Application of Dynamic Insulation Technique to Airflow Window System

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Abstract. It is necessary to improve solar blocking performance and reduce solar heat gain coefficient (SHGC) of openings in office buildings in order to reduce the cooling loads. Airflow windows are often practiced in Japan's office buildings. In this research, we apply a Dynamic Insulation (DI) technique into an airflow window system to improve the solar blocking performance. Computational fluid dynamics (CFD) analyses have been used to measure the thermal performance of the numerical opening model. In the case of using a conventional airflow window model, the inner-surface temperature of the inner glass is 29.4°C. In case the DI technique is applied, it is 27.0°C. The declination of the inner-surface temperature of the window improves the radiant environment in the building perimeter space. Moreover, the heat flux into the room is decreased due to the decline in the temperature difference between indoor temperature and the inner glass surface temperature.

1 Introduction

1.1 Objective

Window is commonly used to access the view and conveys the daylight into the building interior. Nowadays, most of designers intently enlarge the window size. At the same time, it is necessary to minimize the solar radiation to reduce the cooling load of the air-conditioning system. Improvement in the solar blocking performance of openings in order to decrease the solar heat gain coefficient (SHGC) is effective to reduce the cooling load.

Airflow windows have been widely recognized as high performance window systems. They are often introduced into openings of office buildings because the solar blocking performances is high [1]. We consider the application of the dynamic insulation (DI) technique into the airflow window system to further improve the solar blocking performance. The objective of this study is to suggest the optimal specification of the airflow window system with the DI technique.

1.2 Airflow window system

Figure 1 shows the diagram of the airflow window system. The airflow window system is a facade system that aims to make the surface temperature of inner glass reaches equally the air temperature of the interior. It contributes to improve the thermal environment in perimeter office-spaces. The cavity is separated by the outer glass with high heat insulation performance and the inner glass with

Figure 1. Diagram of the airflow window system

a simple window frame. The indoor air is introduced from the lower part of the inner glass and it flows through the outlet. In summer, heat due to hot blinds heated by strong solar radiation in the cavity, is exhausted. In winter, the flow warms up the temperature of inner glass, so that the surface temperature of the inner glass reaches the indoor air temperature [2].

1.3 Dynamic Insulation technique

The DI technique is a common technique to reduce heat flux through building facades by utilizing airflow go through the facades. In references [3] [4], the mechanisms are well explained.” DI describes a novel, energy efficient method of delivering fresh filtered ventilation air to the

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interior of a building, or air handling unit, through an air-permeable, dynamically insulated envelope or facade. This integration of fabric element into the Heating, Ventilation & Air Conditioning (HVAC) system of a building offers significant benefits. Since a proportion of the exterior skin of the building is used as the ventilation source, the flow velocity through the intervening DI media required to deliver the number of fresh air changes per hour, or liters per second, is ultralow. Under such conditions, efficient heat transfer and filtration of the incoming air takes place as a function of air change rate - the dynamic effect- and so forms the basis for a new and readily accessible distributed ventilation system. Ventilation air enters the building pre-heated in winter and pre-cooled in summer, using the heating and cooling energy that would otherwise be lost through conduction and convection to atmosphere". [5]

We are developing "DI window", windows applying DI technique for housing, and some of them have already been released on the Japanese market. The DI window for housing comprises a double window, blinds in an air layer and ventilation ports. The air layer performs as a ventilation route. The DI window system transports air by the pressure difference between indoor and outdoor driving ventilation. A mechanism in winter, a negative-pressure mechanical ventilation system, is illustrated by Figures 2. The ventilation ports at the top of the DI window serve as inlets. The outside air enters a layer via the exterior inlet at the window frame, and it is drawn into the room through the interior inlet at upper window frame after circulating in the layer. The intake air flows downward along the outer window, and rises upward along the inner window. The descending flow along the outer window obtains the Coanda effect by forcing flow downward, by using the flow guide. The airflow in the cavity has inertial affect reducing the temperature difference between the inner and the outer regions of the outer window. It makes difficult for heat to transfer out, this result in improving the thermal insulation performance. [6] Figure 3 is illustrated a mechanism in summer, a positive-pressure mechanical ventilation system. The ventilation ports at the top of the DI window serve as outlets. The blinds are heated by strong solar radiation, thereby increasing the temperature of the air layer. This causes the intrusion of heat through the inner window. The flow, is generated by the positive-pressure mechanical ventilation system, exhausts the heat in the air layer to the outdoor environment and makes it difficult for heat to enter the room, this also result in improving the solar blocking performance.

Figure 2. Airflow in DI window by negative-pressure mechanical ventilation system (in winter)

Figure 3. Airflow in DI window by positive-pressure mechanical ventilation system (in summer)

2 Methods

Figure 4 and Table 1 show the CFD analysis model and the analysis conditions, respectively. The analysis model comprises the inner window, the outer window, the blinds, the inlet and the outlet. We assumed a window with a depth of 400 mm and a ceiling height of 2800 mm. The inner/outer window is a float glass, and thickness of 8 mm. Ventilation volume is set at 25 m³/h, based on the numerical value of the reference [7] (6.2L/ m².s). Figure 5 shows the division of mesh. The area including the blinds was divided so that the inter-slat was divided into 5 meshes or more.

