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13320

NUMERICAL STUDY OF A NEW VENTILATION TOWER SYSTEM FOR FRESH AIR SUPPLY IN AN AIR-CONDITIONED ROOM

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ABSTRACT

In an air-conditioned office building, the ventilation air is normally mixed with the return air from the room in the air-handling unit. Therefore, the value of the air exchange efficiency defined by age of air is usually about 1.0, which is close to the perfect mixing case. If the fresh air and air-conditioning air are supplied separately, it is possible to increase the value of the air exchange efficiency at the breathing zone if the former is supplied directly to the breathing zone.

In this paper, the results of the CFD investigations for the ventilation tower system are described. In this system, fresh air is directly supplied to the breathing zone without mixing it with the return air from the room. This is achieved by supplying fresh air through a vertical duct rising from the floor and distributing fresh air to breathing zone height. With this system, the indoor air quality at the breathing zone will be improved and the requirement of the fresh air will be reduced in comparison with usual air-distribution systems.

The CFD simulation for isothermal conditions was carried out to compare the value of the air exchange efficiency between a conventional air-conditioning system and the ventilation tower system.

The results from CFD simulation show that the age of air at the breathing point is about 37 minutes for the conventional air-conditioning system and about 20 minutes for the ventilation tower system when the nominal time constant for the room was about 31 minutes. This result shows that the IAQ at the breathing zone provided by the ventilation tower system is better than the conventional systems.

KEYWORDS

Fresh Air, Ventilation and Air-Conditioning System, Ventilation Tower, IAQ, Smoking, Saving Energy, Age of Air, Scale for Ventilation Efficiency 3 (SVE3), Computational Fluid Dynamics

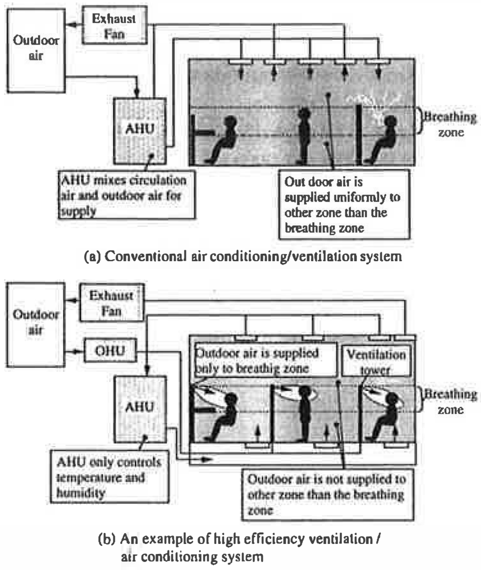


Figure 1 Concept of high efficiency ventilation/air conditioning systems taken as the object of this study

INTRODUCTION

Because of the concept of ventilation efficiency indices established recently, both the distribution efficiency of fresh air at each room point and the local air exchange efficiency at each room position can be obtained by the experiment and the numerical simulation.(e.g. Kuwahara et al 1999) These items were considered as difficult to obtain in the past. In the revised edition of the HASS102 Ventilation Standard and Description issued by The Heating, Air-Conditioning and Sanitary Engineers of Japan, the ventilation design employing the ventilation efficiency is proposed.

The indices of ventilation efficiency include the age of air as one of the items. The age of air is defined with a time required for supplied fresh air to reach any desired point such as the human breathing zone. Using this index, therefore, the supply efficiency of fresh air can be clarified.

In this study, high efficiency ventilation/air conditioning systems are investigated by considering the age of fresh air. Figure 1 shows the concept of the system. With the system shown in Figure 1 (b), the fresh air is independently supplied from the ventilation tower, that can be considered to reduce the required fresh air volume in comparison with the conventional system leading to a success in saving energy. Further this may provide a new solution in relation with smoking problems. Faulkner et al (1999) have studied a method for supplying outdoor air to a human body directly by mounting air supply outlets on a desk. However this system may require laborious work in changing the office layout. Therefore in this paper, the ventilation tower independent from a desk was studied for convenience in changing the office layout.

