Planning of the Blind Position Considering Thermal Performance in the Intermediate Space of Double-Skin Facade

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ABSTRACT: The blinds in the intermediate space are installed to block the direct solar radiation. As the blind divides the airflow of intermediate space into two parts, thermal performance of Double-Skin Facade (DSF) is affected by the blind position. Therefore the blind position should be planned with careful consideration in order to maximize the thermal performance of DSF. In this study, CFD was performed to analyze the effect of blind position in multistory-type DSF in variation of other DSF elements. The simulation results showed that the case with narrow depth of intermediate space and outlet on upper side of outer-facade, it is profitable to place blind as close as possible to the outer facade. In the other cases, the blind should maintain 0.15 m distance from outer facade.

Nomenclature

C : constant
G_b : generation of turbulent kinetic energy due to buoyancy
G_k : generation of turbulent kinetic energy due to mean velocity gradients
k : turbulent kinetic energy [m^2/s^2]
q : heat flux [W]
T : temperature [℃]

Greek symbols

α_k : inverse effective Prandtl number for k
ε : turbulent kinetic energy dissipation rate [m^2/s^3]
μ_{eff} : effective viscosity [Pa·s]
ρ : density [kg/m^3]

1. Introduction

In modern buildings, glass facades are often used to ensure a view and improve the aesthetic value. However, as glass facades are unfavorable with regard to the thermal environment, the Double-Skin Facade (DSF) is often used to strengthen thermal insulation. The DSF consists of two glass skins and an intermediate space between which acts as a thermal buffer space. It also contains outer and inner openings (outlet/inlet) that allow airflow from the outside to the internal rooms though the intermediate space. The airflow in the intermediate space is activated by thermal buoyancy force that is motivated by solar radiation. During the cooling and intermediate period, the outlets installed on the upper part of the outer facade are open to exhaust the heated air. During the heating period, all of the openings are closed to allow the intermediate space to act as a thermal buffer space.

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Blinds are installed in the intermediate space to trap direct solar radiation. Usually, blinds are lowered when direct solar radiation comes into the indoor space, regardless of the season. This is more profitable than blinds installed indoor or outdoor space since the blinds are protected from rain and dust, etc. Therefore the durability of the blinds is lengthened.

However, the blinds installed in the intermediate space can be an obstacle to airflow, since the vertical airflow is divided into two parts by the blinds. This changes the temperature and airflow distribution within the intermediate space. As a result, the performance of the DSF and the indoor thermal environment are affected as well.

Considering that the blinds are a vertical element and that the main airflow within the intermediate space is upward flow, the spaces between each facade and the blinds can be put to good use. Therefore, if the blinds in the DSF are evaluated and planned with careful consideration, the performance of the DSF can be improved and a better environment can be attained for the adjacent room.

In this study, CFD was performed to analyze the effect of blind position on airflow within the intermediate space in multistory-type DSF in variation of other DSF elements.

2. Thermal performance analysis of the intermediate space of DSF

2.1 Thermal mechanism of the intermediate space of DSF

The DSF is a system in which the solar radiation reaches the intermediate space through the outer facade and causes natural convection by thermal buoyancy force, which enables natural ventilation in the DSF. The thermal analysis model of the DSF is quite complex, and involves conduction, convection and radiation as shown in Fig. 1.

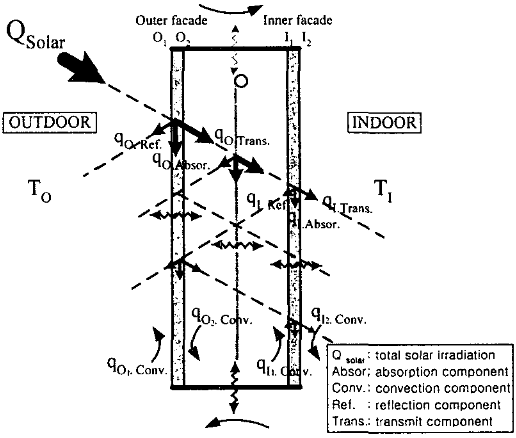


Fig. 1 Thermal mechanism of the DSF.

