DYNAMIC INSULATION APPLIED TO THE RESIDENTIAL BUILDING (PART 1)
Numerical Evaluation of Window Frame applied Various Dynamic Insulation Patterns

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ABSTRACT

It is important to insulate the glazing or frames of windows efficiently because they usually contribute to some of the greatest heat loss from dwelling houses. To improve window insulation, we propose a new dynamic system applied to window frames. This system is composed of three parts: a dynamic insulation system applied to window frames, a mechanical ventilation system, and a heat-recovery heat pump system. In order to confirm its feasibility, we evaluated various insulation patterns, materials and structures, by computational fluid dynamics.

INTRODUCTION

To realize energy-saving houses, it is important to improve thermal insulation performance and airtightness. However, these improvements can lead to poor indoor air quality (IAQ) due to ventilation shortage, and health problems due to mold caused by trapped condensation. Therefore, a 24-hour ventilation system is required together with a standard of thermal insulation performance in Japan. For these reasons, various architectural technologies have been designed. Dynamic Insulation (DI), one of these technologies, provides well-insulated ventilation. The DI principle prevents heat transport, which is opposite to the incoming direction, by advection when incoming air enters via porous insulation. DI for the building envelope has already been studied. However, there is no application example for window frames, which contribute to some of the greatest heat loss from dwelling houses. Thus, the danger of the condensation and the effect of heat loss reduction have not been analyzed.

This paper proposes a new DI window system that can decrease the heat loss from window frames, due to enhanced window thermal insulation performance and has weak airtightness using the window frame as a ventilation hole, and studies the feasibility of the system.

NEW SYSTEM

Figure 1 shows the composition of the newly proposed system. This new system focuses on using window frames in dwelling houses as ventilation holes. The system is composed of three technologies: a dynamic insulation system applied to window frames, a mechanical ventilation system, and a heat-recovery heat pump system. These technologies bring about the realization of an energy-saving house.

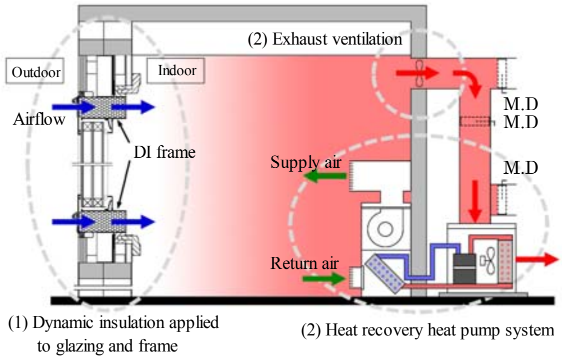

Fig. 1 Composition of the newly proposed system [Operation mode for winter season]

SIMULATION

1) Study the structures of DI window frame

1-a) Basic structure

When the structures of a DI window frame are determined, it is necessary to satisfy the basic performance as a window unit: Resistance to wind load, water tightness, and air permeability. Therefore, DI was implemented to the basic cross section with no modification as a porous medium packed into a hollow chamber (Ex. Fig. 2). The metal frame itself is easy to image becoming a heat bridge. Then, the insulated frame is examined. These three insulated frames were considered: plastic frames (PVC), metal frames with thermal break (aluminum-poliamid-aluminum), metal-plastic comb structure (Aluminum-PVC). To predict the thermal performance of these insulated frames with the porous medium, CFD simulation was conducted. The preconditions, analysis conditions, and analysis models are shown in Table 1 and Fig. 3, 4. Also the results: internal frame surface temperature, incoming air temperature, indoor/outdoor pressure difference, thermal transmittance of frame (Uf-value) are shown in Fig. 5, 6.

As a result, the following matters were clarified:

1. The metal frame has the greatest heat loss and thus must be insulated with thermal breaks or a metal-plastic comb structure.

2. At the metal frame and metal porous medium that is placed internally, the internal surface temperature and incoming air temperature could be raised. This would be beneficial to reduce internal surface condensation and achieve appropriate air temperature at the surroundings of the indoor window. Meanwhile, at the plastic frame and plastic porous medium, the Uf-value is the lowest; both the internal frame surface temperature and incoming air temperature are lower than the metal frames with a thermal break or metal- plastic comb structure.
3. The velocity for almost zero Uf-value would be 10 times faster than one for a DI building envelope (DI frame inflow : $1m^3/hm$=0.016m/s). For this reason, the amount of total ventilation is increased. It would be possible to secure the ventilation requirement for indoors only with a DI window.
4. Indoor/outdoor pressure difference would increase in proportion to the inflow.

