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"Energy Retrofitting of Facade: Curtaining with Building Integrated Photovoltaic" (A Context of Kathmandu)

By

Shirjana Shrestha

A THESIS

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Declaration

I hereby declare that the thesis entitled **"Energy Retrofitting of Facade: Curtaining with Building Integrated Photovoltaic" (A Context of Kathmandu)** submitted to the Department of Architecture in partial fulfilment of the requirement for the degree of Master Science in Engineering in Energy Efficient Building, is a record of an original work done under the guidance of Ar. Yam Prasad Rai, Institute of Engineering, Pulchowk Campus. This thesis contains only work completed by me except for the consulted material which has been duly referenced and acknowledged.

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Energy Retrofitting of Facade: Curtaining with Building Integrated Photovoltaic" (A Context of Kathmandu)** submitted by Shirjana Shrestha in partial fulfilment of the requirements for the degree of Master of Science in Energy Efficient Building.

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Abstract

The use of renewable resources helps reduce reliance on fossil fuels, improve global energy security, and address environmental challenges, including climate change. Building Integrated Photovoltaic (BIPV) is on the rise because it serves the dual purpose of power generation and coordination of the indoor environment. This study demonstrates an analysis of energy innovation by BIPV on the façade of Kathmandu Valley buildings. Research is focused on comparative analysis of placements and types of BIPV in appearance that produce maximum energy. For this purpose, various types of BIPV have been studied and the appropriate type has been used for further calculations. PV sizing is conducted to build a manual calculation case, and for comparison, computer-based energy simulations were also performed using various software. The outcomes show that placing BIPVs at maximum efficiency on the east and south façades of the case building reduces 46.5% of the total monthly consumption units. Exterior energy innovations with BIPV can significantly reduce the building's monthly bills and serve as future energy mixes.

Keywords: Building Integrated Photovoltaic, Energy Retrofit, Solar energy, Building facade

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List of Acronyms and Abbreviations

AAGR	Average annual growth rate
AC	Alternating current
ACP	Aluminum Composite Panel
AEC	Architecture Engineering and Construction
AEPC	Asian Pacific economy Corporation
AH	Ampere hours
AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
A-Si	Amorphous Silicon
BAPV	Building Applied Photovoltaics
BIM	Building Integrated Modeling
BIPV	Building Integrated Photovoltaics
BOS	Balance of system
CDTE	Cadmium telluride
CHTC	Convective heat transfer coefficient
CIGS	Copper indium gallium selenide
CRE	Commercial real estate
DC	Direct current
DHM	Department of Hydrology and Meteorology
EMI	Equated Monthly Installment
EPBT	Energy Pay-Back Time
EPW	Energy Plus Weather file
EROEI	Energy Return on Energy Invested
ESIS	Employees State Insurance Corporation
ETFE	Ethylene tetra Fluoro Ethylene
EU	European Union
GHG	Greenhouse gases
GW	Gigawatts
HVAC	Heating, Ventilation, and Air Conditioning

IEA	International Energy Agency
kWh/year	Kilowatt Hour per Year
KWp	Kilowatt power
LCA	Life cycle assessment
MSU	Michigan State University
MW	Megawatt
NASA	National Aeronautics and Space Administration
NEA	Nepal Electricity Authority
NEB	Net Electrical Benefit
PJ	Peta joule
POA	Plane of Array
PTFE	Poly tetra Fluoro Ethylene
PV	Photovoltaic
PVF	Photovoltaic façade
Rs	Series resistor
RT	Thermal regulation
SELF/USA	Solar Electric Light Fund/USA
SHS	Solar Home Systems
STC	Standard Test Conditions
TENG	Triboelectric nanogenerator
TLSC	Transparent luminescent solar concentrator
TWH	Terawatt-hours
VAT	Value added tax
VLT	Visible light transmittance
WECS	Water and Energy Commission Secretariat
Wp	Watt peak
WWF	World Wildlife Fund
WWR	Window to wall ratio

Chapter 1. Introduction

1.1. Contextual Background

Renewable energy is the face of the future of energy. Renewable resources and knowledge be able to be well utilized to balance some or all of a building's electrical and thermal energy load. According to the new policy scenario of the International Energy Agency around the world, power demand will increase by about 80% between 2012 and 2040 (Elhalwagy & Ghone, 2017). The IEA believes that the clean energy revolution is critical to the world in breaking our dependence on fossil fuels. Today more than half of the world's population is in towns, and by 2050 that will almost double to a projected 6.4 billion people. Most of the growth in city population occurs in the average class and low income countries, where new risks are created and their ability to carry out existing risks reinforced by global urban migration is limited.

These rebellions improve universal energy security, encourage sustainable financial progress and solve ecological problems such as environment change. This breaks the long connection between financial growth and carbon dioxide (CO_2) emissions. The demand for energy harvesting technology is increasing as we continue to seek more environmentally friendly and efficient solutions. Engineers have created a variety of methods, including solar panels, wind turbines, and hydropower.

Given the current technology and market conditions, the most favorable renewable energy tools for generating electrical energy in buildings is solar power. Photovoltaic (PV) systems are frequently considered for rooftop installation, with façades being overlooked due to their unfavorable inclination (Freitas & Brito, 2019). However, PV façades can not only deliver a clean image to the building, but also function as an optimization of distributed power.

In photovoltaic technology, BIPV technology integrates the functions of the building envelope and PV modules into the building envelope. BIPV is considered as a building material with added PV functions to contribute to envelope functions such as mechanical stability, water tightness, noise reflection, insulation heat reflection, shading, etc. Building envelopes to which the BIPV module can be used on a range of building envelopes, the majority of which are spread on the building façade, which grows in size as the building rises in height (Yadav & Panda, 2019). If a PV structure is integrated into a building, a compromise must be found between the photovoltaic technology requirements of the PV system, the traditional functions that the building envelope must meet, and the aesthetic needs of the building. The degree of integration can vary widely, and it is difficult to evaluate.

The use of BIPV is widely recognized for the popularization and acceptance of PV. PV avoids the use of land for energy systems and reduces the cost of capital of the system by providing various purposes for multiple functions of PV components, for instance double use of the outer surface of the building. Especially from an architectural design point of view, building PV can transform a PV module into a familiar appearance of glass or a sloping roof that is better accepted than a traditional bulky PV module.

The energy integration of BIPV systems is an important aspect related to the new conception and energy supply of buildings. The orientation of the PV modules strongly influences the performance of BIPV systems. To support the energy transition, energy innovation in the building stock plays an important role, and the application of local renewable energy systems, such as solar power, is important. These energy supple buildings consume, produce, store and supply energy. The diverse types of modules used in BIPV include insulating PV glass, tailored PV modules for exterior ventilation, waterproof PV membranes and metal sheets with PV modules. Integrating solar power systems into the national power grid can reduce losses in transmission and distribution lines, increase grid resilience, reduce power generation costs, and decrease the need to finance in first-hand utility generation capacity. This helps policymakers’ of local government of the region work with respective provincial government strategists under the central government of Nepal to manage their energy systems.

1.2. Need

Buildings are among major contributors of greenhouse gases and consuming more than 40% of total primary energy (Agency, 2011). Due to the high population density of the world, buildings are being built rapidly. Buildings that are considered a high energy consumption set, especially when considering the existing building stock. Large glass openings on the building façade absorb solar radiation from the sun, reducing indoor air quality. The south façade of the building can be used for power generation using BIPV instead of glass windows. Therefore, it is necessary to remodel the energy of the existing building.

BIPV is clean, renewable and produces eco-friendly energy production. Building integration not only saves the space and cost required for separate mounting structures, but also has the advantage of including aesthetic improvements obtained by integrating renewable technology into the building's architecture. Most BIPV systems interface with the available utility grids. The advantage of the grid BIPV system is that the storage system is basically free in cooperation utility policy. It is also totally efficient and has unlimited capacity. Both building owners and utilities are profiting from grid BIPV. Solar contributions reduce the energy costs of building owners, while exported solar power helps support the grid during periods of huge demand of energy.

Electricity produced by Nepal's hydroelectric power generation business is often short supply throughout the four seasons. Trade electricity in India, a neighbor during a power shortage is essential backup in circumstances of shortage to fulfill the prerequisite demand. The BIPV system helps reduce these transactions and save the huge amount of money that must be paid to neighboring countries for energy exchange. There is also the need to diversify energy sources to enhance energy security. Therefore, it could be one of the important components of the future energy mix (Freitas, et al., 2020).

1.3. Importance

Firstly, Building Integrated Photovoltaic (BIPV) will help the country's infrastructure development because it will generate electricity. Not only that, it also increases industrialization. Declining electricity imports in India, the road to a self-reliant country. This technology can be easily used by the general public and economic benefits can be obtained from the government through various incentive schemes. More energy production is to increase the country's energy self-reliance. Solar energy has the least environmental impact compared to other energy sources. It does not generate greenhouse gases and does not pollute water. Being a renewable energy source, it promotes a healthy environment, minimizes the use of non-renewable energy sources such as petroleum products and gas, and ultimately helps clean the atmosphere.

BIPV can be used as a new material for the façade of buildings contributing to the architectural field. Thanks to new manufacturing processes, BIPV systems have evolved into innovative and attractive building materials both in urban and rural areas. The wide variety of colors, textures and formats currently available can be seamlessly integrated into roofs and façades to add aesthetic value to the building. Integrating PV systems into the national grid can reduce transmission and distribution line losses, increase grid elasticity, reduce power generation costs, and reduce investment requirements for new utility power generation capacities.

1.4. Problem Statement

Developing countries like Nepal need to refrain from using fossil fuels and focus on renewable energy and energy effectiveness to meet the growing demand for energy, according to the paper released in an event on 2019 from World Wildlife Fund (WWF). There is a big strain between energy supply and demand. Vulnerability of supply and reduction of foreign exchange reserves due to existing dependence on energy imports. Nepal is growing overly reliant on fossil fuels; petroleum product imports against Nepal's commodities exports have increased from 24% in 2004 to over 200 percent in 2019 (MoF, 2018/19) .Nepal, on the other hand, relies primarily on hydropower for its energy demand. Solar and wind are recognized as important complements to solving the energy crisis.

With rapid population growth, there is increase in commercial buildings and With increasing economic activities, the need for energy (especially fossil fuels) is growing faster in the valley along with other suburb regions like Pokhara, Biratnagar, Dharan, Dhangadhi, Janakpur, Itahari and other provincial capitals than in the rest of the country. BIPV system can be used for the alternative source of electricity for the buildings. The BIPV system can be used as an alternative power source for buildings. With BIPV, the extent of solar radiation is abundant and it helps development. BIPV is increasing to regulate the indoor environment and fulfill the dual purpose of producing electricity.

According to a study done by Ng & Mithraratne, 2014, the energy payback period of PV glass is shorter than 2 years, and the lifecycle performance of six translucent commercially available BIPV windows in commercial buildings in Singapore compared to typical double-glazed windows in terms of environmental and economic performance. Later on, the analysis came to the conclusion that energy investment yielded were more than 35 times higher in returns.

1.5. **Research Objectives**

General Objective

The general objective of the thesis work is to energy retrofit the facade curtained with BIPV of a commercial building in a context of Kathmandu valley.

Specific Objective

The specific objectives that could be the basis of this topic are summarized as follows:

1. To find the type of BIPV that can be used in the building for maximum generation of energy.
2. To calculate the power generation from BIPV systems used in the building.
3. To analyze the cost as well as payback period of the BIPV used in the façade of the building.

1.6. Expected Output

This research found out suitable material that can be used in BIPV system. As the glass of the façade was replaced by the BIPV, this research helped find the correct angle of the PV segments placed as louvers in façade of the building so that it captured maximum sunlight. This study also calculated the energy generated by the BIPV and energy payback period after using BIPV.

1.7. Limitation Of The Study

Due to the time limitation, the study was focused only on the selected place and not for whole municipal area. This study also does not account for the product components itself. Different components and materials of solar PV could generate a different energy output, regardless of the variable force. As well as, the research does not include the manufacturing processes of BIPV.

