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Application of Building Integrated Organic Photovoltaic Various Building Forms in Malaysia

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ABSTRACT

Research on Building Integrated Photovoltaic BIPV with Organic Photovoltaic (OPV) materials and systems has increased because of their promise to deliver low-cost solar energy conversion. Since OPV devices' efficiency has quickly risen to above 10%, there is a huge commercial need for further development and manufacturing. The development of specialized materials and device designs, together with an improved understanding of the BIOPV efficiency. This paper discusses recent advances in OPV material, with a particular emphasis on various methods for forming OPV facades and modifying the orientation of the form to better absorb incoming light sources. The findings need to go through 6 form designs that have been divided into dynamic and organic forms. This research used simulation from ARCHIWIZARD and PV*Sol to evaluate different building forms in terms of solar exposure and shadow effect. The result shows that the pyramid building form receives higher solar exposure compared to other forms, thus better electricity generation. The solar-optimized pyramid introduces an innovative fusion of architectural principles and contemporary solar technology to enhance energy generation and sustainability. By capitalizing on the pyramid's design, orientation, and light-concentrating attributes, it not only captures abundant sunlight but also symbolizes renewable energy, bridging historical aesthetics with modern eco-conscious solutions.

1. Introduction

The Malaysian government's 8th and 9th Plans, which are now in effect, provide several incentives for renewable energy. Solar Photovoltaic PV systems are among the most widely investigated renewable energy sources now in Malaysia. There are just a few states in Malaysia with greater sun radiation levels, which creates a significant opportunity for solar PV research. On a map of the globe, Pulau Pinang is one of the states receiving a good amount of solar radiation. In comparison to other countries across the globe, the amount of solar radiation that is received in Malaysia is one of the least. The amount of solar radiation that Malaysia receives falls between 4.0

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and 4.9 kWh/m^2/day in comparison to other locations across the globe that have the highest potential for solar energy, which ranges between 6.0 and 6.9 kWh/m^2/day [1-3]. Researchers have carried out statistical analysis on data pertaining to solar radiation for the cities of Kuala Lumpur, Penang, and Kota Baru in Malaysia. It is crucial to have estimates for metropolitan areas when designing integrated photovoltaic applications. As can be seen, the area known as the Klang Valley, which contains the cities of Kuala Lumpur, Putrajaya, and Seremban, has the lowest irradiance value. The greatest levels were found in the region of Kota Kinabalu and Penang Georgetown, on the northwest coast [1,4].

The most well-known aspect of solar energy is PV, which is a clean and environmentally friendly source of power. Using solar energy is a fantastic method to decrease carbon impact. Solar energy does not damage the environment in any way. Solar energy emits zero greenhouse gases and utilizes no other resources than pure water [5]. It is thus safe and ecologically beneficial. Despite this, individuals continue to question the merits of solar energy. Solar energy is self-sufficient, and putting solar panels on roofs is a secure and straightforward way to contribute to a sustainable future. With a fantastic approach, it will demonstrate environmental concern. The drop in the price of PV panels is an excellent illustration of why solar energy should be used more often. Traditional power mainly depends on fossil fuels such as coal and natural gas [6]. Not only is it detrimental to the environment, but it also represents scarce resources. This results in a dynamic market in which the price of energy fluctuates throughout the day. Solar power enhances energy autonomy! By investing in a 4kW solar system, which is the most popular residential size, it can easily protect against unforeseen spikes in utility bills and enjoy affordable power throughout the whole day - the sun will never raise its rates and it provides energy security. Once solar panels are installed on the roof, it theoretically achieves energy independence. Solar battery storage systems may also be used to store power for use throughout the night and on days with inclement weather.

Several harmful compounds, like cadmium and arsenic, are used in the PV manufacturing process [7]. These environmental effects are negligible and are readily manageable via recycling and appropriate disposal. Due in part to the cost of producing PV devices and in part to the conversion efficiency of the equipment, solar energy is more costly. PV will become more cost-competitive with conventional fuels as conversion efficiencies continue to grow and manufacturing prices continue to decrease.

The roof is a point of interest where people may take in the view. However, there is no space for customers to enjoy the view since solar panels are often installed on the top to get more solar radiation [8]. Because solar materials produce power and need maintenance in the case of damage, the PV area needs to become a service area. In addition, it must be in a secluded location since PV materials are costly and may be stolen or damaged by unauthorized individuals. Apart from that, PV materials also have harmful compounds during manufacturing [7]. Therefore, this research uses one of the most recent material technologies to be used in BIPV organic photovoltaic OPV. Specially crafted, printed organic molecules known as OPVs gather natural and artificial light to produce power. The research aims to discover the abilities and benefits of OPV that can help in terms of building energy consumption and production usage. Therefore, a simulation is carried out to determine the photovoltaic potential. It's to find out more details in terms of location, position, and form. Figure 1 shows the flowchart of this research and the objective is to investigate solar exposure with different building forms and shapes and evaluate the performances of OPV on the simulation with the result of solar exposure.