As the first step of the present study, this paper conducts a numerical simulation on the different air conditioning/ventilation systems shown in Table 1 under isothermal condition for comparison and investigation of the results obtained. The simulation results were evaluated by adapting the Scale for Ventilation Efficiency 3 (SVE3)(=$\overline{\tau_p}$: local mean age of air / τ_n: nominal time constant) proposed by Murakami and Kato (1986).

OUTLINE AND PROCEDURE OF ANALYSIS

The object of the simulation employs a part of the laboratory where the experiment will be conducted. The analysis model is shown in Figure 2 and the boundary and calculation conditions are in Table 2. For the simulation, the airflow field was applied with steady state simulation beforehand. Then tracer gas is generated from the fresh air supply outlet by the step-up method, and the age of the room air is calculated by unsteady state calculation with a time step of 60 seconds until the mean room concentration reaches the concentration of the gas generated.

TABLE 1
AIR CONDITIONING / VENTILATION SYSTEM FOR COMPARISON

	Air conditioning system	Ventilation system
Case 1	Floor supply / ceiling return	Supplied after mix into circulation air
Case 2	Floor supply / ceiling return	Supplied from ventilation tower directly into room
Case 3	Ceiling supply / ceiling return	Supplied from ventilation tower directly into room

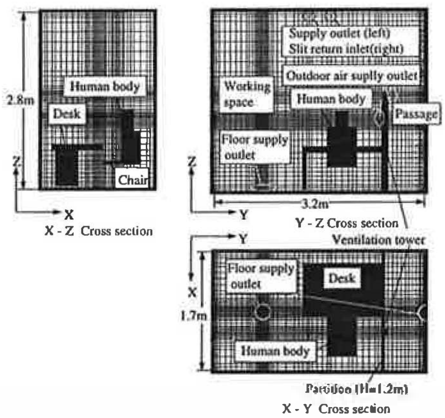


Figure 2 The analysis model

TABLE 2
CALCULATION AND BOUNDARY CONDITION

CFD grid points	47(X) x 70(Y) x 55(Z) Supposing a part of interior space, 1 occupant
Turbulent flow model	Standard k-ε model
Difference scheme	Advection term QUICK
Simulation method	Finite volume method based on SIMPLE method
Flowing boundary	$k_{in} = (U_{in}/100)^2$ $\varepsilon_{in} = C_\mu k_{in}^{3/2}/L_{in}$, L_{in} = Supply outlet opening width $C_\mu = 0.09$
Boundary condition	Free slip supposing continuous space for X-face wall, Y-face wall at passage side, Standard log-law for others
Nominal ventilation time	Fresh air volume: 30m³/h Fresh air volume + Circulation air volume: 150m³/h Air exchange rate: 2.0 times/h Circulation rate: 9.8 times/h Nominal ventilation time: τ_n = 30.5 min.
Floor supply outlet	Mesh splitting 10 x 10 per one spot. Reference 5) Supply air volume 80m³/h.set (Case 1) ,100m³/h.set (Case 2)
Ventilation tower (for Fresh air)	Mesh splitting per one supply air outlet: 3 x 3 Two supply air outlets per 1 tower (For working space and passage) Each 15m3/h supposing a case when occupied and moving hours are equal Supply outlet dimension: 0.058m x 0.058m Set to Uin = 1.24m/s to suppress wind velocity supposed breathing zone less than 0.5m/s according to Act for Maintenance of Sanitation in Buildings of Japan
Ceiling supply outlet	0.025m wide slit outlet, U in = 0.78m/s (Case 3)
Ceiling return inlet	0.025m wide slit inlet, U out = 0.98m/s (Case 1-3)

