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Research paper

A Study on the Energy Load Evaluation according to the Installation of Multistory Facade and Exterior Shading Device

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Abstract

Background/Objectives: The purpose of this research is to get a better plan to reduce the energy used for heating and cooling as a result of thermal energy loss in curtain wall buildings.
Methods/Statistical analysis: In order to achieve this goal, the study executed a building energy simulation to evaluate the factors that from a double skin façade and curtain wall building. The factors that were considered in this study are the air gap distance of the double skin façade, the area ratio of the inner window, the direction of the building and the shading device conditions. The results of this study are based on the weather data of Busan input in DesignBuilder.
Findings: When the inner window area ratio was installed at 40% without the double skin façade, the energy load reduction effect was better with the exterior shading device at South-45°-West and South. With the double skin façade, the energy load reduction effect was better without the exterior shading device in West, South-45°-East and East. When the inner envelope window area ratio was installed at 70% and 100% the, the energy load reduction effect was better with the exterior shading device in all direction.
Improvements/Applications: The optimal double-skin design study will be carried out by adjusting the installation location and angle schedule of the shading device after the orientation.

Keywords: *Double-skin facade system, Design Builder, Air Gap Space, Exterior Shading Device, Curtain Wall Building.*

1. Introduction

Discussion about the environmental problems of the earth began at the United Nations Conference on Human Environment held in Stockholm in 1972 and the recognition that the reduction of greenhouse gas emissions and energy consumption is a task that is more important than anything else become to be widely shared at the United Nations Conference on Environment & Development held in 1992. The recognition has led to the General Conference of the Parties to the United Nations Framework Convention on Climate Change held in Paris, France. The Ministry of Land, Infrastructure and Transport established a goal to supply zero-energy houses in 2015 and has been making effort to reduce the energy consumption energy-saving rate of new apartment buildings from 30% to 40% from March 2015. Given that the heat loss through window is 17%, curtain wall buildings with the entire area of the outer walls consisting of windows are judged to be disadvantageous in terms of energy saving although they are advantageous in term of the view of the occupants. As methods to reduce energy consumption in a curtain wall building, the layout plan, the envelope plan, the improvement of the insulation performance, the solar shading, and the double-skin façade system of the building can be considered. Among them, the double-skin façade system is judged to reduce the energy consumption by installing an intermediate space between the outside and inside of the building to play the role of a thermal buffer space during the cooling and heating periods.

Studies on the double-skin façade system began with numerical analysis of heat flows in the double-skin in a mathematical method[1], analyzed thermal environments made by installing blinds with a mathematical model[2], and simulated the building cooling energy reduction scheme of high-rise apartment applied with the double-skin façade system using ESP-r[3] to demonstrate that the double-skin façade system is effective for building cooling energy saving. In addition, through field measurement and simulation analysis of the thermal environment and ventilation performance of building already installed with double-skin façade system[4], a study revealed that differences between indoor / outdoor temperatures in summer are not large and that upper windows have large effects on the increase or decrease of the amount of ventilation of the double-skin. Another study analyzed energy load variations using the TRNSYS program[5] and emphasized that air inflows and outflows are important in the double-skin façade system. In addition, a measurement and experimental study was conducted to compare the cooling season thermal performances of box type double-skin and curtain walls[6], and a study on energy loads according to blind operation schedules[7] were conducted and a study researched into the solution of the air current stagnation phenomenon occurred in upper area of multistory double-skin in summer[8] and emphasized the importance of the double-skin design stage. The energy performance of the building was analyzed by changing the blind and natural ventilation mode of the double-skin system. In the case of summer, the energy performance difference of the double skin according to the control method showed a relatively low rare change of 8.4%, and a great change rate of 46.5% in winter. The application of a dual envelope system to the office building confirmed that a control strategy that maintains external circulation for a week is valid. In addition, if the outside temperatures is not too high or low, the energy saving effect of the blind slat control is greater than the airflow control[9]. As a result of the experiment on the internal thermal environment of the season in the front type double-skin, it was found that the temperature distribution in the upper part of the upper part of the double-skin was similar to that of the inside of the double-skin in summer, was kept at 18℃, and the hollow layer of the outer shell between the outer and inner sides formed a thermal buffer space and contributed to the heating load[10]. In the double-skin system, the indoor and outdoor blinds are controlled by variable, and the temperature of the building is controlled by using the experiment and simulation. As a result of the analysis, it was found that the condition where the external blind was installed maintained the lowest indoor temperature compared to the condition in which the blind was not installed. In the analysis of the cooling load using the simulation, the external blind condition was 54.9%, and 28.2% respectively[11]. The building energy performance was analyzed according to the layout of buildings, the presence and the presence of double-skin and double-skin system. Building layout was set as simulation protection for South-North and East-West, and the deployment of the Double-skin façade system was set as simulation protection for the South, West, North, and East. In South-North buildings, double-skin system showed the lowest cooling energy load for the South, and the lowest heating energy load for East-West buildings without double-skin system. In the South-North building, the double-skin system showed the lowest energy load to the North and reduced about 29%[12].

