

## **A Study on Energy Conservation Refurbishment for Existing Office Buildings toward Zero Energy Building**

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**Abstract:** In this paper, the potential for zero-energy-building (ZEB) was examined by means of refurbishment of existing office buildings. Most existing buildings have not improved yet while the technology of energy conservation is applied to new buildings. Therefore, we assessed an influence of refurbishment for energy conservation, even as were aimed at proposing proper method to obtain adequate effect. This paper assumed four refurbishment cases based on standard case and computer simulations were performed to calculate heat load and primary energy consumption for air conditioning. Furthermore, installation effect of photovoltaic power generation and energy consumption of lightning and outlet were estimated. This result showed that it was quite difficult to achieve ZEB by reason that photovoltaic power generation couldn't make up for all of the electric requirements. In the future, application of unused energy and innovative approach will be needed in addition to building energy saving methods and high-efficiency system.

**Key Words:** ZEB, Refurbishment, System Efficiency

### **1 INTRODUCTION**

In the context of the energy consumption of commercial buildings has increased in the past decades in Japan, there is a move to be the ZEB. The ZEB is an attempt to be close to zero primary energy consumption per year of building. In Japan, the goal for fulfillment of the ZEB is on average of new buildings by around 2030). In short, achievement in existing building is an important issue in the future.

In order to achieve the ZEB, thorough energy saving ,creating energy and energy of zero are required in addition to exact energy management. It should be noted that showing the effect of energy saving is a very important, and also it is necessary to consider the guidelines for the ZEB of existing buildings .

The purpose of this study is to evaluate the expected energy savings by energy conservation renovation and to propose a strategy for obtaining a sufficient energy-saving effect .The paper shows the effect obtained by the energy-saving renovation assumed an existing building, the effect on the system efficiency and the effect of introducing photovoltaic power generation.

### **2 OUTLINE OF THE CASE STUDY AND OBJECT**

Figure 1 shows the model office building outline. The author assumed that the building located in Tokyo with a total floor area of about 5,000 m<sup>2</sup>. Figure 2 shows the heat source

system diagram for the model building. The building is the centralized air conditioning system and consist of three air cooling heat pump units.

In this study, it is assumed that the two types of refurbishment . The one is a refurbishment of building which conduct energy saving measures (building envelope performance improvement, internal load reduction and outdoor air load reduction). The other is a refurbishment of building equipment which convert to a high efficiency heat source equipment or variable flow control. Table 1 shows an outline of each cases.

As shown in Table 1, four cases were assumed in this study. Case 1 is assumed the building of the general level using the currently available standard energy efficient technologies. Case2 is conducted energy saving of a building on Case1. Case3 is conducted energy saving of a building equipment on Case1. And Case4 is conducted two types of the energy saving (building and building equipment).

First of all, We consider the effect on the heat load due to building refurbishment conducting an annual heat load calculation using the Micro HASP/TES ver2.6 to study these cases. Annual heat load calculations were performed by applying heat load conditions in Table 1. Cooling period is May.1 to Oct.31 and heating period is Nov.1 to Apr.30. The HVAC equipment is operated 9:00 through 18:00 (pre-cooling started at 8:00 or preheating started at 7:00) on working days, and shut down on Saturdays, Sundays and holidays. Also, annual primary energy consumption of each cases were calculated by using the Life Cycle Energy Management (LCEM) tool that is energy simulation tool for the air conditioning equipment.