1.8. Validity Of Research

The literature review is done in order to indicate validity of above mentioned research purpose. There are many researches done in this topic all around the world but not in our context. This research will bring use of BIPV to the cities and helps NEA grid with the electricity generation through it. Unlike water, sunlight is abundantly available regardless of the season, so electricity can be stored and used later. BIPV is now a necessity in the future, given fossil fuel consumption trends and increasing urban trends in most parts of the country. If we do not consider alternative energy to meet the demand, it will be very difficult to meet the future energy demand. Although not promised that BIPV will meet all demand requirements on its own, it may be considered one of the major competitors standing as an alternative to fossil fuels. This research is suitable for the study.

Chapter 2. Literature Review

2.1. Historical Background

2.1.1. Chronological Development of Solar Photovoltaic

The sun has been the ultimate energy source since the beginning of life on Earth. It traces the unconscious utilization of all living things and fossil energy to a constantly coherent shower of sunlight. But the big part started when humans started using energy to transform it into other forms and use it in more versatile ways. The solar panels was first discovered by Becquerel's discovery (Chapin, Fuller, and Pearson of Bell Labs invent the first solar cell) in 1839. In 1954, Photovoltaic technology was developed in the US by Daryl Chapin, Calvin Fuller, and Gerald Pearson in the form of silicon photovoltaic cell at Bell Labs, the first solar cell capable of turning enough sunlight into electricity to power everyday appliances.

In 1964, NASA launched the first Nimbus spacecraft of satellites driven by a 470-watt photovoltaic array. In 1998, Subhendu Guha, a prominent scientist in pioneering research in the field of amorphous silicon, invented the state-of-the-art flexible solar cell roofing material, a roofing material that converts sunlight into electricity. BIPV construction products specially designed to be integrated into building face were commercialized in the 1990s. BIPV first appeared worldwide as roof integration in 1985 in Germany. Again, Germany underwent the first frontal integration in 1991. In recent years, Germany still considers itself a global leader in roof-integrated solar cells and has pioneered the largest global market for solar systems. Similarly, in 2000, world's largest solar power manufacturing plant in Perrysburg, Ohio, began solar energy production, which is estimated to be capable of producing enough solar panels annually to produce 100 megawatts of electricity.

Several nations have pledged to put sun's radiation at the core of their energy policies and to use solar power to meet a large portion of their solar energy demand. Power generation from solar PV is has approximately increased by 22% to 720 TWh. Due to these increases, photovoltaic power generation accounts for almost 3% of the world's electricity production. PV generation has surpassed biofuels to become the third-largest source of sustainable electricity after hydroelectric power and wind turbines. Solar power surged in Southeast Asia as Vietnam's new capacity surged from 0.1GW to 5.4GW. Additional capacity will increase in the US, European Union, Latin America, Middle East and Africa, offsetting China's downturn together and PV placement record year with 109GW installed in 2019. It's worth noting that in most nations, government support courses and grants have fueled the expansion of solar power.

2.1.2. **Solar PV development Trend in Nepal**

Solar energy has a long history dating back to the 1960s, when it was initially used to power transceivers by the Nepal Telecommunications Corporation. The Civil Aviation Administration and traffic signals also utilized it. With the help of SELF/USA, the first solar power system for home lighting was installed in 1993. This Solar Home System (SHS) included each system of 36 W PV panel 70 Ah battery. In Pulimarang of Tanahu area, a 10 W tube light was put in 48 houses. The centralized power supply by photovoltaic power generation was implemented by Nepal Electricity Authority (NEA) with the support of the French government in 1988 to build a concentrated solar power system in three places: In Pulimarang hamlet in Tanahu area, a 10 W tube light was put in 48 houses. However, neither of the systems are operational at this time**.** In 2018, construction of a solar energy plant (25MW) began in the Nuwakot district. In 2019, Nepal's Department of Electricity Development approved 56 solar power plants, which has been growing in recent days. The fall in the price of solar PV modules on the worldwide marketplace and the good purchase prices of electricity from NEA attract the private sector to develop International Policies about Solar PV.

Different countries around the world have different policies around the world. Some are discussed below:

In France, there is a Feed-in-Tariff system where self-consumption is not allowed. The entire production needs to be fed back to the grid. Charges for every kWh generated ranges from 11 to 72 c€/kWh depending on the size of the system. The RT Thermal Regulation aims to limit energy consumption in new residential and commercial buildings. This is in response to the application of some of the efforts to better manage energy consumption as defined in the Grenelle Environmental forum.

In Germany, there is a specific financial support mechanism called "Tenant Electricity Surcharges" for real estate owners who sell solar power to tenants residing in buildings. Power must be supplied and consumed within the building itself, and grid injection is not supported.

In Netherlands, it allows collective community solar where citizens can invest in big installations and are exempted from the energy tax and VAT up to a maximum of 10.000kWh (ICARES Consulting, 2019).

Solar panel innovation is a stated priority in China's Five-Year Plan (includes manufactured single crystal silicon cells with a minimum efficiency of 23% and commercialized multi crystalline silicon cells with a minimum efficiency of 20%.). Its government invests considerably in solar energy research and development in order to achieve these and other objectives (Ball, et al., 2017) .

In India, both the central and state governments provide subsidies to people who install solar rooftop systems. For these schemes, the government gives a 30% grant to countries in general areas. The national government provides up to 70% subsidy to special states such as Uttarakhand, Sikkim, Himachal Pradesh, Jammu & Kashmir, and Lakshadweep. Without a subsidy, the typical cost of installing a rooftop PV system should be between Rs 60,000 and Rs 70,000. To qualify for a generation-based incentive, the consumer must generate between 1100 and 1500 kWh per year (Loom Solar, 2021).

2.2. Energy Retrofitting

Energy retrofitting of existing buildings is a hopeful action plan to decrease the environmental impact of the building environment due to the low energy performance of existing buildings and the low expansion and construction rates of developed countries. Renovation, retrofit or remodeling of existing buildings represents an opportunity to upgrade energy performance during the continuous life of the assets of a commercial building. Remodeling can often improve energy efficiency, reduce energy demand, and include modifications to existing commercial buildings. Retrofitting may also be used at the right time to install distributed power generation in the building. Improving energy efficiency will not only reduce operating costs, especially in older buildings, but can also help attract tenants and secure market advantage.

2.3. Solar Photovoltaic System

A photovoltaic (PV) system is a system that captures the energy of the sun and converts it into useful energy, electricity. It can be defined as a system consisting of multiple solar panels combined with inverters and other electromechanical hardware that uses solar energy to generate electricity. PV systems can be of different sizes, from small rooftops or portable systems to large utility scale power plants.

Light hits the solar panel with photons (solar particles). Solar panels convert these photons into electrons, or direct current. Then electrons flow through the conductor to the various devices. A solar power system basically consists of two component modules and a Balance of System (BOS). The material responsible for making this transformation is called a cell. Batteries, inverters, and other accessories are among the BOS components. Electronic components, Charge controllers, cables, system installation, and management are all items that need to be considered. The four basic components of solar power are:

PV Array:

A solar panel is a set of specialized silicon cells to produce sun's energy and is the first element of a photovoltaic power grid. A solar panel is a set of specialized silicon cells to produce sun's energy and is the first element of a photovoltaic power grid. When a photon hits the surface of a thin silicon wafer, it creates an electric current.

Batteries:

Batteries are evaluated in terms of the amount of current they can supply in a matter of hours, or amp-hours (Ah). The design should ensure amp-hour capacity sufficient to account for periods of bad weather. An additional $1/5^{th}$ capacity seems to be sufficient to cover this situation.

Inverter:

An inverter is an electronic device or circuit that converts direct current (DC) to alternating current (AC). Input voltage, output voltage, and frequency, as well as overall power processing, depend on the design of the particular device or circuit. Power is provided from the DC source. The inverter does not generate electricity.

Charge Controller:

The charge controller is used to control the charging of the battery. The output of the solar panel is variable, and since it needs to be adjusted, the charge controller will get a variable voltage/current from the solar panel and adjust it to the safety of the battery. The main function of the charge controller is to prevent battery discharge from the solar panel to the overcharge load of the battery and to control the function of the load.

2.3.1. **Specifications of Solar panels**

Solar panels consist of multiple individual solar cells composed of silicon, phosphorus (providing a negative charge) and boron (providing a positive charge) layers. The solar panel absorbs photons and starts an electric current. As a result of the generation of photons that collide with the surface of the solar panel, energy causes the electrons to deviate from the atomic orbital and be emitted into the electric field generated by the solar cell, turning these free electrons into a directional current.

Electrical Specifications:

1. Peak Power (W): It is the maximum instantaneous power of the particular system over a long period. e.g. - P: 195 W

2. Optimum operating Voltage: At STC, it at max output, the panel's highest working voltage, Vmp: 36.6V, for example. It is used to determine the number of panels required in series.

3. Optimum operating current: It is the highest operating current of panel at the maximum power at STC. e.g. - Imp: 5.33A. It is used to calculate the power loss across the panels by determining the wiring gauges.

4. Open Circuit Voltage: Under STC, it is the output voltage when no load is attached. It establishes the voltage output and volume of components that can be placed in series.

5. Short Circuit Current: The number of bypass diodes is included in the protection level of the electrical casing at the rear of the panel at the time of usage. e.g.- Isc: 5.69 A. It is used to determine the conductor size and fuse to be used for safety has a power capacity.

6. I-V Characteristics: It analyzes the panel's voltages and currents fluctuation and display I-V curves for various irradiances. It is commonly used to determine the current of the module and voltage for a certain value of the irradiation value and is used to obtain the output voltage in the lowest irradiation for an area.

7. Module Efficiency: It is the module's conversion efficiency (which is generally lesser than the single solar cell used in the module). -15.3 percent, for example.

8. Operating Temperature: It is the range of temperature to function the module. e.g. - 40 C to 85 C. It is used to determine the temperature range for the environment in which the panel can be stored.

9. Max. Series Fuse Rating: It is the maximum current that the module can handle without causing damage. 15 A, for example. It is used to determine the fuse rating for use with the module.

10. Power Tolerance: It refers to the range of power departure from specified power ratings because of changes in operating conditions. It is generally defined in percentage. e.g. - 0/+5 %. It is used to determine the upper limit for power of a module.

11. Temperature Coefficients: It is described as the possible rate of increase of values in the presence of varying module solar irradiation and temperature. It may be used to determine the maximum panel voltage at the lowest predicted temperature and calculate the module's power, current, and voltage.

2.4. Building Integrated Photovoltaics (BIPV)

PV modules, which convert some of the available solar energy directly into electrical energy, and solar thermal systems, which convert solar energy into thermal energy, i.e.

heat, are the two primary categories of solar energy technologies. Building's shell and PV components into the building block in BIPV technology. At one time, the only option available for solar power installations was the familiar roof panel mounted on a metal frame. In fact, many people still think of solar panels as rigid modules added to buildings, so they often contradict the structure.

2.5. Types of Solar Panels

Solar panels are available in a variety of shapes and sizes to meet a variety of requirements. Solar panels are divided into three main types.

2.5.1. **Mon crystalline solar panels**

Mon crystalline solar panels are composed of monocrystalline silicon cut into wafers. Since silicone glasses (also called ingots) are cylindrical. If you cut them into waffles, they will get rounded edges.

Figure 2-2: Mono-crystalline PV

Figure 2-3: Poly-crystalline PV

Figure 2-1: Thin film PV

Polycrystalline solar panels (also called multi-crystalline) have solar cells that contain multiple fragments of silicon crystal. These fragments can be the rest of the monocrystalline solar production. They are arranged irregularly. They are then melted to form a solid block and then thinly sliced. Each wafer is more rectangular than your single crystal wafer.

