

MOISTURE-BUFFERING CHARACTERISTICS OF BUILDING MATERIALS

YOUNG CHEOL CHOI*, #SEONGCHEOL CHOI**, CHI WON SONG**, JI SOO LEE**

*High-Tech Construction Materials Center, Korea Conformity Laboratories, Seoul, Korea

**Department of Civil and Environmental Engineering, Chung-Ang University, Seoul, Korea

#E-mail: schoi@cau.ac.kr

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The humidity level of indoor air is an important factor influencing the air quality and energy consumption of buildings, as well as the durability of building components. Indoor humidity levels depend on several factors, such as moisture sources, air flow, and the adsorption/desorption properties of materials. The moisture-buffering characteristics of building materials that are in contact with indoor air may help moderate the variations of indoor humidity, especially in the summer and winter. In this study, the moisture adsorption/desorption properties of building materials were investigated experimentally and numerically. These properties can be used to characterize the ability of building materials to exchange moisture with the indoor environment. This study indicates that a building material's surface resistivity was the main factor creating variations of moisture buffering.

INTRODUCTION

Indoor humidity is an important parameter in a building's occupants' perception of the indoor air quality, and is closely related to potentially harmful processes such as microbial growth on the surfaces of materials. Several experimental and numerical studies [1-5] emphasized the importance of such interior moisture buffering to the overall interior humidity evolution. Interior moisture buffering is indeed shown to have positive effects on energy consumption, component durability, thermal comfort, and air quality. Therefore, quantitative and qualitative assessments of the interior moisture-buffering properties of building materials are required to enable the construction and maintenance of sustainable, durable, healthy, and comfortable buildings.

The use of building materials to maintain a balanced and comfortable indoor environment has been a topic of research in the field of hydrothermal conditions [6-10]. By appropriately applying hygroscopic building materials, it is possible to improve indoor humidity conditions in all climate zones.

In this study, the characteristics of moisture buffering in porous media were investigated using the numerical model, considering material properties such as surface exchange coefficient, vapor surface resistance factor, diffusivity, moisture capacity, and sorption iso-

therm. Based on the results in the numerical analysis, various building materials—gypsum board, wood-based materials and ceramic tile—were tested and analyzed.

THEORETICAL

Mechanism of moisture transfer

The internal moisture distribution of a building material changes in accordance with the variation of atmospheric humidity and the material's own moisture-related properties. Building materials are generally porous materials consisting of solid and porous components. Because the pore structures are irregularly shaped, analytically defining their boundaries is extremely difficult; therefore, the model used in this study employs equations and properties based on an average local volume. The following assumptions, which allow the problem to be simplified, can be reasonably made considering the experimental conditions:

- Moisture transfer through the building materials is one dimensional.
- The transport process within the building materials is pure diffusion of water vapor.
- Water vapor behaves as an ideal gas.
- Volume changes (swelling and shrinkage) due to humidity are negligible.

If the vapor concentration is the only potential considered for moisture flow, one-dimensional moisture vapor transfer can be expressed as

$$\frac{\partial w}{\partial t} = -\frac{\partial}{\partial x}(q_v) = -\frac{\partial}{\partial x}\left(-\delta_v \frac{\partial v}{\partial x}\right), \quad (1)$$

where w is moisture content ($\text{kg}\cdot\text{m}^{-3}$), t is time (s), q_v is moisture flux rate ($\text{kg}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$), v is vapor concentration ($\text{kg}\cdot\text{m}^{-3}$) and δ_v is the vapor permeability ($\text{m}^2\cdot\text{s}^{-1}$).

The rate of change of the moisture content can be rewritten using partial differentiation as

$$\frac{\partial w}{\partial t} = \frac{\partial w}{\partial v} \cdot \frac{\partial v}{\partial t}. \quad (2)$$

By assuming that the vapor permeability and the temperature are constant in the materials, Equations 1 and 2 yield:

$$\frac{\partial v}{\partial t} = \frac{1}{\left(\frac{\partial w}{\partial v}\right)} \delta_v \frac{\partial^2 v}{\partial x^2} = D_w \cdot \frac{\partial^2 v}{\partial x^2}, \quad (3)$$

where D_w is the moisture diffusivity ($\text{m}^2\cdot\text{s}^{-1}$), which can be formulated as

$$D_w = \delta_v \frac{1}{\left(\frac{\partial w}{\partial v}\right)}. \quad (4)$$

