An Analysis of a Photovoltaic Panel-Based Roofing for A Two-Storey Residential Building

Rosalyn L. Samson[1], Michael A.Castro[1], Trina F. Infante[1], Blessed B. Peña[1], Engel Justine O. Castillo[1], Joefill C. Jocson[1], Noel T. Florencondia[1]

[1]*Graduate School Nueva Ecija University of Science and Technology, Nueva Ecija, Philippines.*

Corresponding Author: michaelacastro0211@gmail.com

Abstract: - A new approach in harnessing electrical energy from the sun is Residential Building Integrated Photovoltaic (RBIPV). Design structure, architectural design and economic regenerative energy conversion of the panels are integrated in a way that all three of the systems are working a single unified function of maximizing output generated of panels as well as safety of the building. Due to its renewable energy features, it gives designers a chance of limiting the amount of carbon footprints released by using traditional source of electricity. The study provides information and ideas in designing of residential building transformed into a sustainable technology. It also analyzed through a literature review, direct interviews and surveys, as well as design computations to support the objectives of the study. The proponents used various principles of engineering and software to ensure the strengths and life of RBIPV. The proponents were able to determine the function of photovoltaic as building materials that may decrease the cost of materials, labor and economic considerations for future use. The approximate net income generated after 25 years is P250,000, saving money as well as minimizing the effects and release of carbon footprints which contributes to environmental wellness of the surroundings. The application of RBIPV will result in production of quality electricity very close to demand points. These will directly boost the energy efficiency and reduce electrical supply loses without causing undue environmental damages. These works abridge the increasing demand for zero energy and zero emission residential building of the near future.

Key Words— ***photovoltaic, RBIPV, solar panel, energy harnessing, integrated systems.***

I. INTRODUCTION

Due to the significant increase of the demand for energy consumption in the residential building sectors in the last decade different variety of engineering techniques were developed [1]. One of the techniques considered is the usage of energy harnessing devices like the photovoltaic systems or solar power system. Recently, Building-Integrated Photovoltaic or BIPV is being considered as an innovative technique for clean energy production and reduction of greenhouse gases [2]. This is also a way in helping people who are experiencing scarcity of electricity especially in the communities of the rural areas here in the Philippines [3].

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Electricity in to today's modern world is vital in the operations of the households as well as the industries but according to the report by the Energy Department of the country or DOE, Philippine electricity rates remain one of the highest in Southeast Asia due to high demand but low supply. Based on the Power Development Plan 2017 to 2040, the country's electricity rates are among the highest in the region, at par with the level of Singapore [3]

According to Philippines Statistics Authority (PSA, 2005), household's electrical energy consumption continues to rise up as population increases. From the result of 2011 Household Energy Consumption Survey (HECS), electricity remains as the most common source of energy used by household in the Philippines. Residential sector consumed 8,134 GWh (Giga watt hour) of electricity in the country which is higher by 18.8 % than the last 6-year period. This reflects an average of 215 GWh per year.

A reliable and sufficient electrical supply system is essential and important for any developing country like Philippines. One of the Sustainable Developmental Goal of the United Nations or UN is to have a reliable and clean energy which important for all countries around the world. Some provinces in the Philippines have insufficient and unreliable supply of electricity because of their mountainous, up-land and out-grid location. This kind of situation is very particular in municipality of Porac province of Pampanga. Residential buildings in some places in Porac are out of the line and off- grid to the electrical distribution utility due to higher location, lose and poor installation to deliver the generated power. Hence, introduction of an integrated photovoltaic design for residential building is needed.

The Philippines is located right above the equator. Therefore, it has a good potential for solar energy particularly the proposed design of residential building – integrated photovoltaic. The import of fossil fuels and other sources of electricity, that causes environmental damages are relatively high that is why Philippines needs this alternative solution.

The building-Integrated Photovoltaic Design is an electric power system not only to produce electricity but it will also work as part of the residential structure. It concerns is to the utilizing of photovoltaic devices and to substitute conventional building materials in components of the building envelope such as shading devices, roof, windows, balcony railings and skylights of facades. It can also provide the building envelope functions such as weather protection (water proofing, sun protection), noise protection, thermal insulation, daylight illumination and safety.

