EVALUATION OF TEMPERATURE DISTRIBUTIONS AND AIRFLOW PATTERNS WITH THREE AIR DIFFUSING SYSTEMS IN HEATING PERIOD

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ABSTRACT

This study is to investigate the characteristics of indoor air temperature distributions and airflow patterns with three air diffusing systems in heating period and to find the methods which can predict those indoor environmental conditions effectively. A series of measurements and corresponding numerical analysis were done.

Selected three air diffusing systems for this study are as follows; 1) ceiling supply-ceiling exhaust, 2) ceiling supply-floor exhaust, 3) floor supply-ceiling exhaust.

As a result, ceiling supply-floor exhaust system and floor supply-ceiling exhaust system showed similar temperature difference between supply air and occupied area. Floor supply-ceiling exhaust system resulted in nearly uniform air temperature throughout the room and high ventilation effectiveness was obtained.

INTRODUCTION

Recently, as the concern of energy saving and comfortable environment gets higher, the control of indoor air temperature and airflow patterns became one of major topics in building science. Also, forecasting of indoor air temperature and airflow patterns are actively being developed.

This study is to understand the characteristics of indoor air movements for three air diffusing systems, and to investigate the application possibility of numerical analysis to the development of an effective prediction.

For the purpose, we performed a series of measurements on three air supply systems in heating period, and we did numerical analysis based on macro and micro models with the same conditions as experiments.

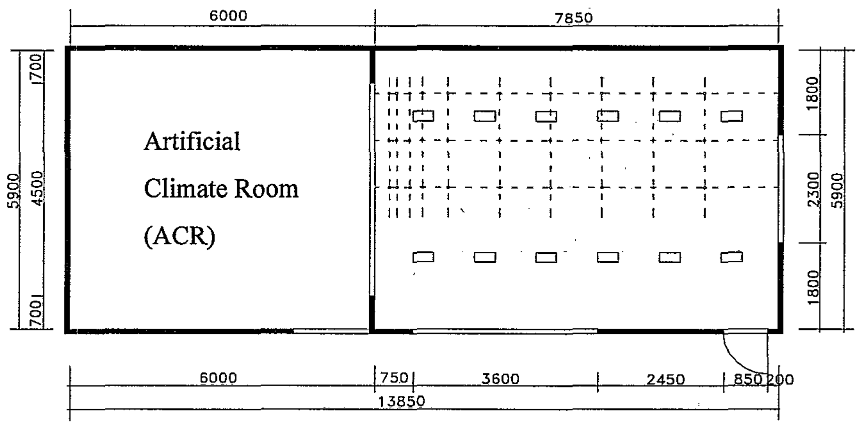


Figure 1. Plan of real scale model room [mm]

METHODS

Experimental setup

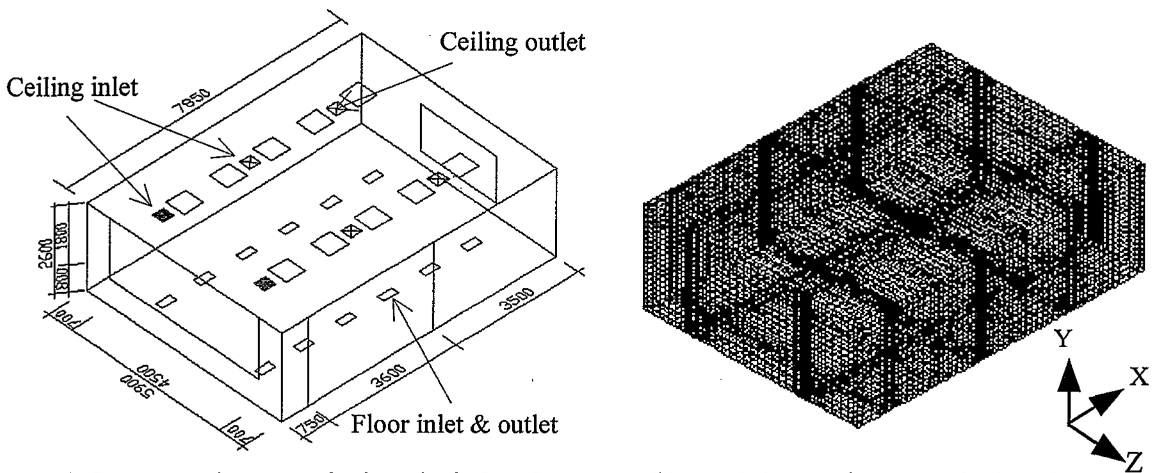
The Dimension of model room is 7.85m(W)* 5.9m(D)*2.6m(H). One side of the model room faces Artificial Climate Room(ACR) which can control to outside weather conditions, and the other side faces adjacent room. Figure 1 shows the plan of model room and the measuring points of horizontal air temperature. Table 1 and Table 2 show measuring conditions, items and instruments in each case.