2.5.2. **Thin-film solar panels**

Second-generation solar cells are thin-film photovoltaic built of a range of materials, including:

a) Amorphous silicon

b) Gallium arsenide

c) Copper indium gallium selenide

d) Cadmium telluride

Compared with other types, each wafer in a thin film battery is very thin and therefore flexible. Solar panels can be mounted on a roof, a boat, or an RV, or they can be mounted on a sturdy frame (rack) like other common forms of solar panels (magazine, 2020).

Table 1: Three most common solar panel types are summarized as:

Solar panel Type	Material	Efficiency	Cost	Appearance
Mono-crystalline	Clean, single silicon crystal	High (18 % or slightly greater)	Highest	Black or dark blue cells
Poly-crystalline	Silicon fragments	Average (15-17 %)	High	Blue four-sided cells
Thin-film	Numerous	Low (11%, but may attain 15%)	Lowest	Black or blue even surface

Solar panels also have other types based on the flexibility, transparency and other characteristics. For the aesthetics purposes also, in the entire world, various trials for newer types of solar cells are being conducted. Some are as follows:

2.5.3. **Solar roof Shingles/Tiles**

Solar tile, also known as photovoltaic tile, is a type of solar panel whose appearance and function are similar to traditional roofing materials (such as asphalt or slate tiles), and can generate electricity at the same time. Monocrystalline silicon solar cells, it should be mentioned, are extremely delicate and cannot be twisted. These flat solar shingles can still be used with common curved shingles, but special installation guidelines must be followed. The solar panels and protected glasses for the skylight tiles depicted in the illustration are contained in a depressed region on the tile's upper layer. To protect solar protection from environmental impacts, glass is employed as a shield.

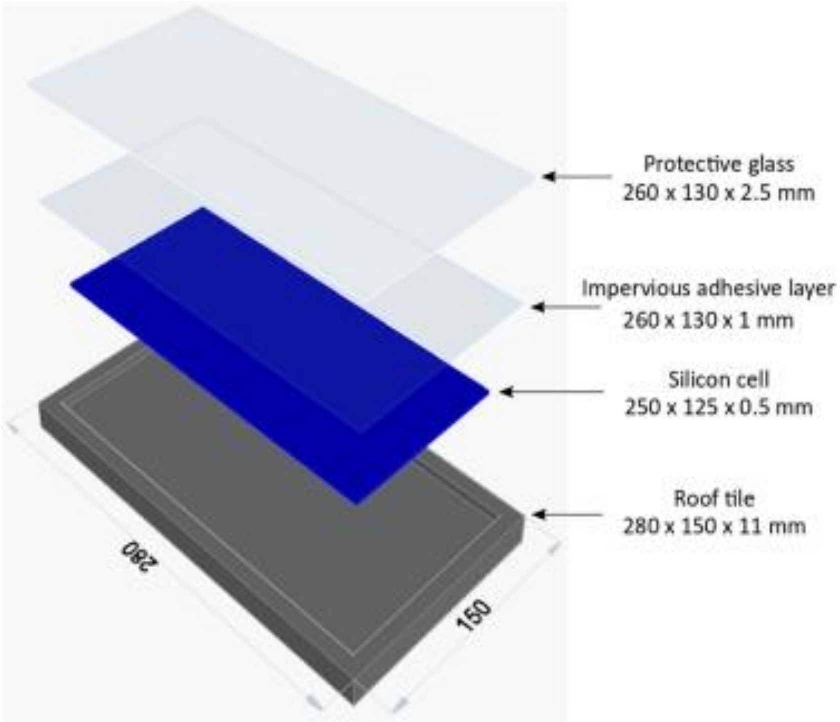


Figure 2-2: Schematic of the solar roof tile

2.5.4. **Flexible Solar Laminates**

Solar panels made on elastic silicon cells are especially appealing since they can be applied to new rising mobile and electronic devices. Its versatility, endurance, and low cost make it a viable power source for a wide range of electronic devices, including smartphones, smart clothes, and elastic recharging battery packs. Solar energy collecting efficiency rarely meet the intended effect during overcast days, rainy days, or at night (Chopra, et al., 2004).

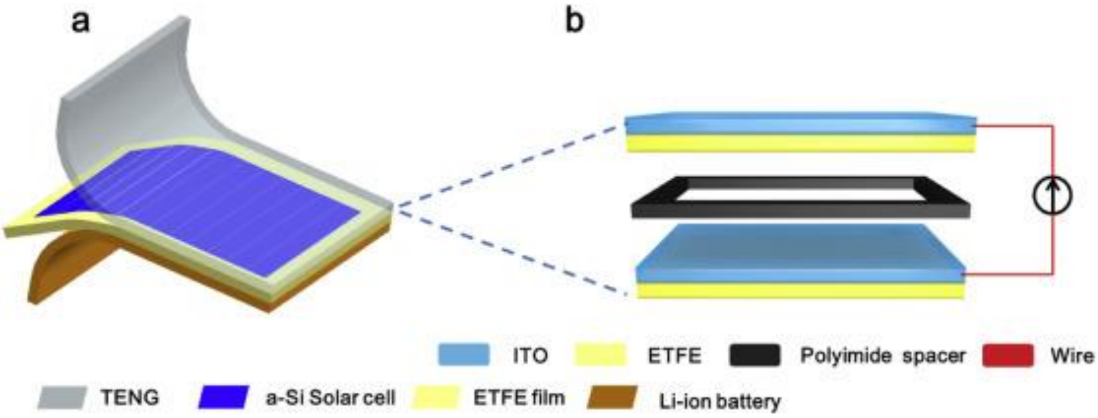


Figure 2-3: (a) the hybridized flexible energy collecting device's structure diagram. (b) An enlarged view to show the dual-mode TENG in greater detail

2.5.5. **Transparent Solar Glass**

Due to this innovative solar panel systems, the way photovoltaic absorb sunlight is improving. The cell works by tapping into a portion of the spectral region that is undetectable to the naked eye yet permits visible light to pass through. Instead of attempting to achieve the impossible aim using translucent Photovoltaic glass cell, researchers devised a Transparent Luminescent Solar Concentrator (TLSC) to achieve this technological marvel. Photovoltaic arrays that are translucent can produce power from business curtains, home windows, automobile sunroofs, and then even phones.

Solar window are now being developed using several technologies, similar to how numerous technologies (Tesla sun tile as well as other innovations) are now utilized to generate solar cells on roofs. Partially transparent solar panels and fully transparent solar panels are the two primary varieties of transparent solar panels.

Partially transparent solar panels

Heliatek Gmb, a German company, created this semi translucent photovoltaic panels which can receive roughly 60percent of total of daylight. The effectiveness of semitransparent solar cells is lower than regular solar photovoltaic, at only 7.2 percent. Moreover, by altering the proportion between received and collected sunshine, the solar irradiance electricity generated can be enhanced. In south-facing window structures, for example, decreasing radiated sunlight is frequently crucial.

Fully transparent solar panels

The efficiency of these fully translucent PV could be as high as 10%. When it comes to windows from solar panels here, it's vital to recognize that panel efficiency isn't everything, but it won't finish everything. In fact, an inefficient solar window just means you need to make the window larger equated toward a more proficient panel to produce the equal quantity of power.

Solar panel blinds

When using glass to produce power, photovoltaic cell curtains are used in combination to transparent crystal cells. Photovoltaic curtains merge two disparate roles in a seamless manner. Solar Gaps, an innovating company, has developed solar array curtains that, according to the firm, could save approximately 70% on electricity bills. Hundred watts of power will be generated by 10 sq ft of glass area. These photo voltaic blinds may be used inside or outside, as well as an application could be used to manage its degree and location as well as provide information about energy generation. It has a feature that adjusts the degree of the shutters conveniently depending on the position of the sunlight.

Figure 2-4: Solar Gaps in Solar window

2.5.6. **Economic impacts**

There are more ways in which solar energy can directly or indirectly benefit the economy. By reducing the usage of traditional energy in a household, it helps maintain the natural ecosystem and reduce taxpayer-funded cleanup work and potentially devastating oil spills. Photovoltaic solar panels can be sold back to local utilities that generate more energy than they use and spend more money on financial investments.

Pay Back Period Method:

The asset reclamation period is called the payback period of the project. Payback period can be calculated assessing following data for a project:

- Overall Investment Value
- Grant
- Yearly Revenue
- Yearly Spending together with renovation expenses

Payback period can be calculated by using the formula illustrated below:

$$\text{Payback time} = \frac{\text{Investment value - Grant}}{\text{Yearly Revenue – Yearly Spending}}$$

2.5.7. **Environmental impacts**

The sun provides an excellent resource to produce clean and sustainable electricity without the emission of poisonous effluence and global warming. The probable environmental impacts connected with the land use of solar power and loss of habitat, water use and the use of risky substances in developing are significant, liable on the technology, including two broad categories of Concentrating Solar Thermal Plants (CSP) or PV solar cells. The size of a systems affects its ecological consequences, spanning smaller scattered rooftops Photovoltaic panels to big efficiency PV and CSP installations.

2.5.8. **Potential impacts**

Energy from the sun has been recognized as an environmentally friendly energy source. Photovoltaic modules manufacturing technique (which converts energy to electrical energy) necessitates a high intensity yield. The primary source of sun power's negative impact on the environment is the photovoltaic panels' producer. The manufacturing of solar panels uses a lot of energy and generates a lot of effluent and harmful by-products that are then emitted into the environment.

2.5.9. **Benefits**

The benefits of solar energy is not only sustainable but also renewable, which means it is never-ending. The generation of solar energy is mostly maintenance-free. Solar panels are installed and optimally operate at maximum efficiency, and the annual maintenance required to ensure they are functioning properly is negligible. Solar panel technology is constantly advancing, making it more cost-effective as it can improve efficiency and reduce manufacturing costs. Many everyday items, such as calculators and other low-power devices, can be effectively powered by solar energy. World oil reserves are estimated to last 30 to 40 years from now on. Meanwhile, solar energy is infinite (forever).

Building Integrated Photovoltaic (BIPV) is one of the most promising and elegant ways to quietly generate on-site power directly from the sun without environmental pollution, other source pollution or depletion of resources. As it is a new, efficient, and prospective implementation for attaining a net zero - emissions structure, the BIPV system has a great commercial viability for BIPVT around the globe.The highly transparent glazing material of the BIPV system is a major advantage. It provides a variety of functions, such as shading, by increasing energy yields and providing additional contributions to development.

2.5.10. **Drawbacks**

Solar energy does not cause pollution. Solar energy has "collector" buildings, but there are other devices that convert solar energy into electricity. However, plain and other related equipment/machines are manufactured in the factory and induce some pollution.

The efficiency of photovoltaic power generation is based on the location and availability of sunlight. Another drawback of solar energy is that it depends on the sun. At night, electricity cannot be produced, so surplus energy generated during the day must be stored or connected to an alternative power source, such as the local power grid, which is an additional cost to that of high cost of solar panels. The main barrier to producing solar electricity on a global scale, according to most people, is storing significant amounts of electrical energy. Solar panels need extra support to attach securely to the weight of the panel. If the roof is not durable or weak, the panels can crack or "flatten" the roof over time because of the added weight.

Factors affecting performance of PV system

Like everything else left in the sun, solar panels are degraded by ultraviolet radiation. Sun is a tremendous resource for providing clean, long-lasting electricity without polluting the environment or contributing to global warming. Several factors influence the external efficiency of Photovoltaic panels. These kind of problems are caused by the unit, while others are caused by the module's position and atmosphere. Some of these key elements are discussed below.

Degradation of PV Module

Solar power system manufacturers usually guarantee the performance life of their modules at 25 years. The warranty curve generally promises that the module will produce at least 90% of its rated capacity in the first 10 years, and around 80% in the next 10 to 15 years.

Solar Radiation difference

The enactment of photovoltaic units under different lighting circumstances will be considerably different that will have a serious influence on the performance of the photovoltaic system.

Module Temperature

Like other semiconductor devices, PV cells are extremely temperature sensitive. The efficiency and power output of PV batteries decrease as the temperature increases.