Many tests were done to prove that the PV's are good and durable as building materials. According to the test of solar world (2018), the international hold requirements of photovoltaic is 1131lns/m^2 or 54.2 KN/m^2 It can also withstand high wind loads and snow loads. Photovoltaic which are from silicon currently provide a combination of low cost, high efficiency and long lifetime. PV modules have an expected efficiency lifespan of 25 years or more, still producing for almost 80% of their original efficiency or power after this time. When it comes in maintenance, these systems generally do not require a lot of maintenance as long as it is relatively clean; still, it can work effectively and runs at maximum efficiency (Office of Energy Efficiency and Renewable Energy or EERE, 2013).

II. METHODOLOGY

The main purpose of the study is to analyze a photovoltaic roofing system as an alternative to the traditional roofing system and compare its benefits and advantages for future use. The study is based on the two-storey building or a family home. The proponents searched information about related studies in order to considered all the factors and evidences to make this study is feasible. The different government agencies like PAGASA (Philippine Atmospheric, Geophysical and Astronomical Services Administration), DOST (Department of Science and Technology) and municipality of Porac also provide some data as a support detail in the study. Information of the consumption of energy within the various building sectors in Babo Pangulo, particularly the housing is presented, followed by information about the behavioral pattern of consumption of energy. Research continues on the technologies in line with the renewable energy and integration of the available photovoltaic technologies in today's market. An analysis of equipment and electricity to use in the design building (washing machine, lighting, cooking, eating, and entertainment) is also considered, then calculation of the total number of photovoltaic products in order to find out the suitable and reliable source of electricity to power the propose design of two-storey building in close relation on the integrating of the modules as part of the households' envelope.

Battery configuration in a photovoltaic system will be designed as an important component in the off-grid or stand alone with battery back-up system. The system will be using an off-grid system. Calculation of the size and the capacity of the battery are also considered. For the creation and design of the PV system, the researchers adopted the methods based on North American Board of Certified Energy Practitioners (NABCEP) Study Guide for Photovoltaic System Installers Version 4.2. Environmental analysis will also perform to determine the applicable site and locations of the study. The study continues with discussion regarding the designing of the whole building including the floor plans, architectural plans, and structural using the various principles of engineering like USD and LRFD with the provision of NSCP 2010.

III. RESULTS & DISCUSSION

Six (6) parts were provided for the data presentation of the study. The first part is the Household Electricity Consumption, the second part Battery Sizing, the third is Size and Design of Photovoltaic Electricity Production, the fourth is Design

Analysis of the Structure, the fifth is Design of Footing and the last is Return of Investment.

3.1 Household Electricity Consumption

In order to design a photovoltaic system, the load of electricity must be analyzed and determined. This will help and provide the size of the system, whether it can or not support and cover this load.

The proponents provide questioners to some residences of Babo Pangulo, in order to describe the type of appliances, quantity and the time usage. From here, the electricity load was calculated as shown in Table 1.

Table.1. Household Electricity load

Appliances	Quantity	Electricity use (W)	Usage (hr/day)	Electricity Use (kW/h)
Electric fan	3	65	7	1.365
Television	2	180	6	2.160
Refrigerator	1	300	13	3.900
Oven toaster	1	1000	0.0434	0.0434
Rice cooker	1	450	1.11	0.4995
Air Conditioner	1	944 (1HP)	2.28	2.1523
Flat iron	1	1000	1.18	1.1800
Washing Machine	1	500	1.108	0.5540
Miscellaneous		500	4	2.0000
Total (KWh)				**13.8542**

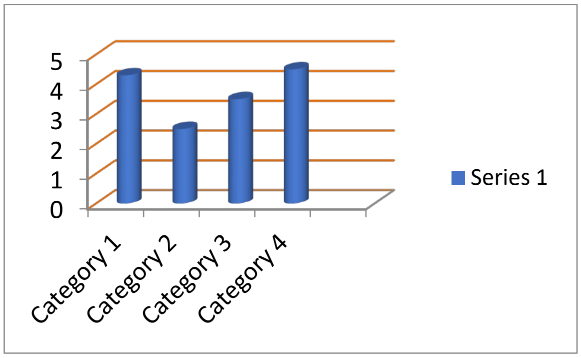


Fig.1. Electricity Bill of the respondents. Percentage vs the actual electricity bill

In figure 1, it shows the summary of the conducted survey about the average of monthly electrical bill in Babo Pangulo. The highest cost of electricity consumed ranges P 2000.00 – P 3000.00 and the least is between P 400.00 – P600.00. This will help the researchers to accumulate the possible budget that could save.

