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SIMULATION OF ROOM AIR TEMPERATURE, HUMIDITY AND HEAT LOAD CONSIDERING MOISTURE ABSORPTION AND DESORPTION IN BUILDING ELEMENTS

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ABSTRACT

This paper describes the integration method of moisture absorption and desorption of building elements into the simulation of room air temperature, humidity and heat load. The implicit finite difference method is used in this procedure for the calculation of the unsteady state heat conduction and moisture transfer of walls. The simulation of a model building was carried out in order to discuss the effects of time and space slicing method, and it was found that the moisture transfer in the wall could be considered only in the thin layer behind the room surface area. As the processing time and a memory area of computer could be reduced using this method, it was conclude that the method could be used for the practical simulation.

INTRODUCTION

The humidity is a important factor when considering the thermal comfort in a room and the moisture condensation on wall surfaces of building. However, the present room temperature and energy simulation programs are not able to consider the absorption and desorption on surfaces of building elements. As the moisture transfer is very slow, both time increment and space slicing thickness in the finite difference calculation must be very small. Therefore, long processing time might be need if solving the simultaneous equation of moisture transfer directly.

This paper describes a procedure for the calculation of room temperature, humidity and heat load considering moisture transfer. For the calculation of the unsteady state heat conduction and moisture transfer of walls the implicit finite difference method was used. For reducing the processing time, the moisture transfer in wall was considered only in the thin layer behind the room surface area.

FUNDAMENTAL EQUATIONS

The heat and moisture transfer equation in the hygroscopic region was presented by Matsumoto(1). One dimensional unsteady state heat and moisture transfer in a homogeneous wall is expressed by follow equations.

Heat diffusion equation:

$$C\gamma\frac{dT}{dt}=\lambda\frac{d^2T}{dx^2}+r\frac{dW}{dt}\quad .....(1)$$

Moisture diffusion equation:

$$C'\gamma'\frac{dX}{dt}=\lambda'\frac{d^2X}{dx^2}-\frac{dW}{dt}\quad ....(2)$$

where,

T:temperature [°C], W:water content of material [kg/m^3]
X:humidity ratio [kg/kg'], γ:specific weight of material [kg/m^3]
r :latent heat of vaporization or absorption [J/kg]
C :effective specific heat of material [J/kg°C]
λ :thermal conductivity of material [W/m°C], C ':porosity [m^3/m^3]
γ ':specific weight of humid air [kg/m^3]
λ ':effective vapor diffusivity [kg/m(kg/kg')], t :time [h]

Eqs.(1) and (2) can be linearized using coefficient κ and ν.

$$(C\gamma+r\nu)\frac{dT}{dt}=\lambda\frac{d^2T}{dx^2}+r\kappa\frac{dX}{dt}\quad ..(3),\qquad (C'\gamma'+\kappa)\frac{dX}{dt}=\lambda'\frac{d^2X}{dt^2}-\nu\frac{dT}{dt}\quad ...(4)$$

where,

$$\kappa=\frac{dW}{dX}\quad (\text{ for humidity variation [kg/m}^3\text{(kg/kg')] })$$

$$-\nu=\frac{dW}{dT}\quad (\text{ for temperature variation [kg/m}^3{}^\circ\text{C]})$$

The boundary conditions are as follows:

$$-\lambda\frac{dT}{dx}=\alpha(Tr-Ts)\quad .....(5)\ ,\qquad -\lambda'\frac{dX}{dx}=\alpha'(Xr-Xs)\quad ....(6)$$

where,
α :heat transfer coefficient [W/m^2°C]
α ':vapor transfer coefficient [kg/m^{2}h(kg/kg')]
Tr:room air temperature [°C], Xs:surface temperature [°C]
Xr:room air humidity ratio [kg/kg'], Xs:surface humidity ratio [kg/kg']

IMPLICIT FINITE DIFFERENCE EQUATION

The wall is divided into the thermal and moisture node. Using the implicit finite difference method, Eqs.(3),(4),(5) and (6) are expressed as followings.

