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Numerical Simulation of Humidity Control Building Material using Porous Soil "Allophane"

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Recently, the problems related to the damp of indoor environment have been increased with the change of lifestyles and architectural methods. Humidity control material using porous soil "allophane" has been developed to control humidity environment in living space. Numerical simulation method based on heat and moisture transfer model was studied to estimate performance of humidity control material in various living space. Numerical model was calculated by the relative humidity changes in the physical space with temperature changes. Simulation result was compared with experimental measurement. Simulated values by calculating with non linear material property were in good agreement with experimental measurements.
Key words: humidity control, porous materials, numerical simulation, non linear

1.INTRODUCTION

As Japan is located at the northern end of Asian monsoon area, it is very sultry in summer. The traditional Japanese houses are open to the outside air, therefore ventilation is very good. They were mostly made of woods, paper and soils, and dew condensation had been prevented naturally. The performance of moisture adsorption and/or desorption of woods, papers, and soils were used.

In recent years, the current houses are highly airtight and shut out the fresh air, therefor the quality of indoor air has been inferior. A typical problem is a damage due to dew condensation. It causes the occurrence of molds, tick, and the decay of structural body[1].

To solve these problems, some humidity control building materials have been developed[2]. We selected porous soil "allophane" for the original material to develop building material. It is easy to form into a certain shape, and has minimal influence on the environment.

Humidity control performance is evaluated by the relative humidity changes in the physical space with temperature changes. For instance "B-value[3]" were used for the index in the case of temperature changes. To develop the humidity control building materials, it is necessary to design thickness of material and execution area. And it is also needed to predict the humidity control performance at various times of the day such as when cooking and sleeping. It is not reasonable to verify all conditions with experiments, as it takes forever to do the experiments about the dampness in buildings.

It is very effective to predict the humidity control performance of materials by numerical simulations. Method of numerical simulation based on Fick's low were reported[4]. However, material properties for Fick's diffusion model were calculated by fitting for experimental results. So, it is difficult to discuss material property physically. In architecture, simultaneous heat and moisture transfer model were applied for the methods of numerical simulations to evaluate humidity control behavior. Usually, linear material property was used to calculate. A few cases were reported from a material point of view. In this study, simultaneous heat and moisture transfer model with non linear material property were applied for the methods of numerical simulations. We report comparison between experimental values and simulated values, and application to design building material.

2.EXPERIMENTAL

2.1 Materials

Porous soil "allophane" sintered at 800℃ were used for this study. Allophane has high performance with respect to moisture adsorption and/or desorption. The specimens used were board-shaped (0.0056m^2, thickness 0.005m). These samples were sealed with silicon without one face. Moisture transfer in the thickness direction was studied.

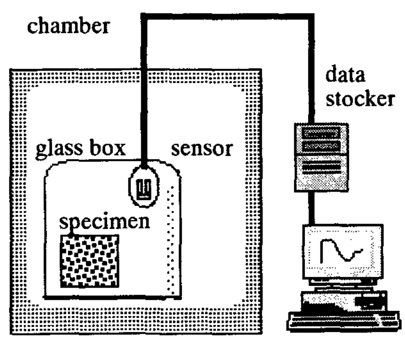

Fig.1. Experimental apparatus.

2.2 Apparatus and experiment

An airtight glass box (volume 0.011m^3) in the temperature and humidity chamber was used as the closed space for the humidity measurements. Temperature and relative humidity in the glass box were measured by sensor, and collected with data stocker (SHINEI TRH-DM3, Japan). After equilibrating the sample in air at a certain relative humidity and temperature, the relative humidity changes in the box were measured under temperature changes. The temperature change ratio was 1℃/hour. Figure 1 shows the schematic system for measurement.

3.CALCULATING

3.1 Method of calculation

The humidity control property of material was generated by moisture diffusion in the material. The driving force of moisture diffusion is gradient of absolute humidity in material's pores. In construction wall without dew condensation, transfer of moisture in the material is dominated by diffusion of vapor. It is named "hygroscopic". In hygroscopic condition, balance of heat and moisture is shown as follow equations based on local equilibrium. Where equations (1) and (2) are named simultaneous heat and moisture transfer equation[5]. Equation (1) shows balance of heat, and equation (2) shows balance of moisture. Numerical model was calculated explicitly with 1-dimensional finite difference. The specimen was divided into constant thickness of 0.5mm, by humidity and temperature-reference planes. The difference equations were calculated every 0.1 second.