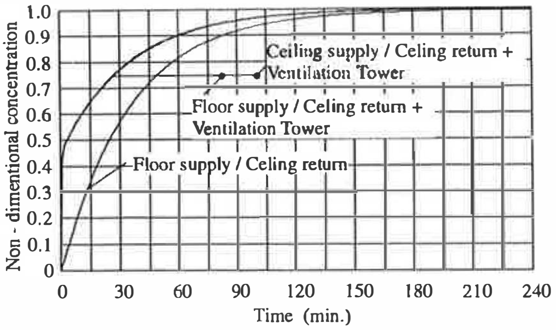
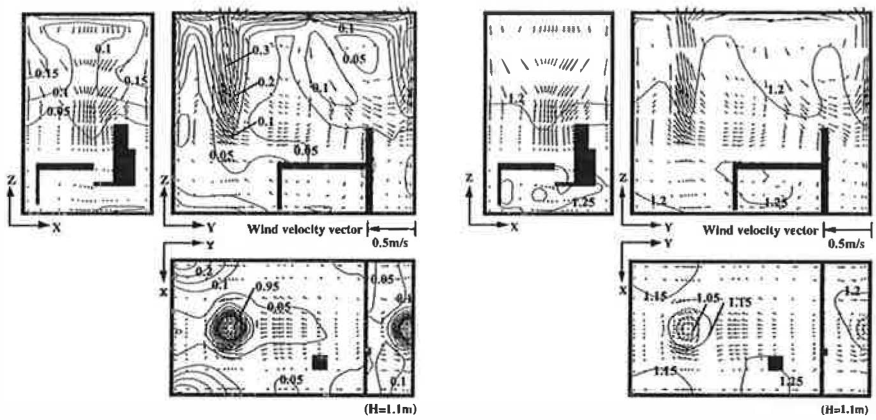


Figure3 Time-based change of concentration rise at breathing point supposed in each air conditioning/ ventilation system



(a) Wind velocity distribution

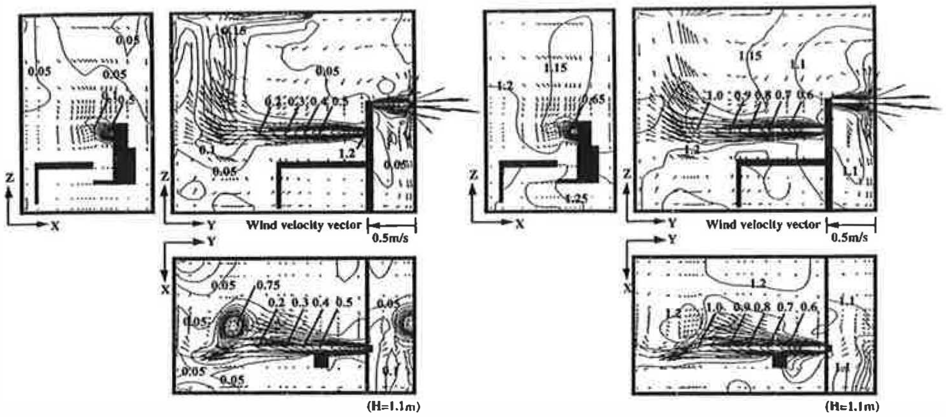
(b) SVE3 distribution (τ_n = 30.5 minutes)

Figure 4 Wind velocity and SVE3 distribution when fresh air is mixed into circulation air (Floor supply/ceiling return)

SIMULATION RESULTS

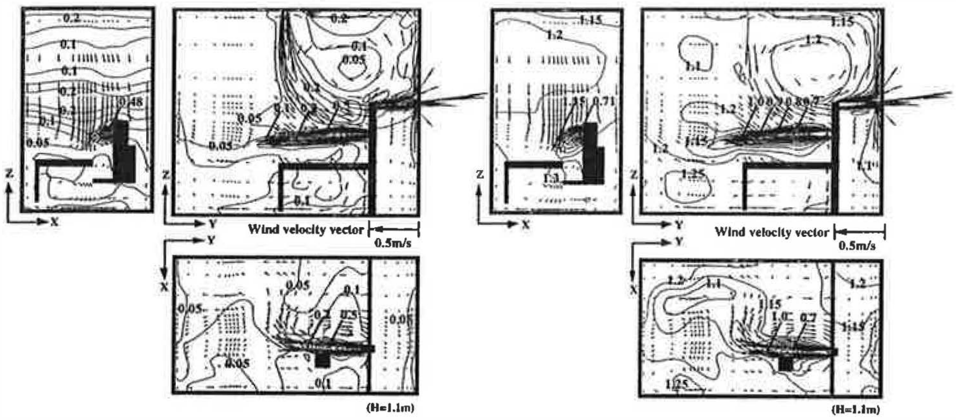
Figure 3 shows the time-based change of an increase in the non-dimensional concentration of the tracer gas at the supposed breathing point in each air conditioning/ventilation system. The supposed breathing point represents the location of FL + 1.1m at the position where the occupant is sitting in a chair. In the two systems where the ventilation tower was installed to supply fresh air directly, the concentration exceeds 0.4 at 1 minute after the tracer gas was generated. Although the increasing speed of the concentration in the case of the floor supply was higher, no significant difference was found between the two systems both showing quick concentration increase. After about 145 minutes elapsed, it reaches a concentration of 99% under an early steady state. In the case when fresh air is mixed into the circulation air on the other hand, about 205 minutes were required to reach a concentration of 99%, 1.4 times of the former value approximately.

