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Numerical Simulation of Indoor Air Environment in an Office Building

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ABSTRACT
Indoor air environment in an office building is analyzed by means of numerical simulation. The stable spatial distribution of velocity vectors, temperature values and concentration of contaminants are presented. Furthermore Air Change Effectiveness at some particular locations are calculated referring the decrease of concentration as well as the tracer decay procedure. The results of numerical simulation are compared with the results of previous field measurement concerning their utility. It is found that the numerical simulation is one of the effective methods to diagnose the indoor air environment, taking account of the results, the operation and the least disturbance of the office activity.

KEY WORDS Office building, Air environment, Numerical simulation, Air Change Effectiveness

INTRODUCTION

In recent years the renewal of building equipments has taken place in many office buildings for the improvement of office environment, and office functions. In advance of designing a new HVAC system, a diagnosis of indoor air environment is very important to clarify the effects of renewal. Though the necessity for such a diagnosis of indoor air environment is widely recognized, there are only few reports which describes the real state of office environment or a drop of the performance of ventilation system. The reason why the results of diagnosis is reported in such seldom cases lies in the indistinctness of the performance of some diagnostic methods or concerns for the building owner's feeling against arousing occupant's dissatisfaction.

It is very important to clarify the performance of each diagnostic method of indoor air environment, such as the field measurement, the sensory checking and the numerical simulation, and it is also important to clarify the real state of indoor air environment in many buildings. In this paper the results of diagnosis of indoor air environment in an office building are presented by means of numerical simulation. And they are compared with the results of previous field measurement.

OFFICE BUILDING ANALYZED

A quarter of the standard floor in an office building is analyzed. Its floor plan and the inside view are shown in Figure 1 and 2. The analyzed area conditioned by a single VAV system consists of four blocks, which include office area, OA room, corridor and lavatory. The fresh air is supplied through the anemo type diffusers set on the ceilings of office area and OA room. The room air is exhausted mainly through lined slit type inlets on the ceiling. Additional fan coil units are placed near the windows. The type of these units is one of the usual types of the supply exhaust systems in the office buildings.

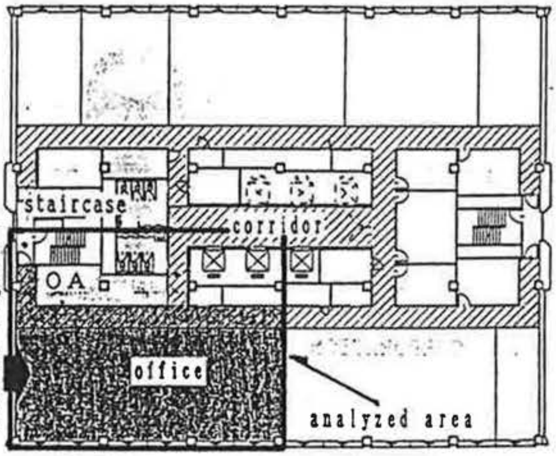


Figure 1 Floor Plan of the Office Building Analyzed

Figure 2 Inside View of the Office Area

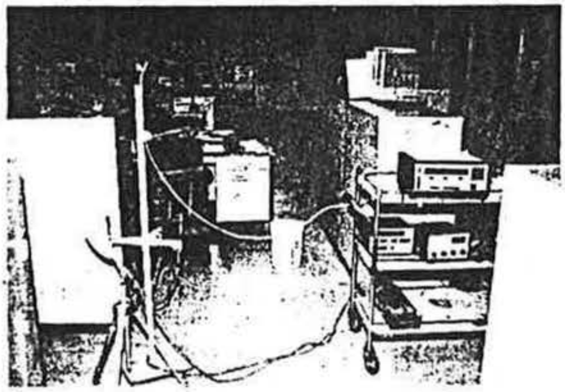


Figure 3 Measurement on the Indoor Air Environment

Figure 4 Sensory Checking of the Indoor Air Environment

Table 1 Results of Field Measurement and Sensory Checking

	office	O A	corridor
temperature (℃)	25.5	25.5	25.6
relative humidity (%)	70.0	69.0	65.5
air velocity (m/s)	0.08	0.14	0.14
P M V	0.50	0.60	0.50
carbon monoxide (ppm)	2.5	2.7	3.4
carbon dioxide (ppm)	330	320	480
particulates (mg/m^3)	0.02	—	—
TVOC concentration (ppm)	1.4	1.4	1.9
acceptability	0.39	0.05	0.19

