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Economic Evaluation of Vertical Photovoltaic System on High-rise Building in Malaysia

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Abstract - *In order to provide sufficient information to the designer, investor and the end user regarding the implementation of the photovoltaic system on building façade, forecasting energy generation and cost involved is required. Using System Advisor Model developed by National Renewable Energy Laboratory. This paper focuses on the financial evaluation of vertical photovoltaic façade system on a high-rise building in Malaysia based on 5 possible design scenarios using amorphous silicon heterojunction module with a nominal efficiency of 15.6%. Based on the financial analysis the payback period for the vertical photovoltaic system in Malaysia is about 12 years while the horizontal system is 6 years. On a monthly average, PV system on vertical façade able to save about MYR 33,000 to 68,000 each month compared to PV on roof installation is about MYR 21,000 each month. This shows that photovoltaic on vertical façade of a high-rise building can potentially be implemented in Malaysia climate condition and with carefully design approach, its can open a new demographic in Malaysian built environment and Renewable Energy industries.*

Keywords: solar photovoltaic, high-rise building, vertical façade, economic evaluation

1.0 INTRODUCTION

In late 2010, Malaysia has announced the 10th Malaysian Plan 2011-2015 and the New Energy Policy have been addressed with focuses on national electricity supply security, economic efficiency and sustainable social and environmental development. The 10th plan also specified a target of 985 MW by 2015 for grid-connected generation from renewable energy (RE) sources to contribute 5.5% to the total electricity generation mix [1]. A shift towards renewable energy is necessary in order to meet the increase energy demand in Malaysia while to secure both energy security and the environment [2].

Under the New Energy Policy, Renewable Energy Act and Feed-in Tariff (FiT) mechanism have been legislated and introduced with aims to enhance the utilization of RE resources towards national electricity supply security and sustainable socio-economic development [3]. The FiT mechanism was introduced to change Malaysia's electricity production through renewable energy where domestic and industrial user able to generate and sell backs the electricity to the national power grid at a premium rate [4]. Tax incentives for the clean/green project also have been provided through Malaysia Investment (MIDA) to stimulate the development of RE products by creating manufacturing facilities [5].

European Photovoltaic Industry Association [6] urged the PV's industry, together with the network operators and building sector, needs to develop economical and technical solutions that will allow a large penetration of PV at a competitive level. The building sector needs BIPV to meet its goals of sustainability and the PV industry is looking forward to utilizing the available building surface areas for PV to secure its long-term market growth [7].

Beside performance analysis and financial analysis is also required to assess the potential of PV vertical installation on building façade in Malaysia. A study about renewable energy technologies acceptance in Malaysia has shown that the cost of renewable energy has an indirect effect on Malaysian attitudes towards using the renewable energy [8]. The economic evaluation of PV system helps to facilitate the decision making for the system implementation either the system is cost beneficial or not to the market participant that ranges from residential customers to large-scale project developer and utilities.

There are several methods to evaluate the economic performance of PV systems and the result from each of these methods has a different outcome. Each market participant uses the different financial metric to evaluate the PV system value which depends on the type of investment in return. The fundamental differences in PV market prices, revenues, incentives and financing option for each market caused by different metric parameter will generate different outcome to the PV value. PV module market price can be twice as high on a capacity basis ($/W) as a large-scale system, however, residential electricity tariff rates can be twice as high as wholesale electricity rates [9].

The aim of this paper is to assess the feasibility of vertical photovoltaic system on a high-rise building in Malaysia with a focus on economic evaluation. Based on performance evaluation of various design scenario of PV vertical façade on a high-rise building in Malaysia, the financial analysis of the design was carried out using System Advisor Model (SAM) developed by National Renewable Energy Laboratory (NREL).

2.0 SYSTEM DESIGN AND CONFIGURATION

The design of high-rise building in Kuala Lumpur city area built with various shape and form. The average gross floor area (GFA) for high rise in Kuala Lumpur is 1225m^2 with average height 120m and the floor to floor height is 4m [10]. Based on this configuration, a built-up model of a high-rise building in Kuala Lumpur is developed. The building shape is a square shape with 1:1 ratio of width and length so that each vertical façade have an equal surface area for comparison. Figure 1 shows the dimension of the built-up base model and Table 1 shows the configuration of the built-up base model for a high-rise building in this study. The entire building surfaces were considered as opaque solar collector surface. The solar insolation received by exposed surface was estimated as the sum of the solar radiation on its facades acting like a flat solar collector [11].

Figure 2 shows the possible PV design on high-rise building based on 5 scenarios. The highest level of average daily solar insolation is received on the east wall, followed by south, west and north wall [12] [13]. East (90 deg), west (270 deg) and roof (horizontal) façade were selected in this simulation as these façades received the highest incident solar radiation. Amorphous silicon Heterojunction (HIT-Si) module was used in this simulation as HIT-Si module manufactured by Sanyo give the highest module efficiency available in the market today with 15.62% nominal efficiency and 180Wdc maximum power. Meanwhile, the weighted efficiency for DC to AC inverter is 95%. Each system design has a different configuration based on the nameplate capacity and module area.

