EXPERIMENTAL EVALUATION FOR THE DYNAMIC INSULATION APPLIED TO WINDOW FRAME

Shinsuke KATO[1], Sihwan LEE[*2], Kyosuke HIYAMA[1], Daisuke KAWAHARA[3]
Yoshikazu NOMURA[4], Yutaka OURA[4], Katsuhiko MORI[4], Satoshi SAWAKI[4]

1 Institute of Industrial Science, The University of Tokyo
4-6-1-Cw403, Komaba, Meguro-ku
153-8505, Tokyo, Japan

2 Department of Architecture, Tokyo University of Science
1-14-6-KS504, Kudankita, Chiyoda-ku
102-0073, Tokyo, Japan
**Corresponding author: shany@rs.tus.ac.jp*

3 Department of Architecture, The University of Tokyo
4-6-1-Cw403, Komaba, Meguro-ku
153-8505, Tokyo, Japan

4 Building Technology R&D, Sankyo Tateyama Al, Inc.
70, Hayakawa, Takaoka
933-8610, Toyama, Japan

ABSTRACT

An efficient thermal insulation of glazing or window frame is important because poor insulating performance usually cause the largest heat loss on any buildings. As one of the methods decreasing heat loss of buildings, we proposed a dynamic insulation system applied to window frame, and its energy saving performance and applicability for buliding had been confirmed using numerical simulation in previous study [1].
The aim of this study is to evaluate the thermal insulation efficiency of the proposed system by field test using experimental model houses among which we mainly focus on the dynamic insulation applied to window frame. First, the prototype of proposed system is designed to ventilate through the dynamic insulation in a window frame based on the fixed window which uses argon gas injected triple glazing. Then, we verify its thermal insulation efficiency in transient state, we constructed two experimental model houses located in Sapporo, Japan. The one of the house is installed a normal window frame with argon gas injected triple glazing coated Low-E film and the other one is installed in the proposed window frame. Finally, we evaluated the U-value of the proposed window frame by changing the ventilation rates through the dynamic insulation, after measuring the heat loss differences and the effective air leakage area to compare the airtightness and thermal insulation efficiency of two experimental model houses.
Although it could not measured the same U-value on the proposed window frame compare with the chamber test and field test unfortunately, the thermal insulation efficiency is increased by increasing ventilation rates through the dynamic insulation. The field test results show that the thermal insulation efficiency is increased approximately 89 % (U-value :1.80 $W/(m^2 \cdot K) \rightarrow 0.20$ $W/(m^2 \cdot K)$) at the experimental model house installed in the proposed window frame by increasing ventilation rates (0.00 $m^3/h \rightarrow 30.00$ m^3/h). The ventilation volume led through the DI frame by pressure differences of inner/outer space heightens the thermal insulation performance. Therefore, DI window frame is an effective means of increasing the thermal insulation efficiency in any building.

KEYWORDS

Dynamic insulation, Window frame, Airtightness, Ventilation rate, Field test

INTRODUCTION

Approximately 24 % of global energy consumption goes on the heating, ventilating and air-conditioning of residential and commercial buildings. As one of the methods to reduce heat loss in buildings, we proposed a dynamic insulation system applied to window frames (the DI window frame), the energy saving performance of which was confirmed using a numerical simulation in a previous study [1].

OBJECTIVE

The purpose of this paper is to evaluate the insulation performance of the DI window frame via a field test using experimental model houses, among which we mainly focus on the DI window frame.

