Prospects of BIPV in a Typical Residential Building in Dhaka City

By

Nur Jahan Beanta Sorower
16121163
Abu Niem Seum
16321008
Rawnak Reza Raka
16321058
Md. Shifain Mahathir Alvi
16321158

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BRAC University
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Declaration

It is hereby declared that

1. The thesis submitted is my/our own original work while completing degree at Brac University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. We have acknowledged all main sources of help.

Student's Full Name & Signature:

Nur Jahan Beanta Sorower 16121163	**Abu Niem Seum** 16321008
Rawnak Reza Raka 16321058	**Md. Shifain Mahathir Alvi** 16321158

Approval

The thesis/project titled "Analysis of energy consumption and overall effect by simulating BIPV system in a residential building in Dhaka, Bangladesh" submitted by

1. Nur Jahan Beanta Sorower (16121163)
2. Abu Niem Seum (16321008)
3. Rawnak Reza Raka (16321058)
4. Md. Shifain Mahathir Alvi (16321158) of Summer, 2021 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelors of Engineering in Electrical and Electronic Engineering on 3rd October, 2021

Examining Committee:

Supervisor: _______________________________
(Member)
Dr. Md. Mosaddequr Rahman
Professor, Department of Electrical and Electronic Engineering
BRAC University

Program Coordinator: _______________________________
(Member)
Dr. Abu S.M. Mohsin
Assistant Professor, Department of Electrical and Electronic Engineering
BRAC University

Departmental Head: _______________________________
(Chair)
Dr. Md. Mosaddequr Rahman
Professor, Department of Electrical and Electronic Engineering
BRAC University

Abstract

Building Integrated Photovoltaic System (BIPV) is the incorporation of Photovoltaic (PV) into the structure envelope in the top, the exteriors or potentially might be utilized for the structure. In this work on BIPV system simulated in a residential building, authors look forward to comparing energy consumption and exploring a considerable amount of possible and potential factors that would conclude with a significant contribution. It is seen that, the world is consistently fighting against climate change and the increasing demand as well as the rising prices of fossil energy products globally draws our attention to the Renewable Energy Sources (RES) of the earth. The earth provides us with so many RES, among them solar is the most effective , accessible and relatively cheaper- more sustainable than the existing others. Lately, BIPV (Building Integrated Photovoltaic System) is arising as an expected area for buyers just as altruists. According to the viewpoint of Bangladesh, BIPV is moderately inexistent and the people entitled under this work decide to evaluate the energy consumption of a specific aspect as well as the energy evaluation of the solar in terms of the electrical energy. After doing energy assessment, it has been looked for whether the simulated BIPV energy is adequate for the load demand or whether it is sufficient enough to be given to the national grid. Finally, some financial and environmental aspect has been assessed for non-technical advantage and scopes of the BIPV system. The result shows that, for seven months, the system can not only meet up the load, it can be grid independent and it can provide power to the grid. On the other hand, for the rest five months, the building needs to be dependent on grid.

KEYWORDS: BIPV, Solar Irradiance, Incident Energy, Grid Dependency, Carbon Emission, Payback.

Dedication

We would like to dedicate our thesis to our parents and instructors for their unwavering support and encouragement to achieve perfection, as well as for pouring love and support on us at every stage of our life, without which we would not have made it this far.

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List of Acronyms

BIPV	Building Integrated Photovoltaic System
RES	Renewable Energy Source
EPBT	Energy Payback Time
NPV	Net Present Value
IRR	Internal Rate of Return

Chapter 1

INTRODUCTION

In the year 2021, the population and economic growth of a country have increased owing to a repaid industrialization increase demand for electricity to improve quality of life in emerging economics [1]. Economic growth and providing affordable clean energy remain as the extensive priority of the Governments in the last decades [2]. In Bangladesh economics has begun to make strategic changes in their energy policies after 2008 [3]. The main objective of these economic energy policies was to provide affordable accessible, clean, and green electricity for the next decades. Under that plan, growth in the region has been adept by high energy consumption and thus, its acute high pollution. A large scale of energy policies in South-East Asian countries specify a greater balance between sustainable and security concerns and focus on to utilization of energy by the side of sufficient supply of energy [4]. In the context with current scenario prices of energy, supply and demand conditions, security of energy, unsettled climate, and all the developing countries are paying their attention on the energy sector and to Carbon emissions. One of the most important strategic responses is setting more prominence energy conservation and efficiency and source of sustainable energy although decreasing Carbon emission.

1.1 Background

BIPV is a PV system that is integrated with a building permanently in roof, skylights, windows, or facades [5] and reduces the heat transmission in the building through it. There is much more research done with solar PV cells and BIPV based on their performance and optimum tilt angle for maximum power generation and monthly or yearly demand would be met the maximum. An Egyptian group [6] of student research on the different types of BIPV and the photovoltaic technologies and architecture form of a building to implementation of BIPV. A research paper was published based on the performance of building-integrated photovoltaic applications concerning tilt angle and azimuth. It is recommended to perform this work to optimize the inclination and azimuth to achieve maximum energy efficiency. The analysis [7] shows that as the tilt angle is reduced from 50° to 10°, the performance of the proposed array is improved by 26.154%. When the azimuth angle is reduced from 160° to 20°, the power increases by 8.93%.

NREL has provided the data [8] for the optimum default tilt angle of 23.81° which is equal to the latitude of Bangladesh by observing eight different locations of Bangladesh are Bogura, Chittagong, Cox's Bazar, Dhaka, Ishwardi, Jessore, Rangpur, and Sylhet. A group of students study [9] on the tilt angle optimization by using two methods one default tilt angle used for the whole year which varies (20.20° to 23.30°) for different divisions of Bangladesh the other method was the two tilt angle for two halves of a year system for April to September tilt angle varies (7.20° – 10.70°) for different division and for October to March its varies (36.40° - 39.80°). Another team of BUET [10] works on an average tilt angle optimization of a PV panel for meeting the maximum demand over the year. Their findings are at 23° tilt angle they get the maximum power generation of 63,158 KWh yearly and the second maximum power generation gets at 12° tilt angle of 61,705 KWh over the year. They found 12° tilt angle met the maximum demand for a remote area. Another study [11] was taking place by the students of the University of Palermo, Italy about the comparison of the use of PV systems in the vertical walls. They used three different methods are a Dye-Sensitized Solar Cell (DSSC), grey and blue caved silicon panels these systems can be placed behind the window or glass walls. The efficiency of DSSC and silicon panel is accordingly 5% and 15% in the vertical orientation it's 2.5% and 7.5%, experimentally they got for DSSC 0.31% and both grey and blue caved silicon panel got 1.31% efficiency. BIPV cells are classified as silicon and non-silicon based. Silicon-based are most commonly used in markers and it consists of 3 types; Monocrystalline, Polycrystalline, and Amorphous. Before that, the non-silicon-based is either Cadmium Telluride or Copper Indium Gallium Selenide. BIPV system can reduce the cooling load and electric consumption of a building by 35-50% [12]. In addition, to be clean, available, safe, and renewable from solar energy one of the main advantage of the BIPV technique is reducing the primary cost of the construction due to the integration of the PV material. Different parameters should be taken into consideration for the proper function and a primary factor is the temperature of the PV cells [13]. The operating temperature of the PV cells' performance and the result depends on the weather, when exceeding the temperature its performance will exceed. Hence, different models have been studied to predict the temperature at the panels and a precision of 50% [14].

1.2 Motivation

In the modern world, the number of the high-rise building has been seen to increase day by day, and the number of buildings the demand for electrical energy also increasing exponentially. Statics says that building is one of the main sources of consumption of global energy around the world; buildings consume around 40% of global energy [15]. Buildings are also responsible for a large amount of CO2 emission which composing a threat to the ecology and contributes to global warming. Various policy directions have been encouraged to minimize worldwide environmental pollution from the Kyoto Protocol of 1997 to the Paris Agreement of 2015 [16]. Building Integrated Photovoltaic (BIPV) is the new option for the future design of buildings to generate clean energy along with without creating any damage to the ecology. Building Integrated Photovoltaic (BIPV) is a multipurpose design that is used to the façade of the buildings. The main purpose of using BIPV is to generate energy at the same time installing BIPV on the façade can have different advantages like solar and glare protection. In addition, solar energy is abundant and free of cost and the system of BIPV maximizes the collection rate of energy. Integration of BIPV enlarge of scope to the utilization of the exterior of the building in different ways and the use of transparent PV panel can be applied as the safety glass as well as eco-friendly heat protection system for the building. BIPV can minimize the area required for future fossil-fuel-based power generating plants by lowering electric bill expenditures. Installing BIPV on Curtain Walls or Windows may act as a heat insulator and sunshade in addition to capturing additional energy. In the context of Bangladesh, we merely see people's participation towards energy sustainability and as far as photovoltaic generation is concerned, we observe the placement of photovoltaic modules on rooftops only to satisfy the building regulatory code. The increasing price of fossil fuel can be refuted by the economic growth, but the supply of fossil fuel to generate energy is not infinite and hence renewable energy comes into being. To conclude, this work is expected to indicate the greater community that at which dimensions and level the inauguration of consumers and building owners can contribute to mitigating the crisis mentioned above.

1.3 Objective

The objective of this study is to the analysis of the prospect of a BIPV system in an old typical residential building of Dhaka city. In this study, a BIPV system will have been designed considering the load demand of the building. Besides, different factors such as Sun position, seasonal effect, sheading, tilt angle, building position etcetera will be considered in this design. Finally, the environmental impact and payback analysis will be examined to assess the system.

1.4 Scope of the Study

This study requires knowledge of Building Integrated Photovoltaic (BIPV) systems. The scopes of this study include the irradiation model of the different types of photovoltaic (PV) systems. Similarly, energy accumulation by the BIPV system will be assisted. The impact of cloud and environment are also taken to account. However, a payback analysis will be a help to assess the financial anticipation of the studied BIPV scheme.

1.5 Thesis Organization:

This study is divided into five chapters, each of which examines the potential of BIPV (Building Integrated Photovoltaic) in a typical residential building in Dhaka. To begin, the first chapter of this book covers BIPVs and their performance, as well as the best tilt angle for maximum power generation. In addition, chapter 1 explains the study's aim and goal, stating that (BIPV) is a new choice for future building design that generates clean energy while causing no harm to the environment. Second, the "Theoretical Background" section of Chapter 2 supports the accessible PV system and working principle, as well as the essential parameters, equations, and energy calculations. In addition, Chapter 3 focuses on the structure and technique of system design. Chapter 4 also displays the outcome and discussion based on many economic and environmental components of the entire system over the months. Finally, in Chapter 5, the conclusion is presented.

Chapter 2

THEORETICAL BACKGROUND

2.1 Basic Information about BIPV

A building-integrated photovoltaic (BIPV) framework is made up of solar modules that are integrated into a structure's envelope, such as rooftops, walls, and other surfaces. BIPV is regarded as an important structural component of the power-generating modules, which are both a practical unit of the completed construction process and a development component of the structure skin, since they replace traditional materials. PV is characterized by this methodology as a structurally appropriate component, as a functioning energy-generating unit that also adds visual value to the overall construction.

Other than collecting energy, all around coordinated PV-modules are reasonable to add to the solace of the building: they fill in as climate assurance, heat protection, concealing tweak, commotion assurance, warm confinement furthermore, electromagnetic protecting, and so forth Since entire parts of the structure shell are supplanted by picking this way, investment funds are made as far as the expenses of building materials: so PV modules are presently ready to supplant the brickwork covering for a whole rooftop and simultaneously convey power, which is likewise the situation for the components utilized in the structure façade. After an underlying expense of preparation and finance costs, the multi-functionality of PV modules connected to BIPV hence favorably affects the general expenses of a structure project and on the amortization of the PV framework itself [17].

2.2 Discussion about Panels Properties

2.2.1 Available BIPV Material

PV technologies can be integrated within the building structure or façade it called BIPV. BIPV materials are used as grouped based on their efficiency, cost, usage, and material because some of them are very costly but less efficient and some others are used for the architectural purpose, at the same time power generation. The primary materials used in BIPV will be analyzed in-depth, as well as their functioning, to compare all of the materials used in BIPV. This comparison cloud gives you a good idea of how feasible it is to construct BIPV for properties.

Crystalline Silicon PV, Sandwich cells (SPV), transparent solar cells, dye-sanitized cells (DSC), Copper Indium Gallium Selenite firms (CIGS), inverted pyramid cells, and thin-film PV are some of the materials often utilized in BIPV.

2.2.2 Why to use Solar Energy

Fossil fuels are cost-effective and convenient at least for the time being. Because the global supply of fossil fuels is limited so they will be demolished one day because of that experts do not consider them as renewable energy. On the other hand, solar energy is fully renewable energy because the supply of solar is unlimited. Meaning, as long as the sun exists, we will not run out of sunlight as sunlight is the source of solar energy to generate the power. However, the amount of sunlight is depending on the location, time of day, season, and weather conditions that varies the sun power we received.

The initial expenditures of solar are very costly for the customer but in the longterm, it's going to money saver. The cost of electricity generated from fossil fuels ranges from 5 cents to 17 cents per kilowatt-hour. According to the National Renewable Energy Laboratory, the cost of solar energy averages between 3 cents to 6 cents per kilowatt-hour and trading down.

2.2.3 Potential of Solar Energy in Bangladesh

Bangladesh has a total area of 1.49E+11 m2 and is located between 200 30' and 260 45' north latitude. The terrain receives an average of 5 KWh/m2 solar radiation falls over 300 days each year. The most quantity of radiation is available in March-April, while the least amount is available in December-January. According to 2012 research, shows that daily sunshine hours in Bangladesh range from 7 to 10 hours, with an additional 54 percent reduction (to 4.6 hours) to account for rainfall, cloud, and fog [18]. As a result, solar energy has a large potential for application in a variety of sectors in Bangladesh as decreasing conventional fossil fuel-based power consumption while also maintaining a green environment for future generations.

2.2.4 PV System

PV system is converting solar energy through the photovoltaic effect which may deliver electric energy to a given demand. The system's procedure is relatively flexible. The construction of PV modules is arranged into arrays to improve electric energy output. In most cases, extra equipment is required to convert energy into a usable form or to store energy for future use. As a result, the energy demands (or loads) in a given application will decide the final system. PV system classified into two major group

- **Stand-Alone:** These systems are not connected to the electrical grid. The most common system setup is seen in Figure 2.1. The system portrayed in Figure 2.1 is one of the most complicated since it contains all of the components required to operate an AC appliance in a typical residential or commercial scenario. An alternative generator (biodiesel or wind, for example) might be considered to improve dependability, although it is not required. The number of components in the system will be determined by the sort of load provided. If only DC loads are to be powered by the PV modules, the inverter might be replaced with a DC-to-DC converter. When using other energy sources, it is also feasible to connect a PV array to a DC load directly. When other storage mechanisms are employed or operation schedules are not necessary, it is also possible to connect a PV array directly to a DC load.

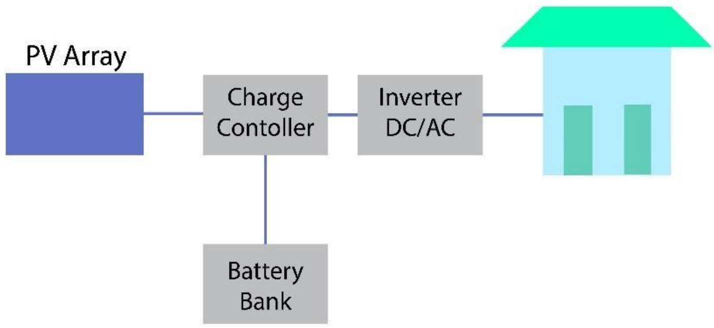

Figure 2. 1 Stand-Alone Photovoltaic System

- **Grid Tied:** These systems do not require battery storage since they are directly connected to the electric distribution network. The basic system setup is shown in Figure 2.2. Depending on local energy load patterns and solar resource variation throughout the day, electric energy is either sold or bought from the local electric utility; this operating mode requires the use of an inverter to convert DC to AC currents. There are several advantages to having grid-connected PV systems rather than typical stand-alone systems. These advantages are [19] [20] [21]. Smaller PV arrays can supply the same load reliably.
- Smaller PV arrays can supply the same load reliably.
- Less balance of system components is needed.

- Comparable emission reduction potential taking advantage of existing infrastructure.
- Eliminates the need for energy storage and the costs associated to substituting and recycling batteries for individual clients. Storage can be included if desired to enhance reliability for the client.
- Takes advantage of the existing electrical infrastructure.
- Efficient use of available energy. Contributes to the required electrical grid generation while the client's demand is below PV output.