To analyze the temperature and the velocity of airflow in the intermediate space, a precise airflow analysis technique is required. In particular, careful planning is essential since the intermediate space is divided into two parts by the blinds. In order to analyze the temperature and airflow distribution in the two spaces with the variations in the features of blinds, a CFD analysis model is suitable which enables the analysis of complex temperature and airflow fields.(1)

2.2 The governing equation

The airflow within the intermediate space was assumed to be a steady state 3-dimensional flow, and the corresponding governing equations were used. For the modeling of turbulence, the RNG k-ε turbulence model was applied.(2-4) The governing equations are presented in the following equations. The analysis was performed using a commercial CFD code, FLUENT.

Turbulent kinetic energy equation

$$\frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_i}\left(\alpha_k \mu_{eff} \frac{\partial k}{\partial x_i}\right) + G_k + G_b - \rho\varepsilon \tag{1}$$

Table 1 Boundary conditions of DSF elements

DSF elements		Boundary conditions
Outer facade	Glass	$u=v=w=0,\ T=T_{out},\ Q_{solar}$
	Wall	
	Inlet	$u=v=w=0,\ T=T_{out}$, atmospheric pressure
	Outlet	
Intermediate space	Blind	-
	Grating	free area ratio
Inner facade	Glass	$u=v=w=0,\ T=T_{in}$
	Wall	
	Aperture	
Ceiling		$u=v=w=0,\ T=T_{out}$, heat transfer coeffcient
Floor		$u=v=w=0,\ T=T_{out}$, heat transfer coeffcient
Side wall		symmetry

Turbulent kinetic energy dissipation equation

$$\frac{\partial}{\partial x_i}(\rho\varepsilon u_i)=\frac{\partial}{\partial x_i}\left(\alpha_\varepsilon\mu_{eff}\frac{\partial\varepsilon}{\partial x_i}\right)+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}-R_\varepsilon \qquad (2)$$

2.3 Boundary conditions

Since the DSF consisted mainly of glass and the solar radiation that comes through the glass is the main source of heat transfer in the intermediate space, it is critical to set up the proper boundary conditions of solar radiation in analyzing the temperature and airflow within the intermediate space.

Table 1 presents the boundary conditions of DSF elements. In order to ensure that the intermediate space is analyzed accurately applying the following boundary conditions, the verification was carried out by comparing with experiment data.(5)

3. Evaluation model for the planning of blind position

As the DSF has complex structure and mechanism, thermal environment of indoor space is affected by each DSF elements. In order to evaluate the influence of blind position on thermal performance of DSF, the effect of other elements of DSF should be considered in advance. It is because the blinds are planned in the last step of the design stage considering the use of the room and the aesthetic aspect.

As the position of the blind in DSF has influence mainly on the airflow within the intermediate space,(1) the elements which have effect on the airflow were evaluated. Then the evaluation models of DSF for the planning of blind position were set up by the previous results.

3.1 The factors that have effect on the airflow of DSF

The classification of DSF elements on consideration of effect on airflow of DSF is shown as Table 2. The gratings installed in the bottom of each floor of intermediate space in the multistory-type DSF were not included as it has slight effect on the airflow of DSF.

3.2 Evaluation of DSF factors

The DSF factors that were chosen in the

Table 2 Classification of the DSF elements⁽¹⁾

DSF elements		Flow related factors
Outer facade	Glass	-
	Aperture	position, size
Intermediate space	Size	height, width
	Blind	position
	Grating	free area ratio
Inner facade	Glass	-
	Aperture	position, size

above were evaluated. The factors are the height/width of intermediate space and the position/size of inlet/outlet.

3.2.1 Description of the building and simulation conditions

As this study focuses on the airflow within the intermediate space and the airflow is motivated mainly by thermal buoyancy force, the multistory-type DSF were chosen to evaluate at the maximum effect of the force. The blind type was selected as roll screen. It is made of fabric which has high heat absorptance. Moreover, the airflow penetration through the roll screen is weak because of the weave of the fabric.

