CFD analysis of Airflow Characteristics inside Office Room with Hybrid Air-conditioning System

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ABSTRACT

The hybrid air-conditioning system is consists of natural ventilation and mechanical air-conditioning system in this paper. The airflow characteristics inside office room with different way to introduce the natural ventilation were analyzed by means of CFD analysis. The office has the same air-conditioning system by Under Flow Air Distribution (UFAD). Three ways to introduce the natural ventilation were used in the analyses. Outdoor air is introduced into office room from Outdoor Air Intake (OAI) on ceiling, outward wall upper window, and floor. Conceptual diagrams of analyzed model were shown in Figure 1. The airflow characteristics of office room were examined by the distribution of temperature and Scale for Ventilation Efficiency No.4 (SVE4, Murakami and Kato, 1992) that presents the contribution ratio of each supply outlet. Influence of way to introduce natural ventilation on thermal and airflow environment is large. Among models, the Window Model, which fresh outdoor air is supplied from outward wall upper window, has the widest zone where a lot of fresh outdoor air was supplied (the SVE4-n values are larger than 0.6).

1. INTRODUCTION

Natural ventilation is of considerable concern as energy saving method in office building recently. Natural ventilation can provide the fresh outdoor air for occupants and maintains acceptable indoor air quality. However, only the natural ventilation cannot keep comfortable indoor air temperature. Therefore the hybrid air-conditioning system that is air-controlled by natural ventilation and mechanical air-conditioning system was proposed. Introduced outdoor airflow rate in hybrid air-conditioning system is larger than existing air-conditioning system and perceived air quality is increase. In fact, the number of building with hybrid air-conditioning system is increasing (Heiselberg, 2002).

Here, the hybrid air-conditioning system is consists of natural ventilation and mechanical air-conditioning system. Authors have been investigated the airflow mechanism of indoor by means of measurement (Ushio at al., 2006), (Ushio at al., 2007) and CFD analysis for existential building (Kotani at al., 2006), (Lim

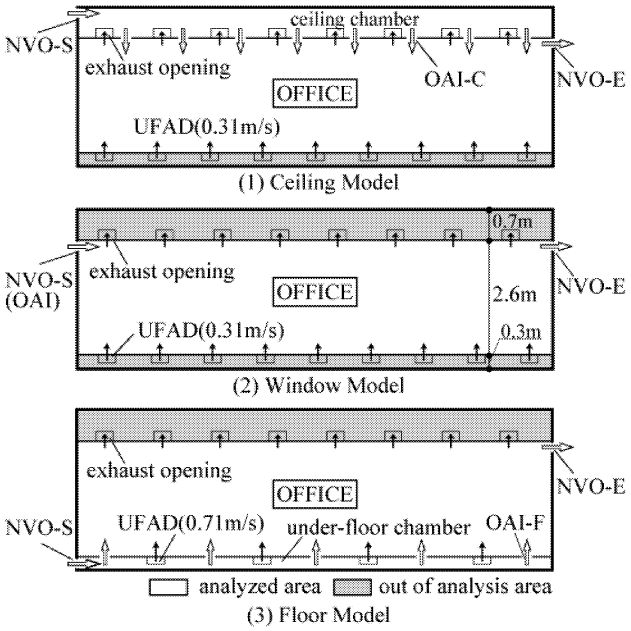

Figure 1. Conceptual diagram of analysis model

et al., 2007). Influence of the location of natural ventilation openings on thermal and airflow environment was presented in the previous paper (Lim et al., 2007). The purpose of this study is to establish the design method of hybrid air-conditioning system for office buildings. It is necessary to examine the thermal and air environment in an office room with hybrid air-conditioning system. This paper presents the influence of combination of the ways to introduce natural ventilation and the air-conditioning systems on the indoor airflow characteristics by means of CFD analysis.

