Predicting Energy Efficiency Performance for Building Integrated Photovoltaic
(Towards Greener Building, Universitas Ciputra Surabaya)

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ABSTRACT
One-third of the world's energy are consumed by buildings. In Indonesia, the main source of this energy is fossil fuel that act as the main contributor to global warming and climate change. Improving energy efficiency on a building is important to approach greener environment. EDGE is a tool that respond to the need for a measurable and credible solution to approach green design, including the energy-efficient building design. Here, the calculation of energy efficiency covers the comparative measurement of base case and improved case, including the comparison of geometry and building orientation, mapping of energy use, and prediction of energy harvesting from renewable energy resources. Studying this concept further is important to predict cost of going green, to ensure utility savings, as well as to reduce negative impacts to the environment. This study presents Universitas Ciputra building as the proposed case. This building is chosen since it already had some green features. Additionally, the building also has the potential for on-site renewable energy integration, particularly for solar energy with BIPV concept. Experimental method with simulation as its tool is used to find the energy-efficiency performance of the proposed case. Base case is provided by EDGE. The UC's existing building is set as the 1st treatment (improved case 1) and UC building with additional PV is set as the 2nd treatment (improved case 2). The result from EDGE simulation shows that the improved case 1 has 28.66% better energy-efficiency performance. While the improved case 2 (with only 7% annual electricity substituted by renewable energy from PV) has 33.23% better energy performance.

Keywords: *Consumption, EDGE, Efficiency, Energy, Renewable.*

1. INTRODUCTION

Buildings conventionally consume huge amount of electrical energy. They are responsible for 40% of the total energy consumption in all sectors [1]. The energy sources mainly come from fossil fuel, which act as the main contributor to global warming, climate change, and other environmental damage. Regarding to these issues, concept of energy efficiency building is widely discussed. Tools and application are widely improved. Buildings are expected to be designed towards net zero-energy building and renewable energy sources need to be implemented to buildings. Ciputra as one of the largest developers in Indonesia is responding to this issue as well. Some schools under the Foundation of Ciputra Education have already installed photovoltaic (PV), to substitute some percentages of fossil fuel into renewable energy. The data recorded from this small-scaled pilot project indicates a good performance of the photovoltaic system. Based on this experience, a proposal for greater energy-efficiency is planned for an existing building, Universitas Ciputra Surabaya. Following the success of the pilot project, the energy efficiency is proposed to be achieved through the installation of PV as on-site renewable energy tool.

The most visible on-site renewable energy in Indonesia is solar energy. The availability of this resource reach 207.8 GWp (Energy Indonesia 2019 Sekretariat Jenderal Dewan Energi Nasional). Photovoltaic, as already proved at Ciputra schools, is a potential on-site microgeneration technology. Its ability to produces energy without any pollution is beneficial to achieve greater energy-efficiency and reduce carbon emissions. Three types of PV that are commonly found in the market are Mono-crystalline, poly-crystalline, and amorphous. As wall cladding, monocrystalline is mostly used, since it has the highest efficiency. While as glass cladding, poly-crystalline and amorphous is more preferable. Aside from its types, the efficiency of PV is depending on some other factors. The factors can be divided into two main groups, the PV internal factors and the external factors.

Internal factors cover the number of cells [2], PV's efficiency [3], an PV's temperature [4]. The range of the PV cell's number typically around 36-216 cells, with 100Wpeak – 300Wpeak. The number of cells drives the voltage of electrical energy generated. However, smaller modules are preferable since it is handier for installation process. PV's efficiency represents the ratio of electrical energy generated to the solar radiation received. Latest technology of PV reached an efficiency number to 21%. Related to PV's temperature, the efficiency of PV will be optimal if it works at 25°C. To maintain the temperature, an air gap between PV and building façade could act as an effective treatment [5]. The pilot project at Ciputra Schools Jakarta uses monocrystalline PV which has mechanical specification as PV with 144 cells, 2015mm x 1000mm x 35mm size, and 20.3% efficiency.

