ENERGY SAVING AND THERMAL COMFORT IN RESIDENTIAL BUILDINGS WITH DYNAMIC INSULATION WINDOWS

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ABSTRACT

To realize the concept of low-energy buildings, an increase in the thermal insulation performance of building parts, especially the openings that show poor insulation performance, is necessary. In addition, an adequate level of thermal comfort is also needed within residential buildings. We have developed window-applied dynamic insulation (DI), and verified thermal insulation performance in chamber and field tests. The purpose of this study is to verify the thermal comfort level within residential buildings using DI windows, via measurements obtained from an equivalent temperature-calculated thermal manikin, and to verify energy consumption values in consideration of disturbances by dynamic simulation. The thermal comfort evaluation results showed that, with DI window installation, the equivalent room temperature decreased to approximately 5% of the temperature difference between the exterior and interior. This implies that the effect of the DI window on thermal comfort was small. The dynamic simulation results also showed that the energy consumption reduction reached a value of 2% during a 3-month period at a cold region (Sapporo) in Japan.

KEYWORDS

Dynamic insulation, thermal comfort, ventilation, energy savings, windows

1 INTRODUCTION

There is an urgent demand worldwide for the construction of low-energy buildings. Designs for low-energy buildings generally require thicker walls or the use of thermal insulation. However, these methods have drawbacks, such as decreased floor space and high costs. Dynamic insulation (DI) systems are gaining prominence because they can mitigate such problems and provide effective ventilation. A cross section of a DI window is shown in Figure 1. A DI system has a heat recovery mechanism that uses the airflow produced by the pressure difference between the interior and exterior of a room. This airflow transports into the room heat that would otherwise be lost, because the airflow direction is opposite to that of heat loss. In previous studies of DI systems, Baily (1987), Qiu (2007), Gan (2000), and Imbabi (2013) focused on walls. However, a few studies applied DI systems to building parts other than walls.

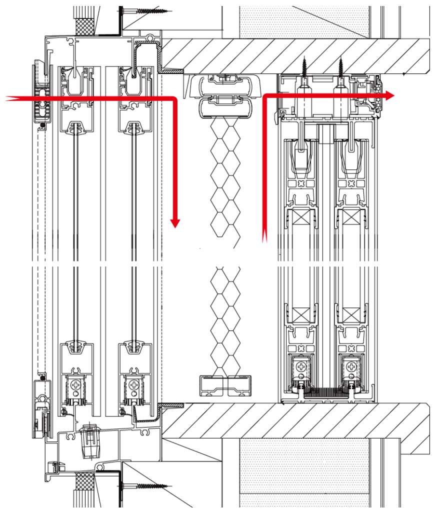


Figure 1: Cross section of a DI Window

Because building openings generally have a low thermal insulation performance, we produced a DI window prototype and used it in an existing building, and we verified its thermal insulation performance (0.73 W/m^2K) using a chamber test.
The temperature of a DI windows' inner surface decreases during the winter, due to the passage of air through the window. For this report, we evaluated the thermal comfort in a residential building with DI windows installed, because the air inlet of DI windows are set at a relatively lower position than vent holes. The experimental model house is located in Sapporo, Hokkaido, which is a cold region in Japan. This residence is an existing house for which the thermal insulation performance and airtightness were improved during the winter of 2012. The thermal comfort evaluation criterion was equivalent temperature, which is based on local drift and air temperature. Table 1 shows the cases for four standards: position, clothes, ventilation type, and ventilation amount. These variables will be described in more detail in the following section. We measured the local equivalent temperature using a thermal manikin in the winter of 2014. The indoor air temperature was set to approximately 20°C–22°C, which is the daily average interior temperature range in this area. We also simulated the differences in energy consumption and comfort as compared to fixed insulation, and then evaluated these differences in relation to the additional costs for a DI window.

2 THERMAL COMFORT ANALYSIS

The ventilation inlet of the DI window is in a relatively low position, although the general ventilation inlet is arranged in a higher position. In this study, we measured thermal comfort by using a thermal manikin and compared the general vent cap to the DI window.