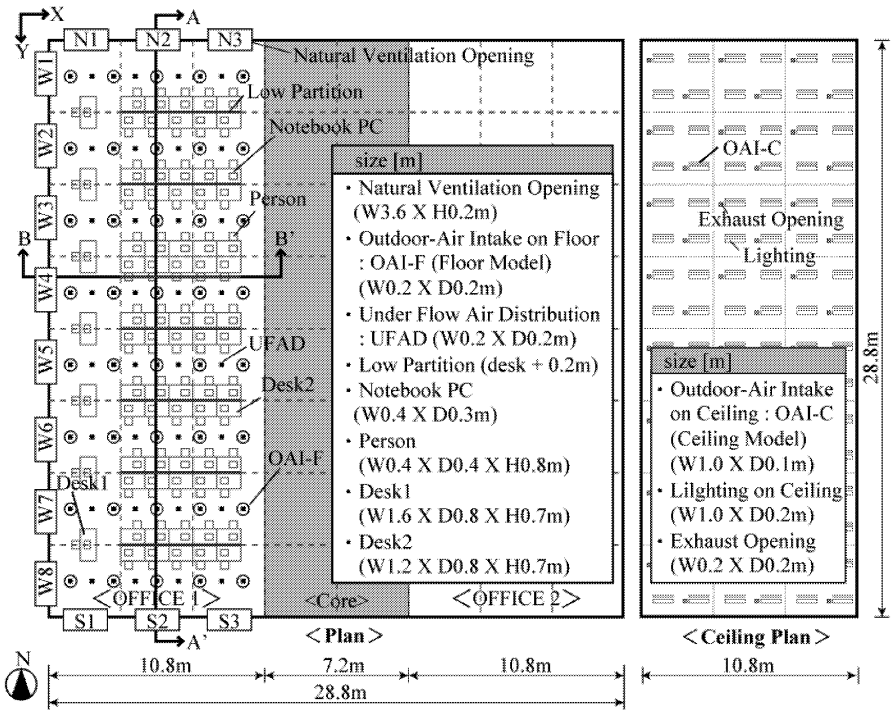

Figure 2. Office floor plan and ceiling layout

2. DEFINITION OF INDEX (SVE4)

SVE4 (SVE4, Murakami and Kato, 1992) was defined by the following equation.

$$SVE4(P,i)=C_i(P)/C_{io} \qquad (1)$$

where:

$SVE4(P,i)$: contribution ratio of the i-th supply opening at the point P in the room

$C_i(P)$: concentration at the point P where tracer is generated at the i-th supply opening at generation rate q (m^3/s)

C_{io} : concentration of the tracer at the i-th supply opening, $C_{io}=q/Q_i$

q : tracer gas generation rate at the i-th supply opening (m^3/s)

Q_i : air flow rate at the i-th supply opening (m^3/s)

3. METHOD OF CFD ANALYSIS

3.1 Model and Cases

The plan of office floor and the ceiling layout were shown in figure 2. The building is so called central core type. There are two office rooms on both sides of core area. The size of each office room has plan of 10.8m x 28.8m and 2.6m height. Only west-side office was analyzed. The office room is air-controlled by natural ventilation and mechanical air-conditioning system. The air of mechanical air-conditioning system is supplied by UFAD (0.2x0.2m) and exhausted through exhaust openings (0.1x1m) on ceiling. Three analyzed models have different way to introduce the natural ventilation. The natural ventilation openings were settled at outward wall upper ceiling in Ceiling Model, outward wall upper window in Window Model, and outward wall under floor in Floor Model (see Figure 1). In Ceiling Model, fresh outdoor air is flowed into the building through Natural Ventilation Supply Openings (NVO-S, height: 0.2m) on outward wall upper ceiling. The outdoor air is flowed into ceiling chamber and it is introduced into the office room through Outdoor-Air Intakes on Ceiling (OAI-C, 0.1mx0.1m). And contaminated air is flowed to outside through Natural Ventilation Exhaust Openings (NVO-E, height: 0.2m) on outward wall upper window. In Window Model, fresh outdoor air is directly flowed into the office room through NVO-S on outward wall upper window. And contaminated air is flowed to outside through NVO-E on outward wall upper window. In Floor Model, fresh outdoor air is flowed into the building through NVO-S on outward wall under floor. The outdoor air flowed in under floor chamber and it is introduced into the room through Outdoor-Air Intakes on Floor (OAI-F, 0.2mx0.2m). And contaminated air is flowed to

outside through NVO-E on outward wall upper window.

Lighting equipments, exhaust openings, and outdoor air intakes used in Ceiling Model were installed on the ceiling.