Most previous studies are simulation and experimental studies on the amount of ventilation, indoor temperatures, and the amount of solar radiation of the double-skin façade system and comparison of energy loads between before and after installation of the multistory double-skin façade system and external shading devices in lacking. Therefore, the present study in intended to review energy loads according to azimuth of buildings installed with a multistory double-skin façade system changes in the window area ratio inside the double-skin, and the space of the intermediate space in the double-skin.

2. Materials and Methods

Energy Plus is a representative building energy analysis tool, which was made by combining the advantage of BLAST(Building Loads Analysis and System Thermodynamics) and DOE-2 developed in the 1970s ad tools to analyze building loads. In the present study, energy loads were reviewed using the Design Builder(V.3.2) program, which uses Energy Plus as an analysis engine to review energy loads before and after installing the multistory double-skin façade system and external shading devices. The 10 year average weather data of Busan area provided by the Passive House Institute Korea were used as weather data for simulation, the indoor set temperatures were set to 20℃ for building heating and 26℃ for building cooling according to the 2016 "building energy saving design standards" of Korea Energy and "AHSRAE-2013", and the calorific value of the lighting was set to 3.86W/m^2. The number of time of ventilation was set to 0.7 times per hour, and the interior illuminance was set to 400lx. Other criteria are as shown in [Table 1].

Table 1: Input condition

1. Location : Southern, Busan City, Korea	3. Occupants : 17W/m^2
2. Indoor Temperature : Cooling 26℃, Heating 20℃	4. Office Equipment : 11 W/m^2
	5. Infiltration : 0.1 ACH

In addition, one year was divided into a cooling season(June, July, August, September), a heating season(November, December, January, February, March, April), and intermediate season(May, October) according to the seasonal double-skin façade system operating methods, and the ventilation inside the double-skin façade system was set to be done in summer and not to be done in winter. Simulations were implemented in schedules divided into one during weekdays (08:00~09:00 : 50%, 09:00~12:00 :100%, 12:00~13:00 : 50%, 13:00~18:00 :100%, 18:00~19:00 : 50%, 19:00~08:00 : 0%), one during weekends (0%), and other during holidays (0%). The analytical model was set to have a floor area 2,000m^2(50m ×40m), a story height of 3.9m, a number of stories of 15 above the ground, and a window area ratio of 40% on the side where no double-skin façade system was installed. The window area ratios of the façade installed with the double-skin façade system were set to 100%, for the outer skin, 40%, 70% and 100% for the inner skin, and the curtain wall building as show in [Figure 1].