$$C\frac{\partial\theta}{\partial t} = \lambda\frac{\partial^2\theta}{\partial x^2} + \gamma\frac{\partial w}{\partial t} \quad (1)$$

$$C_a'r_a'\frac{\partial H}{\partial t} + \frac{\partial w}{\partial t} = \lambda'\frac{\partial^2 H}{\partial x^2} \quad (2)$$

C: specific heat
λ: heat conductivity
γ: latent heat
C_a': moisture capacity of air
γ_a': pore ratio
λ': vapor conductivity
w: moisture concentration
θ: temperature
H: absolute humidity
t: time

3.1 Material properties

Material properties shown in Table I were used for numerical simulation. Figure 2 showed moisture capacity of specimen. This material has big moisture capacity equal to or higher than wood. The moisture capacity changed non linearly with relative humidity changes. Accordingly these equations were calculated with non linear material property which is given as equations (3) and (4).

$$\frac{\partial w}{\partial\theta} = C'\times H\times\frac{\partial Hs^{-1}}{\partial\theta} \quad (3)$$

$$\frac{\partial w}{\partial H} = C'\times\frac{1}{Hs} \quad (4)$$

Hs: saturated absolute humidity
C': moisture capacity

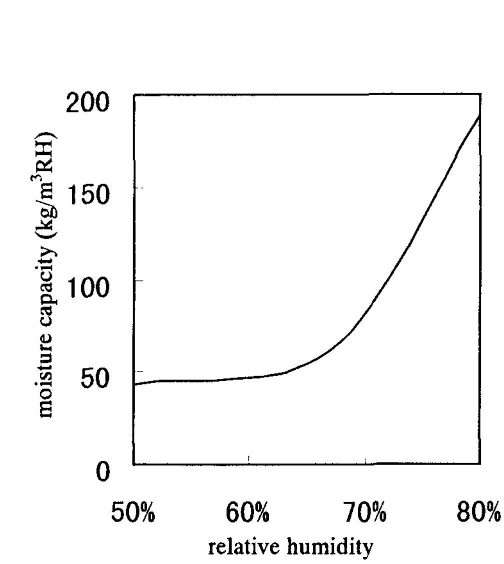

Fig.2. Moisture capacity of specimen.

Table I. Material properties for numerical simulation

material property		unit
heat conductivity	9.51E-02	W/mK
density	1.74E+03	kg/m^3
specific heat	5.70E+05	J/m^3K
vapor conductivity	1.65E-06	kg/msec(kg/kg')
pore ratio	3.50E-01	
surface emission coefficient of heat	9.44E+00	J/m^2secK
surface emission coefficient of vapor	4.44E+00	$kg/m^2sec(kg/kg')$

4.RESULTS and DISCUSSION

4.1 Humidity control performance in the closed glass box

Measured values of Relative humidity changes in the closed glass box under 1℃/hour temperature changes, is shown in Figure 3. Relative humidity in the presence of the material decreases compared to without material. Therefore, it appears that this material has humidity control performance. Comparison calculated values with experimental values were shown in Figure 4. The calculated values were in good agreement with experiment by reason of calculating with non linear material property. The driving force of humidity control property is gradient of absolute humidity in material's pores. In this case, the gradient of absolute humidity was made by heat transfer in material. It is considered that the temperature changes of space and material in the closed box were the same. Thus, the numerical simulation is applied for the prediction of humidity control property of porous materials.

4.1 Humidity control performance of layered structure

In this section, humidity control performance with layered structure were discussed. Usually walls of a building is structured by many materials. Consequently, numerical simulation were applied to predict humidity control process for the wall which were structured three materials. Indoor layer was humidity control building material (thickness:5mm), middle layer was wood board (thickness:10mm) and outdoor layer was concrete (thickness:30mm). The volume of indoor areas was $20m^3$. The execution areas were $5m^2$. The relative humidity changes in materials and indoor areas were calculated with outdoor temperature changes. Fluctuations of outdoor temperature were given as following equation.