For the parametric analysis, outdoor wind direction and outdoor air temperature were changed as shown in Table 1. The outdoor wind direction was set at north wind and west wind. In the case of north wind, inflow openings (NVO-S) are north-side openings (N1~N3) and outflow openings (NVO-E) are south-side openings (S1~S3). The west-side openings (W1~W8) are closed. In the case of west wind, outdoor air flows into the office room from west-side openings (W1~W8) and flows out through north-side and south-side openings (N1~N3 and S1~S3). Outdoor air temperatures were set at 18ºC, 20ºC, and 22ºC. The supply air temperature of UFAD was fixed 20ºC in all cases.

Table 1. Analysis case

	Model		Ceiling Model		Window Model		Floor Model	
			-N	-W	-N	-W	-N	-W
Analysis condition	Outdoor air temperature		18 ℃, 20 ℃, 22 ℃					
	Supply air temperature		20 ℃					
	Inflow opening	Wind direction	North	West	North	West	North	West
		Location	Outward wall upper ceiling	Outward wall upper ceiling	Outward wall upper window	Outward wall upper window	Outward wall under floor	Outward wall under floor
	Outflow opening	Wind direction	South	South North	South	South North	South	South North
		Location	Wall upper window	Wall upper window	Wall upper window	Wall upper window	Wall upper window	Wall upper window

Table 2. Summary of CFD analysis

Turbulence model	Standard k-ε
Algorithm	Steady state (SIMPLEC)
Analysed area	28.8m(W)X10.8m(D)X2.6m(H)
Meshes	Ceiling-Model : 108(W)x208(D)x30(H) Window-Model : 108(W)x208(D)x26(H) Floor-Model : 108(W)x208(D)x29(H)
Discretization scheme for advection term	QUICK
Wall boundary	Standard log-low, Adiabatic

3.2 Summary of CFD

SIMPLEC was used as pressure-velocity coupling algorithm for the calculation with quick discretization scheme of advection term. Standard k-ε Model was used as for the turbulence model. Table 2 summarizes the setting of CFD analysis. The sizes of mesh are 10×10×10cm except space upper ceiling in Ceiling Model and space under floor in Floor Model.

3.3 Boundary Conditions

The boundary conditions of velocity are based on results of measured wind pressure coefficient. Table 3 shows the boundary conditions of velocity. Air change rate by the natural ventilation only was set at 5 ACH in all cases. 5ACH was assumed as a round number from the measurement values in the hybrid ventilated-building that authors measured (Ushio at al., 2007). The outdoor air was supplied horizontally from NVO (Natural Ventilation Opening) and air-conditioned air was supplied vertically. Boundary conditions of internal heat load were shown in Table 4. The

Table 3. Boundary conditions of velocity

	Analysis condition		Ceiling Model		Window Model		Floor Model	
			-N	-W	-N	-W	-N	-W
Velocity boundary condition	Natural ventilation opening	N1	0.50	-0.27	0.50	-0.27	0.49	-0.32
		N2	0.52	-0.26	0.52	-0.26	0.52	-0.26
		N3	0.54	-0.25	0.54	-0.25	0.55	-0.20
		W1		0.19		0.19		0.15
		W2		0.19		0.19		0.18
		W3		0.20		0.20		0.21
		W4		0.20		0.20		0.23
		W5		0.20		0.20		0.23
		W6		0.20		0.20		0.21
		W7		0.19		0.19		0.18
		W8		0.19		0.19		0.15
		S1	-0.51	-0.27	-0.51	-0.27	-0.50	-0.32
		S2	-0.52	-0.26	-0.52	-0.26	-0.52	-0.26
		S3	-0.53	-0.25	-0.53	-0.25	-0.54	-0.20
	UFAD		0.31	0.31	0.31	0.31	0.71	0.71
	Exhaust opening on ceiling		Free Outflow					

note) '+' value means that the air flows from outside to inside.
'-' value means that the air flows from inside to outside.

Table 4. Boundary conditions of internal heat load

Heat load		Number
Person	60 W	77
Notebook PC	30 W	77
Lighting on ceiling	32W (60% on setting position, 40% on floor and desks)	96
OA load except PC	30 W/m^2	

office room has person, notebook PC, OA load except notebook PC, and lighting on ceiling as internal heat load. Total internal heat load of office room is 14,668W.