Table 1. Measuring condition

Case	Air supply system	Room air temperature	ACR air temperature	Supply Air Volume	Inlet air velocity
1	Ceiling supply-Ceiling exhaust	23 ℃	0 ℃	2,000 m^3/h	2.5m/s
2	Ceiling supply-Floor exhaust				
3	Floor supply-Ceiling exhaust			1,000 m^3/h	1.3m/s

Table 2. Measuring method

Temperture – measured using thermocouples			
Vertical distributions at 8 heights			
0m(Floor level), 0.025m, 0.6m, 1.1m, 1.6m, 2.1m, 2.575m, 2.6m(Ceiling surface)			
Total points = 240 points			
Air inlet and outlet	10 points	Outdoor air	3 points
Indoor wall surface	19 points	Outdoor wall surface	4 points
Air velocity – measured using Three dimensional anemometer			
Vertical distribution at 5 heights			
0.1m, 0.6m, 1.1m, 1.6m, 2.1m			
Total points = 60 points			



(a) Geometry for numerical analysis [mm] (b) Mesh layout for numerical analysis

Figure 2. Geometry and mesh layout for numerical analysis

Numerical Analysis

The analysis of radiative heat transport on the objective space primarily based on the measurement results in the macroscopic study.

In the microscopic study, a RNG(ReNomalization-Group) k-ε turbulent model was used, which was considered buoyancy effects. In the analysis of convective heat flux, the result of macroscopic study was applied to wall boundary condition. Table 3 shows RNG k-ε turbulent equations and Table 4 shows boundary and calculation conditions.

Table 3. RNG k-ε turbulent equations

The momentum equation
$\frac{\partial u_i}{\partial t}+\frac{\partial}{\partial X}(u_i u_j) = -\frac{1}{\rho}\frac{\partial p}{\partial X_i}+\frac{\partial}{\partial X_j}[\nu_{eff}(\frac{\partial u_i}{\partial X_j}+\frac{\partial u_j}{\partial X_i})]$
K equation
$\frac{\partial k}{\partial t}+u_i\frac{\partial k}{\partial X_i}=\nu_t S^2-\varepsilon+\frac{\partial}{\partial X_i}\alpha\nu_t\frac{\partial k}{\partial X_i}$
ε equation
$\frac{\partial \varepsilon}{\partial t}+u_i\frac{\partial k}{\partial X_i} = C_{1\varepsilon}\frac{\varepsilon}{k}\nu_t S^2-C_{2\varepsilon}\frac{\varepsilon^2}{k}-R+\frac{\partial}{\partial X_i}\alpha\nu_t\frac{\partial \varepsilon}{\partial X_i}$

