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Analysis of building energy savings potential for metal panel curtain wall building by reducing thermal bridges at joints between panels

Jung-Min Oh[a], Jin-Hee Song[a], Jae-Han Lim[a], Seung-Yeong Song[a,]*

[a] *Department of Architectural Engineering, Ewha Womans University, 52 Ewhayeodae-gil, Seodaemun-gu, Seoul 03760, South Korea*

Abstract

To achieve national greenhouse gas reduction in the building sector, heating and cooling energy in buildings should be reduced. The government has strengthened regulations on insulation performance for building energy savings. However, the building envelope has various thermal bridges. In particular, a metal panel curtain wall comprises a number of thermal bridges at joints between the panels and the fixing units, thus degrading the overall thermal performance. To reduce building energy, it is necessary to reduce thermal bridges in building envelopes. This study aims to analyze the energy saving potential achieved by reducing thermal bridges. For this, the insulation performance and building energy needs of the existing and alternative metal panel curtain wall were evaluated. The alternative metal panel curtain wall that uses plastic molds at joints between panels and the thermally-broken brackets was suggested to reduce heat loss through thermal bridges. As results, the effective U-value of the alternative metal panel curtain wall was reduced by 72% compared with the existing metal panel curtain wall. In addition, annual heating energy needs of the alternative metal panel curtain wall building was reduced by 26%, and annual total energy needs was reduced by 6% because annual cooling energy needs of it slightly increased compared with the existing metal panel curtain wall. In conclusion, the alternative metal panel curtain wall considerably influenced the savings in building energy needs by reducing thermal bridges.

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Keywords: Metal Panel Curtain Wall; Thermal Bridge; Linear Thermal Transmittance; Building Energy

* Corresponding author. Tel.: +82-2-3277-3913; fax: +82-2-3277-2437.
E-mail address: archssy@ewha.ac.kr

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Nomenclature

U_{eff}	Effective U-value $[W/(m^2K)]$
q_{tot}	Total heat loss [W]
A_e	External surface area $[m^2]$
T_i	Indoor temperature [℃]
T_o	Outdoor temperature [℃]
R_{cavity}	Thermal resistance of cavity $[(m^2K)/W]$
Δq	Additional heat transfer coefficient due to the thermal bridge [W/K]
Ψ	Linear thermal transmittance [W/(mK)]
l_{TB}	Length over which the value Ψ applies [m]
L_{2D}	Thermal coupling coefficient obtained from a 2-D calculation of the component separating the two environments [W/(mK)]
U	U-value $[W/(m^2K)]$
l	Length over which the value U applies [m]
Ψ_{P-P}	Linear thermal transmittance between panels [W/(mK)]
U_{wall}	U-value of the panel $[W/(m^2K)]$
l_{wall}	Length over which the value U_{wall} applies [m]
Ψ_{P-W}	Linear thermal transmittance between the panel and the window [W/(mK)]
U_{frame}	U-value of the frame $[W/(m^2K)]$
l_{frame}	Length over which the value U_{frame} applies [m]
$U_{glazing}$	U-value of the glazing $[W/(m^2K)]$
$l_{glazing}$	Length over which the value $U_{glazing}$ applies [m]
Ψ_{F-G}	Linear thermal transmittance between the frame and the glazing [W/(mK)]

1. Introduction

The Paris Agreement will be effective by 2020 according to the 2015 United Nations Climate Change Conference of the Parties. At the Cabinet meeting conducted in South Korea in June 2015, it was decided to reduce greenhouse gas emissions to 37% compared to business as usual (BAU) by 2030. To help achieve a national target of greenhouse gas reduction in the building sector, heating and cooling energy savings is as a major goal, and the government has reinforced insulation regulations, which mandate a strengthened U-value. Other countries around the world are also facing similar situations. However, various thermal bridges occur in actual building envelopes. Despite strengthening a required U-value, it is often the case that the actual insulation performance does not live up to the required U-value because the U-value, which assumes one-dimensional heat transfer, cannot reflect the multidimensional heat transfer through thermal bridges. Thus, it is essential to reduce thermal bridges to reinforce the actual insulation performance of building envelopes.

Meanwhile, easy-to-install metal curtain walls are increasingly used because high-rise buildings are becoming more common. A large number of thermal bridges occur in metal curtain walls because a multitude of metal materials with an extremely high thermal conductivity are installed in the walls. Although metal panel curtain walls use insulation-embedded metal panels, which cover insulation materials with metals as major exterior wall materials, and are widely adopted in buildings in general because they are easy to install and affordable, it is necessary to address a thermal bridge issue because multiple thermal bridges repeatedly occur in metal panel joints and significantly reduce the insulation performance. In this regard, this study aims to make suggestions to reduce thermal bridges in joints between metal panels and evaluate the effects of the alternative metal panel curtain wall on energy reduction compared with existing metal panel curtain wall. To accomplish this, this study used Physibel TRISCO v.12.0w [1], conducted a three-dimensional steady-state heat transfer simulation on a typical external wall area of the existing and alternative metal panel curtain walls, calculated the effective U-value, and compared and evaluated the insulation performance. On a 10-story office building in which the existing and alternative metal panel curtain walls were applied, the study used DesignBuilder v4.5 [2], carried out dynamic energy simulations, calculated annual heating and cooling energy needs, and compared and evaluated them.

