A STUDY ON THE IMPROVEMENT OF SUMMER THERMAL ENVIRONMENT AT THE ATRIUM OF KIMHAE NATIONAL MUSEUM

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ABSTRACT

An atrium of a building not only accommodates the functions of a medium and node as a middle region of the building's indoor and outdoor spaces, but is also utilized as a place for rest and communication by the building's users. Therefore, an atrium must be planned so that it can perform the function of indoor climate control as an all-weather open space due to its physical nature, and also have management efficiencies, such as with regard to energy consumption. Generally, due to its spatial characteristics, an atrium is constructed using glass, which is one of the materials that can express openness along with architectural design.

However, if the architectural planning of a glass atrium goes wrong, this significantly reduces the comfort of the building's users in summer and the intermediate seasons, and rapidly increases the cooling energy consumption used to overcome this situation. Therefore, this study was conducted as the preliminary study for selecting the best improvement plan for the atrium's thermal environment. For this purpose, the study selected an atrium building which has a v ery poor summer and intermediate season environment, conducted experiments on the thermal environment in the summer, drew architectural alternatives for improvement according to the results, and conducted thermal environment simulations on their effect.

THE BACKGROUND

This study targeted Gayanuri Hall, which is an education building affiliated with Kimhae National Museum, located in Kimhae-si, Gyeongsangnam-do, Korea. The Gayanuri Hall atrium is located at the front part of the west side of the hall. Some parts of the south and east sides, as well as the ceiling of the atrium were finished with glass, so in the daytime during summer, solar radiation that flowed into the building accumulated and created a green house effect that increased the room temperature.

Thus, it could not provide a comfortable indoor environment to the building's visitors, and raised the cooling load, increasing energy consumption. Accordingly, there is a rising demand for an architectural solution as part of the plan for improving this building's poor indoor thermal environment. Also, the window from which a natural ventilation cooling effect from outdoor air could be expected is inadequate, resulting in a very hot indoor environment, even in spring and autumn, as well as in summer. Therefore, this study investigated the cooling effect of an increased natural airflow through the building in the intermediate seasons. For this study, architectural alternatives for the improvement of the indoor thermal environment of the Gayanuri Hall atrium were drawn, and regarding these alternatives, simulations were conducted to assess the amount of solar radiation inflow, maximum cooling load, and indoor air temperature according to the ventilation rate change, using Building Designer, which is a load/energy analysis program, and suggestions made as to the best plan for improvement.

SPACE ORGANIZATION

The Kimhae National Museum is designed with a main building for exhibitions and Gayanuri Hall, which is used for experience and education. Gayanuri Hall consists of three stories. The building summary is shown in Table 1, and each floor plan's organization is shown in Figure 1 and Figure 2. The west facade of Gayanuri Hall is shown in Figure 3.

Table 1 Building summary of Gayanuri

SITE AREA	8,248 ㎡	**TOTAL FLOOR AREA**	6,108 ㎡
NUMBER OF FLOORS	3 stories above ground and one underground floors	**AREA OF GLAZING ON THE ROOF**	292 ㎡
STRUC-TURE	Reinforced Conc. & steel structure		
SPACE PLACE-MENT	1st Floor	Cinema room, experience-learning hall-1	
	2nd Floor	Conservation laboratory	
	3rd Floor	open gallery, experience-learning hall-2	

