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# TECHNICAL AND ECONOMICAL ANALYSIS ON THREE TYPES OF PHOTOVOLTAIC MATERIALS

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**ABSTRACT**
As Malaysia is one of the developing country, the requirement and demand of the energy is rapidly increasing. In order to cope with this increasing demand, Malaysia has started to encourage more alternative methods of power generation and one of the most emerging renewable power generation is solar. Various researches had been conducted to identify the best solar material which is capable in providing the best output power from the harvesting process. This paper encompasses the finding of three solar materials on both perspectives by analysing and comparing the performances of these solar materials on a residential roof top application. The outcome of this study had provided several useful information and guideline in assisting future home owners who plan to install a PV system either to 'buy or lease' it in the first place. Home owners have the potential to gain the optimum benefit from their photovoltaic (PV) system through selecting the best solar material at the first place. Sharp NU-U180FC (monocrystalline), Hanwha Q-Cells-Q.PRO-G4 265 (polycrystalline) and Kaneka G-SA060 (amorphous) are among the available PV solar modules in the market. These models had been selected in this study and their performances were outlined based on the respective parameters measured through the Solar Advisor Model (SAM) software and PV Analyzer Kit. The survey conducted among the home owners in Bangi area who had own a workable PV system had resulted in 85 % of the respondents preferred to buy rather than leasing the solar system.

**Keywords**:Technical and Economic Impact; Roof Top Solar Application; Solar Advisor Model (SAM); PV Analyzer Kit; 'Buy versus Lease' System.

## 1. INTRODUCTION

Energy is essential to human being and is required in various day to day activities such as cleaning, cooking and etc. More than that, it is a basic need for the industries operation, commercial centre and other sectors such as transportation and agricultural too. As Malaysia is one of the developing countries, the demand of the energy is rapidly increasing. Hence, depending solely on the conventional type of power generation is no longer a strategic and sustainable plan for the country. Moving forward, the Malaysia government has started to look up and establish more alternative methods of power generation. One of the most emerging renewable power generation method is solar power generation.

As Malaysia is located in the equatorial region that receive high average daily solar radiation, photovoltaic conversion of solar energy appears to be one of the most promising ways of meeting and fulfilling the increasing energy demands in this country. It is able to provide relatively small amounts of electrical power at or close to the point of demand (Hilger, 1989).

The Malaysia government has set an incentive program through the FiT which has made the PV system as an attractive long-term investment. When cost of solar modules is decreasing while cost of energy on the grid is increasing, many people are seeing solar PV as a sound investment which can also add value to their home, as a means of safeguarding their future energy costs and as a way of significantly lowering the carbon footprint (Sivanagaraju et al., 2007). Malaysia has similar act like Germany which provide fixed amount of payment through FiT plan to individual who wish to install solar photovoltaic system on the rooftop or personal premises. This scheme is offered to various parties; residential as well as the commercial sector (Kai, 2011).

Since the early years of solar power generation, the technology of solar module has continuously evolving and has positively contributed in its output power performance. However, the performance of the solar panel is believed could be better. Due to this, many research had and are continuously conducted by the government, companies and researchers in obtaining the optimum performance of this power generation. From the research point of view, there is tremendous number of research carried out on the different PV materials in order to analyze their performances from both the technical and economic standpoint. In order to arrive to the higher dependencies on the renewable power generation in this country, it required not only actions from the government and selected parties. Hence, despite of being a sector that consumes less power compare to the industrial and commercial, contribution from the residential sector in PV solar power generation should not be overlook. Hence, encouraging home owners to install a PV system on their roof top and individual premises was indeed a brilliant move.

Moving in this direction, awareness and positive return from installing a PV system in residential area (mainly roof top) need to be highlighted to encourage higher number of participation and application on FiT among the home owner. In able to encourage more participations, recommendation on the suitable model and size of solar system, shortest payback period and decision either to buy or lease the PV system need to be provided.

The outcome of this study had revealed and recommended the best PV solar material from the standpoint of a residential roof top. Optimization was based on both technical and economic analysis conducted on three different type of PV solar material that are commonly use. Furthermore, the findings will enable the potential home owners to make the decision either to buy or lease the PV system based on the current practice.

## 2. LITERATURE REVIEW

Solar cells operate by converting sunlight directly into electricity using the electronic properties of a class of material known as semiconductors (Green, 1981). It represents the fundamental power conversion unit of a PV system. In practical operation, solar cells are usually assembled into modules. There are more than a dozens of different type of materials that can be choose as the solar module. In this study, three different brands of three different categories of PV solar materials had been selected. As most solar cells are made of crystalline silicon of a very high purify, monocrystalline silicon, polycrystalline silicon and amorphous silicon were chosen. In specific, Sharp NU-U180FC (monocrystalline), Hanwha Q-Cells-Q.PRO-G4 265 (polycrystalline) and Kaneka G-SA060 (amorphous) were selected for each category and the selection was based on their popularity and availability in the Malaysia market.

### *2.1 Monocrystalline Silicon (Sharp NU-U180FC)*

Sharp NU-U180FC (Monocrystalline Silicon) has been selected as the reference model for the monocrystalline group. This high-quality residential solar module is designed and engineered in conjunction with the Sharp OnEnergy solar system. Sharp's OnEnergy system has replacing the bulky look of traditional solar roof mounts with a clean, elegant appearance that blends beautifully with rooflines. Using breakthrough technology, made possible by nearly 50 years of proprietary research and development, this module incorporates an advanced surface texturing process to increase light absorption and efficiency (SSE, 2017). Table 1 and Table 2 show the electrical and mechanical characteristics of monocrystalline solar module Sharp NU-U180FC. These rated measurements are measured at Standard Test Conditions (STC) of 25°C, 1kW/m$^2$ insolation, AM 1.5 (SSE, 2017). Therefore, these measurements are used as the rated values for reference in this study. Figure 1 shows the reference unit of Sharp NU-U180FC monocrystalline solar module that was used in this study.

### *2.2 Polycrystalline Silicon (Hanwha Q-Cells, Q.PRO-G4 265)*

Hanwha Q-Cells Q.Pro-G4 265 (Polycrystalline Silicon) has been selected to be the reference model for the polycrystalline group for the analysis. The Q.PRO BFR-G4.1 solar module collections is the new standard as the reliable best seller series by Q-Cells and are suitable for various application. These polycrystalline high performance modules with all module efficiency classes up to 270 Wp represents the next evolutionary phase of the best polycrystalline solar modules (according to the output tests conducted by the acclaimed trade magazine PHOTON in 2013 and 2014). The Q.PRO BFR-G4.1 solar module collections provide excellent output values and maximum reliability which ensures high yields for individual solar module solution. In addition, polycrystalline solar modules are characterized by an excellent price performance ratio and are perfectly suitable for private and commercial solar systems as well as solar power plants (QSP, 2016)

Table 1 Electrical Characteristics of Monocrystalline Solar Module (Sharp NU-U180FC) (SSE, 2017)

| Electrical Characteristics | |
|---|---|
| Maximum Power (Pmax)* | 180W (+10%/-5%) |
| Open Circuit Voltage (Voc) | 29.6 V |
| Maximum Power Voltage (Vpm) | 23.8 V |
| Short Circuit Current (Isc) | 8.40 A |
| Maximum Power Current (Ipm) | 7.57 A |
| Module Efficiency (%) | 13.6% |
| Temperature Coefficient (Pmax) | -0.485%/°C |
| Temperature Coefficient (Voc) | -0.36%/°C |
| Temperature Coefficient (Isc) | 0.053%/°C |
| Normal Operating Cell Temp (NOCT) | 47.5°C |

Table 2 Mechanical Characteristics of Monocrystalline Solar Module (Sharp NU-U180FC) (SSE, 2017)

| Mechanical Characteristics | |
|---|---|
| Dimensions (A x B x C below) | 39.1" x 52.3" x 2.3"<br>994 mm x 1328 mm x 57.5 mm |
| Cable Length (l) | 43.3"/1100 mm |
| Output Interconnect Cable | 12 AWG with MC4 Locking Connector |
| Weight | 36.4 lbs / 16.5 kg |
| Max Load | 50 psf (2400 Pascals) |

Figure 1 The reference unit of Sharp NU-U180FC monocrystalline solar module that was used in the study.