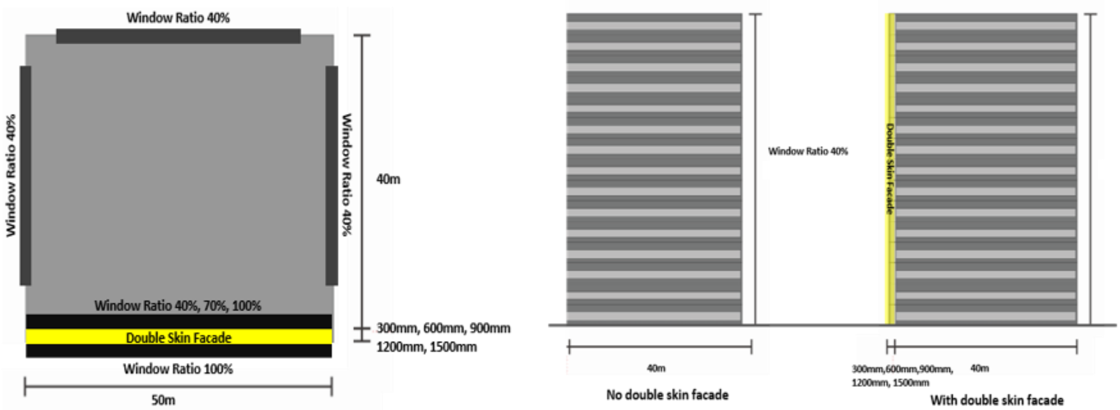


Figure 1: The plan of analytical model

Referring to the 2016 building energy saving design standards, a structure that satisfied the southern area thermal transmittance standard(roof 0.75W/m^2K, outer wall 0.282 W/m^2K, floor 0.246, window 1.78 W/m^2K) was constructed.In the present study, the shading device was set to 0° in the cooling season (June 1 ~ September 30) when simulations were implemented. Venetian blinds were installed on the outer skin of the double-skin façade system and differences in energy loads between before and after the installation were reviewed [Table 2] below shows the blind conditions.

Table 2: Shading Device Condition

1.	Blind-to glass distance : 0.350m	5.	1 Slat thickness : 0.01m
2.	Slat orientation : Horizontal	6.	Slat angle : 0°
3.	Slat width : 0.03m	7.	Slat conductivity : 0.9W/m · k
4.	Slat separation : 0.03m	8.	Slat reflectivity : 0.9

Five simulation azimuths were set as West, S-45°-W, South, S-45°-E, and East. Cases were set with changes in the window area ratio, the space of the intermediate space of the double-skin façade system, and the installation of external shading devices as shown in [Table 3].

Table 3: CASE setting

1.	Without shading Device : W - window ratio - air gap(window ratio : 40%, 70%, 100%, air gap : 0, 300, 600, 900, 1200, 1500mm)	2.	Within Shading Device(SD) : W - window ratio – air gap SD(window ratio : 40%, 70%, 100%, air gap : 0, 300, 600, 900, 1200, 1500mm)

3. Results and Discussion

3.1. Review of Energy Load before Double-Skin Installation

Changes in the window area ratio of the analysis model before installing the double-skin façade system and the energy loads following the installation of the external shading devices area as shown in [Figure 2].