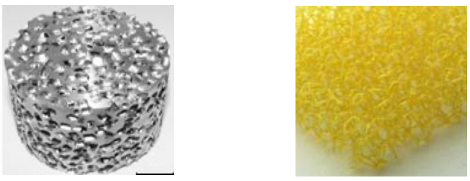

Fig. 2 Example of metal or plastic porous medium

Table 1 Boundary conditions

Item	Conditions	
Solver	ANSYS FLUENT ver. 13.1	
Calculation domain	0.50 m × 0.30 m × 0.10 m	
Turbulence model	Standard high Re k-ε model	
Thermal condition	Outside : 276.15[K], Inside : 293.15 [K]	
Materials properties	Aluminum	Conductivity (λ) : 210.00 [W/(m·K)] Specific heat (C_P) : 917.00 [J/(kg·K)] Density (ρ) : 2690.00 [kg/m^3]
	Plastic	Conductivity (λ) : 0.35 [W/(m·K)] Specific heat (C_P) : 5000.0 [J/(kg·K)] Density (ρ) : 200.00 [kg/m^3]
	Glazing	Conductivity (λ) : 1.00 [W/(m·K)] Specific heat (C_P) : 753.00 [J/(kg·K)] Density (ρ) : 2500.00 [kg/m^3]
Perforated plate	Material : Aluminum Thickness : 1.20 [mm] Porosity : 40.30 [%]	
Porous medium	Material : Plastic Thickness : 25.00 [mm] Porosity : 97.80 [%]	
Porous medium cof.	Plate : C1 = 4.35 × 10^7, C2 = 1960 Porous : C1 = 1.71 × 10^7, C2 = 139	
Volume flow rate	1.08, 2.16, 4.32, 8.64, 17.28 [m^3/hm]	

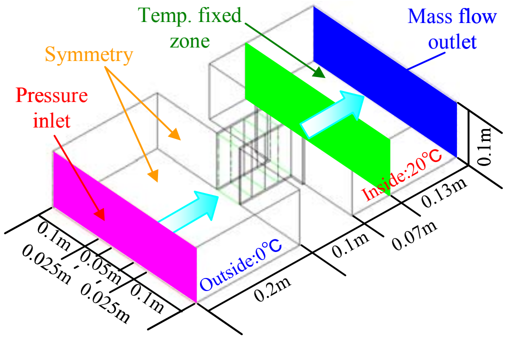

Fig. 3 Analysis model

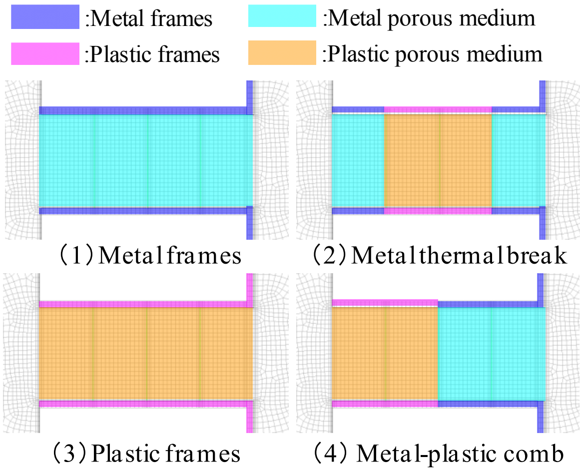

Fig. 4 Analysis conditions (Porous medium)

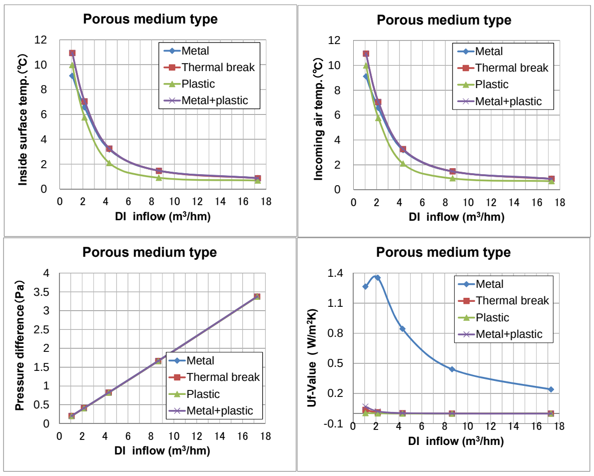

Fig. 5 Comparison results (Porous medium)