Table 3 and Table 4 detail out the electrical characteristics and mechanical characteristics of polycrystalline solar module (Hanwha Q-Cells, Q.PRO-G4 265). Figure 2 shows the reference unit of the polycrystalline solar module for brand Hanwha Q-Cells, Q.PRO-G4 265 that was used in the study.

*2.3 Amorphous Silicon (Kaneka G-SA060)*

Kaneka G-SA060 has been selected to represent the material from the Amorphous Silicon material group due to its availability in Malaysia's market. Kaneka's Amorphous Silicon PV module has superior light absorption compared to monocrystalline silicon PV modules or polycrystalline silicon PV modules.

Table 3 Electrical Characteristics of Polycrystalline Solar Module (Hanwha Q-Cells, Q, Pro-G4 265) (QSP, 2016)

| Electrical Characteristics | |
|---|---|
| Maximum Power (Pmax)* | 265 W |
| Open Circuit Voltage* | 37.93 V |
| Maximum Power Voltage (Vpm) | 31.03 V |
| Short Circuit Current (Isc) * | 9.15 A |
| Maximum Power Current (Ipm) | 8.54 A |
| Module Efficiency (%) | ≥15.9% |
| Temperature Coefficient of Pmax | -0.41%/K |
| Temperature Coefficient of $V_{oc}$ | -0.3%/K |
| Temperature Coefficient of Isc | 0.04%/K |
| Normal Operating Cell Temp (NOCT) | 45°C |

Table 4 Mechanical Characteristics of Polycrystalline Solar Module (Hanwha Q-Cells Q.Pro-G4 265) (QSP, 2016)

| Mechanical Specification | |
|---|---|
| Dimension (mm) | 1670 × 1000 × 32 |
| Cable Length | 39.37"/1000 mm |
| Connector | IP68 41.45 lb (18.8 kg) |
| Weight | Tyco Solarlok PV4, IP68 |
| Max Load | -- |

Figure 2 Reference Unit of Hanwha Q-Cells, Q.PRO-G4 265 Polycrystalline Solar Module That Was Used In The Study

In addition, Kaneka's module generates considerably more power. Kaneka's amorphous silicon modules provide superior performance under high temperatures during summer, making a difference in actual generated watt-power. Monocrystalline modules lose some power generating capabilities when the temperature rises. The Kaneka's amorphous silicon PV module on the other hand generates higher power during summer. It can deliver maximum performance during summer when the electricity is mostly demanded for air-conditioners in houses and offices (Kaneka-GSA060, 2017). This is one of the advantages of the material made from amorphous silicon.

Kaneka's amorphous silicon PV module maintains initial energy conversion efficiency (after full stabilization) over a long period, attesting to its outstanding reliability. Another advantage of Kaneka's amorphous silicon module is it uses less material and energy, thereby enabling high productivity for mass production. Kaneka is able to do this because the single junction of a-Si layer can be made extremely thin. The thickness of a-Si is 0.3 μm, which is 1/600th of a crystalline silicon cell (approximately 200 μm). Energy Payback Time (EPT) is the time a PV module "pays back" the energy used in its manufacture by its own power generation. The EPT of an Amorphous-Si PV is 1.6 years, which is approximately 6 months shorter than that of a crystalline silicon PV (2.2 years). EPT is one of the most important aspects when evaluating the ecological benefit of PV systems. Table 5 and Table 6 detail out the electrical and mechanical characteristics of Kaneka G-SA060. Figure 3 shows the reference unit of the amorphous solar module for brand (Kaneka G-SA060) that was used in the study.

Table 5 Electrical Characteristics of Amorphous Solar Module (Kaneka G-Sa060) (DPVS, 2017b)

| Electrical Characteristics | |
|---|---|
| STC Power Rating | 60 W |
| Open Circuit Voltage* | 91.8 V |
| Maximum Power Voltage (Vpm) | 67 V |
| Short Circuit Current (Isc) | 1.19 A |
| Maximum Power Current (Ipm) | 0.9 A |
| Peak Efficiency | 6.3% |
| Temperature Coefficient (Pmax) | -0.26 %/K |
| Temperature Coefficient of Voc | -0.285 V/K |
| Temperature Coefficient of Isc | -- |
| Normal Operating Cell Temp (NOCT) | -- |

Table 6 Mechanical Characteristics of Amorphous Solar Module (Kaneka G-Sa060) (DPVS, 2017b)

| Mechanical Characteristics | |
|---|---|
| Dimension | 37.8" x 39" x 1.6"<br>960 mm x 991 mm x 41 mm |
| Cable length (l) | -- |
| Connector | Multicontact Connector Type 3 |
| Weight | 30.2 lb (13.7 kg) |
| Installation Method | Rack-Mounted |

In general, the outcome from the study conducted has allow the home owner to decide on the most suitable solar material for their solar roof top installation from both technical and economic impact which was based on three different solar materials which are easily found in Malaysia's market. The individual performances of each solar material will impact in different aspect of the application, thus this study will benefit the future home owner who might be interested to install a solar PV system on their rooftop.

Figure 3 Reference Unit of Kaneka G-SA060 Amorphous Solar Module Used in the Study

*2.4 Efficiency and Surface Area*

As this study is focusing on the residential roof top application, it is wise to observe the common household electricity consumption. Malaysian electricity consumption is averagely 3012 kWh per household per year or 251 kWh per month. Figure 4 shows one of the electricity bill released by Sabah Electricity Sdn. Bhd. (SESB) which shown the consumption of electricity per month being 472 kWh or 5664 kWh annually (GM, 2013). It is understood that the energy consumption varies from one home to another, but in this study, the average electricity consumption read as 251 kWh is referred.


Figure 4 SESB Electricity Bill: 472 kWh/Month is Above the National Average of 251 kWh

As per displayed in Table 7, the efficiency for these three selective materials varies from one another. Monocrystalline silicon has the highest efficiency range between 11%-16% with only small surface area needed for 1 kWp. This shows that with only a small surface area (7 m$^2$ - 9 m$^2$), monocrystalline silicon can provide the highest efficiency compared to the other silicon modules. Polycrystalline-Si give intermediate efficiency which read between 8 % - 10 % with surface area required to produce 1 kWp is between 9 - 11 m$^2$.

Table 7 Module Efficiency and Surface Area of Three Different Silicon Module

| Type | Efficiency (%) | Surface area for 1 kWp | Surface area of 251 kWh for one month |
|---|---|---|---|
| Monocrystalline Silicon | 11- 16 | 7 - 9 m$^2$ | 20.07 - 25.82 m$^2$ |
| Polycrystalline Silicon | 8 - 10 | 9- 11 m$^2$ | 25.82 - 31.55 m$^2$ |
| Amorphous Silicon | 4 - 7 | 16 - 20 m$^2$ | 45.9 - 57.37 m$^2$ |

The efficiency of amorphous is the lowest which lies between 4 - 7% and its module required the biggest surface area for 1 kWp power generation (Antony et al., 2007). Therefore, for electricity consumption in average of 251 kWh per month, the roof top surface area required to installed a Monocrystalline-Si module is found to be the smallest which is within 20.07 - 25.82 m$^2$ followed by Polycrystalline-Si and Amorphous-Si which require 25.82 - 31.55 m$^2$ and 45.9 - 57.37 m$^2$ accordingly (Antony et al., 2007). This shows that Monocrystalline-Si material, in general requires the smallest module area on the residential rooftop to generate average energy consumption of 251 kWh per month which is average monthly energy consumption in Malaysia household.

