A Time Dependent Analysis of Thermal Environment in Beehouse

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INTRODUCTION

The design or analysis of beehouse inside temperature environment based on steady heat transfer theory causes much deviation and theoretically it is impossible to control the inside temperature lower than the outside temperature under the condition that the bee produces heat and no cooling equipment is installed. But in practical use of beehouse, the inside temperature is somehow lower than the outside temperature because of the heat inertia of concrete floor. To make a reasonable design of the enclosure and the ventilation system of a beehouse, a time-dependent analysis of the inside temperature shows its significance under the condition of chronologically changing of outside temperatures. The objective of this research is to develop a mathematical analysis method to predict the inside thermal environment of a given design and to improve the design to maintain the interior temperature at 2~9℃, a satisfactory temperature for bee wintering.

MATHEMATICAL MODEL

The outside meteorological data and the interior temperature and humidity are always of time-dependent value. One of suitable method to solve the unsteady heat transfer problem in this case is the response-factor-method. The basic idea of this method is to disperse the time-dependent disturbance into time-sequence unit disturbance and then calculate the thermal response of the structure to the unit disturbance. Finally, the hourly heat transfer through the unit area of the structure is calculated by numerical integration.

The number of the surfaces in the beehouse model is shown in Fig.1. The materials of side walls are the same. Because the side walls are usually constructed with thick insulation materials, the outside surface temperature difference of each side wall caused by solar radiation is neglected in the analysis.

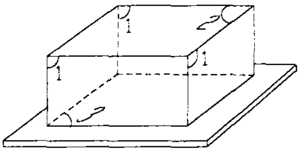


Fig.1 Surface number

Heat Balance of the Inside Surfaces of Roof and Side Wall

The heat balance is expressed as:

conductive heat + convective heat transfer to the interior air + radiation heat obtain from other surfaces = 0, i.e.,

$$\sum_{j=0}^{Ns} Y_1(j)\, t_{oi}(n-j) - \sum_{j=0}^{N_s} Z_1(j)\, t_1(n-j)$$

$$+\sum_{\substack{k=1\\ k\neq i}}^{N_i} \alpha^r_{i,k}\cdot[\,t_k(n)-t_i(n)]+\alpha^c_i\cdot[\,t_r(n)-t_i(n)] = 0 \qquad i=1,2 \tag{1}$$

Heat Balance of the Floor

Heat conductivity through the floor is divided into two parts. One part is the heat transfer through the perimeter, and the other is the heat transfer to the soil. So heat balance of the floor surface is:

heat obtained from foundation perimeter + conductive heat obtained from the soil + radiation heat from other surfaces + convective heat from interior air = 0, i.e.,

$$K_p\cdot L_p[\,t_o(n)-t_3(n)]/A_3 + \sum_{j=0}^{Ns} Y_3(j)\cdot t_{o3}(n-j) - \sum_{j=0}^{Ns} Z_3(j)\, t_3(n-j)$$

$$+\sum_{\substack{k=1\\ k\neq 3}}^{N_i} \alpha^r_{3,k}\cdot[\,t_k(n)-t_3(n)]+\alpha^c_3\cdot[\,t_r(n)-t_3(n)] = 0 \tag{2}$$

Heat Balance of Inside Air

The heat balance of inside air is expressed as:

Convective heat transfer from inside surfaces + heat produced by bee + heat obtained through air exchange = sensitive heat increment, i.e.

$$\sum_{k=1}^{N_i} F_k\cdot\alpha^c_k[\,t_k(n)-t_r(n)]+q_{bee}(n)+L_a(n)\,(c\rho)_a[\,t_o(n)-t_r(n)]/3.6$$

$$=V\,(c\rho)_r\frac{t_r(n)-t_r(n-1)}{3.6\Delta\tau}+M_b\,C_b\frac{t_r(n)-t_r(n-1)}{3.6\Delta\tau} \tag{3}$$

The above equation can be expressed into matrix

$$A\cdot T_i(n)=B \tag{4}$$

where $T_i(n)=[\,t_1(n),\,t_2(n),\,t_3(n),\,t_r(n)]^T$

$$A=\begin{bmatrix} -[\alpha_1+Z_1(0)] & \alpha^r_{1,2} & \alpha^r_{1,3} & \alpha^c_1 \\ \alpha^r_{2,1} & -[\alpha_2+Z_2(0)] & \alpha^r_{2,3} & \alpha^c_2 \\ \alpha^r_{3,1} & \alpha^r_{3,2} & -[\alpha_3+Z_3(0)+K_p\,L_p/A_3] & \alpha^c_3 \\ -F_1\cdot\alpha^c_1 & -F_2\cdot\alpha^c_2 & -F_3\cdot\alpha^c_3 & A_{4,4} \end{bmatrix} \tag{5}$$