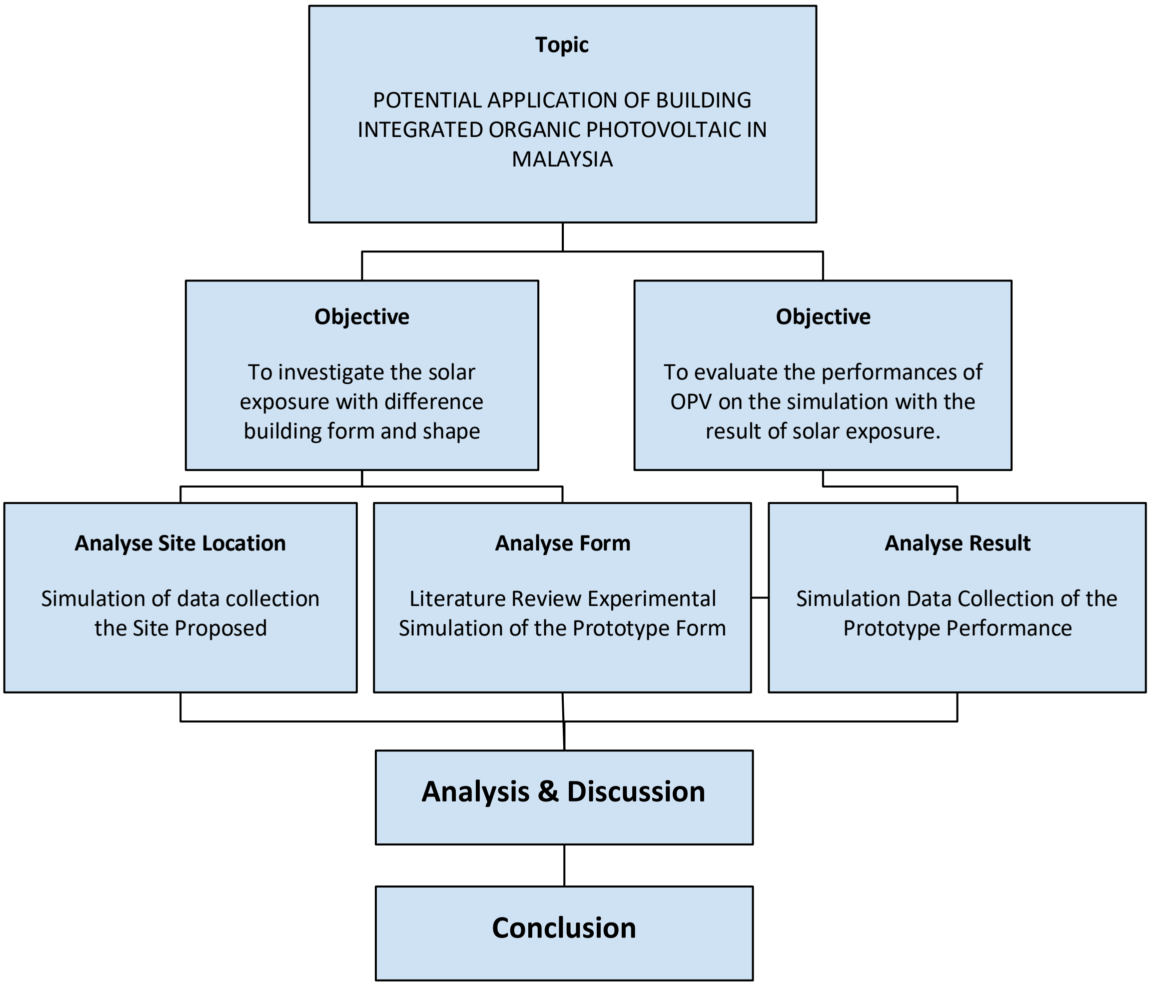


Fig. 1. Research Flowchart

1.1 Organic Photovoltaic the 3rd Generation of Photovoltaic

The third generation of solar cells is additionally referred to as OPV cells (Figure 2). The ability of these organic cells to absorb sunlight and artificial light is extraordinary. In comparison to other solar cells, currently, OPV can capture above 10% - 19% efficiency [9]. According to the reports, organic electricity holds the key to the future of solar technology. It won't be possible for conventional solar technologies to surpass organic electricity, even when they are able to catch up and match it [10]. The extraordinary qualities that organic power possesses give it virtually infinite potential. An OPV, commonly referred to as a plastic solar cell, is a form of polymer solar cell that uses organic electrons. These are a subfield of electronics that work with conductive organic polymers, or tiny organic modules, to absorb light and move charges. This will enable the photovoltaic effect to use sunlight to generate power [9]. The OPV converts solar energy into electrical energy at rates that are far higher than those of any other solar cell technology, including the silicon cells that make up the bulk of solar panels.

Due to its unique advantages of inherent flexibility, lightweight, high throughput large-area printing, cheap cost, and non-toxic raw ingredients, OPV has received a lot of interest for PV applications. The OPV should forge a different path to achieve their practical use, such as flexible and portable power sources, creating integrated PV, to compete with the more mature crystal silicon-based PV market [9,11]. OPV envelopes may take on any shape or form with the aid of an organic photovoltaic material that is flexible to enhance the number of light energy sources [12,13].

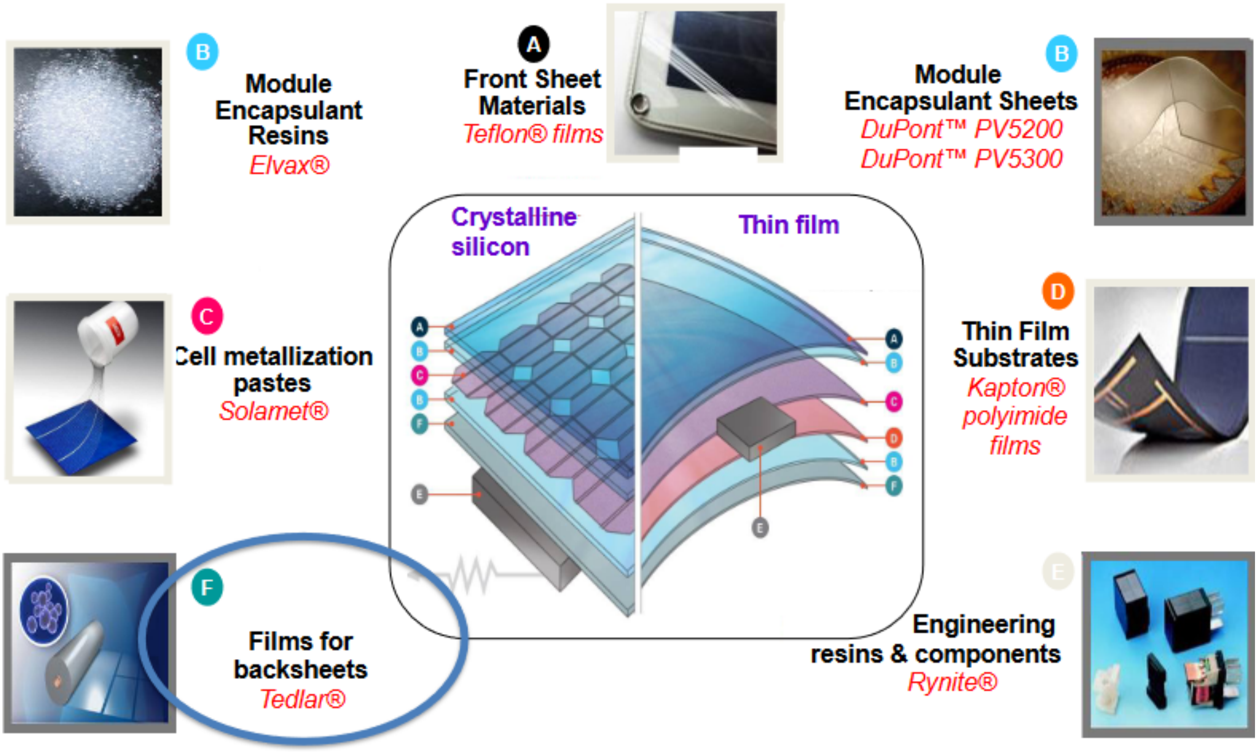


Fig. 2. A Photovoltaic and Organic Photovoltaic material [11]