2.1 Measurement

To verify the effects of DI windows on thermal comfort, we utilized a thermal manikin. The manikin has a total of 16 body parts, as shown in Figure 2, which control the surface temperature and heat flux. The heat regulation mode of the manikin that controlled surface temperature satisfied the below thermal neutral equation:

$$\Theta_i = 36.4 - 0.054Q_i \quad (1)$$

where Θ_i (°C) is the area-weighted average surface temperature of a certain part *i*, and Q_i (°C) is the area-weighted average heat flux on a certain part *i*. An index of this measurement, equivalent temperature $\Theta_{eq,i}$ (°C) as defined by ISO 14505-2 2006, is stated as the "temperature of a homogenous space, with mean radiant temperature equal to air temperature and zero air velocity, in which a person exchanges the same heat loss by convection and radiation as in the actual conditions under assessment" (ISO 13731). The associated equation is shown below:

$$\Theta_{eq,i} = \Theta_i - Q_i / \alpha_i \quad (2)$$

where α_i (W/m^2K) is the area-weighted average total heat transfer coefficient on a certain part *i*.
A measurement in which the thermal manikin is nude effectively evaluates the draft from the DI window, and another measurement in which the thermal manikin is clothed evaluates thermal comfort in a normal mode of life.

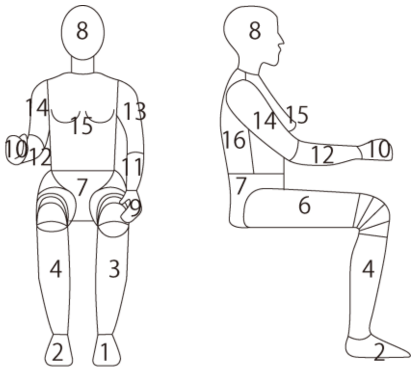


Figure 2: Thermal manikin parts

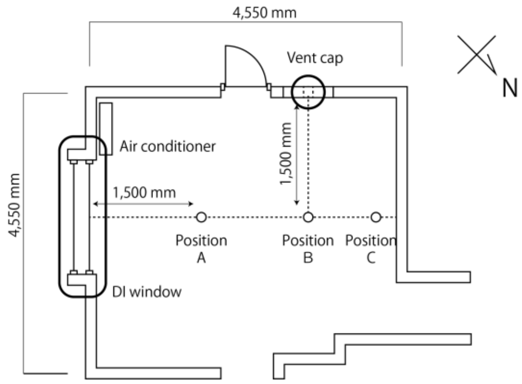


Figure 3: Position of the thermal manikin within the room

Note: 1:Left foot, 2:Right foot, 3:Left leg, 4:Right leg, 5:Left thigh, 6:Right thigh, 7:Pelvis, 8:Head, 9:Left hand, 10:Right hand, 11:Left forearm, 12:Right forearm、13:Left shoulder, 14:Right shoulder, 15:Chest, 16:Back

Figure 3 shows the position of the thermal manikin within the room; position A is 1.5 m, position B is 3 m, and position C is 4 m from the DI window. Table 1 shows measurement cases, which study the equivalent temperature changes based on the following effective factors: position, ventilation type, and ventilation amount. The measurements were carried out in January of 2004 in Sapporo, Hokkaido. The exterior temperature ranged from -5.1°C to -2.1°C during the measurement period, and the interior room temperature was approximately 20°C with utilization of an air conditioner. However, the indoor room temperature fluctuated because of changes in the exterior temperature and solar radiation. The temperature of the interior environment, prior to measurements, ranged from 19°C to 20°C.

Table 1: Measurement cases (°C).