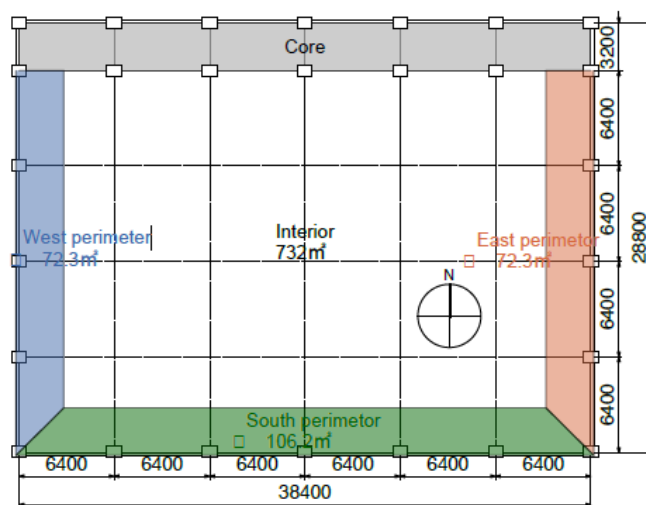


Figure 1 : Floor Plan

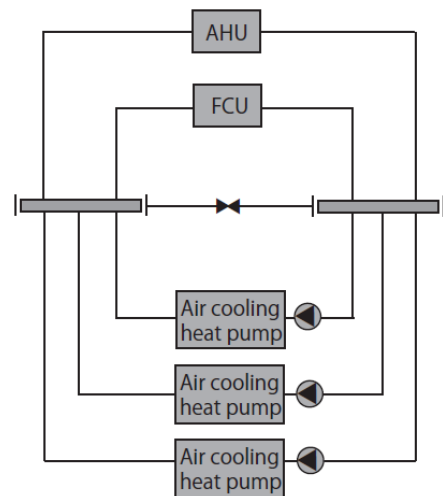


Figure 2 : Heat Source System Diagram

### 3 IMPACT ON THE ANNUAL HEAT LOAD

Based on the building conditions in Table 1, annual heat load calculation of Case 1 and Case 2 were carried out. It was confirmed heat load reduction effect by building refurbishment.

#### 3.1 Comparison of Annual Cumulative Equipment Load

Figure 3 shows a comparison of annual cumulative equipment load. Compared to the Case 1, the cooling and heating cumulative equipment load have successfully reduced by 48% and 59% respectively. The ratio of the cooling load to heating load of the buildings in the same order is 1:0.66 and 1:0.51 respectively. This is because the proportion of outdoor air load in the heating period is large, outdoor air load has been significantly reduced by the outside air load reduction scheme where total heat exchanger, the cool tube.