1.2 BIPV System

The most significant factor influencing the energy demand, energy consumption, and thermal performance of buildings is thought to be the building form. It also has an impact on the amount of solar radiation that is received as well as how much energy is used overall. Apart from that, High temperatures can decrease the efficiency of solar panels by 10 to 25 percent [13]. As a result, the building shape performs the seemingly incompatible tasks of identifying the façade/roof surface regions that may be used to capture solar energy while limiting energy losses caused by its exposed surfaces. As a result, although using an ideal surface-to-volume ratio might be helpful in the early stages of design, it would not be adequate.

Opportunities for photovoltaic PV integration as a Building Integrated Photovoltaic (BIPV) system in the exposed structure are provided by the building envelope [14]. BIPV, which first gained attention in the late 1990s, is the most promising approach to generating energy [13]. The notion of a multi-functional building component uses semiconductor PV modules to generate usable electricity and integrate PV into the building envelope by swapping out the traditional materials used for the structure's roof, façade, windows, and sun shading components (Figure 3). Additionally, it offers climate control, thermal and acoustic insulation, and a reduction in the carbon footprint of a building while generating power in response to the building's energy demand for internal use. The power may also be stored and fed into the electrical grid, adding value to the building at the same time. The BIPV system is designed using similar principles to a PV system, with the location's latitude used to determine the necessary tilt angles and orientation toward the south in the northern hemisphere for optimal energy output. Increased warmth, inadequate ventilation, non-optimal tilt angle, and azimuth all influence how well it performs [15-17]. It should be noted that difficulties such as partial shadowing, improper tilt, and azimuth have a detrimental influence on the performance ratio PR. Under actual conditions, non-uniform PV generation performance is predicted for PV installation in partly shaded open regions. Therefore, shaded modules absorb less energy from the sun, which serves as a load. However, the shading impact on PV panels caused by a building's layout may be properly simulated using Sketchup and PoV tools, and the results can then be evaluated.

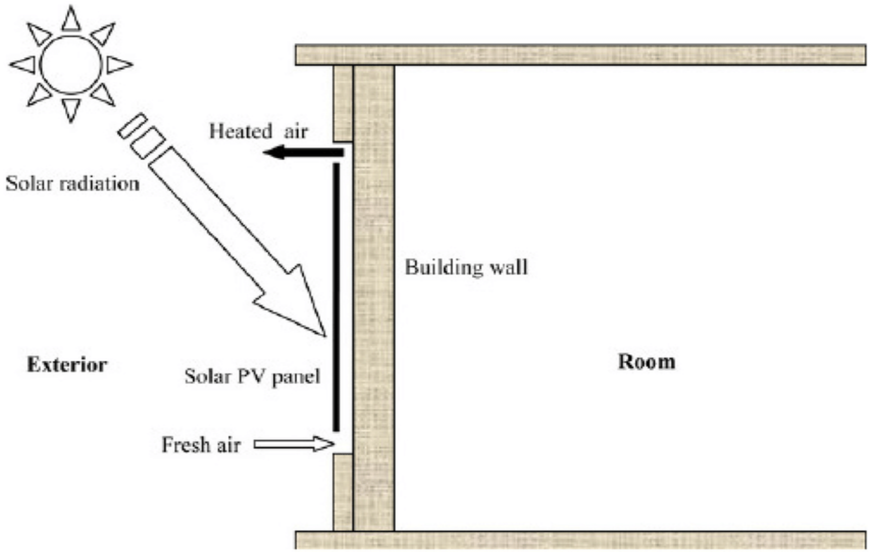


Fig. 3. Schematic Diagram of Building Integrated Photovoltaic System [17]

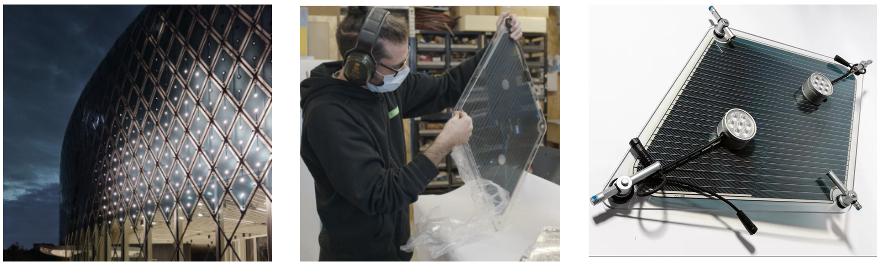
Currently, BIPV roof systems are favoured because they provide a greater power supply with less shadowing, although PV integration in façades is growing in popularity for aesthetically pleasing reasons. However, 80% and 20%, respectively, of the BIPV industry is made up of roof-mounted and façade integrated technologies. A BIPV roof-mounted system's output may also provide 14.5% to 58% of a building's energy needs, depending on the local climate, solar yield availability, and mounting geometry [17].

1.3 Building Integrated Organic Photovoltaic with Media Façade

In Basel, Switzerland, the Novartis Pavilion designed by AMDL CIRCLE and Michele De Lucchi has opened (Figure 4 and Figure 5). The new exhibition, meeting, and event center on the Novartis Campus is the first publicly accessible facility. It intends to stimulate a debate about life sciences and serve as a repository for the history, present, and future of healthcare.

