APPLICABILITY OF AIR SUPPLY TYPE AIRFLOW WINDOW SYSTEM APPLIED TO DOUBLE-PANE WINDOW

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ABSTRACT

It still remains heat loss and high risk of moisture condensation occurrence at glass of window because they have relatively poor insulating qualities and usually contribute the greatest heat loss by heat conduction in residential buildings. Although many attractive window systems are proposed to reduce heat loss such as double and triple glazing, low emissivity film coated glazing, argon gas injected glazing, vacuum insulated glazing, double-pane and triple-pane window etc., it has also demerits such as high initial cost and indoor air quality problem. To solve these problems, this paper propose air supply type airflow window system applied to double-pane window combine with a mechanical ventilator and a heat-recovery heat pump system.

The aim of this paper is to evaluate the thermal insulation efficiency and probability of moisture condensation in the air supply type airflow window system applied to double-pane window combine with 2 double glazing using numerical simualtion in order to confirm its feasibility and applicability in residential buildings. First, the proposed system is designed to ventilate through the air space of a double-pane window combine with 2 double glazing. Then, to verify its thermal insulation efficiency, the temperature distribution of the glass of window was evaluated using computer fluid dynamics (CFD) with a coated position of low emissivity film, after confirming calculation accuracy using double-pane window model, double glazing, and low emissivity film coated glazing. In addition, to verify the probability of moisture condensation, the dew-point temperature in the glass of window was calculated based on the various low emissivity film positions.

The calculated results show the thermal insulation efficiency of the proposed system is enhanced approximately 25.48% and 62.95% by airflow effect in comparison with the double-pane window and single-pane window with double glazing. Moreover the calculation results show that it is effective to use low emissive film in the proposed system to avoid moisture condensation occurrence. Therefore, it is confirmed technically feasible to reduce the energy consumption and to avoid moisture condensation occurrence the in residential buildings.

KEYWORDS

Air supply type airflow window system, Double-pane window, Moisture condensation, CFD
INTRODUCTION

Window glass remains prone to heat loss and considerable moisture condensation, due to its relatively poor insulating qualities and is usually the major source of heat loss via heat conduction in residential buildings. Although many attractive window systems have been proposed to reduce heat loss, such as double- and triple-glazing, glazing with low-emissivity film coating, argon gas-injected glazing, vacuum-insulated glazing, double- and triple-pane windows etc., these also have disadvantages such as the high initial cost and indoor air quality problem. To solve these, the author’s previous paper proposed air supply via an airflow window system applied to the double-glazing combined with mechanical ventilation and heat-recovery heat pump systems. However, the problem of moisture condensation on the internal surface of the window remains.

OBJECTIVE

The purpose of this paper is to evaluate thermal insulation efficiency in the proposed new air supply via an airflow window system applied to dual double-glazed double-pane windows to confirm its feasibility and applicability in residential buildings. We also evaluate whether it produces excessive moisture condensation, depending on the position of the low emissivity film coating.

METHODS

CFD calculation is used to evaluate the proposed air supply type airflow window system. Although this method has been widely used to simulate air movement, heat transfer and mass transfer in indoor and outdoor environments, the experimental data or theoretical values must be validated. Accordingly, this paper evaluates the thermal insulation efficiency of the proposed system using CFD calculation, after confirming the calculation accuracy using a double-pane window model.

1. CFD validation on the double-pane window

In this section, we evaluate the CFD accuracy on the double-pane window with the position of the low-emissivity film coating. The model size is 765 × 1,870 × (6-12-6-12-6-12-6 double-glazing) mm and the calculation cases used are shown in Fig. 1. A low-Reynolds number k-epsilon turbulence model was used to compute the turbulent viscosity and diffusivity. The boundary conditions and material properties for the calculation are summarized in Tables 1 and 2. Outdoor/indoor air temperatures are assumed to be 00.00 ºC and 22.00 ºC respectively. The total heat transfer coefficient of the window surface is assumed to be 23.25 W/(m^2·K) outdoors and 9.09 W/(m^2·K) indoors for calculation. Moreover, the theoretical method makes reference to ISO10092 to calculate the theoretical U-value of the double-pane window.

