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Energy Performance and Improvement in University Library

- Concentrated on 'K'University Library located in Seojong City -

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ABSTRACT

The problem of energy consumption is more serious in university buildings than primary, middle and high school buildings. Because university buildings have generally heating and cooling systems, and various incidental facilities.

In university, the library is one of the building that many people use and the most energy is spent. So, investigation on energy saving is very important and urgent.

This study aims finally to present the guideline for low-energy design of University library by aiding a designer to select best solution in the side of energy-saving. In this paper, composition of space, utilization schedule and performance of construction materials are grasped, some primary factors that effect to energy saving are analyzed by energy simulation.

The result of this study is as follows;

First, the subject library has more cooling load than heating load because of cooling load generated during middle season. Second, green roofs is the most effective to heating load saving, but not to cooling energy. Third, outdoor air cooling is the most effective to cooling energy saving among the investigated strategies included in this study.

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KEYWORD

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1. Introduction

1.1. Background and Objectives of Research

According to a report on UNFCCC, the CO_2 level in the atmosphere exceeds 400ppm (as of 2013) for the first time since the observation began. Also, the average global temperature has increased by 0.85, the sea level 19cm (as of 2010) for the past 1333 years. These are the warning signs that catastrophic results might be caused if there is no measure against global warming. In this context, Korea, the 9th largest carbon emitter in the world, is under pressure to take concrete measures to reduce carbon emissions. Therefore, the Korean government has adopted low-carbon, green growth as a key policy direction, and pushed forward the development of renewable energy and a sustainable growth engine in cooperation with enterprises. Therefore, it is required for the building energy sector, which consumes about 1/3 of the total energy, to develop practical energy reduction measures.

In the past, school buildings were designed and constructed to provide relatively low-level indoor environment compared to other types of buildings. However, the number of school buildings with heating and cooling systems has rapidly increased in a bid to improve the education environment, resulting in energy issues.

The problem of energy consumption is more serious in university buildings than primary, middle and high school buildings. Because university buildings have generally heating and cooling systems, and various incidental facilities.[1] In particular, university libraries spent more energy than any other university buildings, but there are only a few studies that identify whether energy is efficiently spent and suggest improvements, calling for more research on this area.

1.2. Methods and Scope of the Research

This research aims to assist an architect to make an optimal decision on designs in terms of energy saving when he/she tries to provide a guideline for a low-energy library design. Sejong city was chosen as a target location, and a fundamental case study was conducted in the previous research.[2] This time, space composition, use schedule, performance of the structure, etc. of the library in the same city were identified, and an energy simulation was performed by applying several measures that affect the improvement of energy performance. The results of the each case simulation on

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[1] Hong won hwa, Lee chun mi, Kim ju young, Cho soo, A study on the characteristics of the energy consumption unit of university, Journal of the architectural institute of korea planning and design, 2008.11

[2] Roh, Ji Woong, A Basic Study on Energy Saving of University Library, Journal of the Institute of Ecological Architecture and Environment vol.13 n.4, 2013.8

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heating and cooling load and energy consumption were compared. The K library uses EHP system for heating and cooling, but the energy analysis by the characteristics of the system was not included in this research. It will be covered in the next research after a careful inspection.

2. Simulation

This research used VE (Virtual Environment), an energy analysis program, to analyze improvements for energy saving. Developed by the IES (Integrated Environmental Solutions), VE is an integrated simulation program which include the Apache-sim for a heat simulation, the Radiance for a light environment simulation, the Suncast for a solar radiation analysis, and the ModelIt, a 3D tool to describe a model.

2.1. Solar Radiation Analysis

This program calculates the solar radiation that reaches to the entire surface of a building at every step of every hour. The solar radiation is divided into two – direct solar radiation and diffuse solar radiation – and then calculated as shown below.

Direct solar radiation I_{dir} Idir is calculated as follows:

$$I_{dir} = I_{beam}\cos(\theta) \tag{1}$$

I_{beam} represents the vertical incidence component, $\theta$the incidence angle.

Diffuse solar radiation is divided into two – sky radiation (I_{sdiff}) and terrestrial radiation (I_{gdiff}) and then calculated as below.

$$I_{sdiff} = I_{hdiff}\cos2(\beta/2) \tag{2}$$

$$I_{gdiff} = \rho g I_{hglob}\sin2(\beta/2) \tag{3}$$

Ihdiff represents diffuse sky radiation on the horizon, β the surface tilt, and ρg albedo. The total solar radiation on the horizon can be described as below.

$$I_{hglob} = I_{hdiff} + I_{beam}\sin\alpha \tag{4}$$

But, here, α is the solar altitude.

