COMPUTER SIMULATION OF MULTIROOM TEMPERATURE AND HUMIDITY VARIATION UNDER VARIABLE INFILTRATION CONDITIONS

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ABSTRACT

Developed in this study is the computer simulation program which can predict the temperature and humidity variation in multiroom of a residence, especially under variable opening conditions such as doorway open or close according to inhabitants behaviors. In the multizone infiltration calculation, the special process is devised to make the computation stable, never failing to converge. In the humidity calculation, two parameters related to the absorption and desorption of the surface finishing of a wall are, also, presented. The validity of this model is examined and the application to a single family with four persons are demonstrated.

INTRODUCTION

Several reports can be found which developed the modelings of the combined heat and moisture transport in buildings to predict the cooling loads for air-conditioned environments with higher accuracy (Fairey and Keresteciogh 1985; Istti et al. 1988). In those cases, the modeling of absorption and desorption of interior wall surfaces is considered, but the calculation of multi-room infiltration and/or ventilation is not included.

In our country, the portable kerosene oil heater is commonly used in residential buildings. This open fired type heating appliance generates a lot of moisture which amount to about 1.1 times as much as consumed oil quantity. That causes serious water condensation problems as air tightness of building components has advanced. To prevent these problems, the more accurate and precise model is essentially required for simulating the indoor humidity transport between rooms of a residential building associated with the various house-hold activities.

In this report, a time-dependent model is presented that can predict the indoor temperature and humidity variations in a residence, and also condensation quantity on none-porous surface materials such as glass. The developed model is composed of three parts.

(1) the procedure for calculating indoor temperature based on thermal balance equations

(2) the procedure for calculating multi-room infiltration and/or ventilation caused by both natural and mechanical driving forces

(3) the procedure for calculating indoor humidity based on moisture balance equations with the effects of absorption and desorption of the wall and multi-room infiltration and/or ventilation.

The characteristics of the simulation model developed in this study lie mainly in the following two points. One is that the multizone infiltration calculation procedure which never fail to converge was established. The other is that the available data of two parameters, K" and Cw, which denote the absorption and desorption of a wall finishing material, were presented. After the validity of this

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model is evaluated by comparing measured with predicted indoor environment of a test residence, the specific features of indoor environment ,especially the humidity are examined according to the type of heating appliance, open fired or not and the living pattern selected by inhabitants, such as doorway open or close, or on-off schedule of exhaust fans.

PRINCIPAL GOVERNING EQUATIONS

Thermal Balance

We can get the set of n linear differential equations as written in the form of Eqn.(1) based on the thermal balance of a room (say, i-th room).

$$(\gamma CpV)d\theta i/dt=\Sigma(q_T-q_A) + K_G A_G(\theta j-\theta i)+\Sigma\gamma CpQ(\theta j-\theta i)+H$$

$$(\gamma CpV)(\theta i^n-\theta i^{n-1})/\Delta t= \Sigma(\Sigma\theta j^{n-k}\phi_T^{\ k}-\Sigma\theta i^{n-k}\phi_A^{\ k})\ A_w+K_G A_G(\theta j^n-\theta i^n) +\Sigma\gamma CpQ(\theta j^n-\theta i^n)+H \quad (1)$$

In Eqn.(1), the first term of right hand side denotes the heat transmission and absorption on the peripheral walls in terms of the response factors. The second term is the instantaneous heat transmission through thermally thin walls such as a window glass. The third term represents the heat introduced by the infiltration and/or ventilation from the surrounded adjacent rooms. The last term denotes the heat generated by human, equipment and lighting, and/or the solar direct heat gain.

Air-Mass Balance(Multizone Infiltration)

The air-mass flow within a given building is, as is well established, caused by pressure differences due to driving forces such as wind, thermal buoyancy, mechanical fan systems or a combination of them. According to the air-mass balance, we can get the set of nonlinear equations as shown in Eqn(2).

$$\Sigma Qi=0\ :\ Q=14400(\alpha A)\Delta P^{1/2} \qquad al\Delta P^{2/3} \quad (2)$$

Moisture Balance

Multiroom moisture transport is governed by the set of equations expressed in the form of Eqn(3).

$$GdXi/dt=W-dw/dt+\Sigma\gamma Q(Xj-Xi) -\alpha' A_G(Xi-f_s)+\Sigma K'A(Xj-Xi)$$

$$dw/dt=K''A_w(Xi-\phi_w)$$

$$\phi_w=\phi_{sw}((w/Cw)T-5.46)/41$$

$$dw_G/dt=\alpha' A_G(Xi-f_s) \quad (3)$$

The first term of the right hand side in Eqn(3), is the moisture generation. The second term indicates the rate of moisture absorption or desorption of the boundary wall surfaces including the floor and ceiling. The expression of the absorption and desorption mechanism is based on that only thin layer of a wall surface is effective to the mechanism and these occurs an instantaneous equilibrium of moisture content(Tsuchiya,T. 1980;Kusuda,T. 1983). Therefore, the characteristic property for absorption and desorption of material can be reduced to two parameters, K" and Cw. The K" and Cw are related to the permeability and the moisture storage capacity of a material, respectively. The third term denotes the moisture migration due to infiltrations. The fourth term represents the water condensation. And the last term denotes the transmission of a composite wall.