2. Literature review

Many existing studies have examined insulation performance in consideration of thermal bridges and their on the total energy of a building. Regarding studies that examined insulation performance in consideration of thermal bridges, Koo et al. [3] looked into the effects of thermal bridges on the insulation performance of curtain walls based on the ratio of metal parts in the walls, whereas Song et al. [4] divided building envelopes into various types, conducted a three-dimensional heat transfer simulation, calculated the effective U-value, and evaluated the actual insulation performance affected by thermal bridges. Regarding studies that examined the effects of thermal bridges on the total energy of a building, Song et al. [5] applied linear thermal transmittance to parts in which thermal bridges occurred and evaluated the effects of removing thermal bridges and increasing the thermal capacity in apartment houses with an external insulation system as opposed to an internal insulation system in terms of the savings in annual heating and cooling energy. Shin et al. [6] used the effective U-value that reflects the impact of thermal bridges and evaluated the annual energy performance of a curtain wall office building. Kim et al. [7] conducted three-dimensional simulation on parts with thermal bridges, calculated the effective U-value, and then applied the value to dynamic building energy simulations and evaluated the annual energy performance of apartment houses. In addition, Ascione et al. [8] calculated the U-value based on approaches to thermal bridges and then applied the value to the dynamic building energy simulation and analyzed differences in thermal behavior depending on the modeling method. Martin et al. [9] introduced the homogeneous multilayer equivalent wall, which behaved similar to thermal bridges, and reflected thermal bridge effects on the building energy simulation. Thus far, however, there seems to have been few studies that examine ways to reduce thermal bridges in metal panel joints and analyze their energy-saving effects.

3. Comparison of Insulation Performance Based on Three-dimensional Heat Transfer Simulation on a Typical External Wall Area

3.1. Outline of Alternative Metal Panel Curtain Wall

To install metal panel curtain walls, cross or vertical steel trusses are usually fixed on the floor slab, and then insulation-embedded metal panels are fixed to the steel trusses with H-shaped aluminum brackets. The front and rear of insulation of metal panels are made of steel sheets, whereas the insulation sides are wrapped and manufactured by an aluminum mold that has bracket insertion slots. Sometimes, a polyurethane thermal breaker (Azon) is inserted into the aluminum mold to reduce thermal bridges. Because metal panels are installed repeatedly from top to bottom and left to right, joints between metal panels where aluminum molds are installed become linear thermal bridges, which occur over and over again. Aluminum brackets that fix metal panels to steel trusses become point thermal bridges. The alternative metal panel curtain wall that improves on the aforementioned existing metal panel curtain wall aims to reduce lineal thermal bridges that occur repeatedly in metal panel joints by replacing the existing aluminum molds where a polyurethane thermal breaker (Azon) is inserted with the acrylonitrile butadiene styrene (ABS) plastic molds that have lower heat conductivity and stronger structural strength. In addition, the alternative metal panel curtain wall attempts to reduce point thermal bridges that occur in some metal panel joints by applying an insulated bracket with an inserted polyurethane thermal breaker (Azon) instead of the existing H-shaped aluminum bracket. Table 1 describes the existing and alternative metal panel curtain walls, and Table 2 and 3 show the existing and alternative molds and brackets.

Table 1. Descriptions of the existing and alternative metal panel curtain walls

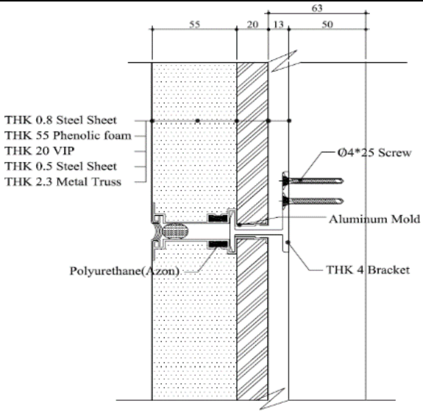
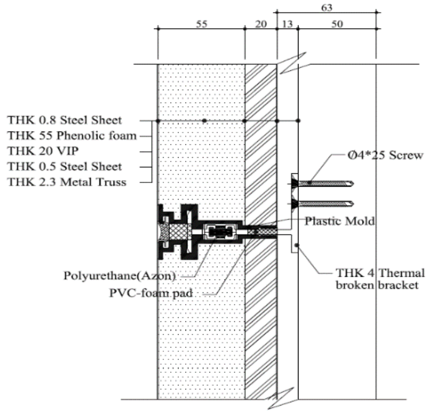
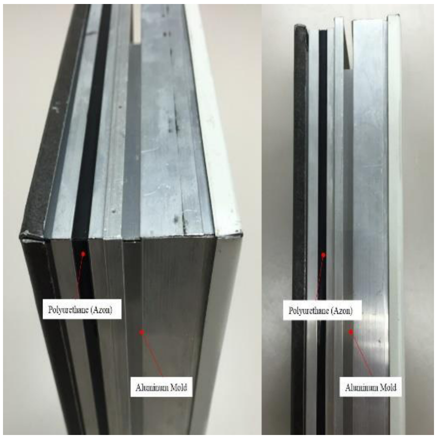
(a) Existing Metal Panel Curtain Wall	(b) Alternative Metal Panel Curtain Wall
Aluminum mold with an inserted polyurethane thermal breaker	ABS plastic mold (reducing linear thermal bridges)
Aluminum bracket	Aluminum bracket with an inserted polyurethane thermal breaker (reducing point thermal bridges)
	