Table.2. Electricity Consumption for Lighting

Area	**Type of Lighting/ Quantity**	
	9W	**40W**
First floor		
• 'Living area	1	1
• Kitchen/Dining	3	1
• Room 1	1	
• Guest room	1	
• Bathroom	1	
• Utility room	1	
• Laundry	1	
Second floor		
• Bedroom 2	1	
• Bedroom 3	3	
• Master Bedroom	1	
• Family Hall		1
• Bathrooms	2	
• Ceiling features/Others	8	
Total quantity	24	3
Electricity use (KWh)	0.648	0.0438
Total (KWh)	0.6918	

3.2 Battery Sizing

The recommended battery type for photovoltaic system is deep cycle battery. It is specifically designed to be discharged to low energy and rapid recharged day after day. The battery should be large enough to at least provide and store sufficient energy to operate the residential building at night and cloudy days. The deep cycle battery also adapts a longer lifespan compared to other batteries used for solar PV systems. It is also relatively cheaper compared to the other type of batteries.

Table.3. Battery specifications

Nominal battery voltage	12 V
Design margin	713.04 Ah
Battery capacity	7843.43 Ah
Rated capacity	600 Ah
Number of batteries	14 cs

3.3 Size and Design of Photovoltaic Electricity Production

In designing and sizing PV modules, all data were provided by the manufacturer data sheet and adopted from NABCEP Study Guide for Photovoltaic System Installers Version 4.2.

Table.4. Photovoltaic panel specification

Peak sun hour	2.5
NOCT	45 ℃
P_{max}	201.13
Temperature coefficient	0.4 ℃
Ambient temperature	20 ℃
G	$161.7\ \frac{w}{m^2}$
T_c	25.05 ℃
HLD	0.02%
HL	99.98%
$Pv_{efficiency}$	89.982%
E.H	$321.82\ \frac{wh}{day}$
$\#_{Pv\ design}$	50 PV modules
$\#_{Pv\ actual}$	46 V modules

3.4 Design Analysis of the Structure

3.4.1 Design of Roof Truss

In designing the roof truss, the wind pressure or the wind load must be considered. Section 207 of National Code of the Philippines 2010; provide the parameters and factors in order to calculate the wind load. LRFD approach was used to justify the outcomes below.

Table.5. Structural Analysis Specifications for Roof Truss

Wind Load

Velocity	200KPh
Wind Load	6.856 KN

Purlins

Section	C 2” x 4” x 2
Bay Length	2.1m
Spacing	0.6m

Truss 1

Section (for top and bottom)	L 2 ½ x 2 x ¼
Web section	L 75 x 75 x 8
Span	11.25m
Spacing	2.1m

Truss 2

Section (for top and bottom)	L 2 ½ x 2 x ¼
Web section	L 75 x 75 x 8
Span	7.75m
Spacing	2.1m

3.4.2 Design of Reinforced Concrete Slab

In designing of reinforced concrete slabs, designers must assume preliminary member thickness to ensure that the deflection requirements are satisfied. 1995 ACI Building Code provides the required minimum thickness of the slab and the moment coefficient for different slab condition. The number of reinforcements was varying based on the area needed for resistance. All slabs were designed both one-way and two-way depending on their long and short span.