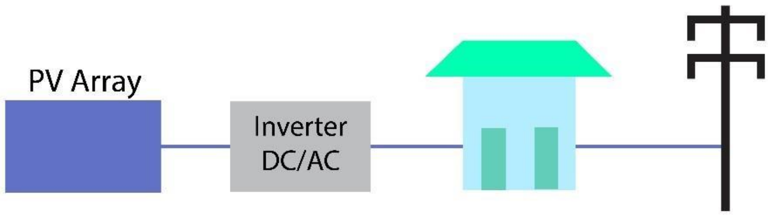

Figure 2. 2 Grid-Tied Photovoltaic System

A hybrid system, in which battery storage or a generator (or both) are coupled with a grid connection for increased dependability and scheduling flexibility, may be available (at additional cost). Because prefabricated flat plate solar modules are generally accessible, they are used in the majority of installed residential, commercial, and largescale systems. As a result, the majority of publications on PV system costs are focused on this technology.

2.2.5 Solar Cell, Panel and Array

Solar cells are the components of a solar panel. When light strikes a cell, electrons are separated from the silicon atoms of the cell. The flow of electrons across the cell creates direct current (DC) electricity. After that, the DC electricity is transferred to an inverter, which transforms it into alternating current (AC) electricity. AC electricity is the type of electricity that is used in homes, workplaces, and other buildings. Different types of solar panels classified according to the generation of solar panel:

1. First generation of solar panel
    a. Monocrystalline Solar Panel (Mono-SI)
    b. Polycrystalline Solar Panel (Poly-SI)
2. Second generation of solar panels
    a. Amorphous Silicon Solar Cell (A-Si)
    b. Thin-Film Solar Cell (TFSC)
3. Third generation of solar panels
    a. Biohybrid Solar Cell
    b. Concentrated PV Cell (CVP and HCVP)
    c. Cadmium Telluride Solar Cell (CdTe)

The solar array is the most essential part of a photovoltaic system since it affects the system's efficiency and overall cost. Semiconductor materials, such as silicon, are commonly used in photovoltaic cells. A single PV cell can only provide around 2 watts of electricity, which is insufficient even for a small calculator or watch [19] [20] [21]. As a result, a group of PV cells is linked together, and this group of PV cells is called a module. Figure 2.3 illustrates the configuration of a PV cell, a PV module, and a PV array in diagrammatic form.

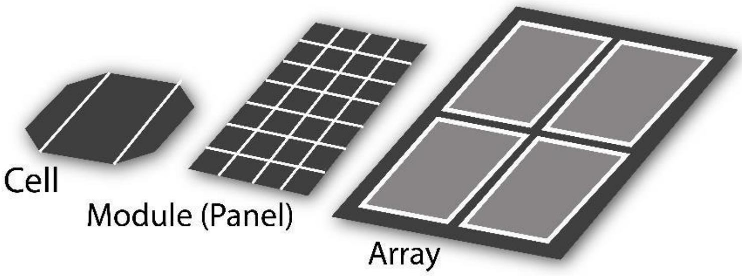

Figure 2. 3 Solar cell, panel and array figuration

Solar arrays come in a variety of shapes and sizes. The two most common forms are crystalline silicon and thin films. Mono-crystalline silicon (M-Si) and poly-crystalline silicon (P-Si) are two types of crystalline silicon (P-Si). Another kind, such as gallium arsenide (GaAs) PV modules, can be produced from non-crystalline or amorphous silicon or other materials.

The high cost of PV arrays is the major barrier to solar PV's widespread use as a renewable energy source. The high price is primarily attributable to the high cost of solar cell manufacture. Users' increasing demand for PV arrays may help in making PV prices more competitive and affordable. Due to research and development in improved material and production processes, the cost of PV has decreased considerably over the previous two decades and will continue to drop. Since 1990, the price of PV has been gradually decreasing [22].

2.2.6 Solar Cell Working Principle

We need to consider both the idea of the material and the idea of daylight to comprehend the activity of a PV cell. Solar cells comprise two kinds of material, first frequently p-type silicon, and n-type silicon. Frequencies of a specific light can ionize the molecules in the silicon and the inward field created by the intersection isolates a portion of the positive charges (openings) from the negative charges (electrons) inside the photovoltaic device. The holes are cleared into the positive layer and the electrons are cleared into the negative layer. Albeit these contrary charges are drawn to one another, due to the interior potential energy boundary the vast majority of them can just rejoin by going through an outer circuit outside the material. In this manner if a circuit is made, the force can be delivered from the cells with lighting, so the free electrons need to go through the heap to rejoin with the positive openings. The force acquired from a PV cells is managed by:

- First, the sort and space of the material,
- Second, the frequency of the daylight,
- Third the force of the daylight.

A single piece of a cell cannot change over 25% of the sun's energy into power, due to the radiation in the infrared locale of the electromagnetic range needing more energy to isolate the positive and negative charges in the material.

On account of the greater inner energy misfortunes than single crystal silicon, polycrystalline silicon solar cells have proficiency of under 20% and indistinct silicon cells are by and by about 10% effective. A regular single crystalline silicon PV cell of 100 can create about 1.5 watts of force at 0.5 volts DC and 3 amps under full daylight ($1000 Wm{-2}$). The force yield of the cell is straightforwardly relative to the power of daylight. It implies for instance if the force of the daylight is divided the force will likewise be split.

One more significant component of PV cells is that the voltage of the cell doesn't rely upon its size, and remains genuinely consistent with changing light power. Be that as it may, the current in a cell is straightforwardly dependent on solar power and size. At the point when we appear to be unique estimated cells, we need to record the current thickness or amps per square centimeter of the cell region.

To build the force yield of a solar cell, it should keep the PV cell straightforwardly pointing toward the sun, or by concentrating the daylight utilizing focal points or mirrors. Nonetheless, there are cutoff points to this cycle, because of the intricacy of the components, and the need to cool the cells. Temperature influences the voltage. The current yield is moderately steady at higher temperatures, yet the voltage is diminished, prompting a drop in power as the cell temperature is expanded [26].

2.3 Necessary Parameters

2.3.1 Solar Radiation

Solar radiation is radiant energy emitted by the sun as a result of an atomic reaction that produces electromagnetic energy. Solar-oriented radiation has a wavelength range similar to that of a dark substance with a temperature of roughly 5800 K. A significant fraction of the radiation falls within the visible short-wave section of the electromagnetic spectrum. The remaining half is mostly in the near-infrared region, with a few exceptions at the bright end. Watts per square meter are the measurement units. The device is often used in agricultural applications and is used to calculate evapotranspiration. Evapotranspiration is the capacity of sun-powered energy, wind, and temperature to evaporate moisture from the soil (or the inverse of precipitation).

The sun's radiation and its spatial relationship to the planet provide an essentially constant power of sun-oriented radiation outside of the world's climate, which is commonly referred to as extraterrestrial radiation. Because of the estimation procedures or suppositions for essential assessments, the features for this sun-powered consistent found in distinct writings may vary slightly. The World Radiation Center has adopted a value of 1367 W/m^2; the sunlight-based force arrives at the 1m^2 region of the earth when the sun is opposite to space and with a vulnerability in the request for 1%. In comparison to petroleum-based products, the energy thickness of solar radiation is often low. Despite this, the total amount of incident radiation is many times greater than the global energy interest. Regardless of whether only the land-shrouded portion of the world's surface is considered, the sun could potentially provide many sources of energy.

2.3.2 Solar Irradiance

Irradiance is a short-term estimate of solar control over a certain area. Irradiance is measured in watts per square meter. Irradiance is transmitted and isolated into diverse pieces for plausible reasons behind estimation and understanding. As a result, solar irradiance can be defined as solar radiation.

Measurements of irradiance can also be arranged by the amount of daylight being observed. For example, some estimations may just measure direct irradiance, whereas others may measure both immediate and diffuse irradiance.

2.3.3 Insolation

The usual unit of insolation is kilowatt-hours per square meter. Insolation is an estimate of the combined energy estimated over some space for a described timeframe (e.g., yearly, month to month, every day, and so on). The period must be clearly defined for these units to be interpreted successfully (e.g., KW-hr per square meter yearly insolation).

2.3.4 The Extraterrestrial Radiation

The strength of the sun at the greatest point of the Earth's environment is known as extraterrestrial radiation. It is usually expressed in irradiance units (Watts per square meter) on a sun-like plane. It varies over time due to the Earth's bent circle, which causes the Earth-Sun distance to fluctuate predictably over the year.

The extraterrestrial sun-oriented range at a mean earth-sun distance can be partitioned into the following three fundamental districts, generally separated into wave groups (1 micron = 1m = 10-6, mm = 10-6 meter) [40].

- Ultraviolet region (l < 0.38 mm). Level of sun based radiation 7%.
- Visible region (0.38 < l < 0.78 mm) Percentage radiation 47.3%.
- Infrared region (l > 0.78mm) rate proportion 45.7% [40].

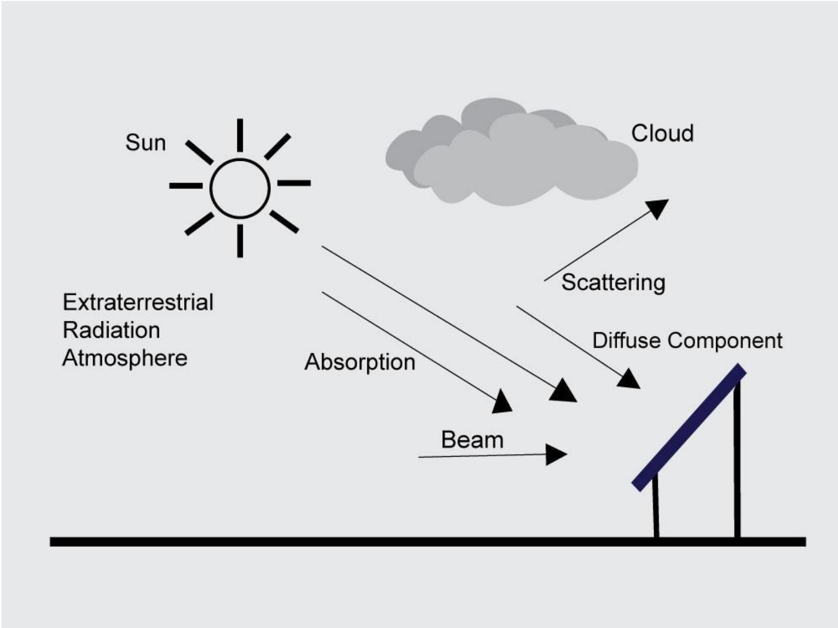

Figure 2. 4 Extraterrestrial Radiation

The extraterrestrial sun-oriented range at a mean earth-sun distance can be partitioned into the following three fundamental districts, generally separated into wave groups (1 micron = 1m = 10-6, mm = 10-6 meter) [40]. Overall, the extraterrestrial solar frequency can be defined as the amount of solar energy per unit time measured on a unit space of a solar surface at the earth's mean distance from the sun. Other than the percentage of the total radiation that is lost during the journey via the air, sunbeams that scope to the earth's surface is normally the brilliance. Thus, the total of the sun-oriented brilliance restricted by the climate and the accessible irradiance on a superficial level is the absolute irradiance discharging from the sun or extraterrestrial radiation [28].

Gon is the extraterrestrial radiation occurrence on the plane on the nth day of the year. The solar constant Gsc= 1367 W/m^2 [28].

$$Gon = Gsc \times 1 + 0.033cos\frac{360n}{365} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

2.3.5 Incident Solar Radiation

Incident solar radiation (G_s) is the brilliant sun based energy that hits the world's surface and is alluded as "worldwide radiation" on a surface (W m−2). Complete or worldwide sun oriented radiation comprises of:

Beam (or direct) Radiation (G_b) is the piece of absolute radiation that arrives at earth's surface straightforwardly without being dispersed by the climate (Wm^{-2})

Diffuse Radiation (G_d) is the piece of complete radiation that arrives at earth's surface after a shift of its bearings because of dissipating by the climate (Wm^{-2}).

Incident solar radiation to typical alludes to sun based radiation falling opposite on a surface, i.e., having a point of 90° to the surface.

Global irradiance (G) is the total solar flux density (Wm^{-2}).

Intensity of solar radiation is the exchange pace of the bars energy across the unit space of a body (Wm^{-2}).

Irradiance (E, H) is known as the rate by which the brilliant sun based energy hits the unit space of a surface. Irradiance might be beam (G_b), diffuse (G_d), or incident solar radiation (G_s). In G_o, addendum 'O' alludes to radiation over the world's climate, i.e., extraterrestrial irradiance. By incorporating irradiance throughout a fixed time, typically an hour or a day infer the occurrence sun oriented energy per unit space of surface which is classified "light or explicitly insolation."

Air mass: (m): The proportion of the mass of air through which bar radiation passes to the mass it would go through if the sun were at the pinnacle.

Latitude (L): The precise area north or south of the equator, north certain.

Slope (β): The point between the plane of the surface being referred to and the flat.

Surface azimuth angle (γ): the deviation of the projection on a flat plane of the typical to the surface from the nearby meridian, with zero due south, east negative, and west sure.

Point of incidence (θ): The point between the shaft radiation on a surface and the typical to that surface.

Zenith angle (θz): The point between the vertical and the line to the sun, that is, the point of frequency of bar radiation on a level surface.

Solar altitude angle (α_s): The point between the level and the line to the sun that is, the supplement of the apex point.

Solar azimuth angle (γs): the rakish relocation from south of the projection of bar.

Declination angle (δ): The precise situation of the sun at sun oriented early afternoon. The rakish situation of the sun at sun oriented early afternoon, $\boldsymbol{\delta}$ can be determined by the inferred condition given bellow [28].

$$\delta=23.45°\sin\left[\frac{n+284}{365}\times 365°\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

This specific declination point is determined on the nth day of the year.

Hour point (H): The precise dislodging of the sun east or west of the nearby meridian because of pivot of the earth on its hub at 15◦ each hour; morning negative, afternoon positive.

According to the viewpoint of northern half of the globe, hour point is negative from the dawn time Sr, Hs is the dawn point and t are the hour of a day in 24-hour design clock.

$$H = -H_s + 2\frac{H_s}{T}(t-S_r) \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$H_s = cos^{-1}(-tan\delta.\,tan\gamma) \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Altitude: The altitude point is the place directly beneath the sun where the sun meets the skyline of the region. The sun-based height angle (α_s) is combined with latitude (L), declination angle (δ), and hour point in the equation (H).

$$\text{Cos}(\theta_z) = \text{Sin}(\alpha_s) = \text{Cos}(L)\,\text{Cos}(\delta)\,\text{Cos}(L)\,\text{Cos}(H) + \text{Sin}(L)\,\text{Sin}(\delta) \ldots\ldots\ldots (5)$$

$$\text{Zenith angle } (\theta z):\ \theta z = 90° - \alpha_s \ldots\ldots\ldots\ldots\ldots (6)$$

Azimuth Angle: The azimuth point is the compass bearing that the light is coming from. The sun is always directly south in the northern half of the globe and directly north in the southern half of the earth's surface when the sun is oriented early in the afternoon. The azimuth point fluctuates throughout the day, as seen in the liveliness below. At the equinoxes, the sun rises straight east and sets straight west, regardless of the scope, making the azimuth points 90 degrees at dawn and 270 degrees at sunset.

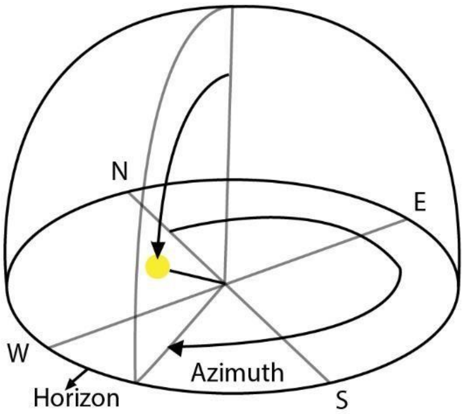

Figure 2. 5 Azimuth and Horizontal Angles

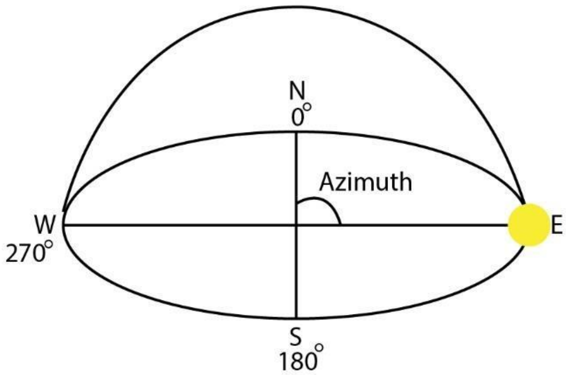

Figure 2. 6 Azimuth 180 Degree Angle

2.3.6 Solar Irradiance Equation & Calculation

The measure of energy that must pass through the environment can be transmitted as beam sun-oriented irradiance, which is not difficult to establish; nevertheless, other climate factors such as residue, cloud, contamination level, and the moistness of the climate alter from one location to another. Several conditions must be met to calculate the value of beam sun-powered irradiance: [28]

$$I_B = A\, e^{-km} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Conditions expressed above, I_B is the ordinary beams coming to the earth surface, A is the evident extraterrestrial flux lost in space.