METHODS

1. Specification of the experimental model house

Figure 1(a) and Table 1 show experimental model houses and the specification of these models. The constructed model has insulation performance standardized by the society of heating, air-conditioning and sanitary engineers of Japan for cold districts. These models include timber framework and feature enhanced air-tightness by pasting adhesive tapes and sheets. The thermal resistances of the wall, ceiling and floor are 3.6, 6.6 and 3.9 $m^2 \cdot K/W$ respectively.
To keep variable pressure in the model, we achieve pull ventilation by installing an exhaust sirocco fan. The ventilation air quantity is varied using an inverter and dumper in the middle of the fan and vent cap in each model. The window, which is 2.3 m^2 in size, includes an argon gas-injected triple-glazing Low-E film coating, while the DI window frame has surface inlets (Fig. 1(b)). The normal window frame in the other model has the same internal shape without allowing the passage of air for ventilation and without porous material in the frame (Fig1(d),Fig(e)). We installed the window system on the north side to control disturbance due to sunlight. Walls were also erected adjacent to the models to control the amount of solar radiation heat by considering the solar radiation calculation shown in Fig. 1(c).

2. Primary experiment for the experimental model house

(1) Air leakage test for the experimental model houses
A precise relational expression between differential pressure and the ventilation air quantity is required for a simple air leakage tester based on JIS-Z-8762, comprising a venturi tube and fan, a wall with a connecting hole and a digital manometer (NAGANO KEIKI GC15). To approximate a condition equivalent to that of airtight experimental models, we adjusted the air vent of the model with a normal window frame.

(2) Thermal insulation performance of the experimental models
To evaluate the heat loss coefficient of these models, we measured the electrical differences amount per hour in each case under steady conditions. As the heat source, we used an 800 W radiant heater, the installation of which is shown in Figure 3(a). In the experiment, we set 90 mm insulation to decrease heat loss at the door. It was assumed that all electricity consumption per hour was heat loss. The measurement was performed in December from 20:00 and we measured the electricity consumption between 9:00 and 10:00 the following

day. We considered the interior air temperature distribution to be constant because an electric fan was used to circulate the inner room air. The method used to measure the sol-air temperature here was a SAT temperature measuring instrument installed in the middle of the window.

3. Evaluation of thermal insulation efficiency

(1) Methodology

The U-value of the window frame, U_{window_frame} determines the composition between the total heat transfer coefficient (α_{out}) and the thermal resistance of the window frame including the inner total heat transfer coefficient ($r_{window\_frame+inner}$) as shown in Eq. 1.

$$U_{window\_frame} = \frac{1}{r_{window\_frame+inner} + \frac{1}{\alpha_{out}}} \tag{1}$$

where, U_{window_frame} is the U-value of the window frame [W/(m^2·K)], α_{in} is the total indoor heat transfer coefficient [W/(m^2·K)], α_{out} is the total outdoor heat transfer coefficient [W/(m^2·K)] and r_{window_frame} is the thermal resistance of the window frame [m^2·K/W].

To determine r_{window_frame}, the measurement points on the frame surface are shown in Figs. 2(a) and 3(b). We obtained the window glass heat flux (q_{window_glass}) by using heat flux meter.The total outer heat transfer coefficient, α_{out} is obtained from the heat flux and differences between the surface temeperature of the heat flux meter ($T_{s\_heatflux\_meter}$) and outer sol-air temperatures ($T_{outer\_environment}$).

$$\alpha_{out} = \frac{q_{normal\_winodow\_frame}}{(T_{s\_heatflux\_meter} - T_{outer\_environment})} \tag{2}$$

In this experiment, the total outer heat transfer coefficient of the normal window frame is regarded as that of the window frame. The heat resistance, including the inner total heat transfer coefficient, $r_{window\_frame+inner}$, is calculated by measuring the outlet air temperature ($T_{outlet\_temperature}$), outdoor temperature ($T_{s\_out\_DI\_window\_frame}$) and sol-air temperature. In addition, we also measured the total interior heat transfer coefficient α_{in}.

$$r_{window\_frame+inner} = \frac{(T_{outlet\_temperature} - T_{s\_outer\_window\_frame})}{\alpha_{out} * (T_{s\_outer\_window\_frame} - T_{outer\_environment})} \tag{3}$$