$$A_{4,4}=\sum_{k=1}^{Ni} F_k\cdot\alpha^c_k+\frac{L_a(n)\,(c\rho)_a}{3.6\Delta\tau}+\frac{V\,(c\rho)_a}{3.6\Delta\tau}+\frac{M_b\,C_b}{3.6\Delta\tau}$$

$$B=\begin{bmatrix} -\sum_{j=0}^{N_t} Y_1(j)\, t_{o1}(n-j)+\sum_{j=1}^{N_t} Z_1(j)\, t_1(n-j) \\ -\sum_{j=0}^{N_t} Y_2(j)\, t_{o2}(n-j)+\sum_{j=1}^{N_t} Z_2(j)\, t_2(n-j) \\ -\frac{K_p \cdot L_p}{A_3}\, t_o(n)-\sum_{j=0}^{N_t} Y_3(j)\, t_{o3}(n-j)+Z_3(j)\, t_3(n-j) \\ q_{bee}(n)+L_a(n)\,(c\rho)_a \frac{t_o(n)}{3.6\Delta\tau}+[V\,(c\rho)_r+M_b\, C_b]\frac{t_r(n-1)}{3.6\Delta\tau} \end{bmatrix} \tag{6}$$

A FORTRAN program BS.FOR was designed to solve this equation. The diagram of the simulation program is illustrated in Fig.2.