2. Evaluation of thermal insulation efficiency on the air supply window system

To evaluate the thermal insulation efficiency of the proposed air supply window system, the temperature contribution of the window panes were calculated using 3-D steady-state CFD calculation, including detailed ray tracing-based radiation modeling. Figure 3(a) shows a plan of the building model used for the calculation, which is proposed as a model of a standard dwelling house in Japan by the Institute for Building Environment and Energy Conservation. In this study, a children's room on the second floor (2.40 (H) × 2.90 (W) × 3.50 (D) m = 24.36 m^3) is only used for calculations as shown in Fig. 3(b). Figure 3(c) shows the detail of the window (1.95 (H) × 1.65 (W) m) installed in the calculation model with Figs. 3(d) and 3(e). The air supply window system applied to the window glass allows fresh outdoor air into the room. The opening size was determined at 0.001 (H) × 0.765 (W) m and the applicable ventilation rate was applied 12.93 m^3/h to satisfy the requirement of the room, because the required indoor ventilation rate is at least one half air change per hour (0.5 ACH) over an entire 24 hour period in Japan. The turbulence model, material properties and boundary conditions for the CFD calculation used the same values as summarized in Tables 1 and 2, respectively. Unfortunately, to keep the calculation model simple in this study, the window frame is not considered.

RESULTS AND DISCUSSION

1. Result of the CFD validation on the double-pane window

The result of the CFD validation on the double-pane window with the position of the low-emissivity film coating is shown in Fig. 2. Figure 2(a) shows the surface temperature of the 4 plate glasses forming the double-pane window. Figure 2(b) shows a comparison of the theoretical and calculated U-values by CFD calculation. To calculate the U-value from the CFD results, the integrated value of the outdoor surface temperature of the plate glass, the outdoor air temperature and the total heat transfer coefficient of the outdoor window surface are used. As shown, the temperature difference peaks at the air space in contact with the glass coated with the low-emissivity film. Moreover, the indoor to outdoor heat loss fell when increasing the number of low-emissivity film coatings. Conversely, the outdoor surface temperature approached the outdoor air temperature of 0˚C by increasing the number of low-emissivity film coatings. The calculation results of the double-pane window showed the U-value to be 1.20 $W/(m^2 \cdot K)$ when using glazing with the low-emissive film coating. This represents an insulation performance enhancement of approximately 20.00 % based on the comparison 1.50 $W/(m^2 \cdot K)$ with glazing without low-emissivity film applied. The error value of the CFD calculation was calculated to within approximately 5.62 % by comparison of the theoretical surface temperature and within approximately 2.04 % by comparison of the theoretical U-value. Therefore, the reliability of the CFD calculation was confirmed.

2. Result of calculation on the air supply window system

(1) U-value (thermal insulation efficiency)
The thermal insulation efficiency was predicted for the air supply type airflow window system, based on the position of the low-emissivity film coating. The result of the calculated U-value and the surface temperature of the glass are given in Table 3 and Fig. 4. Although the calculation results show that thermal insulation efficiency rose when increasing the number of low-emissivity film coatings, the glazing insulation performance is unchanged with the position of low-emissivity film coating. As shown, the thermal insulation efficiency increased approximately 25.48 ~ 38.43 % (U-value : 1.50 $W/(m^2 \cdot K)$ → 1.12 $W/(m^2 \cdot K)$ (Case 1), 0.90 $W/(m^2 \cdot K)$ → 0.55 $W/(m^2 \cdot K)$ (Case 9)) by applying the air supply window system in comparison with a double-pane window.

(2) Moisture condensation

The result of the calculated surface temperature of glass to confirm the occurrence of moisture condensation is also given in Table 3. The calculated results show that moisture condensation only occurred on the lower surface of glass where a low-emissivity film was applied close to indoors (Cases 6, 7), when the indoor air temperature and relative humidity exceeded 22.00 ºC and 50.00 %RH respectively (dew-point temperature : 11.10 ºC). Considering this, the outdoor air did not warm quickly because the low-emissivity film was applied close to indoors. It did not occur in the other cases (Cases 1 ~ 5) and the 2 low-emissivity film coated cases (Case 8, 9). The presence of moisture condensation depends not only on the outdoor temperature and humidity ratio but also the position of low-emissivity film coating and supply air flow rates.