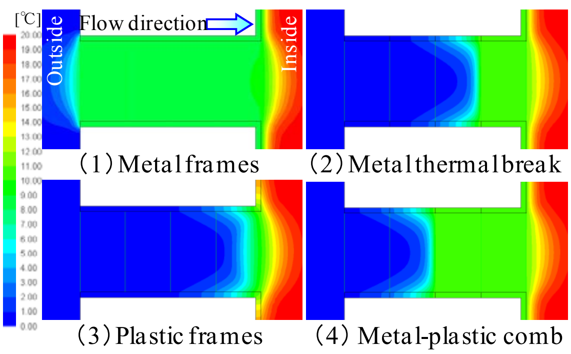

Fig. 6 Results of temperature (Porous medium)

1-b) DI window frame without porous medium

The porous medium plays a role in conducting heat from the frame to incoming air, as already mentioned. DI without a porous medium is studied in this section.

It is necessary to conduct heat from the frame to incoming outside air. There are two means of attaining this (Ex. Fig. 7): heat sink type, in which the incoming air circumvents, and perforated plate type, in which the incoming air passes directly through with heat conduction.

The analysis conditions and analysis results are shown in Figs. 8 and 9, 10.

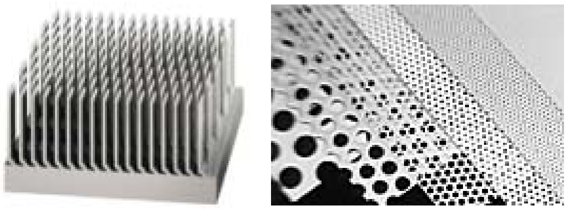

Fig. 7 Example of heat sink and perforated plate

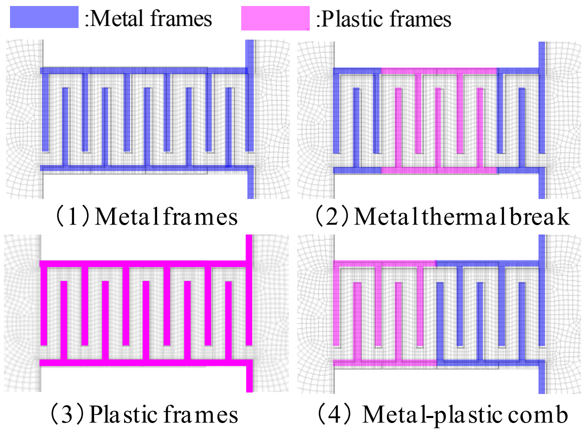

Fig. 8-1 Analysis conditions (Heat sink)

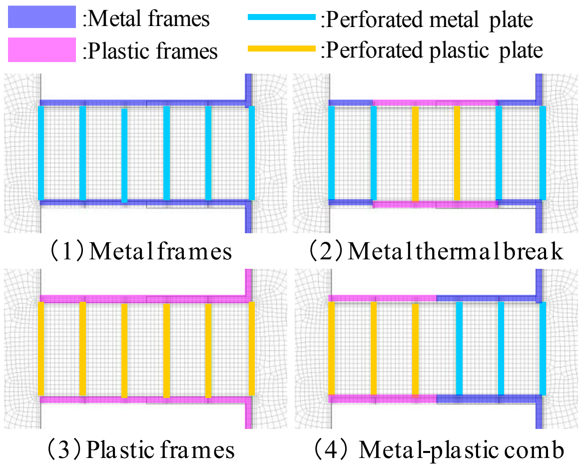

Fig. 8-2 Analysis conditions (Perforated plate)