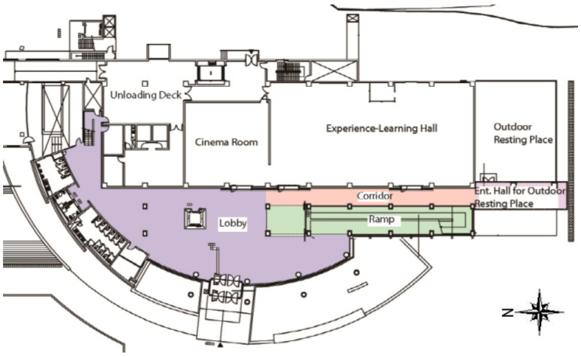


Figure 1 The 1st floor plan of Gayanuri Hall

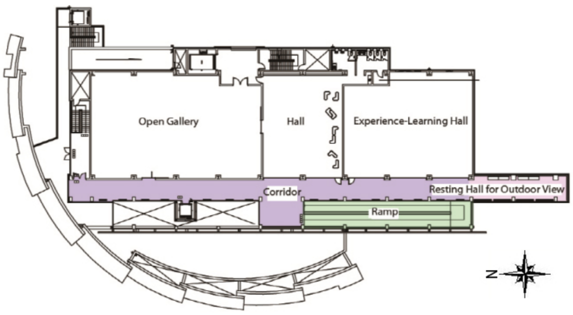


Figure 2 The 3rd floor plan of Gayanuri Hall

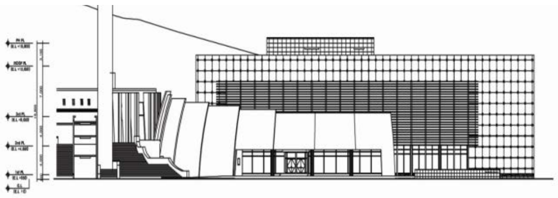


Figure 3 The west facade of Gayanuri Hall

The facade of Gayanuri Hall faces west, and some parts of the main building are designed with an atrium where two great and small boxes in curtain wall structure with glass are stacked on one another. There is a lobby and an entrance hall leading to an outdoor resting place on the first floor of the atrium, which is in a great box, and there is a corridor and a resting hall for outdoor viewing located on the third floor. The ramp space connecting the floors is planned in a small box.

Figure 4 The west elevation view Gayanuri

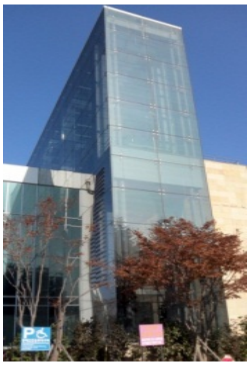


Figure 5 The south elevation view of Gayanuri Hall

Among the atrium domains, the spaces that are most relevant to the thermal environment can be separated into the lobby hall, ramp space, entrance hall to the outdoor resting place, and the resting hall for outdoor viewing. T he present condition and problems regarding these are as follows.

a. Lobby Space

In the Gayanuri Hall lobby space a metal plate wall in grey and horizontal shading in the facade of the entrance act as thermal environment controlling factors. The strong solar radiation around sunset in summer is blocked from flowing inside by the grey metal plate wall, installed in the facade of the west entrance, but due to the low altitude of the late afternoon sun, it is difficult to control the solar radiation with horizontal shading.

Figure 6 The grey metal plate wall and horizontal shades in the facade of the entrance

b. Ramp Space

The west and south elevations of the ramp space have a glass curtain wall structure, and the roof is an opaque structure that blocks solar radiation. Three windows are manually operated (approximate size of 0.9m x 0.5m) in the middle staircase landing on the south side, but they are inadequate to the amount of hot air which needs to be released in summer.

Figure 7 The view of ramp space

Figure 8 Manually operated window in the stair landing of the south side

c. Entrance Hall for Outdoor Resting Place and Resting Hall for Outdoor Viewing

Between the two domains which are located in the great box form of the atrium, the solar radiation flowed in through the exterior glass envelope of the three sides on the east, west, and south of the entrance hall for an outdoor resting place that is located on the first floor. And in the outdoor resting place located on the third floor, solar radiation flowed in through four sides comprised of the east, west, and south sides of the atrium plus the glass roof top. Because of this, a very severe temperature stratification effect occurred in the lower part of the first floor and the upper part of the third floor of the atrium. And since the exhaust outlet for releasing the heated upper air was not installed, Gayanuri Hall's users and employees experienced discomfort. The curtain wall glass installed in the atrium is tempered colored glass covered in heat-reflecting film 15 mm thick, and it adopted and installed the SPG (Special Point Glazing) system.

Figure 9 The view of Entrance Hall for Outdoor Resting Place

Figure 10 The view of installed the SPG system

THERMAL ENVIRONMENT EXPERIMENT

The indoor thermal environment experiment at the atrium was conducted for thirty days between 23 July and 21 August 2012, measuring the indoor air temperature and relative humidity, and two measuring points were selected and measured as shown in Table 2.