*2.5 Temperature Coefficient*

Temperature coefficient is the relative change of a physical property that is associated with a given change in temperature). Each solar cell technology comes with a unique temperature coefficient which can direct influence on the power output of a PV solar module. The smooth performance of a PV solar module is strongly related with the temperature effect. Above the standard conditions, temperatures will cause losses to the maximum output power ($P_{max}$). Once the temperature of a solar module operates above the Normal Operating Cell

Temperature (NOCT); refer Table 1 and Table 3 as the example for both Monocrystalline-Si and Polycrystalline-Si material, the output power of the solar module will decrease accordingly (Sinovoltaics, 2017). In summary, the rises of temperature are affecting the performance of solar module installed on the roof top. Thus it is important to review the NOCT and understand the losses incurred from the temperature increment in specific area of a country/region. The best material claimed for the residential roof top application in the European country might be not the best material for the residential roof top application from the Malaysia perspective. Crystalline solar cells are the main cell technology and usually come with a temperature coefficient of the maximum output power ($P_{max}$) of -0.5 %/ºC. The rated power as generally indicated on the module's label is measured at 25ºC, hence with any temperature increase above 25ºC will affect the power losses of 1 % for every 2ºC increase (Sinovoltaics, 2017). On the other hand, Amorphous-Si which is well known to be superior under high temperature is basically come with a temperature coefficient of -0.2 %/º C (refer to the SAM software data used in this study). Based on the temperature coefficient data provided for the three selected brand of PV solar materials, it is found that Kaneka G-SA060 from the Amorphous-Si type will provide better performances during the sunny day compare to the other two.

*2.6 Power Tolerance*

Power tolerance is a measure of how much electricity can be produce by the solar module which is above or below its rated power Pmp at Standard Test Condition (STC) (Posharp, 2017). Quoting a solar module's STC power rating will present the best solar modules abilities. One must also consider that the power tolerance will be quoted based on STC power ratings (EE, 2017a).

The range of power tolerance is expressed as a positive or negative percentage. Ranges are typically from -5 % to +5 %. The closer it is to zero, the better its performance, and if it is a positive percentage value, the solar will give slightly better performance compare to negative value (Balfour et al., 2013). It is important to choose the best solar modules with nearly zero or positive percentage of power tolerance as it describe that module is consistently having a rated STC max power ($P_{max}$) greater than or equal to the specification (Peacock, 2002). For example, if the peak power (Wp) of a module is 250 W and the power tolerance is + / - 5 %, this means that the peak power output could be either 237.5 W to 262.5 W under rated conditions. Obviously, a high positive power tolerance is an advantage to the residential owner because it will give better performance of solar module (PVFT, 2012). This study outlined the power tolerance of three different solar materials using the data obtain from both the PV Analyzer Kit and Solar Advisor Model (SAM) and a direct mathematical formulation is applied as to calculate the power tolerance as per following;

$$\text{Power Tolerance} = \frac{\text{Measured power output}}{\text{Rated peak power}} - 1$$

*2.7 Total Installed Cost*

Total installed cost is the amount of money invested in a business venture with an expectation of income and recovered through earnings generated by the business over year (CI, 2016). The net capital cost for PV system depends on the dimension of the surface area. The larger surface area covered with PV module required a larger net capital cost. However, the larger surface area also able to generate more energy and able to save more on electricity cost for the building. Same applies in the context of PV power generation in a residential based application, one must consider the total installed cost, cost of operating and maintenance, payback period and profit earn based on the FiT rate to estimate the Return of Investment (ROI). In general, solar system costs vary mainly depending on the type of solar modules and the overall size of the system and other impacting cost. It was found that PV module covers seventy percent of the capital cost, whereas inverter covers ten percent and the balance is the miscellaneous cost (Kai, 2011). For instance, an example of cost incurred for PV system in the United States of America (USA) is shown in Figure 5.

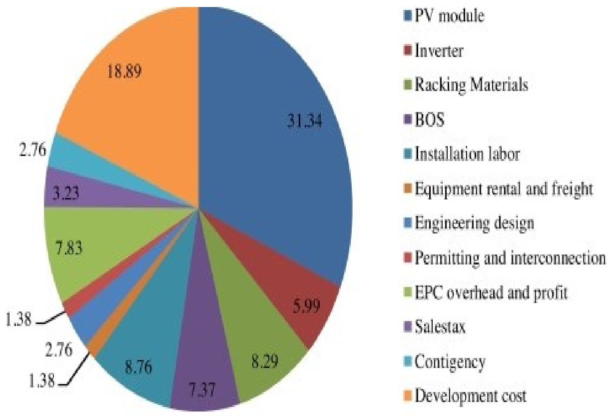


Figure 5 Benchmark of cost breakdown percentage (%) for PV system in US

In this study, the capital cost to purchase and install the whole photovoltaic system will be analyse to evaluate the economic impact of generating power through this method. The analysis had neglect the impact of the inverter installation and other costs for these three PV materials. The details analysis will be shown in the methodology and result section. Table 8 shows the cost ($/Wdc) obtained from the distributor (Intelligent Power System Technology Sdn. Bhd) who is supplying the three selected brand of solar PV materials that were been analysed in this study. As per highlighted above, the total cost calculated in this study was based on just the cost per Watts generation ($/Wdc) for each selected solar module brands. It is a direct measurement to show the impact of different solar module. The exact quantity of the panel required for each model to produce the general electricity consumption of a standard residential sector in Malaysia was not taken into consideration. Eventhough SAM software allow to include various other parameters such as labour, margin and overhead, grid interconnection and many more, the authors had decided to neglect the effects of these parameters as it will lead to more complex analysis and study.

Table 8 Cost ($ / Wdc) or (Rm / Wdc) For Each Solar Material

| Type | Cost ($ /Wdc) or (RM / Wdc) | Brand |
|---|---|---|
| **Monocrystalline Silicon** | 0.6 ($ /Wdc) or 2.64 (RM / Wdc) | Sharp NU-U180FC |
| **Polycrystalline Silicon** | 0.48 ($ /Wdc) or 2.11 (RM / Wdc) | Hanwha Q-Cells, Q.PRO-G4 265 |
| **Amorphous Silicon** | 1.00 ($ /Wdc) or 4.40 (RM / Wdc) | Kaneka G-SA060 |

*2.8 Cost of Maintenance*

In optimizing the amount of power generation through PV solar system, it is highly important to ensure a regular cleaning is carry out. On top of that, this exercise will help to prolong the module's life span especially the modules that are installed in the dusty area. Surface of a solar module can be cleaned with warm water and dish washing soap in order to remove any accumulated dirt and grime. In addition, bird droppings should be removed to prevent the reduction of the module's energy producing capacity (Kai, 2011). More important reason for a maintenance of the solar system is to prolong the module's useful life especially for modules that are installed in the dusty area.

The average cost of having the modules cleaned by a reputable solar installation company ranges from RM44 to RM88 per module annually (Green, 1981). Hence, if a home owner has an average size; say 2 kWp system, with say 10 modules, a total cost of maintenance lies approximately between RM500 – RM1000 should be considered every year.

*2.9 Payback Period*

Payback period represents the minimum number of years required for the discounted sum of annual net savings to equal the discounted incremental investment costs (Denholm et al., 2009). The break-even point happens when the electricity generated by the system, tax benefits, and project incentives has created sufficient cash inflow to pay the net capital cost (Perez et al., 2004; Paidipati et al., 2008). Through FiT, there are default payback period which is usually about 21 years for residential owners to gain back their modal of total installed cost (PVFT, 2012).

The government has set up the FiT to encourage people to generate their own electricity. The electricity that is produced from the solar modules will be metered and used for claiming the FiT. The higher return will reduce the payback period. The residential owner must apply a Microgeneration Certification Scheme (MCS) registration installer for photovoltaic solar module systems to qualify for the FiT (PVFT, 2012).