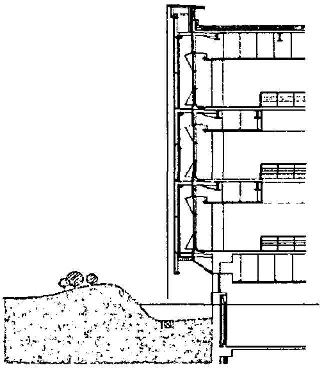


Fig. 2 Cross section of DSF model.

The building located in Goyang, Korea, which is in its planning stage, was selected for the case model. The DSF is applied on the south-west facade of the building with the inlet and outlet installed at the bottom and upper part of intermediate space as shown in Fig. 2. Roll screens are installed in the intermediate space 7 cm distant from the outer facade. Table 3, 4 lists a description of the DSF applied in the model building.

The DSF element of the building is a repeti-

Table 3 Description of DSF model

DSF		Description
Type		Multistory-type
Orientation		South-West
Outer facade	Glass	8 mm single glass
	Outlet	30 m × 0.7 m (length × height)
	Inlet	
Intermediate space	Volume	30 m × 0.9 m × 15.8 m (length × width × height)
	Blind	Roll screen
Inner facade	Glass	24 mm pair glass
	Aperture	1.5 m × 1.1 m (length × height)

Table 4 DSF material properties

DSF elements	Transmissivity (%)	Reflectivity (%)	Absorption (%)	Emissivity (%)	U-value ($W/m^2 \cdot K$)
Outer glass (8 mm SG)	69	27	19	84.5	1
Blind (roll screen)	41	48	11	0.9	0.06
Inner glass (24 mm DG)	36	33	21	84.5	0.14

tion of 2.5 m modules in the length direction. Therefore, assuming the DSF is symmetrical across the side wall, the case model was set up to be 2.5 m × 0.9 m × 15.82 m (length × depth × height) and the boundary condition was applied as Table 1 in the previous chapter.

Operation of the DSF can vary according to outdoor conditions. Generally, the openings on the outer facade are open during the cooling period, the openings on the inner facade are open additionally during the intermediate period, and all of the openings are closed during the heating period. The openings of DSF are considered to have an impact on airflow distribution within the intermediate space.

The cooling period in which the outlet/inlet of outer facade is open is chosen as the evaluation period. The inflow of heat to the intermediate space is the highest in the condition of maximum outer temperature and solar radiation. When the inflow of heat is the highest, the airflow within the intermediate space is most activated by thermal buoyancy force. The Sept. 30, 15 : 00 when the outer temperature is 33℃ and solar radiation at the vertical plane is 600 W/m^2 was chosen as the evaluation period. The effect of wind was not considered in the process to focus mainly on the airflow by thermal buoyancy force.

3.2.2 Simulation results

The size of outlet on the outer facade should be at least the effective depth of intermediate space to ensure proper exhaust of heated air. Therefore, the depth of intermediate space was evaluated prior to the size and position of the outlet. The evaluation criteria is shown as Fig. 3. The outer surface temperature of inner facade and heat influx into the inner facade were evaluated to estimate the temperature and airflow distribution of intermediate space as well as indoor thermal environment.

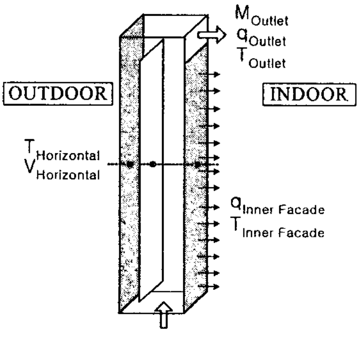


Fig. 3 Evaluation criteria.

(1) Depth of intermediate space

The effective depth of intermediate space in the model building should be at least 0.6 m.(6) Therefore the effect of depth of intermediate space was evaluated by the case of original width, 0.7 m and extended width, 1.4 m. The result showed some difference as shown in Fig. 4. The case with extended width, the surface temperature of inner facade is lower because of active airflow in the space.

