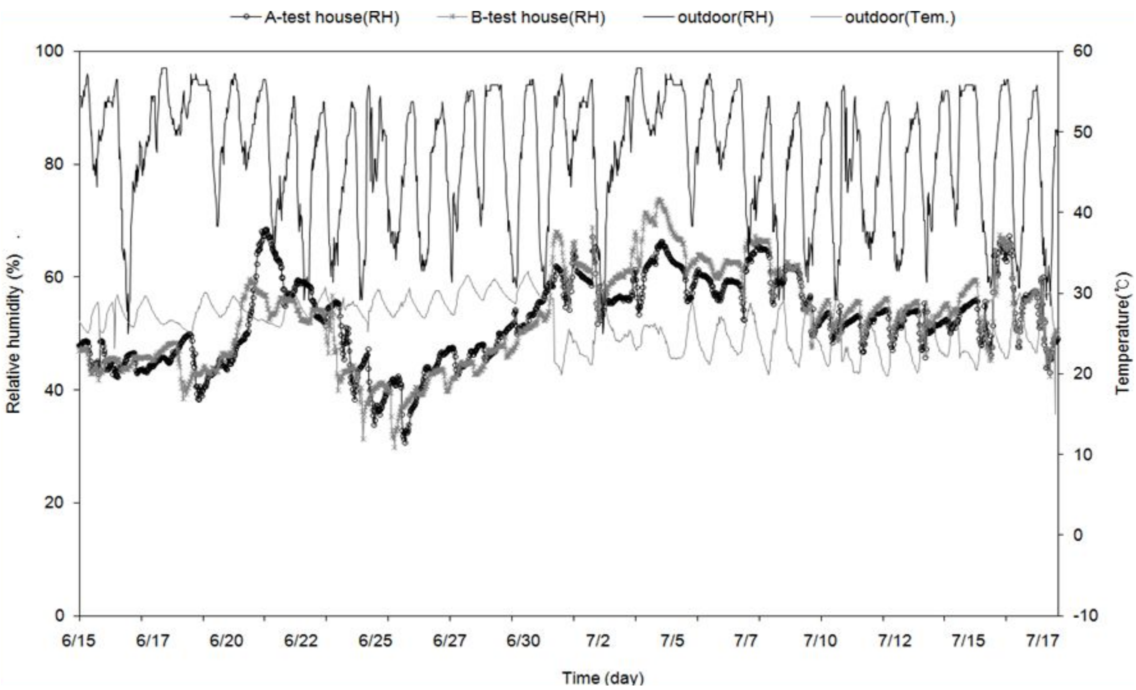

Fig. 11. Relative humidity profiles of Case 5.

NOMENCLATURE

Symbol	Description	Unit
A	Surface area of adsorption/desorption	m^2
G_n	Adsorption/desorption rate at time *n*	$kg/(m^2 \cdot h)$
m_o	Mass of the specimen after preconditioning	kg
m_a	Mass of the specimen at the time of completion of moisture adsorption process	kg
m_d	Mass of the specimen at the time of completion of moisture desorption process	kg
$\rho_{A,a}$	Change of moisture content at the time of completion of adsorption process	kg/m^2
$\rho_{A,d}$	Moisture desorption content at the time of completion of desorption process	kg/m^2
$\rho_{A,s}$	Difference between moisture absorption and desorption contents at the time of completion of the test	kg/m^2
m_n	Mass of specimen at time *n*	kg
m_{n-1}	Mass of specimen at time *n-1*	kg
Δt	Elapsed time	h

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