*2.10 Feed-In Tariff (Fit) In Malaysia*

Feed-in Tariff (FiT) mechanism obliges energy utilities to buy renewable energy from producers, at a mandated price. By guaranteeing access to the grid and setting a favorable price per unit of power, it ensures that renewable energy is a sound long-term investment, for companies, industry, and individuals, thereby creating a string economic incentive for investing in renewable energy (SEDAM, 2013). The FiT is Malaysia's new mechanism under the Renewable Energy Policy and Action Plan to catalyze generation of RE, up to 30 MW in size. This mechanism allows electricity produced from indigenous renewable energy resources to be sold to power utilities at a fixed premium price for a specific duration (SEDAM), 2013.

Table 9 shows the capital price of solar, expected average monthly payment by TNB in RM (FiT), expected payback period (years), expected net income (for 21 years) and investment yield for each size (kWp) of solar system installed on residential roof top. This data is provided by the Intelligent Power System Technology Sdn. Bhd which had supplied the three hardware unit of the three different solar materials for this study. This information is found to be the current retail price for the PV solar material in Malaysia market.

Table 9 IPS Solar PV System Price with Net Metering Payment

| Size (kWp) | Price (RM) | Expected Average Monthly Payment by TNB (FiT), (RM) | Expected Payback Period (Years) | Expecte d Net Income, RM (For 21 years) | Invest ment Yield (%) |
|---|---|---|---|---|---|
| 4 | 32000 | 418.00 | 6.39 | 98500 | 15 |
| 6 | 47000 | 613.00 | 6.39 | 144726 | 15 |
| 8 | 63000 | 818.00 | 6.42 | 192929 | 15 |
| 10 | 76500 | 1022.00 | 6.24 | 241133 | 15 |
| 12 | 92000 | 1227.00 | 6.25 | 289337 | 15 |

*2.11 Buy or Lease' Decision On Solar Module Installation*

Before commencing on the decision of installing a PV solar system on the rooftop, home owner has to consider two options; either to buy or lease the system. The financial affordability of the home owner is eventually the influencing factor in the decision making (EA, 2017).

In specific, the decision of either to 'buy or lease' a PV solar system is based on various factors such as availability of capital and maintenance cost, terms, financial offsets and savings/returns on investment. In current situation, not all companies offer a service of leasing a PV solar system to the consumers. In addition, Power Purchase agreement (PPA) or solar leasing service is not legally permitted in many areas (EA, 2017)

*2.12 Solar Advisor Model (SAM) Software*
In this study, the analysis conducted on three different PV materials was carried out using the Solar Advisor Model software (SAM). The Solar Advisor Model (SAM) is a performance and financial model designed to facilitate decision making for the people involved in the renewable energy industry; ranging from project managers and engineers to incentive program designers, technology developers and researchers. SAM makes performance predictions for grid-connected solar PV, concentrating solar power, wind, biomass and geothermal power systems. The model calculates the cost of generating electricity based on information you provide; for instance, a project's location, type of material, installation and operating costs, type of financing, applicable tax credits and incentives, and system specifications (SAM. 2016). SAM models a range of renewable energy technologies for electricity generation, including photovoltaic systems, solar thermal troughs, power towers, and dish-Stirling systems. SAM uses an hourly performance model to estimate a power system's total annual output, and a cost and financial model to calculate a project cash flow. SAM reports performance and financial metrics in tables and graphs, which can be exported for use in reports or for further analysis in other models (SAM, 2016).

*2.13 PVA-1000S PV Analyzer Kit*
PVA-1000S PV Analyzer Kit is a measuring tool used in this study and compare with the rated value of module characteristics at reference conditions stated in Solar Advisor Model (SAM) software.

Table 10 Advantages and Disadvantages of Buying Versus Leasing Solar Module System

| Buy or Lease / Category | Solar Loan/Cash Purchase | Solar Lease/PPA |
|---|---|---|
| **Installation Cost** | Solar power systems can cost RM66000 to RM132000 before rebates and incentives.<br>Cash rebates can reduce the total cost by up to 50 percent. Most solar installers will manage the paperwork and adjust the purchase price to reflect the net amount. | Consumer can get a solar energy system for little or no money down.<br>Consumer does not qualify for tax credits, rebates or incentives. Those belong to the third party owner of the system. |
| **Maintenance** | Consumers own the system and are responsible for maintaining it. Note that solar equipment is durable and carries warrantees, so consumers would not have much maintenance to worry about.<br>The purchase may not include an app to track your system's performance. | The solar company owns and maintains the solar power system.<br>Most leases include free apps that track the performance of solar module system. |
| **Terms** | Loans are generally available for 10 to 20 years, with interest rates ranging from 3 percent to 8 percent if the consumer has a FICO credit score of 640 or above. | Solar leases and PPAs are generally for 20 to 25 years, at which point consumer can renew the agreement or purchase the system outright. |
| **Savings and return on investment** | Consumer can save between 40 percent and 70 percent on electricity costs over the lifetime of the solar module system, depending on their property and the incentives in their state.<br>Consumer can receive free electricity for the life of the solar energy system (usually 25 to 35 years). | Consumer can save between 10 percent and 30 percent off the prices that they can pay their utility for electricity, depending on their property and the incentives of their state. |

PVA-1000S PV Analyzer Kit is a 1000 volt I-V curve tracer with built-in PV performance modelling and advanced wireless irradiance, temperature and tilt sensing. It provides unprecedented measurement throughput and accuracy and delivers deep insight into the performance of the arrays (PVA, 2017). For each string, the PV Analyzer measures the I-V (current vs. voltage) and P-V (power vs. voltage) curves with a single button click. The measured results were compared to the expected one; taking into account the irradiance and module cell temperature at the time of the I-V measurement. The I-V Unit communicates wirelessly to Windows tablet or laptop (not included), enhancing safety and allowing freedom of movement during testing. Automated data analysis and reporting save the time to measure the performance of solar system (PVA, 2017).

High measurement throughput means it can measure 1 MW in less than 2 hours even in hot environments where other curve tracers shut down. The rugged enclosure is moisture and dust resistant. The incident angle corrected Sol Sensor is able to make accurate irradiance readings in lower light conditions extending the working window (PVA, 2017).

I-V curve testing is the preferred method for commissioning, O&M, and troubleshooting of PV arrays because it provides the most complete performance measurement possible. Populations of curves can be analyzed quickly for outliers and data can be archived as a baseline for future reference if performance questions arise (PVA, 2017).

## 3. RESEARCH METHODOLOGY
There were few steps of analysis that involve in this study. In general, the analysis was divided into two stages; Stage A and B (refer Figure 6). Stage A covered the initial process such as selecting three different materials and the available PV solar manufacturer's brand to represent each material group and identifying the suitable parameters to be analyse. Furthermore,

referring to the Stage B process, the outcome from various measurements are collected, analyse and use for comparison on both technical and economical performances.

Specifically, on the financial performances, authors had calculated the financial impact (installation, maintenance and the payback period) for three selected PV solar materials in identifying the optimum benefit that can be expected upon installation on the residential roof top.

Finally, survey was conducted on the 'buy versus lease' option of photovoltaic system to provide the best practice of installing a PV solar system which is more beneficial to the home owner. This survey was based on the technical and economic factors on a niche area.

In general, this study involves hardware, software and mathematical solution analysis in identifying the performances of three different PV solar materials.