	15th Jan		16th Jan				17th Jan			
Position		B	A	B	B	C	A	B	B	C
Ventilation type	DI	DI※	DI	D	General	DI	DI※	DI※	General※	DI※
Ventilation amount	0 m^3/h		0.5 ACH				0.5 ACH			

※denotes the addition of clothes (=approximately 0.6 clo)

Table 2. Measurement equipment

Sensor	Type	Range	Accuracy
Surface temperature Inlet air temperature	Thermocouple type T	-200°C to 400°C	±1.0
Pressure difference between interior and exterior	SDP1000-L025	-62 Pa to 62 Pa	0.5% FS /1.5% m.v.
Data logger	GRAPHTEC mini logger GL 820		

The measurement results are shown in Figures 4 to 7 and the measurement conditions are shown in Tables 2 and 3. The equivalent temperature with DI window installation decreased to approximately 5% of the temperature difference between the room interior and exterior, regardless of whether the manikin was clothed or nude, showing that the effect of the DI window on thermal comfort was minor.

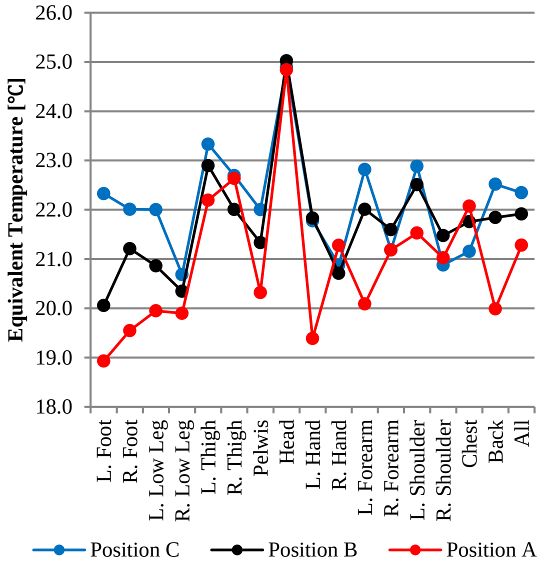


Figure 4: Equivalent Temperature "nude-position"

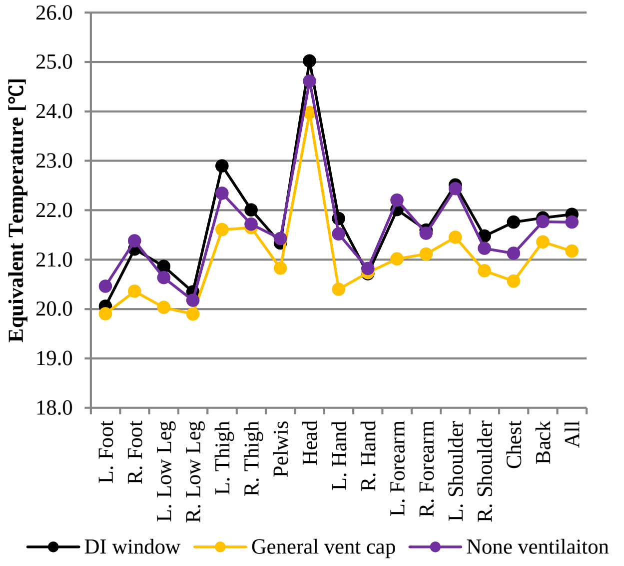


Figure 5: Equivalent Temperature "nude-ventilation type"

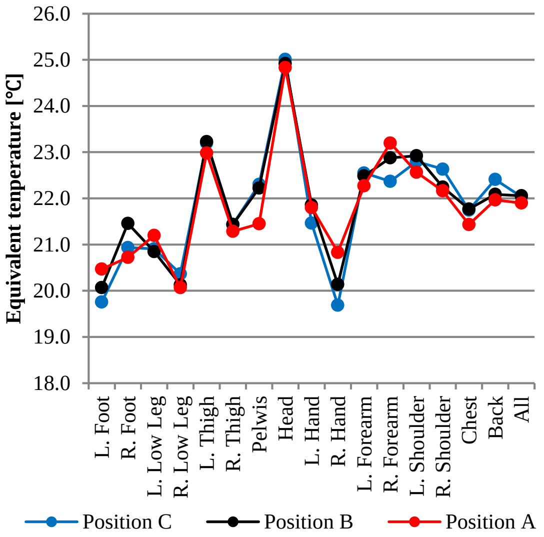


Figure 6: Equivalent Temperature "cloth-position"