COMPUTATIONAL PROCEDURE

Approximation by Backward Finite Difference Method

Two sets of first order differential equations, Eqns(1) and (3), are replaced by the backward finite difference approximation and transformed into the set of linear algebraic equations in respect of unknown variables θ^{n+1}, x^{n+1} at (n+1)th time step.

Solution of Heat and Air-Mass Flow(Infiltration)

Because the heat and the air-mass flows are closely connected with each other, it is necessary to solve Eqn.(1) and (2) simultaneously. However, it is impossible to solve mathematically due to their nonlinearity. Therefore, the iterative procedure may be inevitable. In this case, one can easily suppose that the oscillation will take place. Fig.1 shows the example. In order to avoid this oscillation, the damping factor a in Eqn.(4) should be introduced. The value of 0.6~0.7 may be recommended as shown in Fig.1.

$$\theta=a\theta^{\kappa-1}+(1-a)\theta^{\kappa} \quad (4)$$

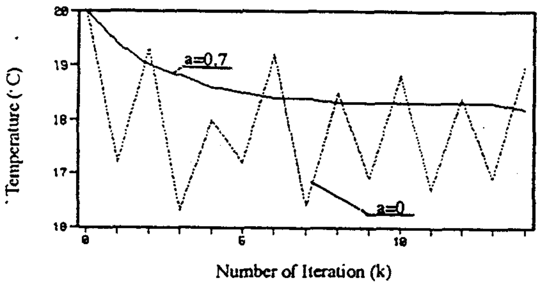


Fig.1 Temperature Fluctuation in Iterative Process for Eqns.(1) and (2)

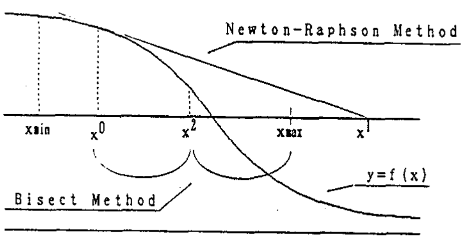


Fig.2 Combined Newton Raphson and Bisect Method

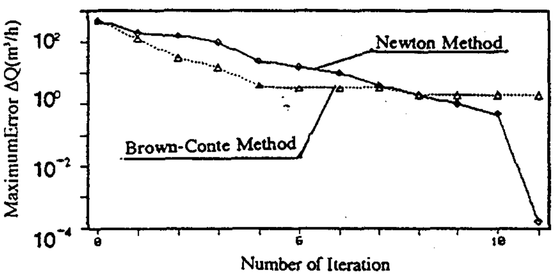


Fig.3 Comparison of Convergence by Newton and Brown-Conte Method

Infiltration Calculation without Divergence

In the infiltration calculation, the divergence often annoys us, if the appropriate initial values for unknown pressure of each zone can not be chosen. Still much often is the case, when the calculation will be conducted to simulate under variable opening conditions,such as doorway open or close and the on-off of exhaust fans according to inhabitant behaviors. Therefore, the computational procedure which never fail to converge is required. The following is the proposed procedure for this purpose, which is composed of three steps.

Step1. is represented by the Over Relaxation Method with Bisecting Method, which makes the initial set values the better estimates,never failing to converge.

1) Initial value x^0 is set within the range of two reasonable extremes x_{min} and x_{max}. 2) The substitution $x_{min}=x^0$ or $x_{max}=x^0$ will be made according to the sign of the functional quantity. 3) Estimate the first approximate value x' by means of Newton-Raphson method. If $x_{min}<x'<x_{max}$, then $x_{min}=x'$ or $x_{max}=x'$, else no change is made. 4) The second approximation is given by $x^2=(x_{min}+x_{max})/2$. Repeat the process 3) and 4). This step is used only to estimate rough approximation. Therefore, the process should be ended after several iterations.

Step2. is represented by Brown-Conte Method (Brown and Conte 1967), which is effective to get closer estimation. This step will be stopped when the maximum error ΔQ reaches less than 20,m³/h.