Total solar beam irradiance I_{BC}, can be calculated from the value of normal ray irradiation I_B.

$$I_{BC} = I_B cos\theta \quad \text{...} \quad (8)$$

Here, the sun based azimuth point (γ) is shown as the result of the declination point (δ) and the Hour point isolated by the surface tilt angle (β).

$$\text{Surface tilt, } \beta = cos^{-1}(cosHcos\beta_a) \text{..........................} \quad (9)$$

$$sin\gamma = \frac{cos\delta cosH}{cos\alpha_s} \text{..} \quad (10)$$

To established the incident angle of the sun we need to calculate altitude angle, surface azimuth, solar azimuth and the angle of the surface tilt associated within this system.

To be exact, incident angle is the typical beam point on the photovoltaic panel face and the solar beam irradiance, [28].

$$cos\theta = cos\alpha_s cos(\gamma - \gamma_s) + sin\alpha_s cos\beta \text{.....................................} \quad (11)$$

2.3.7 Diffuse Irradiance

The diffuse light is calculated based on the assumption that the sky is isotropic, and thus the amount of cloud, dust or a brighter day with a clear sky and factors such as a shady day with downpour is communicated based on factor C when calculating the diffuse illumination of any side of the gatherer [28].

$$I_{DF} = CI_B \frac{1+cos\beta}{2} \text{................................} \quad (12)$$

$$C = 0.095 + 0.04\sin\left[\frac{360}{365}(n - 100)\right] \text{..................................} \quad (13)$$

$$\text{Rear side solar diffusion, } I_{DR} = CI_B \frac{1+cos\beta}{2} \text{................................} (14)$$

2.3.8 Cloud Effect

The isotropic diffuse module specifies that all diffuse illumination is isotropic, implying that diffuse light power is uniform over the sky arch. The productivity of solar energy transformation is influenced by the presence of clouds. Because of cloud quality, a significant portion of the sun's beam may not reach the earth's surface right now. The sun-based insolation that may be consented to the cloud thickness, elevation point of the sun's region based on a particular time-frame can be evaluated as the solar radiation energy accumulated on a surface. The associated numerical condition is given below [28].

$$E_{Sunny=} \int_{T_{SR}}^{T^{SS}} (Isin\alpha + 0.1I)dx \quad (15)$$

$$E_{Cloudy=} \int_{T_{SR}}^{T^{SS}} 0.2I \, dx \quad (16)$$

$$E_{total} = x \times E_{sunny} + y \times E_{Cloudy} \quad (17)$$

x + y = total days for a particular month

Table 2. 1 Month wise cloud day's data

Month	Number of Sunny Days	Number of Cloudy Days	Total Days
Jan	28	3	31
Feb	23	5	28
Mar	25	6	31
Apr	20	10	30
May	18	13	31
Jun	12	18	30
Jul	9	22	31
Aug	11	20	31
Sep	13	17	30
Oct	21	10	31
Now	25	5	30
Dec	26	5	31
Total	231	134	365

2.3.9 Energy Calculation

In this part, we are going to establish some general formulas for the energy calculation of the system. To do so some necessary parameters are needed such as parameters of PV panels & battery, daily solar irradiance, insolation hour, and some other factors which will be described in the next part.

Firstly, for panel calculation here we are generating a general formula from which we will calculate how many panels to be needed for the system as well as the orientation of the panels in a later chapter.

1. Parameters for panel calculation:

- Area of the portion of the subjected building (such as roof-top area)
- Selected panel size
- Panel maximum output voltage (POV)
- System battery voltage

Highest possible number of Panel setup = $\frac{\text{Area of the portion of the subjected building}}{\textit{Selected panel size}}$ …...(18)

Required Panel in series = $\frac{\text{System battery voltage}}{\textit{Panel maximum output voltage}}$ ……………………………..(19)

Hence, number of Parallel panel will be = $\frac{\text{Highest possible number of Panel setup}}{\text{Required Panel in series}}$...……...(20)

Total panel = Required Panel in series $\times$ Number of Parallel panel will be………….(21)

2. Parameters for energy calculation: [41]

- Battery utilization efficiency (BUE) = 90%
- Wiring efficiency (WE) = 98%;
- Temperature correction factor (TCF) = 90%;
- Depth of discharge (DOC) = 80%;
- Inverter efficiency (IE) = 90%;
- PV array degradation factor (PDF) = 90%
- Insolation hour (IH)
- Panel maximum output current (POC)

Panel produces (Current, Ah) = POC $\times$ number of Parallel panel $\times$ IH$\times$ PDF……..……… (22)

Total output energy for one day = Panel produces Current $\times$ POV $\times$ Required Panel in series $\times$ BUE $\times$ WE $\times$ IE……………………..……………… ………………………………....... (23)

Battery storage setup calculation/equations & parameters:

- Percentage of energy which would be stored.
- Total energy of the selected areas.

Battery required: Percentage of energy which would be stored $\times$ Total energy of the selected areas.

Current for battery= $\frac{\text{Battery required}}{System\ battery\ voltage}$………………………(24)

In order to maintain 60V in the charging station,

Required number of battery in series = 60V/12V = 5

One battery can store = 150 Ah $\times$ TCF $\times$ DOC... (25)

So, the required number of batteries in parallel = $\frac{Current\ for\ battery}{one\ battery\ can\ store}$……………………… (26)

Chapter 3

SYSTEM DESIGN AND METHODOLOGY

3.1 Design Methodology

In this design methodology, we are trying to visualize PV integration to a building and try to establish a design according to the usage of load/electricity of the dwellers of the building. In this chapter, we are going to describe the process of the system design. As we have decided to integrate panels into a building so we have chosen a building according to our work. After selecting the building, we have calculated the load assessment of the building and come to an end with the information of load demand of the subjected building. After that, we have selected the places of PV installation and done the area calculation of most sun exposure places. In addition, with the help of some set of equations and simulation, we have found the solar irradiance of the places which have been chosen.

Then with the help of the calculated area, we have selected the number of panels that will be needing and according to the sun exposure the module wattage has also been selected. Furthermore, according to the specifications which have been provided in chapter 2, the final total module energy of the selected area will be determined and evaluated in some other aspects as well.

In addition, this work has been evaluated focusing on the energy evaluation of solar concerning the demanding load which was done with the help of the concept of BIPV. Moreover, it has also been evaluated that the generated energy has been able to maintain the demand of the load of the proposed building and also in the future if possible supply to the grid. The whole process of the work evaluation has been depicted in Figure 3.1 with the help of a Flow Chart.

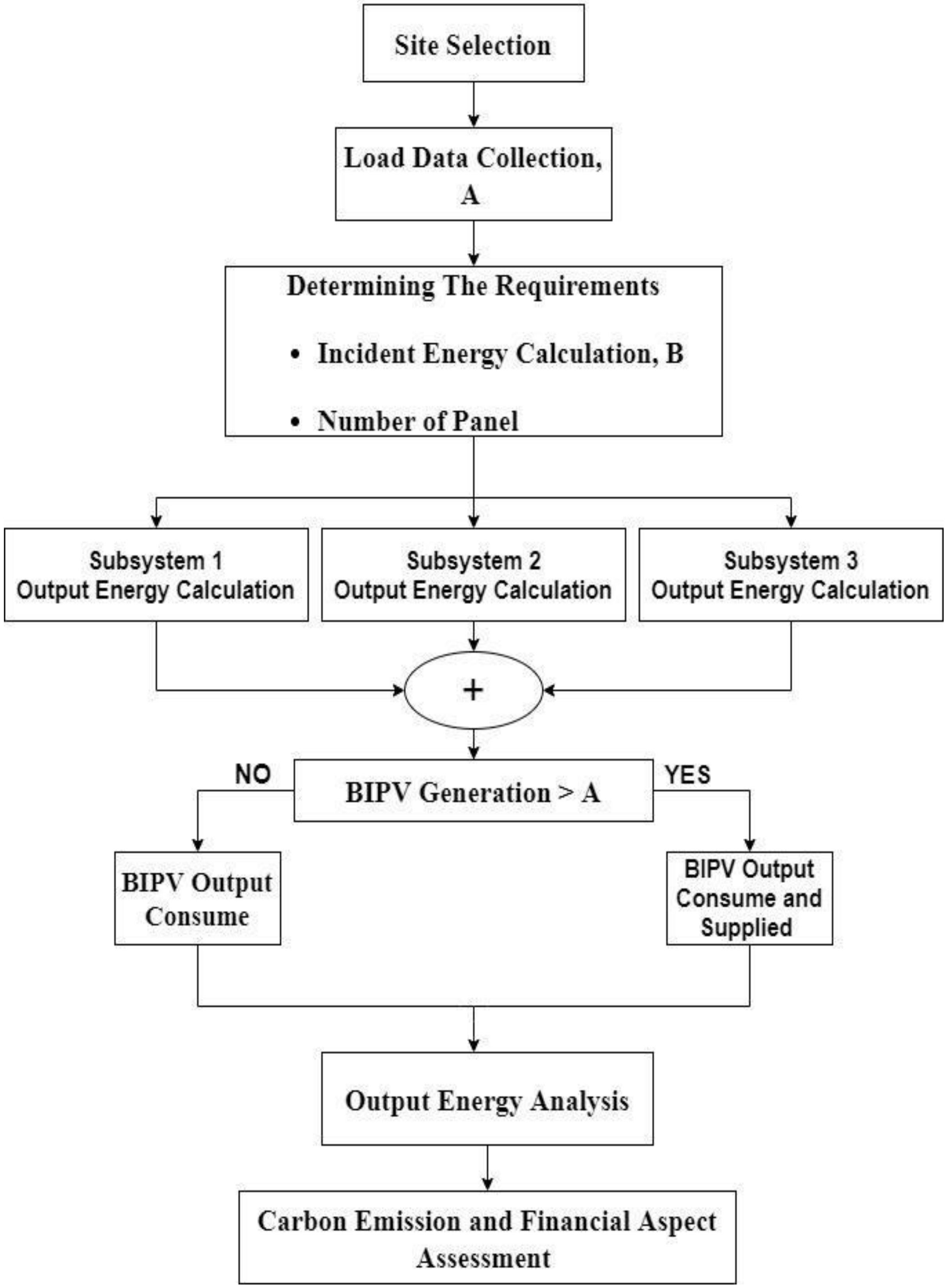

Figure 3. 1 Flow chart of the Methodology of this study

The design process is consisted of five main phases:

- Location & graphical design of building
- Building requirements or load information
- Choosing the places of PV installation
- Number of PV module & module energy calculation
- Brief discussion about Inverter, Battery & Wire Sizing

3.1.1 Location & Building Information

The six storied subject building is located in the capital of Bangladesh, Dhaka, Mirpur. The exact geographical location in latitude and longitude is 23.813381, 90.359351 accordingly, which means the building is 23.813381 degrees north of the equator and 90.359351 degrees east of the prime meridian. The building is exposed on two sides, and the other two sides are covered by other residential buildings.

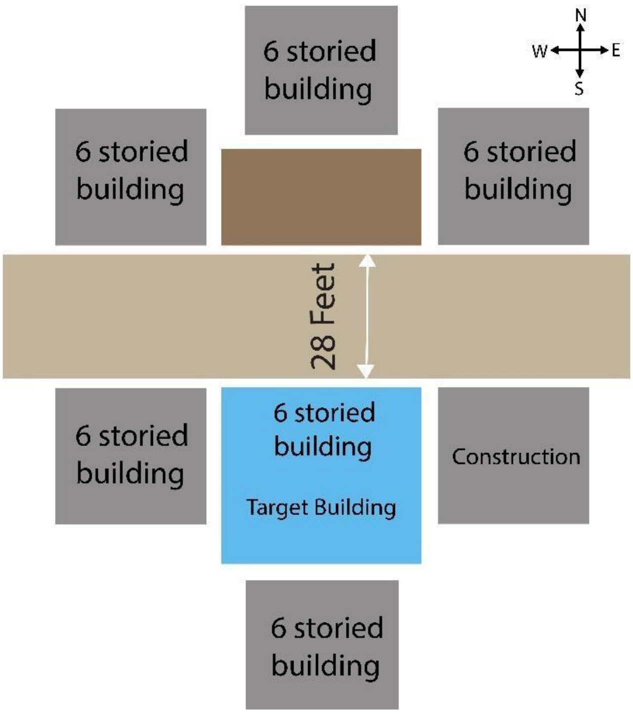

Figure 3. 2 Subject building location in block diagram for understanding position

The area of the building is 100.33m^2 after leaving a sufficient amount of area around according to BNBC (Bangladesh National Building Code) around the structure. The building has five livable floors and the distance from the floor to floor is 3.048 meters and with ten families consisting of four people on average. The ground floor of the building is partially occupied by a payee family and space for car parking.

Figure 3. 3 Subjected building real picture

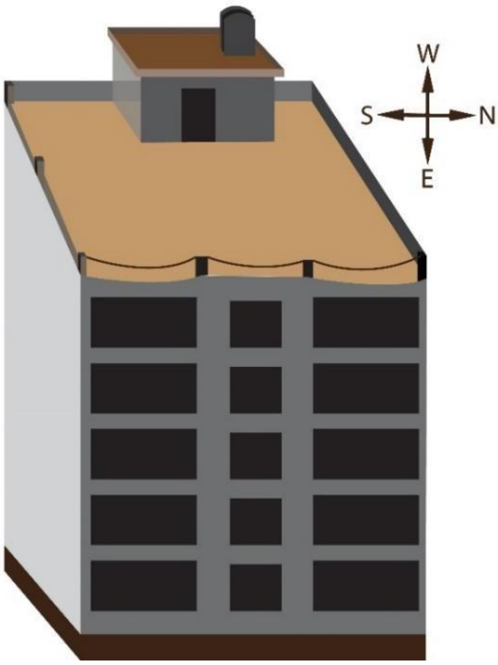

Figure 3. 4 Illustration of subjected building

3.1.2 Load Assessment of the Building

The subject building is entirely a residential building, dwelled by families. Hence the loading electrical equipment is moderately heavy and mostly light weighted. This entire load analysis will be done from three aspects:

- Present Electrical equipment
- Utility tools
- Energy consumption sectioned according to floor and months

The data has been collected by surveying. For some electrical products such as television, microwave oven, and refrigerator average of all the types and brands (that are being used in the building) have been taken. However, usage of some moderately heavy power-consuming machines such as washing machines, electric stoves, and the heater has not been found. As far as the miscellaneous load is concerned, the things which are not constantly used, have been considered are mobile phone chargers, laptop chargers, electric iron, and table fans. Hence, floor wise electrical equipment used corresponding to rated or average power consumption is given as follows:

Table 3. 1 List of electrical equipment with load classified by Floors

Floor	**Dwellers**	**A.C**	**C.F**	**E.L**	**T.L**	**E.F**	**R.R**	**Oven**	**Mis**	**TV**	**Total (KWh)**
GF	3	NA	2	02	1	2	1	NA	25	02	0.13
1st	4	01	6	16	6	6	2	1	100	01	4.201
2nd	8	01	6	15	6	6	2	2	100	02	4.221
3rd	7	01	6	15	6	6	2	NA	100	02	3.621
4th	9	NA	6	15	6	6	2	NA	100	02	1.621
5th	5	NA	6	15	6	6	2	1	100	01	3.16
Roof-top	0	NA	1	2	1	NA	NA	NA	25	NA	0.165
											17.085

Equipment Standards:

- AC: Air Conditioner
- C.F: Ceiling Fan
- E.L: Energy Saver Light
- T.L: Tube Light
- E.F: Exhaust Fan
- R.R: Refrigerator
- Mis: Miscellaneous

The table of the following shows the tools used as utility and associate power consumption:

Table 3. 2 Utility associated with power consumption

Tools	Piece(s)	Per Unit Power Consumption(Watt)	Total Power Consumption (KWatt)
Close Circuit Camera	9	6	0.054
21.5 Inch LED Monitor	1	25	0.025
Water Pump(1.5hp)	1	1100	1.1
Stair Case Light	6	20	0.120
Automatic Fire Alarm	12	8.6	0.0344
			Total:1.3334 KW

The electrical equipment present in the building has a total load configured is **18.413KWatt.**

The building we choose for the BIPV installation is a residential building. The number of dwellers is 38. After collecting the consumption of load for a month, we prepare a monthly load profile

N.B: The data has been collected from a bill provided by DESCO (Dhaka Electric Supply Company Ltd).

Table 3. 3 Consumption of load profile of the subjected building for a month

	Ground Floor	Floor 2	Floor 3	Floor 4	Floor 5	Floor 6	Total
Months	(KWh)	(KWh)	(KWh)	(KWh)	(KWh)	(KWh)	(KWh)
September’19	183	402	317	551	381	390	2224
October’19	150	328	278	476	325	347	1904
November’19	133	306	370	463	276	329	1877
December’20	83	171	299	351	208	260	1372
January’20	64	89	241	245	132	231	1002
February’20	60	91	259	282	157	235	1084
March’20	92	126	282	325	188	237	1250
April’20	110	151	338	390	226	285	1500
May’20	139	275	507	510	439	353	2223
June’20	153	244	508	504	421	357	2187
July’20	151	228	492	473	440	303	2087
August’20	182	268	552	530	506	332	2370
TOTAL	1500	2679	4443	5100	3699	3659	21080

3.1.3 Site Selection of PV Installation

As it has been chosen six storied building for this work, we need to think about some ideal places of the structure for the PV establishment. Concerning there could be no other reasonable place than the rooftop of the building. Likewise, we think about the south side wall just as the east front wall of the building for introducing the PV panels.