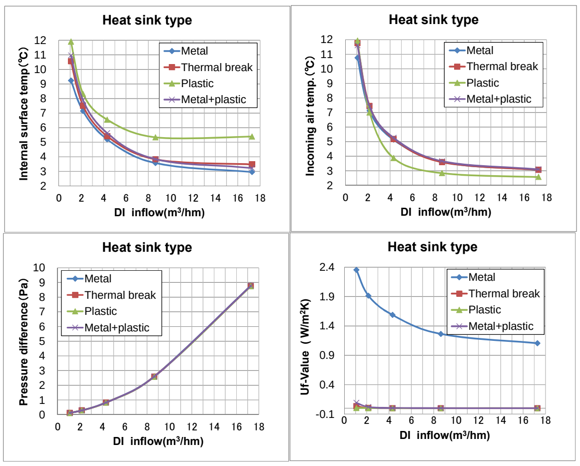

Fig. 9-1 Comparison results (Heat sink)

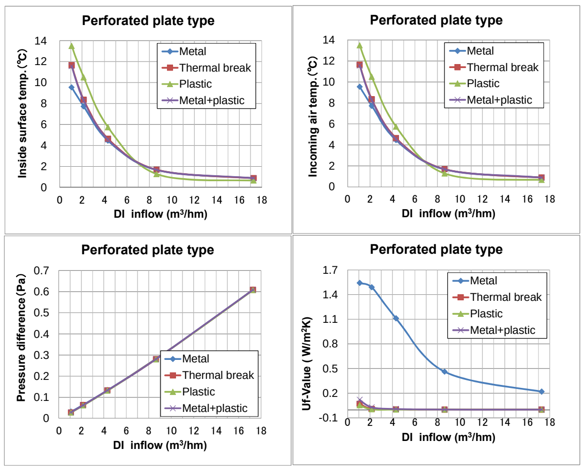

Fig. 9-2 Comparison results (Perforated plate)

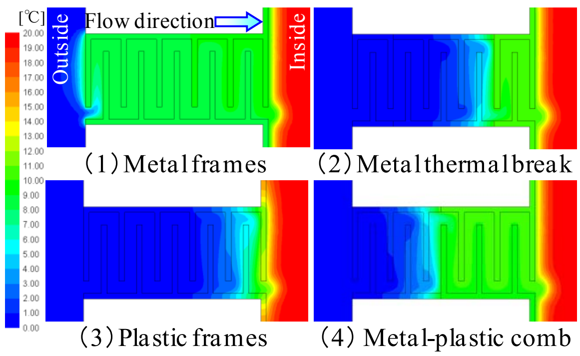

Fig. 10-1 Results of temperature (Heat sink)

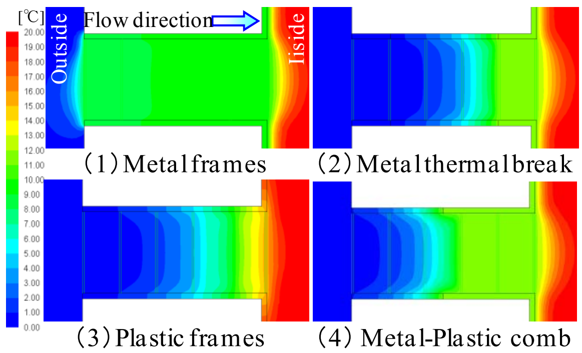

Fig. 10-2 Results of temperature (Perforated plate)

According to Figs. 9 and 10, the results are as follows:

1. As well as the examination of 1-a), according to the results of the plastic frame, the Uf-value is the most enhanced, but the incoming air temperature does not increase significantly, even though the inflow is increased. At the metal frames with a thermal break or metal-plastic comb structure, with the aluminum located on the internal side, it was clarified that thermal performance is improved, incoming air temperature is increased, and the indoor frame surface temperature does not reach the dew point.
2. At the heat sink type and perforated plate type air is packed into the frame, when inflow is small, heat convection occurs in each hollow chamber, because there is also a small difference in the indoor/outdoor pressure. In particular, the backflow was seen in the upper side of the plastic frame (Fig. 11). This backflow that is caused by ventilation due to buoyancy grows in proportion to the window height. To prevent that, some resistance can occur, and appropriate pressure loss is necessary to the frame.
3. In the heat sink type and perforated plate type, each pressure loss that originates by inflow is greatly different. This pressure difference can be adjust not only to modify the aperture ratio of the perforated plate type, but also to add more porous medium into the hollow chamber, since it is possible to adjust if it is required for the DI window.

2) Designed DI window frame

In view of the above discussion, a DI window frame was designed. The following points were considered:

A) The drainer was located outside in consideration of the weather.

B) Aluminum is located on the internal side in order to easily transmit internal heat to inflowing air.

