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A Study on Indoor Environment of Interior with Ventilation

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Abstract : There are no solar loads through windows and heat transfer from outer walls of the building to the interior. This study analyzes indoor air temperature and air flow distribution for the interior of buildings or vessels occupying space. Numerical method is adopted to visualize the indoor side environmental situation, that is without heat transmission to outside the building in various cooling load conditions; supply ventilation lighting, occupancy and infiltration in conditioned spaces. Reaching time of an air conditioner is predicted theoretically by cooling load variations. Theoretical modelling of the reaching time shows good agreement with experimental results.

Key words : Interior, Ventilation, Cooling Load, Reaching Time

Nomenclature

- Q : Cooling load (kcal/h)
- Q_{AC} : Cooling capacity of air conditioner (kcal/h)
- Q_{CL} : Total cooling load of indoor (kcal/h)
- q_E : The heat removing from indoor side to reach setting temperature from initial (kcal)
- t_{SR} : Reaching time to the setting temperature of the air conditioner (min)

1. Introduction

The interior space of buildings or vessels increascs as a result of enlarging the floor space area. The cooing loads from sun light and heat transmission through the walls are dominant in the exterior, but the effect of these cooling loads have a comparably small portion in the interior of the buildings. The light, and office automation equipment cause the cooling load of the interior space to increase in new intelligent office buildings. In this kinds of space, mechanical ventilation is very essential because outdoor air cannot easily reach to the interior, so more strict guidelines are recommended[1]-[5].

Ventilation is the process of supplying air to, or removing air from a space for the purpose of controlling air contaminant, humidity, or temperature within that space. When the outdoor air is supplied inside of the building by ventilation, the cooling load of a space is

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increased and required reaching time to the setting temperature of an air conditioner is delayed[6],[7].

In this study, the reaching time of setting temperature modeling is also performed and investigated by the experiment at environmental chamber. Indoor heat environment distributions are also predicted with numerical analysis with the different cooling loads at the 35 m^3 interior space: supply ventilation air flow rate, 0 and 570, two lights and an occupant.

2. Required Ventilation rates and Reaching Time

2.1 Required ventilation rates

Ventilation is the process of removing indoor air contaminants by supplying outdoor air and changing the air between indoor and outdoor to supply fresh air to indoor side. Each country has guidelines or regulations that should be supplied to the occupants space. That means the minimum outdoor air requirements for ventilation.

Table 1 prescribes supply rate of outdoor air required for acceptable indoor air quality in U.S.A (ASHRAE Standard 62-1989), Japan (HASS102), and EU[8]-[10]. These values have been chosen to dilute human bioeffluents and other air contaminants with an adequate margin of safety and to account for health variations among people and varied activity levels. In case of one occupant in a 35 m^3 area space, outdoor air for ventilation is required for 450 lpm by ASHRAE and 500 lpm by HASS. Therefore the numerical analysis and experiment have been performed in the each condition of 0 and 570 lpm.

Table 1 Outdoor air requirements for ventilation[8-10]

Nation	Ventilation Standard	Application	Ventilation rate
United States of America	ASHRAE Standard 62-1989	Shop	1.25(L/s · m^2)
		Classroom	2.8(L/s · m^2)
		Conference room	5.0(L/s · m^2)
		Office space	0.7(L/s · m^2)
		Residence	0.25(L/s · m^2)
			7.5(L/s · person)
Japan	HASS102	Living room of residence	8.3(L/s · person)
Europe	EU	Office space (Private)	1.4(L/s · m^2)
		Conference room	4.3(L/s · m^2)
		Auditorium	11.0(L/s · m^2)
		Restaurant	3.2(L/s · m^2)
		Classroom	4.3(L/s · m^2)

2.2 Reaching time to the setting temperature

When the heat of a specific space is removed by an air conditioner, the indoor temperature reaches the setting temperature of the air conditioners. The reaching time will be delayed in the condition of bigger cooling loads compared to the cooling capacity of air conditioner[7],[11].

$$t_{SR} = \frac{60 \times q_E}{Q_{AC} - Q_{CL}} \tag{1}$$

Cooling load calculations are the primary design basis of most air-conditioning systems and components. The cooling load results from many heat transfer processes through the building envelope are from internal source and system components[10],[11]. Generally there are total 6 types of cooling loads in the indoor space: internal heat gains from equipment, people, lights and infiltration and heat gains through walls and windows. The heat gains from the outside are comparably small to the interior because the heat accumulated in the wall is then transmitted into the indoor side or delivered to the exterior through the windows. Therefore the heat gains through the wall and windows are assumed negligible if the exterior of the building is also conditioned. In this study, the reaching time of a wall mount type air-conditioner installed in environmental chamber which has neatly same condition as interior are calculated.