Step3. is so called Newton's Jacobian Method, which leads to the full convergence. These three steps are not always necessary at every time step in the whole course of calculation. Only first 24 hours is sufficient, and the previously obtained values will be used as the initial estimates for Newton-Jacobian Method after 2nd day.

Derivation of Two Parameters, K" and Cw

The selected specimens of 30cm×30cm, which are commonly used as a surface finishing, were exposed to the ambient atmosphere in a laboratory with cyclical temperature and humidity variation as shown in Fig.4. The weight changes were measured and the two parameters K",Cw in Eqn.(3) were determined so as to make measured and predicted weight as closer as possible by means of multi variable regression analysis. For example, the measured and calculated weights of veneer plywood are given in Fig.5. Table 1 denotes the part of results.

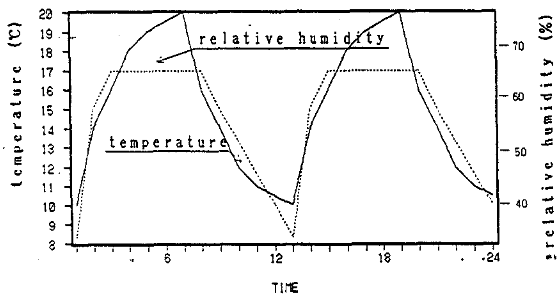


Fig.4 Ambient Air Temperature and Humidity Condition

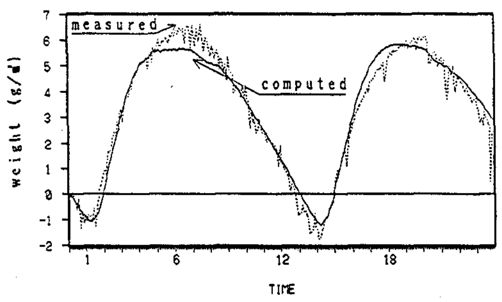


Fig.5 Weight Changes of Veneer Plywood, Computed and Measured

TABLE 1
Values of K" and Cw of Finishing Materials

Finish	K"	Cw
carpet	4.0	800
flooring board	1.5	200
'tatami*' mat	4.5	1000
veneer plywood	3.0	300
vinyl cloth	0.2	50
'husuma**' paper	1.5	50

* Japanese style floor mat

** Japanese style sliding door

COMPARISON OF MEASURED AND PREDICTED INDOOR ENVIRONMENT

In order to evaluate the validity of the simulation model, the comparison of measured and predicted indoor temperature and humidity variations were made. The monitoring of indoor temperature and humidity variation was conducted in a RC(reinforced concrete) apartment house built for field measurements shown in Fig.6. Outdoor conditions of temperature, humidity, wind velocity and insolation were also measured.

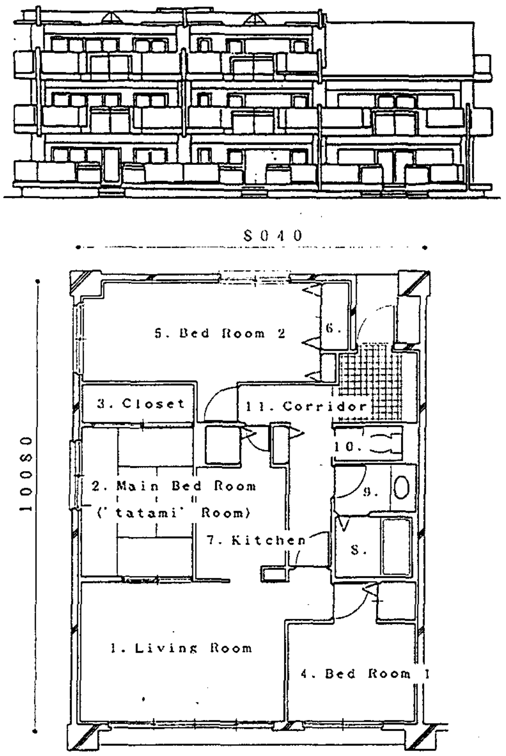
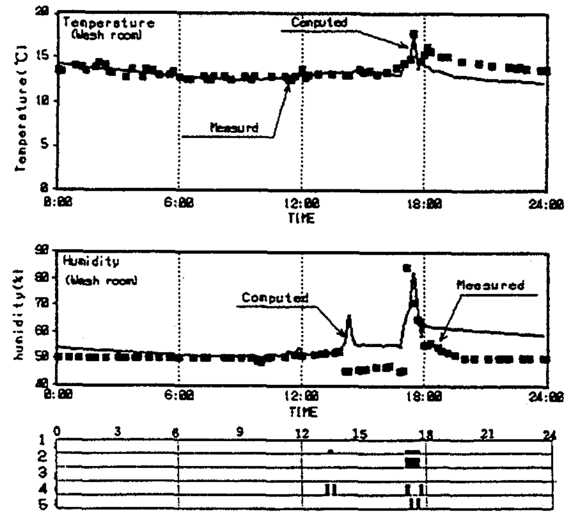