C) To conduct heat exchange with incoming air and frame effectively, the duct is a maze (heat sink type)

D) To suppress the thermal conduction of the frame itself, it must be a metal frame with a thermal break.

E) In order to add moderate pressure resistance to incoming air, porous medium is located in a plastic hollow chamber.

F) To prevent heat convection, the rubber material is located at the glazing width as a partition.

G) In case huge indoor/outdoor pressure difference as such as typhoons occur and rainwater enters, a cover that closes the duct is attached.

3) Drawing

Figure 12 shows a cross section of the DI window frame.

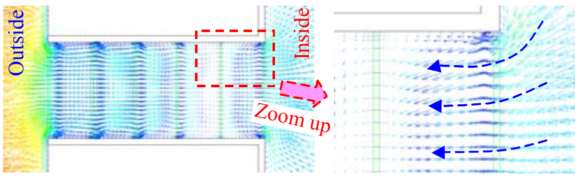

Fig. 11 The backflow can be seen on the upper side of the plastic frame

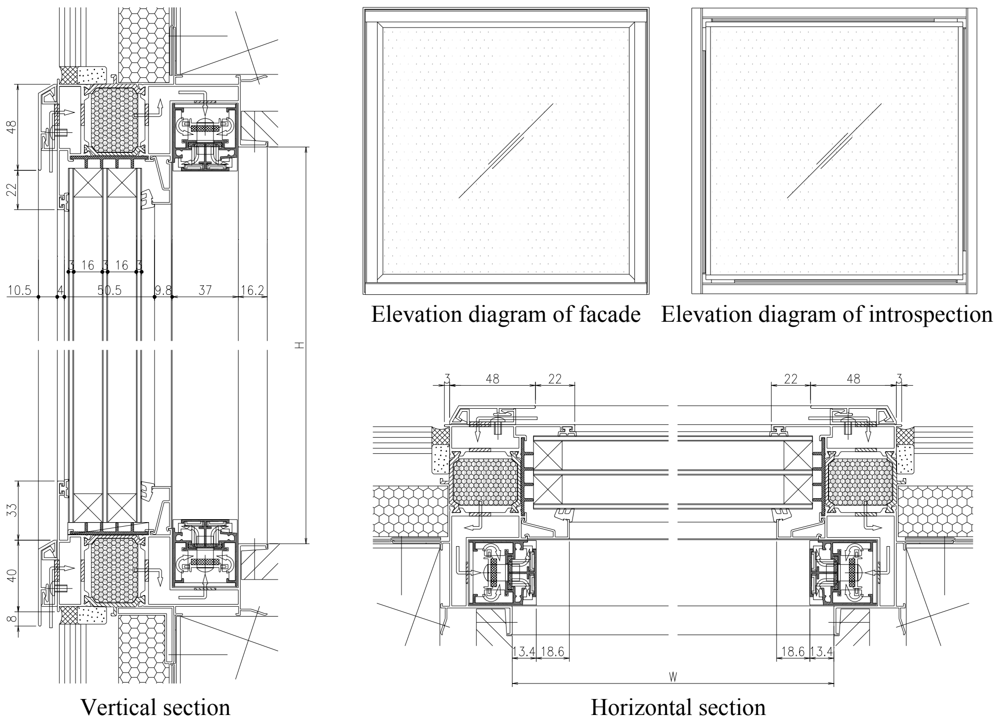

Fig. 12 Example of heat sink and perforated plate

4) Thermal performance of the designed DI frame

The thermal performance of the designed DI window frame was studied by CFD. The preconditions and analysis conditions were as follows (Fig. 12, Table 2). The results are shown in Fig. 14 and 15.

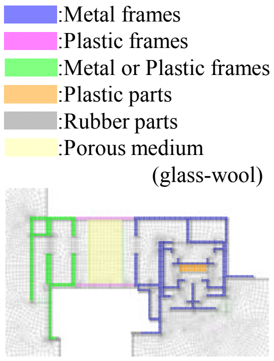

Table.2 Conditions

	Frame Type	Porous medium
1	Metal only	×
2	Metal thermal break	○
3	Metal thermal break	×
4	Metal-plastic comb	○
5	Metal-plastic comb	×

Fig. 13 Analysis conditions (DI frame)