Table 2 Experiment summary

MEASUREMENT ITEMS	Air temp. & relative humidity, etc.
MEASUREMENT POINTS	at the entrance of the first floor experience-learning hall & the third floor open gallery
MEASUREMENT PERIOD & INTERVALS	23 July and 21 August in 2012, measurement time interval each 24 hours

The result of measuring the points at the entrance of the first floor experience-learning hall in Gayanuri Hall is shown in Figure 11. It was discovered that the outdoor mean temperature 1 was 29.91 ℃ and the indoor mean temperature was 29.87 ℃, almost no difference.

At the time of the experiment, air-conditioning was being used at Gayanuri Hall, but its effect on lowering the indoor temperature was barely noticeable. And as for the entrance of the first floor experience-learning hall, it was agreed that such condition was due to the effect of exposure to outdoor air through the opening and closing of the main entrance of Gayanuri Hall.

During the thirty days of measurement, Gayanuri Hall was closed on five Mondays. And among the twenty-five days that it was open, the indoor temperature was higher than the outdoor temperature for eight days, 30.8% of the whole. It is judged that there was a problem in the capacity or operation of the air handling unit, along with the thermal characteristics of a glass atrium in summer.

The result of measurements at the entrance to the third floor open gallery is shown in Figure 11. The outdoor mean temperature was 29.91 ℃, and the indoor mean temperature was 32.61℃, 2.7℃ higher than the outdoor temperature. During the twenty-five days of measurement— excluding the five Mondays from the thirty days of the measuring period— the indoor temperature was always higher than the outdoor air temperature. It was judged that this huge difference compared to the first floor experience-learning hall was due to the outdoor temperature and solar radiation inflow. And as for the third floor open gallery, it was deemed necessary to devise a plan for blocking the transmitted solar radiation through the glass in order to expect any effect from the air-conditioning.

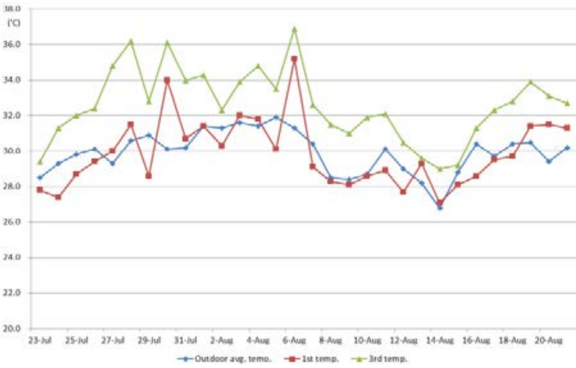


Figure 11 Measurement of air temperature at the entrance of the first experience-learning hall and third floor open gallery

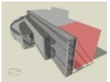
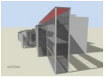
SIMULATION OF ALTERNATIVES

The biggest problem with Gayanuri Hall is the solar radiation transmitted into the hall and hallway of the glass-constructed atrium in summer.

As shown in Table 3, this study selected eleven alternatives (or cases) from the five categories for reducing the solar radiation heat gain. These alternatives include (1) extension of the Gayanuri building towards the east side of the atrium to provide a shadow, along with various means of (2) improving the roof skylight at the atrium, (3) installing an indoor shading device at the atrium, (4) improving the outdoor shading device at the atrium, and (5) combining the aforementioned architectural alternatives.

1 Korea Meteorological Administration , http://www.kma.go.kr/weather/observation/

Table 3 The selection of architectural categories and cases for simulation

CATEGORY/ CASES		SUBDIVISION / CORRESPONDING IMAGE
Case0		Current state 
Category 1	Case 1	the alt. of extending the Gayanuri building towards the east side of the atrium 
Category 2	Case 21	the alt. of replacing the current skylight with a roof structure 
	Case 22	the alt. of installing fixed interior blinds light translucent, always on) 
	Case 23	the alt. of attaching the Low-E film to the present 15 mm single skylight 
Category 3	Case 31	the alt. of installing interior blinds with high reflectivity (operable, provided that insolation intensity is more than 120W/㎡) on the west side on the fourth floor 
	Case 32	the alt. of installing interior blinds on the east, south, west sides of the atrium 
	Case 33	Case31 +Case32 
Category 4	Case 41	the alt. of changes the exterior horizontal shading device angle from the present angle of 0 to 30 degrees 
	Case 42	the alt. of changing the exterior horizontal shading device angle from the present angle of 0 to 45 degrees 
Category 5	Case 51	Case22+ Case33 
	Case 52	Case22+ Case33 + Case41

The building input data for the simulation is shown in Table 4 and the weather data for analyzing the simulation assessed hourly insolation that flowed into the atrium's indoor space as in Figure 12, after having selected 15 July as the summer design day.