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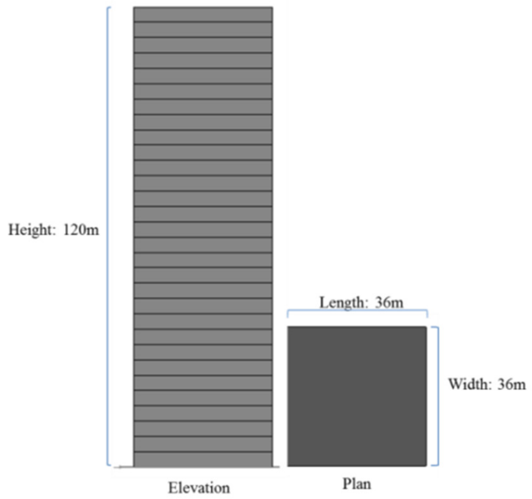

Figure 1: Dimension of the built-up model of high-rise building

Table 1: Built-up base model configuration

Gross floor area	1296 m^2
Height	120 m
Vertical façade surface area	4320m^2
Horizontal roof surface area	1296m^2
Floor to floor height	4m

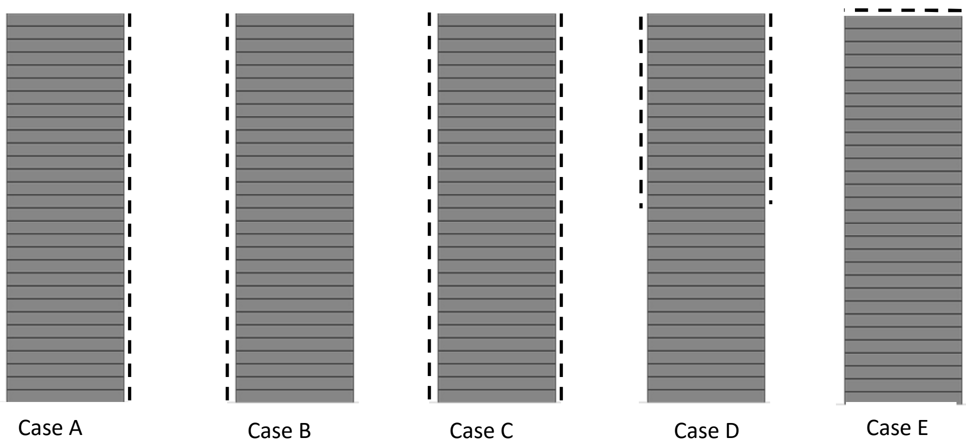

Figure 2: Possible PV application on high-rise building. (Case A) 90deg azimuth, east façade. (Case B) 270deg azimuth, west façade. (Case C) 90 and 270deg azimuth. (Case D) Upper half of building. (Case E) roof

2.1 System Characteristic and Performance Data

The technical input for the module that applied in the system is required, such as the type of PV module, nominal efficiency, module area and module maximum power. The technical input also includes the overall system characteristic such as the nameplate capacity of the system, number of modules used in the system and number of the inverter. Meanwhile, the system performance input such as annual energy generated will help to evaluate the cost saving with the system. Table 2 shows the technical and performance input for each design case of the PV system generated from SAM performance analysis.

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Table 2: Technical inputs required for each system design.

Technical Input	Case A	Case B	Case C	Case D	Case E
Module Model			Sanyo HIP-J54BA2 (2004 E)		
Module Material			HIT-Si		
Nominal efficiency (%)			15.62		
Maximum power - Pmp (Wdc)			179.663		
Module Area (m^2)			1.15		
Nameplate capacity (kWdc)	672.657	672.657	1348.188	684.155	201.222
Number of modules	3744	3744	7504	3808	1120
Modules per string	8	8	8	8	8
Strings in parallel	468	468	938	476	140
Total module area (m^2)	4305.6	4305.6	8629.6	5612	1288
Number of interters	12	12	25	12	4
Performance Input					
Annual energy (kWh)	403,860	389,922	794,424	404,311	243,576
Capacity factor (%)	6.9	6.6	6.7	6.7	13.8
First year kWhAC/kWDC (kWh/kW)	600	580	589	591	1,210
Performance ratio	0.75	0.75	0.75	0.75	0.77

2.2 System cost

System cost which constitutes the direct and indirect cost of the overall system that defines the installation cost and operating costs of PV project. Direct capital cost PV system represents the expenses for a specific equipment or installation services that apply such as module, inverter, the balance of system (BOS), installation labor cost, installer margin and overhead cost. Meanwhile, the indirect capital cost is the cost of the system that cannot be identified with a specific piece of equipment or installation service. There are 5 indirect cost categories; permitting-environmental studies, engineering, grid interconnection and land cost. Include in these categories also the sale tax rate for each category. In addition to direct and indirect cost, the operation and maintenance cost (O & M) also need to include in the overall system cost. The O & M presents the annual expenditures on equipment and services that occur after the system is installed.

In this simulation, the cost associated with the PV system is made an assumption based on past studies and obtained from local authorities. For this analysis, the benchmark percentage of cost breakdown for PV system in the US was used as a reference. Figure 3 shows the percentage of cost breakdown for modeled commercial PV system in US Q1 2015 [14].