* TVOC : Total Volatile Organic Compouds

RESULTS OF PREVIOUS DIAGNOSIS

Before the numerical simulation, a field measurement and a sensory checking have been executed. These are shown in Figure 3 and 4. At a particular point of blocks several environmental elements, such as air velocity, temperature and so on, are measured and evaluated. The results of the field measurement and the sensory checking are tabulated in table 1. As shown in Table 1 the most of measured values are within the legal allowance level, however the results of sensory checking for the air environment is not so good in the OA room and in the corridor, and therefore reducing TVOC(Total Volatile Organic Compound) concentration is to be recommended.

NUMERICAL DIAGNOSIS

3-D numerical simulation of nonisothermal flowfield is adopted using $k-\varepsilon$ two equation models. The Analyzed region is divided into about 70,000 cells using rectangular mesh system shown in figure 5. The smallest mesh size is 4 cm near the supply or exhaust openings. The boundary conditions tabulated in Table 2, are assumed to be those in the summer season. After the calculation of the flowfield, some cases of contaminant diffusion are simulated referring the eddy kinematic viscosity.

RESULTS OF NUMERICAL SIMULATION

Flowfield

The distribution of velocity vectors is shown in Figure 6. The supply airflow is mixed rightly near the supply outlets and the air velocity is rather small in the whole room. The air flows from the supply outlet to the nearest slit exhaust inlet through the occupied area. Near the windows recirculating flows are formed involving supply jets from the fan coil units. Since there is no exhaust inlet at the OA room, the supplied air in the OA room is exhausted to the office area or the corridor.

Temperature Field

The temperature distribution is shown in Figure 7. The results correspond rather well to the measured results at some points (* marked in Figure 7). Though there are slight increase of temperature in the area nearby the walls in the OA room, the lavatory and the corridor, where the difference is within 1 degree, the uniform temperature distribution is formed in the whole region.

Contaminant Diffusion Field

The cases of contaminant generatation at the source point

The distributions of the contaminant concentration when some passive scalar contaminant is generated at the typical source points are shown in Figure 8. The contaminant concentration at exhaust inlets are assumed 1.0.

In the case when some contaminant like tobacco smoke is generated at the center of office area, the contaminant is exhausted through the lined slit openings. The highly contaminated area is limited near the source point, and the contaminant spreads out about one half of the office area.

In the case when some contaminant like a smell from the lavatory is generated in the corridor, the air in the corridor and in the lavatory are highly contaminated. Furthermore, the contaminant spreads out up to a half of the office area. This situation is not so good.

Decay stage of the concentration

After the room is filled with the contaminated air uniformly, the decay stage of concentration caused by supplying 100 % fresh air is analyzed. The distribution of the contaminant 6, 12, 24 minutes (respective air exchange rates are 0.5, 1.0, 2.0) after the time when supplying of 100 % fresh air started is shown in Figure 9. The decrease lines of concentration at particular points are also shown in Figure 10. The contaminants in the OA room (point B) are rightly exhausted and most of the contaminants in the office area (point A) are exhausted within 24 minutes. However, the contaminants in the recirculating flow region near the windows (point D) or the contaminants in the corridor (point C) stay for a long period.