Table 4. Boundary and calculation conditions

Inlet condition	Inlet vel. U_{in}, Inlet temp. T_{in} : Measurement value $k_{in}=3/2\cdot(U')^2$, $\varepsilon_{in}=C_\mu{}^{3/4}\cdot(k^{3/2}/l_{in})$
Outlet condition	$P=P_s$, pressure outlet B.C., K_{out}, ε_{out}, T_{out} [free-slip]
Surface Condition	(Temp.) $q=h_f\cdot(T_w-T_f)$ (Vel.) $\varepsilon_1=C_\mu{}^{3/4}\cdot k_1{}^{3/2}/k\cdot y_1$ • Outdoor temp.: 0 ℃ • Indoor temp.: measurement value • Convective heat transfer Coefficients: Outdoor(10 W/m²℃) Indoor(4 W/m²℃)
Calculation condition	A number of cell: X(77)*Y(22)*Z(54)=91,476 cells SIMPLE algorithm Power-Law & Quick scheme

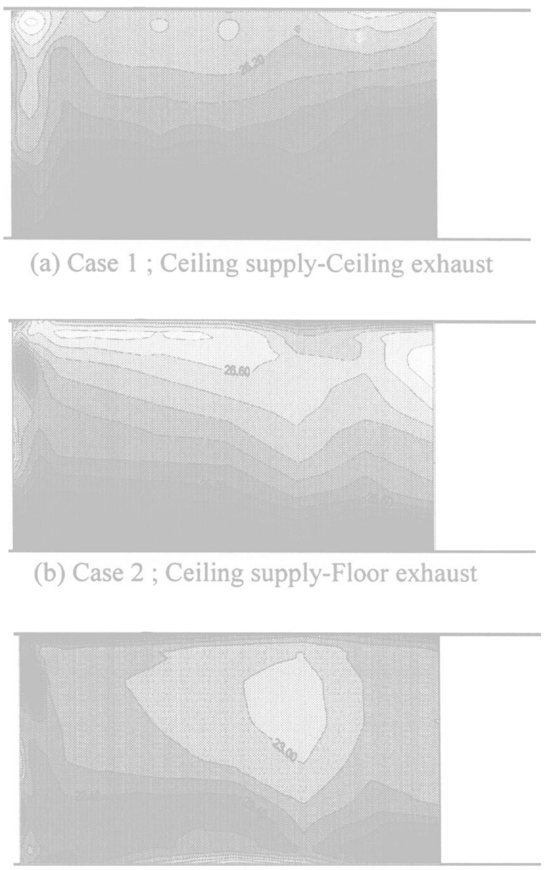
RESULTS

Temperature distributions

The results of numerical simulation in each condition showed very similar to those of measurement.

Room air temperature of each case ranged similarly from 22℃ to 25℃ in occupied area, although supply air volume in case 1 and case 2 was as double as that in case 3. Air temperature difference was less than 3℃ between supplied air and occupied area. But in case 1, temperature difference of over 5℃ was found, as supply air was discharged to outlet nearby inlet. Figure 3 and Figure 4 showed vertical air temperature distributions at the center of the room(Z=2.95m) by measurement and numerical analysis.

In case 1 and case 2, thermal stratification with height was found, however case 3 showed little temperature deviation. Air temperature deviation with height in each case is plotted in Figure 5.