Fill-Factor

A Photovoltaic cell's fill-factor is determined as the percentage of max output to the product of Voc and Isc.

Parasitic Resistances

The PV cell series and shunt resistors, called parasitic resistors, increase the I2R loss and ultimately reduce the efficiency of the module. Series resistance (Rs) indicates the internal resistance of the PV cell.

Shading

Due to shading, the currents generated in the individual cells of the module do not match**.** Like all units were shadowed, partly darkening a cell could considerably decrease the total wattage of the modules. Darkened units produce significantly less power than non-shaded cells. The identical current passes through each of the module's units because the units are placed in series. If more current than the shaded capacity is forcibly transferred through the shaded cell, it can overheat and be damaged.

Soiling

The collection of sand, grime, and other pollutants on the Photovoltaic modules is known as soiling. It forms a thin screen on top of the module to reduce the light falling on one or more cells. The collection of sand, grime, and other pollutants on the Photovoltaic modules is known as soiling.

PV Module Orientation and Tilt Angle

In the northern hemisphere position, the PV module should point to true south which is different from magnetic south shown by a compass. In the other direction, shade affects the efficiency, so the intensity and duration of sunlight is very different. Modules heading north will always be under some shadow, and in winter the effects are even worse. This is the worst case and should be avoided.

2.6. Application of BIPV

There is a wide range of applications for solar panels. Below are listed a few applications of BIPVs:

2.6.1. **Façade**

PV is integrated into the sides of the building, replacing existing glazing with translucent thin films or crystalline solar panels. It has less surface area than these rooftop systems, but offers the benefit of increased usable area.

Figure 2-6: Solar PV as facade

Figure 2-6: Roof Top PV (Lumen Solar)

2.6.2. **Rooftops**

PV material replaces the roof material, sometimes; the roof itself. They are all-in-one solar rooftop solar singles that can be integrated.

2.6.3. **Glazing**

Ultra-thin solar cells can be used to produce translucent surfaces, which allow sunlight to pass through while producing electricity. These are often used to create PV skylights and greenhouses (Anon., 2015).

Figure 2-7: Solar Transparent surfaces (Onyx Solar)

2.7. Obstacles and Challenges of BIPV

Despite the great potential and advantages of using solar energy, there are several barriers to overcome. One of the main challenges is the low user interest in BIPV installations due to the higher early expenditure cost. Below are the barriers and challenges of solar BIPV technology.

2.7.1. **Social**

- Absence of procedural and promotion professionals in the BIPV field.
- Internal resources for data gathering, analysis, and project management are limited.
- Lack of skill in commissioning, development, operating and maintaining solar BIPV plans.

2.7.2. **Information**

- A lack of knowledge about the value of Solar recourses, as well as BIPV, equipment manufacturers, and prospective fundraisers
- Inappropriate education and capacity structure.
- Insufficient BIPV data for policymakers and civilized society mobilization.

2.7.3. **Technical**

- There is a scarcity of standard technologies
- Limited local production of special equipment.
- Photovoltaic products' advancements in technology have a restricted potential to produce consistent energy

2.7.4. **Policy**

- BIPV is given low priority due to nationwide plans and fragile application structures.
- Ineffective energy policies.
- No discounts or incentives for BIPV

- Rewards for corporate involvement are lacking and policy of contradiction between the Lords.

2.8. Solar PV potential in Nepal

It is especially popular in rural areas where other energy sources are expensive and unrealizable or unusable. Numerous technological outcomes are possible for Photovoltaic systems uses, which are simply explained here.

Two types of PV modules can be mounted described as below:

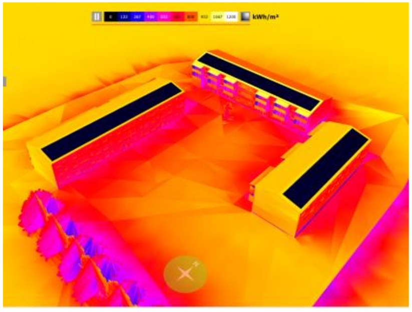
- **Set in an open area with PV panels installed in a stable location on the surface or on solar energy:** Solar trackers change the position of solar pv during the day to an even more comfortable position in reference to the sunlight, allowing them to gather more radiation from the sun.
- **Mounted on the roof or façade of a building**: PV modules in these structures are regularly connected in a non-optimal location (deviation since the optimal angle), resulting in lower efficiency ratios. Because to less excellent natural clearing, PV modules installed at a lower slope have a higher level of surface pollution.

In the case of Nepal, three kinds of a PV system which can be reflected have been described below:

- **Grid-connected PV**
- **Mini-grid PV**
- **Off-grid PV**

2.9. Research Findings on use of BIPV

Different researches have been done on this topic worldwide and some of the findings are as:

Research	Methodology	Findings
i. BIPV For A demo site in Ludvika, Sweden (Quintana,  2018) Figure 2-8: BIPV module's location	i. Build up building 3D models on a BIM platform (PVSITES) PVSITES workflow is done in seven stages here for modelling, simulation, analysis	i. Over a twenty - year period, the BIPV system has a 12 year repayment period and a 61 percent total investment. With the estimated standards costs of the BIPV installation of 35,700 € and repairs costs of 1785 €, Over a twenty - year period, the BIPV system has a 12 year repayment period and a 61 percent total investment.
ii. To use parametric Rhino extensions to build and test BIPV envelope (Freitas, et al., 2020)	ii. Rhinoceros software with Plugins Grasshopper and Ladybug to access and compare 7 institutional office facade Total strategy, counting 3D modelling, solar radiation, shielding devices and PV power simulation process	ii. The shape properties of the building were decisive for the total energy performance. Means of advanced ratios and smaller part of the building ratios were much more desirable Grasshopper/Ladybug allow for quick power and aesthetic simulations with a reasonable amount of precision and effort expenditure, while the Rhinoceros BIM platform offers the essential architectural details.

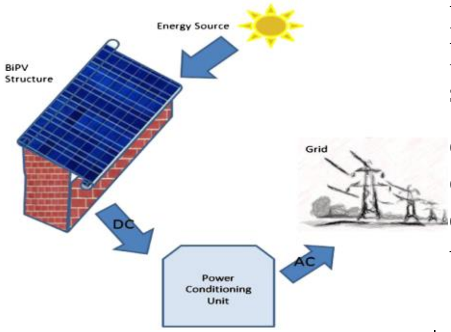
<table>
<tr>
<td>iii. A look at the results of a BIPV setup in Bangalore in actual time. (India) (Aaditya, et al., 2013)


Figure 2-9: Schematic diagram of BIPV</td>
<td>iii. Actual time BIPV performance of the system based on key climatic, location, and system data.

one parameter correlating the diffuse fraction and the clearness index</td>
<td>iii. Singular plan to enhance and the year system efficiency have shown a substantial difference (at an extent of 50%).

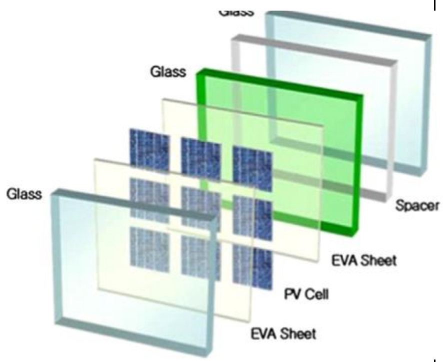
System losses remain constant as compared to capture losses with increasing solar radiation throughout the year</td>
</tr>
<tr>
<td>iv. PV glazing technologies
(Skandalos & Karamanis, 2015)


Figure 2-10: Schematic diagram of a c-Si-PV window</td>
<td>iv. In order to enhance the demand for ambient daylight while maintaining efficiency of the solar.

thin film PV are used for glazing systems</td>
<td>iv. System optimization is more important than PV module efficiency.

Partially translucent photovoltaic scanning efficiently saves power and offers value reductions and ecological profits.

PV window with ventilation can significantly lower the temperature and hence prevent heating.

The amount of opacity affects SHGC, effectiveness and internal illumination.</td>
</tr>
</table>

2.10. International Case Study

2.10.1. **Tehran, Iran; Energy performance of BIPV**

Introduction

The study contains details of the energy performance of BIPV high-rise office buildings in Tehran City and the power production by PV panels that operate in combination with façade. Non-OECD Asia (including China and India) will consume greater than 50% of the globe's total power between 2012 and 2040.BIPV simultaneously offers the benefits of electricity production, reduced chilling energy consumption, and decreased usage of external lighting and heating, as well as more effective usage of sunshine. According to literature reviews, most BIPV projects focus on energy generation rather than other aspects of thermal comfort whereas areas such as surroundings, economy, technology and social issues should take considered simultaneously.

Considering the shortage of BIPV-related studies in high-rise buildings, reduction of thermal energy consumption and improvement of residents' thermal comfort, this study is very important. With a designer-friendly interface (all processes were created in environment of grasshopper) and features as optimization and parametric design, these tools have been used for BIPV of building energy analysis and generation of high-rise management tower designs.

Methodology

The study was based on a selected 20-storey administrative building in the commercial district on Mirdamad Street, Tehran. This location was chosen because the annual average solar irradiance is 6000 MJ/m2 per year and the urban situation and city facilities can save by using BIPV in tall structures.

A suitable location was found and the size of the windows in different building directions was optimized. 3D modeling using 3D rhinoceros and locusts was done, then Grasshopper simulated energy usage power analysis was performed. The quantity of electricity generated by the photovoltaic panels as well as the strength of direct sun received by the structure were measured. Ladybug plugin was provided to track solar irradiation, BIPV model, and climate study taking into account construction of envelopes. With an increased performance of roughly 19.5 percent, a mono - crystalline solar cell has been used. The LG neon 2 solar cell was chosen for the simulations and was obtained from manufacturer's website. Shell material selection was based on ASHRAE 90.12010. Low-emissivity glass was used in the east, west, north, and pure glass in the south.

Findings

From the analysis of the Honeybee plug-in through investigation and observation, 934,540 kWh is the overall energy output of the building was for various uses such as lighting, equipment such as CPUs, and photocopiers. The goal was to provide 20% of the essential light power in June. It was considered because the apparent solar energy intensity is minimal in June, with a BIPV of 186,908 kWh.

It was observed that the optimal percentage of windows in all sides was 0%, which was lowest. Also, increasing the total of this WWR increased the overall energy of the structure.

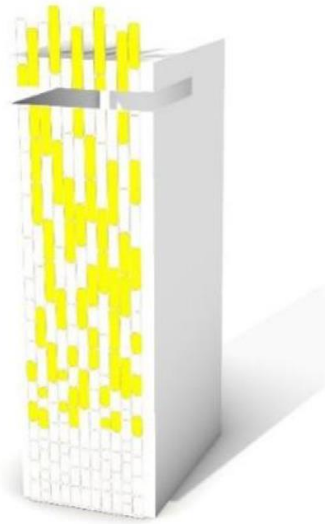


Figure 2-12: The positioning of photovoltaic panels in facade with regard to the number

Figure 2-11: 5.2 kW photovoltaic power station in Mashhad

Conclusion

The goal of this research was to create a tall building based on the premise of reducing power through the use of BIPV energy production. According to the simulation results, the average annual lighting energy consumption of the building is 934,540 kWh. To achieve the first objective 830 panels each 405W totally 336.15 Kw, provided 20% and 51.3% required electricity for lighting and equipment such as photocopier, in June and February, respectively. To validate the Ladybug PV simulator, a 5.2 kW solar power plant in Mashuhad was modeled with the Ladybug plug-in and compared with the real data recorded by the station. Comparison with actual data from a 5.2 kW solar power plant showed that the coefficient of determination between the energy production data was 0.928. To achieve the second purpose of reducing the building's energy consumption, the building was used with appropriate insulation. In this case, comparison of traditional basic materials from Iran was analyzed with the ASHRAE 1402017 Standard. (Hoseinzadeh, et al., 2021).