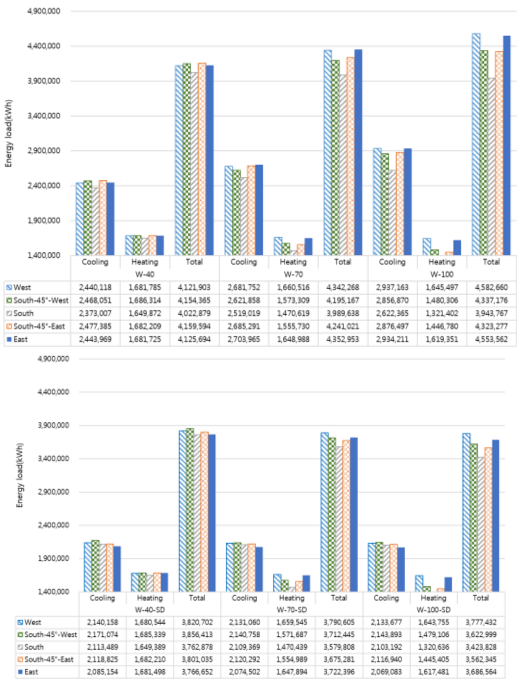


Figure 2: Energy load without the double-skin facade

The results of comparison of the building cooling / heating energy loads when no double skin was set are as show in [Figure 2]. When external shading devices were set on all azimuths, building cooling energy loads were reduced but building heating energy loads were shown to be not much different compared to when no external shading devices was installed. Therefore, it was confirmed that building cooling / heating energy loads were more advantageous when the external shading devices were set. When there where external shading devices, the building cooling energy load was the smallest in case the window area ratio was 100%(2,103,192 kWh) and when there was no external shading device, the building cooling energy load was the largest in case the window area ratio was 100%(2,622,365 kWh). When there were external shading devices, the building heating energy load was shown to be the smallest in case the window area ratio 100%(1,320,636 kWh) and when there was no external shading device, the heating energy load was shown the be the largest in case the window area ratio was 40%(1,649,872 kWh). The sum of cooling / heating energy loads was shown to be the smallest in case the window area ratio was 100%(3,423,828 kWh) when there were external shading devices and the largest in case the window area ratio was 40%(4,022,879 kWh) when there was no external shading device. When there was no external shading device, as the window area ratio increased, cooling energy loads increased while heating energy loads decreased. When there were external shading devices, as the window area ratio increased, cooling / heating energy loads decreased.

3.2. Review of Energy Load after Double-Skin Installation

When the space of the intermediate space was 300mm, the energy loads according to change in window area ratio of the inner skin and the installation of external shading devices are as shown in [Figure 3].

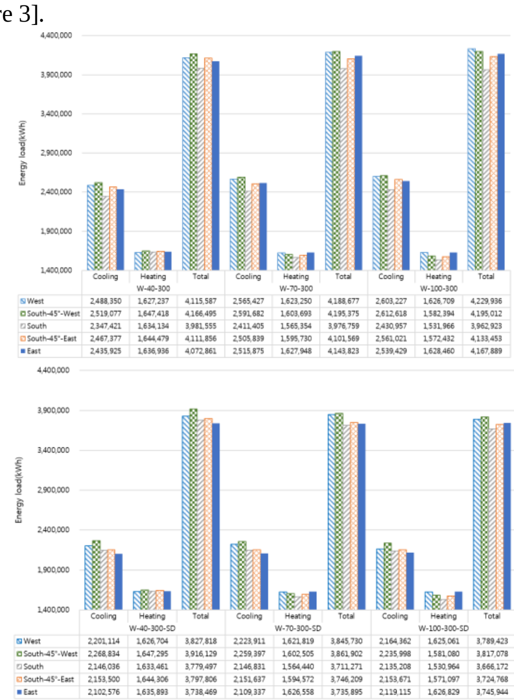


Figure 3: Energy load within double-skin facade(air gap 300mm)

When there were external shading devices, the cooling energy load was shown to be the smallest in case the window area ratio was 100%(2,135,208 kWh) and when there was no external shading device, the cooling energy load was shown to be the smallest in case the window area ratio was 100%(2,430,957 kWh). When there were external shading devices, the heating energy load was shown the be the smallest in case the window area ratio was 100%(1,530,964 kWh) and when there was no external shading device, the heating energy load was shown to be the largest in case the window area ratio was 40%(1,634,134 kWh). The sum of cooling / heating energy loads was shown to be the smallest in case the window area ratio was 100%(3,661,172 kWh) when there were external shading devices and the largest in case the window area ratio was 40%(3,91,555 kWh) when there was no external shading device. When there was no external shading device, as the window area ratio increased, cooling energy loads increased while heating energy loads decreased. When there were external shading devices, as the window area ratio increased, cooling / heating energy loads decreased.

When the space of the intermediate space was 600mm, the energy loads according to changes in window area ratio of the inner skin and the installation of external shading devices are as shown in [Figure 4].