$$-D_jC_jT_{j-1}+\{1+D_j(C_j+C_{j+1})\}T_j-D_jC_j\ \ T_j-E_jD_jX_j=T_j^*-E_jD_jX_j^*\quad ......(7)$$

$$-Cw_jDw_jX_{j-1}+\{1+Dw_j(Cw_j+Cw_{j+1})\}X_j-Cw_{j+1}Dw_jX_{j+1}-Ew_jDw_jT_j=X_j^*-Ew_jDw_jT_j^*\quad ......(8)$$

$$\{1+D_1(C_1+C_2)\}T_1-D_1C_2T_2-E_1D_1X_1=T_1^*-E_1D_1X_1^*+C_1D_1Te_1\quad ......(9)$$

$$\{1+Dw_1(Cw_1+Cw_2)\}X_1-Dw_1Cw_2T_2-Ew_1Dw_1T_1=X_1^*-Ew_1Dw_1T_1^*+Cw_1Dw_1Xr\quad ......(10)$$

where,

$$Dj=\frac{\Delta t}{(Cap_j+rV_j\nu)}\ ,\ Ej=\frac{rVj\kappa}{\Delta t}\ ,\ Dwj=\frac{\Delta t}{(Capw_j+V_j\kappa)}\ ,\ Ewj=\frac{Vj\nu}{\Delta t}$$

Te$_1$:sole air temperature [°C], Cap$_j$:heat capacity of volume j [J/°C]
Capw$_j$:moisture capacity of volume j [kg]

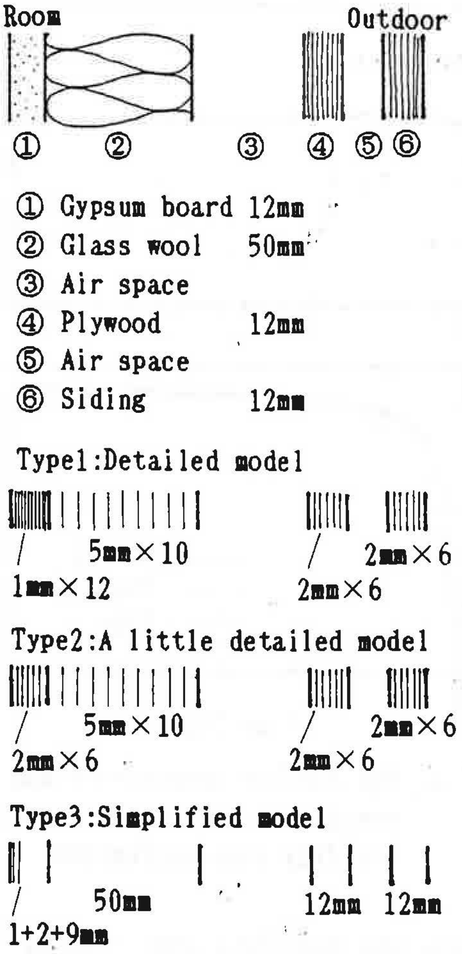
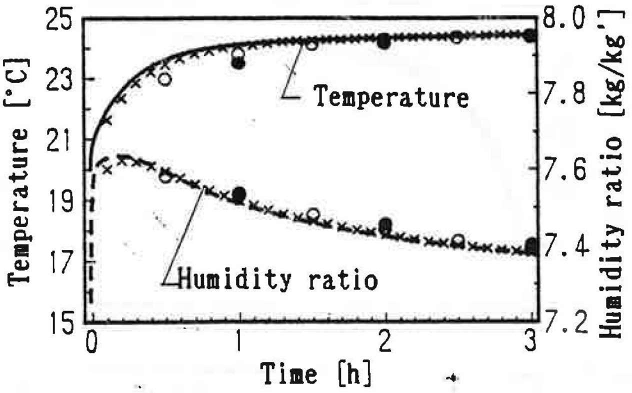