The vapor concentration v can be expressed in terms of the vapor concentration at saturation $v_s(T)$ and the relative humidity (RH) φ as

$$v = v_s(T) \cdot \varphi. \quad (5)$$

Substituting Equation 5 into Equation 4 yields Equation 6:

$$D_w = \frac{\delta_v \cdot v_s(T)}{\frac{\partial w}{\partial \varphi}} = \frac{\delta_v \cdot v_s(T)}{\xi}, \quad (6)$$

where ξ is the moisture capacity ($\text{kg}\cdot\text{m}^{-3}$), which is the derivative of moisture content with respect to the RH. Combining Equations 3 and 6, the governing equation of moisture transfer can be expressed as

$$\frac{\xi}{v_s(T)} \frac{\partial v}{\partial t} = \delta_v \cdot \frac{\partial^2 v}{\partial x^2}. \quad (7)$$

Because the surface layer of materials used inside buildings is very thin, this layer's effect on the vapor resistivity and moisture capacity can be reasonably assumed to be negligible. Each building material has a vapor permeability, δ_v , a moisture capacity, ξ , and a thickness, L . Figure 1 shows the geometry and the material parameters associated with one-dimensional moisture diffusion and drying in the materials.

The boundary and initial conditions associated with Equation 7 are expressed in Equations 8-10:

$$\frac{\partial v}{\partial x} = 0 \quad \text{for } x = L, \quad (8)$$

$$\frac{v_1 - v}{Z_x} = -\delta_v \frac{\partial v}{\partial x} \quad \text{for } x = 0, \quad (9)$$

$$v(x,0) = v_0 \quad \text{for } t = 0, 0 < x < L, \quad (10)$$

where Z_x is water vapor resistivity for the surface layer ($\text{s}\cdot\text{m}^{-1}$) and v_0 is the initial vapor concentration of the building material.

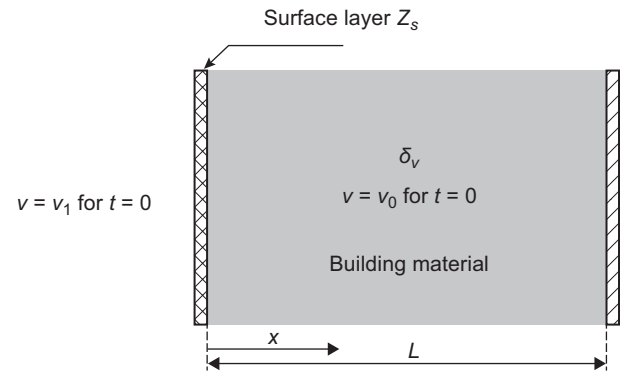


Figure 1. Geometry and the material parameters associated with one-dimensional moisture diffusion and drying in the building materials.

Moisture capacity

Since the hysteresis of the sorption isotherm is usually not critical in indoor environmental conditions, the numerical analysis in this study did not take it into consideration. Equation 7 requires an analytical formulation of the moisture capacity, which is the derivative of the moisture contents with respect to RH. The evaporable moisture content w is known to be highly dependent on the level of RH, as in Equation 11:

$$w = w_{sat} \{1 + [m \cdot \ln(\varphi)]^m\}^{(1-n)/n}, \quad (11)$$

where w_{sat} is the total amount of evaporable moisture at saturation, φ is the RH and m and n are fit parameters. By conducting a regression analysis of test data available in the existing studies, the fit parameters in Equation 11 were numerically estimated.

Effect of surface resistivity

The mass change of moisture in the building materials was numerically predicted when the surface resistivity was in the range of 3.3×10^4 and $3.3 \times 10^8 \text{ m}^2\cdot\text{s}\cdot\text{Pa}\cdot\text{kg}^{-1}$. In the numerical analysis, the initial RH was set at 75 % for the first 12 hours, and then changed to 50 % for another 12 hours. Figure 2a shows the changes of moisture contents in wood fiberboard when the surface resistivity changed. The change of moisture content indicates the weight change of adsorbed/desorbed water through the surface of the materials. The results indicate that the rate of moisture penetration was significantly affected by the surface resistivity of the material. Figure 2b presents the

variation of moisture change over the distance from the surface. More RH variations developed depending on the air RH as the distance decreased.