Fig.6 Plan and South Elevation of Test Apartment House

The open or close of doorways, and the heat and moisture generation in a room accompanied by household activities, were scheduled, as indicated in Fig.7 for example. The 10 minutes was taken as a unit time interval. The excellent agreement between measured and simulated indoor temperature and humidity variation can be seen in Fig.7~8. However, some disagreement is found with the relative humidity at the time when a person enters into a room. This may be supposed largely due to the moisture absorption effect of person's clothes.



1:Persons,2:Light,3:Humidification,4:Door(9-11), 5:Door(8-9)

Fig.7 Comparison of Measured and Predicted Temperature and Humidity in Wash Room

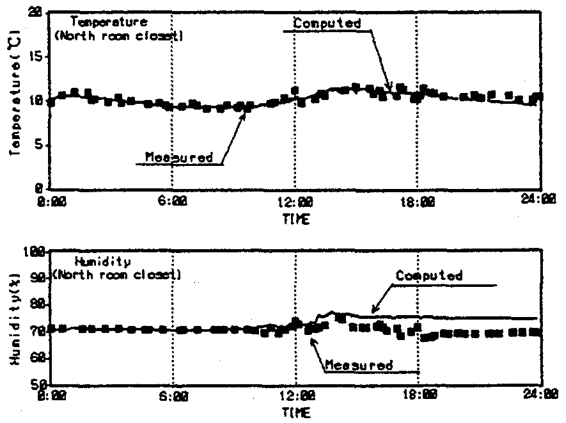


Fig.8 Comparison of Measured and Predicted Temperature and Humidity in Northern Closet

APPLICATION TO A SINGLE-FAMILY WITH FOUR PERSONS

To investigate how differs the indoor environment, especially humidity, according to the heating appliance, whether open fired type or not, and the exhaust fan operation mode, whether appropriate or not, several cases of computer simulation were performed for a 'typical' single family with four persons, parents and two children, who were assumed to live in the above described apartment house.

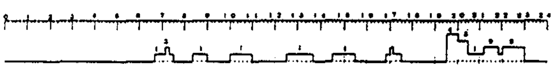
Each person's behavior was assumed to be scheduled as indicated in Table 2. The operation time schedule of heating appliance and other equipments was also listed in Table 2. It should be notified that only a part is given in this table. The quantities of heat and moisture generation for person and equipment were given by the already known data. For an open fired type kerosene heater, the rate of moisture generation per a unit heat generation was assumed to be 0.18(g/kcal).

Computer simulations were carried out for cases, as indicated in Table 2. The 10 minutes was selected as a unit time interval for step by step calculation. Outdoor conditions were given by the standardized climate data on January of Tokyo. Fig.9 denotes the part of computer results for January 25-26. The rapid drop of temperature is caused by making the window sash open while cleaning the room. Fig.10 is the relative humidity variations in the northern closet where the water condensation may much more frequently take place than any other spaces in the residence. The values of the relative humidity vary from 40% through 80% according to the case. Fig.11 shows the infiltration air flow pattern when both exhaust fans were operated.

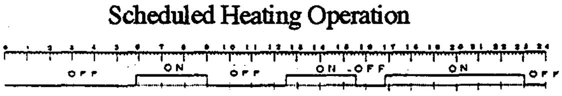
TABLE 2
Computer Run Cases

Case	Type of Heating Appliance	Exhaust Fan Operation	Window Sash
1	Not Open Fire	Scheduled	Open When Cleaning
2	Open Fire	Scheduled	Open When Cleaning
3	Not Open Fire	No Use	Close
4	Open Fire	No Use	Close
5	Not Open Fire	Fan1:Scheduled Fan2:all day use	Open When Cleaning

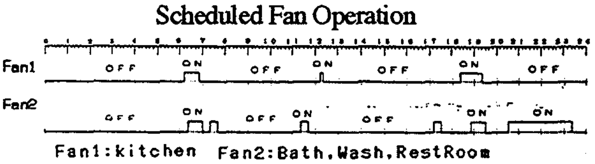
Occupied Numbers of Person (Living Room)