	

Table 2. The existing and alternative molds for metal panels

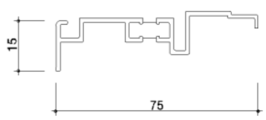
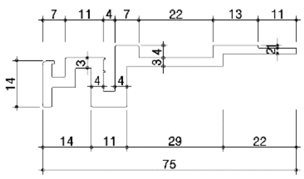
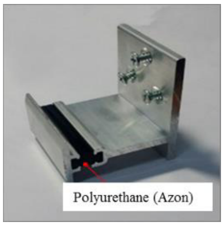
(a) Existing Mold	(b) Alternative Mold
Aluminum mold with an inserted polyurethane thermal breaker	ABS plastic mold (reducing linear thermal bridges)
	

Table 3. The existing and alternative aluminum brackets

(a) Existing Bracket	(b) Alternative Bracket (thermal-broken bracket)
Aluminum bracket	Aluminum bracket with an inserted polyurethane thermal breaker (reducing point thermal bridges)
	

3.2. *Outline of Insulation Performance Comparison*

(1) Conditions for Heat Transfer Simulation

The study used Physibel TRISCO v.12.0w [1], a program for three-dimensional steady-state heat transfer simulation, and compared the insulation performance between the existing and alternative metal panel curtain walls. Table 4 lists the boundary conditions applied in the simulation. The outdoor and indoor temperatures were set at -11.3°C, an outdoor design temperature for heating in Seoul, and 20.0°C, a heating temperature for an office building, as set forth in the Code for Energy-efficient Building Design (Ministry of Land, Infrastructure, Transport Notice No. 2015-1108) [10]. The outdoor and indoor surface heat transfer coefficients also followed those defined in the same standards. Material properties in the Guideline of the Code for Energy-efficient Building Design [11] and other references listed in Table 5 were applied.

Table 4. Outdoor and indoor boundary conditions m

	Set-point Temperatures (°C)	Surface Heat Transfer Coefficient ($W/(m^2K)$)
Outdoor	-11.3	23.25
Indoor	20	9.09

Table 5. Material properties

Material	Thermal Conductivity (W/(mK))	Emissivity Coefficient [a]	Reference Source	Material	Thermal Conductivity (W/(mK))	Emissivity Coefficient [a]	Reference Source
Expanded polystyrene extruded	0.034	0.900	C	ABS plastic mold	0.180	0.900	F
				Sealant (silicone)	0.350	0.900	B
Phenolic foam	0.019	0.900	C	Ordinary glass 5 mm	1.000	0.837	I
VIP (vacuum-insulation panel)	0.00284	0.900	E	Low-emissivity glass 5 mm	1.000	0.037	J
Gypsum board	0.180	0.900	A	Polyvinyl chloride (PVC)	0.170	0.900	B
Azon	0.120	0.900	D	EPDM	0.250	0.900	B
Backup load (polyurethane foam)	0.050	0.900	A	Sealant (butyl)	0.200	0.900	B
PVC-foam pad	0.0389	0.900	G	desiccant (silica gel)	0.130	0.900	B
Wood (light)	0.140	0.900	C	Insulation paint	0.260	0.900	H
Finish (linoleum)	0.180	0.900	C	Steel	50.0	0.660	B
				Aluminum	160.0	0.550	B

A: ISO 10456 [12], B: ISO 10077-2 [13], C: The Guideline of the Code for Energy-efficient Building Design [11],

D: Test report by Korea Testing & Research Institute for Chemical Industry (TAS-034211, 2014.06.19.),
E: Test Report by Korea Research Institute of Standards and Science and Calculated Effective Thermal Conductivity,
F: Test report by Korea Testing & Research Institute for Chemical Industry (TAN-000471, 2016.01.29.),
G: S's product specifications, H: ASHRAE Handbook Fundamentals, Ch33 [14],
I: HanGlass's product specifications, J: Cardinal Glass Industries' product specifications
[a]: Therm 6.0 material library, MIKRON Instrument Company, Inc. [15]