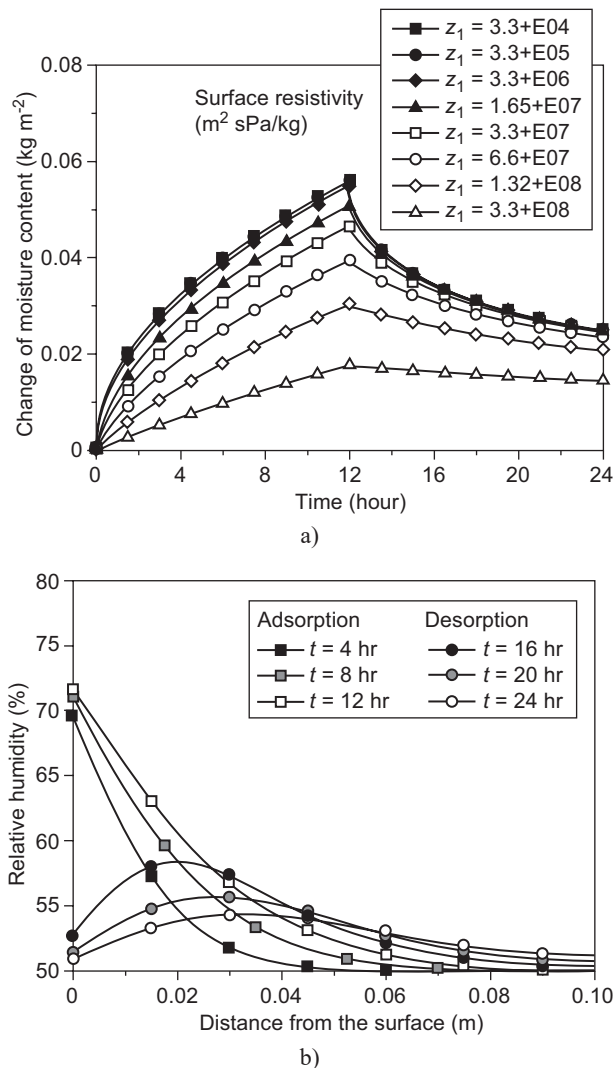


Figure 2. Effect of surface resistivity on change of moisture content (a) and relative humidity distribution in the materials (b).

Effect of moisture diffusivity

The diffusivity of building material is influenced by such factors as pore structure, specific surface area, pore RH, and temperature. As shown in Figure 3a, the influence of RH on the moisture diffusivity can be represented by Equation 12:

$$F_{RH} = \alpha_0 + \frac{1 - \alpha_0}{1 + \left(\frac{1 - \varphi}{1 - \varphi_c} \right)^N}, \quad (12)$$

where α_0 , φ_c and N are the fit parameters.

To evaluate the effect of environmental RH on the moisture content change of the materials, three different environmental RH histories (shown in Table 1)

were considered in the analysis. Figure 3b shows the measured moisture content changes when medium level RH history was applied and predicted changes when three histories were considered. The numerical results were similar to the experimental results. The maximum moisture content change of the materials subjected to a low RH level was about 2.1 times greater than those exposed to a high RH level.