3. Numerical analysis of indoor environment

3.1 Boundary conditions

Fluid flow is assumed steady and unsteady with 3-dimensional, incompressible flow and turbulence. The effects of viscous dissipation and radiation heat transfer are assumed negligibly small. The fluid properties are assumed constant except for the density in the viscous terms of the momentum equation.

Cooling loads varies with supply ventilation air flow rates of 0 to 570 lpm and the internal cooling loads. The initial setting temperature of air-conditioners is 27℃. $k-\varepsilon$ models with Neumann type boundary condition and no slip condition in the flow are used to analyse an indoor environment. Non equilibrium wall functions are adopted to calculate the effect of the wall to the flow. Heat flux from the wall is assumed 0 in this interior space model. The ventilation air to the indoor side circulate along the surface on the wall and then is exhausted to outdoor side in which the constant pressure condition are adopted as an exhaust air condition.

Table 2 Constants of standard $k-\epsilon$ model.

C_{μ}	$C_{1\epsilon}$	$C_{2\epsilon}$	α_k	α_{ε}
0.09	1.44	1.92	1.0	1.3

3.2 Analysis method

Air flow with a big vortex can occur when the sectional areas are rapidly varying in regions such as a supplying grille of ventilators or diffusers. Fluid flow and heat transfer characteristics are very complex on this varying wall conditions. The cell structure and algorithm is considered to minimize false diffusion at the actual complex heat and fluid flow field. The governing equations for three dimensional turbulent convective heat transfer fluid flow are solved using FLUENT which is commercial finite volume CFD code[12],[13]. The reason for using the CFD code is as follows: to obtain the optimum solutions by means of the mathematical optimization technique, and because a fast and reliable computer program must be used because it operates repeatedly for many different geometrical configurations during optimization process. The SIMPLE algorithm is used to calculate the pressure correction equation in the momentum equation. The power law scheme is employed for the treatment of convection and diffusion terms.

3.3 Cell structure

Fig. 1 shows the cell structure of the control space with an air-conditioner and the lights having room volume of 35 m^3. The cell structure is tetrahedral cell with 440,188 mesh.

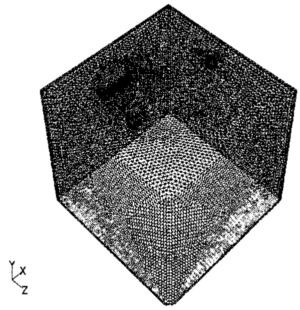
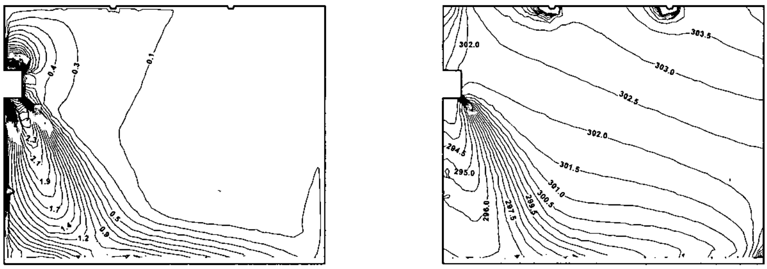
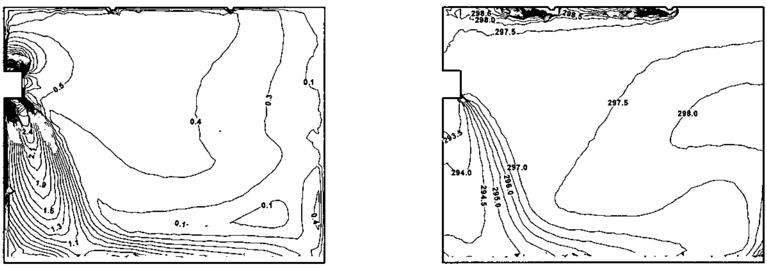


Fig. 1 Schematic figure of the computational domain with the grid pattern.