Average total installed cost per watt for grid-connected PV system above 425kW and up to 1MW in Malaysia is MYR 7.5 per watt ($1.88/W) [15]. Table 3 show the cost breakdown PV system in Malaysia based on MYR 7.5 per Watt. The currency exchange rate used to convert MYR (Malaysia Ringgit) to U.S Dollar was 1MYR = 0.25USD. The land cost was omitted in this analysis as the PV system integrated with building façade. Meanwhile, the O&M cost is around USD 19/kW-yr. (MYR 76/kW-yr)

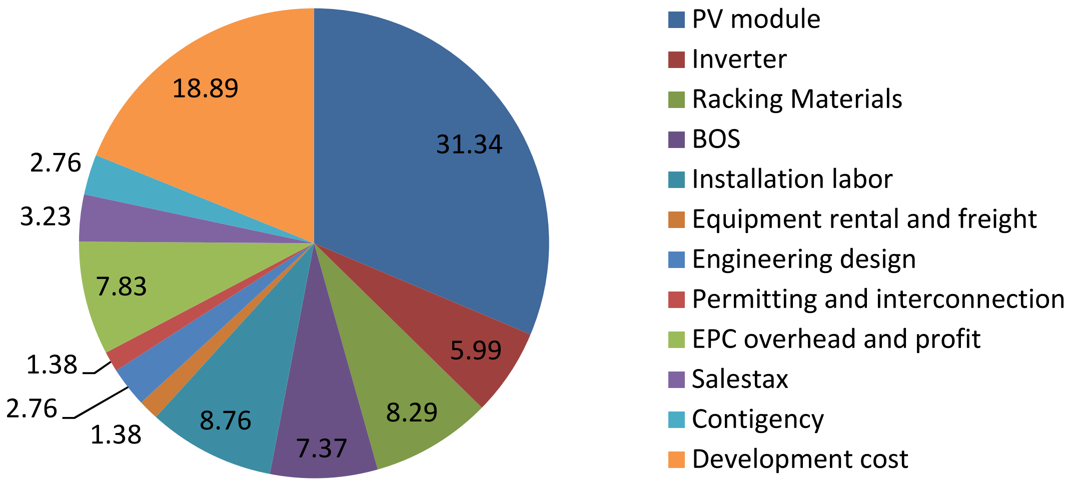

Figure 3: Benchmark of cost breakdown percentage (%) for PV system in US Q1 2015. [14]

Table 3: System cost of PV system in Malaysia.

DIRECT COST	MYR/W	USD/W
PV module	2.35	0.59
Inverter	0.45	0.11
Racking Materials	0.62	0.16
Balance-of-System (BOS)	0.55	0.14
Installation labor	0.66	0.16
Equipment rental and freight	0.10	0.03
EPC overhead and profit	0.59	0.15
Contingency	0.21	0.05
INDIRECT COST		
Engineering design	0.21	0.05
Permitting and interconnection	0.10	0.03
Sales tax basis	0.24	0.06
Development cost	1.42	0.35
Total installed cost per capacity	**7.5**	**1.88**

2.3 Financial input

Financial input indicates the commercial loan parameter to finance the capital cost of the PV project. This loan agreement is between the bank and the building owner which include the debt percentage of the net capital cost to be borrowed, the number of years requires to repay the loan (loan term) and the annual nominal interest rate for the loan (loan rate). Analysis period that determines the number of years covered by the project is required in this analysis. The analysis period is typically equivalent to the asset life which approximately 25 years [16]. The change of costs value of PV system based on price index will decrease over the years of analysis period at a certain rate, known as the inflation rate. According to Central Bank of Malaysia [17], Malaysian inflation rate by the end of 2015 was 2.7%. The real discount rate is a rate used to depreciate future PV revenues and costs into an equivalent present value [18]. The real discount rate is assumed to be the same as the loan rate in the reference scenario. Meanwhile, the nominal discount rate is the sum of the inflation rate and real discount rates [19].

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In order to calculate the utility bill saving from the PV system, both utility bills without the system and with system need to be calculated. The electricity rates from local electricity provider will determine how the retail electricity customer is compensated for electricity generated by renewable energy system. Table 4 shows the current electricity rates for the commercial sector in Malaysia obtained Tenaga National Berhad [20]. From the table, the medium voltage for general commercial tariff 36.5 sen/kWh (USD 0.0913/kWh) was selected. The electricity rate indicated flat buy rate, the fixed energy charge per kilowatt-hour that project paid for electricity to meet the load hours that the renewable energy system's output is less than the electric load.

Table 4: Current electricity tariff for the commercial sector in Malaysia [20].

Tariff Category	Current Rates (Jan 2014)
TARIFF B - LOW VOLTAGE COMMERCIAL TARIFF	
For the first 200 kWh (1 -200 kWh) per month	43.5 sen/kWh
For the next kWh (201 kWh onwards) per month	50.9 sen/kWh
The minimum monthly charge is RM7.20	
TARIFF C1 - MEDIUM VOLTAGE GENERAL COMMERCIAL TARIFF	
For each kilowatt of maximum demand per month	30.3 RM/kW
For all kWh	36.5 sen/kWh
The minimum monthly charge is RM600.00	
TARIFF C2 - MEDIUM VOLTAGE PEAK/OFF-PEAK COMMERCIAL TARIFF	
For each kilowatt of maximum demand per month during the peak period	45.1 RM/kW
For all kWh during the peak period	36.5 sen/kWh
For all kWh during the off-peak period	22.4 sen/kWh
The minimum monthly charge is RM600.00	

Meanwhile, table 5 shows the current FiT (Feed in Tariff) rate for solar PV in Malaysia obtained from SEDA [21]. It also indicated the price per kilowatt-hour paid by the electric service provider to the project during hours that the renewable energy system's output is greater than the electric load. In this simulation, the installed qualifying RE are capacity above 72kW – 1MW with FiT rates of RM 0.6977/kWh, bonus FiT rate; used as an installation in building or building structures (RM 0.1722/kWh) and used as building materials (RM 0.1656/kWh). The total flat sell rate is RM 1.0355/kWh (USD 0.2588/kWh).