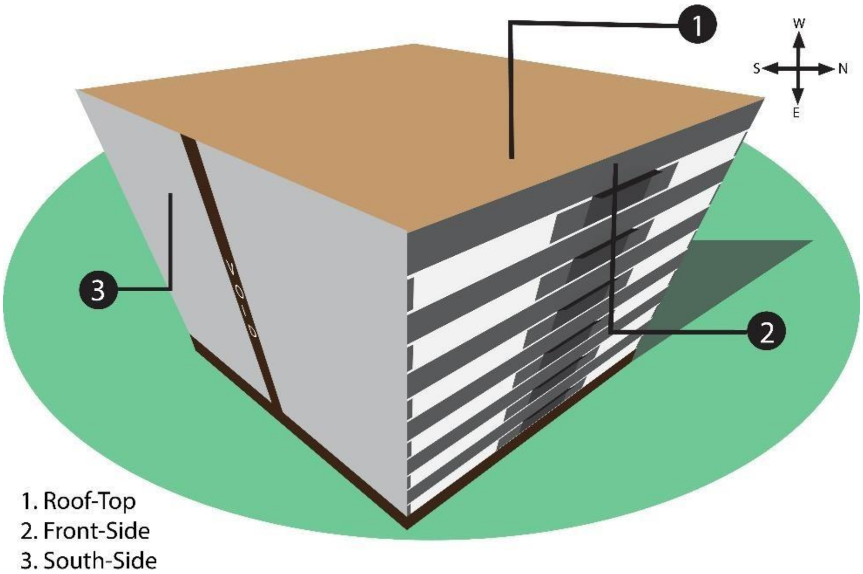

Figure 3. 5 Illustration of subjected building's selected places of PV installation

Table 3. 4 Selected area of the PV installation places

Subsystem-01	Rooftop	100.33 m^2
Subsystem-02	Front Wall	24 m^2
Subsytem-03a	South Wall	44.5034 m^2
Subsytem-03b	South Wall	35.3031 m^2
TOTAL		204.1365m^2

From the above Table: 3.4 we get all estimations of the spaces that we will be utilizing.

It has been chosen the maximum area from the roof-top as the sun irradiance or the solar energy is maximum over there as well as we will get the maximum sun hour from there. From chapter04 we will be able to understand it more.

From Figure 3.4 it can be understood that the front portion of the building is not covering the maximum area of sun exposure so we decide to utilize the top three floors for the PV installation as well as from the south portion the maximum area to the level of top three floors of the front side has been chosen for having the better result. By doing so the structural visualization will not be hampered and the utilization of the areas will be done properly.

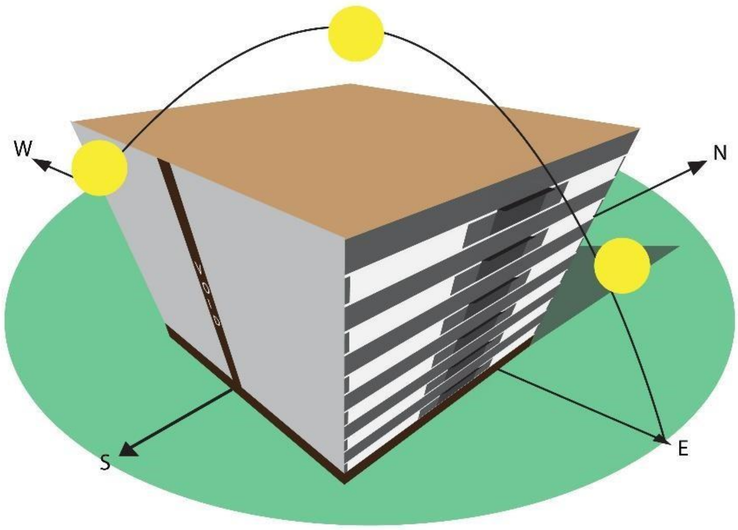

Figure 3. 6 Illustration of building with position of sun

From Figure 3.5 it can be seen the position of the sun through the day. So, it can be said that the front-mounted system would get less amount of sun radiance as the sun hour is low for this portion. On the contrary, the roof-mounted system would get most of the irradiance to sun hour. However, south mounted would get almost 3 times greater irradiance and sun hour than the front-mounted system. Due to all of these facts, the decision has been taken to utilize the above mention places of the subjected building so that the maximum places can be covered to generate and evaluate the energy from the solar with the help of a PV system.

3.1.4 PV Module & Module Energy

As per our load and design requirements, we select to use 340 Watt panels for the rooftop as the sun exposure is highest over there as well as we decide to select 280 Watt panels respectively both for the south side wall and front sidewall.

Cell specification: One detail of a photovoltaic board alludes to the cells situated in the boards that produce power. The cells, regularly 30 to 40 in an ordinary board, contingent on development and size, are comprised of semiconductor material, for the most part, silicon formed in meager wafers or strips with a positive side and a negative side. The daylight striking the positive side enacts the electrons on the negative side with an electric flow as the final product. A board's particulars can demand glasslike silicon in either a solitary precious stone or multiple: polycrystalline. Either glasslike produces a similar outcome. New innovation utilizes formless silicon which is more affordable however not as effective for use in enormous boards.

Physical construction specification of PV panels: As indicated by Naturals Energy, photovoltaic boards comprise clear material, typically uncommon treated glass, to secure the cells and give approximately 25 years of service to the panels. Each panel, or module, is connected to other panels to form an array. The 340W panel size is 1.67 m^2 and the 280W panel size is 1.62 m^2 with a length of 1.64 m.

Energy specification of PV panels: Generation of maximum power, peak power is dependent upon panel efficiency and irradiance of the sun. Our selected panel is specified as a Polycrystalline module of 340W & 280W for the flexibility of our proposed design.

Energy specification of PV panels: Generation of maximum power, peak power is dependent upon panel efficiency and irradiance of the sun. Our selected panel is specified as Polycrystalline module of 340W & 280W for the flexibility of our proposed design.

Table 3. 5 Specification of Panel

Specifications	**340 Watt**	**280 Watt**
V_{oc}	46.6V	38.5V
I_{sc}	9.64Am	9.54Am
V_{mp}	38.1V	31.7V
I_{mp}	8.92A	8.83A
Efficiency	17.52%.	17.21%.

Number of modules calculation:

From Table 3.4 we get all the areas where the PV modules will be going to be installed. From chapter 2 section 2.3.8, according equation (18-21) we get all the calculation process of calculating the number of modules that the work is going to be needed.

Here are some parameters taken from chapter 2 section 2.3.8 to evaluate the calculation:

- Area of the portion of the subjected building (such as roof-top area)
- Selected panel size
- Panel maximum output voltage (POV)
- System battery voltage (SBV)
- Area of the portion of the subjected building(X)
- Selected panel size (SP)
- Highest possible number of Panel setup(HP)

These mentioned parameters have been used to determine the number of panel calculation which has been represented through Table 3.6.

Table 3. 6 Number of panel calculation

Places	Area/length of places	Area/length of panel	Highest possible number of Panel setup (HP)=$\frac{X}{SP}$	Number of panels in parallel, (PP) =$\frac{HP}{RP}$	Number of panels in series, (RP)=$\frac{SBV}{POV}$	Total number of panels, RP × PP
Subsystem 01(340W)	100.33m^2	1.67m^2	60.07	30	2	60
Subsystem 02 (280W)	5.816m	1.64m	3.159	9	1	9
Subsystem 03(a & b) (280W)	14.6304m (each side)	1.64m	9.03	10	2	20

For subsystem 01 it has been calculated with the area of the place and with the area of the selected module as in this subsystem the maximum area has been covered due to the maximum solar irradiance. In Figure 3.6 the orientation of the calculated panels has been showcased through the illustration. For subsystem 02 & 03 the length of the places and the length of the panel module has been considered as per the simplification of calculation as well as cost-effectiveness. Since subsystem 02 & subsystem 03 both have less solar irradiance so the utilization of these places has been minimized to reduce the implementation cost. Moreover, it has been considered that the outer look of the building has not been compromised for the designing of the system. From Figure 3.8 it can be seen that how the organization of the panels has been done for subsystems 02 & 03 respectively. Figure 3.9 has been illustrated that how the wall-mounted panels will be being oriented.

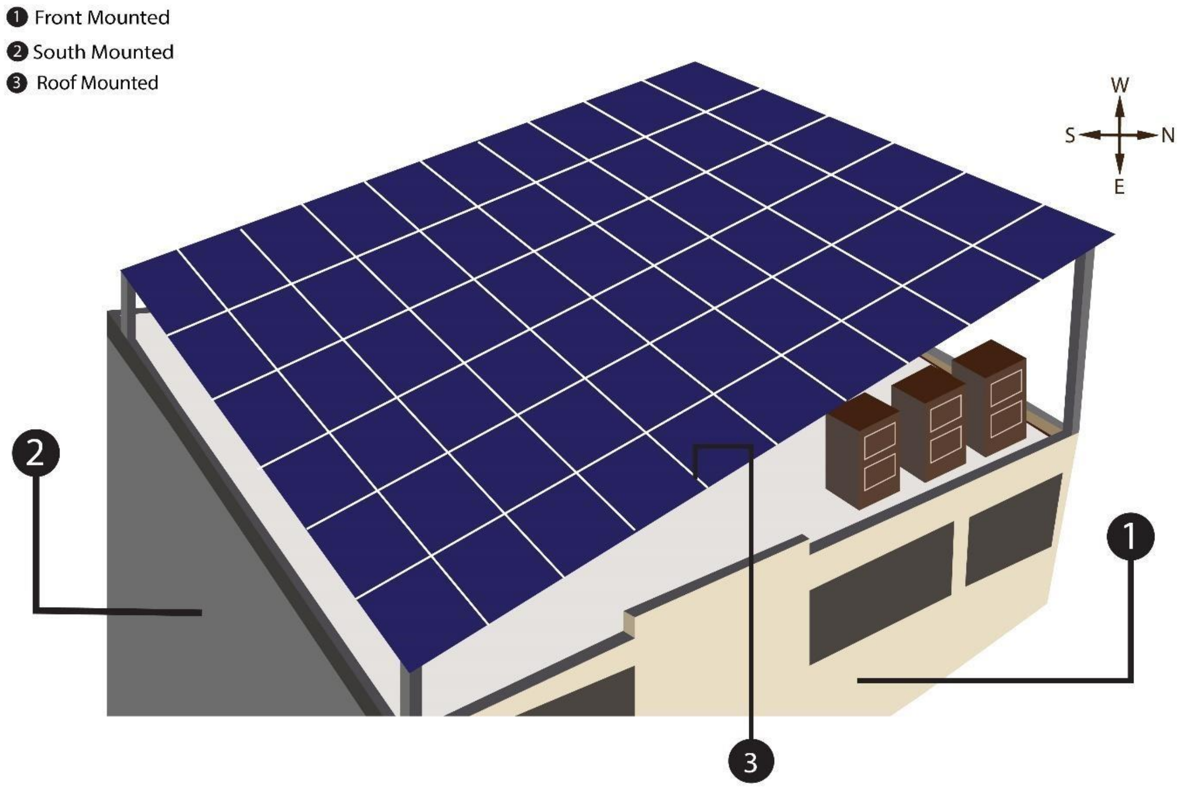

Figure 3. 7 Illustration of visual representation roof mounted panels

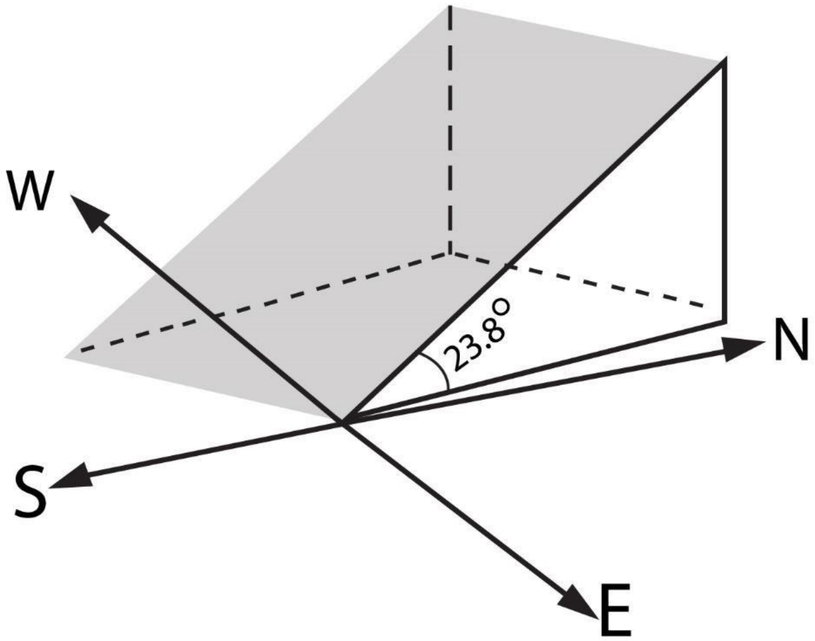

Figure 3. 8 Roof-top panels are tilted with 23.8 Degree

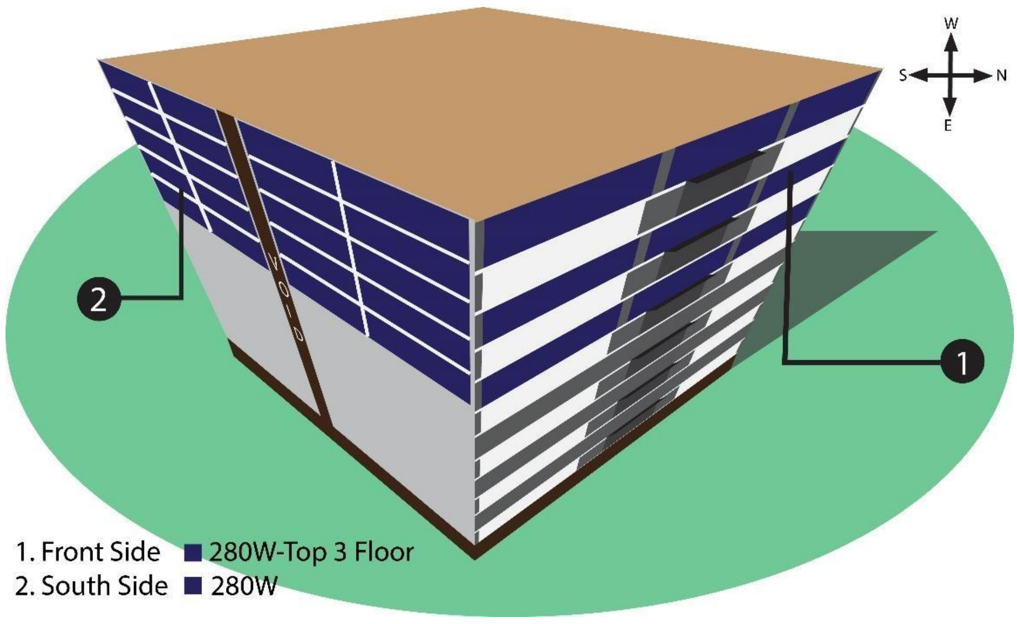

Figure 3. 9 Illustration of visual representation south & front mounted panels

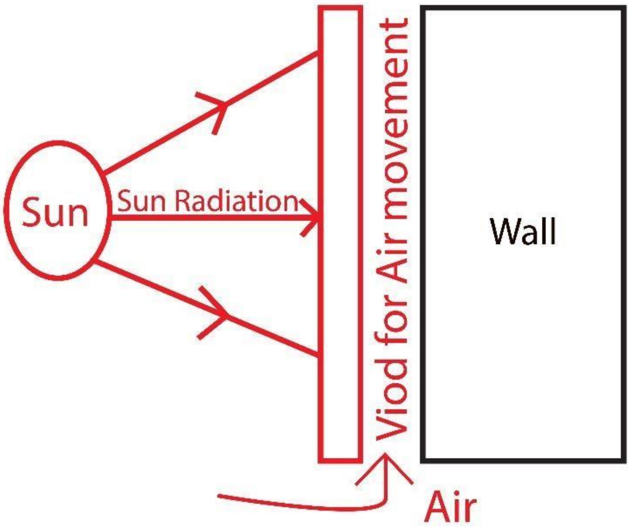

Figure 3. 10 Wall mounted panel connection visualization

According to our proposed design, we decide to use a 340W PV panel for the Rooftop area. As we will have the maximum sun exposure on the top area. With the help of some set of equations from chapter 2 and the sun, irradiance has been calculated for each Sub-system.

Solar insolation is the measure of sun-oriented radiation over the size of a surface region over the long run. The photovoltaic generators which make electrical energy from approaching daylight measure insolation as average irradiance in kilowatt per square meter (KW/ m^2). In some cases, another variety that utilizes a period part is utilized, kilowatt-hours over kilowatt-top year KWh/ (KWp*year). This implies you can make a solar irradiance recipe by estimating the power of daylight over a particular region through a specific measure of time.