*3.1 Stage A: The Pre-Step Carry Out In The Research*

As there are more than a dozens of different type of PV materials, the authors had review many case studies and conducted a market survey to identify the most practical and easily found PV material in the market. No doubt, three material types which are commonly used are monocrystalline, polycrystalline and amorphous silicon. Moving forward, due to various manufacturers and brand available for these three type of PV solar material in the market, author had then decided to choose Sharp NU-U180FC, Hanwha Q-Cells, Q.PRO-G4 265 and Kaneka G-SA060 to represent monocrystalline, polycrystalline and Amorphous Silicon PV material group. The selection of this brand was based base on their availability in Malaysia market and its availability in the SAM software material list. This is important as the comparison between the software and hardware analysis need to be carry out.

Based on the objectives of the study, module efficiency, temperature coefficient, power tolerance, size of suitable module for roof top application and financial involve for the three different types of solar module are the parameters selected.

*3.2 Stage B: Detail Analysis Carry Out In The Research*

In stage B, author had identified four important steps that need to be carrying out which later produce the result that will assist in the decision making of the PV Solar material performance that is suitable for the residential rooftop application. The first step involved the simulation of these three materials using the SAM software. The parameters are shown once the brand is selected. Next, the hardware evaluation using the PV Analyzer and Solar Advisor Model (SAM) software which purposely to measure and compare the output parameters of three solar module materials. Cost affect is stimulated through both SAM and manual mathematical calculation base on the FiT rate and material market price. Finally, a survey is conducted and the respondent's feedbacks are analyzed in choosing whether buy or lease option is more practical for a residential roof top application.

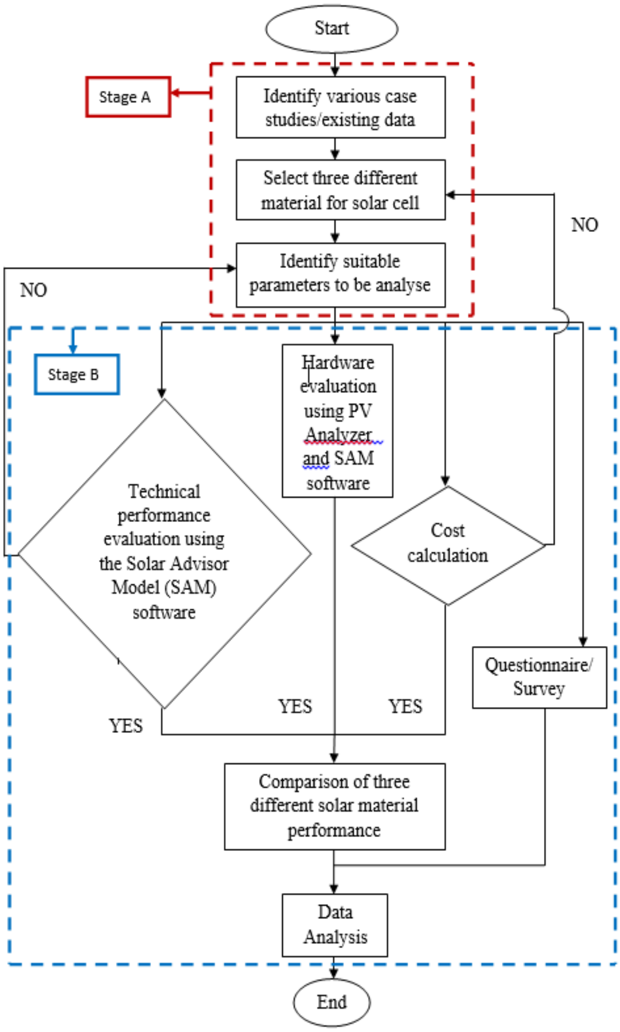


Figure 6 Process flowchart

**4. RESULTS AND DISCUSSIONS**

There are three selected solar module materials used in the analysis which are monocrystalline solar module (Sharp NU-U180FC), polycrystalline solar module (Hanwha Q-Cells, Q.PRO-G4 265) and amorphous silicon module (Kaneka G-SA060). Upon entering the brand of the selected material in the SAM software, nominal efficiency, temperature coefficient and power tolerance data were gathered as per tabulated in Table 11. Even though Monocrystalline-Si is well known to be having higher efficiency compare to other PV solar material, this study proved that some of the manufacturer of Polycrystalline-Si had produce better performances of PV solar material compare to monocrystalline. In this case, Hanwha Q-Cells, Q.PRO G4 265 brand from the polycrystalline type is showing better module efficiency compare to Sharp NU-U180FC Monocrystalline-Si type. On the other hand, amorphous type PV solar material proves to have far lower module efficiency compare to the remaining two. Example of the SAM output result on the module efficiency is shown in Figure 7. In term of temperature coefficient, amorphous type of material shown the best performance (-0.224%). It was well known as a PV solar material that can sustain higher temperature and less impacted in output decrement.

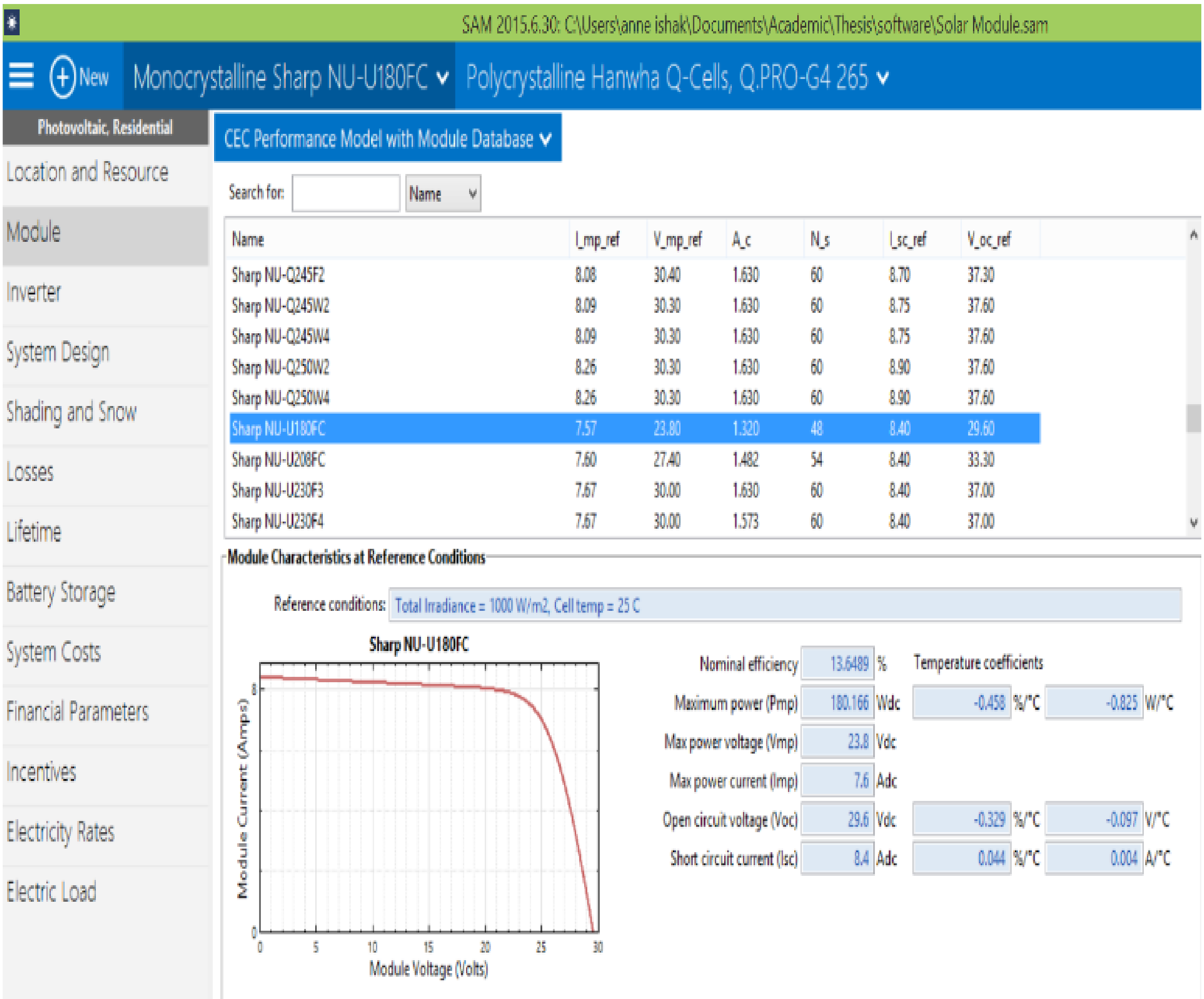


Figure 7 Output result on nominal efficiency for Sharp NU-U180FC monocrystalline through SAM software.