Table 1: Prerequisites of Building

			Case 1	Case 2	Case 3	Case 4
Building refurbishment	Envelope performance	Exterior walls and Roof (typical member)	Heat transmission coefficient: <b>1.01W/m<sup>2</sup>K</b> Concrete 100mm Polyethylene foam plate 30mm Air layer Aluminum 1mm	Heat transmission coefficient: <b>0.6W/m<sup>2</sup>K</b> Concrete 100mm Polyethylene foam plate 60mm Air layer Aluminum 1mm	Heat transmission coefficient: <b>1.01W/m<sup>2</sup>K</b> Concrete 100mm Polyethylene foam plate 30mm Air layer Aluminum 1mm	Heat transmission coefficient: <b>0.6W/m<sup>2</sup>K</b> Concrete 100mm Polyethylene foam plate 60mm Air layer Aluminum 1mm
		Window (typical member)	Shading coefficient: <b>0.52</b> Heat transmission coefficient: <b>3.29W/m<sup>2</sup>K</b> Multilayer clear glass 6mm+6mm Light color blind	Shading coefficient: <b>0.34</b> Heat transmission coefficient: <b>2.6W/m<sup>2</sup>K</b> Highly-reflective insulating multilayer glass (low-E) Light color blind	Shading coefficient: <b>0.52</b> Heat transmission coefficient: <b>3.29W/m<sup>2</sup>K</b> Multilayer clear glass 6mm+6mm Light color blind	Shading coefficient: <b>0.34</b> Heat transmission coefficient: <b>2.6W/m<sup>2</sup>K</b> Highly-reflective insulating multilayer glass (low-E) Light color blind
		Eaves	None	1.2m	None	1.2m
		Air filtration	0.6 times/h	0.2 times/h	0.6 times/h	0.2 times/h
		Lighting	14W/m <sup>2</sup> 750lx (HF)	4W/m <sup>2</sup> 500lx (HX+lighting control )	14W/m <sup>2</sup> 750lx (HF)	4W/m <sup>2</sup> 500lx (HX+lighting control )
	Heat generation of equipment		Daytime: 20W/m <sup>2</sup> Nighttime: 5 W/m <sup>2</sup>	Daytime: 15W/m <sup>2</sup> Nighttime: 3 W/m <sup>2</sup>	Daytime: 20W/m <sup>2</sup> Nighttime: 5 W/m <sup>2</sup>	Daytime: 15W/m <sup>2</sup> Nighttime: 3 W/m <sup>2</sup>
	Natural ventilation		None	Available	None	Available
	Room temperature/humidity settings		Cooling: 23-26 °C 60% Heating: 22-26 °C 60%	Cooling: 23-28 °C 60% Heating: 19-26 °C 60%	Cooling: 23-26 °C 60% Heating: 22-26 °C 60%	Cooling: 23-28 °C 60% Heating: 19-26 °C 60%
	Total heat exchanger		None	Available (Efficiency: Sensible heat 75%, Latent heat 40%)	None	Available (Efficiency: Sensible heat 75%, Latent heat 40%)
	Cool tube /Heat tube		None	Available	None	Available
	Heat source (capacity, COP(cooling/heating))		AHP 352kW(100RT) x3 COP (2.73 / 2.98)	AHP 352kW(100RT) x3 COP (2.73 / 2.98)	AHP 352kW(100RT) x2 COP (4.00/ 3.56)  AHP 246kW(70RT) x1 COP (3.81 / 3.35)	AHP 281kW(80RT) x2 COP (4.02/ 3.57)  AHP 141kW(40RT) x1 COP (4.00/ 3.56)
Equipment refurbishment	Primary pump flow control		CWV	CWV	VWV	VWV

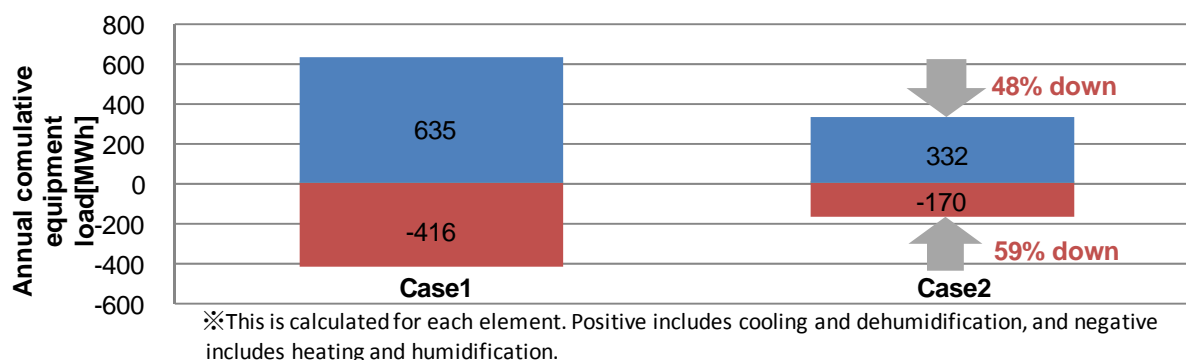


Figure 3: Comparison of Annual Cumulative Equipment Load

### 3.2 Annual cooling equipment load duration curve

Figure 4 shows an annual cooling equipment load duration curve. Pre-cooling load of the start of the operation was reduced depending on the envelope performance improvement (insulation efficiency, solar radiation shielding performance). The peak load of Case 1 and Case 2 is 569kW and 371kW respectively. In addition, it was possible to reduce 360 hours annual air conditioning load time by the adoption of natural ventilation.