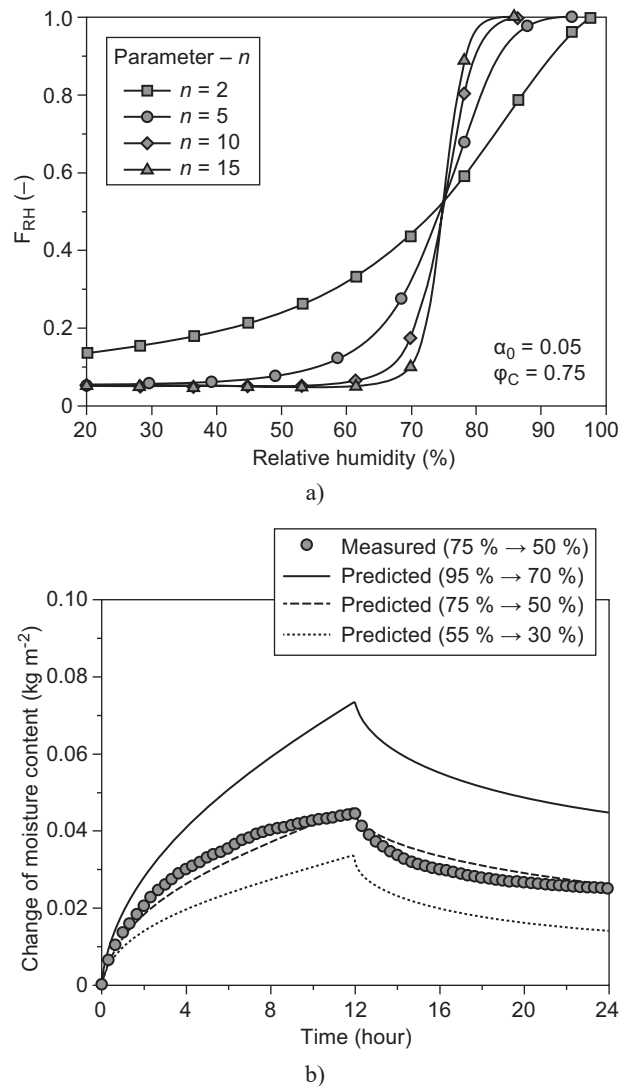


Figure 3. Effect of RH on the moisture diffusivity (a) and effect of environmental RH on the change of moisture content (b).

Table 1. Three different environmental RH histories.

RH history	Relative humidity (%)	
	Adsorption process for 12 hours	Desorption process for 12 hours
Low level	55	30
Medium level	75	50
High level	95	70

From the numerical tests, it can be concluded that appropriate air velocity and RH range are very important because the surface resistance of a building material is affected by air velocity, and the RH level is a key factor in moisture buffering.

EXPERIMENTAL

Preparation of specimens

Figure 4 shows the testing equipment used to evaluate the moisture-buffering performance of the various building materials tested. The equipment consisted of an environmental chamber, wind barrier, anemometer, electronic balance, thermometer, and hygrometer. The environmental chamber used can control the temperature and RH with an accuracy of $\pm 0.3^\circ\text{C}$ and $\pm 2.5\%$ RH, respectively.



Figure 4. Testing equipment used to evaluate the moisture-buffering performance of building materials.

Before the adsorption/desorption properties of the specimens were measured, the specimens were dried until their internal RH reached a state of equilibrium with the air, so that no weight changes in the specimens occurred any more. Since moisture exchanges usually occur only on one side of the materials within buildings, only the top surface of each specimen was exposed to the air, while the other surfaces were completely sealed with aluminum foil tape to ensure one-dimensional moisture diffusion and drying conditions. The air velocity, which can significantly affect the surface resistivity, was $0.1 \pm 0.05 \text{ m}\cdot\text{s}^{-1}$ at 5 cm above the specimens.

Test results

Figure 5a shows the sorption isotherm of a gypsum board with high sorption capacities. The moisture content indicates the amount of water that can be adsorbed per unit volume of the material. The sorption content was strongly nonlinear over the variation of RH and increased significantly as the RH increased. The content near the saturation point was about 2.8 times greater than in the low RH ranges. The results shown in Figure 5a can be effectively used in numerically predicting the moisture content of materials. Figure 5b shows the effects of time allotted to the adsorption/desorption processes on the moisture contents. The RH was maintained at 75 % and 50 %, respectively, in the adsorption and desorption processes for 6, 12 and 24 hours. The different levels of sorption contents were measured at different points in the two processes, and the results indicate that the sorption content is highly dependent on the length of time a material spends exposed to a particular RH level.

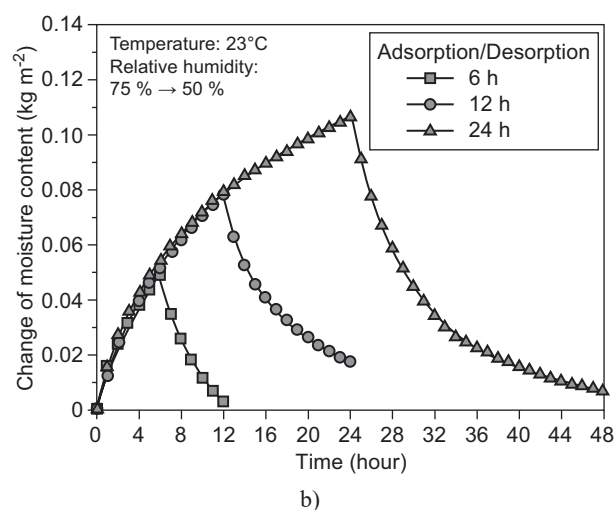
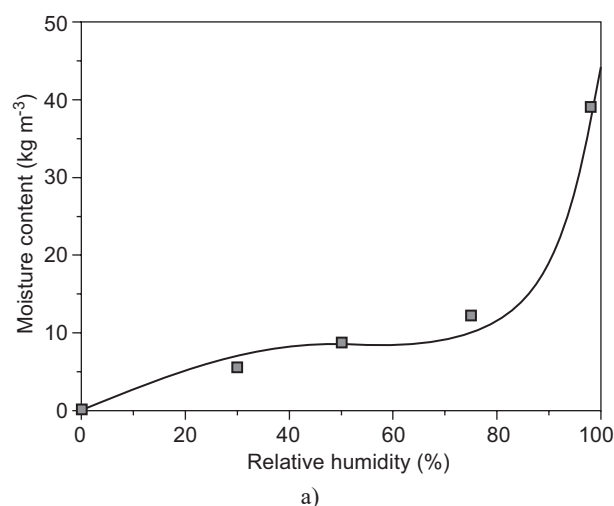