CONCLUSION

This paper proposed an air supply type airflow window system to reduce energy consumption in residential buildings, the effectiveness of which was assessed with a feasibility study using CFD calculation. As a result, we found that the thermal insulation efficiency of the proposed system showed an insulation performance enhancement of approximately 25.48 % in comparison with the double-pane window. Moreover the calculation results showed that it is effective to use low-emissivity film in the proposed system to avoid moisture condensation. Therefore, it is confirmed as a technically feasible method to reduce energy consumption in residential buildings. A summary of the general findings of this study is as follows :

- The error in CFD calculation results was small and the reliability was confirmed by comparison of the theoretical U-value on the double- pane window.
- In the CFD accuracy simulation, the calculation results of the double-pane window showed the U-value to be 1.20 W/(m^2·K), where glazing was used with the low-emissivity film coating. It shows insulation performance enhancement of approximately 20.00 % in comparison to 1.50 W/(m^2·K) in the case of glazing with no low-emissive film applied.
- For the combined airflow glazing with no low-emissivity film applied, the U-value was calculated at 1.12 W/(m^2·K). This shows an insulation performance enhancement of approximately 25.48 % in comparison with a double-pane window using glazing without low-emissivity film applied. Moreover, it is confirmed that the proposed system can further boost thermal insulation efficiency by increasing the number of low-emissivity film coatings.
- Moisture condensation occurs only on the lower surface of glass where low-emissivity film is coated close to indoors when the indoor temperature and relative humidity exceed 22.00 ºC and 50.00 %RH respectively. Moisture condensation not only depends on the outdoor temperature and humidity ratio but also the position of low-emissivity film coating and the supply air flow rates.

FUTURE PERSPECTIVE

A future study is required to evaluate various design models such as triple glazing, argon gas-injected glazing, vacuum-insulated glazing and triple-pane window etc., because it is important to prevent moisture condensation on indoor glass surfaces. Moreover, thermal comfort should be calculated for a realizable room model by examining the effects of any cold drafts, thermal radiation effects and the energy-saving effects of the heat pumps included in the proposed system, which will be evaluated in future investigations. First, the following themes will be studied to avoid backflow and ventilate a stable air supply in the near future :

- The effect of indoor/outdoor pressure caused by outside wind conditions.
- The ventilation rates due to buoyancy caused by differences in indoor/outdoor temperature.

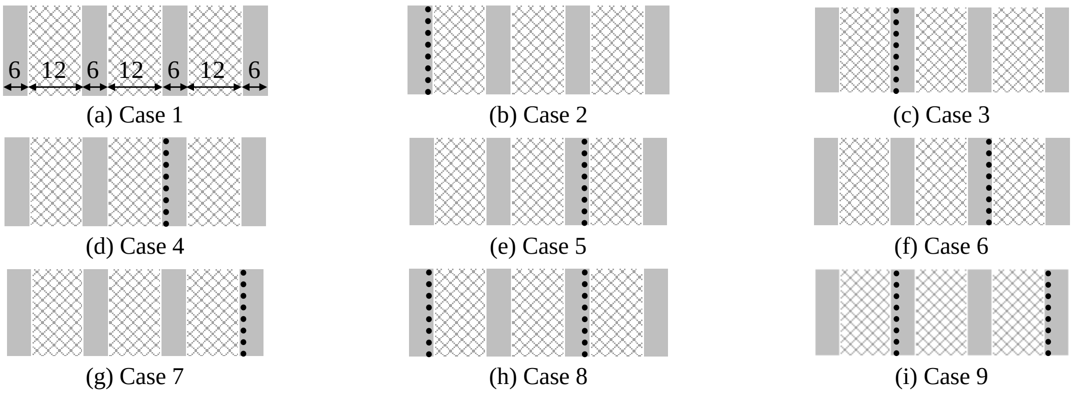
- In case of double-sided-openings (when installed in different directions).
- The effect of thermal environments caused by drafts or thermal radiation.

Item	**Air**	**Water vapour**	**Glass pane**	**Low-E film**
Specific heat (C_P)	1006.43 [J/(kg·K)]	2014 [J/(kg·K)]	753 [J/(kg·K)]	-
Conductivity (λ)	0.0242 [W/(m·K)]	0.0261 [W/(m·K)]	0.65 [W/(m·K)]	-
Viscosity (μ)	1.79×10^{-5} [kg/(m·s)]	1.34×10^{-5} [kg/(m·s)]	-	-
Moler weight (M)	28.97 [kg/kgmol]	18.02 [kg/kgmol]	-	-
Thickness (l)	-	-	6.00 [mm]	-
Emissivity (ε)	-	-	0.90 [-]	0.10 [-]

Table 1. Material properties.