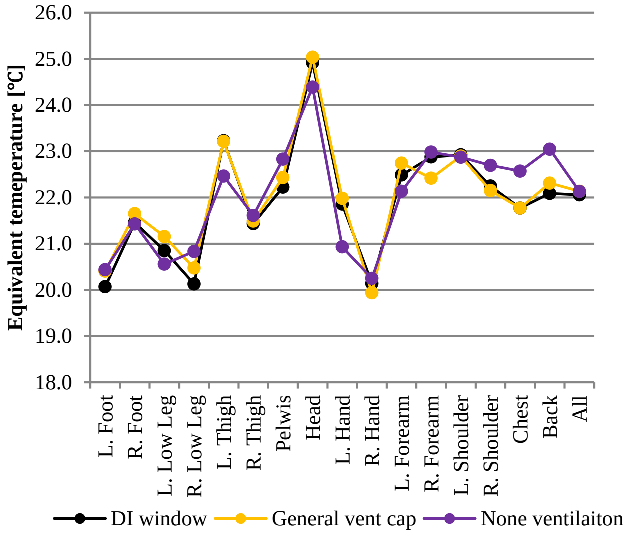


Figure 7: Equivalent Temperature "cloth-ventilation type"

Table 2: Measurement Condition "nude"

	Position A	Position B	Position C	Position B
Ventilation type	DI window	DI window	DI window	General vent cap
Ventilation air amount (m^3/h) (Standard deviation)	20.8 (1.1)	19.6 (3.0)	21.2 (0.3)	21 注 2
Inlet air temperature (℃) (Standard deviation)	22.3 (0.8)	23.0 (0.4)	7.7 (0.1)	-4.9 (0.1)
Exterior temperature (℃)	-3.3 (0.2)	-2.1 (0.1)	-2.9 (0.1)	

Table 3. Measurement Condition "cloth"

	Position A	Position B	Position C	Position B
Ventilation type	DI window	DI window	DI window	General vent cap
Ventilation air amount (m^3/h) (Standard deviation)	21.6（0.4）	21.2（0.4）	21.0（0.6）	21 注 2
Inlet air temperature (℃) (Standard deviation)	10.0 (1.5)	12.8 (0.5)	7.2 (0.2)	-4.8 (0.1)
Exterior temperature (℃)	-5.6 (0.1)	-3.7 (0.1)	-3.7 (0.1)	

3 DYNAMIC SIMULATION FOR ENERGY SAVINGS

3.1 Dynamic simulation conditions

We also simulated differences in energy consumption and comfort as compared to static insulation, and then evaluated these results in relation to the additional cost of DI windows. The thermal insulation performance of DI windows depends on airflow amount, which is determined by the temperature difference between the interior and exterior of the room, and the outdoor wind velocity. In consideration of disturbances by dynamic simulation, we used TRAFlow as based on COMIS 3.1, which is an add-on program of TRNSYS. The model we used was a standard Japanese residential building, as shown in Figure 8.

The simulation conditions were determined by a number of reports and measurement data. In this study, the clearances of the DI window and residential building were both 60 cm^2, and the clearance was partitioned into major sections. The partition ratios, as reported by Seiichi et al. (2001), were 39% for the building frame, 28% for the opening, and 33% for the ventilation equipment. In this study, the clearance of the residential building limits building frame and ventilation, because the clearance of the DI window, including that around the window frame, was made so purposely. The air link in the residential building is shown in Figure 10. In the case with DI window installation, one ventilation fan in an attic space exhausted 120 m^3/h to the exterior, and two ventilation fans in the restrooms exhausted a total of 40 m^3/h, which were ineluctable ventilation amounts in the residential building. On the other hand, in the case with general window installation, the air change rate was 0.5ACRand this ventilation was present in each room. To simulate the ventilation under practical conditions, wind pressure coefficients were determined through reports by Shin-ichi et al. (1994). There were no internal loads and ventilation control, and the regression equation used in this simulation, which determines thermal insulation performance, assumed a DI window with blind installation. The thermal performance of the residential building is shown in Table 4. The positions of the DI windows were arranged at the four points of the compass, as shown in Figure 9. The diagram of airflow direction shows in Figure 10.