4. RESULTS AND DISCUSSION

4.1 Average temperature of occupied zone

Figure 3 presents average temperature of occupied zone (from FL+0m to FL+1.8m) of each model for change of outdoor air temperature. Average temperature of occupied zone shows the lowest value in Window Model under north wind and in Floor Model under west wind. The value varies greatly on each model under west wind than north wind. It is because outdoor air flows into the room through the natural ventilation supply openings at long side of room under west wind, so the reached area of outdoor air is wide.

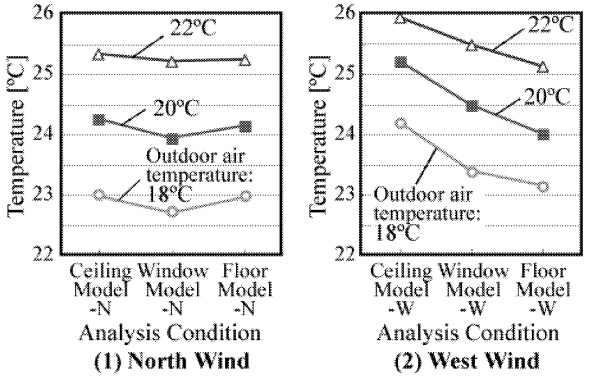

Figure 3. Average temperature of occupied zone

4.2 Distribution of indoor air temperature and SVE4-n at A-A' and B-B' section (outdoor air temperature: 20 ºC)

The temperature distribution at A-A' and B-B' section (see Figure 2) is shown in Figure 4. The temperature distribution in the vicinity of floor is large under all conditions because the office room is air-controlled by UFAD. In Ceiling Model and Window Model under north wind, the temperature of windward-side (north-side) is

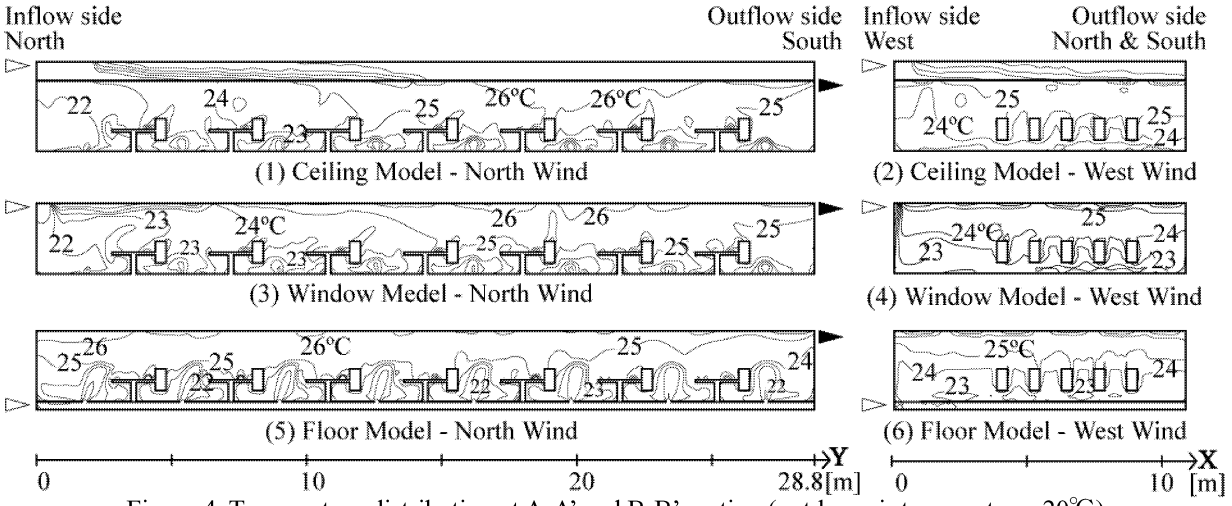

Figure 4. Temperature distribution at A-A' and B-B' section (outdoor air temperature: 20℃)