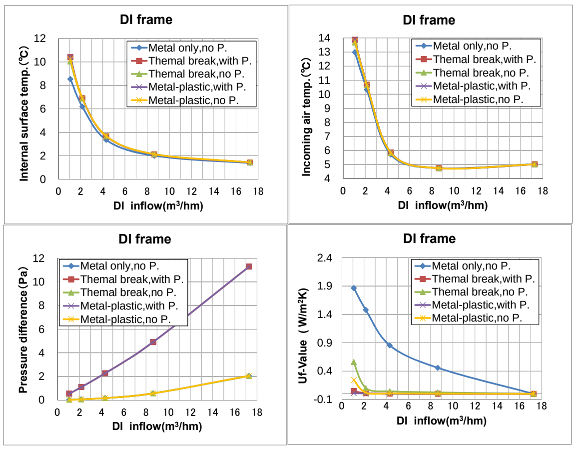

Fig. 14 Comparison results (DI frame)

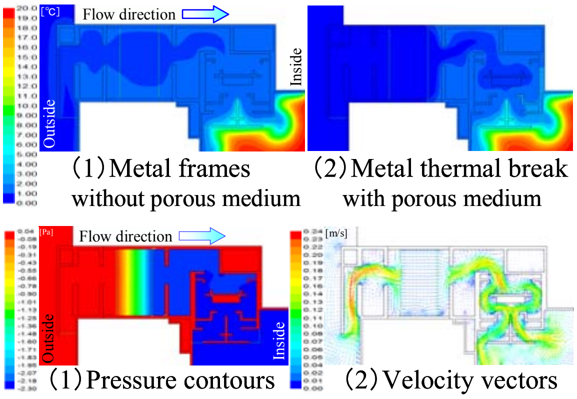

Fig. 15 Calculation results (DI frame)

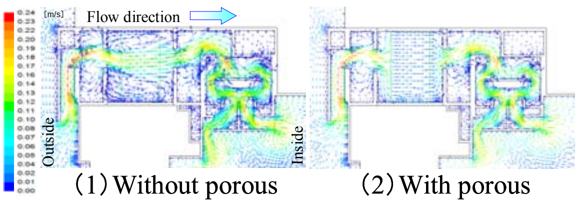

Fig. 16 Adding the porous medium causes less air convection

For comparison, the thermal performance of the general metal frame was also confirmed. As a result, in the case of either the normal metal frame or the metal frame with DI, there was no huge enhancement of thermal performance, such as Uf=1.9. Thus, it must be stressed that a well-insulated frame is a precondition for a high level of thermal performance.

In this phase, porous medium is added to the plastic hollow chamber in the frame. This porous medium was aimed at preparing an appropriate pressure loss of less than 10 Pa (with this pressure difference there is no obstacle in the opening/shutting of the interior door) to the DI window frame in order to reduce the influence of outside pressure changes that depend on the outside wind conditions, but also have an effect on improving the thermal performance. Locating the porous medium at the plastic hollow chamber near the boundary between the aluminum causes less air convection. For this reason, the heat loss was reduced and Uf was enhanced (Fig. 16).

5) Thermal transmittance as DI window

To calculate the thermal performance of the DI window, the thermal transmittance of the DI window (Uw-value) was verified, according to the calculation method shown in ISO-10077-1, -2. Table 4 and Fig.17 show the analysis conditions and window specifications. Figures 18 and 19 show the results.

Table 3 Uw-value calculation

ISO-10077 Thermal performance of windows
— Calculation of thermal transmittance —

$$Uw = \frac{Ag\,Ug + Af\,Uf + lg\,\Psi g}{Ag + Af}$$

Ug is the thermal transmittance of the glazing, *Uf* is the thermal transmittance of the frame, *Ψg* is the linear thermal transmittance due to the combined thermal effects of the glazing, spacer and frame.

Depending on the DI window inflow, Uf changes 0.20 to 0.01 W/(m^2·K), liner thermal transmittance Ψg also changes from 0.033 to 0.006 W/(m·K), which means that except for glazing thermal transmittance Ug, Uf and Ψg is almost zero. In total, when using triple glazing, DI window thermal transmittance Uw is 0.63 - 0.47 W/(m^2·K).