External factors relate to the solar radiation received by PV, tilt and orientation angle, and shading condition. Higher solar radiation received means higher electrical energy generated. The standard test procedure shows that optimal performance of PV happened when it received 1000 W/m2 of irradiance while maintaining its temperature on 25°C. As an on-site renewable energy source, PV installation is often integrated on building's façade. Such installation system is called BIPV (Building Integrated Photovoltaic). In this system, PV usually installed at fixed angle. Tilt angle usually follows the geographical latitude or set in 20°-30° for areas at low latitude works. While optimum orientation for PV is -15° - 15° from a horizontal plane, facing equator [4, 6-8]. Another experiment on PV's installation shows that setting of tilt in 45° facing West and East and setting of orientation in 44° facing North will generate higher amount of electrical energy and higher uniformity ratio [9]. The presence of shading to PV installation will influence its efficiency. In every shading condition, the average amount of power reduction is around 25%-30%.

The on-site renewable energy will contribute to better energy-efficiency performance. However, the building's energy performance is also influenced by other factors. To analyze building's performance, some previous study uses consumption energy index as the standard. Another study uses government's mix energy target. This study thus uses EDGE as tool to analyze the building's performance. EDGE is a green building software application and a certification program as well. It is applied in more than 150 countries. As a building software, EDGE analyze on 3 main criteria. They are energy, water, and material. In its energy criteria EDGE provides 34 parameters to be selected as the input data (Figure 1). Based on the user's input and the selection of green measures, the overall pictures of building performance can be projected. The results can be used to determine the best-practice options for buildings, to reach required efficiency levels.

Figure 1 EDGE's energy efficiency measures.

2. RESEARCH METHODOLOGY

2.1. Site Selection

Following the best practice of the pilot project at Ciputra School Jakarta, Universitas Ciputra Surabaya is planned to apply the PV as well and chosen as the proposed case in this research. The potential of PV installation in this building is supported by abundant solar radiation which is indicated by its geographical location, 07°29 S Latitude and 112°63 E Longitude. Aside of its location, the building itself has a potential of PV installation which is indicated by the availability of façade area to be integrated with PV. The total available area, particularly on the roof, reach 509.79m2.

Another potential towards energy efficient building are supported by its green features. The elongated side that facing north and south, the shallow layout, and the building proportion that range between 1:1.8 – 1:2 will help to reduce building's thermal transfer value and building's cooling load. The roof is made from concrete slab, plastered, and unpainted. The wall is made from hebel and finished with light-colored acrylic paint. The total window area is 5323.96m^2, while the total wall area is 16860.18m^2. The rooms inside UC's building are designed as an area with single-sided natural ventilation. The vertical greenery system in the parking area, secondary skin and vertical shading device are used as well to reduce the thermal transfer value. The vertical shading proportion is 1 (the window width/W equal to the shading depth/D). The inverter AC system, daylight utilization, and 100% electronic ballast for artificial lighting system are other applications used to reduce electrical energy consumption. The total electrical energy consumption in UC for 2018, 2019, and 2020 is range between 1.652.440 kWh – 2.134.140 kWh (as seen in Table 1) (figure 2).

Table 1. UC's electrical energy consumption

Month	2018 (kWh)	2019 (kWh)	2020 (kWh)
January	71240	150440	141600
February	127520	165300	162820
March	167260	168500	131780
April	152700	180840	170720
May	131000	167340	156110
June	84460	116380	93040
July	117800	131960	103700
August	173560	192880	106140
September	151160	192740	110520
October	190260	254480	195220
November	189360	230860	187120
December	96120	182420	160300
Total(Annual)	1.652.440	2.134.140	1.719.070

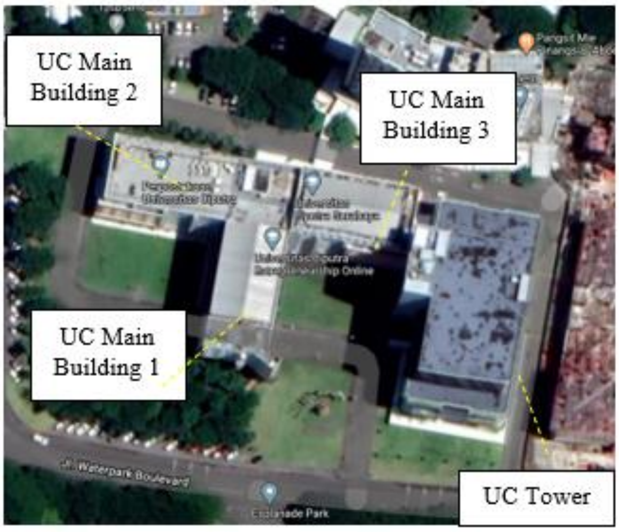


Figure 2 UC site plan.