(2) Experiment method

A radiant heater is set in the model as the heat source. The air pressure of the inner room was kept lower than that of the outside by introducing an exhaust fan to avoid disturbance from outside during the measurement. Measurement was carried out overnight with minimal temperature variation due to solar radiation in August. Preparation was performed for 12 hours before the experiment and the U-value was calculated based on the room temperature remaining steady between 3 and 4 am. An electric fan circulated the interior air to ensure uniform temperature distribution in the room. The outer environment temperature measured in the middle of the window was regarded as the representative temperature of each model and the surface temperature was determined by the weighted average temperature by the 4 parts shown in Fig. 3(b) and each part has 4 points in Fig3(c).

In this study, 4 cases with different ventilation rates (0, 5, 10, 20 and 30 m^3/h) were set in the experiment to evaluate the correlation between U-value and ventilation rates. To consider heat conduction alone, we closed the opening of the DI window frame for 0 m^3/h. All the cases were measured using digital manometer. It must also be noted that the case of 5 m^3/h was actually 6.5 m^3/h due to external disturbance.

RESULTS AND DISCUSSION

1. Results of the primary experiment for experimental model houses

(1) Results of the air leakage test
Because the clearance of the model house with the DI window frame installed with an opening in a closed condition was lower than 2.0 cm^2/m^2 as the standard for cold districts in Japan, we confirmed its effective airtight performance in Table 2. Such model clearance can control the effect of disturbance and enhance the experimental quality. Figures 4(a) and 4(b) show the result of the relationship between ventilation rate and pressure difference. Based on this expression, we controlled the ventilation rates to determine the U-value shown in Table 4 in which NO type means the frame without DI system and DI type means the frame with DI.

(2) Thermal insulation performance
Table 3 shows the result of thermal insulation performance. The heat loss coefficient does not include ventilation load. The heat loss of a normal window frame model is 20 W more than that of a model house with the DI window frame. This result shows how insulation performance varies depending on the construction.

2. Evaluation results of thermal insulation efficiency

Figure 5(a)-(d) show the surface temperature of window frames as taken by an infrared camera under 6 am. Compared with the considerable temperature difference between the case of 0 m3/h and the other case (6.5 m^3/h, 10.3 m^3/h, 20.0 m^3/h), the surface temperature of the DI window frame was much closer to the outdoor sol-air temperature, which confirmed far lower heat loss in qualitative terms in the DI window frame. And we confirm the temperature differences between upper parts and lower parts. The more quantity of ventilation, the closer temperature differences between the upper and lower part. In case of the 6.5 m^3/h, the difference is measured approximately 6 ^{o}C between the upper and the lower parts because of buoyancy. And estimation of the u-value of DI window frame in case of 30 m^3/h is impossible because outer environment temperature and temperature of outer DI window frame are almost equal. It means the measurement of the heat flux is not possible under this condition.

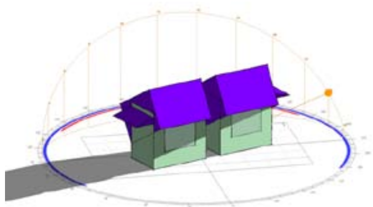
CONCLUSION

This paper described the insulation performance of the DI window frame using an experiment, when the frame model was applied to real buildings. Consequently, we confirmed that the difference in insulation performance between a model with a normal frame and with the DI window frame was approximately 20 W depending on the construction. In addition, we verified the efficiency of a DI window frame applied to an experimental model house by changing the ventilation rates.
The result shows that the U-value of the DI window frame decreases with increasing ventilation air rates and becomes approximately 0 W/(m^2·K) in case of 30 m^3/h. Besides, the primary consideration in terms of the actual ventilation air rates through the DI window frame should be estimated based on the air leakage area, which is approximately half the measured

value. As for the future problems to be solved, we must verify the effect of the DI window frame when its air exchange rate is 0.5 1/h.