2.2. Analysis on Heating and Cooling Load

The indoor conduction, convection, radiation, and infiltration were calculated with the following formula.

The spatial temperature distribution of a solid without internal heat source (Q_{cd}Qcd)(W/m^2) is calculated as below.

$$Q_{cd} = -\lambda\triangle T \tag{5}$$

Here, λ represents thermal conductivity (W/m^{2}K), and T temperature (℃).

As for the convective heat transfer (Q_{cv})(W/m^2),

$$Q_{cv} = h_c(Ta - Ts) \tag{6}$$

Here, hc is the convective heat transfer rate, Ta the air temperature (℃), and Ts the average surface temperature (℃).

A radiant heat emitted from the surface (Q_r) is

$$Q_r = \varepsilon A\sigma\theta^4 \text{Qr = ε A σ Θ4} \tag{7}$$

Here, ε represents surface heat dissipation, A the surface area, σ the Stefan–Boltzmann constant, and Θ a surface absolute temperature (°K).

The heat transfer rate related to an air current that moving around spaces (Q_{vent}) is

$$Q_{vent} = mc_p(Ti - Ta) \tag{8}$$

Here, m is air volume (kg/s), c_p the specific heat under constant pressure of air (J/kg/K), and Ti the air temperature which is supplied (℃).

After consideration on physical figures, solar gain, internal heating value and others, the heating and cooling load is calculated.

2.3. Energy Consumption Calculation

After calculating the heating and cooling load, the heating and cooling systems are set. The efficiency of the systems, auxiliary power use, and power use of an outdoor unit and fan were considered in the calcaulation of the consumption of fuel and/or electricity.

3. Subject Building and Simulation Condition

3.1. Subject Building

The subject of the simulation is the 6-story (including a basement floor) library of K university in Sejong city. The basement floor consists of research rooms and seminar rooms. Reading rooms, stack rooms, reference. etc. are located in ground floors. Fig. 1 shows the campus map and Fig. 2 the library's 1st floor plan.

Excluding the basement floor, the simulation modeled the ground floors from 1st to 5th floors, and zoning by use was conducted – the library and service zones. The library zone consisted of the reading room, stack room, and office, reference, etc. while the service zone includes the elevator core, warehouse, corridors, stairs, etc. The building contents are shown in Table 1, and the model zoning by each zone and their area is described in

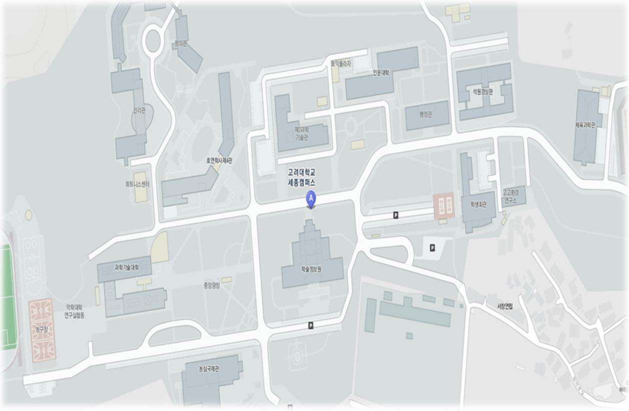

Fig. 1. K university campus

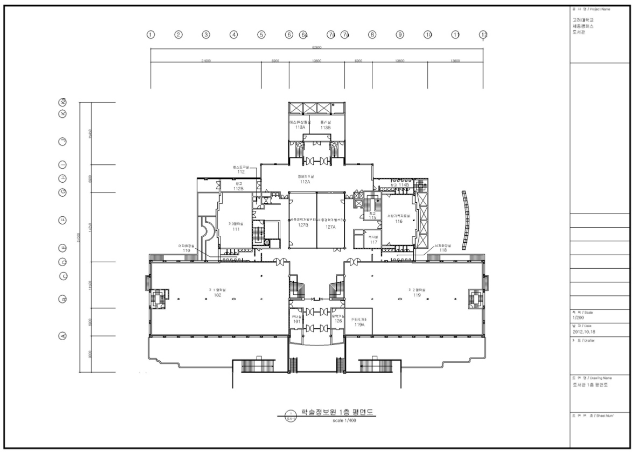

Fig. 2. library 1 floor plan

Table 1. Building contents

contents		floor	area(m^2)
library	reading room	1F, 3F	1,766.0
	stack room	1F~5F	2,856.8
	office, reference etc.	1F~3F	746.9
	elevator core, warehouse, corridor, stairs etc.	1F~5F	3,653.1
non-library	research room, seminar room,	B1	2,888.4
total		B1~5F	11,911.2

Table 2. Model zonning

zone	contents	area(m^2)
library	reading room, stack room, office, reference etc.	5,369.7
service	elevator core, warehouse, corridor, stairs etc.	3,653.1
total		9,022.8

Table 2.