Module Energy for Sub-Systems

According to the equations that have been generated in chapter 2 section 2.3.8 from 22-26, the module output energy has been calculated. With the help of the solar irradiance of each subsystem, the whole process has been done sequentially. First, the output current of the panel has been calculated, following that total output energy has been calculated.

This chart sorts the output of individual panels for a day of the building. Subsystem -01 where the panels are 340W accounts for the maximum electrical output energy of 96.03KWh, whereas subsystem - (2) and subsystem-(03), both having the same powered panel of 280 watt shows values of big difference. The reason behind such difference is due to the different irradiance values. Following to the calculation given above, the values of module energy are sorted below in the chart:

Table 3. 7 Panel Output Energy Calculation of All the Subsystem

Places	Irradiance Value (KW/m^2)	Panel $V_{output\ max}$	Panel $I_{output\ max}$	Panel produces(Ah) = POC × number of Parallel panel × IH ×PDF	Total output energy for one day(KWh)= Panel produces Current × POV × Required Panel in series × BUE × WE × IE
Sub-system 01 (340W)	6.5924	38.1	8.92	1587.71	96.03
Sub-system 02 (280W)	2.2291	31.7	8.83	159.42	8.023
Sub-system 03(280W)	5.7434	31.7	8.83	456.45	22.97

- Battery utilization efficiency (BUE) = 90%
- Wiring efficiency (WE) = 98%;
- Temperature correction factor (TCF) = 90%;
- Depth of discharge (DOC) = 80%;
- Inverter efficiency (IE) = 90%;
- PV array degradation factor (PDF) = 90%
- Insolation hour (IH)
- Panel maximum output current (POC)
- Panel maximum output voltage (POV)

The above chart showcases the energy calculation of three subsystems. The panel output voltage and current have been taken from Table 3.5.

The detailed equation generation, variables, and sources of these parameters have been shown in chapter 2 section 2.3.8. After doing all the energy calculations with the help of equations that have been established. In chapter 2 section 2.3.8, the total system output energy of December month has been determined for all three subsystems. The below table has been given with all the determined output values.

Table 3. 8 Number of panel & Energy of 1 month

Places	Total Number of Panels	Energy of 1 month (December)
Sub-System 01	60	2976.93KWh
Sub-System 02	9	248.735 KWh
Sub-System 03	20	1424.14KWh
		Total: 4649.805KWh

This chart showcases the total number of panels and total output energy of 1 month for the three subsystems.

To evaluate the panel output energy calculation and battery sizing we consider the December month as this month has the lowest irradiance, so from the load demand Table 3.3 we see that the December month's load demand is around 1500KWh which is less than the panel generated energy. However, it can be concluded that only in December month our panel generation energy is much higher than the demanded energy so this system can easily provide the demanded energy rest of the other months of the year as well.

3.1.5 Brief Discussion about Inverter, Battery & Wire Sizing

Inverter Sizing

An inverter is utilized in the framework where AC power yield is required. The info rating of the inverter ought to never be lower than the all-out watt of machines. The inverter should have a similar nominal voltage as your battery.

The inverter should be sufficiently enormous to deal with the aggregate sum of Watts we will use at one time. The inverter size ought to be 25-30% greater than all output Watts of apparatuses. In the event of apparatus type is motor or compressor then inverter size ought to be at least three times the limit of those machines and should be added to the inverter ability to deal with flood current during the beginning. The inverter ought to be the same as the PV exhibit rating to take into account protected and productive activity. For grid-tie systems or grid-connected systems, the input rating of the inverter should be the same as the PV array rating to permit safe and effective operation. [40]

Also some other aspects can be considered for choosing the inverter such as:

- Inverter must be chosen according to the load.
- The ideal power utilization of inverter should be low.
- Consumption of the electricity should be low from the grid.

Now, for choosing an inverter we are considering the load fact, we are going to sum up all the loads and take a ratio with an assumption of power factor. Thus we will find the power or inverter size.

Table 3. 9 load profile with consumption hour

Equipment's	Power(W)	QTY	Total Power(W)	Duration(H)	Power Consumption
AC(1700-2500W)	2100	2	4200	5	21000
Fan(65-75W)	70	30	2100	16	33600
Energy Saving Light(36-40W)	22	80	1760	6	10560
Tube Light(36- 40W)	38	32	1216	8	9728
Exhaust fan(55W)	55	32	1760	5	8800
Refrigerator(150W)	150	12	1800	24	43200
Miscellaneous	1550	All	1550	6	9300
					Total: 136.188KW

So, the total load is 136.188Kw, assuming the power factor of 0.7, the inverter power would be = $\frac{Total\ Load}{Assumed\ Power\ Factor}$

$=\frac{136.188\ kW}{0.7}$

=194.554 KW

So the inverter can be chosen of power with 200KW.

Battery Sizing

The battery type suggested for utilizing in the solar PV framework is profound cycle battery. Profound cycle battery is explicitly intended to be released to low energy level and quick re-energized or cycle charged and released for a long time for quite a long time. The battery ought to be adequately huge to store adequate energy to work the apparatuses around evening time and greatest overcast days to be expected 1 to 4 days [27].

In addition, with some other aspects should be considered to choose a battery. Such as: [40]

- Profound cycle, long lifetime
- Low maintenance
- High charging limit
- The capacity of totally discharge
- Reliability
- Minimum change under extreme temperature

For sizing the battery or how many batteries the system will going to need, we establish some equations in chapter 2 on section 2.3.8. According to this the battery calculation is given below:

Battery required power = (96.03+45.94+8.02) = 149.99x 60% = 89.994 KWh

Current for battery = 89.994 kWh /60 = 1499.9 Ah (from equation 24)

In order to maintain 60V in the charging station,

Required number of battery in series = 60V/12V = 5

One battery can store = 150Ah x 90% x 80% = 108Ah (from equation 25)

So, the required number of batteries in parallel = 1499.9 Ah/108Ah = 13.88 =~ 14 (from equation 26)

So finally we get 70 Batteries, which will be required 14 in Parallel with 5 string or array.

Brief information of wiring sizing

Selecting the proper size and kind of wire will improve the performance and reliability of any PV system. The dimensions of the wire must be large enough to hold the utmost current expected without excessive voltage losses. All wire contains a certain quantity of resistance to the flow of current. This resistance causes a decreased amount of voltage from the source to the load. Voltage drops cause incompetence, especially in low voltage systems (12V or less). There are several different kinds of wire available looking at how and where it'll be used. For instance, there are wire types designed for resistance to sun intensity, high temperatures, and direct burial. Specification of wire will withstand the worst conditions. A drop greater than 5% will reduce this necessary voltage difference, and may reduce the charge current to the battery in a way of greater percentage. In general guidance, here is to size for a 3-7% voltage reduction. If anyone thinks that the PV array could also be lengthened within the future, size the wire for future expansion. The customer will acknowledge that when it comes time to feature to the array [27]. From PV module up to system designing part, electric wiring is required. Voltage drop happens in interior opposition of the wire. PV system home framework this voltage drop should hold under a breaking point. Wire cost is vital and wire length should be a little size. Association the sun-oriented part under twist should satisfy [40].

Chapter 4

RESULT AND DISCUSSION

This chapter forecasts to analyze the outcome of the scheme that has been described in earlier chapters where the output of multiple sections has been found. For all the graphs, the Y-axis has been fixed to be energy and X-axis has been designated corresponding time for a particular section. Here, bar typed graph has been prioritized having the exception of portraying a different graph and for such, deductive reasoning has been mentioned for those specific cases.

The three different mounting or sides described here are,

- Roof Mounted Side (Subsystem-1),
- South Mounted Side (Subsystem-3),
- Front Mounted Side (Subsystem-2)

In the coming discussions, the analysis will be done not only on a month or year basis but also on a season basis as the season plays an important role in load consumption. After every output graph using the numerical chart has been placed to understand not only the trend but also the numerical significance. Additionally, for irradiance energy, 15th December has been considered so that the assumed minimal case can be considered to analyze the aspect of energy for the maximum and safest output as it has been seen to have less solar power generation during the winter season. The description of multiple aspects of the output is sequentially put to refer to a strong coherent that would enable us to come to a closing remark.

4.1 Irradiance and Incident Energy Analysis

4.1.1 Irradiance Analysis

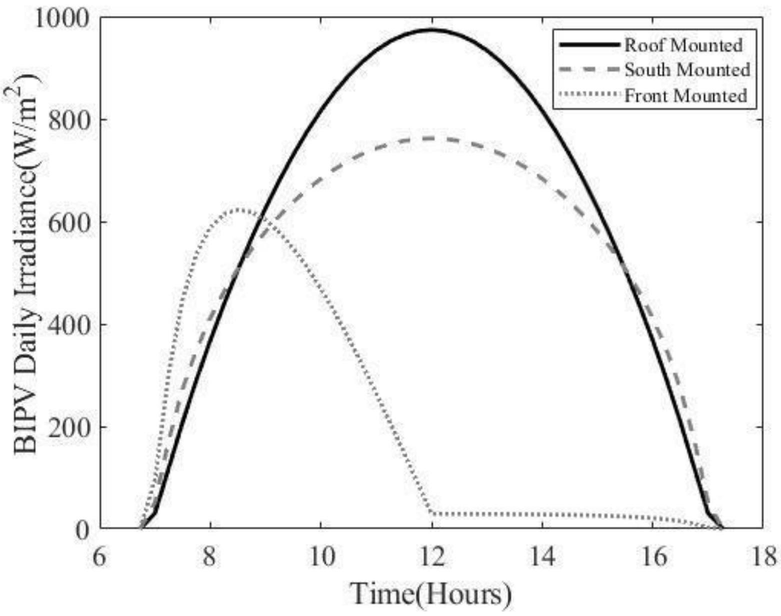

Figure 4. 1 Daily Irradiation of three Subsystems ie. Roof, South and Front Mounted

This is a pictorial depiction of irradiance fallen on the subsystems of the subject building in the given time frame on the 15th of December when the season is winter. The graph has been generated using the specified designated sets of equations mentioned in the 2nd chapter (2.3.6). The reason for such shape of the 3 subsystems are, the varying position of the sun from East to West with increasing time of a day and the tangent visualized from the surface of the subsystems. Hence, the front-mounted section or subsystem does not get remarkable irradiance after 12.00 PM, noon. The value for the magnitude appears to take few differences in the morning, from to and late noon, from to. However, the maximum irradiance energy is achieved as per this graph is from roof-mounted during noon.

Finally, total irradiance energy from these three sides is where the individual irradiance energy for these portions is in the given period on 15th December. Finally, total irradiance energy from these three sides is where the individual irradiance energy for these portions is in the given period on 15th December.

Table 4. 1 PV Panel Mounting and Corresponding Subsystem

Mounted PV Panel	Subsystem
Roof Mounted	Subsystem 01
Front Mounted	Subsystem 02
South Mounted	Subsystem 03

Hence, it is seen that, as far as the solar irradiance is concerned, a relation on the basis of incident energy can be generated.

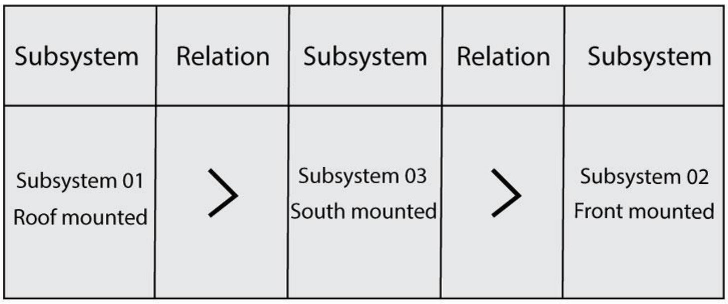

Figure 4. 2 Incident Energy Comparison in Three Subsystems

To take a case in point, this graph would be seen to have considerable contribution over the coming aspects of the calculation of the system which will be discussed further.

4.1.2 Incident Energy Analysis

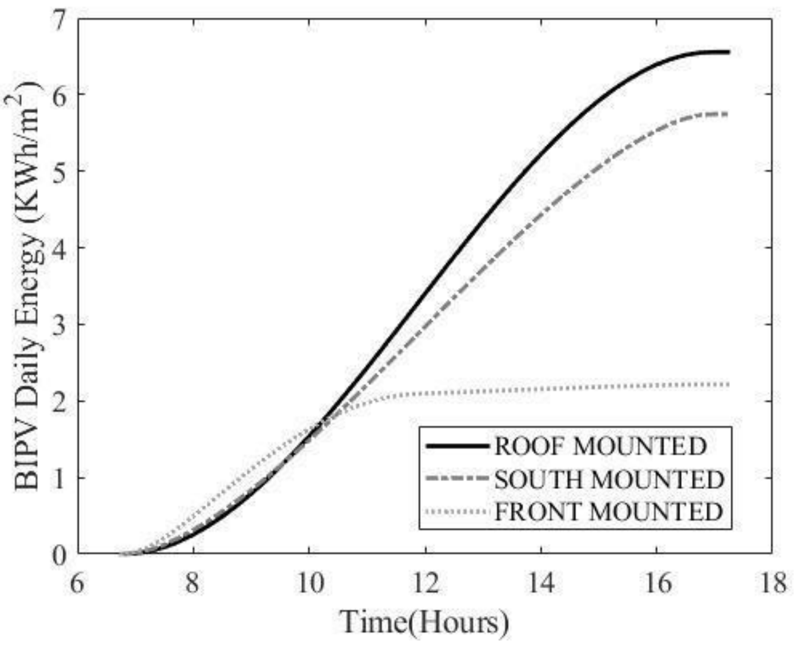

Figure 4. 3 Daily Incident Energy for the three Subsystem i.e. Roof, South, Front Mounted PV Array

This figure scribes the daily energy (generated/ fell on) of the BIPV system on the same 15th December. Having the relevancy with the previous figure, here it might be inspected the same trend of roof-mounted or Subsystem-(01). This graph has been generated with the assistance of parameters and output of calculating irradiance energy in the previous immediate section. The comparative relation among the three subsystems remains the same, however, a significant change is observed. The amount of irradiance is seen to be lessening after 12.00 hours steeply, such is not seen where it will be discussed the energy generated from or fell into the system. Even after 12.00 hours, unlike the front-mounted side, south mounted and roof-mounted is seen to have an upwards trend of energy.

4.2 Incident Energy Analysis in Three Subsystems

4.2.1 Incident Energy in three Subsystems Per Square Meter

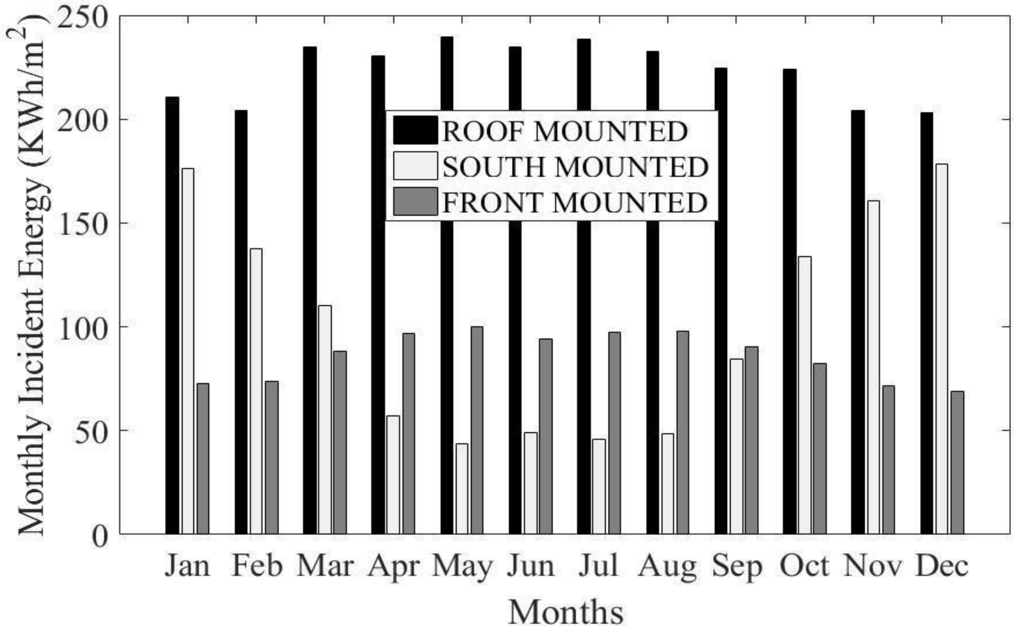

Figure 4. 4 Monthly Incident Energy in three Subsystems (per square meter)

This graph shows three subsystems' incident energy per meter square every month. Although the following chart shows the numerical data, from the graph it seems that south mounted to wall or Subsystem-3(a), 3(b) shows massive fluctuation in nature, and the other two subsystems have a moderate difference in value varying months and seasons.