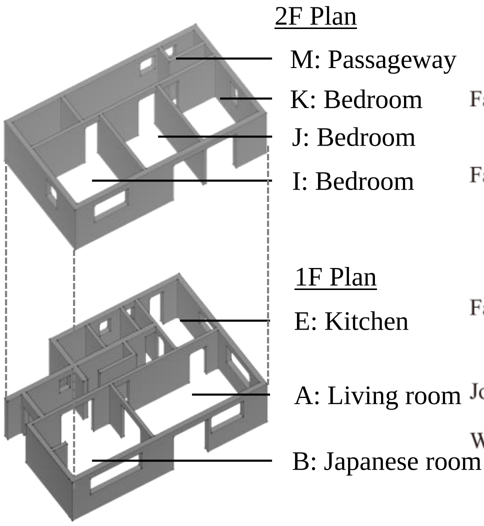


Figure 8: Diagram of a standard residential building.

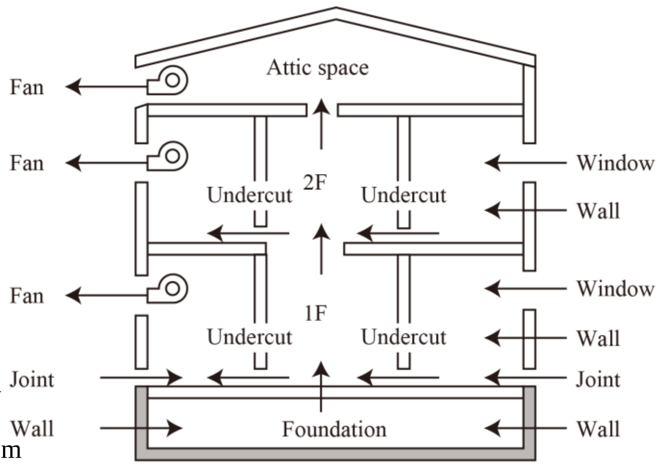


Figure 9: Diagram of airflow direction.