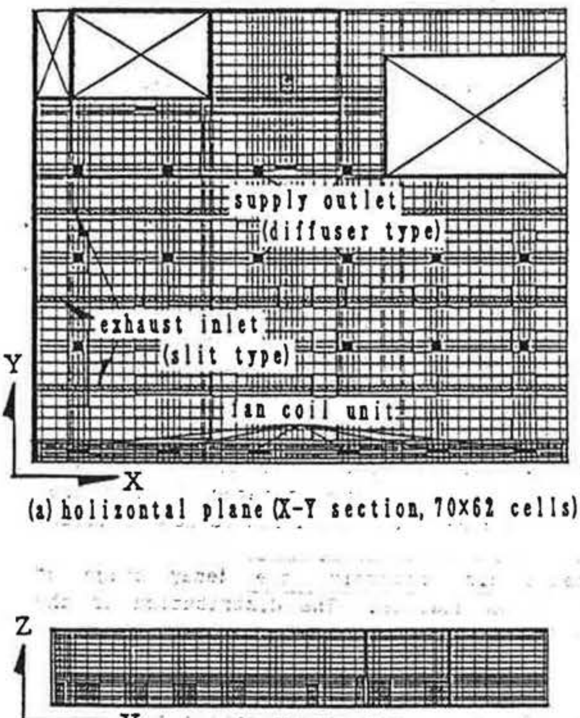
Table 2 Conditions of Numerical Simulation

(a) Conditions of Supply and Exhaust Openings

		numbers	rates	velocity (measured value)	temperature
Supply	ceiling diffuser	16	220CMH	Max. 3.25m/s Min. 2.08m/s	21.19℃
	fan coil unit	6	160CMH	Max. 2.08m/s Min. 1.83m/s	18.73℃
	ceiling diffuser (OA)	2	220CMH	Max. 2.53m/s Min. 1.76m/s	19.05℃
Exhaust	ceiling slit	3	3520CMH	—	—
	grille (WC)	1	440CMH	—	—

(b) Conditions of Walls and Indoor Environment

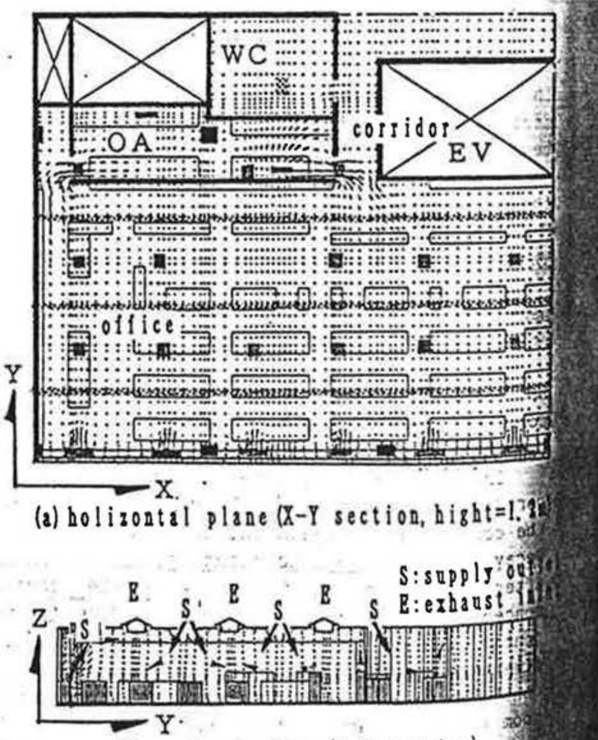
· heat flux (kcal/m²h)	· eastern·northen wall : Pressure zero is assumed
southern wall : 109.90 (from radiation)	scalar quantities : free slip
western wall : 76.15 (from radiation)	· m:1/7 , Power law of profile Ut∝Z^m is assumed
floor : 6.86 (from human bodies)	· heat load from OA machines : 3600 kcal/m²h
ceiling : 7.50 (from lighting system)	· indoor temperature : 26.0℃
eastern·northen wall : adiavatic wall	· air exchange rate : 5 times



(a) holizontal plane (X-Y section, 70X62 cells)

(b) vertical plane (Y-Z section, 62X17 cells)

Figure 5 Mesh Dividing System



(a) holizontal plane (X-Y section, hight=1.