Table 4. 2 Incident Energy in three Subsystems per square meter

Month	**Rooftop/(Subsystem-01(KWh/m^2)**	**South Wall Subsystem03(a)3,(b)(KWh/m^2)**	**Front Wall Subsystem02(KWh/m^2)**
January	210.3566	175.9700	72.4782
February	204.3551	137.6803	73.9916
March	234.9605	110.1105	88.1389
April	230.3833	57.3989	96.8879
May	239.6696	43.5674	99.8342
June	234.6141	48.8358	94.3848
July	238.3020	46.0662	97.4175
August	232.7182	48.4247	97.7858
September	224.2550	84.4423	90.6545
October	223.9829	133.7744	82.2590
November	204.1328	160.5664	71.3581
December	203.2382	178.1432	68.7042

The relation among Subsystem-01, subsystem-02, subsystem-03 from the graph looks like, the incident energy of the Subsystem-01 is the highest with respect to subsystem-02 and subsystem-03. The ratio of monthly incident energy of roof mounted system to front mounted varies from 1: 2.44 to 1: 2.9581 throughout the year and the ratio of roof mounted to south mounted varies from 1: 1.67 to 1: 4.805.

4.2.2 Comparison of Incident Energy for All the Subsystems

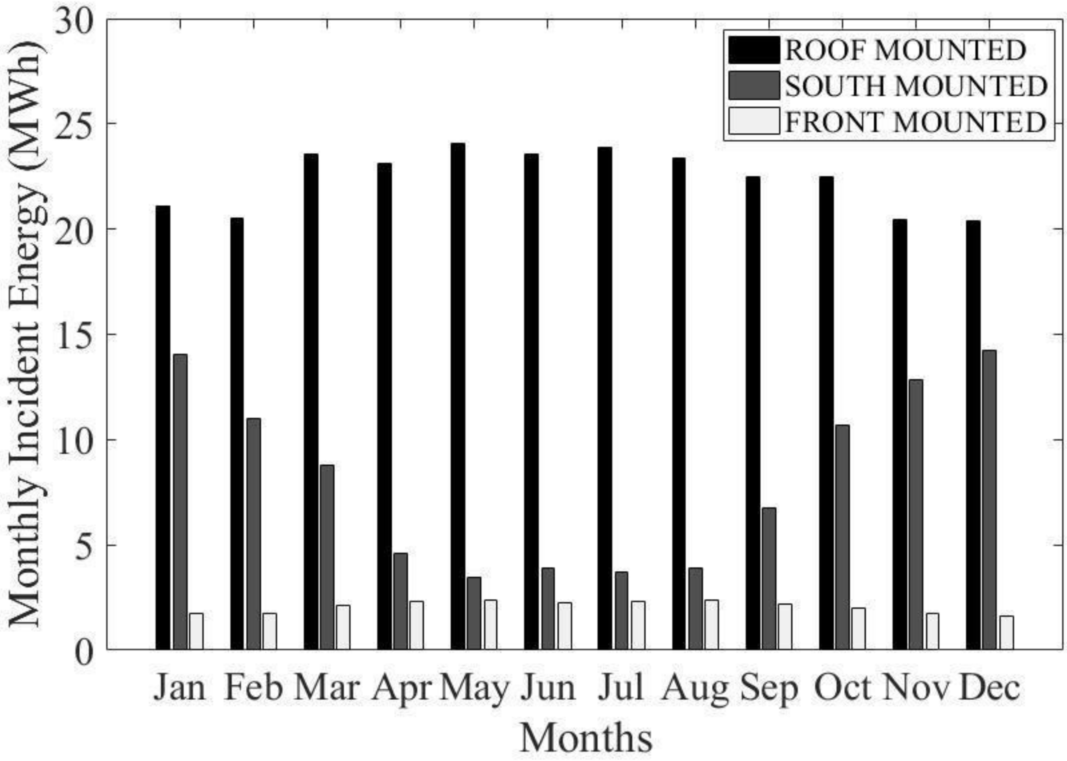

Figure 4. 5 Comparison of Monthly incident energy for the subsystems

In this picture, it can be seen a diagram giving a comparison of incident energy fell on the entire three subsystems. The slightest difference between the previous chapter and this chapter is the multiplication of the entire system area with the value of incident energy. This output graph also has the same trend where it can be viewed as a significant trend of south mounted side having a gradually increasing trend from summer season to the winter season and vice versa.

4.2.3 Summation of Incident Energy

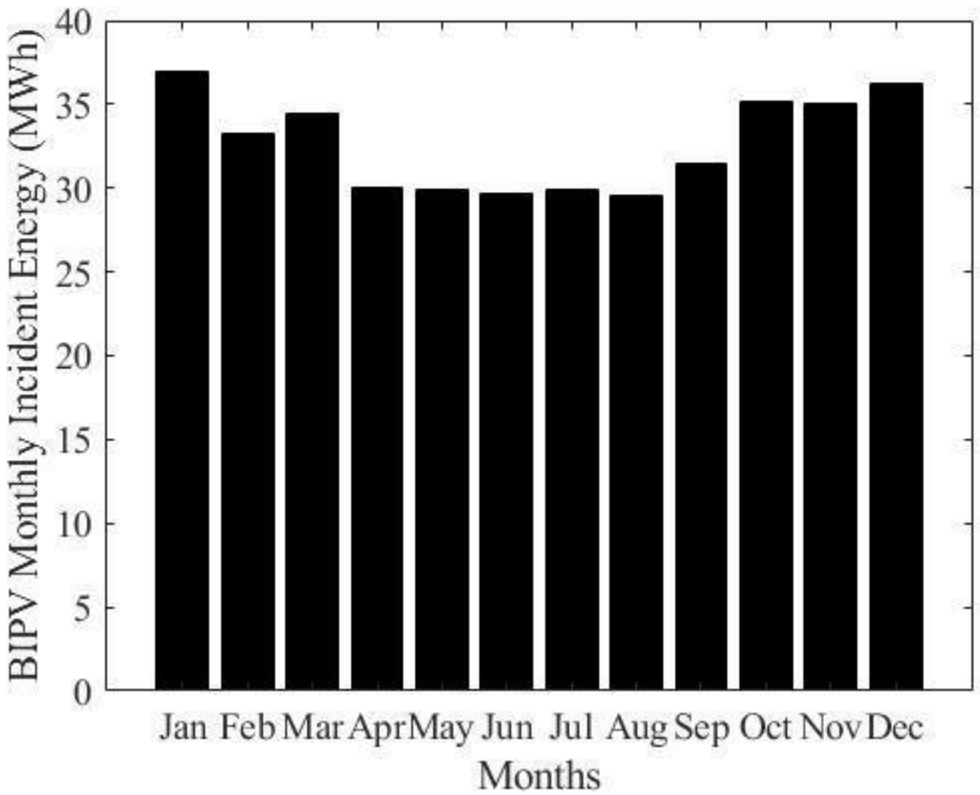

Figure 4. 6 Summation of Incident Energy of the System

This graph tells us about the incident energy fell on all the systems having the area of 204.1365m2 in twelve months. It can be seen that January, February, March, and October, November, December account for higher incident energy. On the contrary, in other months April, June, July, August, September the incident energy is lesser and during this period, the season is summer and rainy season. In January month, the system encounters maximum incident energy of around 34MWh in 204.1365 m2 whereas August month has the minimum incident energy of around 29.5 MWh. One thing is to be noted is that, during April, May, June, July, and August; almost the same incident energy to be fallen on the system is seen.

4.2.4 Incident Energy Comparison with Cloud Impact

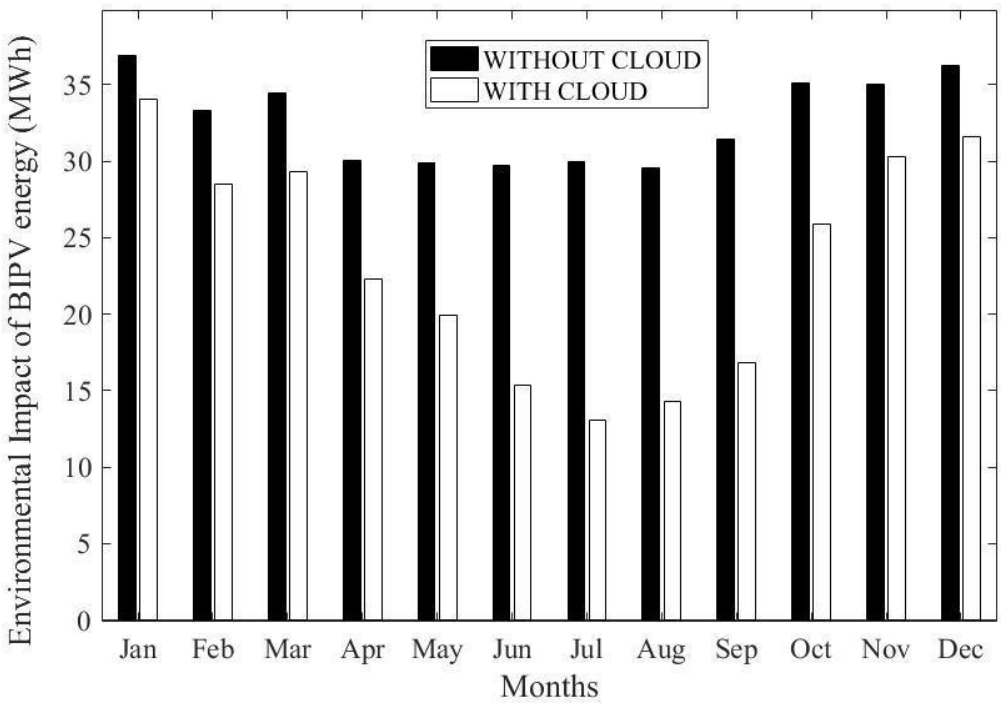

Figure 4. 7 Cloud Impact Analysis of Incident Energy

For the discussion regarding to this image, referring to the following numerical chart that has generated this graph, is given. As environmental fact, the impact of cloud has only been considered.

Due to cloud impact, PV generation has encountered a fall in generation and the least proportioned energy has been generated due to cloud impact bearing a 0.565% degradation percentage in July, which is actually rainy season in Bangladesh. The least impact of cloud is seen during the month of January, considered as winter season in Bangladesh having the degradation percentage 0.078059%. To sum up, throughout the year, degradation percentage is 28.1535%.

4.3 BIPV output Energy Analysis

The output of the entire system, after all the technical calculation related with system designing is going to be examined here with multiple comparisons. This output is going to be analyzed with incident energy, load and finally this section will be deciding the matter of grid dependency.

4.3.1 BIPV System Output Energy Comparison in All Subsystems

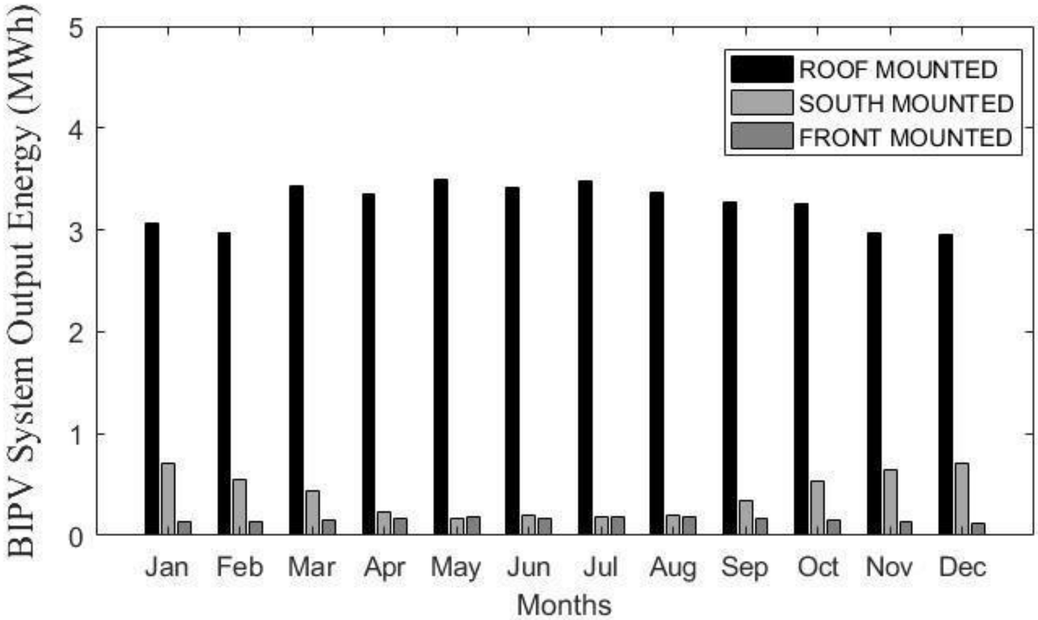

Figure 4. 8 System Output Energy Comparison for all the Subsystems

This tri lateral graph anticipates the output energy and gives us the idea of variance of power generation in the entire system consisting of 204.1365m^2.

It is seen that for front mounting, the output energy essentially does not vary much whereas for south mounting, a gradual declination from the beginning of the year till June has been seen. Inversely, opposite trend of increasing value is seen from June to December.

4.3.2 Total Output Energy from the Entire System

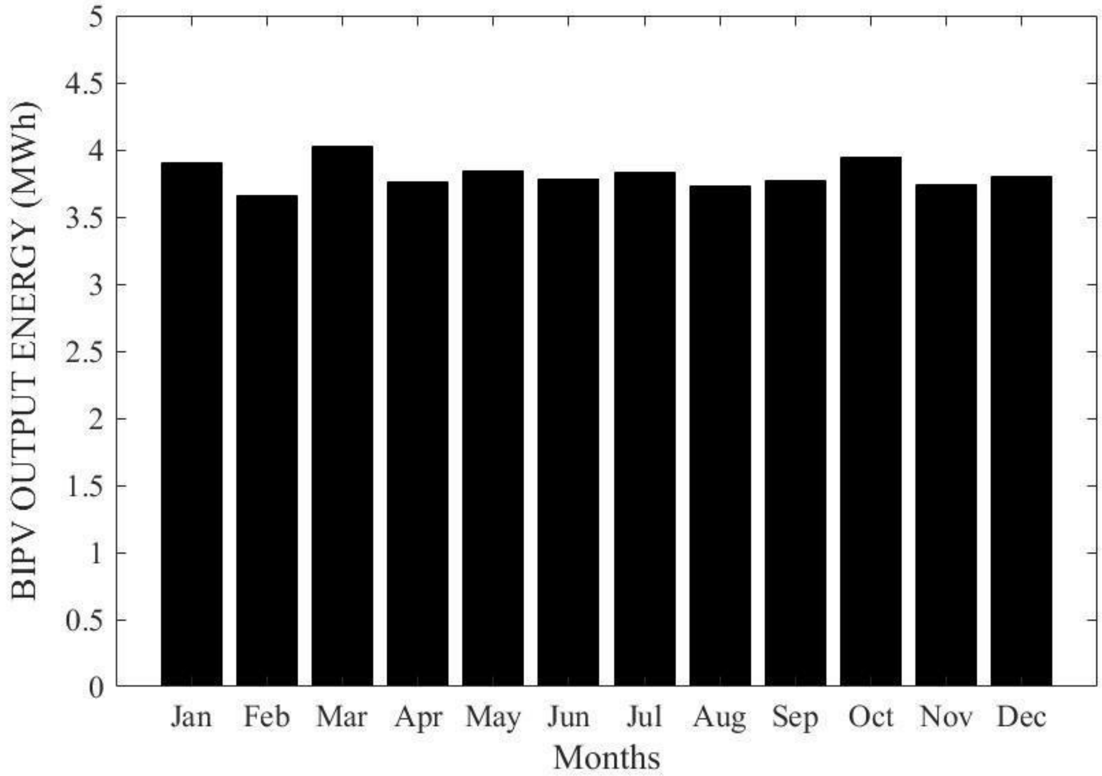

Figure 4. 9 BIPV Output Energy from the Entire System

This graph is the accumulation of outputs for all the three subsystems that make up the BIPV system mentioned here. Although it has been seen that considerably diversified output shape for irradiance and incident energy, however, their addition and the multiplication of 30 days, portrays bar graphs which are sufficiently similar in terms of their values. Finally, it can be regarded that, the output of BIPV system fluctuates around 3.6 to 4 MWh approximately during a year.

From the chart, it can be found out that, in the span of one year, the system would supply 45.8007 MWh of power. It can also be resulted out that, throughout the year, 224.4KWh power is generated from the proposed BIPV system from every $1m^2$.