This energy consumption is used to serve facilities in UC 1, 2, 3 and UC 4 (UC Tower). The total area of UC is 66.174m2 area. The detail of each area at UC can be seen in figure 3.

NO	GEDUNG LAMA	LUAS
	UC1	
1	Lantai 1	295
2	Lantai 2	344
3	Lantai 3	1250
4	Lantai 4	1250
5	Lantai 5	1250
6	Lantai 6	1250
7	Lantai 7	420
8	Lantai 8	265
	TOTAL	6324
	UC2	
1	Lantai 1	800
2	Lantai 2	800
3	Lantai 2A	800
4	Lantai 3	820
5	Lantai 4	820
6	Lantai 5	820
7	Lantai 6	820
8	Lantai 7	800
	TOTAL	6480
	UC3	
1	Lantai 1	823
2	Lantai 2	823
3	Lantai 2A	823
4	Lantai 3	853
5	Lantai 4	853
6	Lantai 5	853
7	Lantai 6	853
8	Lantai 7	823
	TOTAL	6704

TOTAL UC1, UC2, UC3	19.508
Efektif	17.684
Tidak Efektif	1.824

GEDUNG BARU	LUAS	KETERANGAN
UC4		KETERANGAN
Lantai 1	2384	learning space
Lantai 2	1709	19 mobil
Lantai 2A	2299	67 mobil
Lantai 2B	2393	70 mobil + 2 disable
Lantai 3	2335	74 mobil
Lantai 4	2374	75 mobil
Lantai 5	2374	75 mobil
Lantai 5A	2335	75 mobil
Lantai 6	2335	75 mobil
Lantai 7	1833	
Lantai 8	1525	3 kelas, dosen&admin
Lantai 9	1525	6 kelas, 1 theater
Lantai 10	1525	7 kelas, 1 simbis
Lantai 11	1525	9 kelas
Lantai 12	1525	Fikom
Lantai 14	1525	5 kelas, lounge, meeting
Lantai 15	1525	7 kelas, miniteater,lounge
Lantai 16	1525	4 studio, meeting
Lantai 17	1525	3 studio, dosen, lounge
Lantai 18	1525	5 studio, lounge
Lantai 19	1525	
Lantai 20	1525	
Lantai 21	1525	
Lantai 22	1525	
Lantai 23	1525	Pre function
Lantai 24	1420	MPH
Lantai 25	251	Roof deck & LMR
TOTAL UC Tower	46666	532 mobil

TOTAL UC1, UC2, UC3, UC TOWER	66.174
TOTAL UC1, UC2, UC3, UC TOWER Lt 1,7-12	31.350
TOTAL UC1, UC2, UC3, UC TOWER Lt 1-12	49.504

Figure 3 UC'S Area.

2.2. PV Selection and BIPV Model

Previous study [9,10] did an experiment on 16 models of BIPV. On this experiment, PV is simulated to be integrated on roof, opaque wall (north, east, and west wall), transparent wall (north, east, and west side), and shading device. Each is simulated in different tilt and orientation angle, and different PV specification as well. The types of PV were selected based on high-efficiency number, handy dimensions, opaqueness and transparency. PV specification used in the previous research can be seen in Table 2.

Table 2. PV specification

Proposed Integrated Area	PV Type	Number of cells	Efficiency (%)	Peak Power (Wp)	Dimension (mm)
Transparent wall	Amorphous	15	19.0%	80	1000 x 720 x 35
Opaque wall	Mono-crystalline	72	18.6%	235	1580 x 798 x 35
Shading device	Amorphous	15	19.0%	80	1000 x 720 x 35
Roof	Mono-crystalline	72	18.6%	235	1580 x 798 x 35

It is found that the highest electrical energy generated when PV applied in -270° orientation angle, on opaque wall. The lowest amount of electrical energy is generated when PV installed on roof with 30° tilt angle. However, following the pilot project, the model of BIPV on roof will be used in this study (as seen in Figure 4). With this model, the BIPV system can generate 138148.67 kWh electrical energy per year, or 6.5% from the total electrical energy needed by UC's building.