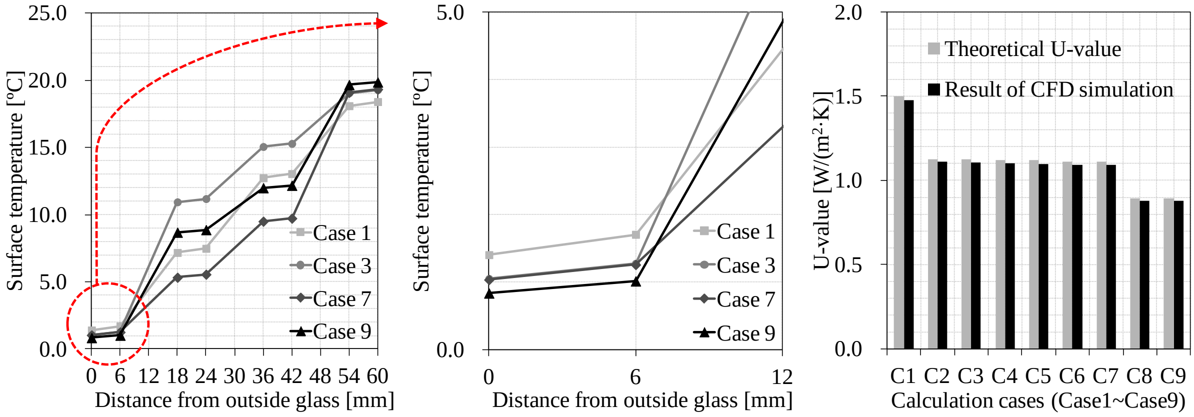
Item	**Contents**	
Model	765 x 1,870 x (6-12-6-12-6-12-6 double glazing) mm : 3-dimentional calculation	
Turbulence model	Abe-Kondoh-Nagano low-Reynolds number k-epsilon model	
Mesh	About 800,000 meshes (near wall y+ < 1)	
Surface of glass	Velocity : No slip, $k\|_{wall}$: No slip, $\varepsilon\|_{wall} = 2\nu\left(\frac{\partial\sqrt{k}}{\partial y}\right)^2$	
Heat transfer coefficient	Indoor	9.09 [W/(m²·K)]
	Outdoor	23.26 [W/(m²·K)]
Temperature condition	Indoor	22.00 [°C]
	Outdoor	0.00 [°C]

Table 2. Boundary condition.



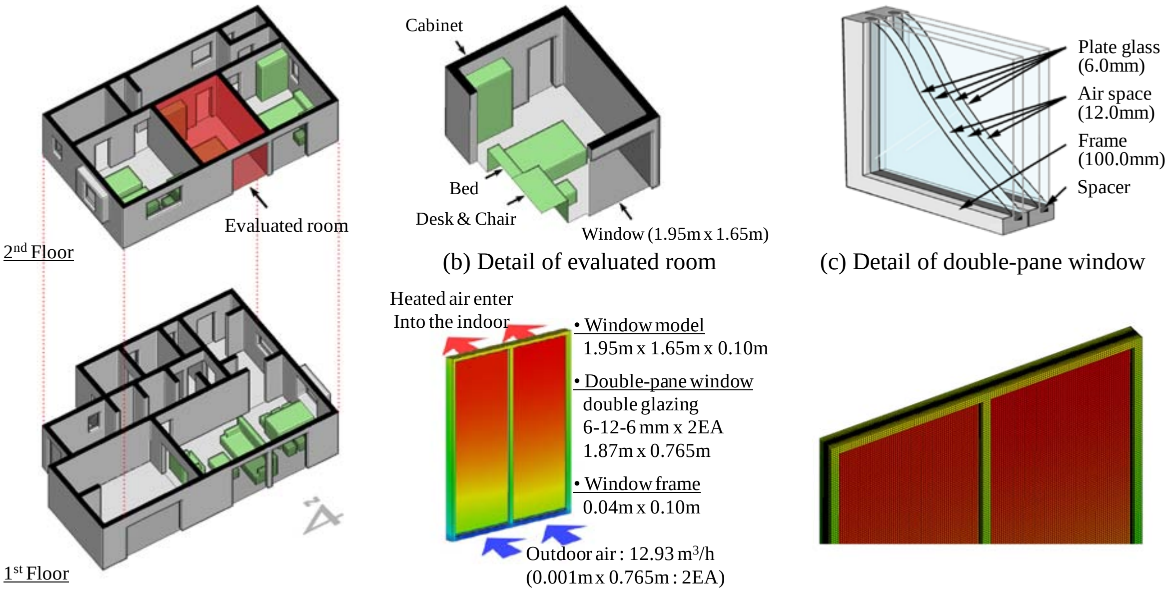
* ×:Air space, ■:Plate glass, ・: Low-E film, Unit [mm]