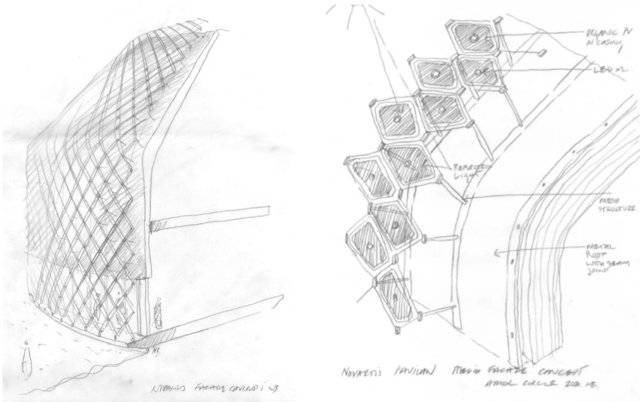
At the Novartis Pavilion, a membrane resembling a net is connected to the building's sheet metal exterior. Organic solar cells in the form of rhombuses are screwed into the mesh for ventilation and the power they produce is utilized to light the structure [13]. Approximately 7,000 outward-facing cells out of approximately 10,000 are fitted with LED modules. The modules are bi-directional in that one LED unit faces away from the façade while the other faces the facade. During the day, the facade is lit by forward-facing LEDs, however at night it is lit by indirect light [18]. The media façade can display low-resolution text and video information that scrolls. Artists develop unique material incorporating creative interpretations of life sciences for the façade to maximize its potential.

(a)



(b) (c) (d)

Fig. 4. Novartis Pavilion, Switzerland Organic Photovoltaic System [18]



(a) (b)

Fig. 5. Sketches system of BIPV Organic Photovoltaic [18]

The solar modules Figure 6 will function at 26% efficiency in low-light conditions [18]. Solar technology provides energy to tiny, connected things inside low-light conditions from 200 lux, such as temperature sensors and geolocation trackers. These flexible, bending, transparent, and highly light-sensitive organic solar modules are perfect for usage on the Novartis Pavilion's dome due to their design and physical characteristics. There is a constant propensity for visual bias in architecture since the built environment is largely created for aesthetic or practical purposes and efficiency. It is critical to investigate how the senses affect building inhabitants and how BIPV with OPV combine to provide energy efficiency and environments that support health and well-being.

2. Methodology

In early design stages, the energy potential produced by the BIPV idea is heavily influenced by the primary solids building shape and outer surfaces commonly used on academic buildings and under Economy Plan Unit with the control of high limit restriction in which each form has the same 3600m³ (Figure 6) and under Economy Plan Unit [19]. The four sections in Figure 7 of the study are data collection of the site, form organization, criteria, analysis outcomes, and validation of each of the form results. To fulfil the building energy demand, the goal is to ascertain the link and correlation between the energy produced on exposed surfaces. Each of the BIPV forms will go through with ArchiWIZARD and PV*SOL photovoltaic simulation software [20]. The prototype shape is first utilized as a reference cube for examination via the 6 phases of criteria in section 2 in accordance with the research methodology (Figure 7). The procedure is then repeated after creating 5 shape varieties Figure 6. Section 3 conducts an analysis of the findings in relation to the scenarios and priorities for both the prototype form and the case study. The early findings of the prototype form are used in section 4 to verify the calculated Based Form Factor BIPV values for the case study [21,22].

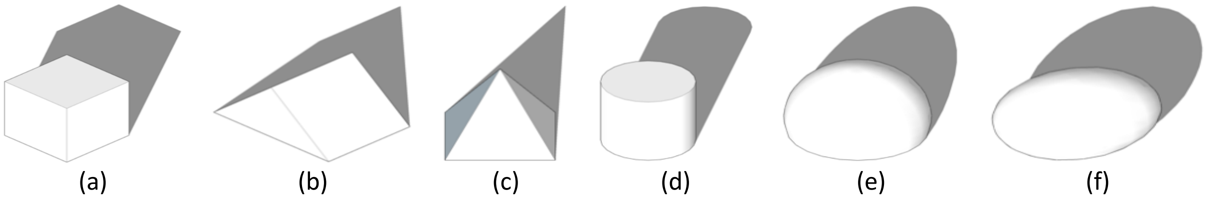


Fig. 6. Types of criteria BIPV forms; (a) cube, (b) triangular prism, (c) pyramid, (d) cylinder, (e) hemi-sphere, (f) ovoid

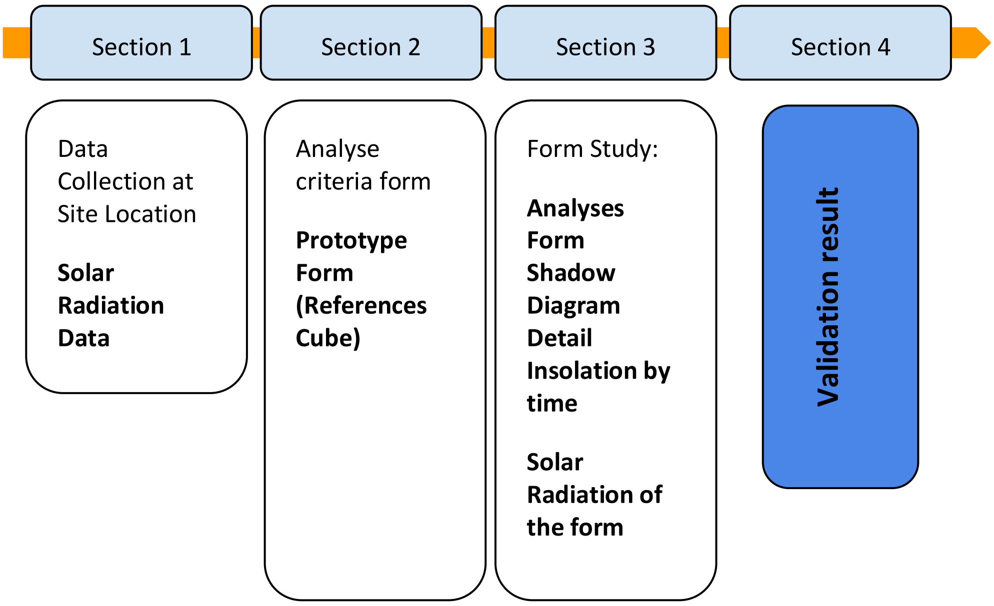
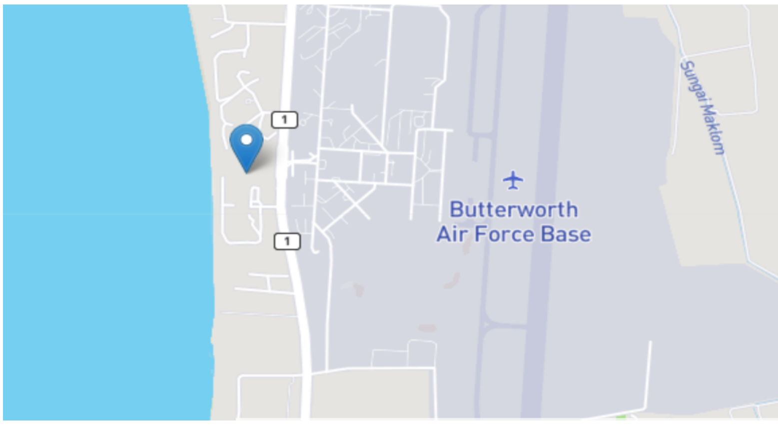