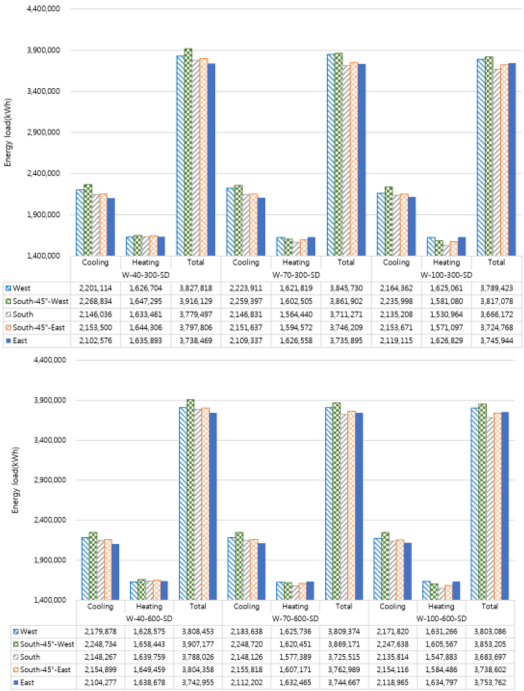
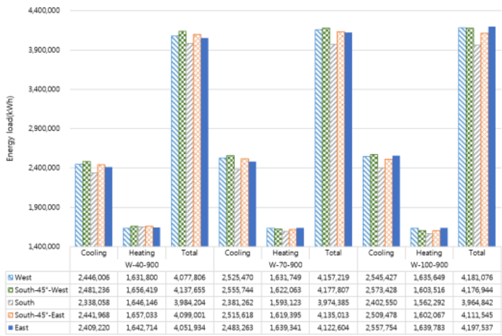


Figure 4: Energy load within double-skin facade(air gap 600mm)

When there were external shading device the cooling energy load was shown to be the smallest in case the window area ratio was 100%(2,135,814 kWh) and when there was no external shading devices, the cooling energy load was shown the be the largest in case the window area ratio was 100%(2,422,485 kWh). When there were external shading devices, the heating energy load was shown to be the smallest in case the window area ratio was 100%(1,547,833 kWh) and when there was no external shading device, the heating energy load was shown to be the largest in case the window area ratio was 40%(1,640,454 kWh). The sum of cooling / heating energy loads was shown to be the smallest in case the window area ratio was 100%(3,683,697 kWh) where there were external shading device and the largest in case the window area was 40%(3,989,909 kWh) when there was no external shading device.

When the space of the intermediate space was 900mm, the energy loads according to changes in window area ratio of the inner skin and the installation of external shading devices are as shown in [Figure 5].



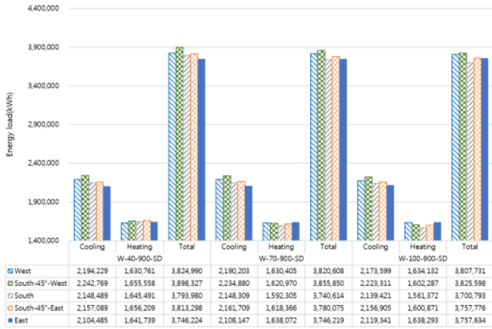


Figure 5: Energy load within double-skin facade(air gap 900mm)

When there were external shading devices, the cooling energy load was shown to be the smallest in case the window area ratio was 100%(2,139,421 kWh) and when there was no external shading device, the cooling energy load was shown to be the largest in case the window area ratio was 100%(2,402,550 kWh). When there were external shading devices, the heating energy load was shown to be the smallest in case the window area ratio was 100%(1,561,372 kWh) and when there was no external shading device, the heating energy load was shown to be the largest in case the window area ratio was 40%(1,646,146 kWh). The sum of cooling / heating energy loads was shown to be the smallest in case the window area ratio was 100%(3,700,793 kWh) when there were external shading device and the largest in case the window area ratio was 40%(3,984,204 kWh) when there was no external shading device.

When the space of the intermediate space was 1200mm, the energy loads according to change in window area ratio of the inner skin and the installation of external shading device are as shown in [Figure 6].