Based on the SAM software, maximum power ($P_{mp}$) value for each PV material specified in Table 1,3 and 5 were proved. The $P_{mp}$ finding shown a value of 180.166 $W_{dc}$, 265.065 $W_{dc}$ and 60.3 $W_{dc}$ accordingly (refer figure 7 for Monocrystalline, Sharp NU-U180FC).

Measurement of the power tolerance consolidate from both output result obtained from SAM software and PV Analyzer Kit was calculated from the mathematical formulation shown in section F of the literature review. For instance, the power tolerance of Monocrystalline Sharp NU-U180FC was found to be -0.647%. The measured power output which measured as 63.51Wdc was obtained from the hardware analysis using the PV Analyzer Kit as per shown in Figure 9. On the other hand, the rated peak power (Pmp) was obtained from the SAM software which in this case shown to be 180.166 Wdc. Next, using the mathematical formulation, the power tolerance was calculated. From this study, the power tolerances for three different PV solar modules were calculated to be -0.647%, -0.643% and -0.389%. As the closer the value of the power tolerance to zero, the better performance is the material. In this case, there was not much difference between the monocrystalline and polycrystalline material, and an impressive value for amorphous was calculated. The data was collected between 2pm to 3pm on a hot sunny day.

$$\text{Power Tolerance} = \frac{63.51\ \text{Wdc}}{180.166\ \text{Wdc}} - 1$$

$$\text{Power Tolerance} = -0.647\ \%$$

Referring back to the information outlined in Table 7, the estimated surface area required for an average consumption of 251 kWh per household in a month for three different PV solar materials were 20.07 $m^2$ - 25.82 $m^2$, 25.82 $m^2$ - 31.55 $m^2$ and 45.9 $m^2$ - 57.37 $m^2$ respectively. The size area required can be calculated as per the following mathematical formula; with solar irradiance is fixed to 1000 $W/m^2$.

$$\text{Area of roof top required} = \frac{\text{Total power output}}{\text{Solar irradiance x Conversion Efficiency}}$$

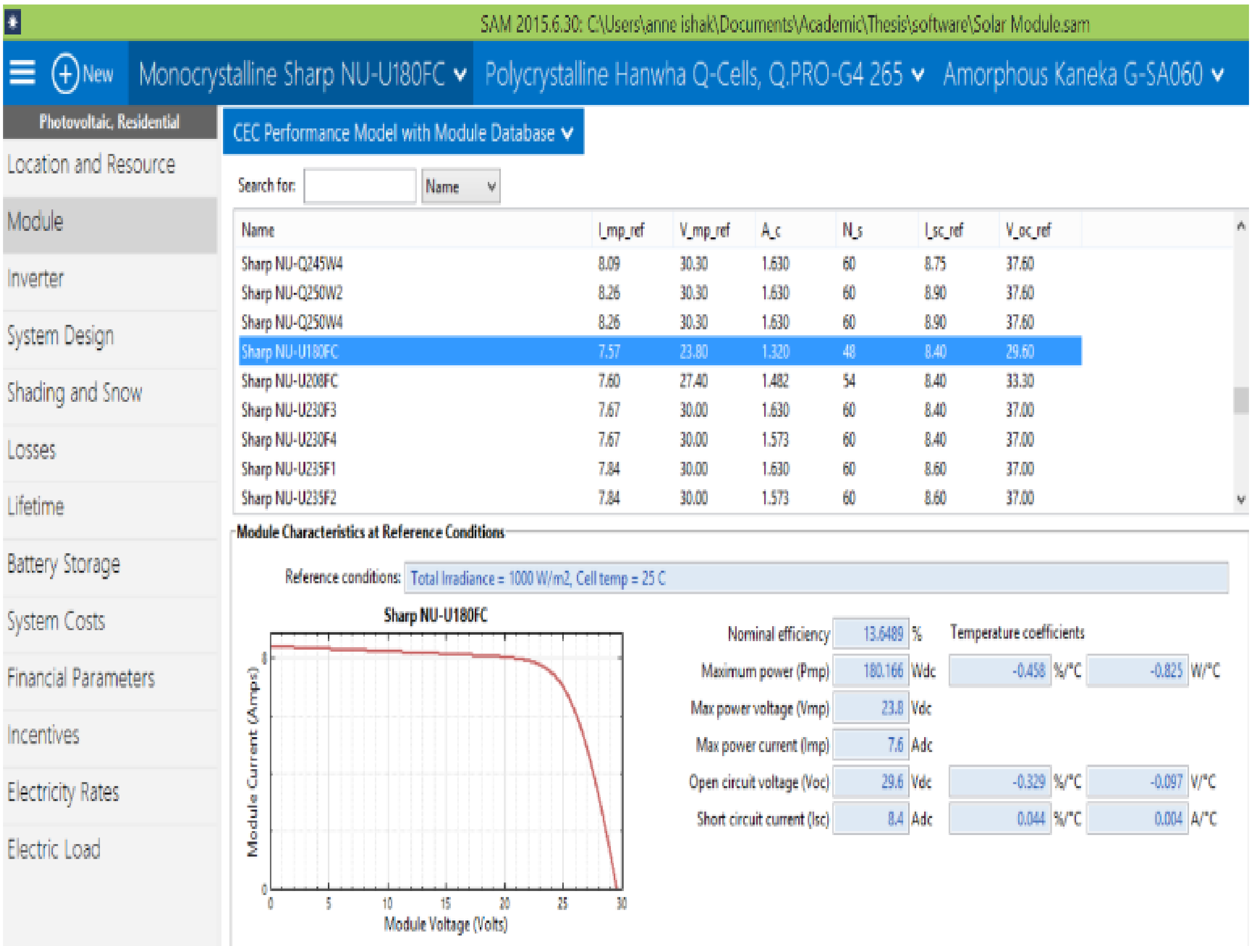


Figure 8 Output result on temperature coefficient for Sharp NU-U180FC monocrystalline through SAM software

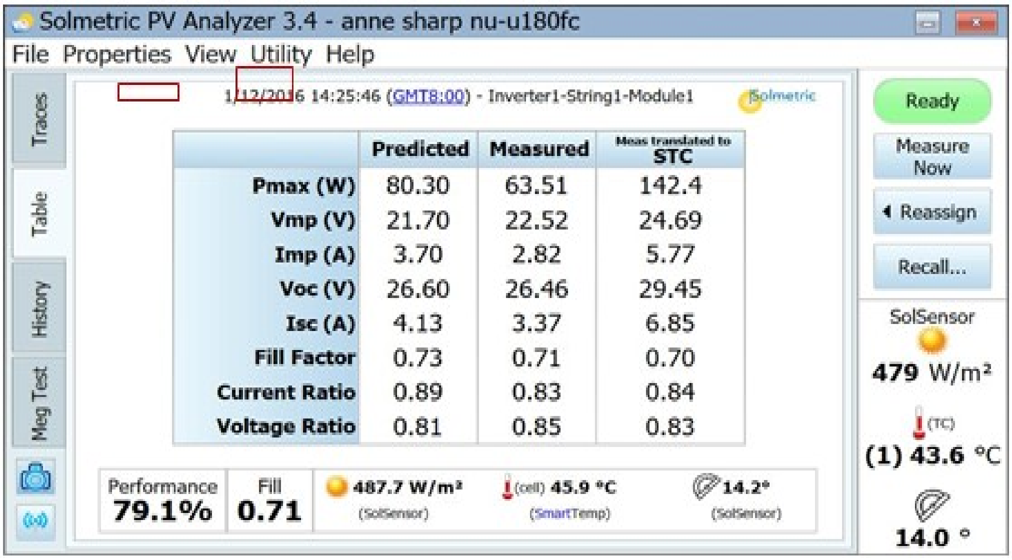


Figure 9 Output result on temperature coefficient for Sharp NU-U180FC monocrystalline through PV Analyzer Kit

In addition, the size area of 1 module for each selected PV solar brand is obtained from SAM software once a brand is selected. Figure 10 demonstrate the maximum power and module area of Sharp NU-U180FC monocrystalline. It was found that the maximum power for 1 module is 180.166 $W_{dc}$ and the module area is 1.32$m^2$. Table 11 outlined the module efficiency, size area required for a module ($m^2$) and total roof top area required for three different PV solar material group obtained directly from SAM software.