(2) Size of outlet

As the heat in the intermediate space gathers

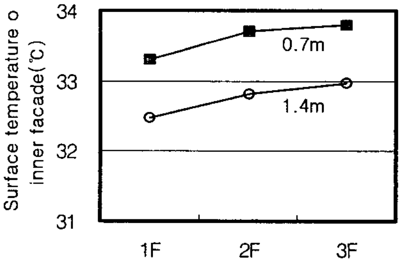


Fig. 4 Surface temperature of inner facade according to width of intermediate space.

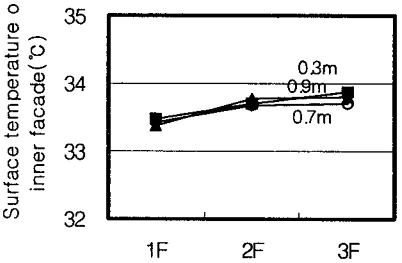
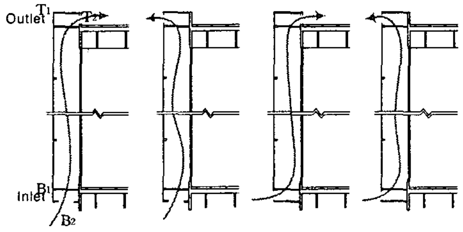


Fig. 5 Surface temperature of inner facade according to size of outlet.

on the top, the size of outlet does important role in the DSF. In order to evaluate the effect of size of outlet, narrow, equal, and wide depth in comparison with the effective depth were set up as an evaluation case. As shown in Fig. 5, there is little difference on the surface temperature of inner facade according to the size of outlet.

(3) Position of outlet

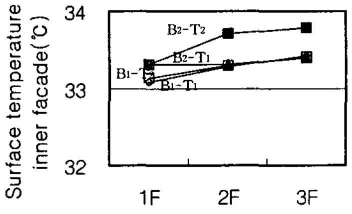
Applying previous simulation results, the position of outlet was evaluated with the effective depth of 0.7 m and 1.4 m. The possible position of outlet in DSF is shown in Fig. 6.



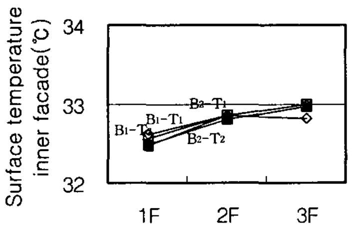
Inlet-Outlet: B*2-T*2 B2-T1 B1-T2 B1-T1

*B: Bottom aperture, **T: Top aperture

Fig. 6 Various positions of inlet and outlet.



(a) Intermediate space width: 0.7 m



(b) Intermediate space width: 1.4 m

Fig. 7 Surface temperature of inner facade according to the position of outlet.

When the outlet is installed on the lower part of outer facade (B1), the outdoor air flows into the space between roll screen and inner facade rapidly. This prevents temperature rise on the first floor. When the outlet is installed on the upper part of the outer facade (T1), the heat stored at the top of the intermediate space exhausts to the adjacent outlet. Although it showed same trend with the wide width (1.4 m) of intermediate space, there showed little difference according to the position of outlet (Fig. 7).

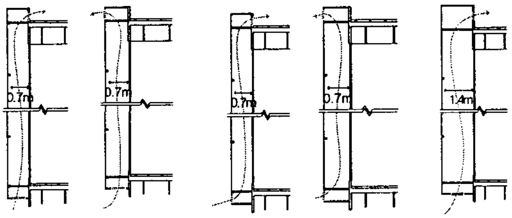
4. Planning the blind position

Evaluation models of DSF for the planning of blind position were set up by the previous result. The evaluation of Blind position was performed in each model. The horizontal distributions of temperature ($T_{Horizontal}$) and velocity ($V_{Horizontal}$) as shown in Fig. 3 were analyzed to evaluate the effect of blind position on the intermediate space in the DSF.

4.1 Simulation case and condition

According to the previous results in the last chapter, height and width of intermediate space and position of outlet play an important role in the temperature and airflow distribution of intermediate space. The evaluation models, model A-1, A-2, A-3, A-4, B, were set up in combination of these factors (Fig. 8).

Simulations were performed with four cases in each model (Table 5): roll screen installed



(a) A-1 (b) A-2 (c) A-3 (d) A-4 (e) B

Fig. 8 Evaluation model.