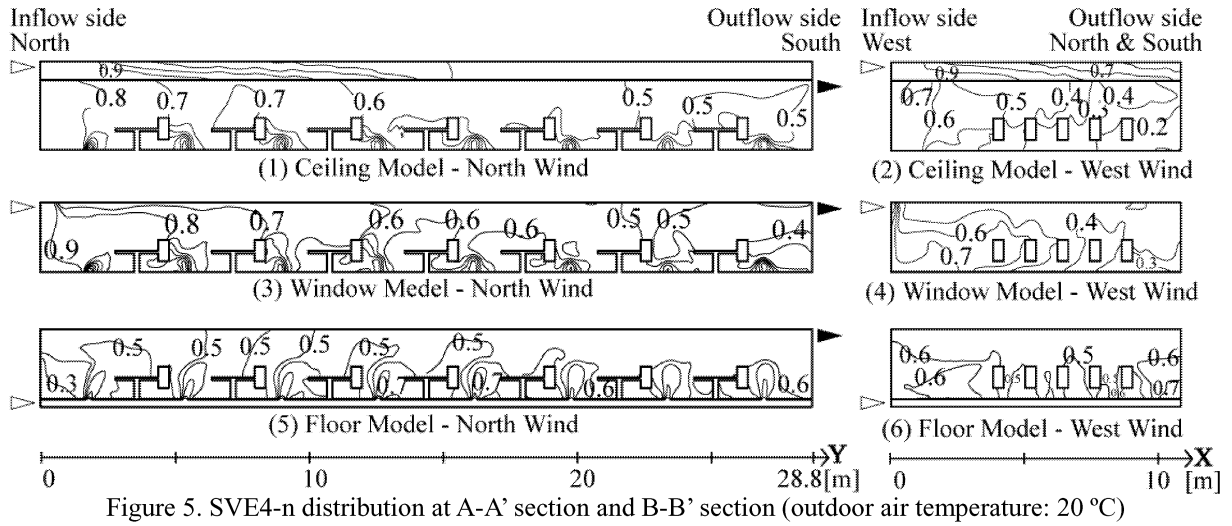

Figure 5. SVE4-n distribution at A-A' section and B-B' section (outdoor air temperature: 20 ºC)