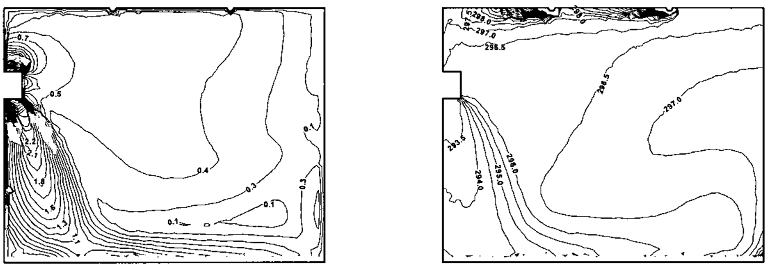
Contour of Velocity [m/s] Contour of Temperature [K]

a. Supply air flow rate = 0 lpm, Time=60 sec



Contour of Velocity [m/s] Contour of Temperature [K]

b. Supply air flow rate = 0 lpm, Time=180 sec



Contour of Velocity [m/s] Contour of Temperature [K]

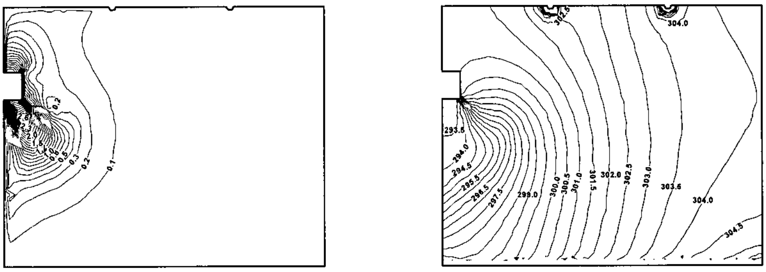
c. Supply air flow rate = 0 lpm, Time=300 sec

Fig. 2 Air flow and temperature distribution with light and no occupant

4. Result and Analysis

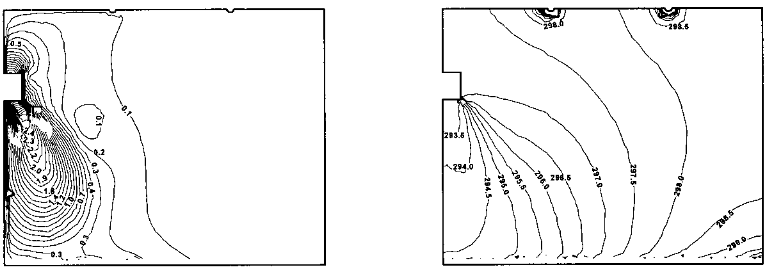
4.1 Air velocity and temperature distribution

Fig. 2 shows the variation of indoor air velocity and temperature distribution with the condition of 2 lights and one occupant at interior for 300 seconds after turing turning the air-conditioner. After 60 seconds from on, air flow has not yet reached the whole space. After 300 seconds, more than 0.1 m/s speed air circulation was shown in all locations. Especially the discharge and suction air flow of the air-conditioner is higher in air velocity than other locations. The room temperature was decreased first time because the air-conditioner removes heat from the space and discharge the cold air into the space. Heat flux from the light is



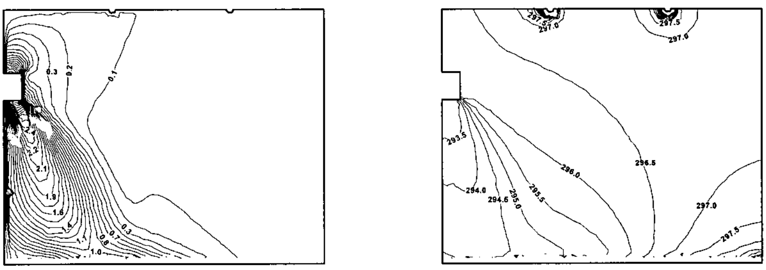
Contour of Velocity [m/s] Contour of Temperature [K]

a. Supply air flow rate = 570 lpm[Time=60sec]



Contour of Velocity [m/s] Contour of Temperature [K]

b. Supply air flow rate = 570 lpm[Time=180sec]



Contour of Velocity [m/s] Contour of Temperature [K]

c. Supply air flow rate = 570 lpm[Time=300sec]

Fig 3 Air flow and temperature distribution with ventilation, lights, an occupant and infiltration .

directly entered into the air-conditioner by the circulation of the indoor air.

