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Determining Appropriate Capacity on Installing Photovoltaic System at Deteriorated Educational Facilities

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ABSTRACT

With high acknowledgements of environmental conservation and energy saving, many architectural technologies using renewable energy have been recently applied at buildings which take about 20% of total energy consumption. Among renewable energy sources, the photovoltaic is considered as the most highly potential one due to advantages of infiniteness and cleanliness. Also, projects to install renewable energy systems have been continuously performed at deteriorated educational facilities as energy efficient remodeling projects or green school projects by the Korean government. This paper proposes appropriate capacities by school level on installing photovoltaic systems at deteriorated school buildings, based on the balance of annual electricity power demand and supply between buildings and systems. Using the Visual DOE program and Merit program, the appropriate installment capacity of photovoltaic system turned out be 40kWp at elementary school building and 60kWp at middle and high ones. In addition, annual energy use proved to be reduced by 20.2% at elementary school, 26.9% at middle school, and 21.0% at high school by installing photovoltaic systems with the appropriate capacities.

KEYWORD

Deteriorated educational facility, Photovoltaic system, Installment capacity

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1. INTRODUCTION

1.1. Research Backgrounds and Objectives

With the recent increase in awareness of environmental protection and energy conservation in South Korea, various construction technologies utilizing renewable energy are being applied to the building sector, which accounts for approximately 20% of the total energy consumption[1)]. The use of renewable energies such as photovoltaic power, solar energy, wind power, and geothermal energy, has been recognized as optimal solution for solving the global energy and environmental issues, and the current state of research and policy has been focusing on the utilization and distribution of renewable energy[2)]. Of these renewable energies, the photovoltaic energy has been in the limelight as alternative energy source because it can provide a limitless amount of clean green energy, and it is appraised as energy source with the highest potential[3)].

As public building, the school facility is an ideal place for installation and distribution of renewable energy, for it will be highly educational and effective in raising public interest, and its relatively wide roof area and modularized configuration space make schools an optimal building for installing solar power systems. Also, according to the Industry and Energy Affairs Notice No. 2012-18 「Regulation on Promoting Rationalized Energy Use in Public Institutions」, it is mandatory for school facilities in South Korea to install renewable energy systems. The government began by passing law, which obligated 5% of the total construction cost to be invested in the installation of renewable energy facilities in the construction of newly-built public facilities with a total floor area of over 3,000m^2 and currently, all newly-built or renovated buildings with a total floor area of over 1,000m^2 are required to invest and install a renewable energy source that can account for over 12% of the expected energy use[4)].

With over 74% of the country's buildings being built over 15 years ago, before the insulation standards were reinforced, remodeling deteriorated buildings for energy efficiency is essential

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1) Korea Energy Economics Institute, Yearbook of energy statistics, 2012.
2) Won-Duck Seo, and 2 others. A study on the power consumption and the generation efficiency and land rate of the building integrated photovoltaic system in university dormitories, Journal of the Korea Institute of Ecological Architecture and Environment. Vol. 11. No. 6. 2011. p.87-93.
3) Hoon Park, and 2 others. The performance evaluation of photovoltaic-integrated lightshelf systems, Journal of the Korea Institute of Ecological Architecture and Environment. Vol. 12. No. 6. 2012. p.129-134.
4) Act on the Promotion of the Development, Use and Diffusion of New and Renewable Energy, Article 15, Korea Ministry of Government Legislation, Government legislation information center, 2014.

and thus the 「Green Remodeling Activation Plan」 was finalized in the Minister of Economic Relations Conference in July 2013. It indicates the need to increase the proportion of energy-saving buildings by the reinforcement of regulations on various energy standards on newly built buildings, but it also suggests the importance of remodeling deteriorated buildings into a more energy efficient design.

In particular, deteriorated school facilities over the typical building lifespan of 25 years account for 50% of all schools [5], the installation of renewable energy systems is being promoted as part of the energy-efficiency remodeling project and the Green School Project, which is the core project of the government's Green New Deal Project.