4.3.3 BIPV System Output and BIPV Incident Energy

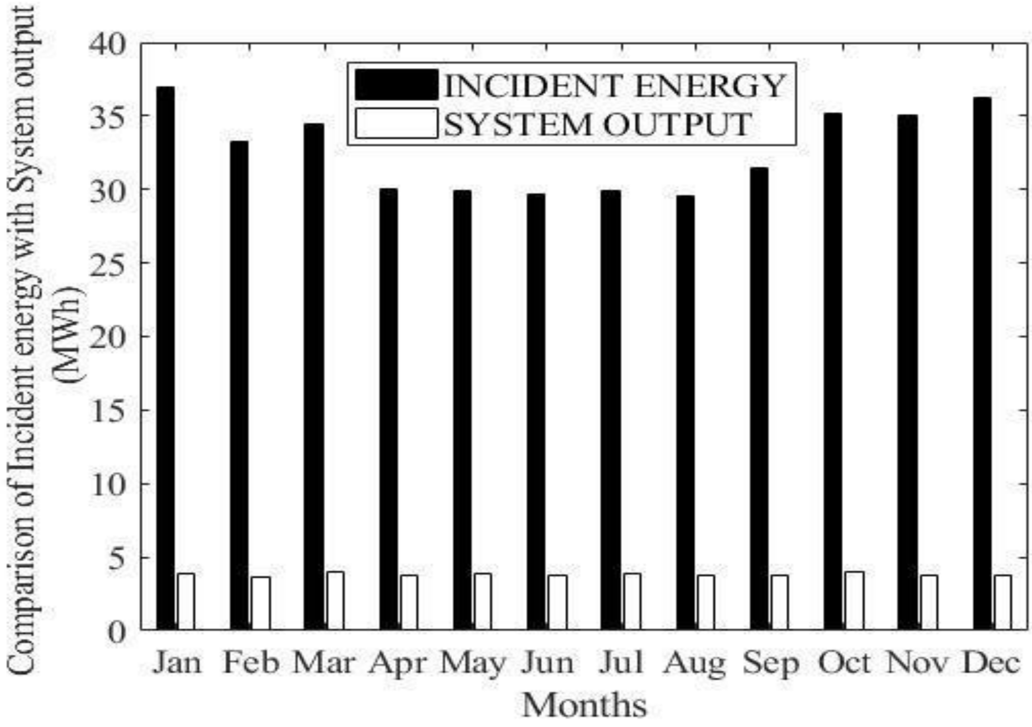

Figure 4. 10 Comparisons of Incident Energy and System Output

This bar graph compares incident energy with the final output energy in MWh.

Now, by seeing it, it is evident that, incident energy is almost six to seven or even more times higher than the final output of the system. It gives us specified cased system output to input incident energy to only of the system for this entire work which is 1:8.551

4.3.4 Output Energy and Load Comparison

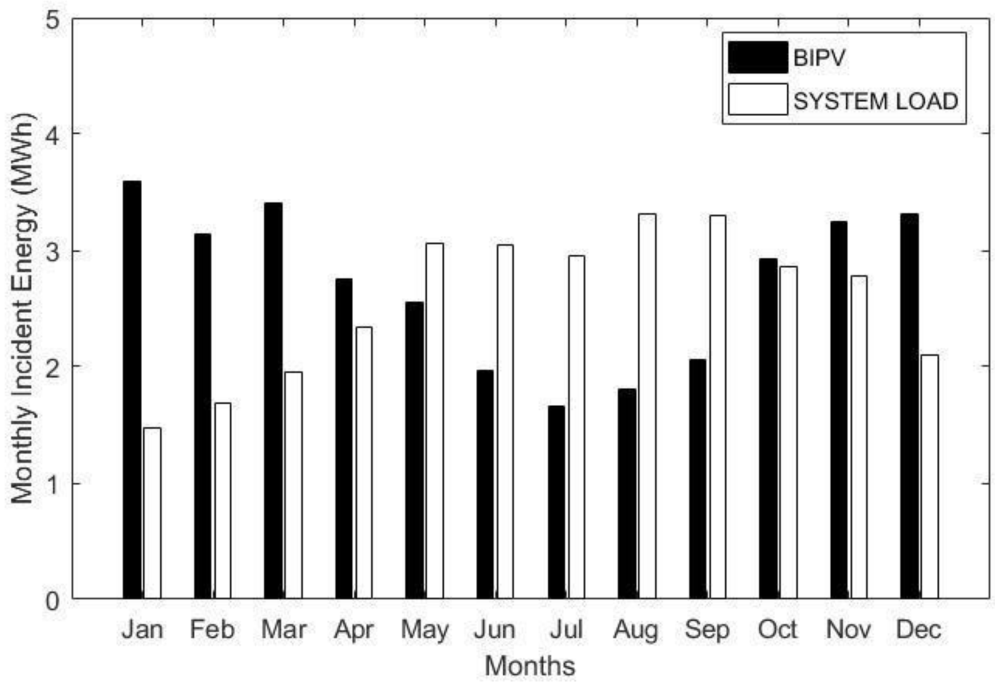

Figure 4. 11 Comparisons of System Output and Load

This evidently comprehensible image expresses the co-existence of power generation by the simulated design and the building load in the form of bar graph and indication regarding identification has been placed in the image. Information about the building load has been mentioned earlier in chapter 3.1.2.

Table 4. 3 BIPV System Output and System Load

Month	**BIPV Energy(MWh)**	**System Load(MWh)**
January	3.8987	2.224
February	3.6620	1.904
March	4.0285	1.877
April	3.7601	1.372
May	3.8454	1.002
June	3.7854	1.084
July	3.8311	1.250
August	3.7344	1.500
September	3.7678	2.223
October	3.9460	2.187
November	3.7444	2.087
December	3.7969	2.370
Total	45.8007	21.080

From the graph, it can be examined that, BIPV generation leads the system consumed load in 7 months and for other 5 months; the value of load is higher than the BIPV generation.

This graph allows us to think about the nature of grid dependency of the system which is elaborately described in the next section.

4.3.5 BIPV Energy Consume and Grid Dependency Analysis

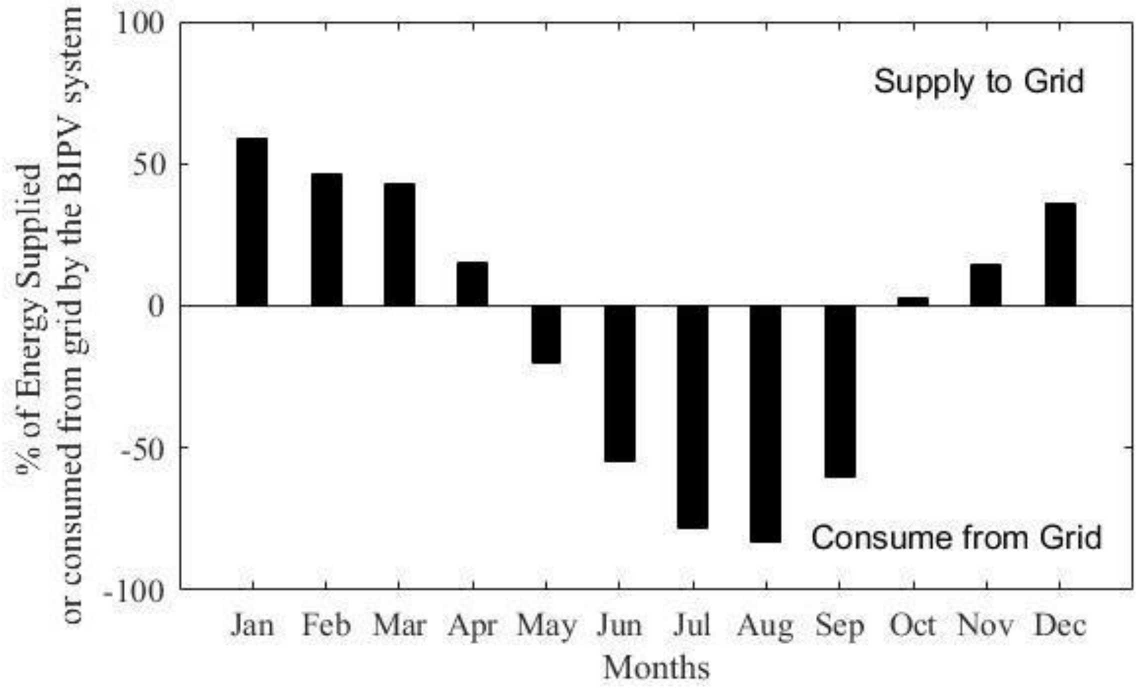

Figure 4. 12 Supply and Consumption to Grid

Figure 4.12 indicates a distinctive relation of the grid and solar generation- which means, as per the simulated and analyzed energy, during a year, when the system or building would achieve the sufficiency of being dependent on the grid and not being dependent on the grid. This graph is paraphrased from the previous graph in a different formation to get a firm idea towards the final yielding of this research work. The positive Y-axis expresses the surplus energy being supplied to the grid after PV generation and the negative Y-axis means the phenomenon of consuming energy from the grid despite PV generation.

It can be asserted that, during a year, in 7 months, the output energy of experimental integration of PV in the residential building would allow to meet up all the energy demand.

For the remaining 5 months, the building has to be dependent on the grid power.

Table 4. 4 Chart of Grid Dependency in Percentage

Month	Supply to Grid (%)	Consume from Grid (%)
January	59.13	Null
February	46.09	Null
March	42.73	Null
April	15.14	Null
May	Null	19.75
June	Null	54.84
July	Null	78.26
August	Null	83.29
September	Null	60.51
October	2.449	Null
November	14.39	Null
December	36.32	Null

A maximum of 59.13% of generated power can be delivered to the grid in January, whereas the maximum of 78.26% of power has to be consumed from the grid to be fed to the building's load in July. The graph also depicts that during the time of summer and rainy seasons, the dependency on grid power increases due to less power generation by the BIPV system. Henceforth, during the early and post-winter and also during the winter season the system can provide power to the grid. In the mentioned three seasons, a gradual increase and decrease have been diagnosed and no abrupt change is seen.

4.4 Output Discussion from Financial Viewpoint

Energy Payback Time (EPBT) Analysis

Energy payback time (EPBT) is the time required to carry out an electricity balance by a PV system [36]. In other words, EPBT is achieved when a system produces the same amount of electricity that it consumed over its lifetime. When we conduct an energy payback analysis, we look at how long it will take to repay.

In particular, the attractiveness of an investment is proportional to its payback duration. Shorter paybacks make investments more appealing. An EPBT tells us whether or not a PV system would provide a net energy gain over its lifespan and, if so, how much.

In this study, the net present values (NPV) and the Energy payback time (EPBT) of a BIPV facade of a residential building in Dhaka city during its lifespan are inspected to identify the economic advantages of building-integrated photovoltaics (BIPV) system. The NPV or net present value of investment mainly denotes the difference of cash inflows and cash outflows of a system over the system's lifetime.

NPV of a particular year can be formulated as follows in Equation (27)

$$NPV_n = \frac{CI-CO}{(1+i)^n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (27)$$

C_I and C_O represents the cash inflows and cash outflows respectively where cash inflow is the income from the BIPV system from the production of electricity and cash outflow is the expenses to run the system throughout its lifetime. Besides, i and n constitutes the interest rate and number of the year correspondingly.

Cash inflows, C_I can be expressed as,

$$C_I = E_T * E_G \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (28)$$

E_T and E_G stands for electricity tariff and annual electricity generation for a BIPV system respectively.

C_O, the cash outflows, is computed as follows:

$$C_O = C_{OM} + C_{REP} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (29)$$

C_{OM} and C_{REP} are the operation & maintenance cost and replacement cost sequentially. The operation & maintenance cost of the system, C_{OM} is formulated as follows:

$$C_{OM} = 0.5\% * Q \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (30)$$

Q, the initial investment of the system, can be expressed as:

$$Q=I_{PIC}-I_{EMC}-I_S \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (31)$$

In equation (30), I_{PIC} represents project initial investment cost, I_{EMC} is the equivalent building envelope material cost and I_S the granted subsidies. The initial investment of the system, Q can be considered as equal to I_{PIC} represents project initial investment cost because in our study the equivalent building envelope material cost and granted subsidies are absent [37].
Table 4.4 presents the initial investment price of the PV modules, inverter, battery and charge controller with the currency rate as $1 = 85.05BDT.

Table 4. 5 System Component Prices

Components	**Specification**	**Quantity**	**Unit price**	**Total price**	**Initial cost**
Solar PV module	280Watt	29	$0.52	$4222.4	$11518.4
	380Watt	60	$0.32	$7296	
Grid tie inverter	200KW	1	$2750	$2750	$2750
Battery	12V	70	$115.18	$8062.68	$10500
Charge Controller	DC 6V-60V Programmable Charge Controller	1	$176.4705	$176.4705	$176.4705
Overall initial price of PV solar system					$24944.87

Table 4.4 depicts that, in our system, total 89 solar panels are used. Total 60 panels are used on the rooftop rated as 380Watt and 29 panels rated as 280Watt are used on the front and south wall. Total 70 batteries rated as 12V, one grid tie inverter and one charge controller are needed as well. Table 4.4 represents the information about the initial investment cost as $24944.87 for our study.

The electricity generation for a BIPV system for n number of year can be formulated as:

$$EG_n = EG_0 * (1 - P_{DR})^n \quad \text{……………………………} \quad (32)$$

EG_0 and P_{DR} stand for the annual generated electricity of the initial year and degradation rate of solar panels respectively. Table 4.5 presents the impactful rates for financial analysis of payback calculation.

Table 4. 6 Rates & Percentages

Different Rates	**Percentages**
Discount Rate	3%
Electricity Tariff	3.5%
Panel Degradation Rate	0.5%
O&M Cost	0.5%

In this study, we are considering a discount rate of 3%, even though it varies from country to country [37]. The discount rate refers to the interest rate charged by a bank on its loans [37]. The electricity tariff rate, ET increases by around 3.5% per year [37]. For this research, the annual operation and maintenance (O&M) costs of a BIPV system is considered to be 0.5 percent of the initial cost of the BIPV system and the degradation rate of solar panels is taken 0.5% per year [37].

Table 4.6 shows the total cash inflows of the system over its lifetime.

Table 4. 7 Cash inflows ($) of the system

Year **(n)**	BIPV annual electricity generation (kWh) **$E_{GN}= E_{G0}*(1-0.5\%)^n$**	Electricity tariff **3.5% increase/ year**	Cash Inflows ($) **$C_I= E_T*E_{GN}$**
1	32261.9795	10.00	3795.527
2	32100.6696	10.35	3908.728593
3	31940.16625	10.71225	4025.306423
4	31780.46542	11.08717875	4145.361187
5	31621.5631	11.47523001	4268.996585
6	31463.45528	11.87688306	4396.319408
7	31308.138	12.29255326	4527.439634
8	31149.60731	12.72279263	4662.470521
9	30993.85928	13.16809037	4801.528704
10	30993.85998	13.62897353	4944.734298
11	30684.69553	14.10598761	5092.210998
12	30531.27205	14.59969717	5244.088191
13	30378.61589	15.11088657	5400.491062
14	30226.72261	15.6395606	5561.580708
15	30075.589	16.18694522	5727.434256
16	29925.21106	16.75348831	5898.254983
17	29775.585	17.3398604	6074.170438
18	29626.70708	17.94675551	6255.332571
19	29478.57354	18.57489196	6441.897865
20	29331.18067	19.22501317	6634.027469
Total Cash Inflows over 20 years of Lifespan			**$101805.8789**

Table 4.7 depicts the cash inflows of the system for over 20 years of its lifespan. According to equation (30)

The O&M cost, C_{OM}= $112.53 will be added each year.

Except that, the system's replacement cost will be applied at the end of every 5 years of use.

The replacement cost of the system over 20 years is shown in Table 4.7 below.

Table 4. 8 Replacement Cost over BIPV Lifespan

Timeline	**Charge Controller**	**Battery**	**Inverter**	**Total**
0-5 years	$0	$7558.08	$0	$7558.08
6-10 years	$176.4705883	$5440.44	$1424.879	$7041.789927
11-15 years	$0	$3916.13	$0	$3916.13
16-20 years	$85.0344	$2818.9	$1025.654	$3642.218448
Overall replacement cost of system				**$47103.08838**

Table 4.8 presents information about the system's replacement cost over BIPV lifespan. In this system, batteries are replaced after every 5 years of use because maximum 12V battery has 56 years durability. On the contrary, charge controller and inverter replacement is done after every 10 years of use. Table 4.8 depicts that the total replacement cost of the system for 20 years' lifespan is $47103.08838.

Table 4. 9 Payback period of NPV and IRR

Year **(n)**	**Cash In ($)** **$C_I$**	**Cash Out ($)** **$C_O$**	**Present Value** **$(C_I-C_O)/(1+3\%)^n$**	**Net Present Value**
1	3795.527	112.53	3575.725243	-21369.14476
2	3908.728593	112.53	3578.281264	-17790.86349
3	4025.306423	112.53	3580.744708	-14210.11879
4	4145.361187	112.53	3583.118276	-10627.00051
5	4268.996585	5803.66228	-2934.261613	-13561.26212
6	4396.319408	112.53	3587.606188	-9973.655934
7	4527.439634	112.53	3589.725547	-6383.930387
8	4662.470521	112.53	3591.765063	-2792.165325
9	4801.528704	112.53	3593.727065	801.5617404
10	4944.734298	5778.930346	-1644.139221	-842.5774808
11	5092.210998	112.53	3597.427504	**2754.850023**
12	5244.086191	112.53	3599.170267	
13	5400.491062	112.53	3600.844171	
14	5561.560708	112.53	3602.451226	
15	5727.434256	3007.097549	1673.851891	
16	5898.254983	112.53	3605.472529	
17	6074.170438	112.53	3606.890509	
18	6255.332571	112.53	3608.249106	
19	6441.897865	112.53	3609.550052	
20	6634.027469	2987.881367	1956.47756	

Table 4.9 shows that after every 5 years of use new replacement cost is added to the system. The income from the system was in negative until year 10.

