Study on Ventilation Efficiency in Underground Car Parks: Part 2 CFD Simulation on Ventilation Efficiency

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Abstract

This paper presents the results of the numerical simulation on the ventilation efficiency and the residual age of air by using CFD in the underground car park in which the field measurement was conducted as shown in a previous paper. The agreement between the CFD result and the measurement one was observed at most of the measuring points. The detailed distribution of local air change effectiveness was examined with the results from CFD in this paper.

Introduction

In a previous paper, the field measurement of the local air change effectiveness in an underground car park, in which the high velocity fan-diffuser units were installed, was described. In this paper, the following two points are studied by using CFD simulation;
1. Distribution of fresh air
2. Distribution of pollutant air
The first one was studied with the age of air, and the second one was estimated with the residual age of air.

Simulation Method

Simulation Cases

Table 1 shows the cases of simulation, which are the same as in the measurement. In Case1 the high velocity fan-diffuser units were operated and in Case2 they were not operated. The simulated domain is shown Figure 1. The various obstacle of flow was considered in the model, for example, beams, ducts etc. The floor plan and the layout of

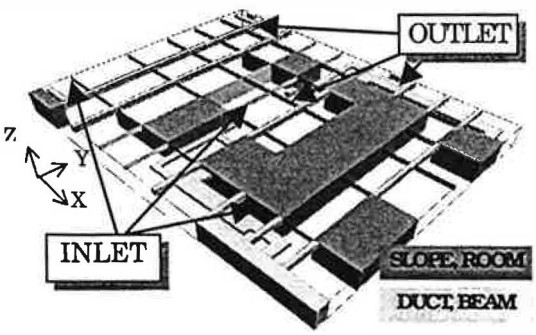


Figure 1. Model of Simulation

Table 1. Simulation Cases

Case number	High velocity fan-diffuser units
Case 1	ON
Case 2	OFF

inlets and outlets of air are shown in Figure 2. The layout of fan-diffuser units and their flow direction were installed the same as in the experimental situation of the previous paper.

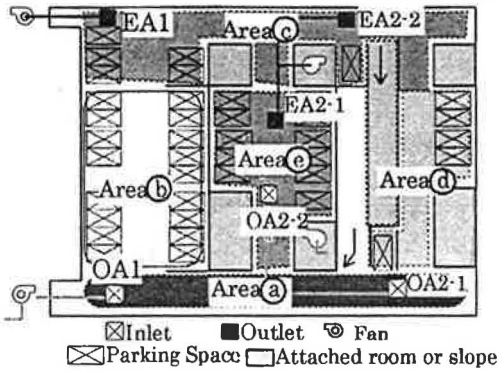


Figure 2. Floor Plan of Underground Car Park Studied in

Method

The simulation was carried out based on the standard k-ε model with the condition shown in Table 2 and Table3. The air volumes of fan-diffuser units, supply inlets and exhaust outlets were given the same as the results of experiment.

Table 2. Boundary Conditions

Ventilation method	Mechanical
Supply air volume	OA1:22680[m^3/h] OA2:40510[m^3/h]
Exhaust air volume	EA1:26590[m^3/h] EA2:36600[m^3/h]
Air change rate	10;ACH=
Nominal time constant	6;min=
High velocity fan-diffuser units a ·6	V 11.1[m/s] Q 615.6[m^3/h]
High velocity fan-diffuser units b ·2	V 10.3[m/s] Q 583.2[m^3/h]
High velocity fan-diffuser units c ·5	V 9.8[m/s] Q 532.8[m^3/h]
Total 13	Q 7524[m^3/h]

Vvelocity, Qair volume

Table 3. Method of Simulation

- The simulated domain was divided into 104(X)·89(Y) ·24(Z)=222,144(meshes)
- In this study, the temperature equation was not solved because each case was carried out under isothermal condition.
- The following equations were used in the comparison between the experimental results and the simulated one.