2.10.2. **Singapore: Performance of semi-transparent BIPV**

Introduction

This study considered the feasibility of long-term energy generation of translucent BIPV windows by employing In Singapore, there are six currently accessible thin-film components that can be used in offices. LCA method was used to evaluate the energy, carbon footprint and cost recovery associated with the consolidation of BIPV-generated power energy and emission intensity clear energy benefits GHGs reductions and reduction in expenses and appearanceIt offered a Photovoltaic judgment tool that was created to help architects and architectural designers make knowledgeable choices regarding BIPV modules selection.

Life cycle assessment of BIPV

The general framework of LCA was set up to be summarized as follows, following the instructions set by the International Organization for Standardization in 1997. LCA considers the following requirements and properties of PV systems, modeling methods for PV scheme LCA and guidelines for LCA result reporting and distribution.

Several studies have considered BIPV appearance integration with other technologies, including the use of avoidance cost technology to investigate the power savings of energy supply in Europe and explained benefits of adopting BIPV. It was estimated that the multi-Si module mounted on the façade required 2.9 MJ / kWh for mounting energy. The BIPV net intrinsic energy value, which was subtracted by BIPV by avoiding the intrinsic energy of the existing glass coating system, was reduced to 2.6 MJ / kWh. EPBT decreased in pure BIPV intrinsic energy in 4.8 years.

Semi-transparent BIPV windows in Singapore

From a holistic point of view, the translucent BIPV window energy performance assessment includes all energy related implications. A figure of merit called "Net Electricity Profit (NEB)" has been introduced that quantifies the electricity profit across a translucent BIPV window. The factors included in the calculation are the difference between solar power generation and natural light Cooling electricity

$NEB = L_{savings} – C_{electricity} + PV_{generation}$ [kWh]

L is the difference in artificial lighting savings by using natural sunlight. C is the difference in the energy consumption required for room conditioning due to the transfer of additional solar heat gains, and PV is the power generation capacity of the photovoltaic windows.

An analysis of the energy simulation results of the six modules in four major directions is given in the table below. The east and west (north and south) energy performance is very similar due to Singapore's sky conditions. They are displayed averaged (e.g. EW and NS). The translucent module increases the requirements for artificial lighting compared to the transparent double-glazed windows used in the default one.

For a holistic view, the energy efficiency ratings of semi-transparent BIPV windows should include all energy-related effects. (Ng, et al., 2013) Created the "Net Electrical Benefit (NEB) direct daylight and the variation in cooled power" performance measure to evaluate the electricity generated benefit of partially translucent BIPV glass.

$NEB = L_{savings} – C_{electricity} + PV_{generation}$ [kWh]

Where L denotes the amount of money saved by using natural daylight instead of artificial lighting; C, the differential in energy use for room cooling due to extra excessive solar transmission, and PV is the power generation capacity of the photovoltaic windows. The following table lists the features of a six commonly produced thin-film units used in the investigation**:**

During the investigation, a separation of the energy modeling findings for the 6 components from across 4 primary categories were evaluated. Due to the general atmospheres in Singapore, the east (and north and south) voltage output are relatively similar. Since the components are partially translucent, the need for artificial lighting has amplified compared to transparent double-glazed windows, which were used as a basic dwelling. Details about the study was released in (Ng, et al., 2013).

Environmental partially translucent

It is concluded that the PV manufacturing procedure and the equilibrium of the system make the greatest contribution for all modules.

a. Energy intensity of PV

The production of greenhouse gas emissions intensity of power produced by facade structures with all these components toward separate ways. Module 1 is the most efficient, using the least amount of energy and emitting the least amount of pollution, 240-310 MJ/kWh and 5 gCO_2eq/kWh.

b. EPBT and EROEI surveys

Over a 25-year period, the six modules provide a net electrical benefit (NEB) of 42,538-197,897 kWh and utilize 29,461-106,234 MJ more primary energy, lifespan than double-glazed windows. For all modules, EW orientations outperform NS in terms of EPBT. EPBT series from 0.68 to 1.52 and 0.87 to 1.98 for EW and NS orientation, with

1 module being the bottom and module 6 being the greatest. The maximum EROEI is found in module 1(26.75-34.39), while the least is found in module 6. (1.52-1.98).

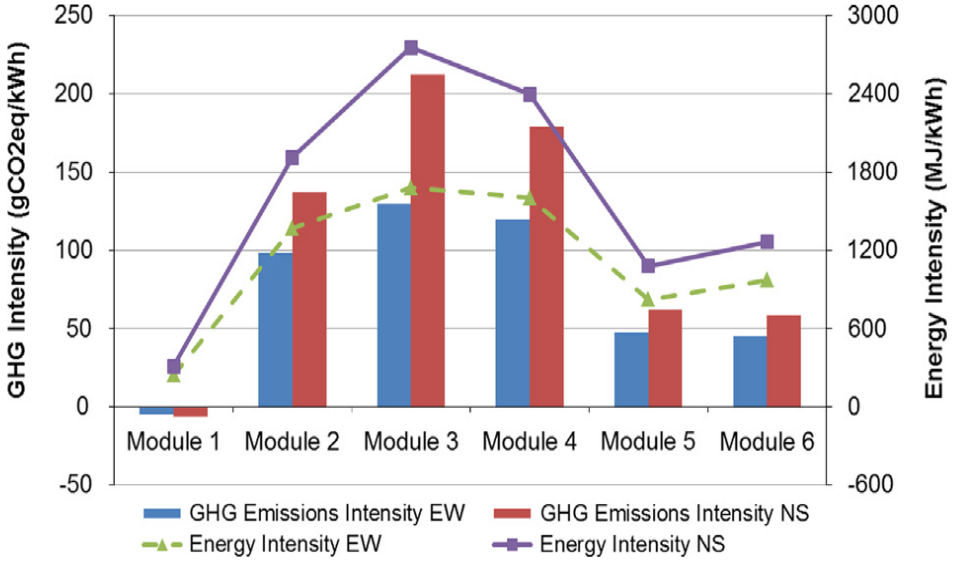


Figure 2-13: Power produced by BIPV components in terms of energy and GHG emissions.

Economic performance of semi-transparent BIPV windows in Singapore

The upfront costs of thin film BIPV windows includes the price module, aluminum frame supply and installation, overall balance, and repair installation. The price of energy is a significant aspect that determines the financial potential of LCA. The Government of Singapore covers up to 30 percent of total of the total investment price of Photovoltaic system in order to encourage ecologically favorable green construction technologies and green energy usage.

a. Payback period of BIPV window systems

Due to construction agencies, PV façade servicing is comparable with that of typical glass, thus it was not investigated. If the NEB is taken into account, the upfront cost of incorporating solar modules 1 and 2 can be returned in 13.1–17.1 and 1.1–1.5 years, correspondingly.

Conclusion

This study reviewed the LCA of six translucent BIPV in a commercial building in Singapore. These included environmental and economic performance compared to traditional transparent double-glazed windows. Module 1 (size 980X950, U-value 5.08 W/m^{2}K) could be used following regulatory or corporate environmental policy governing the use of the material. Module 2 (size 1300X1100, U-value 4.80 W/m^{2}K) could be chosen governing cost limit outlining the building development project. The results showed that the key life cycle stages that required the use of critical primary energy were PV module manufacturing and system balancing as according to (Ng & Mithraratne, 2014).

2.10.3. **Tianjin City, China: Parameters of transparent PV façade**

This study considered the link between the parameters and the power performance of BIPV and sensitivity of the design parameters using 2 types of transparent solar power with different transmittance. 6 PVFs were installed, and the final energy consumption of an office in China Cold Zone in Tianjin City was simulated in 5 directions. Every architectural variable's sensitivities to the structure's renewable energy rate was evaluated.

The transparent photovoltaic material that can be seen through.was an alternative to traditional glass**.** As a result, the process conditions of the directional CHTC and VLT of the solar façade (PVF) have a significant impact on a structure's electricity

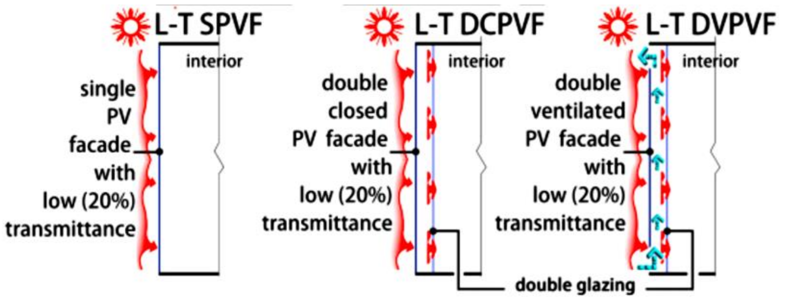


Figure 2-15: Different sections used in simulation process

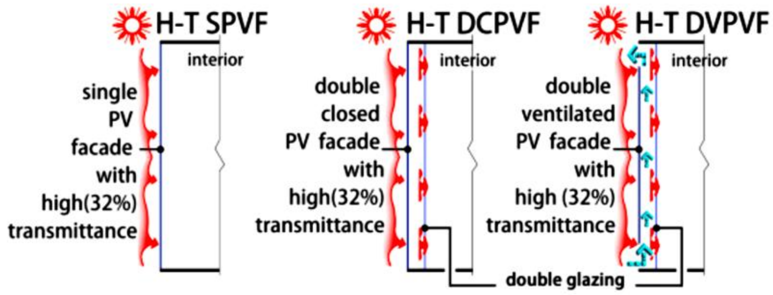


Figure 2-14: Sections of six photovoltaic facades

usage. Two transparent thin-film photovoltaic materials with different transmittance were applied. CHTC of the façade was achieved through mathematical calculations and simulations in the software i.e. FLUENT. The survey considered only east, southeast, south, southwest, west considering solar power.

When PVF had a south face, the monthly development curve was an open parabola. Energy production progressively decreased from January, reached the lowest level in July, and then progressively increased further. When PVF was heading southeast and southwest, energy production did not change significantly during the three months, but rebounded after reaching a low level in July while gradually declining

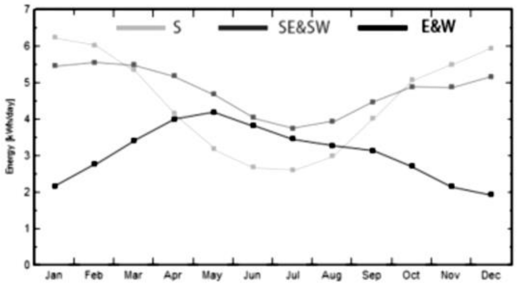


Figure 2-17 Output electricity of H-T PVF

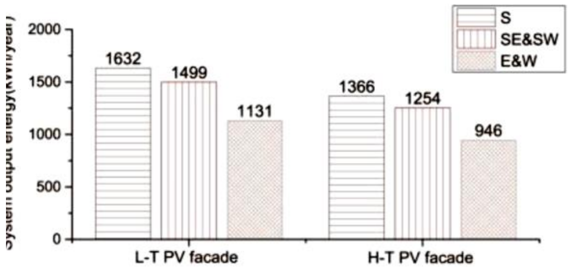


Figure 2-16: Annual system output power

Whenever the facade oriented southward, it saved the most energy, up to 61.22 percent, and the bottom when the PVF faced east, only 13.7%. The variation in renewable energy between PVF in the southeast and southwest was 1.08 percent or less. The west-facing PVF had a higher energy saving rate than the east-facing PVF, and the interval value was 0.55% to 3.59%. The orientation of PVF was perhaps the most sensitive to the room's conserving power rates, and highest responsive was CHTC. If the PVF was facing east or south, the direction was the least sensitive.VLT was the highest delicate, as was the room's power efficiency rate. The sensitivity of VLT and total heat transfer coefficient was almost equal in the front and southwest. The study was reviewed from (Li, et al., 2018).