Figure 4 Modelling and proposed installation area.

2.3. Energy Efficiency Performance byx EDGE

The research observes better performance of energy-efficiency through the use of BIPV as on-site renewable energy tool at UC Building. Experimental research with simulation as its tool is used in this study. The base case is provided by EDGE. The existing building of UC is set as the 1st treatment (improved case 1), and the proposed BIPV concept for UC's building is set as the 2nd treatment (improved case 2). Better energy-efficiency building is aimed as the posttest condition.

To start the simulation in EDGE, 'education' is chosen as the primary building type, and university as the subtype. Basic building data (gross internal area, no. of floors, floor-to-floor height, roof area, working days, no. of holidays, hours of operation, and occupancy density) is inputted in the software (Figure 5). Aside from the basic building data, the software also asked the area and loads breakdown (Figure 6), building dimensions (Figure 7), and building HVAC system (Figure 8).

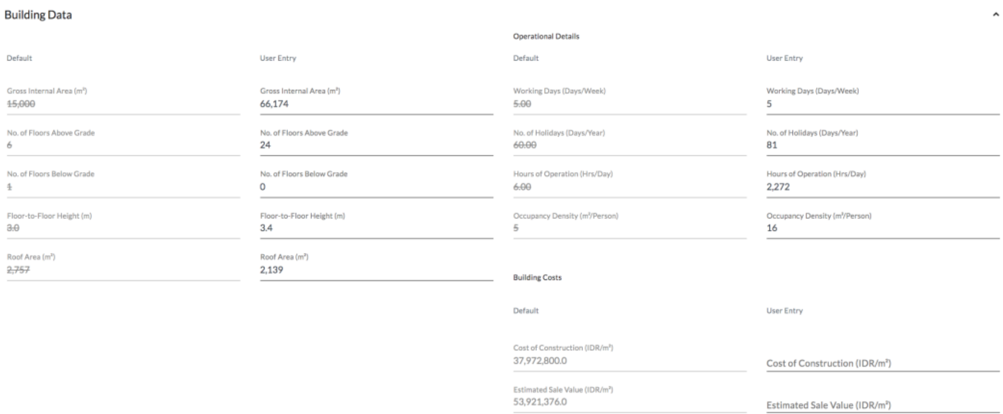


Figure 5 Basic building data.

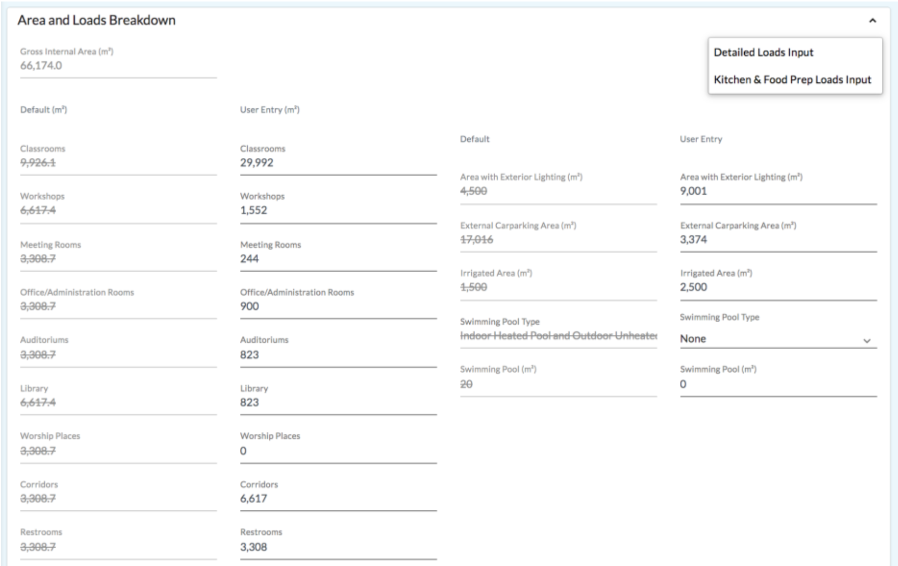


Figure 6 Area and loads breakdown.