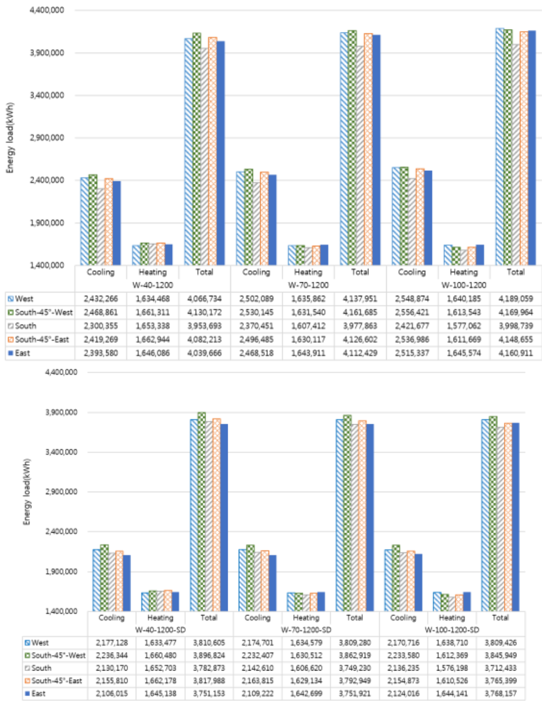
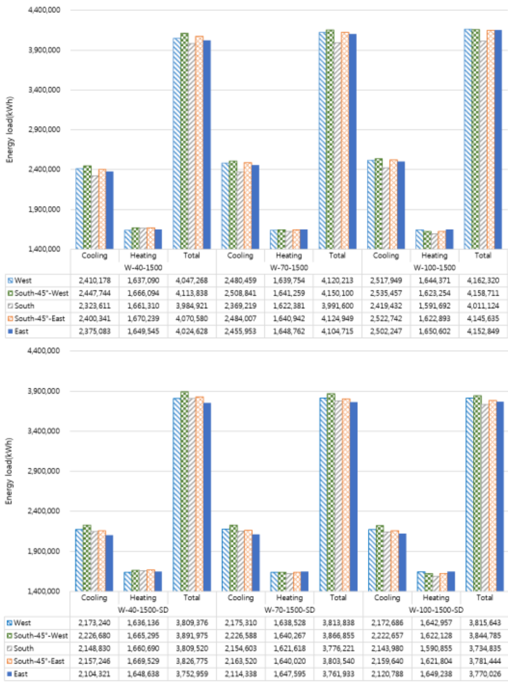


Figure 6: Energy load within double-skin facade(air gap 1200mm)

When there were external shading device, the cooling energy load was shown to be the smallest in case the window area ratio was 100%(2,136,235 kWh) and when there was no external shading device, the cooling energy load was shown to be the largest in case the window area ratio was 100%(2,421,677 kWh). When there were external shading devices, the heating energy load was shown to be the smallest in case the window area ratio was 100%(1,576,198 kWh) and when there was no external shading device, the heating energy load was shown to be the largest in case the window area ratio was 40%(1,653,338 kWh). The sum of cooling / heating energy loads was shown to be the smallest in case the window area ratio was 100%(3,712,433 kWh) when there were external shading device and the largest in case the window area ratio was 40%(3,998,739 kWh) when there was no external shading device.

When the space of the intermediate space was 1500mm, the energy loads according to changes in window area ratio of the inner skin and the installation of external shading are as shown in [Figure 7].



	W-40-1500 Cooling	W-40-1500 Heating	W-40-1500 Total	W-70-1500 Cooling	W-70-1500 Heating	W-70-1500 Total	W-100-1500 Cooling	W-100-1500 Heating	W-100-1500 Total
West	2,410,178	1,637,090	4,047,268	2,480,459	1,639,754	4,120,213	2,517,949	1,644,371	4,162,320
South-45°-West	2,447,744	1,666,094	4,113,838	2,508,841	1,641,259	4,150,100	2,535,457	1,623,254	4,158,711
South	2,323,611	1,661,310	3,984,921	2,369,219	1,622,381	3,991,600	2,419,432	1,591,692	4,011,124
South-45°-East	2,400,341	1,670,239	4,070,580	2,484,007	1,640,942	4,124,949	2,522,742	1,622,893	4,145,635
East	2,375,083	1,649,545	4,024,628	2,455,953	1,648,762	4,104,715	2,502,247	1,650,602	4,152,849