Previous studies on the Green School Project [6] has analyzed that regarding application of renewable energy, the Photovoltaic (PV) system accounts for the largest part of the budget. However, because the PV system highly depends on the natural environment, the supply pattern is inconsistent and unpredictable, and as a result, if the system capacity is determined by the total power demand of the building, it may lead to excess energy due to overproduction. In other words, it may lead to unnecessary investment in renewable energy systems. Therefore, in order to determine the optimal installation capacity of PV systems, the annual electricity consumption patterns of the building must be analyzed, and a strategy for efficient use of power must be implemented.

The objective of this study is to determine the optimal capacity for fixed PV systems based on the conformity degree of demand/supply patterns of renewable energy systems and the annual electricity demands of deteriorated elementary, middle, and high school buildings.

1.2. Research Methods and Scopes

This study analyzed the demand/supply patterns of standard school models of deteriorated schools derived from previous studies [7][8][9] and the input elements of the Visual DOE energy simulation standards applied to standard schools using the Merit program. Based on the results, the optimal installation capacity of PV systems for each school level was determined, and the energy savings effect compared to the deteriorated schools' average annual energy consumption was analyzed.

2. GREEN SCHOOL PROJECT

The previous study on the current status of the Green School Project investigated the content and scope of the Green School Project, which is the core project of the government's Green New Deal Project. The Green School Project was conducted in 108 schools between 2009-2010, and the project analysis for 21 of the schools is as follows.

(1) The Green School Project budget is 1.6 to 5.7 billion won, and about 3 billion won was used on average.

(2) The applied budget for each element is as follows; energy savings facilities (30%), eco-friendly materials (28%), ecological and nature friendly facilities (12%), health and safety facilities (10%), students and staff facilities (2%), and other facilities (18%).

(3) Details of the energy savings budget are as follows; energy-efficient windows and doors replacement (52%), renewable energy facilities (25%), and exterior wall insulation and wall repair (13%).

(4) Details of the renewable energy budget are as follows; PV systems (44%), geothermal and solar thermal facilities (36%), solar street lights (20%).

3. MODELING FOR STANDARD SCHOOL MODELS AND ENERGY CONSUMPTION CALCULATION

3.1. Standard School Setting

In the previous study, a virtual school was set as standard to evaluate energy performance in deteriorated elementary, middle and high schools. Based on the 「School Facility Standard Design」 in 1980 and S-elementary school in Kyunggi-Do selected on time, physical, performance, and operational standards, the establishment year of the virtual school was set in the 1980s, the building structure was set as reinforced concrete structure, and it was set as a four-story building with an area of 1,333m^2. Furthermore, the cooling method was set as package air conditioning, heating systems were designated as gas heaters, the exterior wall insulation was set as T50, roof thermal insulation was T100, flooring was artificial stone floor finishing, and the windows and doors were set as double glazed. Table 1 and Fig. 1 show an overview of the standard school and the typical floor plan.

5) Sung-Cheol Park, and 1 other. Development of determination model to remodel deteriorated education facilities, Korea Educational Development Institute, 2009. p.42.

6) Myung-Hee Sim, and 2 others. Domestic situation and foreign case study of green school, The Fall Annual Conference of the KIEAE, Vol. 11. No. 2. 2011. p.261-266.

7) Sang-Choon Lhee, and 3 others. Comparing performances of factors for reducing energy at deteriorated elementary school buildings, Journal of the Korea Institute of Ecological Architecture and Environment, Vol. 12. No. 2. 2012. p.111-116.