(2) Methods to Compare Insulation Performance

For the purposes of comparing insulation performance between the existing and alternative metal panel curtain walls, the effective U-values were calculated and compared by Equation (1), using the total heat loss derived from heat transfer simulation. For the typical external wall area for heat transfer simulation, including all parts in which thermal bridges occurred repeatedly, modeling principles for thermal bridge parts set forth by ISO 10211 [16] were reflected and set accordingly, and the results are shown in Figure 1. The evaluated wall area for the heat transfer simulation included the opaque exterior walls of an office building, which covered all floor slabs and ceiling plenums to which trusses were fixed. It was assumed that a metal panel unit was 2,000 mm in width and 1,000 mm in height. It was also assumed that insulation materials built in a metal panel consisted of 55 mm thick phenolic foam and a 20 mm thick vacuum-insulation panel (VIP), and gypsum boards were used as interior materials. I-beams and steel materials fixed to ceilings, which were considered to have little effect on insulation performance, were not included for heat transfer simulation modeling. By setting the same external and internal surface areas for the existing and alternative metal panel curtain walls in a heat transfer simulation model, the study facilitated the comparison of insulation performance between them.

$$U_{eff} = \frac{q_{tot}}{A_e \times (T_i - T_O)} \quad (1)$$

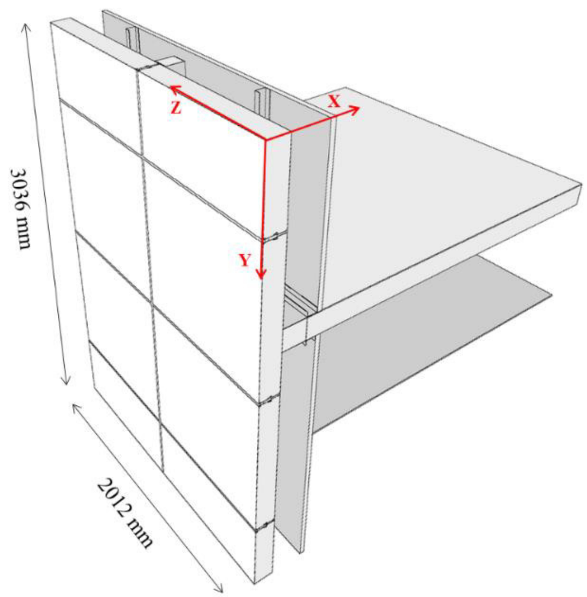
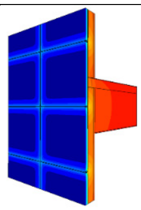
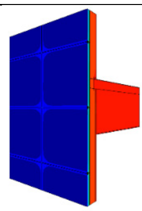


Figure 1. Three-dimensional heat transfer simulation model

3.3. Results of Insulation Performance Comparison

Table 6 shows the results of an insulation performance comparison between the existing and alternative metal panel curtain walls. As in the temperature distribution in Table 6, linear and point thermal bridges occurred in the existing metal panel curtain wall owing to aluminum molds installed on vertical and horizontal joints between metal panels and aluminum brackets installed on horizontal joints near cross joints connecting metal panels, and the external surface temperatures of the parts with these thermal bridges were shown as high. By contrast, in the alternative metal panel curtain wall, local heat loss caused by thermal bridges decreased as ABS plastic molds and thermal broken brackets were applied. In terms of the total heat loss, the alternative metal panel curtain wall showed 26 W, a 72% decrease from the existing metal panel curtain wall, and in terms of effective U-value, the alternative metal panel curtain wall showed 0.14 $W/(m^2K)$, a 72% decrease from the existing metal panel curtain wall.

Table 6. Insulation performance comparison between the existing and alternative metal panel curtain walls

	Existing Metal Panel Curtain Wall	Alternative Metal Panel Curtain Wall
Temperature Distribution		
Heat Loss (W)	94.0 (0.0%)	26.2 (-72.2%)
Effective U-value ($W/(m^2K)$)	0.49 (0.0%)	0.14 (-72.2%)

4. Annual Heating and Cooling Energy Needs Comparison Based on Building Energy Simulation of Entire Building

4.1. Overview for Annual Heating and Cooling Energy Needs Comparison

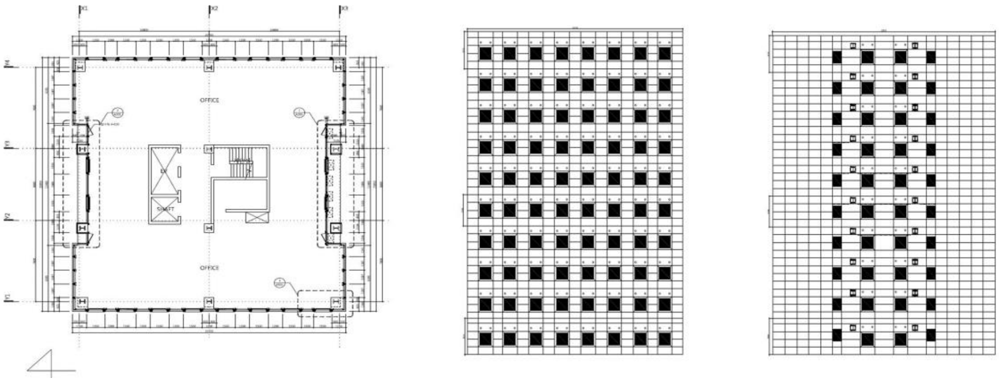
(1) Overview of the Building Energy Simulation

