International Journal of Application on Sciences, Technology and Engineering (IJASTE)
Volume 1, Issue 2, 2023.ISSN:2987-2499

Application of Solar Photovoltaic Technology for Energy Saving and Sustainable Co-Living Buildings

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Submitted: January-February 2023, Revised: March 2023, Accepted: May 19, 2023

Abstract. One of the efforts to protect the environment is to follow the Kyoto Protocol, Paris Agreement, and conferences related to global warming. The tangible manifestation of this issue is that buildings have begun to pay attention to the concept of sustainable architecture by changing single-use energy to renewable energy. The purpose of this paper is to find out how much energy can be saved by co-living buildings that apply passive design and solar photovoltaic systems using the EDGE application. The research method used is a quantitative method by paying attention to the calculation of EDGE energy and the total of solar photovoltaic. This paper concludes that the co-living buildings can be categorized as an energy-efficient building with the use of photovoltaic and with a passive design system. Then the building can be classified as an advanced energy-efficient building with an energy saving of 47% and a break-even point of 216 days. The novelty of this paper is that the use of EDGE application that can determine the amount of energy savings that is very significant in communal residential buildings in Indonesia.

INTRODUCTION

Climate change that is happening worldwide has made many people and organizations worldwide realize the importance of protecting the environment. Multiple major organizations have made various efforts to agree on reducing the causes of global climate change. UNFCC (United Nations Framework Convention on Climate Change) or the United Nations Convention on Climate Change has decided on various agreements and protocols that regulate different countries dealing with climate change, such as the Kyoto Protocol and the Paris Agreement on Climate Change. The Kyoto Protocol was approved in 1997, targeting developed countries to reduce gas emissions by 5.2% of the world's total gas emissions by the 1990s. The first phase of this protocol was completed in 2012 [1]. Then, the protocol was complemented by a new agreement in 2016, namely the Paris Agreement, which encourages all developing and developed countries to be more aware of climate issues. The Paris Agreement is planned to be completed in 2025-2030, with the target of preventing an increase in the global average temperature of 2 degrees Celsius from the current temperature by targeting all aspects of human life to be free from emissions [2].

Several conferences have also been formed to assist and realize existing protocols and agreements, and also several meetings have been created to help this goal from an architectural perspective. They are stated in several points from the MDGs (Millennium Development Goals) and SDGs (Sustainable Development Goals) [3]. According to World Green Building Council data from 2020, 9% in global gas emissions from 2010 is 28%. On a global scale, energy consumption in buildings has also increased by 4% in the last ten years to 36% per year. Meanwhile, the reduction in intensity in the use of heating and cooling energy as well as lighting, only decreased by an insignificant number; space

https://doi.org/10.24912/ijaste.v1.i2.433-439

heating energy consumption decreased by 20%; lighting energy down 17%; and air conditioning energy has only reduced by 7% in the last ten years [4].

Green Building Council Indonesia established a GREENSHIP Net Zero Movement to make all buildings zero emission-building. The steps taken are; a passive design approach with ventilation and natural lighting; an active design approach by optimizing air conditioning, lighting, and other equipment in a building; health and comfort of residents through clean air; as well as a sustainable building approach with renewable energy [5]. The use of solar energy has become one of the leading choices lately. The trend of using photovoltaic as an energy source for a building can reduce the emission load issued by a building [6, 7].

This research aims to find out how much energy is saved by a communal residential building in Indonesia with the use of photovoltaic to achieve the goals of the Kyoto Protocol, Paris Agreement and sustainable points on the SDGs to create a sustainable building. The EDGE application is used as a reference for calculations.

THEORETICAL APPROACH

Eco-Building

Eco-building can also be referred to as eco-design or green design, which is a movement that aims to create an architectural product that is environmentally friendly and sustainable by utilizing environmentally friendly technology and efficient use of resources [8]. In the eco-building principle, one of the typologies of energy-saving architecture is known [9]. Design with an energy understanding is the emphasis of design concerning environmental conservation, especially the preservation of energy sourced from non-renewable fuels, to be replaced with renewable energy [10].