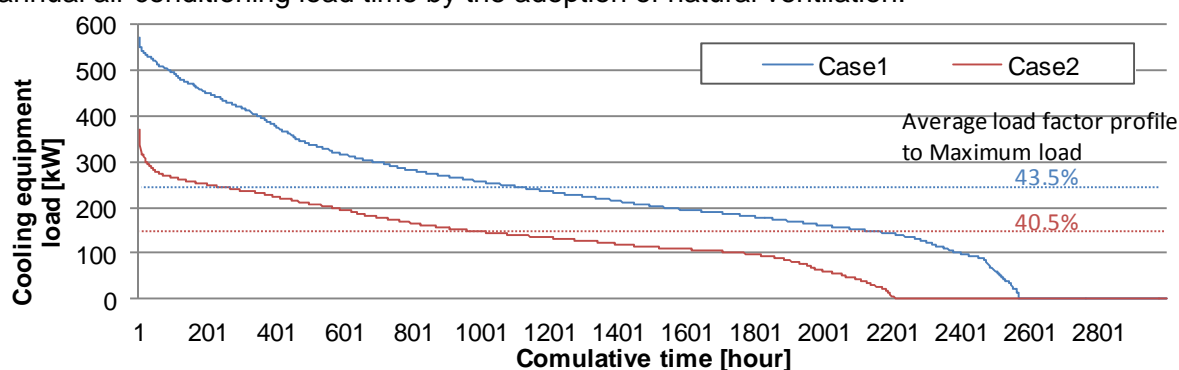


Figure 4 : Annual Cooling Equipment Load Duration Curve

### 3.3 Comparison of Load Factor Profile

Figure 4 shows a Comparison of Load Factor Profile. Here the load factor profile is defined as the ratio of the load of each time to the maximum load of each cases. Average load factor profile to the maximum cooling load of Case1 and Case2 is 43.5% and 40.5% respectively, and load factor profile of Case2 is reduced. This is because in Figure 4, the maximum cooling equipment load of Case2 is significantly larger than the other time zones.

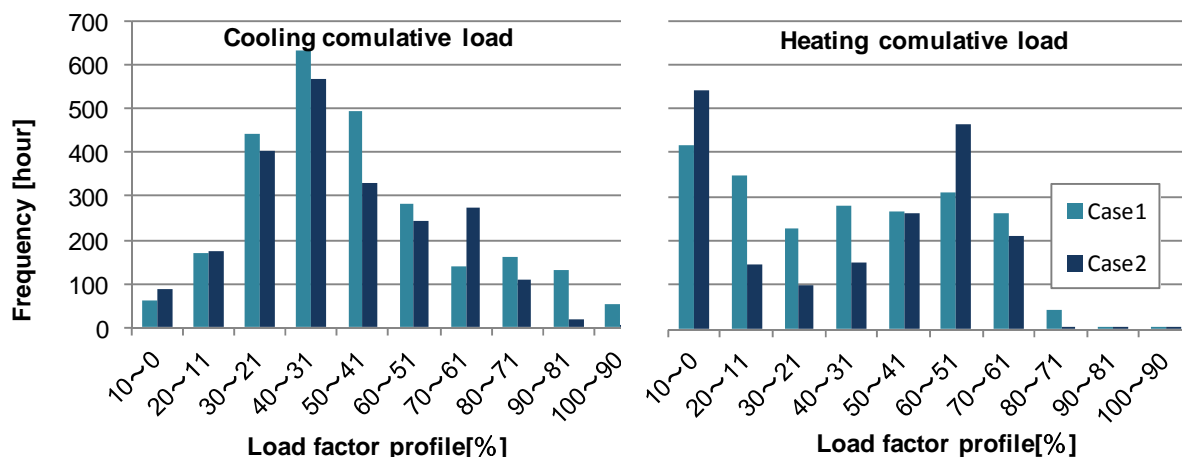


Figure 5: Comparison of Load Factor Profile

### 3.4 Analysis of Load Reduction Factors

This section provides factor analysis on load reduction by individual energy-saving measures supposed to be applied to the buildings. Table 2 shows a equipment load of applying the individual energy-saving measures on the Case 1. For the cooling load, it can be seen that there is a relatively significant impact which is about 30% lightning, 23% equipment heat generation respectively. For the heating load, it can be seen that energy-saving measures have contributed significantly to the load reduction. For example, the total heat exchanger accounted for 70%, and also cool heat tube and natural ventilation is about 13%.