Fig. 3 shows the effect of the ventilation air in the interior environment. When the ventilation air supplied, higher temperature distribution is shown on the surface of ceiling where the ventilator has been installed. The average temperature of the space also become higher and the effect of the lights has been lower than that of no ventilation. From the velocity distribution of the interior with ventilation from the ceiling, the air discharge disturbs the air circulation of the space. Furthermore, the cold discharge air from the air-conditioner is circulated only in the limited region so that the air-flow can not reach the whole space because the induced high temperature air from the ventilator divide the air-flow of the whole space. It means that the location of ventilator can affect the whole space environment. Therefore the location of the ventilator is so important in case of combined installation of air-conditioner and ventilator.

4.2 Reaching time to the setting temperature

The reaching time of the wall mounted type air-conditioner (5,600 kcal/h) was analysed based on the standard of KAITECH and KARSE with the different supply ventilation air conditions. An 89.1 m^3 environmental chamber with well-insulated walls and ceiling from the outside is used for this experiment because of similar conditions with the interior.

Table 3 shows the calculation of total cooling load of the space with varying ventilation air flow rate of 0, 100, 250, 570 lpm, lights, an occupant, infiltration. The results are similar to both standards and the calculations of cooling loads are increased depending on the ventilation flow rate.

Table 4 shows the comparison of the reaching time between the predicted and experimental values in case of 0, 100, 250, 570 lpm of ventilation air supply. The actual reaching time from 35 to 27 ℃ was raised about 20% compared to the result calculated by the leakage of conditioned indoor air from the doors of the environmental chamber. Fig. 4 shows the indoor temperature variation of the experimental chamber. The higher ventilation rate shows the lower variation of the room temperature and these results coincide with the values which is shown in table 4.

Table 3 Total cooling load of the environmental chamber.

Supply air flow rate (lpm)	Cooling load (kcal/h)	
	KITECH	KARSE
0	2140.6	2101.4
100	2168.0	2128.8
250	2209.0	2168.8
570	2296.6	2257.4

Table 4 Comparison of reaching time to the setting temperature

Supply air flow (lpm)	Reaching time to the setting temperature (min)		
	Predicted		Measured value
	KAITEC	KARSE	
0	12.48	12.14	14.66
100	12.73	12.38	15.16
250	13.12	12.74	15.66
570	14.03	13.61	16.83

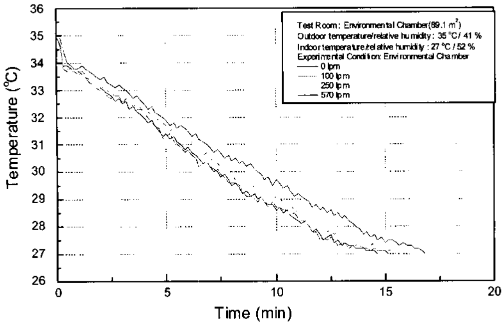


Fig. 4 Reaching time to the setting temperature

5. Conclusions

In this paper, the characteristics of environment in the interior and the reaching time of the setting temperature was dealt with by the numerical method and the experimental method in the environmental chamber.

1) The indoor temperature has a growing tendency with the enlargement of the cooling load such as lights and occupants. The ventilation air which is supplied by the diffuser installed on the ceiling also make an increase in the indoor temperature distribution. In this case, the discharging air of the air-conditioner does not reach the whole space because the supplying air from the ceiling makes a separation of the air circulation in the whole space.

2) Reaching time of the setting temperature at 89.1 m^3 interior space was measured to analyze the relation between the heat to be removed from indoor and cooling capacity of air conditioner installed inside the environmental chamber. The reaching time with 570 lpm ventilation air increased by about 20 % as compared to no ventilation in condition of light and occupant.

3) Cooling load characteristics were analyzed on the standard of KAITECH and KORSE and the latter shows more accurate results as compared to the experimental data. The result can be expanded to the other interior case.

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He got B.A degree in 1987 and perceived the Ph.D. in 2002 from Pusan National University in mechanical engineering with specialization in ventilation. Additionally with the Masters in Air Conditioning from Pukyung National University, he has developed many key components and core technologies such as air-to-refrigerant heat exchanger, low noise fan system and ventilation system since he joined LG Air-conditioning Division in 1987.

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