Figures 4~6 show the wind velocity distribution and SVE3 distribution in the supposed breathing point of each air conditioning/ventilation system. The SVE3 in the supposed breathing point counts for 1.2 approximately when fresh air is mixed with circulation air, while it counts for 0.65 and 0.7



(a) Wind velocity distribution (b) SVE3 distribution (τ_n = 30.5 minutes)

Figure5 Wind velocity and SVE3 distribution when fresh air is directly supplied (Floor supply/ceiling return + Ventilation tower)



(a) Wind velocity distribution (b) SVE3 distribution (τ_n = 30.5 minutes)

Figure6 Wind velocity and SVE3 distribution when fresh air is supplied directly (Ceiling supply/ceiling return + Ventilation tower)

approximately in the floor supply and ceiling supply respectively when using the ventilation tower. From this, it can be judged that the direct supply of fresh air to the breathing point will be effective in improving the IAQ.

Table 3 shows the mean SVE3 by height and the room mean SVE3. The room mean SVE3 shows comparatively high values counting for 1.1~1.2 in any air conditioning/ventilation system. Since the position of the supply outlet and that of the return inlet used in this simulation locate nearby, it likely causes short-circuiting which may lead to such result.

When using the ventilation tower, it would likely be resulted in a longer age of air for most regions although a very short age of air is presented locally. Here, the plane distribution of SEV3 at FL + 1.1m of each air conditioning/ ventilation system is compared. While the region exceeding 1.25 is observed in the case of the ceiling supply/ceiling return + ventilation tower system, it is also observed in the case when fresh air is mixed into the circulation air. The mean SVE3 at FL + 1.0~1.8m counts for 1.1~1.2 without any significant difference in each system, while the mean SVE3 shows a lower value in the case when using the ventilation tower.

Although the influence caused by the layout of the supply outlet and return inlet should be taken into account when using the ventilation tower, it can be considered that the age of air in the major region will not be longer significantly as the region shown with a shorter value locally is limited.

TABLE 3
MEAN SVE3 BY HIGHT AND ROOM MEAN SVE3
IN EACH AIRCONDITIONING / VENTILATION SYSTEM

	Air conditioning system	Ventilation system	FL 0 - 1.0m	FL+1.0 - 1.8m	FL+ 1.8 - 2.8m	Entire room
Case 1	Floor supply / ceiling return	Supplied after mix into circulation air	1.20	1.18	1.16	1.18
Case 2	Floor supply / ceiling return	Supplied from ventilation tower directly into room	1.17	1.13	1.14	1.15
Case 3	Ceiling supply / ceiling return	Supplied from ventilation tower directly into room	1.18	1.16	1.17	1.17

CONCLUSION

For high efficiency ventilation/air conditioning systems that take the age of fresh air into account, a numerical simulation was applied for investigation to a method that supplies fresh air directly to the breathing zone. In the simulation, different ventilation/air conditioning systems were compared under isothermal condition. As a result, it was proved that the IAQ can be upgraded by directly supplying fresh air into the breathing zone. Also proved was that energy can possibly be saved while keeping the IAQ in the breathing zone almost at the conventional level.

The authors wish to conduct simulations in more detail by taking room thermal load into account in future. In addition, the results of the numerical simulation will be verified by real scale experiments.

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