Figure 1. Space slicing method of wall



for temperature step excitation

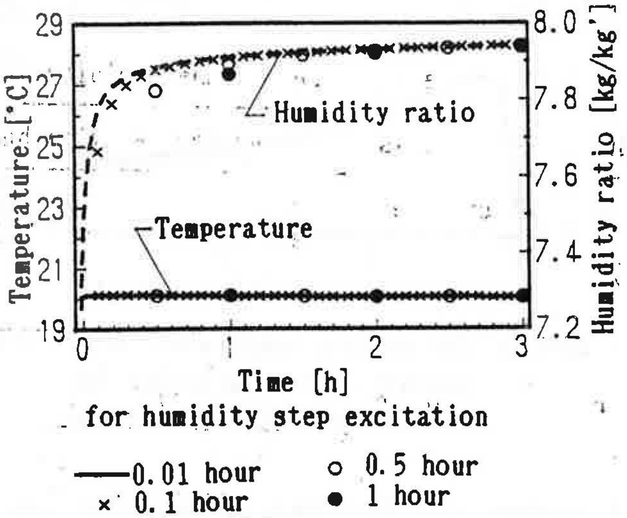


Figure 2. The surface temperature and humidity ratio variation

SIMPLIFIED METHOD

If the simultaneous equation of temperatures and moistures are solved directly, the dimension on the simultaneous equation is twice as much as the number of the nodes of the wall. As the moisture transfer is very slow, it was assumed that the moisture transfer occurred only in the thin layer behind the room surface under the 24 hours periodic condition. The calculation of the moisture transfer was considered only three layers form the room surface. Therefore, the moisture transfer from outside to inside was not considered in this method. The equation of moisture in the third layer is expressed as following:

$$-Cw_3Dw_3X_2+\{1+Dw_3Cw_3\}X_3-Ew_3Dw_3T_3=X_3^{*}-Ew_3Dw_3T_3^{*} \qquad ....(11)$$

The dimension on the simultaneous equation is only the number of nodes + 3 in this method.

TIME SLICING OF WALL

The effects of time slicing were examined for the thermal and moisture

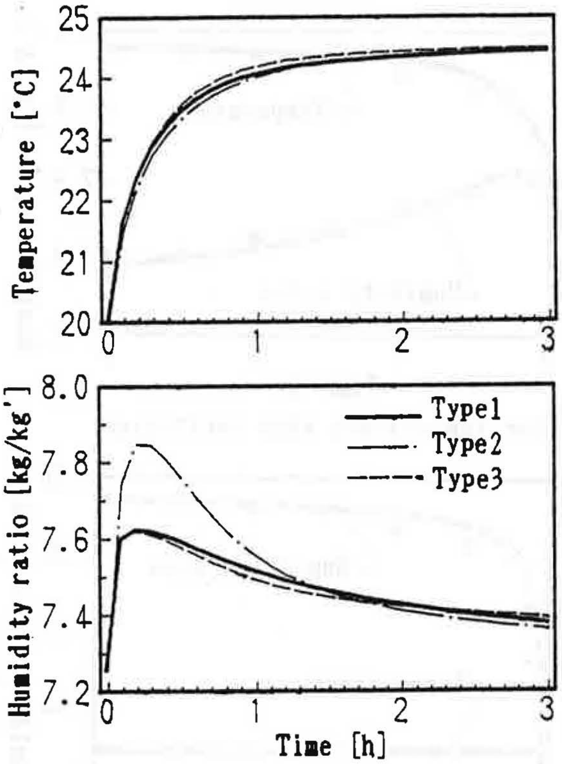


Figure 3. The surface temperature and humidity ratio variation for temperature step excitation

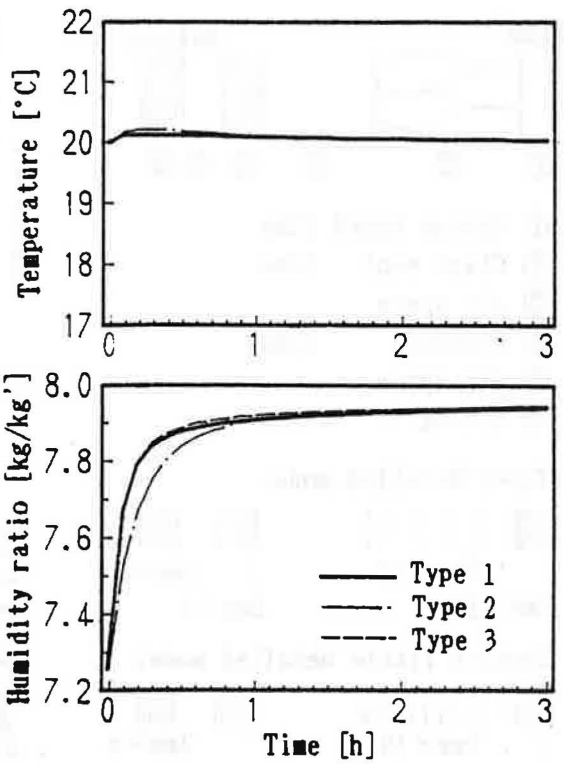


Figure 4. The surface temperature and humidity ratio variation for humidity step excitation

response on the wall surface for temperature and humidity step excitation condition as Table 1. The wall was divided into 36 layers and each 36 thermal and moisture nodes were placed as shown in Figure 1. The time increment were examined for 0.01,0.1,0.5 and 1.0 hour. Figures 2 shows the surface temperature and humidity ratio variation. The temperature and the humidity ratio of the wall surface calculated with $\Delta t=1$ hour agreed with the results calculated with $\Delta t=0.01$ hour. Therefore, it was conclude that $\Delta t=1$ hour could be used for the calculation with small error.