  SVE3(X)=1/ε_{Π}(ε_{Π}=the local air change effectiveness)

  SVE3(X) can be defined as the normalized concentration at X by the concentration under the perfect mixing condition and the numerical simulation method of this index was proposed by S. Murakami and S. Kato(1988).

$$SVE3(X)=C(X)/C_{\Sigma}$$

Where C_{Σ}=q/Q,
C(X):concentration at X[kg/m^3]
C_{Σ}:concentration under the perfect mixing condition[kg/m^3]
q: emission rate of contaminant[kg/s]
Q: supply air volume [m^3/s].

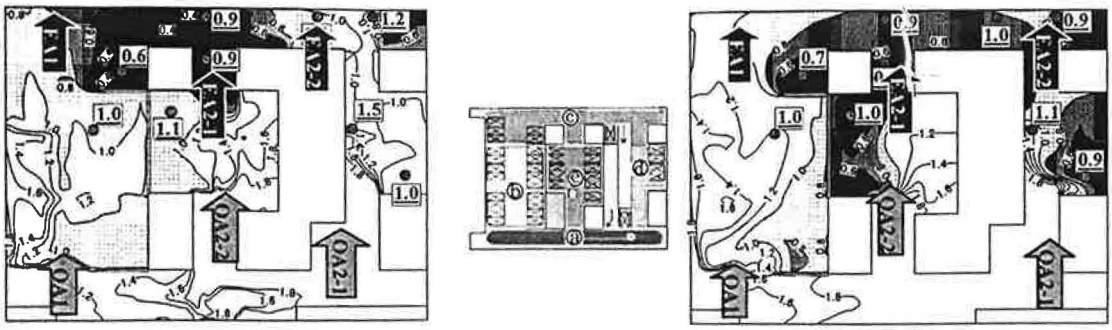
- SVE6(X) was also one of the ventilation efficiency index proposed by S. Murakami and S. Kato. This index means the normalized time required for going through from point X to the exhaust point. The SVE6 means the normalized residual age of air. Therefore the sum of SVE3 and SVE6 is the lifetime of air.

Results and Discussion

In this paper, the domain was divided into six areas, Area a ~Area e as shown in Figure 2 for the sake of convenience.

Local Air change effectiveness

The results of local air change effectiveness ε_p obtained from CFD at FL+1,600[mm], the breathing level, are shown in Figure 3.



(a) Case 1
fan-diffuser units ON

(b) Case 2
fan-diffuser units OFF

Figure 3. Local Air Change Effectiveness FL+1600mm
Note) The number in square is value of experiment.

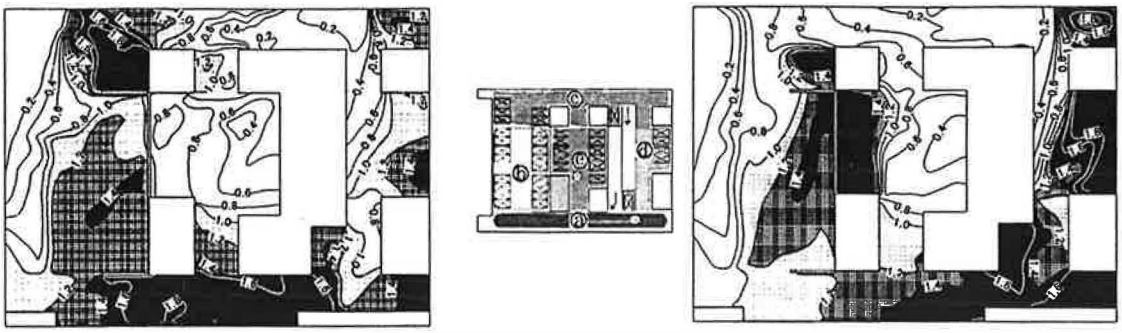
The local air change effectiveness in Area a, Area b Area d Area e was about 1.0 in Case1(fan-diffuser units ON), that means their areas were in well mixed condition. In Area c, the local air change effectiveness was smaller than 1.0, especially in the vicinity of the exhaust outlet (EA1~EA2-2) it was smaller than 0.6. These results mean that the supplied fresh air reached almost area except for in the vicinity of the exhaust outlet. The simulated value agreed with the results of experiment, but the difference between them can be observed locally in Area c.