And among the weather elements on this day, the minimum outdoor air temperature was recorded as 25.7 ℃ at 3 AM, and the maximum outdoor air temperature 32.9℃ at 3 PM. The direct component of the solar radiation had influence on the building from 6 AM to 7 PM. And the maximum intensity of the direct component was 0.86kW/㎡ at 12:30 PM, while the diffuse component of the solar radiation showed solar intensity at the level of 0.10～0.12kW/㎡ from 8:30 AM to 4:30 PM. When examined per alternative, the sums of direct and diffuse solar radiation transmitted into the Gayanuri atrium on 15 July are as follows.

Table 4 Simulation elements input data for atrium

ATRIUM ELEMENTS	INPUT DATA & CONTENTS
Adjacent room	adiabatic boundary condition between above ground and underground floors
Building orientation	3˚ rotation westward from due north
Window	Most atrium windows installed with 15mm single glass (SHGC 0.716, U-Value 5.508W/㎡·K), while west façade of lobby and lamp space installed with double glass (SHGC 0.703, U-Value 2.685W/㎡·K)
External shading	28 horizontal shading louvers, each of which sectional dimension is 240 mm × 80 mm, separation distance from the atrium window is 400 mm, vertical distance is 350mm
Schedule	Of the week, every Monday closed , opening time 9 AM ~ 18 PM from every Tuesday to Sunday

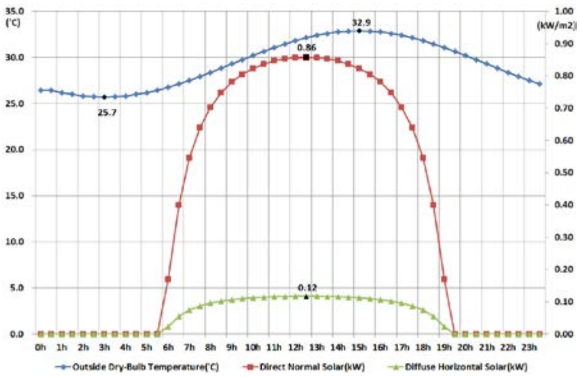


Figure 12 The weather data of 15 July as the summer design day

For Case 0, which is the present state, the sum of solar radiation transmitted into the interior of the atrium in one day was 6,340kWh.

For Case 1, which plans to extend Gayanuri Hall towards the east side of the atrium in order to provide a shadow, the amount of the transmitted solar radiation was 5,552kWh, giving the reduction effect of 12.4% when compared to the present state as shown in Figure 13. It usually blocks the transmitted solar radiation before the afternoon and barely blocks the maximum amount of the solar radiation in the afternoon.

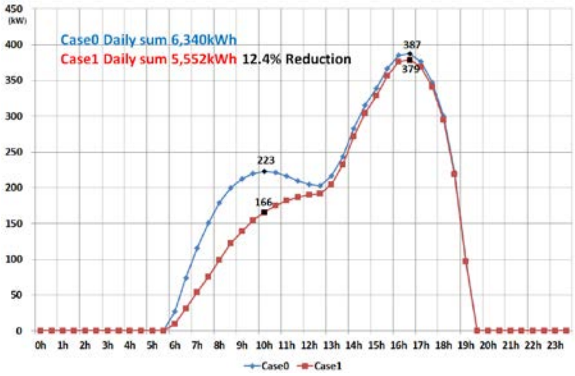


Figure 13 Solar radiation evaluation of Category 1

The simulation result of Category 2, which suggests three improvement alternatives to the roof skylight of the atrium, is shown in Figure 20. The results indicate the amount of solar radiation inflow of Case 21, which replaces the current skylight with a roof structure, is 4,464kWh, giving a relatively large effect of 29.6% when compared to the present state. The amount of solar radiation inflow of Case 22, which installs fixed interior blinds that are lightweight and made of translucent material, is 5,263kWh, giving a large effect of 17.0% compared to the present state. And the amount of solar radiation inflow of Case 23, which attaches the Low-E film to the existing 15mm single skylight, is 6,121kWh, showing a relatively s mall effect of 3.4%. The results show that all three alternatives block more solar radiation inflow in the morning than in the afternoon.