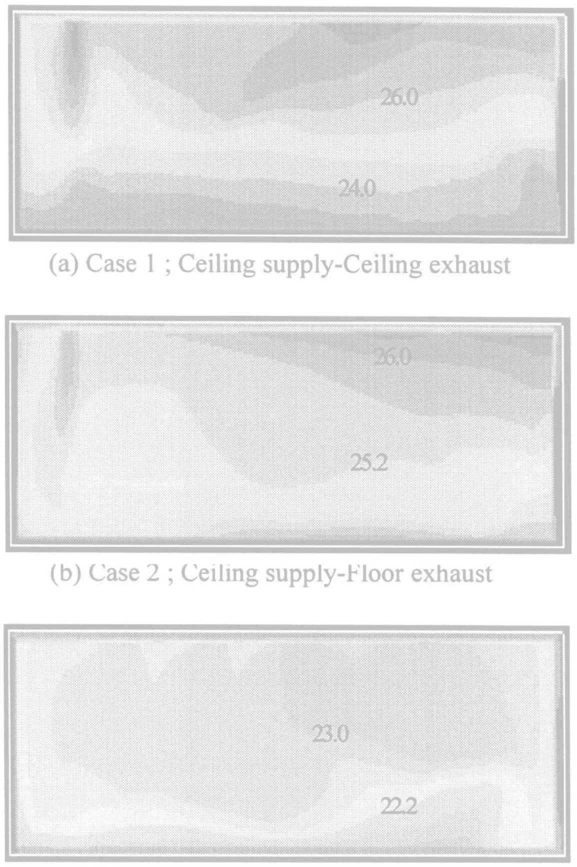


(a) Case 1 ; Ceiling supply-Ceiling exhaust

(b) Case 2 ; Ceiling supply-Floor exhaust

(c) Case 3 ; Floor supply-Ceiling exhaust

Figure 3. Vertical Air Temperature by Measurement [℃]



(a) Case 1 ; Ceiling supply-Ceiling exhaust

(b) Case 2 ; Ceiling supply-Floor exhaust

(c) Case 3 ; Floor supply-Ceiling exhaust

Figure 4. Vertical Air Temperature by Numerical Analysis [℃]

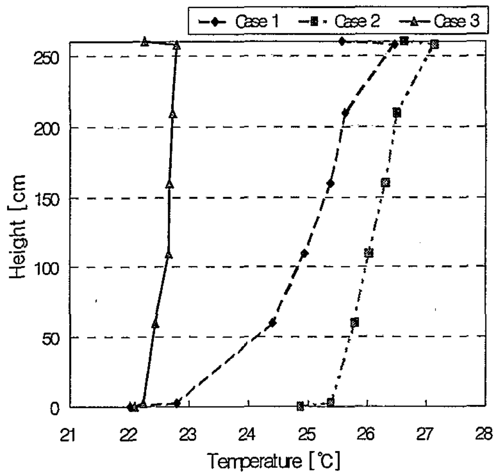


Figure 5. Temperature deviation with height

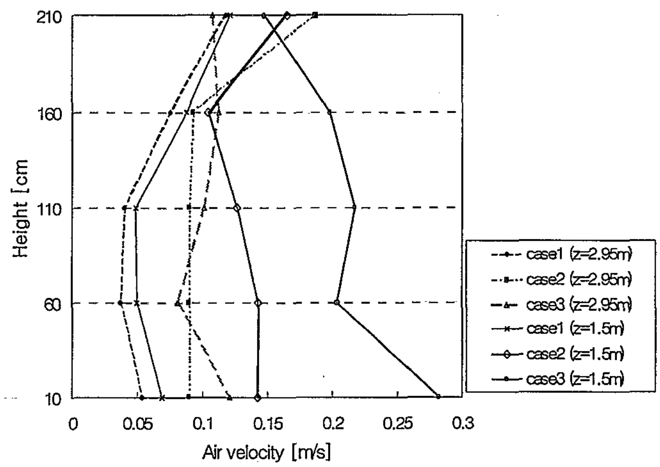
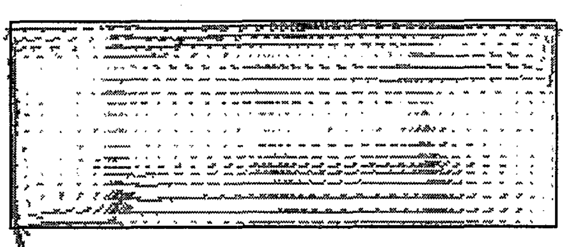