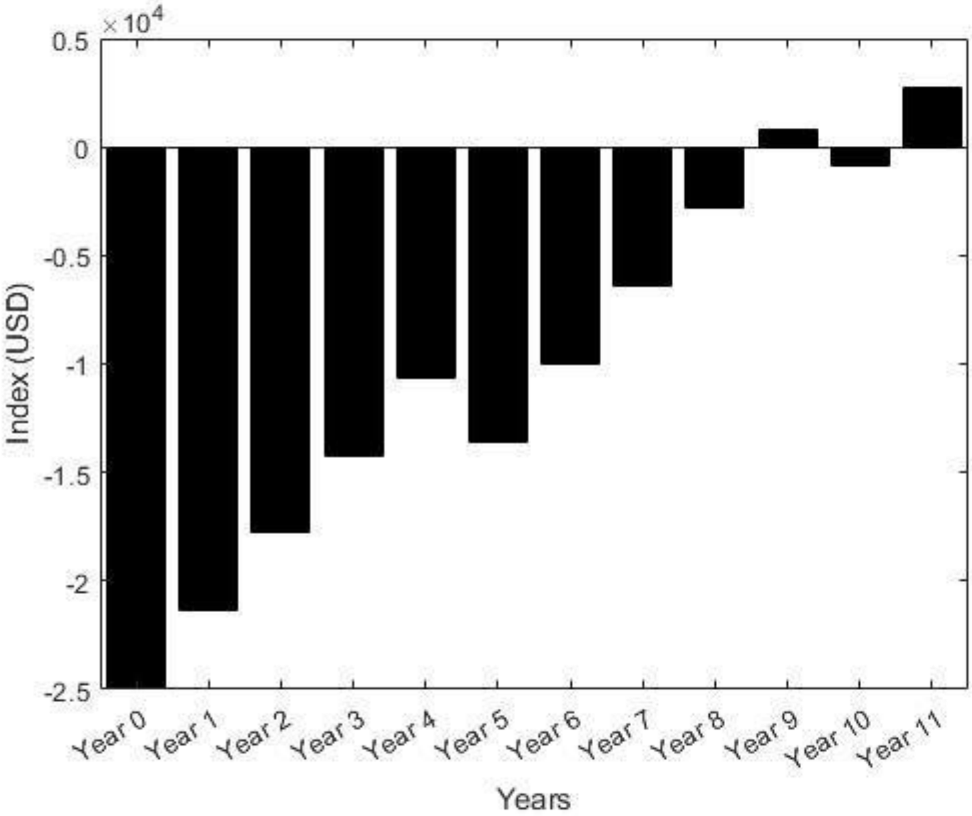

Figure 4. 13 Payback period of the system with cloud impact

Table 4. 10 Outcomes of EPBT, NPV and IRR

Parameters	**Outcomes**
Payback Period	10.23 Years
NPV	$2754.850023
IRR	9%

The Payback period of the system with cloud impact is shown in Figure. 4.13. However, for more clear explanation table 4.5 is given as an analysis of NPV and payback period. Table 4.4 depicts that the initial investment cost is $24944.87 for our study. Additionally, table 4.8 shows that at 11th years $2754.85 is remained extra. So in our study, the payback period is achieved after 10.23 years which is shown in Figure 4.13. According to the majority of the research, the EPBT of a BIPV system spans from 7 to 12 years [36].

The internal rate of return can be expressed as:

$$Q+\sum_{n=1}^{y} \frac{NCn}{(1+IRR)^{n}} = 0 \quad \text{...} (33)$$

In this research, the achieved payback period at 10.23 years. By deriving Equation (33) internal rate of return (IRR) 9% is achieved. It is worth to note that the 9% rate of IRR presents that the project is justified and acceptable.

4.5 Output Discussion from Environmental Viewpoint

At present everyone is increasingly concerned about the need to minimize carbon dioxide emissions from the atmosphere. This is due to the fact that its negative consequences are felt all over the world. One of the various reasons of global warming, i.e. an increase in the global average temperature, is the concentration of greenhouse gases in the environment. Carbon dioxide is one of the foremost greenhouse gases in the earth's atmosphere [32].

The bulk of carbon dioxide emissions in coal-fired and hydrocarbon-fired power plants are created during the combustion process, with the amount depending on the plant's thermal efficiency and the carbon content of the fuel but while in operation, photovoltaic systems emit extremely little direct CO_2, near to zero [34]. Building integrated photovoltaics (BIPV) is a viable technology for harvesting the most plentiful renewable energy - solar energy - in the built environment, and it has the potential to significantly help the rising need for practically zero energy buildings [31].

40% of the local population does not have access to electricity, in Bangladesh [30]. Bangladesh contributes very little to global CO_2 emissions. However, the country's emissions forecast has resulted in a significant increase in CO_2 emissions over time [31]. As a result, the government must establish a national prevention plan/policy, as well as encourage the usage and development of green technology, renewable energy, and green growth in Bangladesh for longterm energy and environmental sustainability [31]. According to [29] renewable energy-based technologies have decreased carbon emissions in Bangladesh by 10–30%.

For BIPV system, the calculation equation of the reduced carbon emission Kg/kWh can be usually presented as follows:

Total Carbon Emission = Energy Generated (KWh) * Emitted kg/KWh of CO_2……….. (34)

Local power plants in Bangladesh emit around 640g or 0.64 kg/KWh of CO_2 [30]. Therefore, Table 4.10 depicts that in our study the total CO_2 emission reduction over a year from a 117KW BIPV system considering cloud impact and without cloud impact will be 20751.296 kg/KWh and 29370.048 kg/KWh respectively.

The monthly approximate values of total reduced CO_2 emission Kg/ KWh by this BIPV system considering cloud as well as without cloud impact are presented in Table 4.10. As output of the system has been analyzed using cloud impact the carbon emission part of this research work will also be examined by cloud and non-cloud impact. The following figures individually and collectively portrays the scenario of impact of cloud over carbon emission.

Table 4. 11 Total reduced CO2 emissions by proposed BIPV system

Month	Energy Generated kWh (Without Cloud)	Reduced Carbon Emission Kg/ kWh **(EGENERATED*0.64 kg)**	Energy Generated kWh (With Cloud)	Reduced Carbon Emission Kg/ kWh **(EGENERATED*0.64 kg)**
January	3988.7	2552.768	3596.8	2301.952
February	3662.0	2343.68	3138.8	2008.832
March	4028.5	2578.24	3404.7	2179.008
April	3760.1	2406.464	2757.4	1764.736
May	3845.4	2461.056	2555.3	1635.392
June	3785.4	2422.656	1968.4	1259.776
July	3831.1	2451.904	1656.0	1059.84
August	3734.4	2390.016	1807.0	1156.48
September	3767.8	2411.392	2059.7	1318.208
October	3946.0	2525.44	2927.7	1873.728
November	3744.4	2396.416	3245.1	2076.864
December	3796.9	2430.016	3307.0	2116.48
Total	**45890.7**	**29370.048**	**32423.9**	**20751.296**

On that account, from equation (34) it can be seemed that total CO_2 emission reduction considering without cloud impact will be 587400.96 kg & considering with cloud impact will be 412550.92 kg in 20 years.

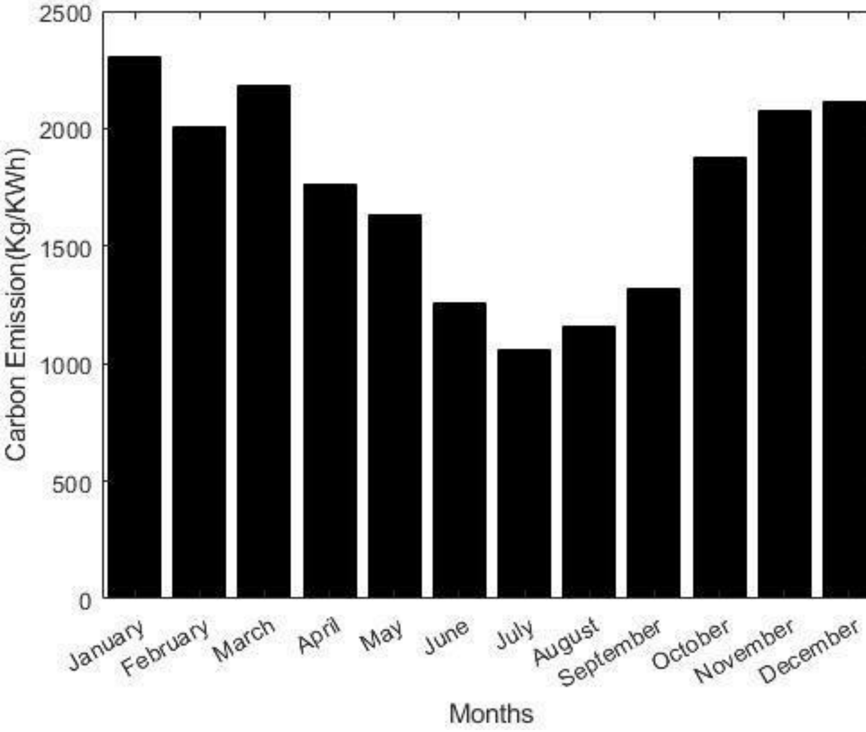

Figure 4. 14 Carbon emission with cloud impact

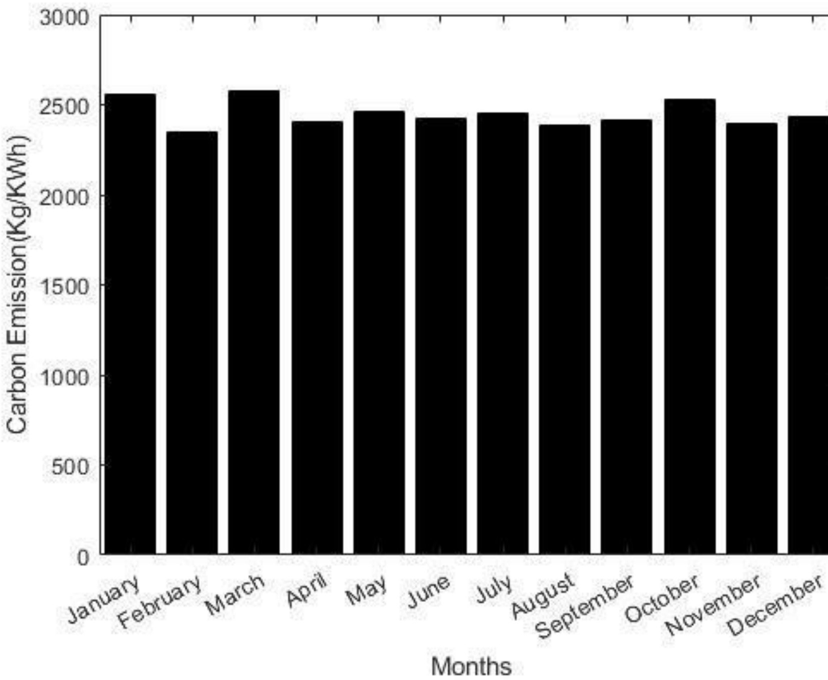

Figure 4. 15 Carbon emission without cloud impact

The month wise variation in CO_2 emissions in kg/kWh outcomes according to each month is shown in Figure 4.14 considering the cloud impact and in Figure 4.15 without considering the cloud impact.

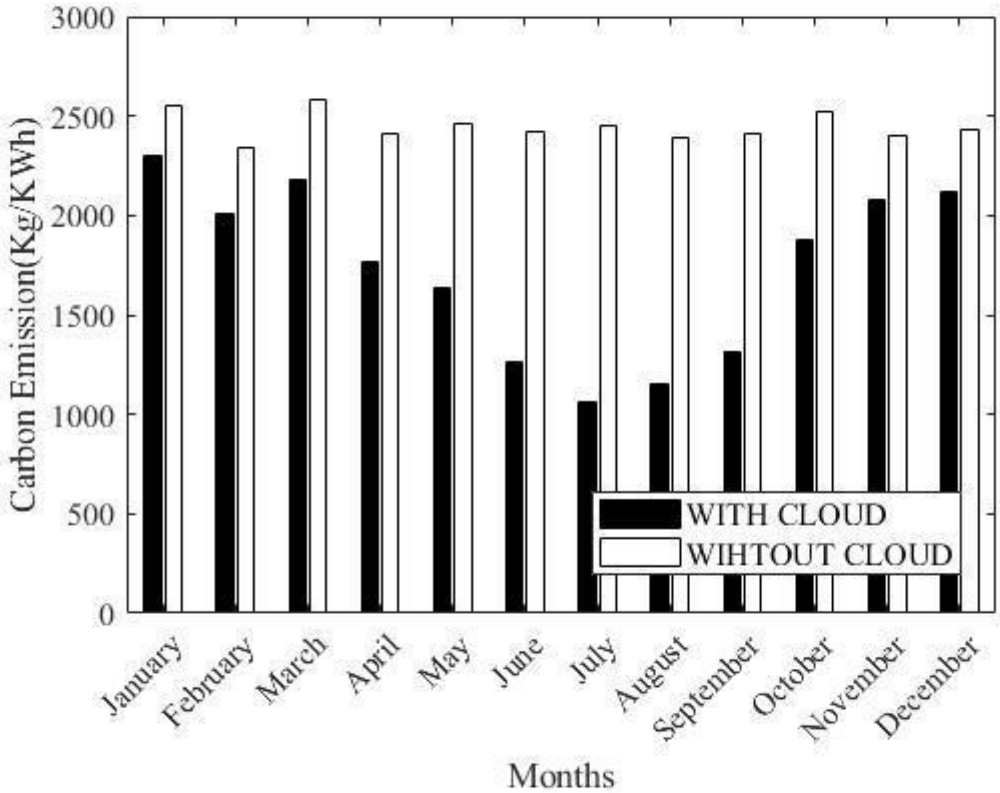

Figure 4. 16 Comparative analysis of carbon emission in kg/KWh outcomes between with cloud and without cloud impact.

The month wise comparative analysis of carbon emission in kg/KWh outcomes between with cloud and without cloud impact is depicted in Figure 4.16 and distinctly represents the reduced amount of carbon emission over the months. In Bangladesh, during the mid-year it is considered as rainy season. Therefore, the overall electrical output reduces. As overall output has reduced certainly it will contribute less for suppressing carbon emission. This phenomenon has been evident in plots plotted upwards during mid-year.

Chapter 5

CONCLUSION AND FUTURE WORK

The entire work has been designed and analyzed from the view point of energy analysis hence; some of the aspects of have been ignored such as, detailed protection scheme, miscellaneous expenses, in depth scientific discussion of wires or modules. After the discussion elicited, we draw the conclusion from technical, financial as well as environmental point of view.

The system has been designed using 70 batteries, 89 panels, and having output energy of 4649.805KWh. We have considered December's panel energy because this month his has the least amount of irradiance energy is achieved and in spite of that, the entire load of the building is filled up with the proposed scheme.

In terms of incident and irradiance energy we have seen diversified output graph for varying season, exposure to the sun, and day time. Reasonably, the roof mounted section (subsystem-01) has been seen to lead than south mounted (subsystem-03) or front mounted wall (subsystem-02) for incident and irradiance energy. Whereas, the final energy output after all the calculations and considerations, in spite of having such differences, do show difference in a minimal level. We have acknowledged that, the house is independent of and supply power to the grid for seven months and it requires assistance of grid power for the other five months.

This system is planned for 20 years of lifespan because after 20 years the performance of PV panels start to degrade. At the end of 10^{th} year 842.5774808 USD were more needed to achieve the positive net present value. After 11 years 2754.85 USD extra can be gained from the income of the system. In this study, the payback period is achieved after 10.23 years with 9% internal rate of return (IRR).

The total CO_2 emission reduction over a year from our 117KW BIPV system considering cloud impact and without cloud impact will be 20751.296 kg/KWh and 29370.048 kg/KWh respectively from this research. CO_2 emission reduction considering without cloud impact will be 587400.96 kg & considering with cloud impact will be 412550.92kg in 20 years.

However, the building that has been selected does not cover the entire scenario for the types of available building in Bangladesh. A comparative analysis of energy focused study with the high rise commercial and residential buildings can be regarded as a prospective work for a profound understanding. A probable obstacle is to persuade the future building owners to shift to BIPV system from mainstream or conventional ones. If the environmental as well as financial rewards of BIPV system are broadly broadcasted, then a considerable amount of conscious citizens are expected to start the initiation of supporting BIPV system. Government can contribute to substantiate this project by providing feeble loans, recognizing and appreciating the owners in national scale as a part of Sustainable Development Goal no-07 [38] as well as to execute the vision 2021-2041 [39].

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