Table.6. Structural Analysis Specifications for Reinforced Concrete Slab

Slab 1

Thickness	120mm
Main bar diameter	12mm
Spacing of bars along short direction	
At midspan	230mm
At continuous edge	170mm
Spacing of bars along long direction	
At midspan	270mm
At continuous edge	230mm

Slab 2

Thickness	100mm
Main bar diameter	12mm
Spacing of bars along short direction	
At midspan	300mm
At continuous edge	160mm
Spacing of bars along long direction	
At midspan	350mm
At continuous edge	150mm
At discontinuous edge	300mm

Slab 4

Thickness	100mm
Main bar diameter	12mm
Spacing of main bars	300mm
Temperature bar diameter	10mm
Spacing of temperature bars	450mm

Design of Stairs

Thickness	100 mm
Thread	300 mm
Riser	200 mm
Dead load	2.99 ${KN}/{m}$
Live load	1.9 ${KN}/{m}$
$M_{u\ Design}$	6.670 KN-m
$M_{u\ actual}$	1.022 KN-m
Spacing (main bars)	300 mm - $\emptyset 12mm$
Spacing (Temperature bars)	450 mm - $\emptyset 10mm$

Slab 5

Thickness	100mm
Main bar diameter	12mm
Spacing of main bars	300mm
Temperature bar diameter	10mm
Spacing of temperature bars	450mm

Slab 6

Thickness	110mm
Main bar diameter	12mm
Spacing of bars along short direction	
At midspan	260mm
At continuous edge	130mm
At discontinuous edge	300mm
Spacing of bars along long direction	
At midspan	300mm
At continuous edge	260mm

Slab 7

Thickness	120mm
Main bar diameter	12mm
Spacing of main bars	210mm
Temperature bar diameter	10mm
Spacing of temperature bars	450mm

3.4.3 Design of Reinforced Concrete Beams

Beams were designed considering the earthquake loads that would probably act on the RBIPV. The concept of the Ultimate Strength Design was adopted in order to determine the dimension to be used and amount of reinforcement to resist the flexure and shear that will subjected to the beams. The design of the beams depends to the composite action of concrete and steel.

Table.7. Structural Analysis Specifications for Reinforced Concrete Beams

C.1 Roof Beams

Location	Size(mm)	pcs	Diameter of bars(mm)
External	250x125	4	16
Internal			
Longitudinal	250x150	4	16
Transversal	175x100	4	16

C.2 2nd floor beams

Location	Size(mm)	pcs	Diameter mm
External	375x200	4	16
Internal			
Longitudinal	250x150	4	16
Transversal	425x225	4	16

C.3 Tie beams

Location	Size(mm)	Pcs	Diameter (mm)
Transversal	450x225	8	16
Longitudinal	400x200	6	16

3.4.4 Design of Columns

In designing columns, grasp analysis provides the axial load and bending moment that will be used to determine the required dimension of columns and number of reinforcement bars to resist the forces using USD approach. The result of the design in column was adjusted due to the dimension of the beam.

Table.8. Structural Analysis Specifications for Column Designs

External Columns (C-1)

Dimension	225mm x 225mm
Main bar diameter	16mm
Spacing	60mm
No. of pcs of bars	4pcs
Lateral tie diameter	10mm
Spacing of lateral ties	225mm

Internal Columns (C-2)

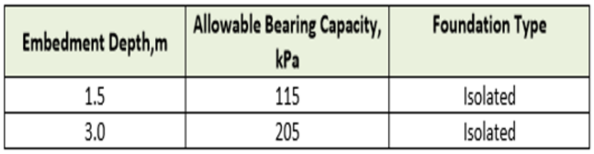
Dimension	225mm x 225mm
Main bar diameter	16mm
Spacing	60mm
No. of pcs of bars	4pcs
Lateral tie diameter	10mm
Spacing of lateral ties	225mm

The researchers solve two columns, considering external and internal columns. Since the properties of two columns were the same, therefore the designated names used of all columns are C-1.

3.5 Design of Footing

The design of footing was reinforced concrete as the most suited material for footing of residential building or any other type of building. In designing of footing, the researchers need the data like soil bearing capacity, height of concrete, height of soil and of course the service loadings that would act in the footing. The soil bearing capacity was provided by DPWH (Department of Public Works and Highways) because the researchers cannot afford to have a soil testing in the exact location. Therefore, soil bearing capacity was based on the geotechnical report of the nearest project in Babo Pangulo.