Figure 5. Sorption isotherm of gypsum board (a) and effect of adsorption/desorption periods on change of moisture content (b).

Figure 6a depicts the sorption content variations of the specimen over time when three different RH conditions were applied. The maximum adsorption contents subjected to high, medium and low levels of RH histories were 30.1, 45.0 and 124.6 $\text{g}\cdot\text{m}^{-2}$, respectively. Most of the moisture adsorbed in the specimens subjected to low and medium RH levels was released during the desorption period, while only 54.5 % of the moisture absorbed in the specimen subjected to a high RH level was released during the desorption period. This result is due to the material's microstructure, including pore size and shape. Figure 6b shows the adsorption/desorption capacities of three interior building materials, indicating that ceramic tile had the largest capacity while gypsum board and plywood revealed low capacities. Based on the test results, the materials can be classified into two levels of moisture-buffering capacity: moderate (20 - 50 $\text{g}\cdot\text{m}^{-2}$) and high (above 80 $\text{g}\cdot\text{m}^{-2}$).

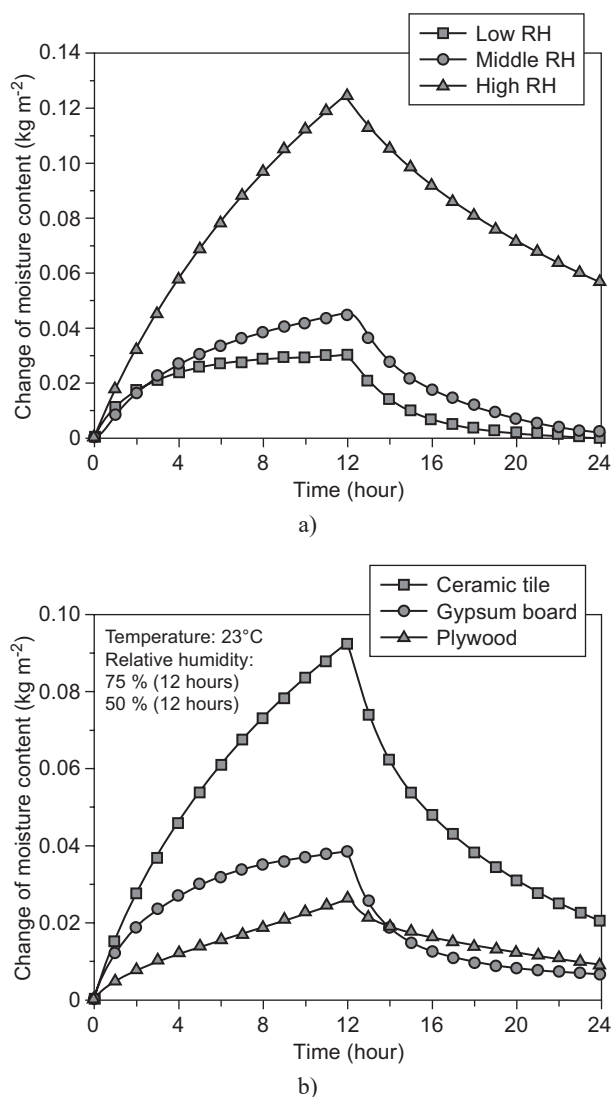


Figure 6. Test results of moisture content change with different environmental RH histories (a) and moisture-buffering characteristics of various building materials (b).

CONCLUSIONS

This study examined the moisture-buffering properties of various building materials based on numerical and experimental approaches. The surface resistivity of the building materials was found to significantly influence the rate of sorption. As a material's resistivity decreased, the moisture buffering increased. The significant role of interior humidity in attaining sustainable, durable, healthy, and comfortable buildings is increasingly recognized. Thus, the moisture-buffering properties of building materials should be assessed by both numerical and experimental methods.

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