The air temperatures of outdoor and indoor were set to 30°C and 25°C, respectively, as we assumed the interior was cooled during summer. Figures 6 and 7 show the air ventilation of the conventional airflow-window and that of airflow-window with DI technique, respectively. We formed the numerical models of the inlet and the outlet in the air layer at the position shown in these figures. The index for the solar blocking effect of the window system is the surface temperature of inner window. When the window system has a high performance of solar blocking, the surface temperature of inner window will be lower, and vice versa.

Figure 4. Analysis model

Figure 5. Division of mesh

Table 1. Analysis conditions

Fundamental Conditions	
Software	STREAM V13
Analysis Area	2800 mm(x)×400 mm(y)× 2800 mm(z)
Turbulence Model	RNG k-ε
Radiation Model	View Factor
Total Number of Cells	Approximately 60,000 (case-dependent)
Discretization Scheme	QUICK
Boundary Conditions	
Radiation	Xmin, Xmax : 0.9 Ymin, Ymax : 0 (Symmetrical Boundary) Zmin, Zmax : 0.9
Details of Model	
Solar Radiation	Flux of Insolation : 500 W/m ² Angle of Incidence : 55°
Ventilation Volume	25 m ³ /h
Blinds	Absorption Ratio of Slat : 0.5 Width of Slat : 24 mm
Glass	Float Glass Absorption Ratio : 0.064 Thickness : 8 mm

Figure 6. Air ventilation in conventional airflow-window

Figure 7. Air ventilation in airflow-window with DI technique

Figure 8. Flow of this study

<table><tr><td>Cases</td><td>a</td></tr><tr><td><div>Cross-section of the model of window system</div><div><div>outlet</div><div>inlet</div></div></td><td></td></tr><tr><td>Specifications of window system</td><td>Conventional airflow-window system</td></tr></table>	Cases	a	<div>Cross-section of the model of window system</div> <div><div>outlet</div><div>inlet</div></div>		Specifications of window system	Conventional airflow-window system	<table><tr><td>Cases</td><td>a</td></tr><tr><td>Temperature distribution</td><td></td></tr><tr><td>Surface temperature of inner window [°C]</td><td>29.41</td></tr></table>	Cases	a	Temperature distribution		Surface temperature of inner window [°C]	29.41
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d-3	d-4												
27.12	27.11

Figure 9. Specifications of airflow-window system

Results and Discussion

This study presents the simulation of air flow during the summer period. Figure 10 shows the temperature distribution of the cross section on each window. Figure 10-a shows the result of conventional airflow window. The average of the surface temperature of inner window was 29.41 °C. The air temperature at the bottom of the air layer, near the inlet, was relatively low. On the other hand, natural convection, generated by heating the blinds due to solar radiation, floated at the top of the air layer. The high temperature at this area where natural convection levitating probably leads to the high surface temperature of inner window. Figure 10-b shows the result of the case which the position of the inlet/outlet was changed, and the airflow of DI type was generated in the air layer. The average of the surface temperature of the inner window was 30.12 °C. It can be described that the DI effect has no effect. The supply air was mixed with natural convection near the inlet and did not cool the inner glass. The results in the case “a” and “b” show that solar blocking performance were not improved. Therefore, we analysed the case in which the blinds were moved closer to outer glass and the inlet was moved to inner of the air

Figure 10. Temperature distribution of cross section on each airflow window system

layer, in order to prevent mixture of the supply air and natural convection (Figure 10-c). However, the DI effect was not sufficiently exerted, because the supply air was not completely separated from natural convection. It was confirmed that the airflow in the air layer was largely influenced by the solar radiation.

We thought that the window system with triple glasses is suitable, in which the flow guide is installed in the air layer, to separate supply air from the natural convection. Figures 10-d1 to d4 show the results in the case of varying the distance between the flow guide and the blinds where the position of the blinds is fixed, while moving the flow guide from the nearest (x = 125) to farthest (x = 334). In the case of d-1, the average of the surface temperature of the inner window was 28.12°C, and this case has the highest temperature among the other case “d.” Natural convection is generated near the blinds flowed along the flow guide because impact of the Coanda effect. The radiative heat transfer from the flow guide to the inner window became bigger, because the warm air flowed along the flow guide and heated by the air. The rest of cases in case “d” have closely surface temperature of inner window. Figures 10-e1 to e4 show the results of the cases which has two outlets at the top of conventional airflow

window. The surface temperature of the inner window, it is higher than cases d2 to d4. The result in this work confirm that DI technique has high effectiveness.

Conclusion

This study considered the optimal specifications when applying the DI technique into an airflow window system. It was found that a system for separating the natural convection from the supply air was necessary. Therefore, a flow guide should be installed in the cavity to make triple-layered glass. It is also found that the flow guide that was too close to the blinds have low efficiency. The flow guide used to force the supply air to innermost window while the temperature of supply air is close to the indoor temperature. This leads to reduction of the surface temperature of the inner glass, thus radiant environment of perimeter zone will be improved. Taking the radiant environment of perimeter zone into consideration, the specification like figure 10-d (except “ $x = 125$ ”) is proper for application of DI technique into airflow window system.

We focused on the solar blocking performance of the window system, and we have been studying the optimal specification by treating the surface temperature of inner window as an indicator. However, the specification figure 10-d may inappropriate in terms of energy consumption, because the airflow window system has large impact on the ventilation load. We are continuing to perform an energy simulation, and study on how the window system works through a year in the future.

Acknowledgements

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