WALL LAYER SLICING

The effects of layer slicing were examined withe Three types of model as follows;

Type 1 : Detailed model with 36 nodes of heat and moisture respectively.
Type 2 : The surface material divided 6 layers with 2 mm thickness. The total number of node was 30 for heat and moisture respectively.
Type 3 : Simplified model. The surface material was divided in to 3 layers of 1mm, 2mm and 9mm thickness. For the heat transfer 8 nodes and 3 nodes for the moisture transfer.

Figures 3 and 4 show the surface temperature and humidity ratio response for temperature and humidity step excitation with the condition shown in Table 1. The results of the simplified model are closed to the results of the detailed model. In spite of 30 nodes considering, the results of type 2 were different form the results of the detailed model.

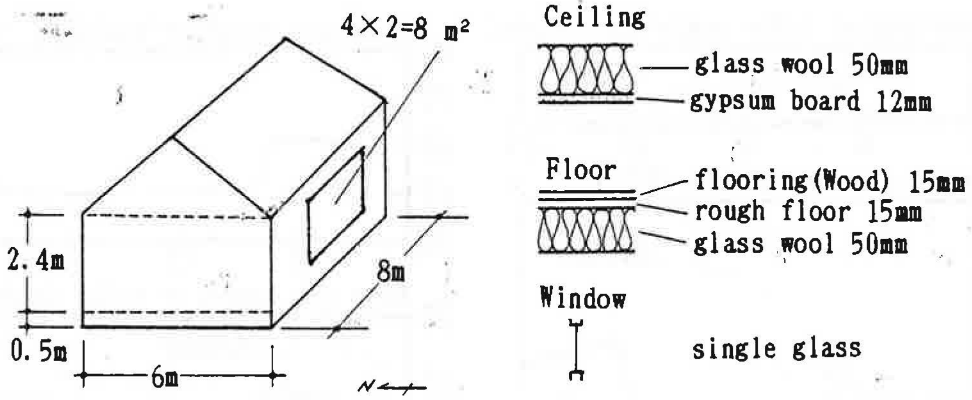


Figure 5. Model building

Table 1. The temperature and the humidity step excitation condition.

The temperature is 20 °C and the relative humidity is 50 % in initial condition.

a) temperature step excitation :
at t=0, temperature is 25 °C (humidity ratio is not change)
b) humidity step excitation :
at t=0, relative humidity is 55 % (temperature is not change)

Table 2. The schedule of model building

Time	6-7	12-13	17-19	other
heat [w]	600	300	600	0
moisture [kg/h]	0.47	0.16	0.65	0
ventilation [m3/h]	400	200	400	35
space cooling [26°C, 50%]	(7:00 - 18:00)			

Table 3. Monthly space cooling load

	Detailed model	Simplified model	
Sensible load	343	347	[kW]
Latent load	215	213	[kW]

EXAMPLE SIMULATION

To examine the effectiveness of the simplified method, temperature, humidity and cooling load of a model building were calculated by the procedure using the moisture transfer equations. The building is constructed wooden framed with 48m2 the total floor area as shown in Figure 5. As the wall, ceiling and floor surfaces have no vapor barrier as such as vinyl cloth or wax, the moisture absorption and desorption are able to occur easily on the surfaces. Table 2 shows the schedule of the operation of the space cooling, internal heat and moisture generations. Using the detailed model and the simplified model, the simulations were carried out during August using the standard weather data of Tokyo. For both cases, the time increment was set to 1 hour.

Figure 6 shows the simulation results on a typical clear day in summer. The temperature and humidity ratio profile of simplified model and the detailed model showed good agreement in all the times. For the latent and sensible cooling loads, the disagreement between the simplified model and the detailed model were very small. The monthly sensible and latent loads by the simplified model and the detailed model were almost same value as shown in Table 3.