On the other hand, the average Building Energy Index (BEI) in Malaysia is 250kWh/m^2/year, while according to "Code of Practice of Renewable Energy and Energy Efficiency for Non-residential Building", buildings in Malaysia should have BEI of 220kWh/m^2/year [22]. Based on a number of floors and floor area of the base model of a high-rise building in Malaysia, the monthly electric load for a typical high-rise building in Malaysia is 689,040kWh per month.

In this analysis, the project cash flow will be calculated over specified analysis period with consideration of electricity generated by the system, incentives in the form of FiT offered by the local government, system cost of installation, operation and maintenance cost. As BIPV system, the building electrical loads also considered in this analysis using the electricity demand and rates established by the provider.

Generally, there is 2 keys driver that determine the power delivery by PV system over the course of time, which is module efficiency converting sunlight to electrical power and

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degradation rate of PV system decline over time [18]. These keys information are important to every stakeholder in PV industry (manufacturer, investor, designer, and researcher). Higher degradation rate will cause less power generated and thus reduce future cash flow [23]. Based on past studies, the mean degradation rate is 0.8%/year and the median value of 0.5%/year [24]. Table 6 shows the summary of financial parameter assumption for this analysis.

Table 5: FiT Rates for Solar PV (Non-individual (≤ 500 kW)) - Jan 2015 [19].

Description of Qualifying Renewable Energy Installation	FiT Rates (RM per kWh)
BASIC FiT RATES HAVING INSTALLED CAPACITY OF:	
up to and including 4kW	0.9166
above 4kW and up to and including 24kW	0.8942
above 24kW and up to and including 72kW	0.7222
above 72kW and up to and including 1MW	0.6977
above 1MW and up to and including 10MW	0.5472
above 10MW and up to and including 30MW	0.4896
BONUS FiT RATES HAVING THE FOLLOWING CRITERIA (one or more)	**(+)**
use as an installation in buildings or building structures	0.1722
use as building materials	0.1656
use of locally manufactured or assembled solar PV modules	0.05
use of locally manufactured or assembled solar inverters	0.05

3.0 RESULT AND DISCUSSION

In this section, the economic evaluation of each proposed design system will be presented in initial cost or net capital cost, potential electricity saving from each scenario, Net Present Value (NPV), Profitable Index (PI) and Payback Period. SAM Financial analysis required input data regarding cost in US Dollar (USD) and direct conversion into Malaysian Ringgit (MYR) will be provided in later explanation. Figure 4 shows the comparison of the net capital cost of installing PV module on each design system. Based on total cost breakdown for direct cost and indirect cost it can be seen that Case C with 8629.6 m^2 module area has higher net capital cost with $2,533,133. Meanwhile Case A and B with similar total module area and a number of modules, the total installed cost is $1,263,866. On the other hands, total installed cost for PV system on roof façade of a high-rise building is about $378,080. Table 7 shows the net capital cost for each design system in MYR.

Table 6: Financial parameter assumption.

Project Term Debt		
	Debt percent (%)	0

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Loan term (year)	0
Loan rate (%)	0
Analysis Parameters	
Analysis period (year)	25
Inflation rate (%/year)	2.7
Real discount rate (%/year)	0
Nominal discount rate (%/year)	2.7
Electricity Rates	
Flat buy rate (MYR or USD/kWh)	MYR 0.365 or USD 0.0913
Flat sell rate (MYR or USD/kWh)	MYR 1.0355 or USD 0.2588
Electricity Load	
Monthly load (kWh)	689,040
Degradation Rate (%/year)	0.5

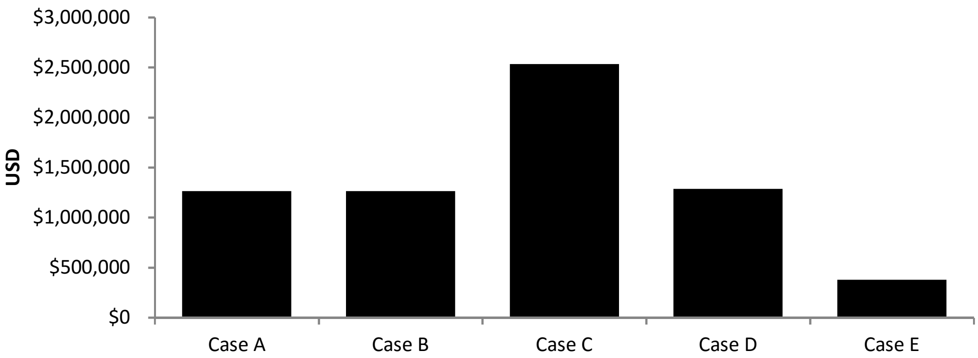

Figure 4: Net capital cost.

Table 7: Summary of net capital cost for each case in MYR

	Case A	Case B	Case C	Case D	Case E
Net capital cost (MYR)	5,055,464	5,055,464	10,132,532	5,141,880	1,512,320

Based on current electricity tariff for the general commercial sector and annual building energy demand, the annual electricity cost or electricity cost without RE system for a base model of a high-rise building in Malaysia is about $754,912 per year. The electricity cost with the system represents the cost of electricity purchased from local electricity provider for hours when the building electricity load was greater than system's output. In Figure 5, both systems with PV design of 90deg (case A) and 270deg (case B) are required to purchase electricity about $650,394 and $654,001 per year to meet the annual building energy demand. However, if the building only applied PV system on roof façade, the cost of electricity with the system is $691,875 per year. Table 8 shows the summary of annual building electricity cost with and without PV system.