(b) vertical plane (Y-Z section)

Figure 6 Distribution of Velocity Vector

Air Change Effectiveness

Air Change Effectiveness of each point, calculated by adopting the equation (1) and (2) to the decrease of the local concentration value, is tabulated in Table 3. In this case the values of air change effectiveness in the OA room (ACE=2.86) and the exhaust air (ACE=1.05) are over 1.0. The former value means that this area is well ventilated , and the latter value means that there is a posibility of a short circuiting of supply air. The other values are under 1.0 and suggest the necessity of improving the ventilation system.

DISCUSSION

As shown in Figure 3 and 4, adopting the field measurement or the sensory checking to diagnosis of the indoor air environment in the actual office building is rather difficult because of its labor and the concern for the disturbance of office activities allthough they presents accurate results. On the other hand, the numerical method based on the flow analysis is free from such a concern and presents detailed results easily, but there is some necessity to assure the accuracy of the results. Thus, it is concluded that a combined diagnosis method, which is composed of the field measurement only for the selected points and the numerical method for entire region, is very effective one.

As shown in the numerical results of the indoor air environment presented in this paper, the effect of the ventilation system adopted is evaluated. Most of the office area is well ventilated, however less supply air is delivered to the corridor area or to the office area by the windows because of the lacking of supply openings, or low air velocities or less recirculating flows. In these regions setting up some additional supply or exhaust openings is recommended to improve the airflows which increase the local air exchange rate.

Comparing Figure 9, 10 and Table 3, the relational tendency of the spatial distribution of contaminants and the decay of concentration, the spatial distribution of contaminants and the values of Air Exchange Effectiveness are well understood. On the other hand, the individual merit of each index is also recognized. Observing the decay stage of spatial distribution of contaminants enables us to evaluate the effect of the supply and exhaust system easily. Estimating the values of Air Exchange Effectiveness enables us to evaluate the real state of contaminant diffusion field at a glance.

CONCLUSIONS

Indoor air environment in an office building is diagnosed by means of numerical method based on flow analysis. The nonisothermal flowfield, the contaminant diffusion field are clarified. The values of Air Change Effectiveness at some typical points are also estimated. Comparing the numerical results each other or with the results of field measurements, the following conclusions may be drawn.

(1) The numerical and experimental combined method enables us detailed analysis on indoor air environment in actual office building with least labor and least disturbance.

(2) The spatial distribution of contaminant or velocity vectors gives us the effective suggestion for the improvement of the ventilation system. On the other hand, the values of Air Exchange Effectiveness present us the available estimation of the performance of the adopted ventilation system.

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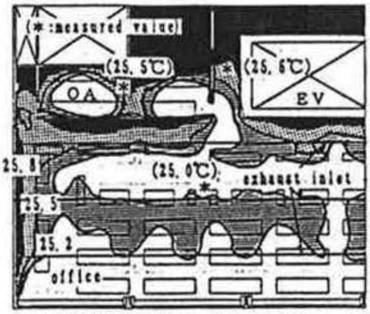
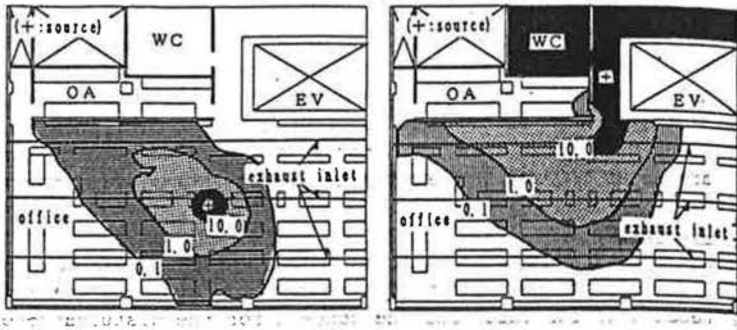