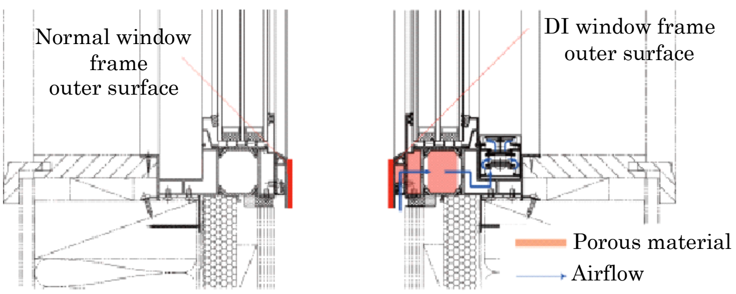
Part		Specification
Outside	Roof	Colored steel sheet, Asphalt roofing
		Structural plywood t = 9 [mm]
	Wall	Siding
	Window frame	DI window frame W1,690×H1,370
		Normal window frame W1,690×H1,370
	Door	W1,870×H730, U-value : 1.23 [W/(m^2·K)]
	Insulation	Ceiling: Wood fiber t=250 [mm]
		Wall: Wood fiber t=140 [mm]
		Floor: Wood fiber t=250 [mm]
	Vapour barrier	Ceiling: Airtight moisture-proof
		Wall: Airtight moisture-proof
		Floor: Airtight moisture-proof
Inside	Ceiling	PB t = 9.5 [mm]
	Wall	PB t = 9.5 [mm]
	Floor	Structural plywood t=24 [mm]

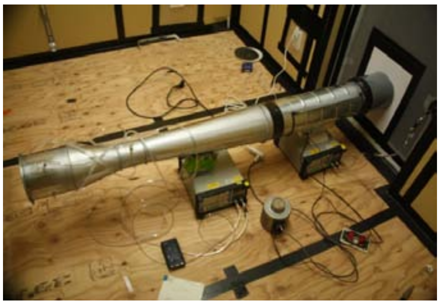
Table 1. Specification of experimental model house



(a) Experimental model houses (b) Opening of DI window frame (c) Solar radiation calculation

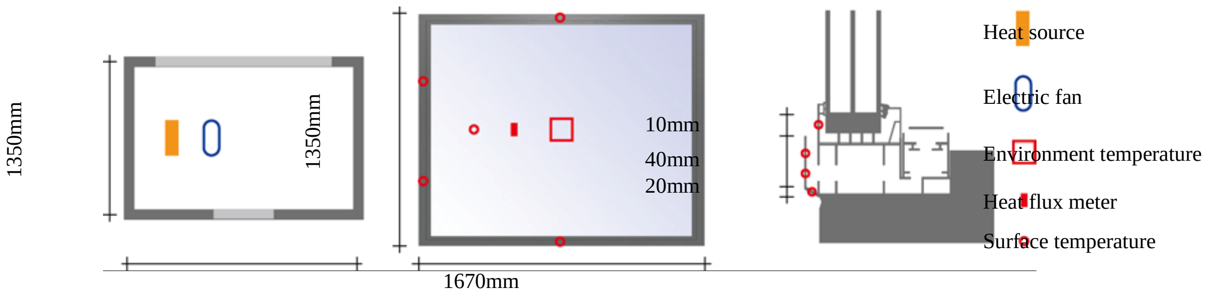
Figure 1. Experimental model house and detail of the DI window frame





(a) Normal window frame and DI window frame (b) Air-leakage tester

Figure 2. Compare with normal window frame and DI window frame, and air-leakage tester