Fig. 7. Methodology Flow

2.1 Site Analysis

The Malaysian government's 8th and 9th Plans, which are now in effect, provide several incentives for renewable energy. Solar Photovoltaic PV systems are among the most widely investigated renewable energy sources now in Malaysia. There are just a few states in Malaysia with greater sun radiation levels, which creates a significant opportunity for solar PV research. On a map of the globe, Pulau Pinang is one of the states and is situated in Malaysia's northernmost area at latitude 5.46427 degrees and longitude 100.38146 degrees Figure 8. According to Figure 9, it receives 1807.9 kWh/m^2 per month of yearly global solar radiation. According to the graph, the months of January through March have the highest levels of solar radiation. The tabulated data in Figure 9 is essential for determining how much solar energy, or more specifically, how much sun irradiation will be received over the whole year. The first step is to convert the solar radiation data from MJm^{-2} to kWhm^{-2}. From this point, the Peak Sun Hour PSH, which is the number of equivalent hours when the sun irradiance is 1 kWhm^{-2}, may be determined.



Latitude	5.46427 °
Longitude	100.38146 °
Annual Global Irradiation	1807.9 kWh/m^2
Average Temperature	27.9 °

Fig. 8. Location of the site propose in PV*SOL

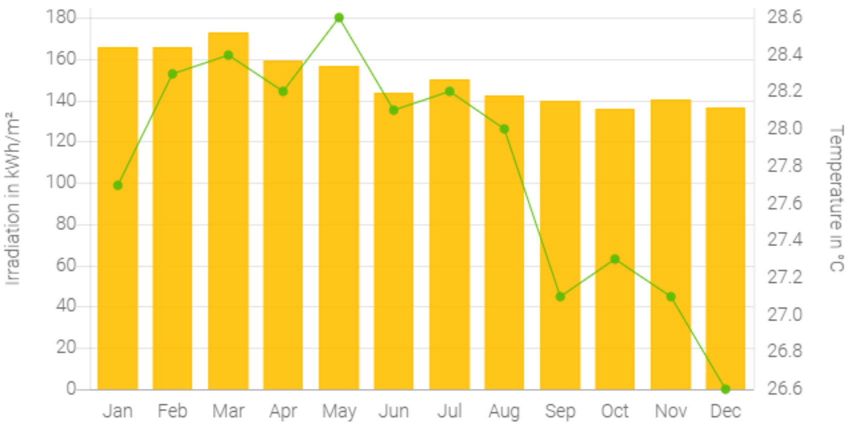


Fig. 9. Annual Solar Radiation of the Location 2023 in PV* SOL

This research uses one of the most recent material technologies to be used in BIPV OPV. Specially crafted, printed organic molecules known as OPVs gather both natural and artificial light to produce power. The material is so thin and adaptable that it may be adhered directly to a building or combined with a steel panel while being built. Even older structures may be modified with it using ornamental adhesive window films. Because installation is substantially less expensive, there is more potential for applications.

2.2 Organisation Form

The Primary solid building shape highly impacts the energy potential created by the BIPV concept and exterior surfaces typically employed on buildings with the control of high limit limitation in which each form has the same 3600m^3 by Economy Planning Unit and 25m in height in Figure 6. In the first step of the process, the prototype shape is divided into 2 categories which is dynamic and organic shape, as shown in Figure 10.

The first to be analyzed is the dynamic shape, the cube, which the step references to another's form. Most building designs are either rectangular or square since these shapes are simpler, more efficient, and more cost-effective to construct out of materials. Following the data collection process, an analysis will be performed on the attributes of the form. It is possible to proceed with the subsequent stage, which is the presentation of the analysis results.