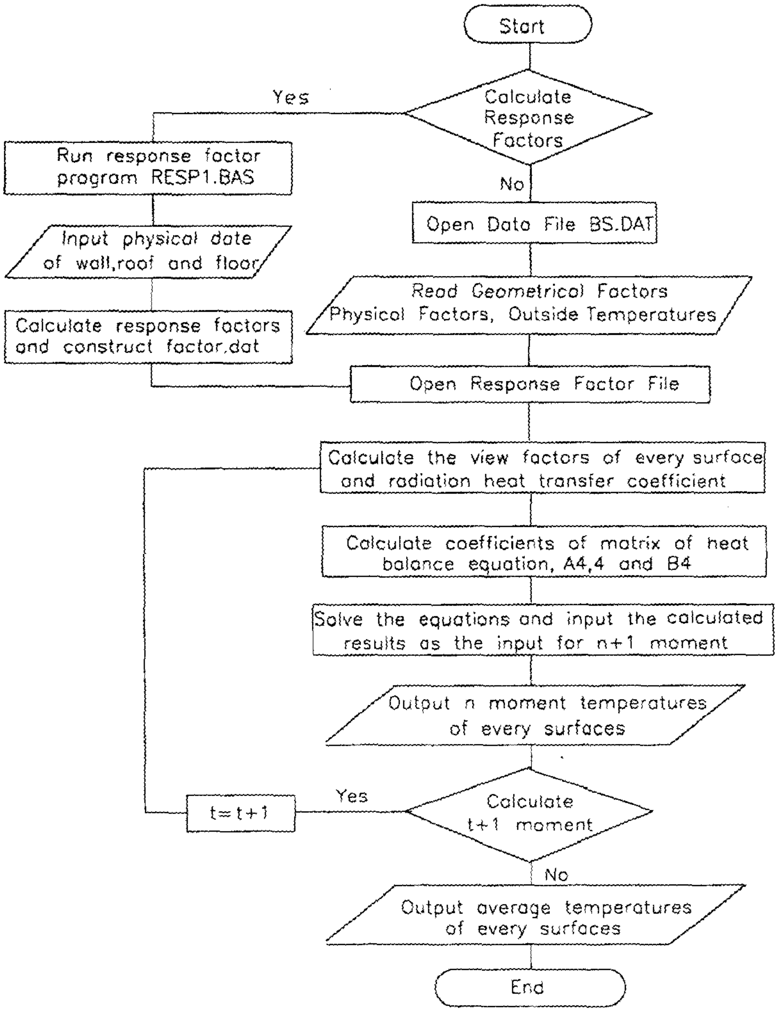


Fig.2 Flow chart of simulation program

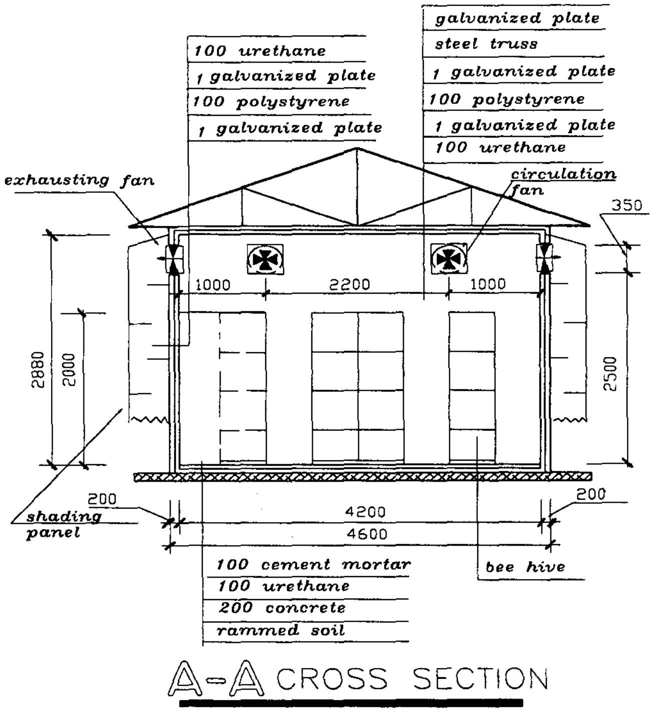


Fig. 3 Simulated beehouse(Youngju)

TESTING THE ANALYSIS

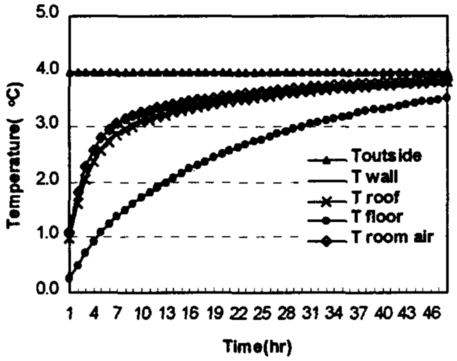
The testing of the model includes theoretical method and practical measuring test. Fig.3 shows the tested beehouse which was constructed in Youngju in Jan. 1997.

Testing for Isothermality

The testing for isothermality was described by Chandra, Albright, and Scott in 1981. In the absence of any thermal potential such as temperature difference, heat flux, or internal heat generation, the beehouse attains isothermality, i.e., uniform temperatures everywhere in the enclosure. When a constant outside temperature is given and whatever the inside temperature is before the calculation, the calculated interior temperatures will finally reach the given outside temperature. Fig.4 shows the isothermality testing for the analysis when the outside temperature was 4℃ constant and the initial inside temperatures are given 0℃. The isothermality testing indicated that the analysis was free of spurious thermal sources or sinks. It is easy to notice that the floor surface temperature increases slowly to reach the given temperature 4℃ due to the heat storage capacity of the concrete floor.

Testing with Experimental Data

The analysis was tested by comparing its predicted results to the measured temperatures of a beehouse constructed in Youngju city(shown in Fig.3). Fig.5 shows the calculated result and the measured value of interior temperature. In general, comparison between measured and computed temperatures is good. The mean deviation between computed and measured value was 0.031℃. Maximum difference of 3.25℃ was observed. It is also easy to observe that 1 hour calculating interval causes a fluctuation of the predicted temperature line around 6℃.



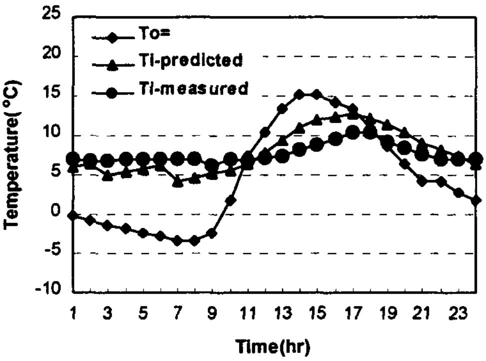


Fig.4 Isothermality testing

Fig.5 Predicted and measured temperatures(Youngju, 02/23/1997)

SIMULATION USING THE MODEL

Once the computer model is verified, the most important application is to predict results which could otherwise be obtained only with extensive and costly experimentation(Chandra, 1981). The following simulations were selected to demonstrate the applicability of the model and give some suggest to the construction of wintering beehouse.

Effect of Ventilation Control Schedule on the Interior Temperatures

Table 1 shows two methods of control schedule for beehouse interior environment in Youngju city. Control schedule VENT1 is the practical control method used during Feb. 18th to Mar. 13th. Control schedule VENT2 is the recommended control method. The simulation result shows that control schedule VENT2 decreases the interior temperature 2.8℃. (Fig. 6).

Table 2 shows the construction materials used for the roof and side wall of the beehouse. Material 1 is the practical materials used in Youngju beehouse. Material 2 is a recommended construction. VENT1 is used in the simulation. The simulation result shows that Material 2 decreases the interior temperature 1.7℃(Fig.7). This is caused by heat storage capacity of materials.