**Table 2: Comparison of Annual Cumulative Equipment Load by Individual Energy-saving Measures**

	Exterior wall	Windows	Eaves	Lighting	Equipment heat generation
Cooling [MWh]	655 (-6%)	608 (8%)	593 (13%)	534 (30%)	557 (23%)
Heating [MWh]	-410 (2%)	-416 (0%)	-418 (-1%)	-420 (-2%)	-421 (-2%)

	Room temperature humidity settings	Natural ventilation	Total heat exchanger	Cool heat tube
Cooling [MWh]	603 (10%)	570 (19%)	620 (5%)	642 (-2%)
Heating [MWh]	-405 (4%)	-382 (13%)	-225 (71%)	-380 (13%)

## 4 RESULTS OF THE ENERGY SAVING REFURBISHMENT

This section indicates the effect of the energy saving refurbishment and impact on a system efficiency. Figure 6 shows annual primary energy consumption of air conditioning and system efficiency of each cases. The bottom of the Figure 6 is the amount of heat output calculated by LCEM, and system efficiency represented as SCOP is calculated using it.

### 4.1 Building Refurbishment

In Case2 was only building renovation, the heat load is reduced, and energy consumption of each cases was 1,285 GJ, 2,237 GJ respectively, which reduced by about 43%. By average load factor profile to maximum cooling load is reduced to 40.5% from 43.5% by building refurbishment, COP of a single heat source became low. Meanwhile, COP of the heat source during heating period can be improved by the average load factor profile of heating improved to 29.1% from 27.9%. However, SCOP fell off as a result, because operating efficiency during cooling period is dominant, which can be seen from heating and cooling ratio of the annual cumulative equipment load of Case2. In addition, ATF which is the air transport efficiency of Case1 and Case 2 is 7.5 and 4.7 respectively. Since ATF of Case 2 was worse than Case 1, it resulted in SCOP ranging from 0.77 to 0.62.

## 4.2 Building Equipment Refurbishment

Next, in Case3 was only equipment refurbishment, primary energy consumption was reduced significantly due to improvement of a single equipment COP applying high efficient equipment (See Table 1). In addition, primary energy consumption decreased by about 38% and also SCOP improved significantly due to a high load factor profile by reducing the heat source capacity despite no change between Case 1 and Case3.

## 4.3 Building and Building Equipment Refurbishment

In Case4 was both building refurbishment and building equipment refurbishment, primary energy consumption was 756GJ, which reduced by approximately 66% compared to Case 1. As a result, Case4 is the most good effect of all cases. SCOP was increased to 1.02 in Case4 from 0.77 in Case1, but it was inferior to 1.24 in Case3. By average load factor profile to maximum cooling load is reduced to 40.5% from 43.5% by building refurbishment, COP of a single heat source became low. Consequently, SCOP was inferior to Case3 due to reduction of air transport efficiency (ATF), in addition to the COP of the heat source equipment is reduced by the reduction of an average load ratio during cooling period like the building refurbishment case.