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Table 1. Overview of Standard School

Structure	Reinforced concrete
Size	Four floors above ground
Building area	1,333m^2
Gross area	5,826m^2
Architectural form	0.5B/1.0B brickmasonry T50 bid-type insulating board, Cement-mortar finish
Window	U-factor: 4.06 W/m^2℃, SHGC: 0.774, Tvis: 0.83 Double window
Roof type	Flat slab
Cooling system	Package air conditioner
Heating system	Gas fan heater
No. of class	25

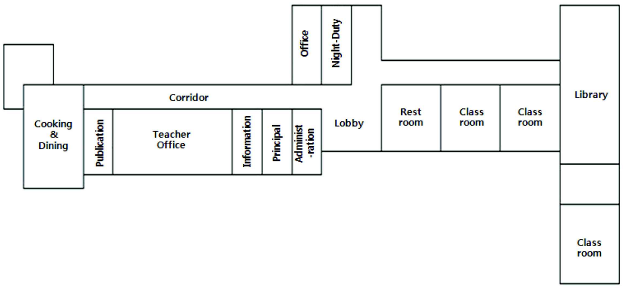


Fig. 1. Typical Floor Plan of Standard School

3.2. Energy Analysis Modeling and Baseline Selection

On the dynamic simulation program of the Visual DOE, zoning was performed with respect to rooms with identical air conditioning when determining simulation analysis models for energy analysis simulations for each school level. In addition, energy consumption calculation for non air-conditioned rooms were included, and input data for standard school energy analysis model such as schedule, infiltration schedule, physical properties for each material, and HVAC system variables of air-conditioned and non air-conditioned rooms were set based on the 「School Facility Standard Design」 and the blueprint for S-elementary school. However, schedules including actual use time, indoor time, density, and air-conditioning time, which are the biggest factors in assessing energy performance in school facilities, were set differently for each school level.

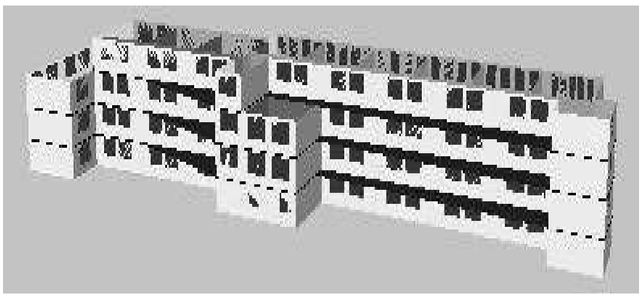


Fig. 2. Energy Simulation Modeling for Standard School

Table 2. Input data for Baseline on Insulation (W/m^{2}K)

Type	Heat transmission coefficient	Note
Exterior wall	0.47	"Level 2" 50T
Interior wall	2.65	Standard drawing suggestion
Roof	0.34	"Level 2" 100T
Exterior window	4.07	Aluminium frame+3T pair glass
Interior window	4.30	Wood frame+pane glass

Table 3. Input Data for Baseline on Other Factors

Type	Input data
Southern louver	None
Indoor setting temperature	Cooling 26℃ / Heating 20℃
System efficiency	COP 2.2 (Package air conditioner) Heating efficiency 80% (Gas fan heater)
Window SHGC	0.78
Infiltration	0.74ACH
Natural ventilation	21.6m^3/hr
Artificial lighting	40W T10 fluorescent lamp

In addition, based on insulation, windows and doors (SHGC), natural light (south shades), control (system efficiency and indoor set temperature), and others (infiltration, natural ventilation, and artificial lighting), which are important factors for energy efficiency remodeling at deteriorated school facilities, energy simulation was performed according to the application of the above mentioned technologies in the standard school model. The baseline input data used for standard school energy analysis were based on the 「School Facility Standard Design」, blueprint of the standard school, school health regulations (indoor set temperature and natural ventilation), and previous studies[10) (infiltration level), and the details are listed on Tables 2 and 3.