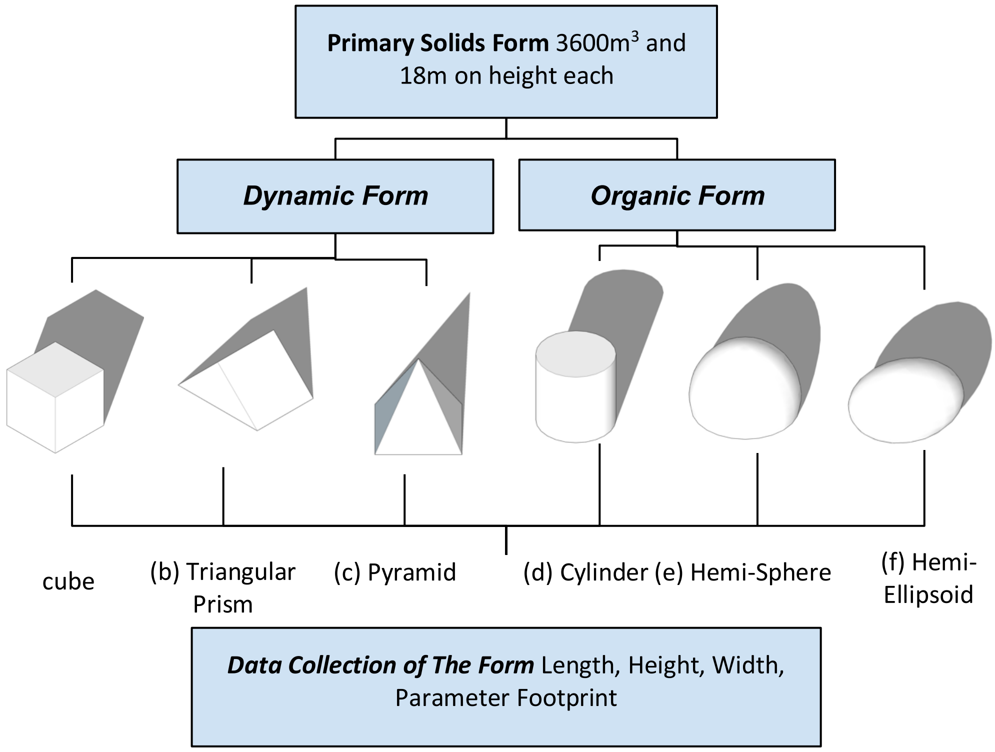


Fig. 10. Analyse characteristics of the form flow

2.3 Specification for Organic Photovoltaic

This project is utilizing Dupont Apollo's C Series Thin Film Modules as the material for OPV (Organic Photovoltaic). Table 1 shows the technical specification of the PV module used in this simulation.

Table 1
Specification OPV [11]

Dupont Apollo	
C Series Thin Film Modules	Model: DA154
Technology	Microcrystalline Silicon (SI-Microcrystalline)
Standard Test Condition	
Nominal power output (Pmpp)	154W
Voltage at Pmpp (Vmpp)	124V
Current at Pm point (Impp)	1.24A
Open circuit voltage (Voc)	159V
Short circuit current (Isc)	1.444
Open circuit voltage, initial (Voc, initial)	163V
Short circuit current, initial (Isc, initial)	1.46A

2.4 Parameters

Using Autodesk Ecotect, a form analysis may be performed in the third portion, which is the section in question. By positioning the form following the direction in which the study is facing the sun. The shape will get statistics on the amount of solar exposure it receives (Figure 11).

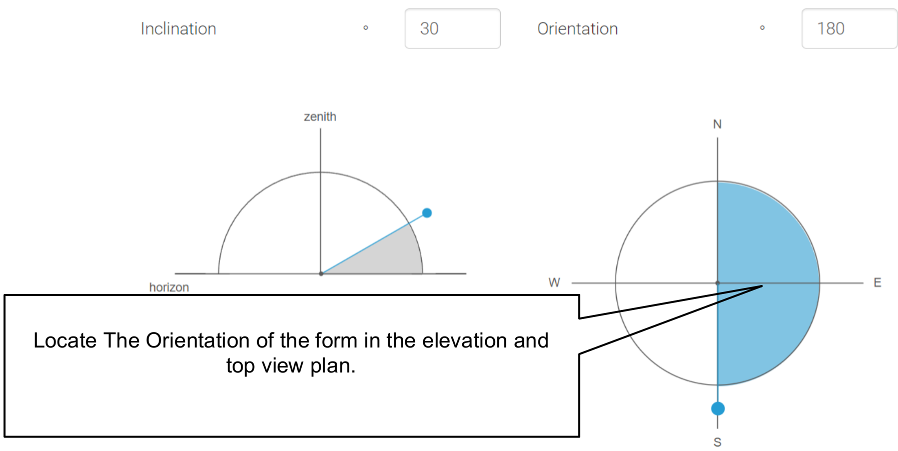


Fig. 11. Orientation Parameter in PV* SOL

The numerals 5 to 10 may represent objects or elements that project shadows on the analyzed surface or object. This may be the result of obstructions such as buildings orientation that prevent sunlight from reaching the surface at certain times of the day. Being outside the shaded area, the numerals from 5 to 0 would be exposed to direct sunlight for a significant portion of the day. This suggests that the surface or object analyzed in this scenario is positioned or oriented to maximize sunlight exposure (Figure 12). Meanwhile, the insolation by time parameter will indicate the color red receives a smaller quantity of sunlight between 0 and 1.5 hours, whereas the color yellow receives a significant amount of sunlight between 1.5 and 3 hours (Figure 13).

Fig. 12. Shadow Parameter in ArchiWIZARD

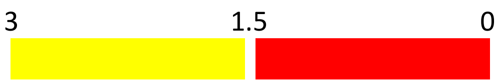


Fig. 13. Isolation by Time Parameter in ArchiWIZARD

Diagrams of solar radiation are used in a variety of contexts, including the design of solar energy systems and architecture (Figure 14). One can determine the sun exposure, intensity, and shading patterns at a particular site by analyzing the diagram, which helps to guide choices regarding the orientation of the structure, the placement of the windows, the positioning of the solar panels, and the overall energy efficiency of the building.

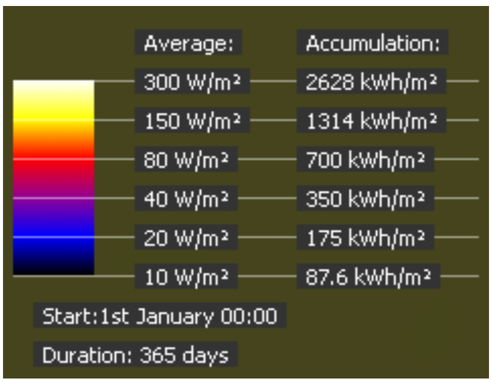
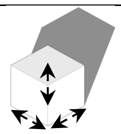
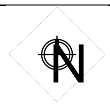
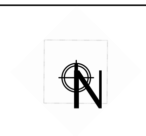
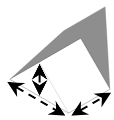
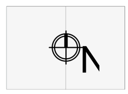
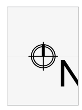
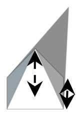
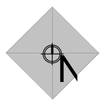


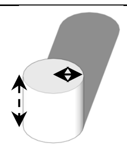
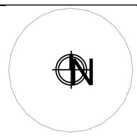
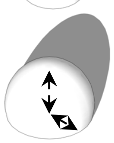
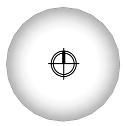
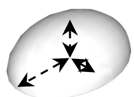
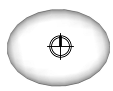
Fig. 14. Solar Radiation Parameter in ArchiWIZARD

2.5 Setup Configuration

The experiment on the object followed by the orientations to explore the sunlight interacts with different forms (Table 2).