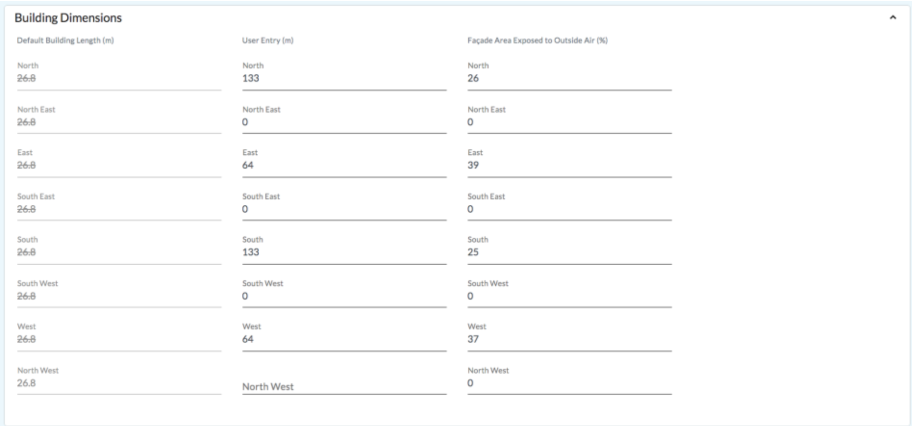


Figure 7 Building dimensions.

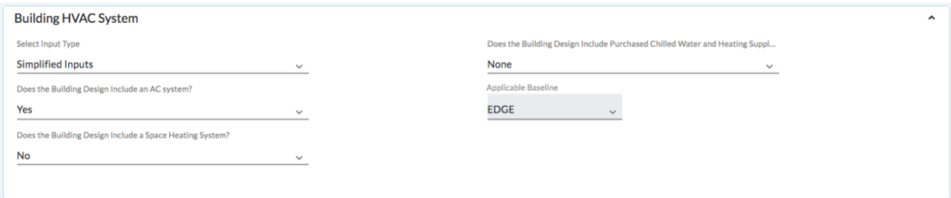
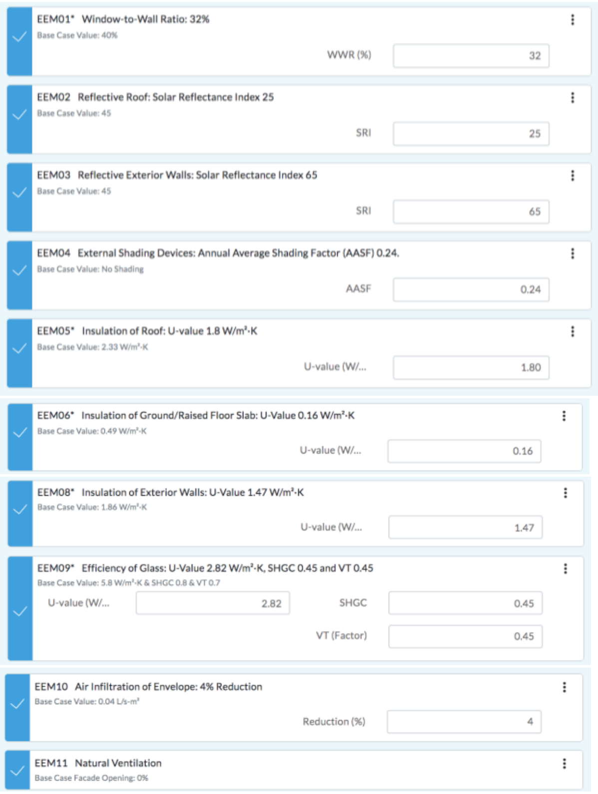


Figure 8 Building HVAC system.

As described before, in energy criteria EDGE has 34 parameters of green measures that can be selected by user, based on the design of the building. As for this study, there are 15 parameters selected for the 1st improved case, and 16 parameters for the 2nd improved case. The first 15 parameters (green measures) are WWR, reflective roof, reflective exterior walls, external shading devices, insulation of roof, insulation of ground/raised floor slab, insulation of exterior walls, efficiency of glass, air infiltration of envelope, natural ventilation, ceiling fans, cooling system efficiency, fresh air pre-conditioning system, efficient lighting for internal areas, and efficient lighting for external areas (Figure 9). Additional one parameter for the 2nd improved case is on-site renewable energy (Figure 10). The other 18 parameters are excluded since the building doesn't have it both in the existing condition and the future planning. Some of those 18 parameters refer to the application of skylight, CO2 sensors, cold storage, washing machines, submeters, smart meters, and other appliances that mostly used for buildings in temperate or cool climate which need energy for heating.