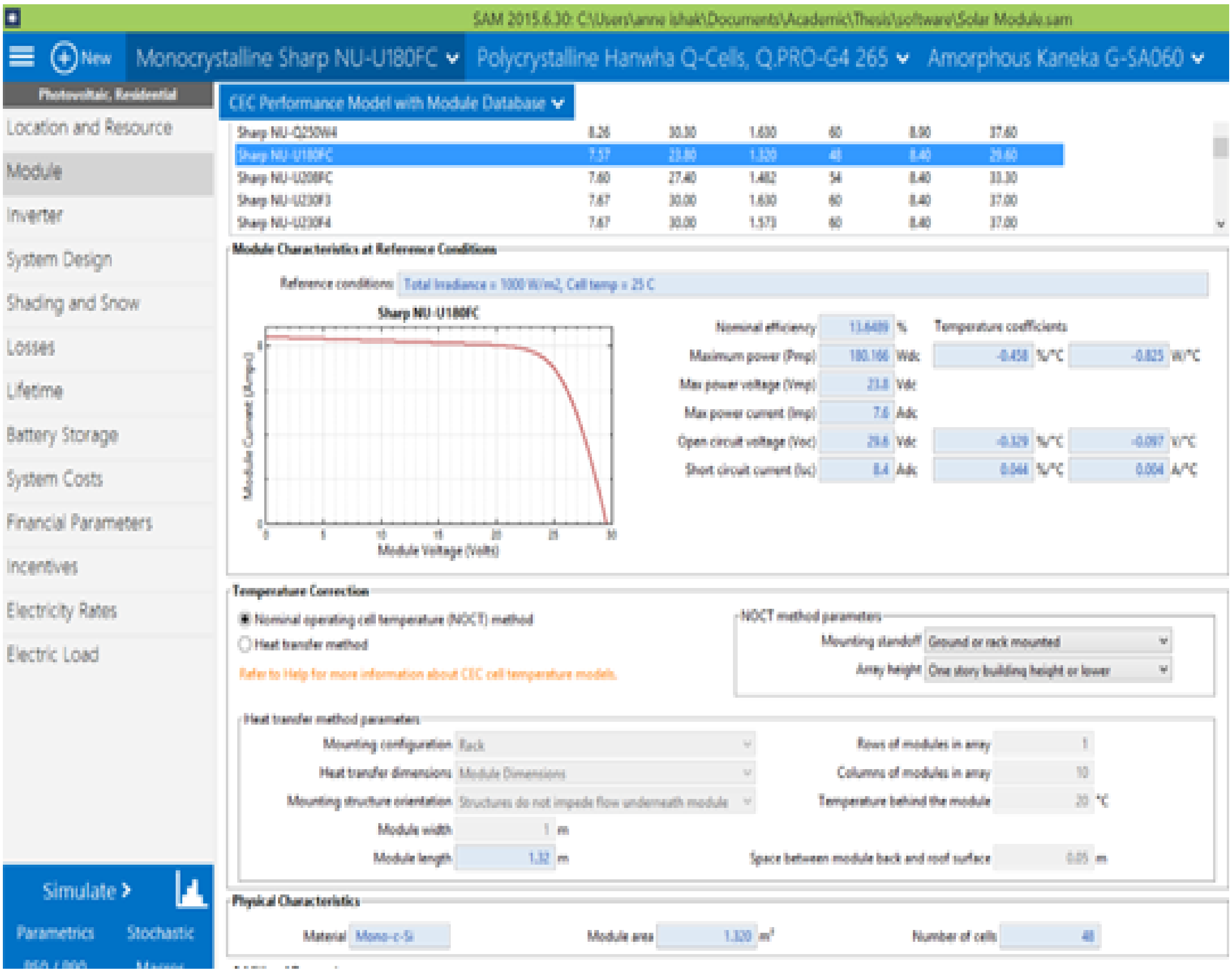


Figure 10 Output result on maximum power and module area of Sharp NU-U180FC monocrystalline through SAM Software

Table 11 Max Power and Module Area Size of Three PV Solar Materials Obtained From the Sam Software

| **Categories** | **Monocrystalline Silicon (Sharp NU-U180FC)** | **Polycrystalline Silicon (Hanwha Q-Cell, Q.PRO-G$ 265)** | **Amorphous Silicon (Kaneka G-SA060)** |
|---|---|---|---|
| **Module efficiency (%)** | 13.6489 | 17.3585 | 6.34737 |
| **Size area of 1 module ($m^2$)** | 1.32 (1 x 0.32) | 1.527 (1 x 0.527 ) | 0.95 (1 x 0.95 ) |
| **Size area of roof top required ($m^2$)** | 21.42 | 17.24 | 47.62 |

Hence using the above mathematical formulation, for a 2 kWp, the monocrystalline silicon module will need around 11 modules as the power output is stated as 180.166 $W_{dc}$ in the SAM software. With 14% efficiency as per stated by the software, hence the total roof top area needed is estimated to be 14.15m$^2$. For Polycrystalline and Amorphous selective brand, roof top area required is 12.47 m$^2$ and 34.17 m$^2$ respectively. The number of modules required is estimated to be 8 and 34 to produce around 2 $kW_p$. The results were tabulated in Table 12. It was found that Hanwha Q Polycrystalline required a small roof top area as it contains the highest maximum power and efficiency compare to the other two brands.

On the financial performances, the total installed cost, maintenance cost, payback period (years) and profit were measured and the results of the three different PV solar material were shown in Table 12 as well. The financial analysis was based on the pricing details outlined in Table 8 and the FiT 2017 scheme. Based on the FiT rate, starting from January 2017, installed capacity for up to and including 4 kWp is rated as 0.7424 (RM/kWh). As this study was considering 2 kWp solar system, hence this rate is used in calculating the payback period and profit.

As mentioned earlier, there are various components involved in the installation of a solar panel on the residential roof top, but for this study, the total installed cost only covers the solar module and the other components are neglected (assuming they are the same across all). Based on the quantity of module required and the pricing details outlined in Table 8, it shown that for a residential roof top application, the highest efficiency material will reduce the quantity of panel required and the size of roof top area which impacted the total installed cost. Assuming a constant inverter cost for all these three material, Kaneka G-SA060 has the highest installed cost compare to the other two brands due to its low module efficiency. Hanwha Q-Cells Q.PRO G4 from Polycrystalline proved to have the lowest total installed cost among these three PV solar materials due to its high efficiency and cheapest cost per module ($/Wdc). Comparing to the study conducted by Bong Yann Kai (5), this study proved that assumption cannot be made that monocrystalline has the highest total installed cost compare to the polycrystalline and amorphous material blindly. Analysis on the total installed cost need to be carried out based on the manufacturer brand as each brand has its own material characteristics that will be impacted both technically and economically to the home owner.