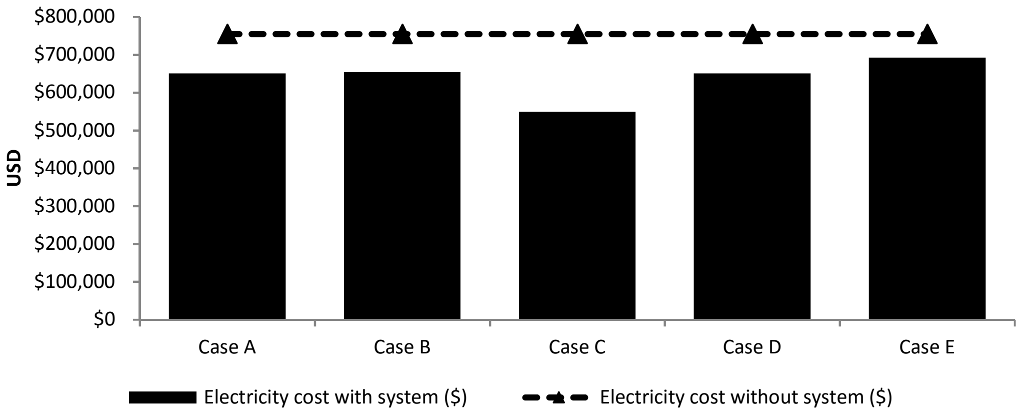

Figure 5: Electricity cost with and without PV system.

Table 8: Summary of annual building's electricity cost with and without PV system.

	Case A	Case B	Case C	Case D	Case E
Electricity cost without system (MYR)			3,019,648		
Electricity cost with system (MYR)	2,601,576	2,616,004	2,197,260	2,601,108	2,767,500

Figure 6 shows the net saving of electricity cost for building with PV system. It shows that building with PV system installed on both east and west façade in Case C able to save about $205,000 during the first year on electricity consumption. Meanwhile, net electricity cost saving for PV on single façade, case A, and B are $104,519 and $100,912 in the first year, while PV on roof façade, the net saving value is around USD 63,037/year. This shows that building with larger PV module area able to generate more electricity and able to save more on electricity bill yearly. Table 9 shows the summary of monthly net saving on electricity cost with PV system according to each scenario. On a monthly average, PV system on vertical façade able to save about MYR 33,000 to 68,000 each month compared to PV on roof installation is about MYR 21,000 each month.

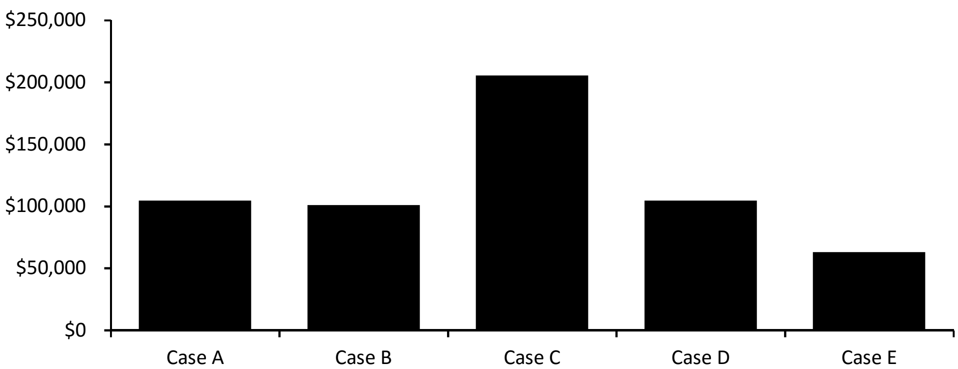

Figure 6: Net saving of electricity cost with the system in Year 1.

Table 9: Summary of monthly saving on electricity cost (MYR/Month) with PV system.

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MONTH	Case A (MYR)	Case B (MYR)	Case C (MYR)	Case D (MYR)	Case E (MYR)
Jan	36314	32996	69374	35307	21298
Feb	33796	31452	65314	33236	20264
Mar	38101	36990	75196	38260	23080
Apr	35706	34898	70670	35961	21563
May	34271	33746	68054	34639	20859
Jun	33972	33460	67491	34349	20464
Jul	35441	33749	69242	35241	21192
Aug	35980	34569	70607	35933	21704
Sep	34984	33535	68574	34899	21145
Oct	34330	33862	68229	34730	21109
Nov	32324	32151	64515	32836	19808
Dec	32856	32238	65122	33151	19664
TOTAL	**418075**	**403647**	**822388**	**418542**	**252149**

Net Present Value (NPV) generally presents the net profit generated by an investment, calculated from the discounted sum of future costs and revenues [18]. When the NPV equal to zero, the cost of PV-generated electricity is equal to the cost of electricity that could have been purchased from the grid [25]. Positive NPV indicates that the project is economically feasible and a profitable investment, while negative NPV means that the project not feasible [19]. Generally, the NPV value will increase with increasing revenues or decrease cost. Below is the Net Present Value (NPV) equation.