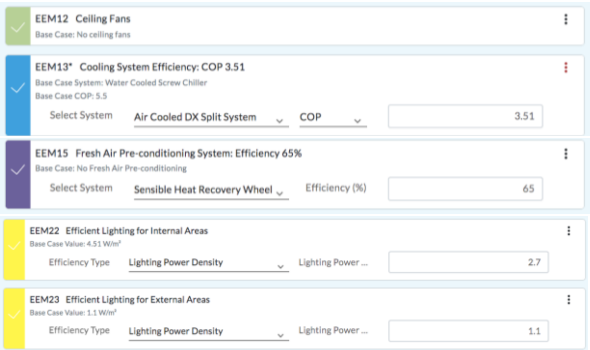


Figure 9 The selected green measures for the 1st improved case.

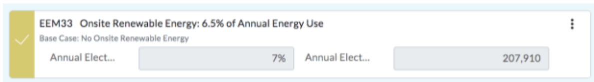


Figure 10 The Additional Green Measures for the 2nd Improved Case.

3. RESULTS AND DISCUSSION

The comparison of base case, 1st improved case, and 2nd improved case as an experimental set up can be seen in Table 3.

Table 3. Experimental set up

Code	Criteria	Base Case	Improved Case 1	Improved Case 2
EEM01	WWR	40%	32%	32%
EEM02	Reflective Roof	45	25	25
EEM03	Reflective Exterior Walls	45	65	65
EEM04	External Shading Devices	No Shading	0.24	0.24
EEM05	Insulation of Roof	2.33 W/m².K	1.80 W/m².K	1.80 W/m².K
EEM06	Insulation of Ground/Raised Floor Slab	0.49 W/m².K	0.16 W/m².K	0.16 W/m².K
EEM08	Insulation of Exterior Walls	1.86 W/m².K	1.47 W/m².K	1.47 W/m².K
EEM09	Efficiency of Glass (U-value, SHGC, VT)	5.8 W/m².K 0.8 0.7	2.82 W/m².K 0.45 0.45	2.82 W/m².K 0.45 0.45
EEM10	Air Infiltration of Envelope	0.04 L/s-m²	4 L/s-m²	4 L/s-m²
EEM11	Natural Ventilation	0%	32%	32%
EEM12	Ceiling Fans	No ceiling fans	No ceiling fans	No ceiling fans
EEM13	Cooling System Efficiency	Water cooled screw chiller, COP 5.5	Air Cooled DX Split System, COP 3.51	Air Cooled DX Split System, COP 3.51

Table 3. Cont.

Code	Criteria	Base Case	Improved Case 1	Improved Case 2
EEM15	Fresh Air Pre-conditioning System	No fresh air pre-conditioning	Indirect evaporative cooling	Indirect evaporative cooling
EEM22	Efficient Lighting for Internal Areas	4.51 W/m²	2.7 W/m²	2.7 W/m²
EEM23	Efficient Lighting for External Areas	1.1 W/m²	1.1 W/m²	1.1 W/m²
EEM33	Onsite Renewable Energy	No Onsite Renewable Energy	No Onsite Renewable Energy	7%

3.1. Energy Efficiency Performance

In the improved case 1, treatment was applied based on the existing condition. Compared to the provided base case, the existing building has lower WWR; lower SRI (solar reflective index) on roof and exterior walls; application of shading device; insulation of roof, ground, and external wall with lower U-value; efficiency of glass through lower U-value and SHGC, availability of natural ventilation, lower COP, fresh air pre-conditioning system, and lower lighting power density for efficiency in internal and external areas. By applying those treatments, the improved case 1 has met 28.66% of EDGE Energy Standard (Figure 11).