Table 5 Simulation case

Model	Case					
	DSF depth (m)	Outlet positon	Blind position (distance from outer-facade [m])			
A-1	0.7	B_2-T_2	0.07	0.15	0.35	0.55
A-2		B_2-T_1	0.07	0.15	0.35	0.55
A-3		B_1-T_2	0.07	0.15	0.35	0.55
A-4		B_1-T_1	0.07	0.15	0.35	0.55
B	1.4	B_2-T_2, B_2-T_1, B_1-T_2, B_1-T_1	0.07	0.15	0.55	1.25

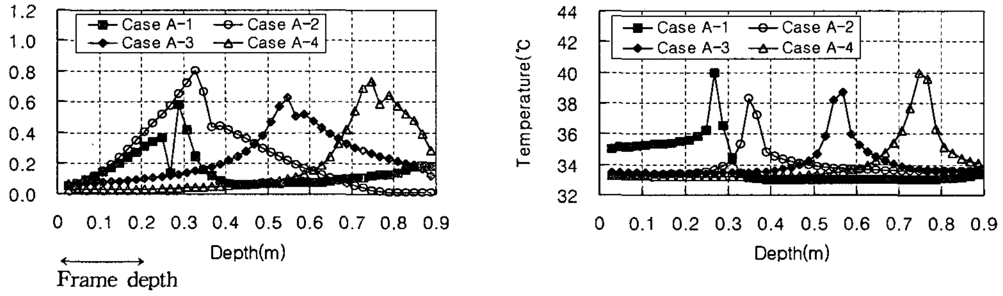
adjacent to the outer facade (distance from outer facade, 0.07 m), the distance between blind and outer/inner facade is 15 cm[7] (distance from outer facade, 0.15 m and 0.55 m), and roll screen installed in the middle of intermediate space (distance from outer facade, 0.35 m).

4.2 Evaluation of blind position

4.2.1 Case with narrow depth of intermediate space (Model A)

The airflow distribution within the intermediate space is shown in Fig. 9. The air velocity is high around the blinds since the blinds absorb solar radiation and act as a heat generator.

The result of evaluation model with inlet installed on the bottom of intermediate space and outlet installed on the upper part of the inner facade (model A-1) shows that the air velocity is the fastest and the temperature of roll screen is the lowest when the distance between outer facade and roll screen is 0.15 m. If the distance is below 0.15 m, the airflow in the space does not flow actively. This results in insufficient heat exhaustion through the outlet. On the contrary, if the distance is wider than 0.15 m,

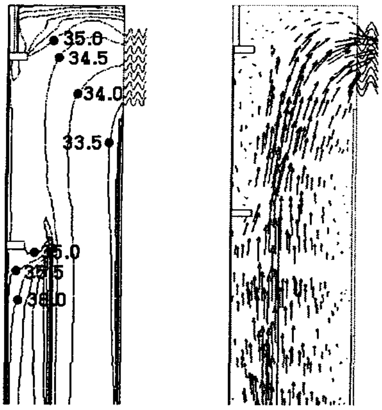


(a) Horizontal velocity distribution (b) Horizontal temperature distribution

Fig. 9 Velocity and temperature distribution in the intermediate space (model A-1).

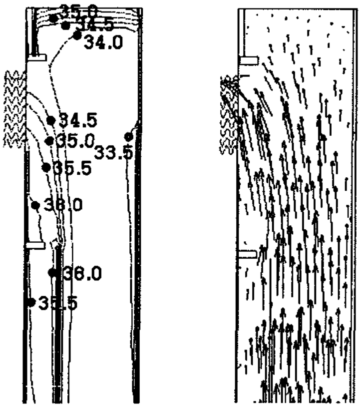
Table 6 The simulation results according to the variation of blind position