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+d_{nominal})^n} \tag{1}$$

Where,

C_n	After-tax cash flow in Year, *n*.
N	Analysis period in years.
$d_{nominal}$	The nominal discount rate is shown in the financial parameter.

In addition, to compare between different investment or project, NPV value need to be scaled by the investment cost, which will result in the profitability index (PI). PI or profit investment ratio (PIR) is the ratio of payoff to investment cost for each project, allowed it to quantify the amount of value created per unit of investment. PI value greater than zero represents a profitable investment [18].

$$PI = \frac{\text{NPV}}{\text{Investment Cost}} \quad \text{or} \quad PI = \frac{\sum_{n=0}^{N} \frac{C_n}{(1+d_{nominal})^n}}{Investment\ Cost} \tag{2}$$

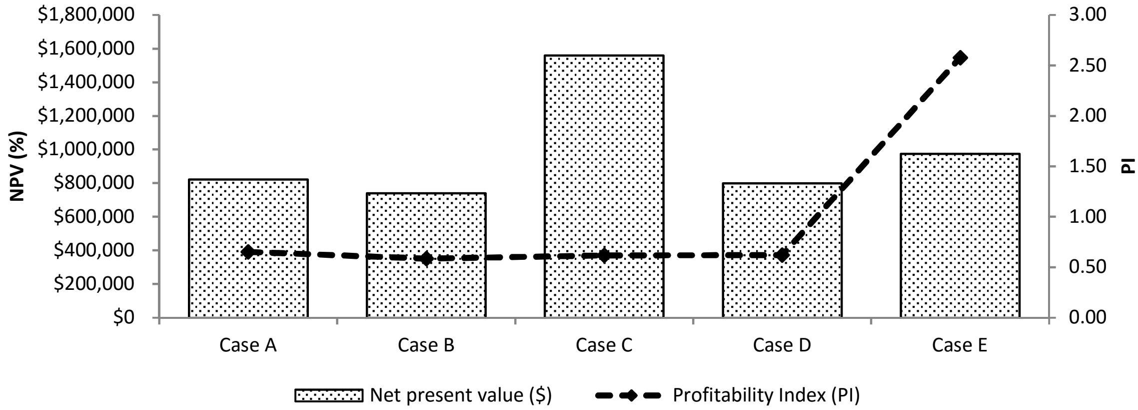

Figure 7: Net Present Value (USD) and Profitability Index.

Table 10: Summary of Net Present Value (USD and MYR) and Profitability Index.

	Case A	Case B	Case C	Case D	Case E
Net present value (MYR)	3,289,336	2,958,412	6,236,072	3,192,364	3,898,880
Profitability Index (PI)	0.65	0.59	0.62	0.62	2.58

Figure 7 and Table 10 shows the net present value and profitability index for each PV installation scenario on a high-rise building in Malaysia. Between the vertical installation (Case A, B, C, D), the NPV for building with PV on both east and west façade (case C) is the highest with USD 1,559,018. Meanwhile between east and west façade (case A and B), building with PV system on east façade have higher NPV compared to west façade. The NPV for PV system on roof façade is about MYR 3,898,000. The profit investment index (PI) analysis shows that Case A has greater PI of 0.65 compared to case B (0.59), C (0.62) and D (0.62). Meanwhile, PV on roof façade has 2.58 PI value.

Payback Period represents the minimum number of years required for the discounted sum of annual net savings to equal the discounted incremental investment costs [18]. 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 [26, 27]. In this analysis, each design system was created without the financial incentive and debt. The payback period in this section is solely on net capital cost including the module and inverter cost, O&M cost, installation labor cost, installer margin and overhead cost and also the cost for permitting and environmental studies.

$$\sum_n \frac{\Delta I_n}{(1+d_{nominal})^n} \leq \sum_n \frac{\Delta S_n}{(1+d_{nominal})^n} \quad (3)$$

Where,

ΔI_n	Incremental investment cost.
ΔS_n	Annual savings net of future costs.
$d_{nominal}$	The nominal discount rate.
n	Analysis period.

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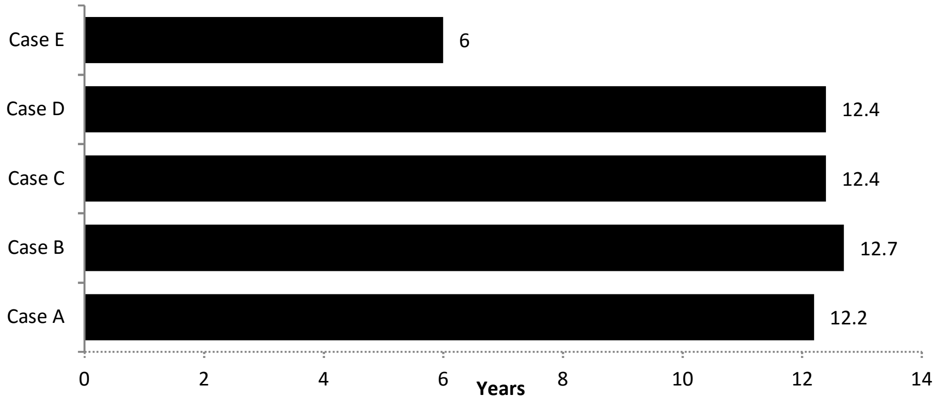

Figure 8: Payback period.