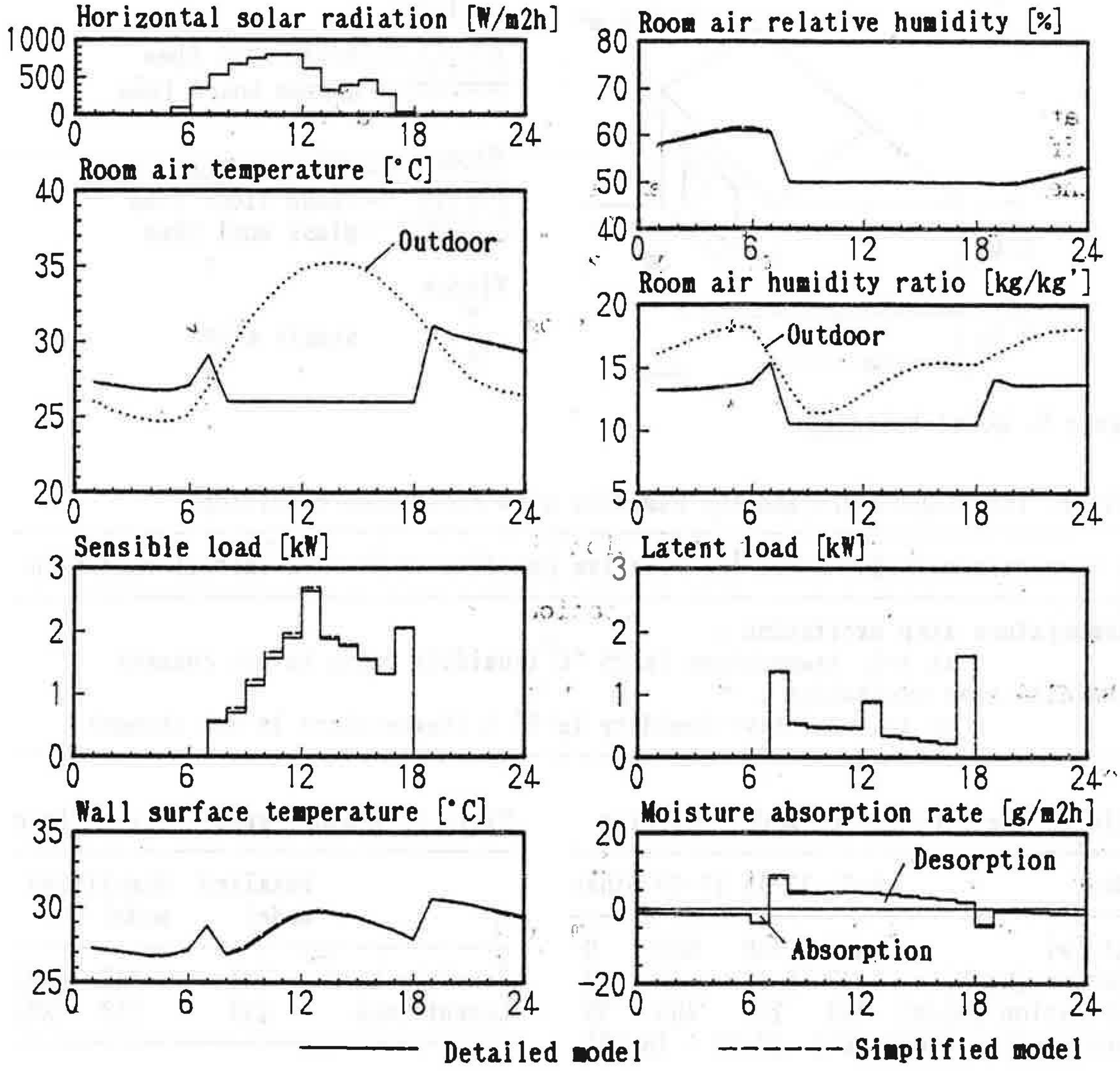


Figure 6. Simulation results on a typical clear day(August,8th).

CONCLUSIONS

This paper describes the integration method of moisture absorption and desorption of building elements into the simulation of room air temperature, humidity and heat load. The simulation of a model building was carried out in order to discuss the effects of time and space slicing method, and it was found that the moisture transfer in the wall could be considered only in the thin layer behind the room surface area. Using this method, the processing time and a memory area of computer could be reduce, therefore the method could be used for the practical simulation.

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(1)Matsumoto, Study on the thermal and moisture transfer on the wall, 1978 (in Japanese)

(2)K.Ishida, M.Udagawa, Calculation method of the room air temperature, humidity and heat load with moisture absorption in walls. Proceeding of SHASEJ annual meeting, Oct. 1989 (in Japanese)