2.10.4. Summary of the findings of above international researches:

Study Area	Reference	Methodology	Findings
Brasília, Brazil Tropical Climate	(Freitas, et al., 2020)	• Rhinoceros CAD software • Ladybug Comparison of seven Institutional	• Higher top layer ratios and relatively small part of the building ratios were more desirable.
Singapore, Tropical Climate	(Ng & Mithraratne, 2014)	• Life cycle environmental and economic performance	• Thin-film BIPV windows – cooling load and artificial lighting • Payback period of not more than 2 years
China Cold zone	(Li, et al., 2018)	• FLUENT Software	• South being the best orientation • Saved up to 61.22% south facade

Chapter 3. Research Methodology

3.1. Research Design

Explanatory studies were performed on previously poorly studied issues, request for priorities, creating operational definitions, and a better research models was requisite. It is a kind of research design that really focuses on explaining aspects of research in a detailed way. In the case of "Energy retrofit of façade curtaining with BIPV". The study is based on the post-positivist and constructivist paradigms. The research approach is also an inductive research approach that theoretically begun with the observations provided at the end of the research process for observation.

Therefore, this study used descriptive research and exploratory design to agree to increase electricity production by BIPV reducing the use of non-renewable resources.

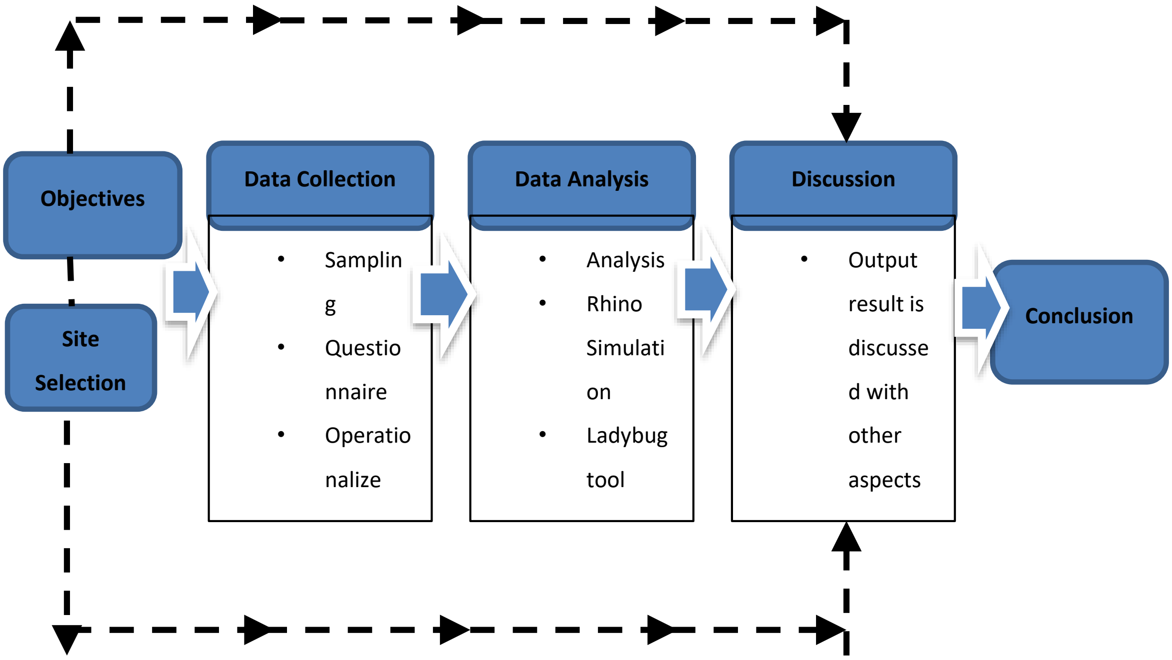


Figure 3-1: Conceptual Framework

This design provides a profile of the relevant aspects of the phenomenon of interest from an individual, organizational and industrial perspective. After 3D modeling by rhino 3D and implementation on Grasshopper, simulation was performed in the Grasshopper bee plugin and analyzed the strength of energy use. The quantity of power produced by panels, the intensity of sunlight on the structure was indomitable. The

Ladybug plugin was used to perform solar radiation, BIPV simulations, and climate analysis considering building hulls.

3.2. 3D generation models

Rhino is such a well and capable 3DCAD program that simply allows the creation of complex shapes and has a wide range of file standards compatible. This program was selected for its ease of application while making virtual models, its mutual use among professionals and architectural students, and the many plugins available to run purpose-built PV simulations. The shape of the building and its surrounding urban environment were modeled with Rhinoceros software and according to the acquired plan section façade. The availability of solar resources was simulated using the Grasshopper and Ladybug plugins.

Grasshopper is a visual algorithmic developer that works in conjunction with the Rhino design software. It is frequently applied in field of virtual modelling as a parameter model maker coupled to 3D rendering software. Modeling of parametric shows generation based on automated parameters of plan fundamentals. As a result, a set of algorithmic generation principles governs the generation and modification of components in a program.

Further energy simulations is done by ladybug which is a plugin which rely on multiple Energy Plus validation models and is simulated based on the Geometry and Target Position Climate File Energy plus Weather File (EPW) generated by Rhinoceros, Grasshopper.

3.3. Research Hypothesis:

BIPV on the façade can be a useful alternative to energy sources, even on a small scale. Along with this, it can be considered as a new approach for sustainability in Nepal. It also cuts greenhouse gas emissions by reducing the usage of non-renewable power sources.

3.3.1. **Ontology:**

Due to the need to reduce carbon emissions and reduce costs, the generation of renewable energies for most governments and technology sectors is becoming increasingly important at this time. As energy generated by solar energy, wind, waves and hydropower can be one of the alternative energy sources.

The power generated by this method (the energy generation by the BIPV system) is environmentally friendly, sustainable and is the instrument to reduce carbon emissions, however, it is considered as a huge payback period tool and generates a small environmental assignment. Therefore, there are concerns about the actual ability of this technology in the context of Nepal.

3.3.2. **Epistemology:**

(Gammal, et al., 2016) studied the feasibility of BIPV generation in the EU and suggested that the continued descending force on PV costs and rising interest of representatives in the implementation of self-consumption schemes will further fuel interest in BIPV. (Saretta, et al., 2019) review, provided a theoretical basis to support the creation of procedures and techniques aimed at making BIPV façades easier to integrate into different energy innovativeness at the city scale.

3.4. Research Methodology

The research methodology itself is based on an epistemological position defined by the ontological assumptions of the research.

To address the main research objectives, this study used both qualitative and quantitative methods and a combination of primary and secondary data. Because data analysis used both qualitative and quantitative data formats, the results obtained have been triangulated. This analysis focused on the amount of energy that can be converted to the monetary savings generated by the building's integrated solar power system. The correlation research strategy involved both social investigation and field observation to search for patterns. Analyzing the degree of correlation between these variables and patterns lead to the development of more generalized theories supported through field observations and literature studies. The survey asked questions in a closed, structured manner. The variables collected were analyzed using a correlation strategy.

3.4.1. **Data Collection**

Sampling

A purposeful sampling method for non-stochastic samples has been selected according to the characteristics of the population and the purpose of the study. Intentional sampling methods were used, including dividing populations and households into smaller groups called hierarchies. Since the study area had various subsidence dimensions, the specimen frame was close to the target and was selected as an option. Specimen households were selected for survey, regardless of social background, economic conditions, or livelihoods, and data were collected through structured questionnaires, manual checklists, and housing measurements for simulation.

Questionnaire design

Structured questions were formulated using various variable scales such as order, spacing, and ratio scales. The questionnaire consisted of four parts: a) general information, b) land and building descriptions, and c) energy consumption. Part (a) contained general information such as temperature and humidity. Part (b) had more descriptive questions for plot size and building. Also, part (c) dealt with the power consumed by the buildings in the context of lighting and other purposes, and these questions were limited to the field of study: solar radiation and thermal comfort.

Structured questionnaires were used for surveys in the Kathmandu Valley. The assigned sample size were investigated through this survey. Quantitative data was obtained from the survey. Microsoft Excel and SPSS analysis tool were used to analyze the information collected.

Operationalization

A subset of respondents were surveyed to collect their opinions on a pre-test questionnaire to verify the reliability of the completed questionnaire and were adjusted accordingly. After, field investigation, questionnaire were filled and on-site interview were conducted. Additionally, each survey site was qualitatively surveyed for the reliability and validity of the data.

First of all pre testing of the questionnaire were done for the credibility of the questionnaire formed by surveying it with some of the respondents and their opinions were gathered regarding the questionnaire and some adjustments were done accordingly.

After that, actual survey were done on site. Questionnaire were prepared and direct interviews were carried out at the site. Furthermore, for the reliability and validity of data, the respective surveyed sites were qualitatively studied.

Research Ethics

Research was done within the guidelines of ethical research of social behavior. The questionnaire was prepared avoiding discomforting discriminatory questions. After that, data was collected through the Correspond Independent Response.

Data Analysis

The data collected in the field through research was analyzed. Relationship strategies were used to identify correlations between variables and to conduct research that lead to research results.

Discussion and Conclusion

Interpretation of data analysis, simulation, and literature review results were discussed along with other dimensions that affected the results to order to meet the research 's objectives. Achieving this goal led to subsequent conclusions.

Chapter 4. National Case Study

4.1. Tri- Ratna Tamrakar Complex, Sitapaila

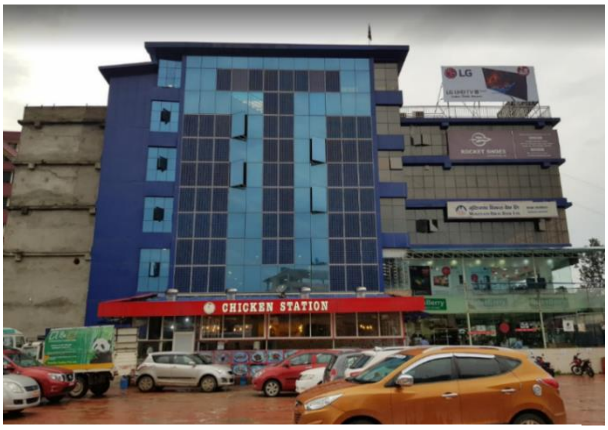


Figure 4-1: Polycrystalline Solar panels used facade of the building

A business center in Sitapaila, Kathmandu, where solar panels are used on the building façade. The building was completed in 2075 B.S.

Characteristics:

This 6-story building has a total of 64 solar panels placed in south of the building façade and is designed to provide existing design goals such as aesthetics and environmental control and energy generation. It is housed with shops like sales berry, chicken station, coffee shop in the ground floor, clothing store for all ages in the second floor, Muktinath Bikas bank, Sunrise bank in the third floor, furniture in the fourth floor and shoes and other offices in the fifth floor.

The use of energy from the solar is used for lighting purposes by all the spaces except sales berry supermarket because it has higher load.

Table 2: Each Solar module specifications used in Tri-Ratna Complex

MODULE TYPE	**RD250TU- 36CP**	
Peak Power (Pmax)	(W)	250
Production Tolerance	(%)	0 +3
Max. Power current (Imp)	(A)	6.61
Max. Power Voltage(Vmp)	(V)	37.81
Short Circuit Current (Isc)	(A)	7.07
Open Circuit Voltage (Voc)	(V)	45.40
Weight	(Kg)	18.0

Dimensions	(mm)	1640*992*35
Max. System Voltage	(VDC)	1000
Application class		A
Fire Safety class	(Pa)	C
Mechanical load tested		5400

Wiring as shown in figure connects these solar panels in parallel and DC current is distributed through the distribution box.