	W-40-1500-SD Cooling	W-40-1500-SD Heating	W-40-1500-SD Total	W-70-1500-SD Cooling	W-70-1500-SD Heating	W-70-1500-SD Total	W-100-1500-SD Cooling	W-100-1500-SD Heating	W-100-1500-SD Total
West	2,173,240	1,636,136	3,809,376	2,175,310	1,638,528	3,813,838	2,172,686	1,642,957	3,815,643
South-45°-West	2,226,680	1,665,295	3,891,975	2,226,588	1,640,267	3,866,855	2,222,657	1,622,128	3,844,785
South	2,148,830	1,660,690	3,809,520	2,154,603	1,621,618	3,776,221	2,143,980	1,590,855	3,734,835
South-45°-East	2,157,246	1,669,529	3,826,775	2,163,520	1,640,020	3,803,540	2,159,640	1,621,804	3,781,444
East	2,104,321	1,648,638	3,752,959	2,114,338	1,647,595	3,761,933	2,120,788	1,649,238	3,770,026

Figure 7: Energy load within double-skin facade(air gap 1500mm)

When there were external shading devices, the cooling energy load was shown to be the smallest in case the window area ratio was 100%(2,143,980 kWh) and when there was no external shading device, the cooling energy load was shown to be the largest in case the window area ratio was 100%(2,419,432 kWh). When there were external shading devices, the heating energy load was shown to be the smallest in case the window area ratio was 100%(1,590,855 kWh) and when there was no external shading device, the heating energy load was shown to be the largest in case the window area ratio was 40%(1,661,310 kWh). The sum of cooling / heating energy loads was shown to be the smallest in case the window area ratio was 100%(3,734,835 kWh) when there were external shading devices and the largest in case the window area ratio was 40%(4,011,124 kWh) when there was no external shading device. When there was no external shading device, energy loads according to increases in the intermediate space and changes in the window area ratio showed maximum reductions of 4.73%(168,619 kWh, E-40-800), 0.82%(29,213 kWh, SE-40-1200), in the case of eastern exposure and southeastern exposure, respectively, compared to before the installation of the double-skin. On the contrary, the energy loads showed maximum increase of 1.68%(59,035 kWh, W-40-400), 2.68%(95,277 kWh, SW-40-800) and 1.16%(39,652 kWh, S-40-1200) in the case of western exposure southwestern exposure, and southern exposure respectively. This means that when the window area ratio of the inner skin in 40% the double-skin façade system is advantageous in the case of eastern exposure or southern exposure but disadvantageous in the case of southern exposure, southwestern exposure, or western exposure.

4. Conclusion

In the present study, yearly energy loads according to changes in the window area ratio of the inner skin of the double-skin façade system, the space of the intermediate space, and the installation of shading devices on the outer skin were simulated to compare and review the amounts of reduction in energy loads with a view to presenting a measure for optimum design of curtain wall building installed with a multistory double-skin façade system and the following conclusions could be obtained. The comparison and analysis of yearly cooling / heating energy loads before and after installation of the double-skin façade system and shading devices are as follows. When the window area was 40%, installing shading devices on the outside without any double-skin façade system was shown to be effective for reduction in energy loads in the case of southern exposure, installing the double-skin façade system with an intermediate space of 300mm was shown to be effective for reduction in energy loads in the case of southern S-45-E exposure, and installing the double-skin façade system with an intermediate space of 600mm and external shading devices was shown to be effective for reduction in energy loads in the case of western exposure. The maximum reduction shown by these methods was around 10%. When the window area ratio was 70%, installing shading devices on the outside without any double-skin façade system was shown to be effective for reduction in energy loads in the case of all simulation azimuths and a maximum reduction of around 17% was shown. When the window area ratio was 100% too, installing shading devices on the outside without any double-skin façade system was shown to be effective for reduction in energy loads in the case of all simulation azimuths and a maximum reduction of around 25% was shown.

The results of the present study are part of studies to derive the optimum intermediate space, window are ratio, and shading device installation in curtain wall buildings through integrated evaluation of cooling / heating energy in the case of multistory double-skin façade systems using simulations. Hereafter, optimum double-skin design will be reviewed considering building layouts(8) and blind installation places.

Acknowledgment

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