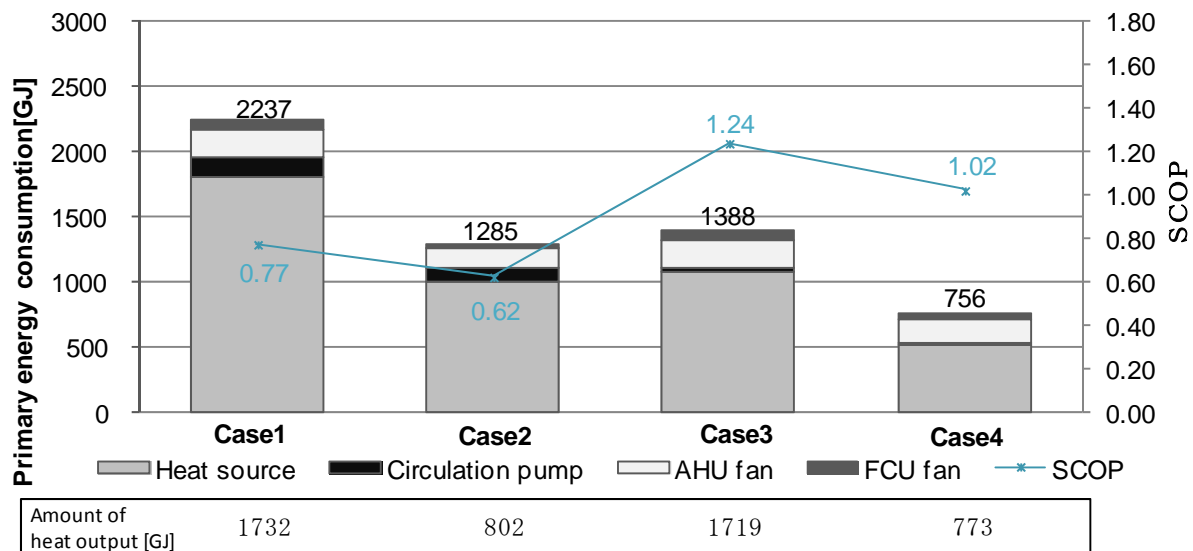


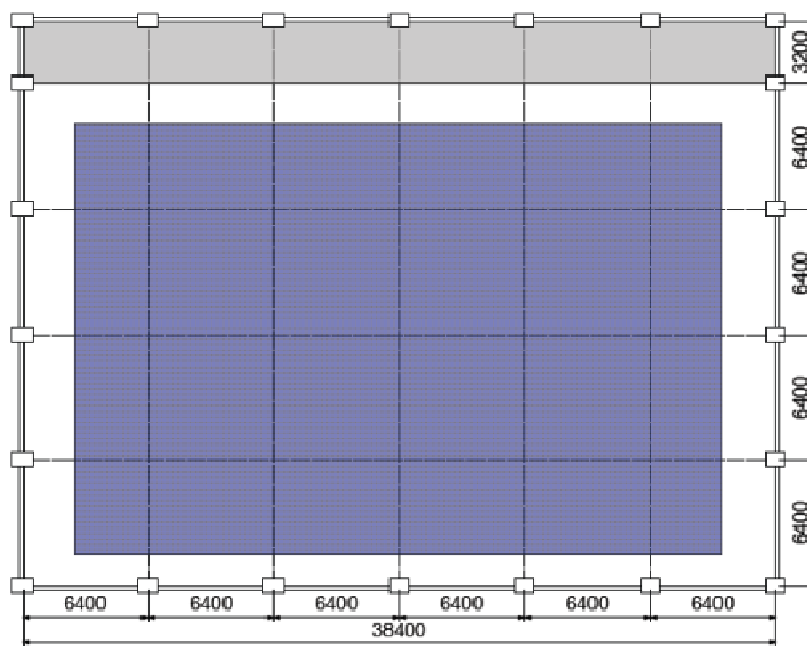
Figure 6 : Comparison of Annual Primary Energy Consumption

## 5 FURTHER EFFORTS TOWARD ZEB

Until now, we have investigated about possible reduction of primary energy consumption and heat load reduction through two types of refurbishment. However, the ratio of the energy consumption occupied of an office building is 28% air conditioning, 40% lightning, and 32% outlet. It indicated that we have to take measures in view of the overall energy consumption in order to realize the ZEB.

Therefore, first of all, reducing primary energy consumption for air conditioning by improving the energy saving performance is needed. Secondly, we estimate whether production of electricity by PV can compensate the energy consumption of a building in case of installing photovoltaic power generation.