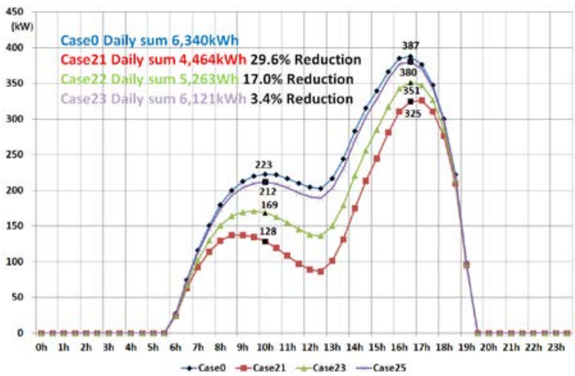


Figure 14 Solar radiation evaluation of Category 2

The simulation result of Category 3, which suggests two alternatives of installing an indoor shading device at the atrium elevation, is shown in Figure 21. According to the result, the amount of solar radiation inflow of Case 31, which installs interior blinds with high reflectivity (operable, provided that insolation intensity is more than 120W/㎡) on the west side of the fourth floor, is 5,609kWh, having a relatively high effect of 11.5% compared to the present state. The amount of solar radiation inflow of Case 32, which installs interior blinds on the east, south, and west sides of the atrium, surrounding the first floor entrance hall for the outdoor resting place and the third floor resting hall for outdoor viewing, is 5,453kWh, giving a significant effect of 14.0% compared to the present state. And the amount of solar radiation inflow of Case 33, which adopts both Case 31 and Case 32, is 4,855kWh, showing a large effect of 23.4%. For Case 31, since it installs the interior blinds on the west wide, the effect of blocking the solar radiation is most significant after noon. And Case 32 h as a substantial effect of blocking the solar radiation in the morning and in the afternoon.

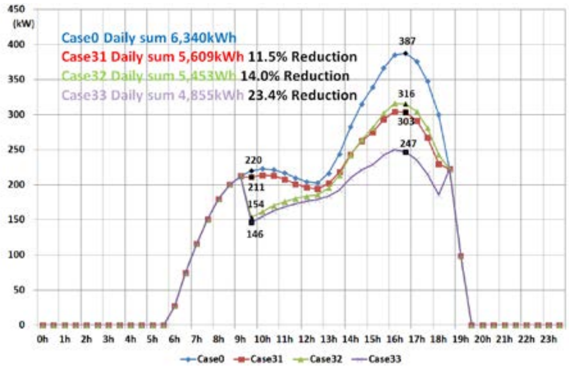


Figure 15 Solar radiation evaluation of Category 3

The simulation result of Category 4, which suggests two alternatives for changing the exterior horizontal shading device angle of the atrium, is shown in Figure 22. The amount of solar radiation inflow of Case 41, which changes the exterior horizontal shading device angle from the present angle of 0 to 30 degrees, is 6,092kWh, giving a relatively small effect of 3.9%, when compared to the present state. The amount of solar radiation inflow of Case 42, which changes the exterior horizontal shading device angle from the present angle of 0 t o 45 de grees, is 6,027kWh, showing an effect of 4.9%. Since the major direction of the exterior horizontal shading device installation faces west, its effect is usually shown after 3 PM.