The subject building changed its heating and cooling system to EHP in response to the government's energy saving policies. Before the change, the building used the central system installed in 1989 together with individual air conditioners that were added to the building when necessary. However, there have been no architectural improvement for energy saving, and control measures such as outdoor air cooling have not been implemented.

Table 3. Property of heating and cooling system

before system change		the present
boiler	flue-smoke tube boiler 3.5 ton	EHP 680 HP + hot water boiler 1 ton
refrigerator	turbo - refrigerator 460 USRT + package air-conditioner 32 eta	

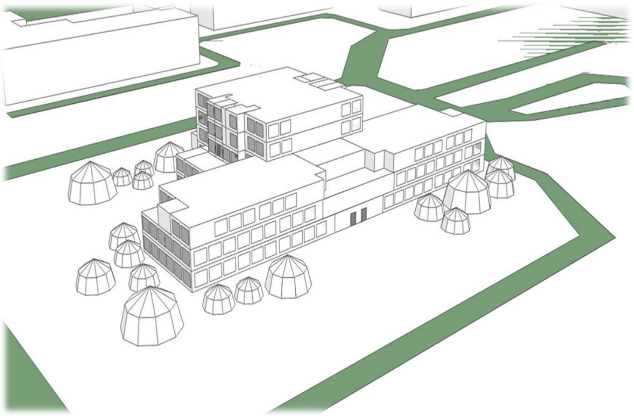

Fig. 3. Simulation model image

The property of heating and cooling system is shown in Table 3.

By analyzing the floor plan and conducting an actual enumeration, the detailed information on the building was identified. Then, the building was modeled using the Model IT of the VE (Virtual Environment). The image is shown in Fig. 3.

3.2. Simulation Condition

The material property of the building is shown in Table 4, and windows used low-e glass with 24mm thick, as shown in Table 5. During the simulation, the standard climate date provided by the Korean Solar Energy Society was used, and heating and cooling

Table 4. Property of materials

	material	thickness [mm]	conductivity [W/m·K]	specific heat [J/kg·K]
ext. wall	mortar	25	0.5	1000
	concrete	150	1.4	840
	insulation	10	0.035	1000
	plaster(dense)	9	0.5	1000
floor	cast concrete	100	1.13	1000
	insulation	63	0.025	1400
	chip board	25	0.15	2093
	synthetic carpet	10	0.06	2500
roof	mortar	24	0.5	1000
	cast concrete	60	1.4	840
	asphalt	5	0.5	1000
	mortar	24	0.5	1000
	concrete lightweight	100	2.3	999.8

Table 5. Property of glass

material	thickness [mm]	conductivity [W/m·K]	U-value [W/m²·K]	g-value
pilkington K	6	1.06	1.98	0.64
cavity	12	0.001		
clear float	6	1.06		

Table 6. Simulation condition

zone		library	service
temterature setpoint (℃)		heating : 18 ℃, cooling : 26 ℃ -	-
internal heat gain (W/m²)	lighting	10	10
	machine	0.0 (but office is 0.3)	0.3
	human	1.8	1.5
operating schedule	week	- stack room : 24 hour on - reading room : 8 : 30 am ~ 12:00 pm - office : 8 : 30 am ~ 6 :00 pm on, weekend off	-
	month	- stack room : 24 hour on - reading room : partially on during summer and winter vacation - office : 8 : 30 am ~ 6 :00 pm on, weekend off	-

temperatures were set 18℃ and 26℃ respectively.

Related research[3)] was used in identifying the amount of internal heat. Based on interviews, week day, weekend, and monthly schedules were surveyed to find out the overall operation schedule. More specifically, the stack room controls temperature for 24 hours while the reading room has different schedules during week days and vacation. During week days, it provides air conditioning from 8:30 to 24:00 while during vacation, from 8:30 to 24:00 for only some reading rooms in 1st and 2nd floors. (see Table 6)

4. Energy Simulation of Subject Building

4.1. Simulation Cases

This research reviewed the standard Case (Case 1) by applying the operation result based on the result of the on-site inspection under the condition that the material properties of the existing walls and windows were applied when windows were closed. To check whether the energy performance of the building was improved, Case 2 with a strengthened wall insulation and Case 3 with roof afforestation were reviewed. Also, to identify changes caused by the change of glass, Case 4 with clear glass instead of low-e insulating glass was examined. The effectiveness of outdoor air conditioning was examined by opening the windows in May when the outside temperature is at 18℃to 26℃ (Case 5).