Table 2
Configuration forms in ArchiWIZARD

Dynamic Form								
Type	3D	Orientation 1	Orientation 2	Measurement				
				Length	Height	Width	Base	Exposure Area
(a) Cube				15.3m	15.3m	15.3m	-	1176.42 m^2
(b) Triangular Prism				20 m	14 m	25.8 m	-	1120.82 m^2
(c) Pyramid				-	22.11m	-	2.11 m	1094.11 m^2

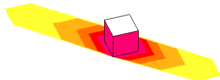
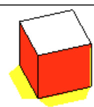
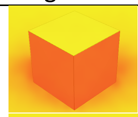
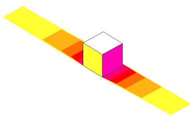
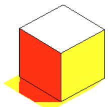
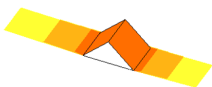
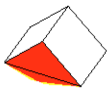
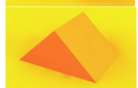
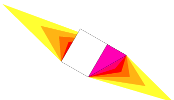
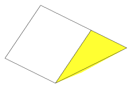
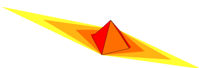
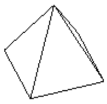
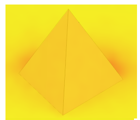
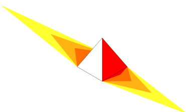
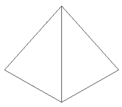
Organic Form							
Type	3D	Orientation 1	Orientation 2	Measurement			
				Radius	Height	Base	Exposure Area
(d) Cylinder			-	84 m	16.25 m	-	870.66 m^2
(e) Hemi Sphere			-	12.2 m	9.9 m	-	913.05 m^2
(f) Hemi Ellipsoid				22.11m	-	22.11m	1094.11 m^2

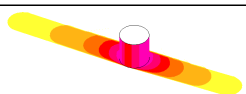
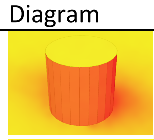
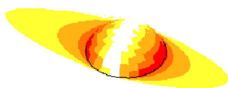
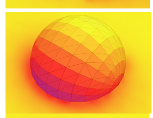
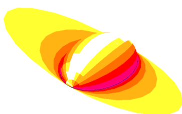
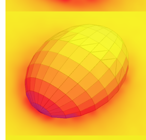
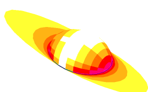
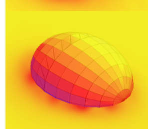
3. Results

3.1 Graphical Sun Exposure

The result discussion discusses the Setup Configuration procedure in Table 2, and Table 3 by analysing and interpreting the simulation results from material Table 1 in OPV. Figure 12 to Figure 14 indicate the parameter diagram colours for the shadow diagram detail, insolation diagram, and solar radiation diagram.

Table 3
Shadow Diagram, Insolation Diagram, and Solar Radiation Diagram of different building forms in ArchiWIZARD

Dynamic Form					
Type	Orientation	Experiment Form Diagram			Area Exposure (m^2)
		Shadow Diagram Detail	Insolation Diagram	Solar Radiation Diagram	
(a)	1				1176.42
	2				
(b)	1				1120.82
	2				
(c)	1				1094.11
	2				

Organic					
Type	Orientation	Experiment Form Diagram			Area Exposure (m^2)
		Shadow Diagram Detail	Insolation Diagram	Solar Radiation Diagram	
(d)	1				870.66
(e)	1				913.05
(f)	1				929.97
	2				

3.2 Numerical Solar Contribution

By utilising simulation software and analysing the data from May to September, it was determined that they produce a substantial amount of energy (Figure 15 and Figure 16). In January, the solar contribution starts to increase, and it continues to rise until May, with a small additional increase observed in March. Apart from that, from May to December, the solar contribution gradually decreases, with December receiving significantly less solar contribution compared to January. By observing the overall pattern of the chart, it clearly has the almost same as the annual solar radiation chart Figure 10 in terms of amount and pattern.

Among the ten forms analysed, Pyramid 1 demonstrated the highest total level of energy generated, making it the most suitable form for the proposed site in terms of solar exposure with 5138kw per year. It gets the highest total value because it has a larger area exposure to absorb sunlight than other forms. While comparing "dynamic form" and "organic form" for BIOPV (Building-Integrated Organic Photovoltaics) in terms of energy generated potential and suitability in Malaysia the Organic form has the least amount of energy generated then Dynamic form because organic form has less area solar exposure then dynamic form in Table 4. Moreover, the value energy generated almost with the dynamic cube form is the cylinder because it gets the longest in the insolation diagram in Table 4 of the other organic forms.