Figure 1. Calculation cases by position of Low-E film.



(a) Surface temperature of glass (b) U-value

Figure 2. CFD validation results on the double-pane window



(a) Applied dwelling house (d) Detail of calculation model (e) Calculation mesh

Figure 3. Schematic of calculation model

Cases	U-value [W/(m²·K)]	T_{supply} [°C]	$T_{s\_outdoor}$ [°C]			T_{s_indoor} [°C]			Moisture condensation < 11.10°C*
			Max.	Min.	Avg.	Max.	Min.	Avg.	
Case 1	1.12	10.63	1.66	0.05	1.06	18.42	12.59	17.57	×
Case 2	0.77	13.01	1.21	0.03	0.74	19.12	13.78	18.01	×
Case 3	0.77	12.98	1.22	0.03	0.74	19.11	13.77	18.01	×
Case 4	0.76	11.06	1.31	0.02	0.72	19.20	13.07	18.37	×
Case 5	0.76	11.03	1.35	0.02	0.72	19.21	12.65	18.38	×
Case 6	0.78	8.33	1.67	0.04	0.74	19.27	11.04	18.79	○
Case 7	0.77	8.27	1.92	0.04	0.74	19.29	10.84	18.80	○
Case 8	0.55	10.28	1.45	0.02	0.52	19.63	12.60	19.01	×
Case 9	0.55	10.23	1.26	0.02	0.52	19.66	12.40	19.02	×

* Dew-point temperature is 11.10 °C when the indoor thermal environment controlled 22.00 °C, 50.00 %RH.

Table 3. Results of calculation on the air supply window system.

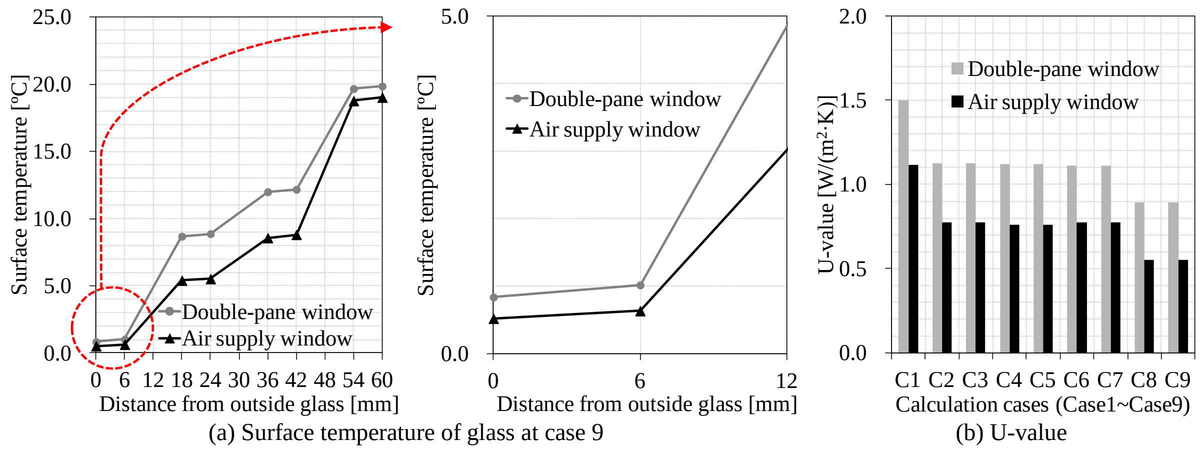


Figure 4. Comparison of the double-pane window and the air supply window system

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