The building chosen by this study for simulation was an office building with metal panel curtain walls in Seoul, whose construction was recently completed. The overview for the building is shown in Table 7, and a plan and elevations are provided in Figure 4. DesignBuilder v4.5 [2], which uses the building energy stimulation program Energy Plus as a calculation engine, was used. Standard weather data of Seoul [17] were applied, and the calculation interval was set to 1 h. To model thermal bridges, the study set an additional virtual layer of materials that had no thermal capacity on top of the existing and alternative metal panel curtain walls and reflected additional heat transfer coefficients caused by thermal bridges. Heating and cooling energy needs, which could be defined as heat to be delivered to and extracted from a conditioned space to maintain the set-point temperatures, were calculated to compare between the existing and alternative metal panel curtain walls. The results of the modeling of the building are demonstrated in Figure 2.

The exterior walls of the building followed the composition of the existing and alternative metal panel curtain walls and the U-value for other parts was set in a way that satisfied the current insulation regulations (The Code for Energy-efficient Building Design, Ministry of Land, Infrastructure, Transport Notice No. 2015–1108) [10]. Tables 8, 9 and 10 illustrate the composition of structure, material properties, and window, and glass composition. Table 11 shows the input value for the simulation. The temperature set for heating and cooling, internal heat gain, ventilation rate and schedule were set in accordance with the Operational Provisions for the Building Energy Efficiency Rating System [18], except for the internal heat gain from lighting. Because these standards did not specify internal heat gain from lighting, it was set at 12.6 W/㎡ in reference to an applicable material [19].

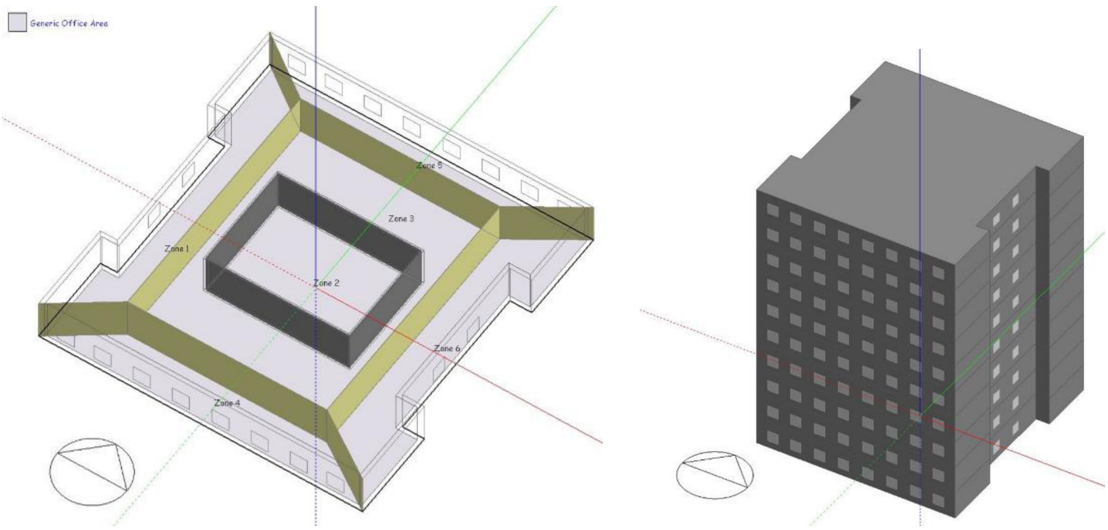
Table 7. Overview of building for simulation

Use	Gross Floor Area (m^2)	Floor Area (m^2)	Floor Height (m)	Number of Floors
Office	5,000	500	3.1	10 floors above the ground



(a) Plan (b) Elevation (south and north) (c) Elevation (east and west)