3.3. Energy Consumption for Each School Level

The annual energy consumption was analyzed according to each school level by the energy analysis model, which applied the baseline settings for standard schools, and the results are listed in Table 4. The results indicated that the average annual energy consumption was 123,719kWh/yr at elementary school, 144,080kWh/yr at middle school, and 199,982kWh/yr at high school. The total annual energy consumption at high school was 61% higher compared to elementary school, and 23% higher compared to middle school, and the total energy consumption at middle school was 32% higher compared to elementary school.

In detail, the annual electric energy consumption was 51,468kWh/yr at elementary school, 58,315kWh/yr at middle school, and 88,268kWh/yr at high school. The annual heating

10) Jin-Il Cho, and 4 others. A study on developing zero energy & ecological school model(II), Korea Educational Development Institute. 2009.

energy consumption was 27,277kWh/yr at elementary school, 32,508kWh/yr at middle school, and 39,342kWh/yr at high school, and as for air-conditioning energy, it was 44,974kWh/yr at elementary school, 53,257kWh/yr at middle school, and 72,372kWh/yr at high school.

Table 4. Annual Energy Use by School Level (kWh/yr)

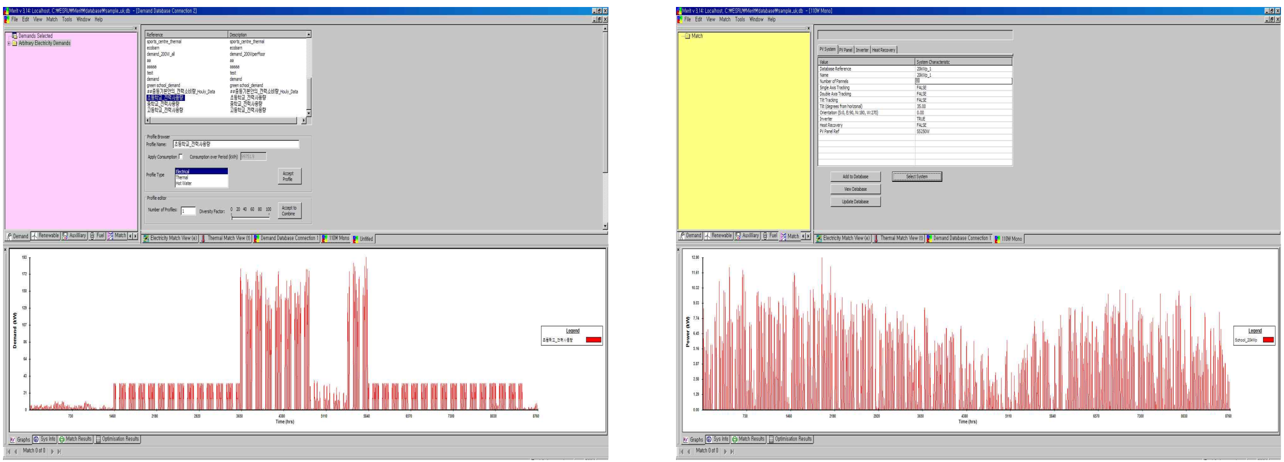
Type	Elementary	Middle	High
Electricity power energy	51,468	58,315	88,268
Heating energy	27,277	32,508	39,342
Cooling energy	44,974	53,257	72,372
Total energy	123,719	144,080	199,982

4. DETERMINING THE APPROPRIATE INSTALLATION CAPACITY OF THE PV SYSTEM

School facilities are ideal places for installation and distribution of renewable energy, for they will be highly educational and effective in raising public interests, and their relatively wide roof area and modularized configuration space make schools an optimal building for installing solar power systems. However, because the PV system is highly dependent on the natural environment, the supply pattern is inconsistent and unpredictable, and as a result, if the system capacity is determined by the total power demand of the building, it may lead to excess energy due to overproduction. In other words, it may lead to unnecessary investment in renewable energy systems. Therefore, in order to determine the optimal installation capacity of PV systems, the annual electricity consumption patterns of the target building must be analyzed, and a strategy for efficient use of power must be implemented. In this chapter, the optimal capacity for fixed PV systems was determined based on the conformity degree of demand/supply patterns of renewable energy systems and the annual electricity demands of elementary, middle, and high school buildings.