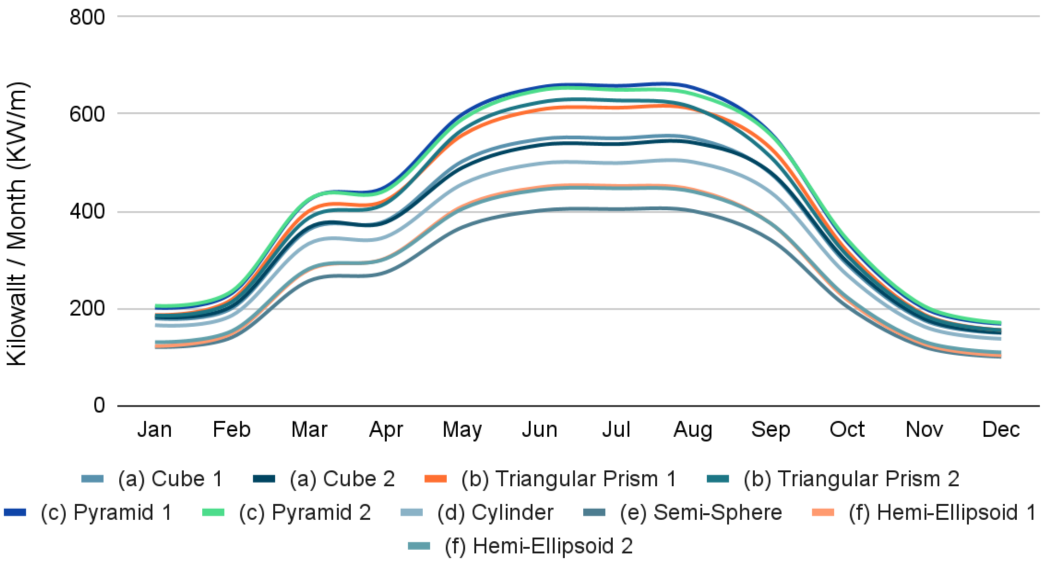


Fig. 15. Monthly Energy Generated

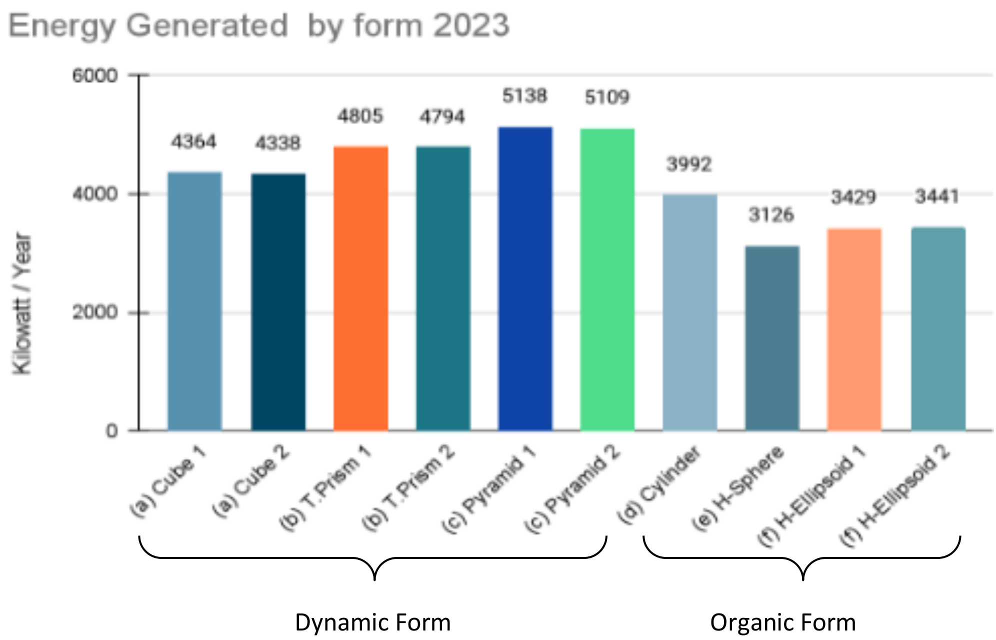


Fig. 16. Annual Energy Generated by Form

Table 4
Monthly Energy Generated

Form's Type		(a) Cube 1	(a) Cube 2	(b) Triangular Prism 1	(b) Triangular Prism 2	(c) Pyramid 1	(c) Pyramid 2	(d) Cylinder	(e) Semi-Sphere	(f) Hemi-Ellipsoid 1	(f) Hemi-Ellipsoid 2
Kilowatt/ Month (KW/m)	Jan	179	182	186	185	201	205	165	120	122	130
	Feb	200	204	218	213	231	235	185	140	148	153
	Mar	362	366	400	386	423	424	333	256	279	281
	Apr	380	377	422	416	450	443	347	274	303	302
	May	503	490	557	568	600	590	456	367	410	405
	Jun	548	536	609	624	655	649	498	401	449	444
	Jul	550	538	613	628	658	650	499	404	452	447
	Aug	550	541	610	613	654	641	501	400	444	440
	Sep	478	480	530	512	561	558	439	341	375	375
	Oct	290	295	317	308	336	341	268	203	217	222
	Nov	175	178	187	185	200	204	162	120	126	131
	Dec	149	150	155	155	168	170	137	100	103	109

4. Conclusion

The solar-optimized pyramid 1 presents an innovative approach to energy generated and sustainability, blending architectural wisdom with modern solar technology in solar contribution. By leveraging the pyramid's shape, orientation, and light-concentrating properties, it can create a structure that not only captures abundant sunlight but also serves as an iconic symbol of renewable energy. The solar-optimized pyramid paves the way for a harmonious coexistence of the past and the future, providing a visually stunning and environmentally conscious solution for our energy needs.

Therefore, the purpose of this research is to analyze the advantages and potential of utilizing BIOPV as an aesthetically pleasing, ecologically friendly, and economically viable material that responds to the community (Figure 17). As the need for solar technology grows, this project aims to expand the architectural form possibilities for building envelopes, while simultaneously reducing material consumption and conserving the environment.

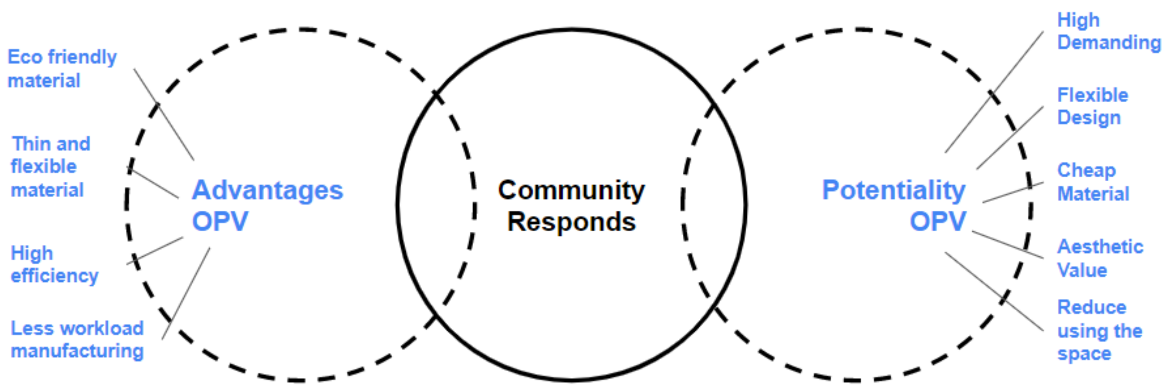


Fig. 17. Benefit of OPV

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