Figure 2. Drawing of the building for simulation



(a) Reference floor (b) The entire building

Figure 3. Building energy simulation model

Table 8. Composition of structure and material properties

Part	Material	Thickness (mm)	Thermal Conductivity (W/(mK))	Specific Heat (kcal/(kg℃))	Density (kg/m^3)
Exterior wall	Steel sheet	0.8	50.0	450	7,800
(outdoor → indoor)	Phenolic foam	55	0.019	1,500	65
	VIP	20	0.00284	850	192
	Steel sheet	0.5	50.0	450	7,800
	Cavity	164		R_{cavity} 0.086 m^{2}K/W	
	Gypsum board	30	0.18	1,130	940
			U-value : 0.096 W/(m^{2}K)		
Roof	Plain concrete	80	1.6	879	2,240
(top → bottom)	EPS	80	0.032	1,210	32
	Concrete	210	1.6	879	2,240
	EPS	90	0.032	1,210	32
	Gypsum board	9.5	0.180	1,130	940
			U-value : 0.176 W/(m^{2}K)		
Ground floor	Cement mortar	45	1.4	921	1,950
(top → bottom)	Autoclaved lightweight Concrete	40	0.13	1,173	650
	EPS	80	0.032	1,210	32
	Concrete	210	1.6	879	2,240
			U-value : 0.314 W/(m^{2}K)		
Intermediate floors	Floor finish	3	0.17	900	1,390
	Concrete	95	1.6	879	2,240
(top → bottom)	Ceiling plenum	500		R_{cavity} 0.23 ㎡ K/W	
	Gypsum board	12	0.180	1,130	940
			U-value : 1.486 W/(m^{2}K)		

Table 9. Window composition

U_{frame} (W/(m^{2}K))	$U_{glazing}$ (W/(m^{2}K))	U_{window} (W/(m^{2}K))	SHGC	VT
1.255	1.229	1.436	0.260	0.475

Table 10. Glass composition in windows

Type	Composition	Thickness (mm)
Triple glazing	Low-e glass (emissivity 0.037)	5
	Air (5%) + Argon (95%) mix	8
	Clear glass	5
	Air (5%) + Argon (95%) mix	8
	Clear glass	4

Table 11. Input value for the simulation

Input Conditions		Values
Set-point temperatures	Heating	20℃
	Cooling	26℃
Internal heat gain (Human body, devices)		20.2 W/m^2
Internal heat gain (Lighting)		12.6 W/m^2
Ventilation rate		6 m^3/hm^2

(2) Thermal Bridge Modeling Methods

To model the additional heat transfer caused by thermal bridges in the existing and alternative metal panel curtain walls, a virtual layer of materials with no thermal capacity was added to the exterior walls, and additional heat transfer coefficients depending on the linear thermal transmittance and the length of a linear thermal bridge were calculated by Equation (2) and reflected in the virtual layer. This method is used for thermal bridge modeling in DesignBuilder v4.5 [2]. Additional heat transfer coefficients were calculated only for linear thermal bridges such as those on molds in joints between metal panels. Because point thermal bridges in brackets were not continuous and showed up in parts that were extremely small compared with the entire exterior wall, they were not included for additional heat transfer coefficient calculation.

$$\Delta q = \sum_i \psi_i \times l_{TBi} \quad (2)$$

(3) Calculation of Linear Thermal Transmittance and Additional Heat Transfer Coefficients

Physibel BISCO v.10.0w [20], a program for two-dimensional steady-state stimulation, was used to calculate the linear thermal transmittance in each linear bridge. Table 4 describes the outdoor and indoor boundary conditions applied to the heat transfer simulation, and Table 5 shows the material properties.

To calculate the linear thermal transmittance, the study applied thermal bridge part modeling principles suggested by ISO 10211 [16] to cut-off planes for heat transfer simulation parts. Vertical linear thermal bridges were divided into those between a panel and a window (P–W) and those between a panel and a panel (P–P) as illustrated in Figure 4 to set cut-off planes. Horizontal linear thermal bridges were also divided in the same manner to set cut-off planes. Point thermal bridges located on cut-off planes were excluded from modeling.

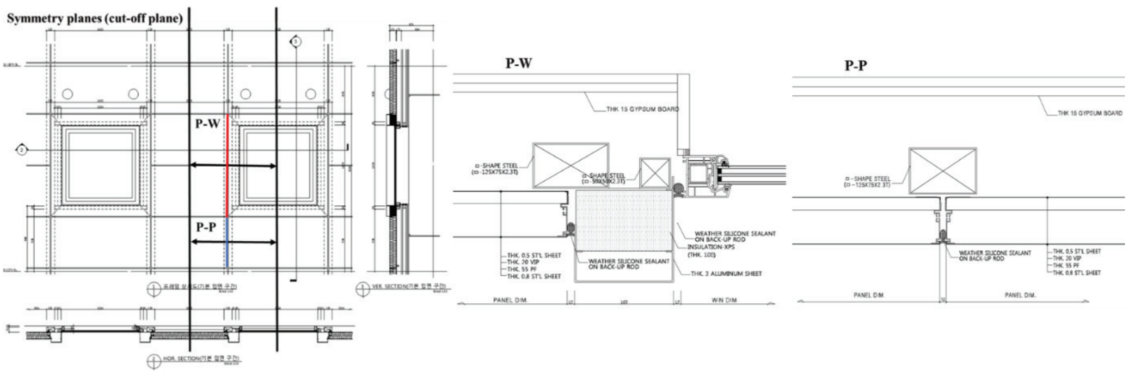


Figure 4. Cut-off planes for vertical linear thermal bridge modeling and plans for P–W and P–P