Figure 8 show the time required for each case discounted revenues to exceed the discounted system costs accrued. It can be seen that the payback period for PV system on east vertical façade (Case A) is 12.2 year, while on west façade (Case B) it's take 12.7 years to recover the net capital cost. Meanwhile, the payback period for PV system on both east and west façade (Case C and Case D) is 12.4 years. However, the payback period for PV system on roof façade is shorter with 6 years. Figure 9 until Figure 13 shows the annual after tax and cumulative cash flow for each design system.

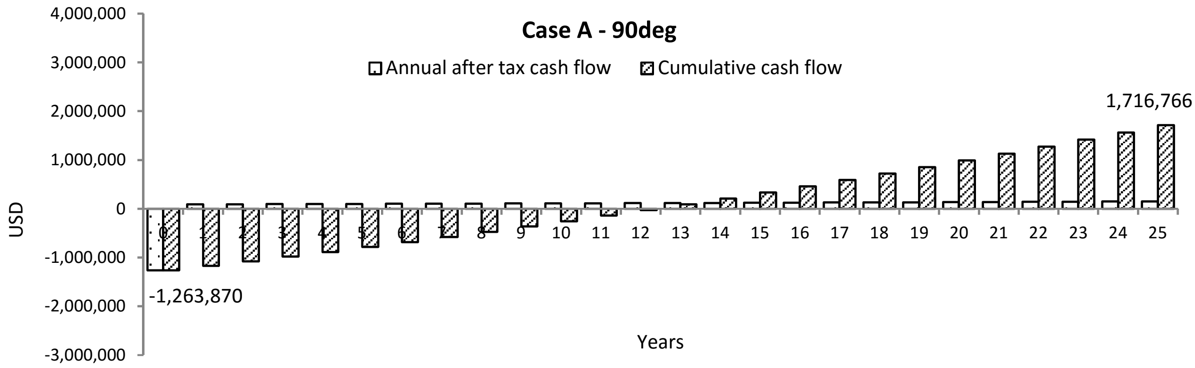

Figure 9: Cumulative cash flow and annual after-tax cash flow for Case A

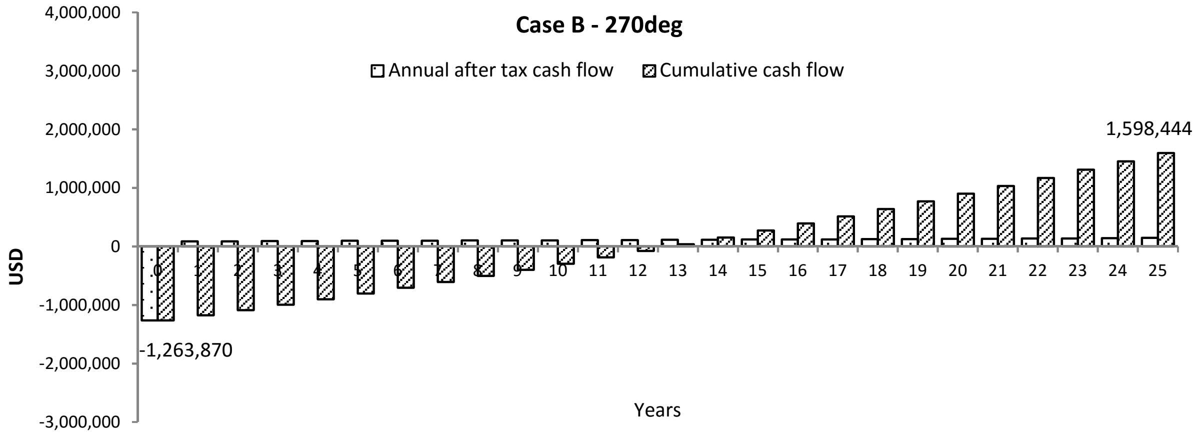

Figure 10: Cumulative cash flow and annual after-tax cash flow for Case B

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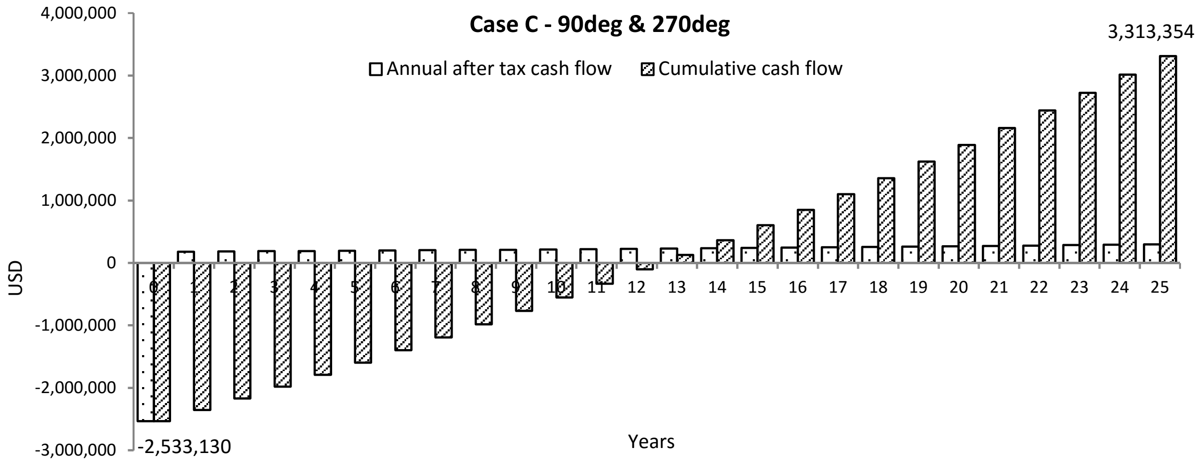