Table 7. Simulation cases

zone	U – value (W/m² · K)			win-dow
	ext. wall	roof	window	
case 1 (standard)	0.92	3.01	1.98	closed
case 2 (ext. wall insulation)	0.39	3.01	1.98	closed
case 3 (roof afforestation)	0.92	0.68	1.98	closed
case 4 (clear glass)	0.92	3.92	2.74	closed
case 5 (outdoor air cooling)	0.92	3.01	1.98	open

Table 8. Improvement of materials

	material	thickness [mm]	conductivity [W/m·K]	specific heat [J/kg·K]
ext. wall (case 2)	mortar	25	0.5	1000
	concrete	150	1.4	840
	insulation	60	0.035	1000
	plaster(dense)	9	0.5	1000
roof (case 3)	grass	50	0.09	2000
	soil	90	0.22	3300
	non-woven	3	0.07	1360
	drain	50	0.36	840
	mortar	24	0.5	1000
	cast concrete	60	1.4	840
	asphalt	5	0.5	1000
	mortar	24	0.5	1000
	concrete lightweight	100	2.3	999.8

Table 9. property of clear glass(case 4)

material	thickness [mm]	conductivity [W/m·K]	U-value [W/m²·K]	g-value
pilkington K	6	1.06	2.1	0.64
cavity	12	0.001		
clear float	6	1.06		

Table 8 shows materials used in Case 2 (wall) and Case 3 (roof material for roof afforestation). Also, Table 9 shows the property of glass used in Case 4 where clear glass was used instead of insulating glass.

4.2. Simulation Result

1) Case 1 (Standard Case)

The monthly heating and cooling load per square meter is shown in Fig. 4. The heating load goes up rapidly and records the highest of 11.4 [kWh/m²] in January. Then it decreases until March.

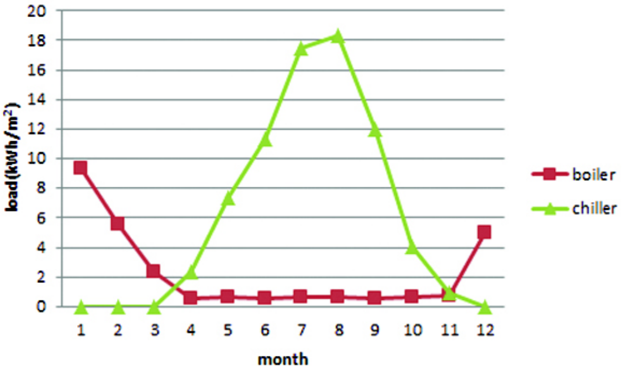

Fig. 4. Monthly heating and cooling load

[3)] Jung, Jae-woong, Kim, Dong-woo, Seok, Ho-tae, Yang, Jeong-hoon, A Study on the Improvement Plans of Energy Performance in University Building through the Analysis of Energy, Journal of the Korean Solar Energy Society, Vol. 30, No.1, 2010

Throughout the year, the total heating load per square meter is 32.5 [kWh/m^2].

The cooling load increases from April and hits the highest of 18.1 [kWh/m^2] in August. Then it decreases till October. This result shows that except for July to August, there is a significant amount of cooling load during the middle season, leading to the increase of the total cooling load. The total cooling load throughout the year is 70.2 [kWh/m^2], significantly surpassing the heating load. It implies that reducing the cooling load is a key in energy saving.

2) Case 2～4

The effects of Case 2～4 to heating and cooling were analyzed based on load per square meter.

First, Fig. 5 shows the effects to the heating load. Case 3 that afforestation of the roof was applied reduces the heating load drastically showing 1/3 of the total heating load of Case 1, standard case. However, Case 4 which compared the effects of glass shows no significant difference. As for Case 2 with improved insulation, the total heating load decreases only about 17%.

Fig. 6 shows the effects of each case to the cooling load, monthly cooling load per square meter.