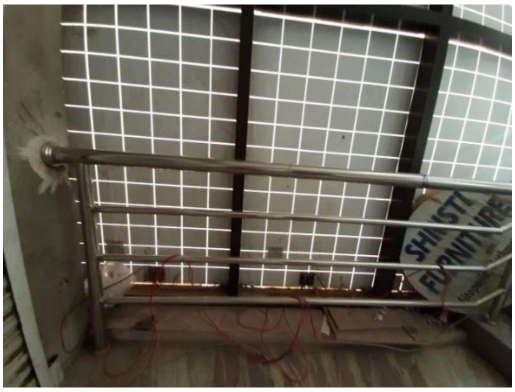


Figure 4-3: Parallel Connection between two solar modules

Figure 4-2: Solar- DC Distribution Box in the first floor

The current from the distribution box enters the charge controller capable of withstanding the short circuit current (Isc) of the plates. It also protects the battery from overcharging and over-discharging.

The installation of the solar inverter was made only one month before the time of study of the building. Otherwise all devices received DC current directly from the panel. The table below illustrates the technical specification of the inverter.

Table 3: Inverter specification:

Model: 50KVA
Battery Voltage: 192 VDC
Input Voltage: AC380±10% 50 Hz
Output Voltage: AC380±10% 50 Hz

Figure 4-5: Charge Controller

Figure 4-5: Low frequency three phase solar Inverter (50KVA)

There are 32 lead-acid batteries (150 Ah), which are connected in parallel combination and are used for the energy storage.

Findings:

Figure 4-6: Lead-acid Batteries used for the energy storage

Since the completion of the Triratna Tamrakar Complex, only direct current (DC) has been supplied to each load, but it is not efficient as the solar panel must supply the maximum current to the device. An inverter has recently been installed which further saves the system. The use of energy from the solar is used for lighting purposes by all the spaces except sales berry supermarket because it has higher load. The flow diagrams of PV panels and charge controllers, inverters, batteries and loads were also known.

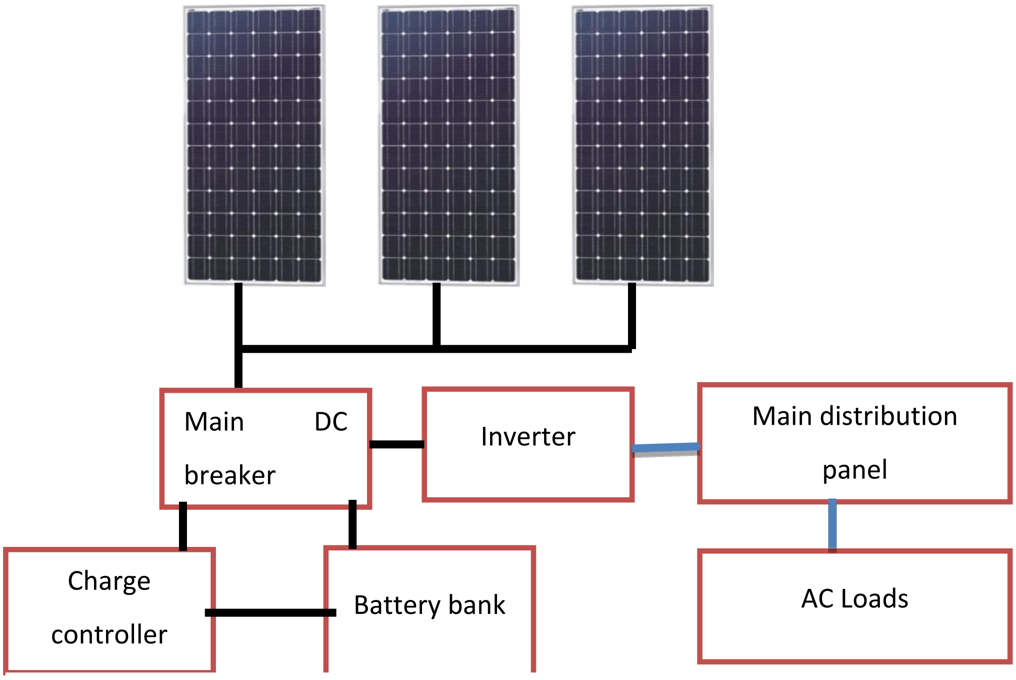


Figure 4-7: Connection diagram of solar panel with other components

4.2. Hotel Sarowar Pvt. Ltd (Swiss International Hotel)

The Swiss International Hotel Saar is a newly completed hotel built in a building that responds to climate, and it is the only hotel of its kind that has been in business since 2018 and officially opened in May 2019. It is the only hotel in town designed and developed in an environmentally sustainable way. The hotel uses solar energy as their main source of electrical load. To further complement Swiss international sustainability, the hotel is designed to recycle organic waste used in the hotel and uses geothermal heating and cooling on the two floors of the hotel.

Solar Energy as the Primary Source of Electricity

The sun's energies can be captured and converted into DC voltage via PV. This electricity is stored or used for household electricity. Solar panels are generally placed on the roof since it is the most feasible location. They are exposed to a great deal of straight sunshine and are generally sturdy without preventing them. Once the panel is attached, huge bolts will lock the panel in place that will create a roof-mounted solar panels. These mounts are drilled into the roof by the solar firms who attach the modules.

Figure 4-8: Solar panels on roof

A Solar system of 140KW has been installed. The total energy demand is 225KW, but based on the utility factor, the typical demand is only about 120KW. Part of the solar energy (50KW) is accumulated in the battery. This solar system is estimated to save about 10 million rupees per year in energy costs.

Figure 4-9: Solar panels on roof

4.3. Saligram Apartment Hotel and Spa, Jawalakhel

The Shaligram Hotel is located in Patan and spans two acres. The famous Patan Durbar Square is just 1.7 km away. A total of 98 solar panels were installed on building's roof and designed to reduce electricity prices in the long run. This solar panel was installed by Saral Urja Nepal Pvt. Ltd. with a 15-year contract with the hotel to use the space and pay the bill of the used units produced by the Solar panels. Fifteen years later, the hotel will own solar panels and is now an asset of Saral Urja.

Figure 4-9: Roof-mounted solar panel in Saligram Hotel

Net metering system has been adopted to control the power of the Nepal Electricity Authority. Net weighing metering is a billing mechanism that provides credit to owners of electric solar energy systems added to the grid. Net users are billed for net kWh using more energy than they provide in a month. Net production is billed for zero kWh for users producing surplus energy. Excess kWh is put into the national power grid. The figure above shows the connections between solar panels, inverters, net meters and national grid transformers.

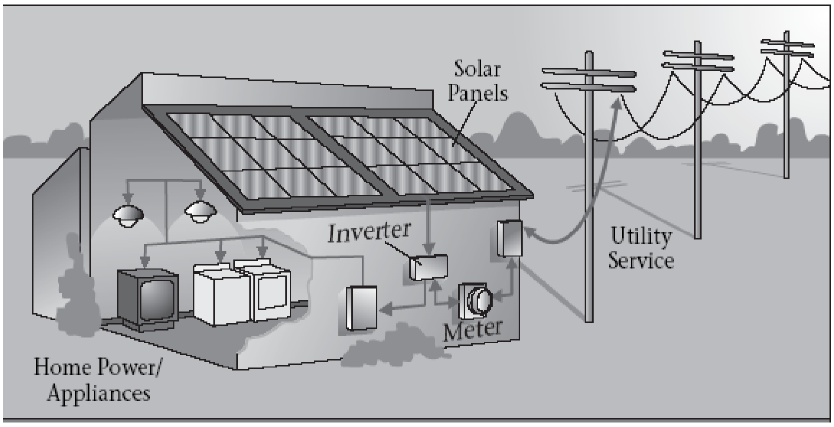


Figure 4-10 Concept of PV System Net Metering

Each Solar module is 250 W Poly-crystalline panels with the following specifications.

Table 4: Each Solar module specifications used in Saligram Hotel

MODULE TYPE	**TPS-P6U(60)-250W**	
Peak Power (Pmax)	(W)	250
Production Tolerance	(%)	0 +5
Maximum Power current (Imp)	(A)	8.26
Max. Power Voltage (Vmp)	(V)	30.30
Short Circuit Current (Isc)	(A)	8.80
Open Circuit Voltage (Voc)	(V)	37.20
Weight	(Kg)	18.6
Dimensions	(mm)	1640*992*40
Max. System Voltage	(VDC)	1000
Operating Temperature	(℃)	-40 to 85

The load of the hotel is higher than that of production by solar panels due to space limitations, and only 98 solar panels have been installed. Here, a 25 KW PV solar grid tie inverter is being used for DC to AC conversion. Few energy is being sent to the NEA if excessive power is generated. 14% to 20% of the total number of units per month is being used from solar energy installed in the building.

MODEL	**SUN- 25KW-G**
DC Input Voltage Range	200V-1000V dc
MPPT Voltage Range	200V-1000V dc
Max. Input DC Current	20* 28.5 A
Rated AC Operating Voltage	3W/ PE 400V
Rated AC Operating Frequency	50/60 Hz

Rated AC Operating Current	36.2 A
Rated AC Operating Power	25 KW
Operating Temp Range	-25 to 60(°C)

Therefore, due to space constraints, it can be confirmed there is decline in interest for installation of solar energy systems, and that there is no government stimulating effort to facilitate the introduction of this energy. The governments at all three levels, viz, local, provincial and central needs to subsidize the installation of PV systems so that surplus energy is transferred to the national grid system.

4.4. Market study of components of Solar PV

Various component's quality, manufacturer brands, warranty/guarantee and after trades service regulations remain the main factor to regulate the scheme amount. It has been detected that the amount is different for identical scheme. The system price changes strongly at the end level of the user. Surveys of the two companies were randomly carried out to support service cost calculations.

When it comes to the range of solar goods accessible in the Nepalese markets, there are over 180 distinct kinds of solar panels (44 different manufacturers) with energies ranging from 10 Wp to 350 Wp. Over 25 local PQ firms are actively involved in bringing these goods to the Nepalese market. Replacement batteries are imported or formed locally. Currently, the native market offers ten distinct kinds of batteries from four various manufacturers. The batteries are imported by ten local Power quality businesses (mainly from India and Bangladesh). Likewise, the market now has 18 distinct types of controllers from ten various vendors. They range in size from 3 to 60 A and thus are supplied by ten various local enterprises.

PIT and Random Sampling Tests must be passed by all goods. Efficiency, wattage and other tests are done by the NAST before import and also random test after the import as well. The test components of the Solar PV system requires different periods of time. Brands are not important to the quality of the most important product.

Chapter 5. Project Area: Kathmandu Valley

5.1. Introduction

Nepal is small nation with extent of 147,181 km² and having an average increase of more than5%, it is among the fastest - growing cities in South Asia. (Muzzini & Aparicio, 2012). The expansion of the city beyond its historical core area began in the Kathmandu Valley in the 19th century. Rapid urban growth among the valleys occurred after political changes in the 1950s. Especially after the construction of the ring road, the pace of urbanization accelerated from the 1970s to the 1980s. The process of urbanization is fast**.** Need for power is increasing as a result of fast population expansion and growing economic activities is increasing more rapidly in valleys than in other regions. In recent years, air pollution has emerged as a major environmental problem in the Kathmandu Valley. Historical background of energy consumption by commercial building

Figure 5-1: Map of Kathmandu valley; Kathmandu, Bhaktapur and Lalitpur

The tremendous increase in global power consumption has caused alarm around the globe, and forecasts indicate that this pattern will persist. According to the IEA analysis, buildings will consume the most energy in the economy, accounting for more than one-third of total final energy consumption and will be equally responsible for global CO_2 emissions in the future. The corporate sector has a lot of possibilities for energy conservation and sustainability development. The power consumption of commercial construction accounts for 7% of overall power generation. Hvac systems account for over 60 percent of total power usage in buildings (Lapisaa, et al., 2018).