It is assumed that Case4 + PV1 was installed solar panels on the roof surface only and Case4 + PV2 was installed on the wall (except the north side ). The reason of applying Case4 is the largest energy saving effect of all cases. Figure 8 shows the floor plan of PV installing on the roof, and Figure 9 shows elevation plan of PV installing on the south wall.

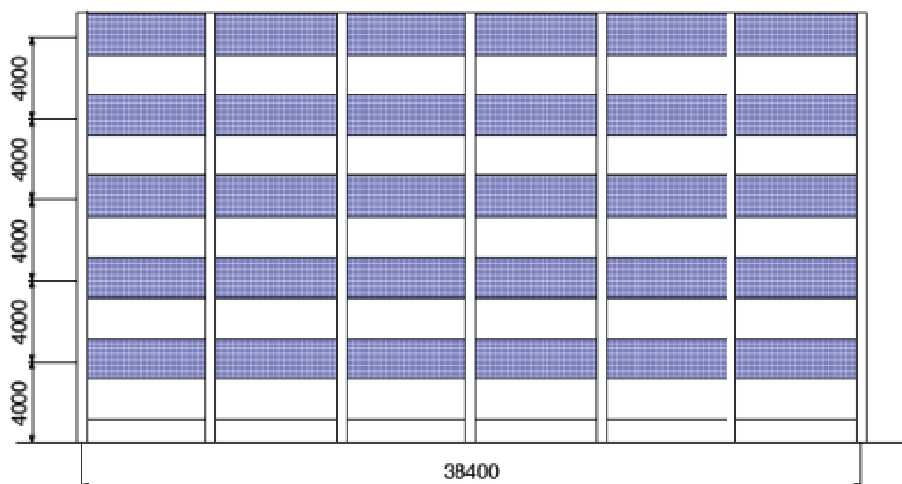


### Floor Plan of PV Installing on the Roof

Tilt angle : 10°

Installation area  
33m×22m = 660 m<sup>2</sup>

Figure 8 : Floor Plan of PV Installing on the Roof



### Elevation Plan of PV Installing on the South Wall

unit 6m×2m=12 m<sup>2</sup>  
Tilt angle : 90°  
Installation area  
360 m<sup>2</sup>

Figure 9 : Elevation Plan of PV Installing on the South Wall

## 5.1 Electric generating capacity of PV

Expected electric generating capacity of PV can be calculated using the equality as follows.

$$E_p = H \times K \times P \times 365 \div 1 \quad (1)$$

Where:

- $E_p$  is the annual expected electric generating capacity [kWh/year]
- $H$  is the amount of annual average solar radiation [kWh/ m<sup>2</sup>/day]
- $K$  is the loss factor : approximately 73%
- $P$  is the system capacity [kW]
- 365 is the number of days in a year
- 1 is the insolation intensity in reference condition [kW/ m<sup>2</sup>]

Amount of annual average solar radiation can be calculated by tilt angle and angle of orientation using amount of solar radiation database browsing system of NEDO. In addition, we assumed the PV which is the nominal maximum output 215W, 1.5 square meters (1.5m ×

1m), 14.0% power generation efficiency solar panels. Table 3 shows the outline of photovoltaic power generation system. As a result of calculation, the expected electric generating capacity is 88,978 kW Case4 + PV1 and 163,428kW Case4 + PV2 respectively.