As per mentioned earlier, as the objective of this study is to identify the most efficient PV Solar material for the rooftop application, the standard energy consumption of a household in Malaysia which is 251 kWh/month is referred. Hence, daily energy consumption is found to be 8.37 kWh or estimated as 8 kWh. The daily solar harvesting in Malaysia is mainly between 10 am to 2 pm. These are the peak time for solar power harvesting. Thus, within the 4 hours harvesting period, the PV solar system is required to generate 2 kW of power daily. With this as the guideline, the study had analyzed the number of module required based on the total power output presented in the SAM software for each of the respective types and manufacturer's brand selected in this study. In summary, the maximum power output provided through the SAM software for Sharp NU-U180FC, Hanwha Q-Cell Q.PRO and Kaneka G-SA060 are 180.166 $W_{dc}$, 265.065 $W_{dc}$ and 60.3 $W_{dc}$ respectively.

Hence, for an estimated 2 kWp output daily, the total installed cost for these three selected PV materials are presented in Table 12. The analysis shown that Kaneka G-SA060 which represents amorphous group type had the higher installation cost compare to the other two materials. It obviously was due to the lower module efficiency, larger quantity of module and higher price per watt $RM/W_{dc}$. In this study, it was found that Hanwha Q-Cell Q.PRO-G4 is outstanding compare to the remaining two manufacturer's brand selection. As per mentioned in the earlier section, the average annual cost of maintenance for a PV solar system for a residential system is surveyed to be between RM44 to RM88 per module, hence, the maintenance cost incorporate in this study is estimated to be RM484, RM352 and RM1496 respectively and displayed in Table 12 (minimum cost is referred).

Regarding the payback period, it was stimulated through a simple mathematical calculation. A 2017's FiT rates of 0.7424 RM/kWh is used in this study. Based on the 251 kWh/months generation, the annual energy generated is assumed to be 3012 kWh. With the above FiT rate, the income generated in a year from the PV solar system for each selected material is RM2236. 1088. In the calculation of payback period, the income considered is RM 2236. Hence, the payback period for these three selective materials were calculated and displayed in Table 12. From the payback period calculated, it was proven that the Hanwha Q-Cell Q.Pro G4 265 Polycrystalline has the fastest payback period compare to the remaining two PV solar materials.

Referring to the entire analyzed data compile in Table 12, it was proven that Hanwha Q-Cell Q.PRO-G4 265 is the best solar PV material for a rooftop application compare to the remaining two. Its performances cover both in the technical and economic aspects. Sharp NU-U180FC which representing the monocrystalline material group result in the second best solar PV material override the Kaneka G-SA060 which representing amorphous.

The outcomes from this study prove that the data presented in Table 7 cannot be the only reference in selecting the best PV solar material for a residential rooftop application. Home owner need to analyses various factors and parameters in making rational judgement before installing a PV solar system at home. Different manufacturer's brand from the same group of PV solar material can provide either better or lesser performance on the outcome.

Part of the objectives of this study is to find out the common practice among the existing home owner on whether the 'buy or lease' of the PV solar system on the residential roof top application is more preferable. Figure 11 shows the results of the surveys conducted on 20 respondents in Bangi area. 17 of them had recommended that it will be good to own the solar module and 3 recommended to lease the solar system from the company provider.

As a wrap up from this study, it is proven that polycrystalline has the highest efficiency compare to monocrystalline and amorphous. Even though it is known that the monocrystalline has the highest efficiency than all types of solar materials, the results obtained through this study had proven differently. Polycrystalline on the other hand has the highest efficiency among the three different materials. This is due to the manufacturer's brand of the monocrystalline material that had been selected for the analysis (due to availability) which is not the best brand that can provide higher efficiency to represent the monocrystalline material group.

Author has calculated and compares the temperature coefficient for three solar materials. The results proved that the higher temperature coefficient (in term of negative value percentage), the lesser the performance of the solar module. These results were observed through the solar module losses output. Monocrystalline has the highest negative value of temperature coefficient followed by polycrystalline and amorphous. This resulting of module losses for monocrystalline is highest compared to polycrystalline and amorphous. Moreover, amorphous has lowest negative value of temperature coefficient, therefore its module losses are the lowest too. This shows that amorphous has better performance in term of temperature coefficient compared to monocrystalline and polycrystalline.

Table 12 Comparison of Three PV Solar Materials Parameters

| Type / Category | Monocrystalline (Sharp NU-U180FC) | Polycrystalline (Hanwha Q-Cell Q.PRO-G4 265) | Amorphous (Kaneka G-SA060) |
|---|---|---|---|
| **Module Efficiency (%)** | 13.6489 % | 17.3585 | 6.34737 |
| **Temperature Coefficient (% / ºC)** | -0.458 | -0.419 | -0.224 |
| **Power Tolerance (%)** | -0.647 % | -0.643 % | -0.389 % |
| **Number of panel for a 2 kWp system** | 11 | 8 | 34 |
| **Size Area of Roof Top Required for a 2 kWp system** | 14.15 $m^2$ | 12.47 $m^2$ | 34.17 $m^2$ |
| **Total installed cost for a 2 kWp system** | RM 4800 | RM 3840 | RM 8000 |
| **Maintenance Cost (RM)** | RM 484 | RM 352 | RM 1496 |
| **Payback Period** | 2 years 3 months | 1 year 11 months | 4 years 2 months |

*currency $1 = RM4.00

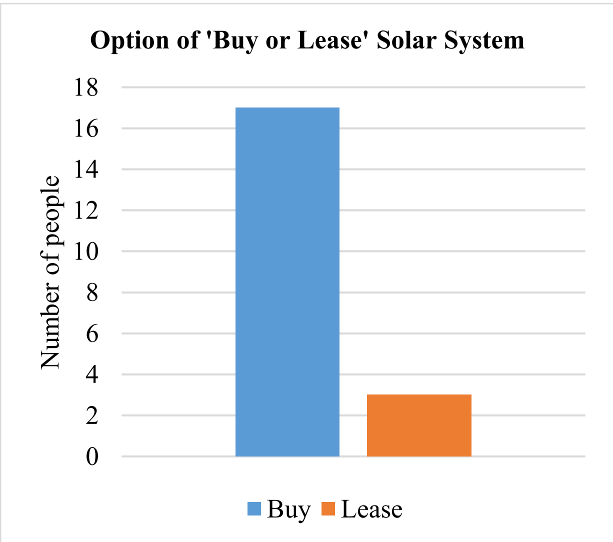


Figure 11 Option of 'Buy or Leasing' A Solar System.

In this research, power tolerance of three solar materials was all below 0 % because the measured power outputs were lower than the rated power output. The power tolerance of monocrystalline and polycrystalline were nearly the same which is -0.647 % and -0.643 % respectively. Kaneka G-SA060 has the greatest power tolerance overriding the other two solar materials which is -0.389 %. Hence, from this analysis, the amorphous has extra advantage compare to monocrystalline and polycrystalline.

As the home owner received a fixed monthly payment from Tenaga Nasional Berhad (TNB) based on the FiT rate, they will start enjoying the profit upon completing the payback period phase. In general, from the results obtained, Hanwha Q-Cell Q.PRO-G4 265 installer will gain the highest profit.

Majority of home owner prefer to 'buy and install' the solar modules instead of leasing the PV solar module system from the company provider. Most of them realized and aware of the return of investment (ROI) and the long term benefit that will be gained.

## 5. CONCLUSIONS

From this research, it is found that Hanwha Q-Cells, Q.PRO-G4 265 (polycrystalline) module has the best technical and economic performance compare to Sharp NU-U180FC (monocrystalline) module and Kaneka G-SA060 (amorphous) Even though amorphous has the lowest negative temperature coefficient, lowest module losses and power tolerance, it has the lowest module efficiency which then affected on the number of module and size of rooftop area required.

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