Photovoltaic

A solar panel or photovoltaic is a device that can convert energy obtained from sunlight into electrical energy. This process is called the photovoltaic effect process [11]. There are three types of a photovoltaic; monocrystalline, polycrystalline, and thin film. The performance level of each material also varies. The highest efficiency performance is with monocrystalline materials by 17% to 22%, then polycrystalline by 15% to 17%, and thin films by 10% to 13%. Although the thin film has the lowest efficiency, this material has the highest temperature coefficient. This material was better at dealing with solar heat without reducing energy absorption efficiency [12]. For calculating energy output from solar photovoltaic and passive design assisted by the EDGE Building application. To meet the energy-efficient building standards according to EDGE, the energy saving of the building must reach a minimum of 20% or more [13].

METHODOLOGY

The method used is a quantitative method by taking into account:

1. Energy-saving calculations from the application of passive design with cross-checked in the EDGE application.
   EDGE (Excellence in Design for Greater Environment) is an application created by International Finance Corporation. The EDGE application calculates the energy savings, water savings, and reduced carbon footprint of a building, demonstrating the most effective scenario of a building to make it a green building [13]. EDGE is used as a reference for the energy saving calculation.
2. The use of solar photovoltaic as a substitute for non-renewable energy.
   Solar photovoltaic is a growing trend in residential building for the last decade. As the awareness of "green building" concept grows, so does the trend of using solar photovoltaic as a substitute of non-renewable energy. Using solar photovoltaic is proven to provide various benefits for its users, including: saving energy and electricity cost, various benefits and regulations from the government, and many other benefits.

RESULT AND DISCUSSION

From the theory and methodology described above, there are two topics of discussion in this paper, namely:

1. Energy Saving Calculation
2. Use of Solar Photovoltaics

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The first discussion is the energy saving calculation, that was provided by EDGE as a reference for the calculation. By inputting the data of the building to the application, EDGE will calculate the utility savings and cost reduction. After the calculation is known, the next discussion is the use of solar photovoltaics to improve the savings even further. The data of solar photovoltaics' savings will change the EDGE data of energy savings for better.

Energy Saving Calculation

By using the help of the EDGE application, the calculation to find out energy saving is obtained with the following data:

TABLE 1. Energy Saving Data Based on EDGE Application

Information of EDGE	Description	Material
Window to Wall Ratio (WWR)	6.25 % (Unit 24) 15% (Unit 36 dan 48)	-
Reflective Roof	70 SRI	White EPDM Rubber Roofing Membrane
Reflective Exterior Walls	70 SRI	White Acrylic Paint
Insulation of Exterior Walls	0.3 $W/m^2.K$	150 mm cement sand bricks
Efficiency of Glass	U-value : 2.6 $W/m^2.K$ SHGC : 0.685 VT : 0.79	Window Type : HS1-C180 Dual pane, one Low-E coating, Argon Visible Light Transmittance : 79%
Natural Ventilation	-	-
Cooling System Efficiency	COP : 3.51 (Split, packed, Air Cooled)	Air-cooled $\leq$ 9 kW
Efficient Lighting for Internal Areas	90 Lumens/W	LED
Efficient Lighting for External Areas	90 Lumens/W	LED
Lighting Controls	-	Timer and Infrared Sensor

Source : Author (2021)

The data above is from the items and descriptions of the EDGE information used in the co-living building plan. Based on the data above, several amounts of energy-saving are obtained from several masses of co-living buildings. The mass of the building is separated based on the available units, namely: mass unit 24 m2 (200 units), mass unit 36 m2 (190 units), and unit mass 48 m2 (190 units). The materials used in each building mass are the same. The concrete roof cover was coated with a White EPDM Rubber Roofing Membrane and used white acrylic wall paint for exterior walls.

The use of dual panes on window panes aims to implement AFVW (Acoustic Friendly Ventilation Window), which can help eliminate air pollution four times better than ordinary windows. AFVW is also useful for maintaining thermal comfort and promoting clean air circulation in tall buildings (Figure 1). By using the AFVW window, energy use can also be reduced.