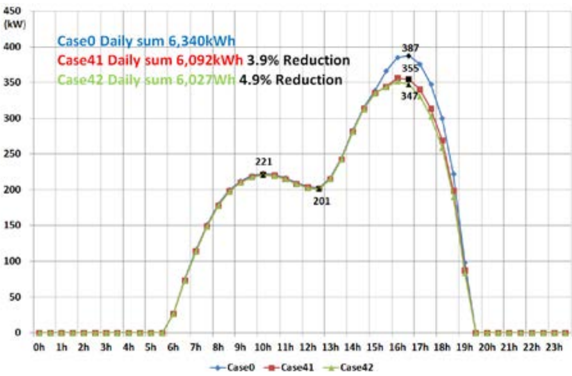


Figure 16 Solar radiation evaluation of Category 4

In the Category 5 simulation, which suggests two comprehensive alternatives that adopt features from the previous cases, the amount of solar radiation inflow of Case 51, which adopts both Case 22 a nd Case 31, is expected to be 3,778kWh. This would give a huge effect of 40.4%, when compared to the present state. And for Case 52, which adopts Case 22, 23, and 41 together, the amount of solar radiation inflow is expected to be 3,531kWh, showing a very huge effect of 44.3%, when compared to the present state. Overall, it reduces the entire amount of solar radiation from the morning to the afternoon. The maximum amount of solar radiation inflow at around 4:30 PM is 387kW, 192kW for Case 51 and 215kW for Case 52, reducing it approximately by 1/2.

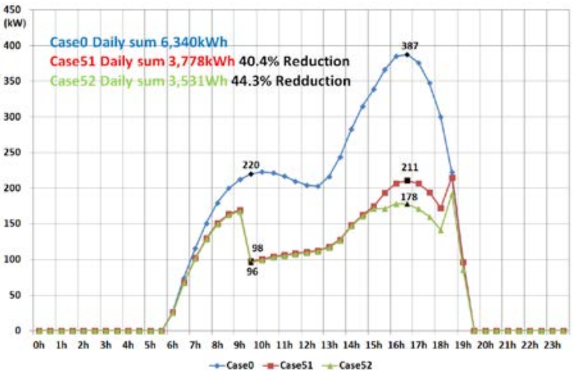


Figure 17 Solar radiation evaluation of Category 5

Case 21 replaces the current skylight with a roof structure. The analysis shows that it is a promising alternative because its effect of blocking solar radiation is 29.6% and the maximum reduction rate of cooling load 12.5%. However, there could be construction or management problems in regards to the installation availability of the roof structure.

In addition to the evaluation of the solar radiation transmitted into the Gayanuri atrium above, the study conducted a simulation evaluation regarding the maximum cooling load, which is an important factor for deciding the capacity of cooling equipment installation in the atrium. The simulation day was the same as the Summer Design Day, 15 July, and the cooling reference temperature point was set as 24℃. As shown in Figure 18, the evaluation demonstrated the maximum cooling load and reduction ratio in contrast to that of the present state, Case 0, for each architectural alternative, and the summary of the results is as follows.

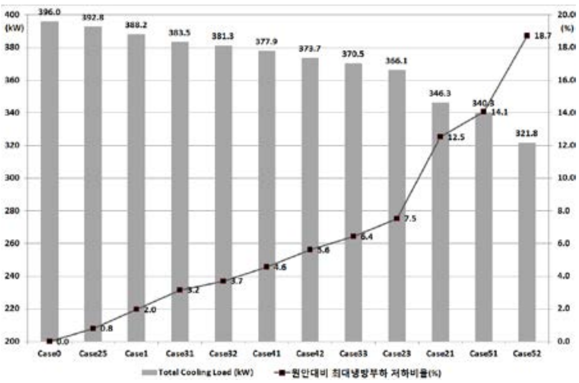


Figure 18 Evaluation and comparison of the maximum cooling load and reduction ratio according to each case

For Case 1 simulation, which plans to extend the Gayanuri building toward the east side of the atrium, the maximum cooling load was 388.2kW, showing an inadequate reduction effect of 2.0%, when compared to the maximum cooling load of the present state Case 0, which was 396.0kW. The cause of its effect being so low was that the extension of the adjacent building towards the east side was not able to demonstrate its influence for decreasing the maximum cooling load in the afternoon, since the summer maximum cooling load occurs at 5 PM.

Regarding Category 2 simulation, which suggests three improvement alternatives for the roof skylight of the atrium, the maximum cooling load of Case 21, the replacement of the current skylight with a roof structure, was 346.3kW, reducing 12.5%, when compared to the present state, and the maximum cooling load of Case 22, which installs lightweight fixed interior blinds made of translucent material, was 366.1 kW, reducing 7.5% when compared to the present state. And the maximum cooling load of Case 23, which attaches the Low-E film to the existing 15mm single skylight, was 392.8kW, reducing 0.8% when compared to the present state.