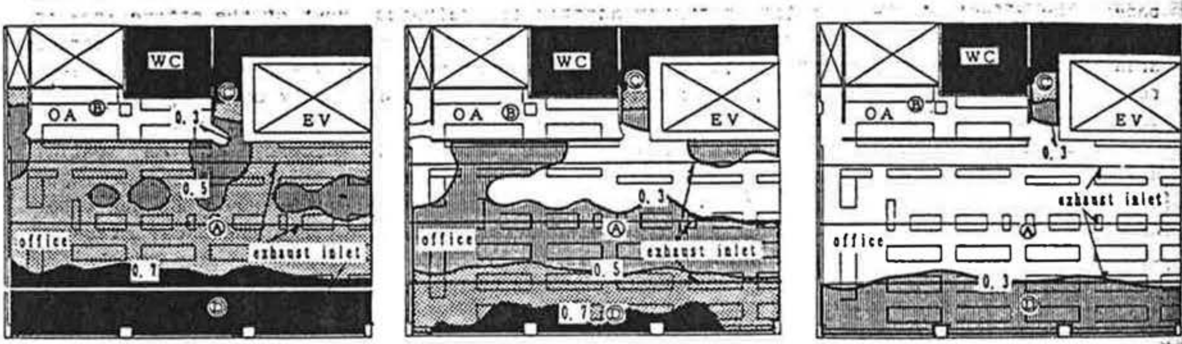
Figure 7 Temperature Distribution



(a) source:the center of office area (b) source:corridor

Figure 8 Contaminant Diffusion Field in case of Point Source

*_Figure7~9:horizontal plane;H=1. 2m(breathing hight)



(a) after 6minutes(air exchange rate:0. 5) (b) after 12minutes(air exchange rate:1. 0) (c) after 24minutes(air exchange rate:2. 0)

Figure 9 Contaminant Diffusion Field in case of Decay Stage

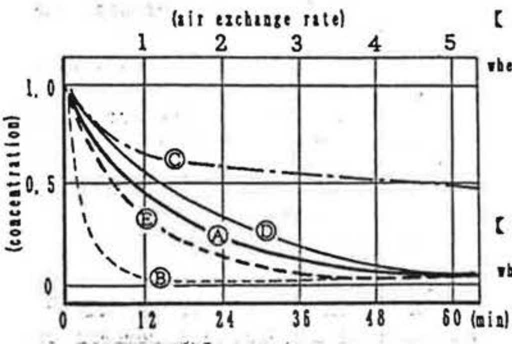


Figure 10 Decay Process of Contaminant Concentration

【 Age of Air at each location (Ai) 】

$$A_i = C_{avg,i}(t_{end} - t_{start}) / C_i(t_{start}) \quad \text{—— (1)}$$

where :

i = an identification number for a specific location ,

Ai = the age of air at location i ,

$C_{avg,i}$ = the time average contaminant concetration at location i for the time period starting at t_{start} and ending at t_{end}

$C_i(t_{start})$ = the contaminant concetration at location i and time t_{start}

【 Air Change Effectiveness (Ev) 】

$$E_v = t_{nom} / A_{BL} \quad \text{—— (2)}$$

where :

t_{nom} = the indoor air volume divided by the outside air supply rate

A_{BL} = the average of air ages at breathing level location

Table 3 Age of Air and Air Change Effectiveness at Each Location

	Ⓐoffice	Ⓑ OA	Ⓒcorridor	Ⓓoffice	Ⓔexhaust	whole region
Ai	0. 26	0. 07	0. 60	0. 33	0. 19	0. 31
Ev	0. 77	2. 86	0. 33	0. 61	1. 05	0. 65