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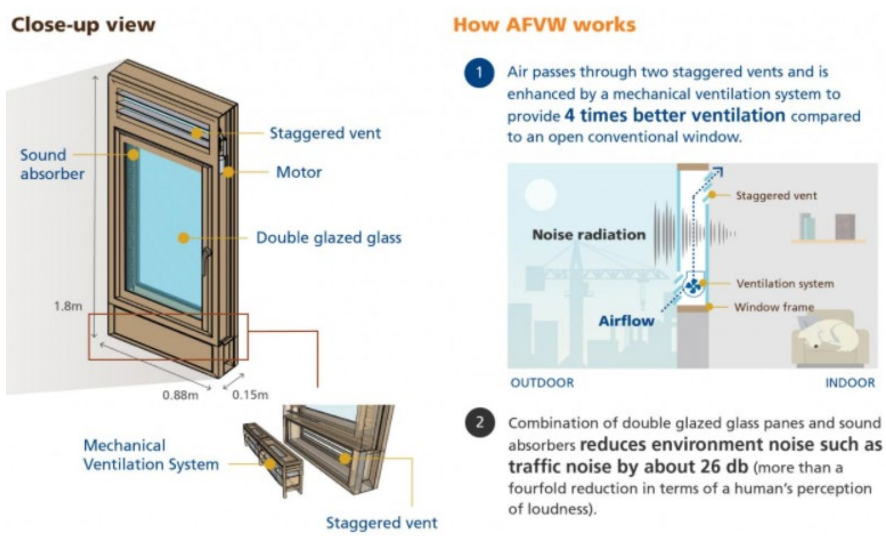

FIGURE 1. AFVW window illustration
Source : https://news.nus.edu.sg/novel-window-design-reduces-outdoor-noise-and-improves-ventilation/. Accessed: October 8, 2021

The lamp used is an LED lamp with an efficacy of 90 Lumens/W, equipped with a timer and infrared sensor to save energy automatically when not in use.

Based on calculations from the EDGE application, some data are obtained based on each building mass.

TABLE 2. EDGE Data Based on Each Massing

Massa	***Energy Saving*** **(%)**	**Energy Usage kWh / month / unit**	**CO_2 Emission Expenditure tCO/year**
Unit 24 m^2	26.39	351	752
Unit 36 m^2	34.98	421	856
Unit 48 m^2	35.68	514	1,045

Source : https://app.edgebuildings.com/project/homes Accessed: October 12, 2021

If calculated using the EDGE energy efficiency standard from the three data above, which requires buildings to save more than 20% of energy, all units have qualified as energy-efficient buildings with the highest total energy saving for unit 48 with 35.68%. The actual energy use for all units per year is 2.974.200 kWh. For CO_2 emission expenditures, it is still far from zero-emission for the 2030 goal. Still, with the development of technology, environmentally-friendly renewable energies can further reduce the expenditure of emission.

After knowing the amount of energy released by the building, it is necessary to look for solar photovoltaic needs that this building can accommodate. So It can find out how much energy this building can save.

Photovoltaic Use

Residential buildings can make more energy-efficient; photovoltaic is used as a source of daily energy. Photovoltaic in the building is located on the roof and is also used on the second skin of one side of the building facing north (Figure 2). The photovoltaic material used for this second skin is thin-film material, while monocrystalline is used for the photovoltaic on the roof.

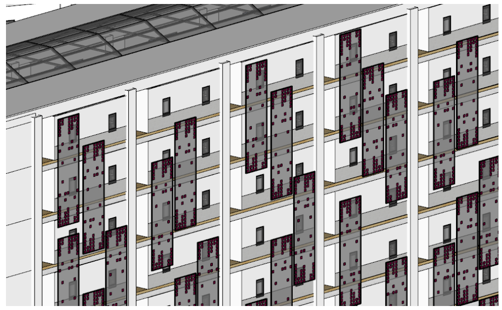

FIGURE 2. The use of thin-film type solar photovoltaic as a second skin
Source : Author (2021)

The area used as a photovoltaic laying area is divided into the roof area and the facade area. The usable roof area is 1,716 m2. Any building mass does not block this area, so it does not reduce the efficiency of the photovoltaic installed. For the facade area facing north, it was using photovoltaic as a second skin with an area of 17.5 m2 per unit with a total of 45 pieces, making the total area of the second skin that functions as a photovoltaic area of 787.5 m2. Based on the materials used, the following annual output is obtained (Table 3).

TABLE 3. Energy Output Calculation Table from Solar Photovoltaic

Formula	**Area**	**Efficiency (average)**	**Energy Quantity**
Energy Output = Area x Efficiency x Annual Average Solar (2044 per year in Indonesia) x 0.75	1.716 m^2 (Roof)	19.5 %	512.972 kWh/year
	787.5 m^2 (Second skin)	11.5 %	138.832 kWh/year
Total			**651.804 kWh/year**

Source : Author (2021)

From the above calculation, the amount of energy produced by photovoltaic per year is 651,804 kWh. Compared to the annual expenditure of buildings of 2,974,200 kWh, photovoltaic can accommodate a yearly energy load of 22% of annual use. After the data on the energy output from solar photovoltaic is obtained, the following is the amount of energy savings, energy consumption, and emission expenditures in buildings according to the EDGE calculation (Table 4).