Table 1. Two control methods for beehouse interior environment

Control schedule VENT1	Control schedule VENT2
Ti≤6℃, L_a=220m^3/hr Ti>6℃, L_a=1850m^3/hr	To>9℃, L_a=220m^3/hr To<9℃, Ti≤6℃, L_a=220m^3/hr Ti>6℃, L_a=1850m^3/hr
When To>9℃, the fans drew much heat into house causing temperature increasing	When To>9℃, maintain interior humidity under 75% with the lowest ventilation rate

Table 2. Construction materials used on the roof and side wall

Material 1	Material 2
From outside to inside 1mm galvanized plate 100mm polystyrene 100mm urethane	From outside to inside 1mm galvanized plate 100mm polystyrene 100mm reinforced concrete

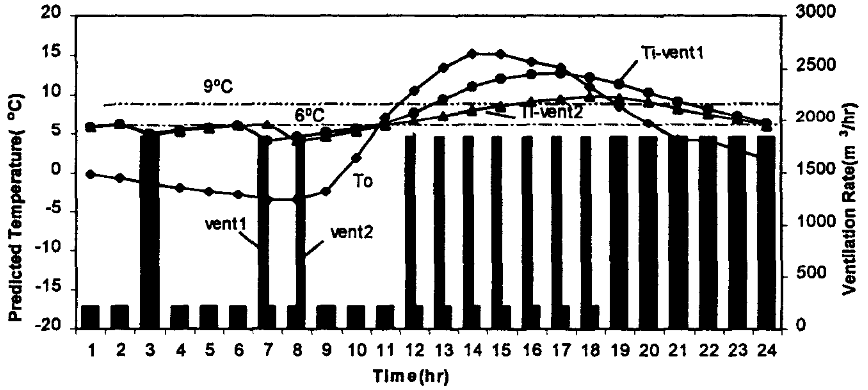


Fig.6 Predicted interior temperatures for two ventilation methods

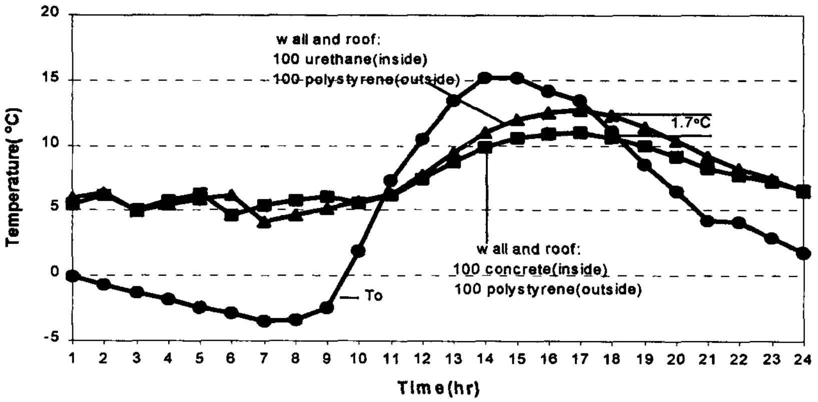


Fig. 7 Predicted interior temperatures for two kinds of materials

CONCLUSION

The mathematical model and the simulation program are valid for the prediction of inside thermal environment condition. It can be used to design the materials of the enclosure and the ventilation system.

NOTATION

A_3	floor area, m^2
C_b	specific heat of beehive box, J/kg
F_k	k surface area, m^2
$L_a(n)$	ventilation rate at n moment, m^3/s
M_b	weight of beehive box, kg
N_s	the number of response factors
N_i	the number of the surfaces of enclosure
$q_{bee}(n)$	heat produced by bee at n moment, W
t_{oi}	temperature of No. i outside surface , ℃
t_i	temperature of No. i inside surface , ℃
t_r	interior air temperature, ℃
V	beehouse volume, m^3
Y_i	No. i enclosure heat conductive response factors
Z_i	No. i surface heat absorbing response factors
$\alpha_{i,k}^{r}$	radiation heat transfer coefficient between surface i and k, $W/m^2 \cdot$ ℃
α_i^c	convective heat transfer coefficient of No. i inside surface, $W/m^2 \cdot$ ℃
α_i	total heat transfer coefficient of No. i surface, $\alpha_i = \alpha_i^c + \sum_{\substack{k=1 \\ k \neq i}}^{N_i} \alpha_{i,k}^{r}$, $W/m^2 \cdot$ ℃
$\Delta\tau$	interval between two calculation moments, hour, here $\Delta\tau=1$
$(c\rho)_a$, $(c\rho)$,	inside and outside air specific heat, $J/m^3 \cdot$ ℃

References

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(2) Pitam Chandra, L. D. Albright, N. R. Scott. 1981. A time dependent analysis of greenhouse thermal environment. TRANSACTIONS of the ASAE. pp.442-449