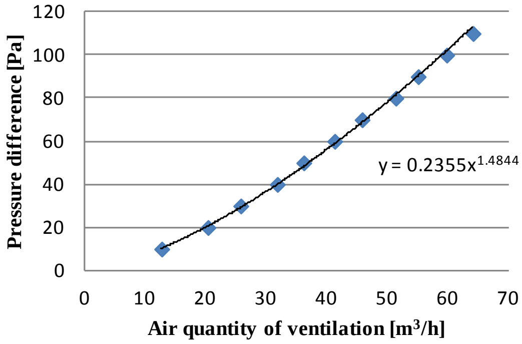


(a) Position of the heater (b) Measured parts (c) Measured points on window frame

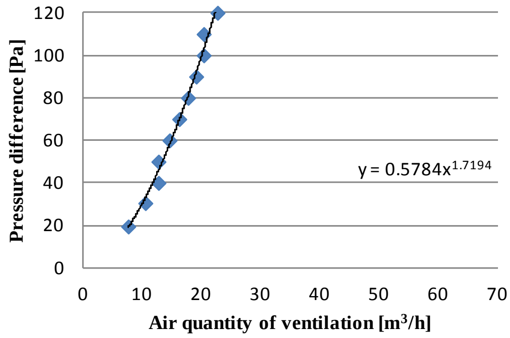
Figure 3. Compare with normal window frame and DI window frame, and air-leakage test

	Ventilation rates (9.8Pa)	**Air leakage area**
Closed the opening of the DI winodw frame	5.24 [m^3/h]	3.6 [cm^2]
Opened the opening of the DI window frame	12.33 [m^3/h]	8.4 [cm^2]
Closed the opening by sheet	1.58 [m^3/h]	1.1 [cm^2]

Table 2. Result of air leakage test



(a) Opened the opening of the DI window frame

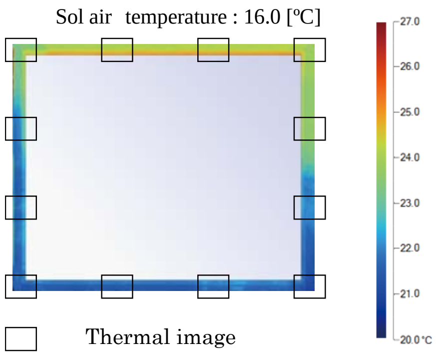


(b) Closed the opening of the DI window frame

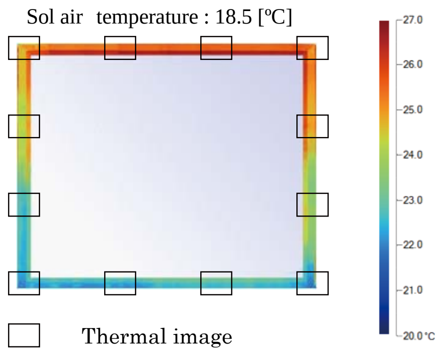
Figure 4. Relation of ventilation rates and pressure difference

	Electrical consumption	**Inner temperature**	**Sol-air temperature**	**Coefficient of heat loss without ventilation load**
Model house installed normal window frame	670 [W]	46.0 [˚C]	-1.28 [˚C]	2.85 [$W/m^2 \cdot K$]
Model house installed the DI window frame	650 [W]	41.7 [˚C]		3.04 [$W/m^2 \cdot K$]

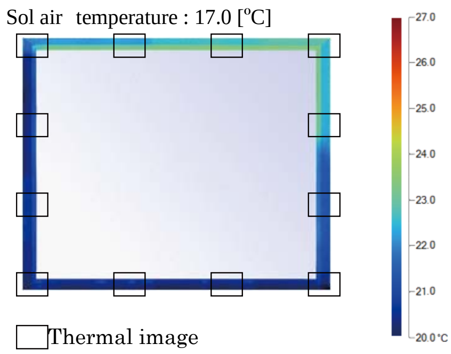
Table 3 : Measurement results of thermal insulation performance