4.1. Analysis Method

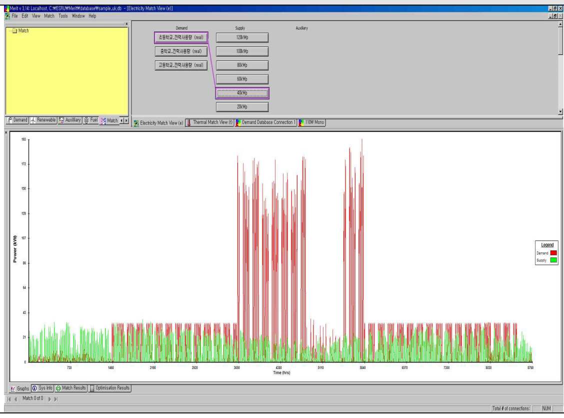
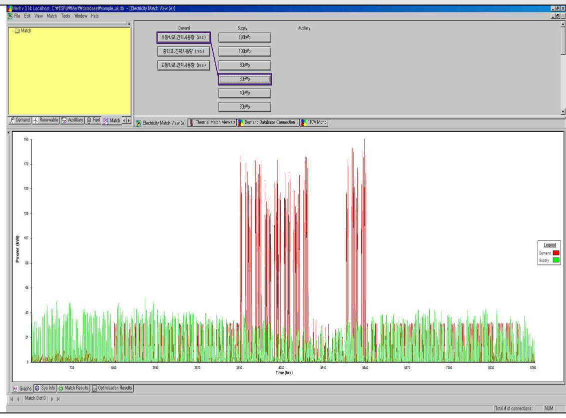
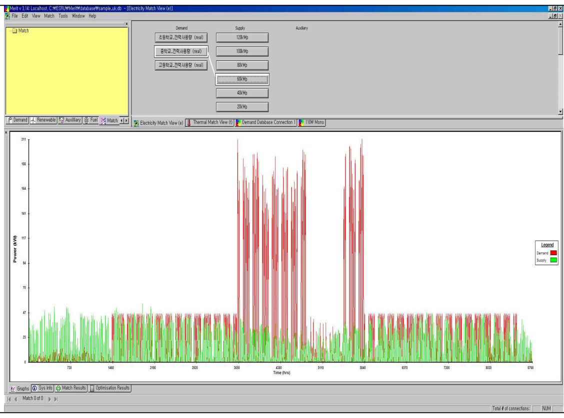
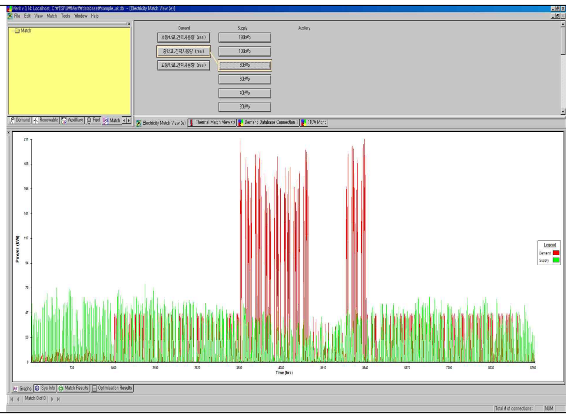
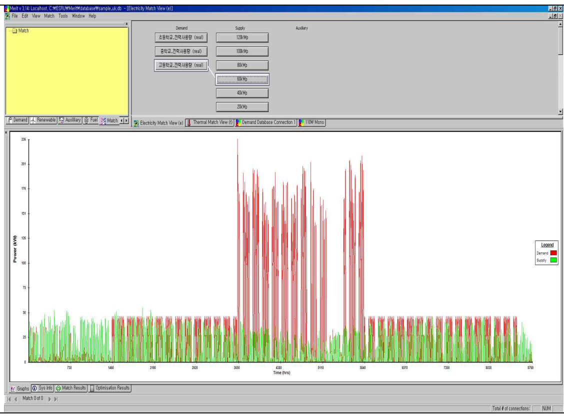
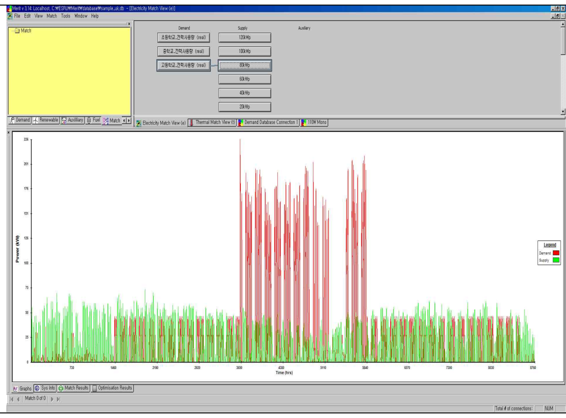
The Merit program was used to analyze the power supply/demand patterns. The Merit is a program used to establish energy plans for building or neighborhoods, developed by the ESRU (Energy Systems Research Unit) of Strathclyde University in Scotland. The program is used as a tool to evaluate the suitability of a given energy supply system by assessing the user's demands through matching analysis. As an input condition for simulation analysis, each school level's energy demands were set hourly for a total 8,760 hours per year by utilizing the Hourly Data Output feature of the Visual DOE program used for energy simulation. The PV installation capacity was divided into six stages from 20kWp to 120kWp, and analyzed (Refer to Fig. 3). Because the availability of the standard school roof area is about 1,200㎡, considering the area required for copper shades and maintenance, the maximum PV installation capacity was set as 120kWp, which is the total required floor area for crystalline solar cells, the most commonly distributed PV system, that needs floor area of approximate 10㎡/kWp per unit. The supply target for the power generated by the PV system was based on the demand of the lights and equipment during the time when the heat source system is not operating, which reflects the fact that the energy sources may be measured differently depending on the type of the heat source system and that operation may be limited, and depending on the operating systems of each school, such as the vacation period, measurements may be low even though it is during the peak usage period.