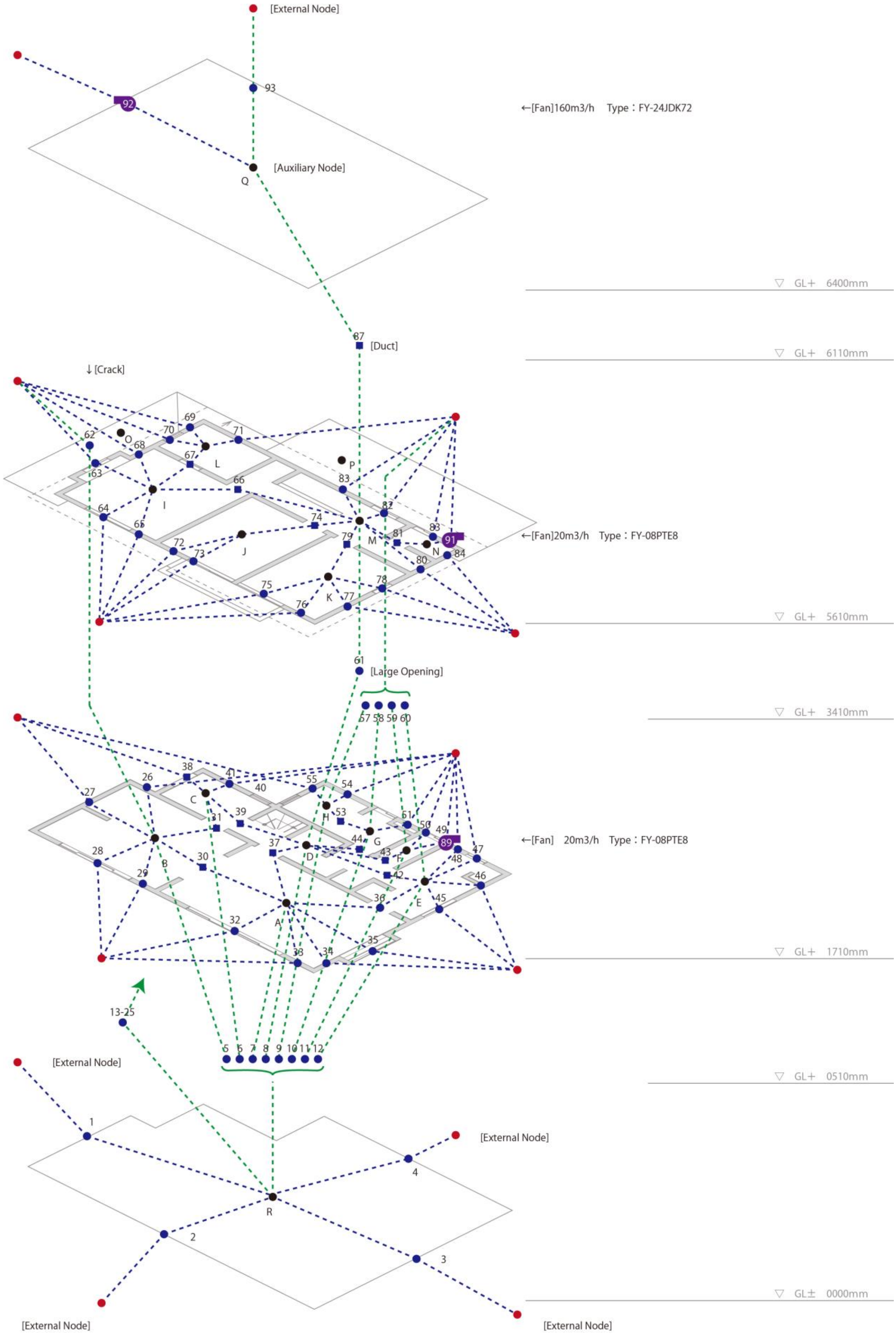
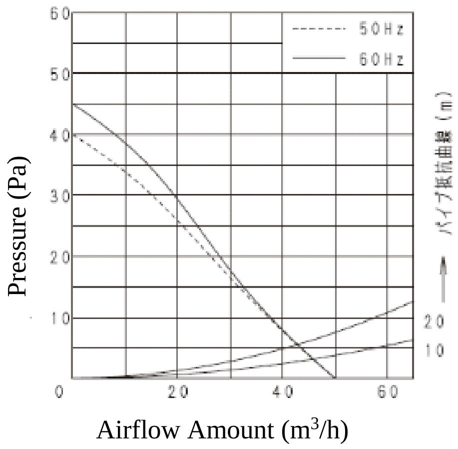


Figure 10: Air link of a residential building



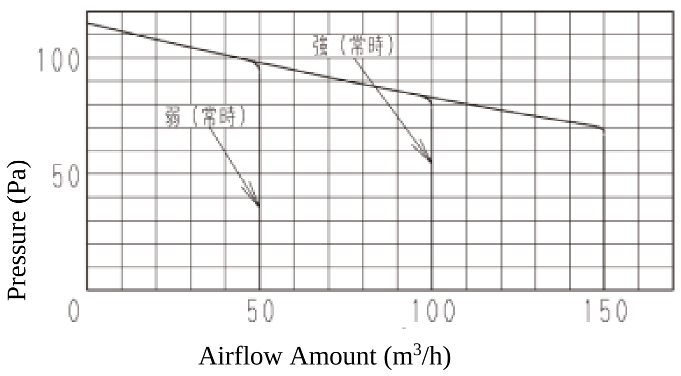


Figure 11: Data from the fan located in the rest room

Figure 12: Data from the fan located in the attic space

Table 4: The simulated thermal performance of the residential building

Building parts		Thermal performance [W/m^{2}K]
Wall	External	0.254
	Internal	3.583
Ceiling		0.167
Floor		0.208
Window		1.240