Figure 11: Cumulative cash flow and annual after-tax cash flow for Case C

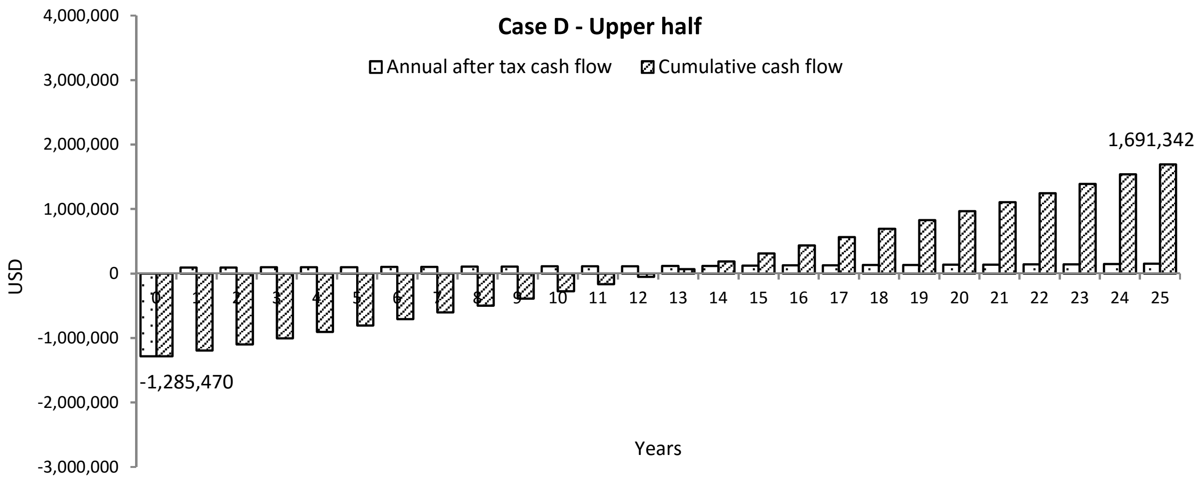

Figure 12: Cumulative cash flow and annual after-tax cash flow for Case D

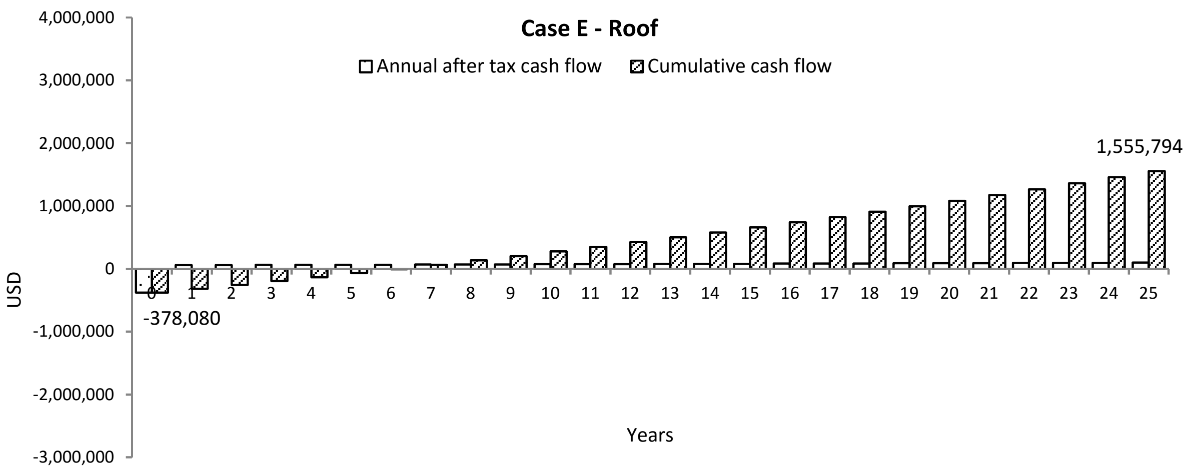

Figure 13: Cumulative cash flow and annual after-tax cash flow for Case E.

4.0 CONCLUSION

Based on 5 possible design of PV vertical façade on the built-up model of a high-rise building in Malaysia, the feasibility of the design in term of performance and financial have been evaluating using System Advisor Model simulation. Table 11 show the summary of a key finding in the performance and financial analysis for each possible design.

Table 11: Summary of economic evaluation.

Financial Evaluation Parameter	Case A	Case B	Case C	Case D	Case E
Net capital cost (MYR)	5,055,464	5,055,464	10,132,532	5,141,880	1,512,320
Electricity cost with system (MYR)	2,601,576	2,616,004	2,197,260	2,601,108	2,767,500
Net savings with system (MYR)	418,076	403,648	822,388	418,544	252,148
Levelized COE (nominal) (MYR/kWh)	0.9128	0.9456	0.9304	0.9276	0.4528
Levelized COE (real) (MYR/kWh)	0.6624	0.686	0.6748	0.6728	0.3284
Net present value (MYR)	3,289,336	2,958,412	6,236,072	3,192,364	3,898,880
Profitability Index (PI)	0.65	0.59	0.62	0.62	2.58
Payback period (years)	12.2	12.7	12.4	12.4	6

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