$$\theta_{outdoor} = 22 - 10\sin\frac{2\pi}{12 \times 3600}t \qquad (5)$$

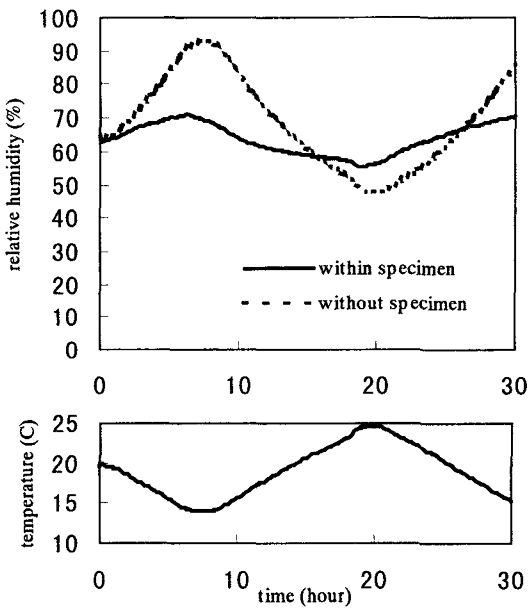

Fig.3. Measured values (inside glass box).

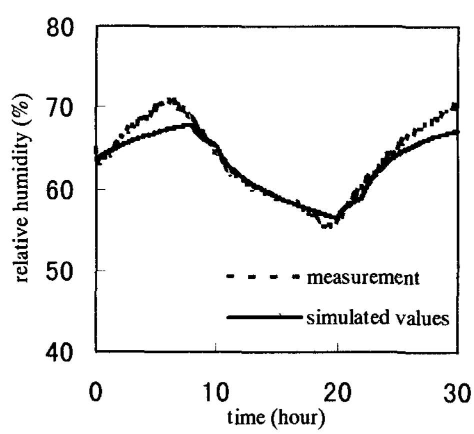

Fig.4. Comparison between experiment and calculation.

Fluctuations of temperature and relative humidity in each materials were shown in Figures 5 and 6. The range of temperature fluctuation in concrete layer was larger than the others. The change of indoor temperature was about three hours behind the change of outdoor temperature. The adiabatic performance of wall was accounted for by concrete. The range of indoor relative humidity changes was smaller than the outdoor. Humidity control performance of wall was generated by humidity control materials. Thus, the numerical simulation is applied for the design of building materials which have humidity control performance.

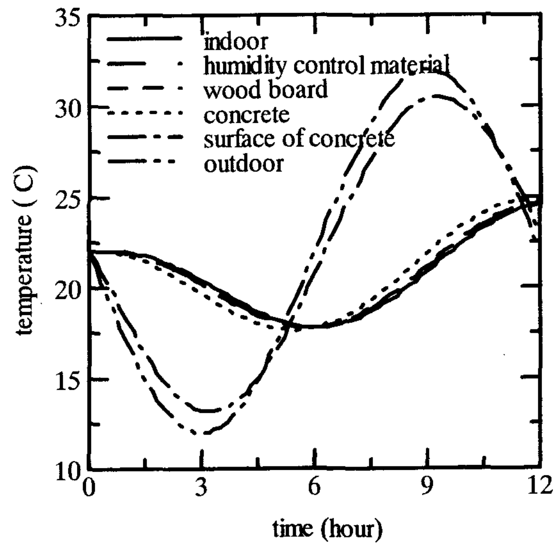

Fig.5. Fluctuations of temperature for each layer.

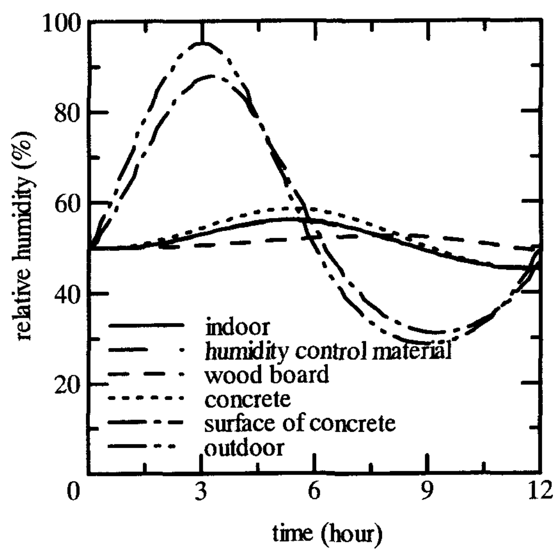

Fig.6. Fluctuations of relative humidity for each layer.

5.SUMMARY

In this study, numerical simulation was applied to predict humidity control performance of porous ceramics. Simulated values by calculating with non linear material property were in good agreement with experimental measurements. We can predict humidity control performance of porous ceramics, and design building materials which include humidity control layer.

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