TABLE 4. Table of EDGE data per Building Mass after using solar photovoltaic

Mass	***Energy Saving* (%)**	**Energy Usage kWh / month / unit**	**CO_2 Emission Expenditure tCO_2/year**	**Break-Even Point**
Unit 24 m^2	42.52	274	586	0.63 year = 230 day
Unit 36 m^2	49.22	328	667	0.56 year =204 day
Unit 48 m^2	49.76	401	815	0.59 year = 215 day
			Average Break-Even Point	0.593 year = 216 day

Source: https://app.edgebuildings.com/project/homes Accessed: October 12, 2021

After using Photovoltaic, there is a very significant change from the data in Tables 4 and 5. Energy savings can be increased by more than two times, while several photovoltaic usages can reduce energy use and CO_2 emission expenditures by 22%. Energy savings of all buildings after using photovoltaic can be said to exceed the standard of EDGE calculations (EDGE advanced) (Table 5), and buildings can be categorized as environmentally friendly buildings for building energy categories above 40% with an average of 47.16% (42.52%, 49.22%, and 49.76 %). There was a break-even point at 0.593 years or 216 days (Table 4 and 5).

https://doi.org/10.24912/ijaste.v1.i2.433-439

Table 5(a). EDGE Building data for 24 m^2

Final Energy Use	Final Water Use	Base Case Utility Cost	Utility Cost Reduction	Incremental Cost	Payback in Years
274.38 kWh/Month/Unit	5.66 kL/Month/Unit	679.56 Thousand Rp/Month/Unit	274.25 Thousand Rp/Month/Unit	2,080.62 Thousand Rp/Unit	0.63 Yrs

Design | Energy 42.52% | Water 0.00% | Materials 1.74%

Table 5(b). EDGE Building data for 36 m^2

Final Energy Use	Final Water Use	Base Case Utility Cost	Utility Cost Reduction	Incremental Cost	Payback in Years
328.68 kWh/Month/Unit	11.13 kL/Month/Unit	942.11 Thousand Rp/Month/Unit	430.17 Thousand Rp/Month/Unit	2,872.95 Thousand Rp/Unit	0.56 Yrs

Design | Energy 49.22% | Water 0.00% | Materials 0.61%

Table 5(c). EDGE Building data 48 m^2

Final Energy Use	Final Water Use	Base Case Utility Cost	Utility Cost Reduction	Incremental Cost	Payback in Years
401.37 kWh/Month/Unit	22.08 kL/Month/Unit	1,214.01 Thousand Rp/Month/Unit	536.93 Thousand Rp/Month/Unit	3,782.65 Thousand Rp/Unit	0.59 Yrs

Design | Energy 49.76% | Water 0.00% | Materials 0.69%

Note. Energy (red box) Break-Even Point in Year (circle)

Source : https://app.edgebuildings.com/project/homes Accessed: October 12, 2021

CONCLUSION

In this research, it seems that a co-living building that implements a passive design system in energy saving has been able to make the building environmentally friendly and energy-efficient. The savings obtained based on EDGE calculations are sufficient to categorize the building as environment friendly buildings. The most significant savings are in the 48 m2 unit with an energy saving of 35.68%, and the smallest is the 24 m2 unit with an energy saving of 26.39%. However, this energy-saving can be increased by using solar photovoltaic in the buildings. Photovoltaics in the buildings are on the roof of the building and one side of facade facing north as a second skin element. The use of monocrystalline and thin-film materials is based on the use and function of the material itself. With a photovoltaic output capacity of 651,804 kWh/year, the solar photovoltaic from this co-living building can accommodate an energy load of 22% of the total annual usage of 2,974,200 kWh/year. The use of photovoltaic in the buildings can increase energy savings and make the buildings categorized as advanced energy efficient buildings and are able to reduce emissions in the buildings. The average energy saving of the entire building is 47.16%, and the average break-even point of the whole building is 216 days, with the longest break-even point being a unit of 24 m2 with a time of 230 days.

ACKNOWLEDGEMENT

Thank you to LPPM-UNTAR (Institute for Research and Community Service-Tarumanagara University) for funding this research.

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