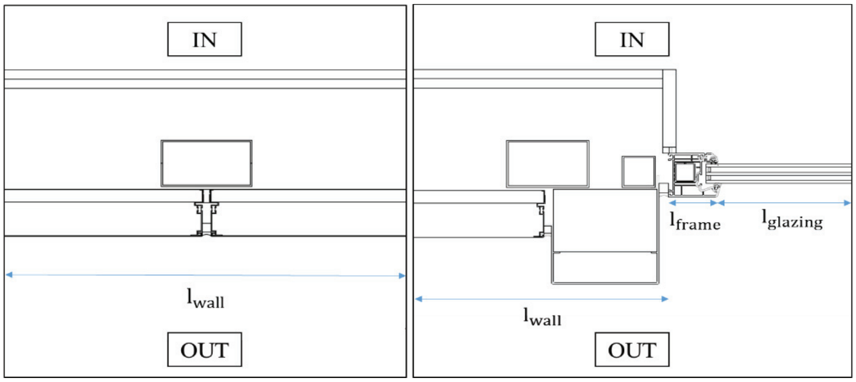


Figure 5. Plan for heat transfer simulation modeling of vertical linear thermal bridge elements and length of each element

The following Equation (3) is an equation that calculates the linear thermal transmittance in accordance with ISO 10211 [16]. The linear thermal transmittance between a panel and a panel (Ψ_{P-P}) was calculated by Equation (4) in reference to Equation (3). The linear thermal transmittance between a panel and a window (Ψ_{P-W}) was calculated by Equation (5) in reference to Equation (2) and the existing study [21]. In Equation (5), Physibel BISCO v.10.0w [20] was used to calculated the frame's U-value, and the linear thermal transmittance between a frame and glazing (Ψ_{F-G}) was calculated in the same way as Equation (4). In Equations (3), (4) and (5), the length of each element (l_{wall}, l_{frame}, $l_{glazing}$) followed exterior dimensions as stated in Figure 7.

$$\psi = L_{2D} - \sum_i U_i \times l_i \tag{3}$$

$$\psi_{P-P} = L_{2D} - \sum U_{wall} \times l_{wall} \tag{4}$$

$$\psi_{P-W} = L_{2D} - U_{wall} \times l_{wall} - U_{frame} \times l_{frame} - U_{glazing} \times l_{glazing} - \psi_{F-G} \tag{5}$$

Depending on the location, metal panel units slightly varied in the horizontal direction, although they were the same in the vertical direction. For this reason, the study classified P–P vertical linear thermal bridges into 8 different types and P–W vertical linear thermal bridges into 4 types based on the horizontal length of a metal panel unit to calculate each linear thermal transmittance. Figure 6 lists the linear thermal transmittances for vertical and horizontal linear thermal bridges in the existing and alternative metal panel curtain walls derived from the process stated above. The alternative metal panel curtain wall showed an 80% decrease in the linear thermal transmittance between a panel and a panel (Ψ_{P-P}) and a 15% decrease in the linear thermal transmittance between a panel and a window (Ψ_{P-W}) compared with the existing metal panel curtain wall, which confirmed a significant level of thermal bridge reduction effects.

By applying the linear thermal transmittances from above and the linear thermal bridge lengths described on building elevations, additional heat transfer coefficients (Δq) of each directional exterior wall were calculated by Equation (2) and are described in Table 12. Compared with the existing metal panel curtain wall, the additional heat transfer coefficients in the alternative metal panel curtain wall showed a 72% decrease in the east and west exterior walls, which had more linear thermal bridges between panel and panel, and a 48% decrease in the north and south exterior walls, which had more linear thermal bridges between panel and window.

Table 12. Additional heat transfer coefficients from linear thermal bridges in exterior walls for each direction

Direction	Existing Metal Panel Curtain Wall (W/K)	Alternative Metal Panel Curtain Wall (W/K)	Change Rate (%)
East and West	28.76	7.96	-72
South and North	31.08	16.01	-48

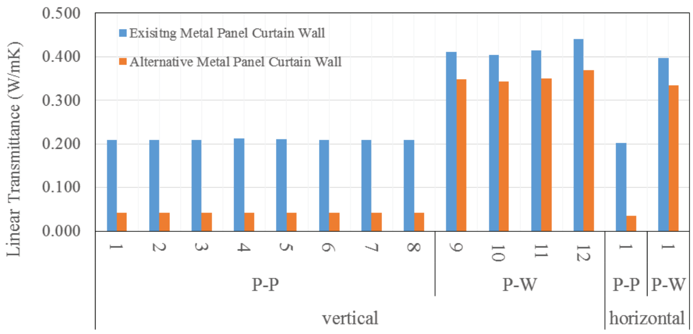


Figure 6. Linear thermal transmittances for vertical and horizontal linear thermal bridges in the existing and alternative metal panel curtain walls

4.2. Results of Annual Heating and Cooling Energy Needs Comparison

Table 13 and Figure 7 show the results of a comparison between the existing and improved walls in terms of annual heating and cooling energy needs. For heating energy needs, the improved wall showed 58,394 kWh, a 26% decrease from the existing wall, which suggests that considerable heating energy-saving effects were achieved by reducing heat loss. For cooling energy needs, in contrast, the improved wall showed 142,470 kWh, a 7% increase from the existing metal panel curtain wall. This resulted because the amount of heat loss through the exterior walls decreased owing to the improved insulation performance of the exterior walls. The amount of heat through the exterior walls is internal heat gain and solar heat gain in summer.