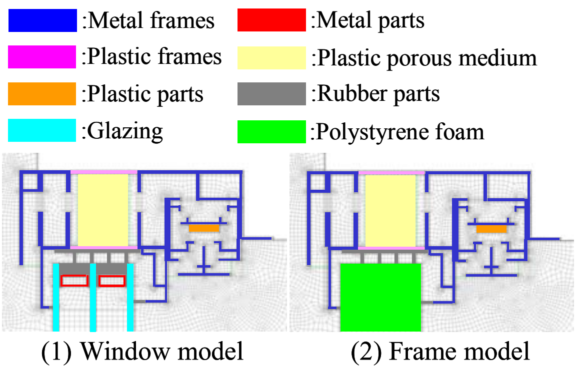

Fig. 17 Analysis conditions (DI window)
Table 4 Window specifications

Window Size: Width 1m × Height 1m
Glazing: Two panes coated Triple glazing filled with Argon gas
3-Ar16-3-Ar16-3 Ug=0.602 W/m^2K
DI inflow: 1.08-17.28 m^3/h (per frame 1m)

DI Inflow (m^3/hm)	1.08	2.16	4.32	8.64	17.28
Uf (W/m^2K)	0.201	0.105	0.056	0.033	0.011
Ψg (W/mK)	0.033	0.024	0.017	0.013	0.006
Uw (W/m^2K)	0.629	0.570	0.529	0.506	0.474

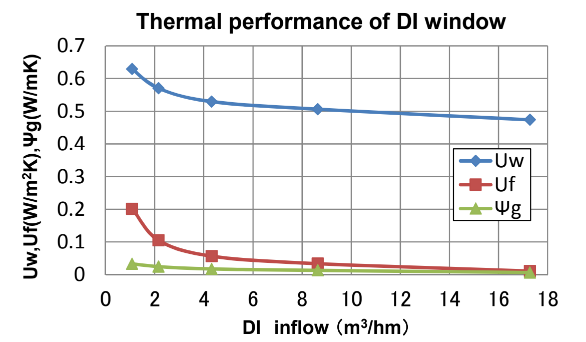

Fig. 18 Uw-value (DI window)

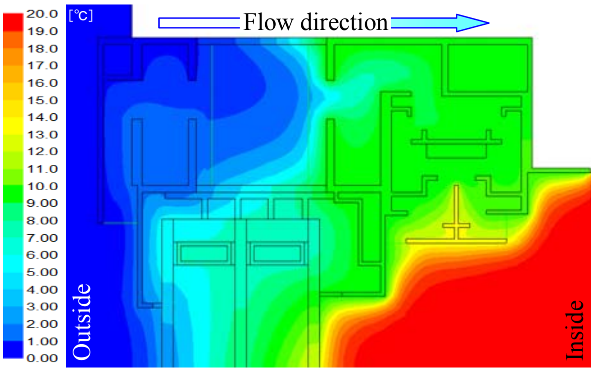

Fig. 19 Temperature contours (DI window)

CONCLUSION

In order to confirm the feasibility of the DI window frame, various insulation patterns, materials and structures were evaluated by using computational fluid dynamics.

The following results were obtained :

- When the DI window has a metal frame, a well-insulated frame is a precondition for high-level thermal performance.
- In order to secure the ventilation requirement only with a DI window, there must be more inflow than by a DI wall for a general building envelope. Thus a huge inflow brings about a reduction of heat loss from the frame, a decrease in the incoming air temperature, and the risk of condensation at the internal frame surface, because of the Uf-value is enhanced.
- Aluminum, which has a high thermal conductivity is placed on the internal side, and with more exposed surface area, the internal surface temperature and incoming air temperature could be raised.
- The DI window frame must have a metal frame with a thermal break or metal plastic comb structure, hence the following are possible: almost zero Uf frame, high incoming air temperature, high internal frame surface temperature that does not reach the dew point.
- The Uf-value of the designed DI window frame is under 0.20 $W/(m^2 \cdot K)$, Uw-value of the DI window with triple glazing is under 0.63 $W/(m^2 \cdot K)$. This is expected to reduce the heat loss from windows.

FUTURE PERSPECTIVES

The following themes will be studied in order to avoid backflow and to ventilate a stable air supply in the future:

- The effect by indoor/outdoor pressure caused by outside wind conditions
- The ventilation due to buoyancy caused by differences in indoor/outdoor temperatures
- In case of two-side-openings (when openings are installed in different directions)

ACKNOWLEDGEMENT

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