Scheduled Heating Operation



Scheduled Fan Operation



Fan1:kitchen Fan2:Bath,Wash,RestRoom

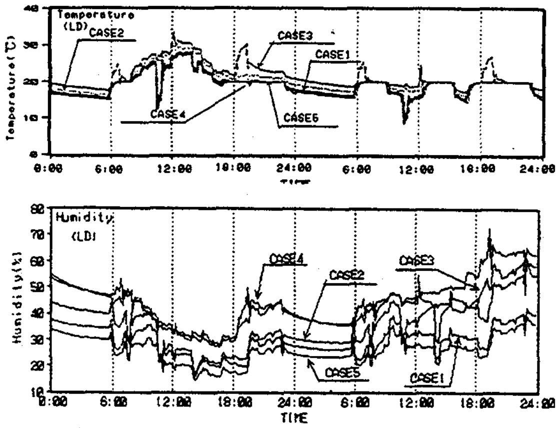


Fig.9 Computed Temperature and Relative Humidity of Living Room

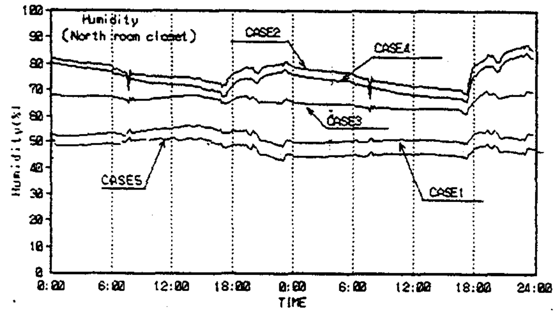
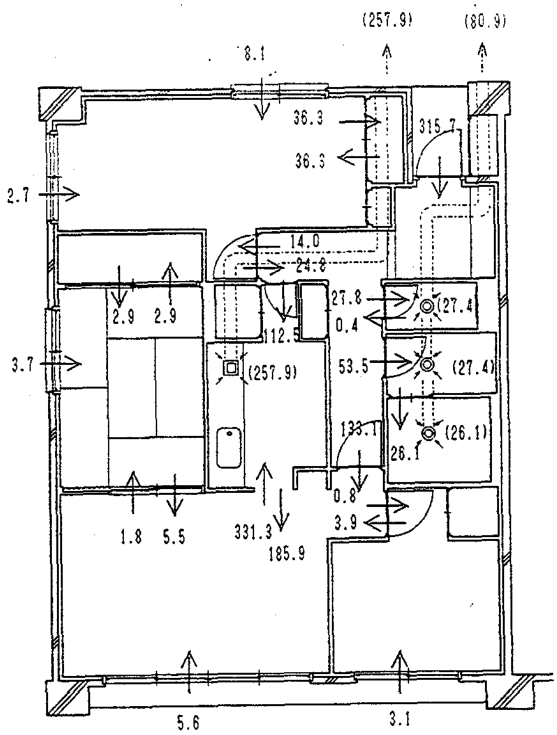


Fig.10 Relative Humidity Variations of Northern Closet for 5 Cases



Date and Time 1/25 19:10
Fan 1 and 2 were on operation.

Fig.11 Air Infiltration Volume (m^3/h)

SUMMARY

The computer simulation program was developed which could predict the time-dependent indoor temperature and humidity variations in a residence more accurately and precisely. This is characterized by the multizone infiltration calculation procedure which never fail to converge and enable the actual detailed inhabitant's behaviors to reproduce. The validity was evaluated by comparison of measured and predicted indoor environment. The special features on indoor relative humidity were pointed out by the computer runs applied to a single family with 4 persons.

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NOMENCLATURE

γ = specific weight of air (kg/m^3)
Cp = specific heat of air (kcal/kg °C)
V = room air volume (m^3)
θ = temperature (°C)
K = thermal transmission coefficient (kcal/m^2h°C)
A = area of wall (m^2)
Q = intake air volume (m^3/h)
H = heat generation (kcal/h)
ΔP = pressure difference (kg/m^2)
X = humidity ratio (g/kg')
G = room air weight (kg)
W = moisture generation (g/h)
α' = moisture transfer coefficient (g/m^2h(g/kg'))
K' = moisture transmission coefficient (g/m^2h(g/kg'))
w = moisture content of wall (g)
f_s = saturated specific humidity of non-porous surface (g/kg')
ϕ_{sw} = saturated specific humidity of thin layer (g/kg')
T = absolute temperature of thin layer (°K)
w_G = weight of condensation (g)
K" = moisture conductance of thin layer one of parameters related to absorption and desorption (g/m^2h(g/kg'))
Cw = moisture storage capacity of thin layer the other parameter described above (g/m^2)