Table 13. Comparison between the existing and alternative metal panel curtain walls on annual heating and cooling energy needs

Month	Existing Metal Panel Curtain Wall		Alternative Metal Panel Curtain Wall	
	Heating (kWh)	Cooling (kWh)	Heating (kWh)	Cooling (kWh)
1	27,199	0	21,757	0
2	19,396	0	14,902	0
3	7,878	0	4,693	0
4	1,295	52	419	292
5	5	1,696	0	3,760
6	0	15,331	0	17,187
7	0	44,769	0	45,918
8	0	53,116	0	53,527
9	0	16,905	0	18,515
10	91	1,626	24	3,235
11	5,048	11	2,861	37
12	18,339	0	13,737	0
Year	79,523	133,505	58,394	142,470
Change rate (%)	-	-	-26	7
Sum (heating + cooling)	212,758		200,864	
Change rate (%)	-		-6	

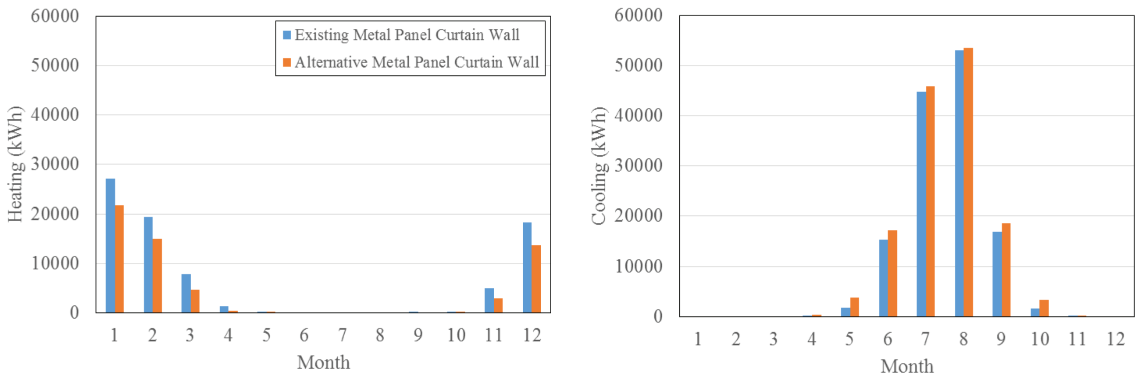


Figure 7. Comparison between the existing and alternative metal panel curtain walls on monthly heating and cooling energy needs

For the total energy needs for heating and cooling, the improved wall showed 200,864 kWh, a 6% decrease from the existing wall, demonstrating that it was effective in saving the total usage of energy.

5. Conclusions

This study aimed to suggest ways to reduce thermal bridges in joints between metal panels and compare and evaluate the heating and cooling energy-saving effects of the alternative metal panel curtain wall over the existing metal panel curtain wall. The results of the present study are as follows.

- According to the results of the insulation performance comparison on a typical external wall area through three-dimensional heat transfer simulation, the alternative metal panel curtain wall, which replaced the existing aluminum mold with an ABS plastic mold and the existing aluminum bracket with a thermal broken bracket, showed a 72% decrease in the total heat loss and a 72% decrease in the effective U-value, demonstrating that it had considerable effects on improving the insulation performance.
- After applying the existing and alternative metal panel curtain walls to an actual office building in Seoul and calculating the linear thermal transmittances of the exterior walls, the study could confirm a significant level of thermal bridge reduction effects in the improved wall with an 80% decrease in the linear thermal transmittance between a panel and a panel (Ψ_{P-P}) and a 15% decrease in the linear thermal transmittance between a panel and a window (Ψ_{P-W}) compared with the existing metal panel curtain wall.
- The results of applying the existing and alternative metal panel curtain walls to the building and calculating its annual heating and cooling energy needs demonstrated that the alternative metal panel curtain wall was effective in saving energy, showing a 26% decrease in heating energy needs and a 6% decrease in heating and cooling energy needs compared with the existing metal panel curtain wall.

The alternative metal panel curtain wall is as good as existing metal panel curtain wall from the aspects of airtightness, load-bearing, installation, and durability. A follow-up study is planned to conduct a mock-up and final verification of the structural stability and fire resistance of an ABS plastic mold.

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