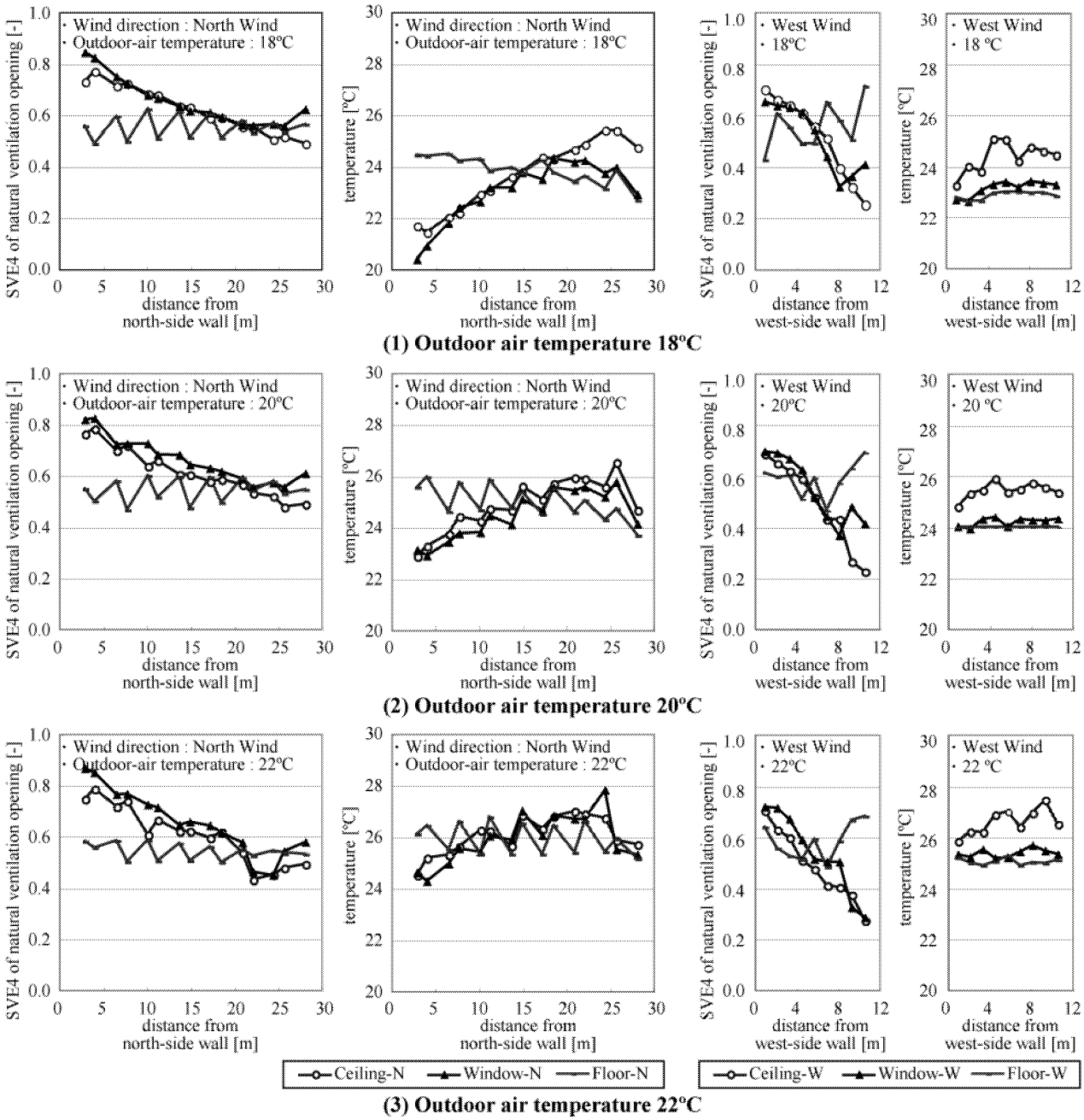

Figure 6. Influence of outdoor air temperature on SVE4-n and temperature at the height of FL+1.1m in A-A' and B-B' section (outdoor air temperature: 18 ºC, 20 ºC, 22 ºC)

approximately 3ºC lower than leeward-side (south-side) (see Figure 4-(1) and 4-(3)). In Floor Model, the temperature difference between north-side and south-side of room is small, because both natural ventilation air and air-conditioning supply air are supplied from supply openings on floor (see Figure 4-(5)).

Under west wind condition (see Figure 4-(2), 4-(4), and 4-(6)), the temperature difference between windward-side and leeward-side is small because room depth is small. It is conjectured that the similar distribution is formed in Floor Model because the influence of wind direction is small. The result of the SVE4 distribution for natural ventilation supply openings (defined as SVE4-n) at A-A' and B-B' section is shown in Figure 5. Here, return air was not considered, so the all air-conditioning supply air was assumed as outdoor air. In addition, supply air from NVO-S and UFAD was calculated. As for the whole cases, the values of SVE4-n are larger than 0.5 in the

upper zone of person. In Ceiling Model and Window Model, the value decreases according to the distance from windward-side (see Figure 5-(1) ~ (4)). Among these models, the Window Model has the widest zone where SVE4-n values are larger than 0.6 under north wind and west wind. Fresh outdoor air is almost uniformly supplied except the vicinity of the floor in Floor Model.

4.3 Influence of outdoor condition on SVE4-n and temperature distribution

Distribution of SVE4-n and temperature at the height of FL+1.1m in A-A' section and B-B' section are shown in Figure 6. As for the whole cases, influence of outdoor temperature on SVE4-n distribution is small. In Ceiling Model and Window Model under north wind, the SVE4-n values become small while air is flowing from windward-side (north-side) to leeward-side (south-side). On the other hand, temperature values become large. This suggests that the influence of introduction way of outdoor air on indoor air temperature is large under north wind. In the west wind, the SVE4-n values also become small while air is flowing from west-side to east-side. However, the correlation of the temperature and SVE4 is not seen. It should be noted that there is a possibility of the low temperature problem in the zone where SVE4-n values are large.

5. CONCLUSIONS

- The airflow characteristics in the office room with different way to introduce natural ventilation were examined by the distribution of temperature distribution and scale for ventilation efficiency No.4 (SVE4-n).
- Influence of introduction way of natural ventilation on thermal and airflow environment is large.
- Among these models, the Widow Model has the widest zone where SVE4-n values are larger than 0.6 under north wind and west wind.
- From results of SVE4-n distribution, the fresh outdoor air is the most uniformly supplied to area in Floor Model except the vicinity of the floor.
- In the zone where SVE4-n values are large, it should be noted that there is a possibility of the low temperature problem.

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