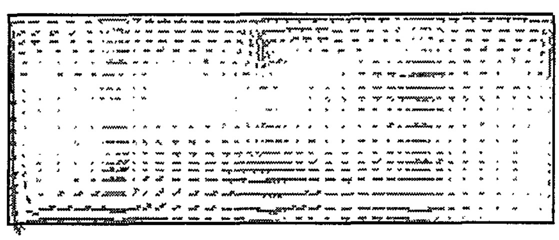
Figure 6. Air velocity with height

Airflow patterns

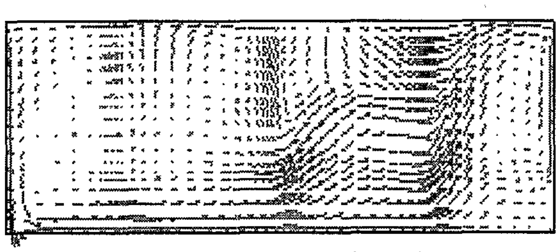
Overally, air velocity resulted in below 0.3m/s in all cases. Figure 6 shows air velocity with height in each case. Airflow patterns by numerical analysis are shown in Figure 7 and



(a) Case 1 ; Ceiling supply-Ceiling exhaust

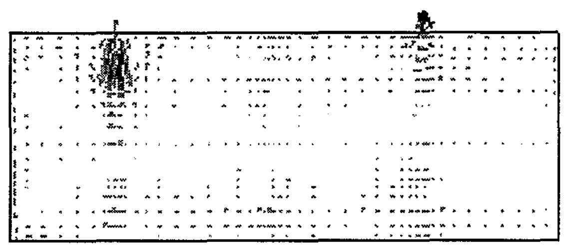


(b) Case 2 ; Ceiling supply-Floor exhaust

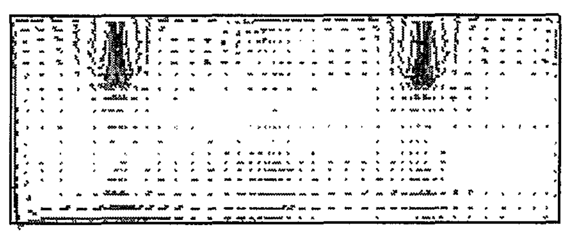


(c) Case 3 ; Floor supply-Ceiling exhaust

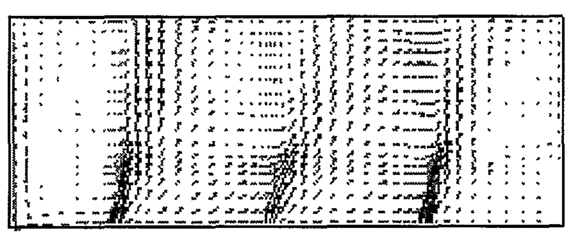
Figure 7. Airflow patterns at the center of the room by numerical analysis



(a) Case 1 ; Ceiling supply-Ceiling exhaust



(b) Case 2 ; Ceiling supply-Floor exhaust



(c) Case 3 ; Floor supply-Ceiling exhaust

Figure 8. Airflow patterns at the section of inlets by numerical analysis

Figure 8. From these figures, we could find case 3 was the best one for the effective ventilation of room.

CONCLUSION

The results of numerical analysis of macroscopic and microscopic model study were approximate to the measuring results in terms of indoor air temperature distributions and airflow patterns for three air diffusing systems.

In the ceiling supply-ceiling exhaust system for heating, air stratification and vertical air temperature difference clearly existed. In addition, we could find that room air temperature in occupied area of this case was lower than other supply systems from numerical analysis. This results could imply undesirable use of energy and thermal discomfort. In ceiling supply-floor exhaust system and floor supply-ceiling exhaust system, the vertical air temperature difference was smaller than that of ceiling supply-ceiling exhaust system. Floor supply-ceiling exhaust system resulted in nearly uniform air temperature throughout the room and it could make better temperature patterns in occupied area.

From comparing and analyzing the airflow patterns for three air diffusing systems, the ceiling supply-ceiling exhaust system and ceiling supply-floor exhaust system formed horizontal airflow instead of vertical airflow. Especially, the ventilation by supply air was only made nearby inlets because of buoyancy effects. On the other hand, in the floor supply-ceiling exhaust system, vertical airflows were active, and the ventilation effectiveness of the room through supply air was very good.

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