Unlike the effects to the heating load, there was no case showing significant effects. Case 2 and Case 3 increase the cooling load. Case 3 in particular, which is the most effective in reducing the heating load, records more increase of the cooling load than any other cases. This cooling load increase is concentrated in the middle season except for July and August, which implies that negative factors of roof afforestation such as blocking radiational cooling in the night time, not positive factors such as solar heat protection, affect a lot. The effects of roof afforestation should be studied and examined in the future.

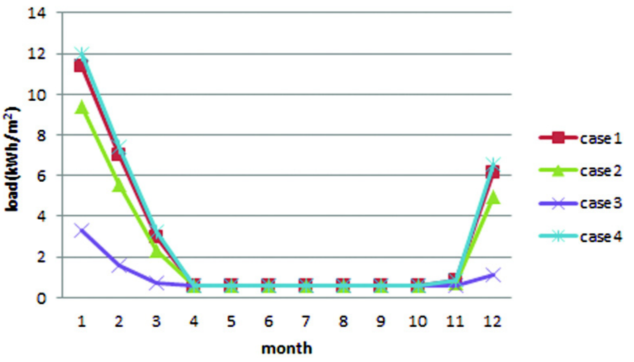

Fig. 5. Monthly heating load

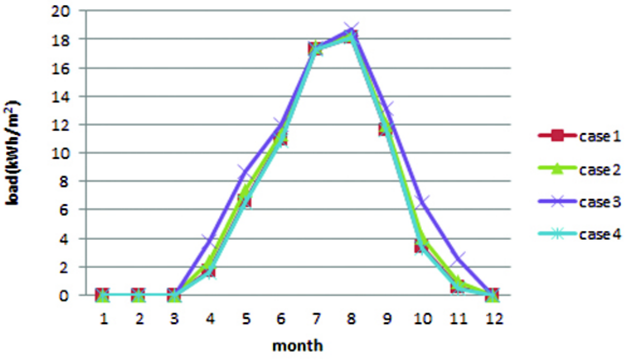

Fig. 6. Monthly cooling load

3) Energy Use Comparison (Case 2～5)

After the calculation of the heating and cooling load, air conditioning system performance was set to compare the amount of energy use. Basically, if the same systems are compared, the energy consumption amount shows a similar trend showed in the heating and cooling load. However, this research examines the effects of outdoor air cooling in May (Case 5) to compare with Case 1~4, which analyzes the annual effects. It will be necessary for future research to consider detailed control conditions such as controlling the schedule of outdoor air cooling when comparing different systems.

Table 10 shows energy consumption of 5 Cases in this research.

Table 10. Simulation results

case	energy (MWh)		
	heating	cooling	sum
case 1	188.5	145.1	333.6
case 2	157.3	152.8	310.1
case 3	66.6	170.8	237.4
case 4	198.0	144.4	342.4
case 5[*1]	3.5(3.5)	2.3(13.7)	5.8(17.2)

*1 is examined only in May, and Case 1's value is in parentheses

As shown in the heating and cooling load comparison, the energy consumption of Case 3, the most effective in reducing the heating load, shows the lowest total energy use despite increase in the energy use for cooling. Case 2 with improved insulation is effective in reducing the heating load, but energy consumption is reduced by only 7% compared to Case 1. Case 4 comparing the effects of different glass is proved to be the least effective. Case 5 examining the effects of outdoor air cooling in May reduces energy use for cooling by about 83% compared to Case 1.

Outdoor air cooling is proved to be the most effective among the cases examined in this research under the condition that the subject building focuses on reducing the heating and cooling load as well as energy consumption. It will be necessary to analyze the detailed outdoor air cooling schedule throughout a year based on this research.

5. Conclusion

Targeting the library of K university in Sejong city, the effects of energy saving measures were analyzed based on the building and facility composition and characteristics in the building use. The result The result of this study is as follows;

1) Roof afforestation (Case 3) is the most effective in reducing the heating load while outdoor air cooling (Case 5) is the most effective in reducing the cooling load.

2) The subject building's cooling load surpasses the cooling load significantly. The reason behind is that a significant amount of cooling load occurs in the middle season except for July to August, leading to the increase of the total cooling load.

3) Roof afforestation is very effective in reducing the heating load, but has negative effects in reducing the cooling load. The reason behind is that negative factors such as blocking radiational cooling in the night time, not positive factors such as solar heat protection, affect a lot. The effects of roof afforestation should be studied and examined in the future.

4) Outdoor air cooling is proved to be the most effective in reducing energy consumption for cooing among the cases examined in this research. It will be necessary to analyze the detailed outdoor air cooling schedule throughout a year based on this research.

Acknowledgement

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