Table.9. Structural Analysis Specifications for Footing Design



Embedment Depth,m	Allowable Bearing Capacity, kPa	Foundation Type
1.5	115	Isolated
3.0	205	Isolated

Factored Pressure	327.507 KN
Dimension	1.5 x 1.5 m
Effective depth	170 mm
Total depth	269 mm
Moment	44.50 KN-m
Rn	0.88
Area of steel	1475.37 mm^2
Number of bars required	8-Ø 16 mm
Required L_d	582.36 mm
L_d provided	1425mm
Permissible bearing stress	1157.97KN
A_{min}	253.125 mm^2
Column bar required	2-Ø 16 mm

The following result above shows that the dimension of footing is 1.5 x 1.5 m with an effective depth to top bars of 170 mm with 7 pcs-Ø 16 mm bars on each side of the footing and at least two column bars (2-Ø 16 mm) must be extended into the footing.

3.6 Return of Investment

The RBIPV is the only building material that has a return of investment (ROI) and profitable. This system offers a total command in monthly electricity expenses that really opens many opportunities for building designers and owners, from the benefits in terms of electricity bill up to the positive image of RBIPV being recognized as "green" and 'innovative".

Table.10. Cost Analysis

Price of PV system per modules	P 8000.00
Estimates of the whole RBIPV system	P 500,000.00
Cost of PV installation	P 15,000.00
Electrical bill per month of the design RBIPV	P 2000.00 – P 3000.00
Electrical bill after 25 years	P 600,000.00 – P 900,000.00 (Average of P 750,000.00)
Interest of return after 25 years	P 250,000.00
Total interest	P 227,000.00
Interest rate per year	1.82%
Interest rate within 25 years	45.4%

This ROI only shows the estimate expenses of integrated photovoltaic. The researchers disregard the expected additional expenses if the PV modules were installed in old manner. Therefore, the RBIPV as building materials is really helpful and profitable as well.

IV. CONCLUSION

The development of any project without any background like RBIPV is a study that needs time and effort. Within the time frame and progress, various steps and principles have been taken for its completion. A huge portion of the time was invested in gathering data and information regarding to the related study of RBIPV and as well as the understanding of the mechanics and methods of calculation. All the methods taken in this research have strengthened the initial view and objectives as a formulation of ideas and tools that can be used for similar research in the future.

In terms of power generation, RBIPV is an ideal development to achieve the desired zero energy goal. The researchers computed the proper design of the RBIPV design system to determine the allowable energy loads that can be covered by it. The questioners and interviews enable to identify the most used appliances and the average amount of electrical bill monthly of residential building within Babo Pangulo. The structural and architectural plans also serve as a design pattern to avoid the possibility of integrating PV modules in an inappropriate manner, leading to a large investment that will have low returns. The integration of the solar panels as a roofing meets the minimum requirements for safety of the building design as an alternative to the traditional design of roofing with an additional advantage of minimizing energy costing due to the presence of the solar panels as roofing.

Therefore, this study presents the new opportunities for the residential building as a model of sustainable techniques in terms of environment and economy.

Recommendations:

The researchers would recommend to use of different applications or software to acquire the optimized dimension of the designs and to avoid the extra complicated way of solutions that will waste of extra efforts and time.

Also, since this study cannot provide the construction of the building, the researchers recommend to make even a real scale model of the study to gather more information and proofs that this study is feasible. Another is to explore the possibility of a net-metering configuration of the RBIPV to give electricity to the grid or to the electric utility

The following will also recommend to do to said that this project is totally completed:

- Masonry works
- Test of soil bearing capacity
- Provide the electrical and plumbing plan
- Detailed estimates

Additional team member with a specialization of the Architectural field is greatly recommended to improve the structure and design of the system. These architects can be useful for future projects like the Clark Green City in Clark Pampanga. Another recommendation is for the implementation of the study for mass production of houses specially designed for the calamity victims.

Lastly, further research and study is recommended to aid better understanding about the crucial information required for this kind of study in the future.

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