Table 5: Conditions of residential building clearance

	Building Parts	Percentage of total clearance [%]		[%]		[%]
Clearance of the residential building	Wall	2.10	North 1F	0.33	B	0.03
					C	0.08
					H	0.05
					G	0.05
					F	0.03
					E	0.08
			North 2F	0.3	N	0.06
					M	0.16
					L	0.09
			South 1F	0.33	B	0.14
					A	0.19
			South 2F	0.3	I	0.12
					J	0.09
					K	0.09
			East 1F	0.24	E	0.12
					A	0.12
			East 2F	0.22	N	0.04
					M	0.04
					K	0.15
			West 1F	0.23	H	0.06
					C	0.06
					B	0.11
			West 2F	0.17	L	0.06
					I	0.12
	Ceiling	1.29	Q			0.99
			P			0.18
			O			0.12
	Floor	0.39	A			0.12
			B			0.09
			C			0.03
			D			0.05

			E			0.05
			F			0.01
			G			0.02
			H			0.02
	Joint between foundation and floor	50.37	North	14.85	B	1.24
					C	3.71
					H	2.47
					G	2.47
					F	1.24
					E	3.73
			South	14.85	B	6.46
					A	8.39
			East	10.33	E	5.17
					A	5.17
			West	10.33	H	2.58
					C	2.58
					B	5.17
Ventilation Equipment	Kitchen	45.84				45.8

3.2 Dynamic simulation results

Figures 13 and 14 show the energy consumption reduction in a 3-month period, from January to March. The reduction rate in Sapporo (a cold region) and Tokyo are 2% and 1%, respectively. The energy consumption of Sapporo was higher than that of Tokyo, because the heat loss was proportional to the temperature difference between the room exterior and interior.

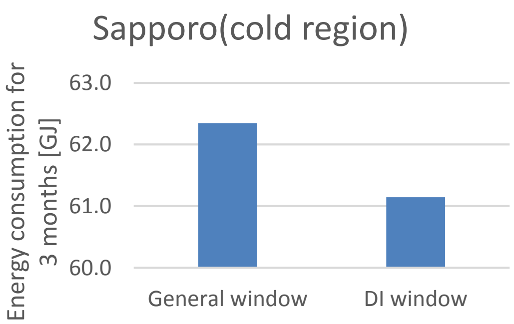


Figure 13: Energy consumption in Sapporo

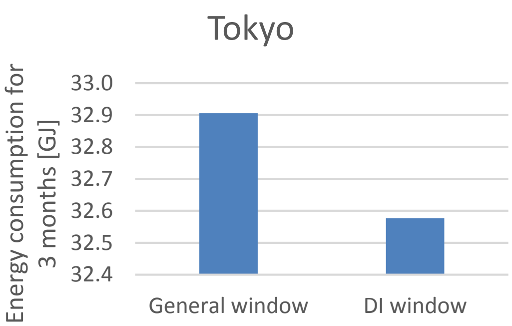


Figure 14: Energy consumption in Tokyo

4 CONCLUSIONS

To verify the thermal comfort of residential buildings using DI windows and energy consumption reduction, we performed various measurements and a dynamic simulation. The result of the thermal comfort measurements showed that the equivalent temperature decreased to approximately 5% of the temperature difference between the room interior and exterior. This suggests that the effect of the DI window on thermal comfort was minor. As well, the dynamic simulation results show that the energy consumption reduction was 2% during 3 months in a cold region in Japan.

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