In Category 3 simulation, which suggests two alternatives of installing an indoor shading device at the atrium elevation, the maximum cooling load of Case 31, which installs the interior blinds with high reflectivity, was 383.5kW, reducing 3.2% when compared to the present state, and the maximum cooling load of Case 32, which installs the interior blinds at the east, south, and west sides of the atrium that surrounds the first floor entrance hall for the outdoor resting place and the third floor resting hall for the outdoor view, was 381.3kW, reducing 3.7% when compared to the present state. Furthermore, the maximum cooling load of Case 33, which combines both Case 31 and 32, was 370.5kW, reducing 6.4% when compared to the present state.

For Category 4 simulation, which suggests two alternatives of changing the exterior horizontal shading device angle, the maximum cooling load of Case 41, which changes the exterior horizontal shading device angle from the present angle of 0 to 30 degrees, was 377.9kW, reducing 4.6% when compared to the present state. And the maximum cooling load of Case 42, which changes the exterior horizontal shading device angle from the present angle of 0 to 45 degrees, was 373.7kW, reducing 5.6%.

Regarding Category 5 simulation, the maximum cooling load of Case 51, which adopts both Case 22 and Case 31, was 340.3kW, reducing 14.1% when compared to the present state. In addition, the maximum cooling load of Case 52, which adopts Case 22, 33, and 41 together, was 321.8kW, having a very huge effect of 18.7%.

EVALUATION OF VENTILATION RATE

In order to verify the natural ventilation cooling effect in the atrium by using low temperature outdoor air during the intermediate seasons, spring and autumn, this study examined the indoor air temperature distribution according to the change of the ventilation rate by applying the original Case 0, namely the present state.

The ventilation rate was categorized into four cases of one, three, five, and ten times/hr. The indoor air temperature analysis of the atrium according to the ventilation rate change was conducted for one month from 1 May to 31 May with the natural room air temperature under the non-operating air-conditioning situation simulation, and two days, 15 and 16 May, which showed the average distribution during the period, were selected, and their results analyzed.

When examining the indoor effective temperature distribution inside the atrium according to the ventilation rate based on the present state Case 0, where the air-conditioning was not operated in the intermediate season, as shown in Figure 19, the indoor average effective air temperature, which considers the radiation effect of insolation, was 27.9℃ for the basic plan with a one time/hr ventilation rate, 26.6℃ for three times/hr, 25.8℃ for five times/hr, and 24.8℃ for ten times/hr.

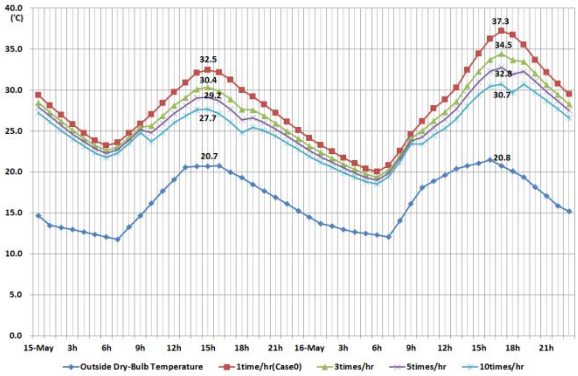


Figure 19 Atrium indoor effective temperature comparison according to the ventilation rate

CONCLUSION

Regarding the fact that the indoor temperature of the Gayanuri Hall atrium, in Kimhae-si, Gyeongsangnam-do, Korea, increases due to solar radiation, resulting in a very high temperature in summer, this study was conducted with a purpose of suggesting optimum solutions after evaluating and analyzing various architectural and ventilation improvement alternatives for improving such circumstances efficiently, and the main results of this study can be seen from the following.

1. As shown in Table 3, this study selected eleven alternatives from the five categories, which include extending the Gayanuri building towards the east side of the atrium to provide a shadow, along with alternatives for improving the roof skylight at the atrium, installing an indoor shading device at the atrium, improving the outdoor shading device at the atrium, as well as combinations of the aforementioned architectural alternatives. It evaluated their atrium insolation and cooling loads with simulations. As a result, the reduction of insolation and reduction ratio of the maximum cooling load at the atrium for each alternative were predicted in Figures 13 ~ 18, respectively.