Model	A-1				A-2				A-3				A-4				B			
Effective distance from blind to outer facade (m)	0.07	0.15	0.35	0.55	0.07	0.15	0.35	0.55	0.07	0.15	0.35	0.55	0.07	0.15	0.35	0.55	0.07	0.15	0.35	0.55
Mass flow rate at outlet (kg/s)	0.92	1.30	1.18	1.07	0.96	0.88	1.10	0.94	0.99	1.08	1.12	1.08	1.00	0.97	1.14	1.05	1.69	1.20	1.63	1.07
Air temperature at outlet (℃)	35.0	34.8	34.9	35.3	35.1	34.5	34.8	34.9	34.7	34.6	34.6	35.1	35.1	35.1	34.8	34.9	33.9	34.1	34.4	34.5
Surface temperature of inner facade (℃)	33.7	33.6	33.8	34.0	33.2	33.3	33.5	33.6	33.3	33.1	33.5	33.6	33.1	33.3	33.5	33.7	32.8	32.7	33.3	33.9



(a) Temperature distribution (b) Velocity distribution

Fig. 10 Temperature and velocity distribution of intermediate space (model A-1, 0.15 m).

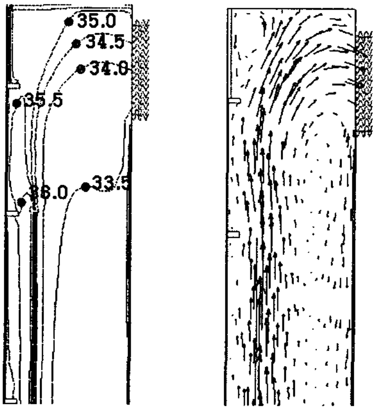


(a) Temperature distribution (b) Velocity distribution

Fig. 11 Temperature and velocity distribution of intermediate space (model A-2, 0.07 m).

that is, closer to the inner facade, the temperature of inner facade rises because of high temperature of roll screen. Therefore, the blind in model A-1 should be installed as far as possible from the inner facade maintaining 0.15 m from the outer facade.

In the case of model A-2, the heat stored between roll screen and outer facade exhausts better than model A-1 as shown in Figs. 10, 11. It is because the outlet in model A-2 is closer to the area where heat is stored. Moreover, the temperature of inner facade is lower when the distance between roll screen and outer facade is 0.07 m as shown in Table 6. In this case, the heat does not stagnate at the top of the intermediate space. Instead, it flows out through the outlet installed closer to the blind. Therefore, the blind in model A-2 should be installed as close as possible to the outer facade.



(a) Temperature distribution (b) Velocity distribution

Fig. 12 Temperature and velocity distribution of intermediate space (model B, 0.15 m).

Model A-3 showed similar result to model A-1 and model A-4 showed similar result to model A-2. Judging from this result, the case with narrow depth of intermediate space and outlet on upper side of outer facade, the blind should be installed as close as possible to the outer facade. In the other cases, the blind should maintain 0.15 m distance from outer facade.

4.2.2 Case with wide depth of intermediate space (Model B)

In the case of model B, it shows better thermal performance when 0.15 m is maintained between outer facade and blind, independent of position of inlet/outlet, as shown in Fig. 12 and Table 6. It is assumed that the distance between blind and outlet does not matter with the wide width of intermediate space.

5. Conclusions

The effect of blind position on airflow within the intermediate space and on the thermal environment of the adjacent room were analyzed by CFD simulation for a multistory-type DSF. The results of this study are summarized as follows.

(1) According to the results of analyzing factors that influence the thermal performance of DSF, the height and width of intermediate space and the position of outlet play an important role in temperature and airflow distribution. These were applied in setting up the blind evaluation model.

(2) In the case with narrow depth of intermediate space and outlet on upper side of outer facade, the blind should be installed as close as possible to the outer facade. In the other cases, the blind should maintain 0.15 m distance from outer facade.

(3) In the case with wide depth of intermediate space, it showed better thermal performance in every case when 0.15 m is maintained between outer facade and blind. The distance between blind and outlet doesn't matter with the wide width of intermediate space.

(4) Careful considerations of the DSF and the building in which the DSF is applied are necessary to determine the precise blind position.

The blind position proposed in this paper can be applied as a guidance for designers and engineers to plan blind that can maximize the thermal performance of DSF. However, this paper deals with exclusively multistory-type DSF and roll screen as a blind type. Therefore further study should be made to propose optimum blind position for various types of DSF.

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