On the other hand, in Case2 (fan-diffuser units OFF), the local air change effectiveness in Area a, Area b was about 1.0, in Area c, Area d Area e it was smaller than 1.0. In Area c, ε_p near the exhaust outlet (EA1~EA2-2) was smaller than 0.6, as well as in Case1, while in Area b Area d Area e, ε_p was about 1.0 in the drive through space where motor cars passed through, ε_p in the parking space was smaller than 1.0. The fresh air was not distributed sufficiently to the parking space because the airflow was stagnant in such an area. The result obtained by CFD was also observed in experiments except for in Area d and Area e. There was no remarkable difference between the ventilation characteristic in Case 1 (fan-diffuser units ON) and that in Case2 (fan-diffuser units OFF). The effect of fan-diffuser units may be relatively low in this underground car park because the layout of supply inlets and exhaust outlets was appropriate and the ventilation efficiently was enough good even if the fan-diffuser units were not operated.

The results of simulations corresponded to the experimental results in Case1 and Case2 except for some regions. One of the main reasons why the difference between the simulation and the experiment was appeared may be due to the measurement error, see Appendix.

Residual Age of Air

The simulated result of the residual age of air is shown in Figure 4(FL+400mm: the height the exhaust gas is emitted from motor cars). The normalized value of residual age with nominal time the constant is expressed in Figure 4.



(a) Case 1
fan-diffuser units ON

(b) Case 2
fan-diffuser units OFF

Figure 4. Residual Age of Air FL+400mm

In Case1 (fan-diffuser units ON), residual age of air in Area b, Area c and Area e was shorter than that in Area a near the inlet. In the area where includes the parking space, the residual age of air was long except for in Area e. Especially in the parking space near the exhaust outlet (EA1) in Area c the residual age was much longer than that in other space. The induction of air with fan-diffuser units was effective in Area|,d, and Area e, but not effective in Area c.

In Case 2, the residual age of air in the parking area of Area e and Area d was much longer than that in Case 1. The fan-diffuser units were very efficient in activating the stagnant air in the parking space.

Conclusions

In this paper, the following conclusions were obtained from simulated results of the age and the residual age by CFD.

(1) There was no remarkable difference between the distribution of fresh air at the breathing level in Case1 (fan-diffuser units ON) and in Case2 (fan-diffuser units OFF)

(2) The simulated results showed agreement in the results of the experiment. However, some differences can be observed between them due to measurement error, etc.

(3) There was little difference on the ventilation characteristics between Case1 and Case2 in the drive through space. On the other hand, fan diffuser units were effective in the stagnant areas such as the parking space. The stagnant air removed efficiently by the fan-diffuser units.

(4) If the layout of inlet and outlet was appropriately designed, then the whole space could be ventilated efficiently. In such conditions, the fan-diffuser units should be used to activate the stagnant air in the parking space.

Appendix

In the experimental study presented in a previous paper, the time interval of the gas monitoring was about 6 minutes (1.5minutes per one point). This interval was relatively long so that the results of experiment may include some error when the start time of tracer gas dosing did not correspond to the start time of sampling. Therefore, a part of experimental result under the step up condition was corrected based on the CFD results

in which the concentration profile was shifted to correspond with the CFD as shown in Figure 5. After the correction, the result of experiment showed agreement with CFD.

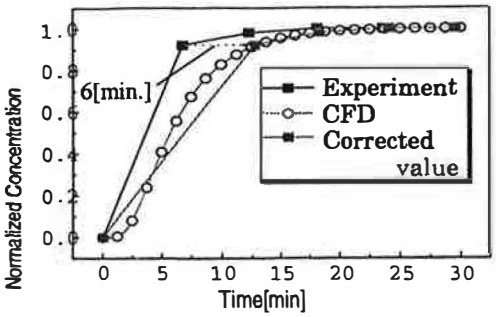


Figure 5. Concentration Profile of CFD and Experiment

References

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2. Kato, S., Murakami, S. 1992. New scale for evaluating ventilation efficiency as affected by supply and exhaust openings based on spatial distribution of contaminant. Proceedings of ISRACVE, University of Tokyo, pp.321–332.