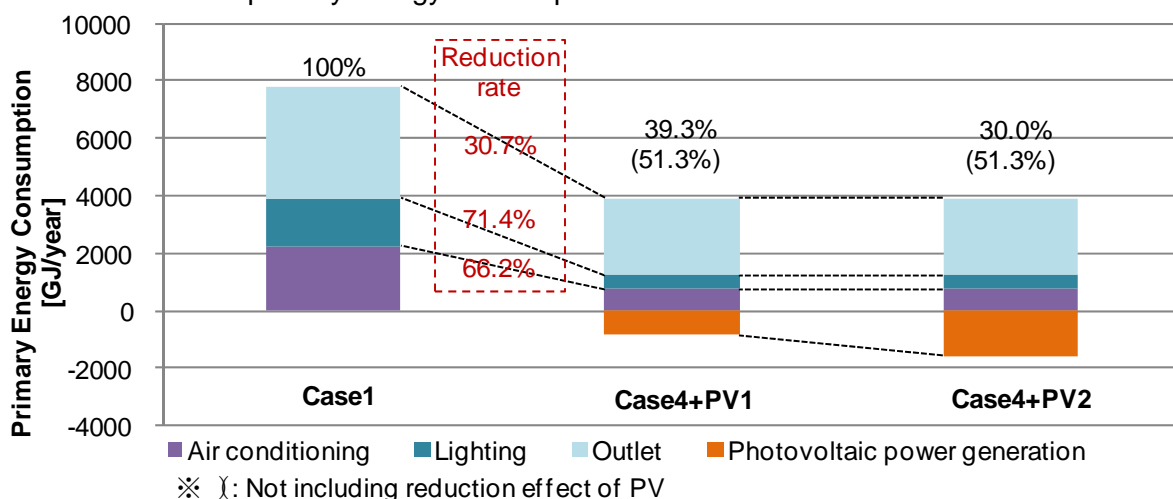
**Table 3 : Outline of Photovoltaic Power Generation System**

	Tilt angle [°]	Amount of insolation [kWh/ m <sup>2</sup> /day]	Number of modules [units]	Installation area [m <sup>2</sup> ]
Roof	10	3.53	440	660
South	90	2.52	240	360
East	90	1.93	180	270
West	90	1.93	180	270

## 5.2 Comparison of the primary energy consumption of the entire year

Figure 10 shows the annual primary energy consumption of the air conditioning, lighting and electrical outlet of Case1 and Case 4. Also, for Case 4, the effect of installing the photovoltaic power generation system take into consideration. By the energy saving (e.g. air conditioning , lighting and outlet), the annual primary energy consumption of Case 4 is reduced by approximately 49.7% compared to Case 1. If the electric generating capacity of PV is added, it is possible to reduce by approximately 60.7% in Case4+PV1 and approximately 70.0% in Case4+PV2 respectively. In this study, it is assumed that the energy saving of outlet is an energy saving of office equipment like converting from desktop PC to laptop.

If you look at the configuration of the primary energy consumption, accounting for outlet both Case 1 and Case 4 is the largest, and the following is air conditioning and lighting. Reduction rate resulting from energy saving of lighting is the largest with approximately 71.4% by updating to LED, the second is approximately 66.2% for air conditioning energy, the third is 30.7% for outlet. Therefore, it can be said that energy saving of outlet which is relatively low reduction rate is effective, even though the percentage of the total is large, to achieve a further reduction of primary energy consumption.



**Figure 10 : Comparison of Total Annual Primary Energy Consumption**

## 6 EFFORTS TO FURTHER TOWARD ZEB

Annual cumulated heat load was reduced by approximately 52% compared to the standard case, and the primary energy consumption was reduced by approximately 43%. In addition, it was resulted that energy consumption can be reduced by approximately 66% together with



building equipment refurbishment. In the case that only building refurbishment, energy consumption is greatly reduced, on the other hand, the system efficiency is rather decreased. It is believed that measures related to efficiency of the entire system including the heat transport system as well as reduction of the primary energy consumption will become important in the case of the energy saving refurbishment.

In this study, as a result of the introduction of PV to Case4 confirmed a certain effect of the energy saving by refurbishment, reduction of primary energy consumption was expected approximately 70% at maximum compared to the standard case. However, it was shown that offsetting all of the energy consumption with the electric generating capacity to achieve the ZEB is not easy. In the future, it is necessary that proposing innovative approaches and the use of unused energy are conducted in addition to the high efficiency of the system and energy saving conventional approaches

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