2. Case 52 was selected as the final alternative, and the architectural improvement points of the Gayanuri Hall atrium, which were proposed based on this alternative, include the following.

a. Alternative for Improving Roof Skylight at the Atrium

First, it a dopted the alternative of installing fixed, lightweight interior blinds made of translucent material, among the alternatives that change the atrium roof skylight, in order to reduce 17.0% of the transmitted solar radiation and 7.5% of the maximum cooling load, when compared to the present state. The alternative of installing a roof structure was expected to have a significant effect, but since Gayanuri Hall would have had to be closed for a considerable length of time, it was excluded from the architectural improvement alternatives.

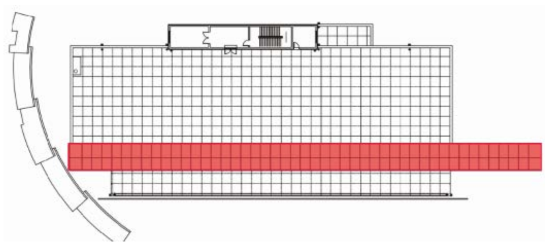


Figure 20 Installation area Of fixed- type roof skylight interior blinds

b. Alternative for Improving the Elevation of the Atrium

As is shown from Figure 21 to Figure 23, 23.4% of the solar radiation inflow and 6.4% of the maximum cooling load could be reduced, when compared to the present state, by installing interior blinds with high reflectivity slats, which are operable provided that insolation intensity is more than 120W/㎡, targeting the whole west window of the atrium, the south window of the ramp space, and the east and south sides of the atrium, and which surround the first floor entrance hall for the outdoor resting place and the third floor resting hall for the outdoor view in elevation. For the current shading louver, its sectional dimension is 240 mm × 80 mm, the separation distance from the atrium window is 400 m m, the vertical distance is 350mm, and a total of 28 louvers are installed. As shown in Figure 24, the angles of the exterior horizontal shading that is installed on the whole west side of the atrium were changed to 30° from the current horizontal direction, in order to reduce 4.6% of the current cooling load. And it is expected that its effect will increase if the vertical distance or number of installation were to be designed optimally.

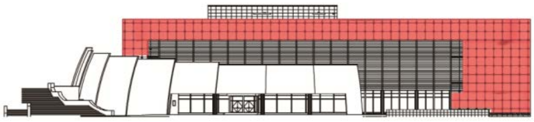


Figure 21 Installation area of operable interior blind for the west elevation of atrium)

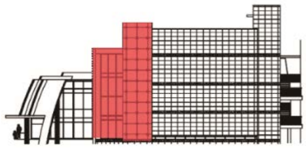


Figure 22 Installation area of operable interior blind for the south elevation of atrium

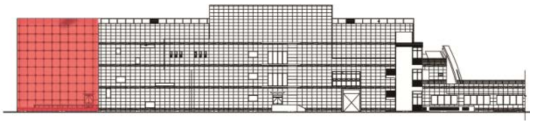


Figure 23 Installation area of operable interior blind for the east elevation of atrium

Figure 24 Alteration area of external shading louver angle for the west elevation of ramp space

3. In order to verify the natural cooling effect of the atrium by using low temperature outdoor air during the intermediate seasons of spring and autumn, the ventilation rate was set in four cases of one, three, five, and ten times/hr, based on the present state Case 0 and simulations were conducted. Figure 19 shows the change of the average effective temperature of the atrium. Therefore, the study established a natural ventilation cooling strategy for the atrium that could actively bring the outdoor air inside by preparing both low level inlet and high level outlet, using windows which can be opened, as it is shown in Figures 25 to 27, taking into consideration the outdoor air and the indoor conditions during the intermediate seasons.

Figure 25 Installation points of openable window for the west elevation of atrium

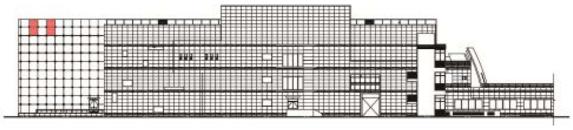


Figure 26 Installation points of openable window for the south elevation of atrium

Figure 27 Installation points of openable window for the east elevation of atrium

Based on the best plan, the current renovation design and construction are in progress, and after completion, the effect of its installation will be verified.

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