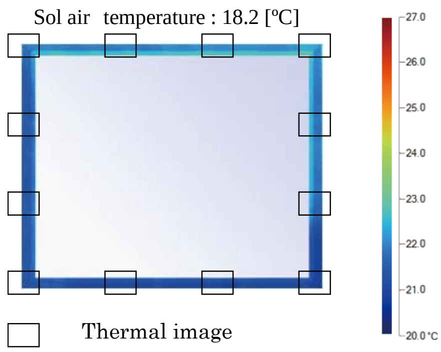
(a) Surface temperature of the window frame air quantity of ventilation is 0 m^3/h



(b) Surface temperature of the window frame air quantity of ventilation is 6.5 m^3/h



(c) Surface temperature of the window frame air quantity of ventilation is 10.3 m^3/h



(d) Surface temperature of the window frame air quantity of ventilation is 20.0 m^3/h

Figure 5. Compare with surface temperature

Type	Ventilation rates	Total heat transfer coefficient		U-value of the window frame
		Inner surface	Outer surface	
NO	0 [m^3/h]	13.5 [W/(m^2·K)]	14.5 [W/(m^2·K)]	2.34 [W/(m^2·K)]
DI	0 [m^3/h]	12.4 [W/(m^2·K)]	15.5 [W/(m^2·K)]	1.80 [W/(m^2·K)]
DI	6.5 [m^3/h]	14.3 [W/(m^2·K)]	14.3 [W/(m^2·K)]	1.17 [W/(m^2·K)]
DI	10.3 [m^3/h]	14.8 [W/(m^2·K)]	18.8 [W/(m^2·K)]	0.96 [W/(m^2·K)]
DI	20.0 [m^3/h]	12.4 [W/(m^2·K)]	15.8 [W/(m^2·K)]	0.20 [W/(m^2·K)]
DI	30.0 [m^3/h]	4.8 [W/(m^2·K)]	21.4 [W/(m^2·K)]	--- [W/(m^2·K)]

Table 4. Result of thermal insulation performance

ACKNOWLEDGEMENTS

This study was made possible by the financial support received from the Ministry of the Environment, Japan. Moreover, we would like to thank the staff of Sankyo Tateyama Aluminium. Inc., J Architecture System. Inc., and Tsuchiya Hometopia. Inc. for their generous cooperation.

REFERENCES

[1] S. Lee, M. Tanaka, S. Kato. 2010. *The evaluation of the thermal insulation efficiency at the proposed window frames - Dynamic Insulation System applied to Window Frames (Part1)*, Air Infiltration and Ventilation Centre, AIVC2010, Seoul, Korea.

[2] M. Tanaka, S. Lee, S. Kato. 2010. *Energy saving effects of the proposed system on the residential buildings - Dynamic insulation system applied to window frames (Part 2)*, Air Infiltration and Ventilation Centre, AIVC2010, Seoul, Korea.

[3] A.Dimoudi, A.Androutsopoulos, S.Lykoudis. 2004. *Experimental work on a linked, dynamic and ventilated, wall component*, Energy and Buildings Vol.36, 443–453.

[4] M.S.Imbabi. 2006. *Modular breathing panels for energy efficient, healthy building construction*, Renewable Energy Vol.31, 729–738.

[5] Dalehaug Arvid, Fukushima Akira, Honma Yoshinori. 1993. *Dynamic insulation in a wall*, Report Collection of Architectural Institute of Japan, No.66, 261–264.

[6] J.M.Wong, F.P.Glasser, M.S.Imbabi. 2007. *Evaluation of thermal conductivity in air permeable concrete for dynamic breathing wall construction*, Cement & Concrete Composites Vol.29, 647–655.

[7] Guohui Gan. 2000. *Numerical evaluation of thermal comfort in rooms with dynamic insulation*, Building and Environment Vol.35, 445–453.

[8] S. Kato, K. Kuroki, S. Hagihara. 2007. *Method of in-Situ measurement of thermal insulation performance of building elements using infrared camera*, 6th International Conference on Indoor Air Quality, Ventilation & Energy Conservation in Buildings.