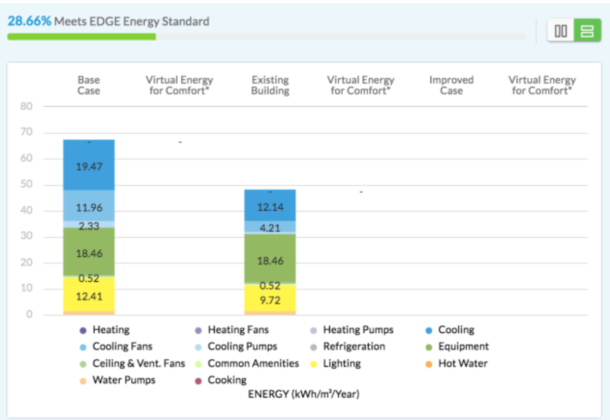


Figure 11 Energy-efficiency performance for improved case 1.

In the improved case 2, additional treatment was applied by planning an application of onsite renewable energy. As described before, BIPV model on roof was chosen for this study. The simulation in EDGE software shows that this strategy makes the improved case 2 meet 32.33% of EDGE Energy Standard (Figure 12).

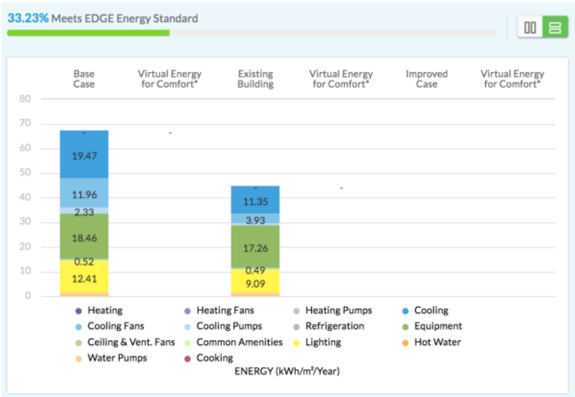


Figure 12 Energy-efficiency performance for improved Case 2.

3.2. Carbon Emissions

Beside from energy efficiency performance, EDGE comply the results with the carbon emissions projection. As seen in Figure 13 and Figure 14, the strategies applied give significance impact on reducing carbon emissions. The base case measured carbon emissions in 3790.6 tCO2e/year. In the improved case 1, it is projected that the carbon emissions reduced into 2707.5 tCO2e/year, particularly from electricity uses. While in the improved case 2, by adding the onsite renewable energy tools, the carbon emissions projected to be reduced into 2531.5 tCO2e/year.

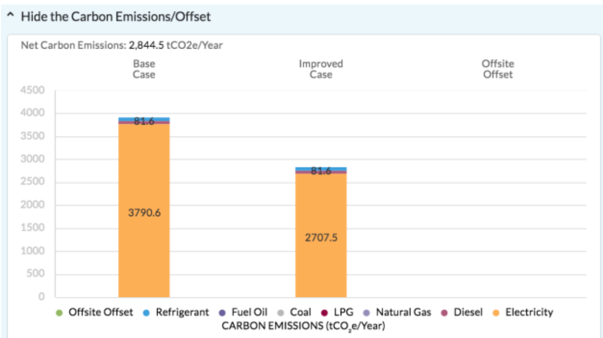


Figure 13 Carbon emissions for improved case 1.

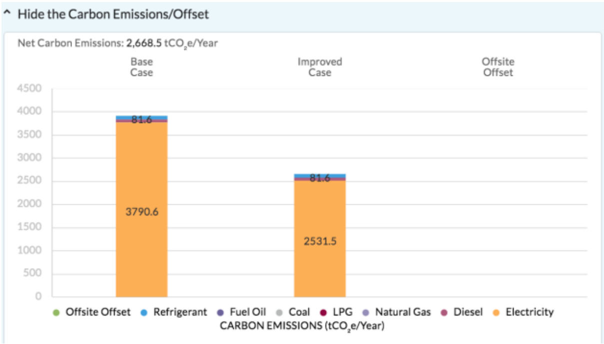


Figure 14 Carbon emissions for improved Case 2.

To achieve the EDGE standard, a building must demonstrate a 20% reduction in projected operational energy consumption. This is means that both improved case 1 and improved case 2 are already meets the EDGE Energy standard. Even though it can't be used for making decisions that require a finer level of detail, the simulation is still useful to evaluate resource demand for greener building purposes.

4. CONCLUSION

The result from EDGE simulation shows that the improved case 1 has 28.66% better energy-efficiency performance. While the improved case 2 (with only 7% annual electricity substituted by renewable energy from PV) has 33.23% better energy performance.

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