a) Annual electricity power demand pattern (elementary school)　　b) Annual electricity power production (20kWp capacity)

Fig. 3. Annual Electricity Power Demand Pattern and Production

Table 5. Result on Electricity Power Demand and Supply Pattern Analysis

Type	Appropriate capacity	Surplus capacity
Elementary school	 Capacity : 40kWp	 Capacity : 60kWp
Middle school	 Capacity : 60kWp	 Capacity : 80kWp
High school	 Capacity : 60kWp	 Capacity : 80kWp

4.2. Analysis Results

Table 5 shows the supply/demand patterns for each school level attained through simulation. As shown in the analysis results, the appropriate capacity of the PV system was 40kWp for elementary school and 60kWp for middle and high schools on the standard school, and the analysis indicates that if the installation capacity is increased by 20kWp from the appropriate installation capacity for each school level, energy production appears to be greater compared to the interim peak hourly demand, leading to oversupply. Based on the analysis results, energy savings depending on PV system installation was reflected in energy analysis, and for the standardization of the appropriate installation capacity for the PV system, the appropriate installation capacity for each school level was proposed in Table 6. The appropriate capacity of PV systems for each school level was indicated as 1.4 times the number of classrooms at elementary school, and 2.0 times the number of classrooms at middle and high schools.

Table 6. Appropriate Capacity of Photovoltaic System by School Level

Type	Capacity determining standard
Elementary school	(No. of Class×1.4) kWp
Middle school	(No. of Class×2.0) kWp
High school	(No. of Class×2.0) kWp

Table 7. Annual Energy Production & Consumption by Photovoltaic System (kWh/yr)

Type	40kWp PV system	60kWp PV system
Produced energy(+)	35,610	60,580
Consumed energy(-)	19,820	30,620
Surplus energy	15,790	29,960

Table 8. Annual Energy Reduction by Photovoltaic System at Elementary School (kWh/yr)

Type	Baseline	Photovoltaic (40kWp)
Electricity power energy	51,468	38,584
Heating energy	27,277	26,449
Cooling energy	44,974	33,716
Total energy	123,719	98,749
Energy reduction rate	-20.2%	

Table 9. Annual Energy Reduction by Photovoltaic System at Middle School (kWh/yr)

Type	Baseline	Photovoltaic (60kWp)
Electricity power energy	58,315	38,701
Heating energy	32,508	31,234
Cooling energy	53,257	35,345
Total energy	144,080	105,280
Energy reduction rate	-26.9%	

Table 10. Annual Energy Reduction by Photovoltaic System at High School (kWh/yr)

Type	Baseline	Photovoltaic (60kWp)
Electricity power energy	88,268	65,620
Heating energy	39,342	38,630
Cooling energy	72,372	53,802
Total energy	199,982	158,052
Energy reduction rate	-21.0%	

4.3. Annual Energy Saving by School Level through the PV Installation

In order to calculate the energy savings of school levels following the PV installation on the roof, appropriate alternatives for each school level were selected and compared with the standard energy use for each different purpose. As an alternative for the PV installation, solar power systems of 40kWp were installed at elementary school, and solar power systems of 60kWp were installed at middle and high schools. Examination of the blueprint of the standard school showed that the fixed PV system could be installed in 1,200m^2, thus approximately 10m^2 of roof area was required per 1kWp of PV capacity. Table 7 indicates the annual production (power generation) and consumption (supply) of the standard school following the installation of the solar power system. For example, if a solar power system of 40kWp is installed, annual energy consumption is 19,820kWp/yr and the annual energy production is 35,610 kWp/yr, which makes the annual excess energy 15,790kWh/yr. Therefore, as shown in Tables 8, 9, and 10, the installation of the appropriate capacity of solar power system reduced the annual energy consumption by 20.2% at elementary school, 26.9% at middle school, and 21.0% at high school, with the largest annual energy saving at middle school building.

5. CONCLUSIONS

Among the renewable energy sources being implemented on deteriorated school facilities as a part of the energy efficient remodeling project or the Green School Project, this study proposed the appropriate installation capacity of PV systems for each school level based on the conformity degree of demand/supply patterns of renewable energy systems and the annual electricity demands of deteriorated elementary, middle, and high school buildings. Furthermore, it analyzed the energy saving effects of PV installation in comparison with the annual energy consumption of the energy simulation applied baseline input data to the standard models of deteriorated schools derived from previous studies. The results from the analysis in this study are as follows.

(1) Based on the standard school model, the appropriate capacity of PV systems is indicated as 40kWp at elementary school building, and 60kWp at middle and high school buildings.

(2) The appropriate capacity of PV systems for each school level is indicated as 1.4 times the number of classrooms at elementary school, and 2.0 times the number of classrooms at middle and high schools.

(3) The installation of the appropriate capacity of PV systems reduces the annual energy consumption by 20.2% at elementary school, 26.9% at middle school, and 21.0% at high school.

The application of the appropriate installation capacity of PV systems found in this study can bring about economic benefits of avoiding unnecessary investment in renewable energy systems by preventing overproduction of power compared to the interim peak hourly demand, leading to oversupply. Future studies would focus on determining the type of solar power system (single-layer and multi-row parallel system) and determining the appropriate capacity depending on the installation angle, and further researches directly focusing on energy costs seem to be required. Moreover, additional researches through comparative analysis with studies assessing the optimal capacity and investment cost of other renewable energy sources applicable to deteriorated school facilities would be conducted in order to determine the best renewable energy system.

Acknowledgement

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