5.2. Energy consumption pattern in commercial sector of Nepal

The business sector in Nepal used 1.3 percent of the country's overall power. Power consumption by sector is minor in Nepal, but dependable projected energy need is a necessary condition for the long-term utilization of available energy resources. From 1996 to 2009, the average annual growth of fuel wood was 5.74 percent. Likewise, 0.12 PJ of LPG was utilized in 1996, and it climbed to 2.29 PJ in 2009, having a 30.41 percent annual growth rate. In this time, the consumption for electricity climbed at an annual rate of 7.44 percent, rising from 0.226 PJ to 0.56 PJ. Of the fuel, kerosene fell from 1.09 PJ to 0.30 PJ over the equal time period, with a -6.4 percent AAGR. Cooking, like in the domestic sector, is the most energy-intensive final use in the corporate sector, accounting for 68.4% of energy consumed, led by lighting (19.3%), liquid boiling (0.3%), area heating systems (5.3%), and electrical services such as water pumps (6.7 percent) (Bhattrai, 2015).

From 2005 to 2030, the overall energy demand of the commercial part will increase 2.5 times, 3.1 times, 4.3 times and 5.7 times to 13.2 times, 16.6 times, 22.9 times and 30.3 times.

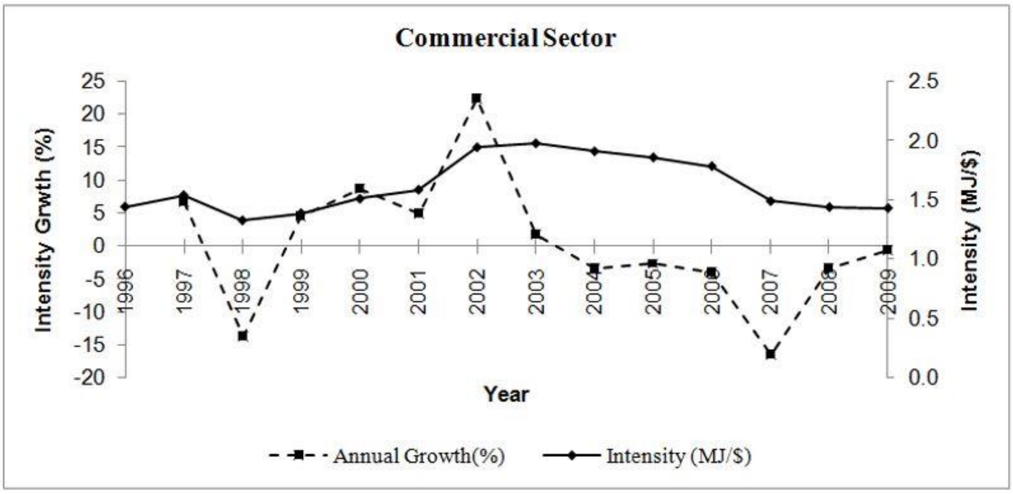


Figure 5-2 Commercial sector's energy intensity and intensity growth rate

Source: (Bhattrai, 2015)

Table 5: Trends in Energy Supply and Consumption, 1990–2014 (ktoe)

Items	1990	1995	2000	2005	2010	2014
Total Primary Energy Supply	5,789	6712	8108	9132	10211	11690
Coal	49	74	258	248	303	484
Oil products	244	501	713	724	983	1359
Natural gas	0	0	0	0	0	0
Hydro	75	100	216	216	276	326
Biomass	5425	6039	7928	7928	8592	9403
Total final Energy consumption	5761	6667	9050	9050	10107	11534
Industry	106	161	388	388	449	665
Transport	111	203	275	275	637	858
Residential	5465	6170	8128	8128	8718	9624
Commercial and public services	43	60	165	165	171	219
Agriculture/Forestry	33	60	75	72	118	151
Non-energy use	4	7	20	20	10	8

Source: (Agency, 2020)

Nepal's energy supply and consumption trends show an increase in energy consumption in various sectors. Data recorded every five years from 1990 to 2014 show a gradual increase in energy consumption in all sectors. Energy consumption can be expected to rise further in the upcoming years. From the data provided here in the table below, we can see that the final energy consumption of the commercial sector increased from 43 kilotons of oil equivalent in 1990 to 219 kilotons of oil equivalent in 2014. The increasing trend of cities and the improvement of the level of comfort, people will work in the building for a longer time, especially the energy use of commercial buildings will increase sharply, and maintenance along with new construction. Better design of things can be promising in energy policy. To minimize the power consumption of these buildings, heating, lighting and ventilation systems focus on energy efficiency.

There are variety of uses in the commercial sector, such as hotel facilities, health, service, offices, department stores, etc. Supermarkets and department stores in this field are used every day by all types of users because they have the daily needs of everyone. Therefore, the flow of people in this service is constant. Also, as the load continues to flow, energy demand is increasing year-round.

5.3. Energy consumption in Supermarkets and Departmental stores

The use of energy in supermarkets and departmental stores is because of the use of electricity, natural gas, etc. In the average supermarket, lighting and refrigeration account for more than half of overall energy consumption, making these systems the greatest sites to explore for energy-saving potential.

For supermarket's continued success and the quality of the customers' shopping experience, energy efficiency improvements may be essential.

5.4. Justification for the case

Supermarkets, departmental stores, and shopping malls are flourishing in Nepal in rapid way promoting development in the field of architectural and economic growth. There are different supermarkets like Bhat babhateni, blue bird, Namaste, Nepal Bazaar, etc. Among such, Bhat- Bhateni is considered as one of the leading supermarket and departmental store chain spreading in Kathmandu valley as well as in major cities around the country. Bhat-Bhateni is one of Nepal's most trusted and famous brand.

Public-oriented bhatbhateni building contains a large variety of products used in people's daily use. So, the flow of people is also maximum here as one can get any essential product in a single building itself. By using the energy efficient BIPV in this building, public interest on this may grow and be motivated to use of BIPV in other sectors as well. It is not limited to Kathmandu valley only, there are branches outside valley also, so it will be beneficial all over the country.

Talking about the design of Bhatbahteni buildings, it is identical and architectural uniformity maintained providing typical façade color, material, fenestration designs and plane geometry. The study for the single building can provide the solution for other

Figure 5-4 Location Naxal

Figure 5-4: Balaju Bhatbhateni

buildings as well. Similar techniques can be applied for bhatbhateni designed in the future as well as other commercial buildings can get influenced by this.

5.5. Background of BhatBhateni Supermarket

BhatBhateni Supermarket began as a “single shutter” 120 sq. ft. cold shop in 1984 by Mr. Min Bahadur Gurung, the company's Owner and Chairman, and has grown to become Nepal's top superstore and department chain, as well as the peak taxpayer in the industry, since 2008 A.D. There are currently 19 stores suitably positioned in Kathmandu as well as in other cities of Nepal. From our studies we found, the building orientation, envelop treatment and space planning for all region are quite similar.

5.6. Trend of bhatbhateni buildings in Nepal

From 1984, Bhat-Bhateni has grown from a small shutter 120 sq ft cold store to become Nepal's top grocery and department chain store, as well as the maximum tax contributor in the industry, with over 40,000 daily consumers. There are currently fifteen stores appropriately located in significant Kathmandu Valley and other in major cities of Nepal.

Figure 5-5: Koteshwor Bhatbhateni

Each level of Bhatbhateni in Anamnagar is equipped with various AHU. The complex was chosen for study because it is equipped with a centralized air systems and is operational for 6 months of the year. In addition, currently, great number of commercial buildings are being built in private and government sectors in major cities of Nepal. The energy consumption is comparatively high in commercial buildings; especially in shopping malls due to air conditioning units.

Figure 5-6: Bhaktapur Bhatbhateni

Table 6: Location of different outlets of Bhatbhateni

Established year	Location of Outlet
2008	Maharajgunj
2011	Koteshwor
2011	Boudha
2011	Pulchowk
2012	Pokhara
2012	Newroad
2013	Baluwatar
2014	Anamnagar
2014	Balaju
2014	Kalanki
2016	Bharatpur, chitwan
2016	Tripureshwor
2016	Dharan

2017	Butwal
2017	Bhaktapur
2018	Biratnagar
2019	Satdobato
2020	Nepalgunj
2021	Itahari

Within just 13 years of time, bhatbhateni has established 19 outlets, which is live a dream now also. It has a very good number of satisfied customers rather than any other supermarkets and departmental stores in Nepal.

The 19th branch of bhatbhateni i.e. Itahari, Sunsari opened just last week is considered to be the largest one in Nepal. The flow of people in the inaugurated date was unbelievable as it consists of different facilities than other. Playground is the center of attraction for the people. It shows the popularity of bhatbhateni among the public. It is expanding very rapidly all over the Nepal.

The maximum use of curtain wall has significantly increased the energy demand of the building. The aim to attain energy efficiency and sustainability can be achieved by alternation of the energy source used in the building. The free energy source i.e. sun can be used for the energy generation with solar panels being used in the building façade.

Most of the outlets of bhatbhateni are north oriented, Anamnagar bhatbhateni is south oriented which is good for the retrofitting of façade with BIPV.

5.7. Site Introduction

This bhatbhaeni Supermarket and Departmental store is located in Anamnagar, Kathmandu. It is easily accessible from putalisadak, baneshwor, thapathali, anamnagar. It is a four and half storey building with the overall floor area of 35913 sq.ft. With a centralized cooling system, the Energy level is air-conditioned.

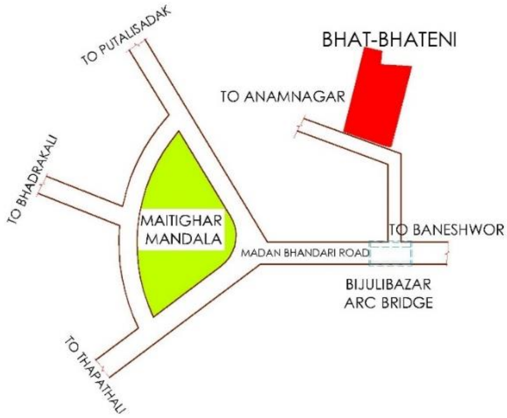


Figure 5-8: Location map

Figure 5-8: Site plan with sun path diagram

Bhatbhateni offers a wide variety of grocery; offers comprehensive selection of apparel, cookware, sports, kids, furnishings, and electronic goods; and a wider array of big global liquor, cosmetics, and makeup brands. The building is extended towards North-South long axis with the main entry toward South. It has rectangular plans and floors are differentiated according to the flow and requirement of people.

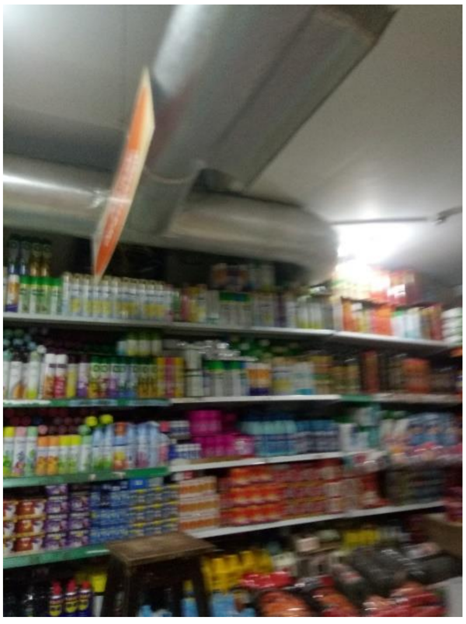
5.7.1. Energy consumption

Bhatbhateni supermarket and departmental store depend mainly on electricity, HVAC system, and refrigeration. Building envelope modification play an important role in energy optimization. BIPV can also be utilized to improve the building performance envelope. As this

Figure 5-9: Anamnagar Bhatbhateni

building uses energy all day for lighting purposes also, we can use BIPV in glazing for maximum energy generation. It is necessary to carry out the energy calculation from BIPV from the façade by simulation through different soft wares for energy savings.

Day-to-day activities and energy consumption of the building were obtained from survey of the site which helps in identifying the energy consumption pattern. In this area, 2500-3000 people visit daily in weekdays and 1000-1500 in Saturday. Although the flow of people is less in Saturday but it does not affect the products sold. This place lies in the office spaces, so here, the flow of people decreases in weekends, holidays. In the morning time, very few people visit here and huge flow of people after office hours. The opening hours of this building is7:30 a.m.-8:30 p.m.



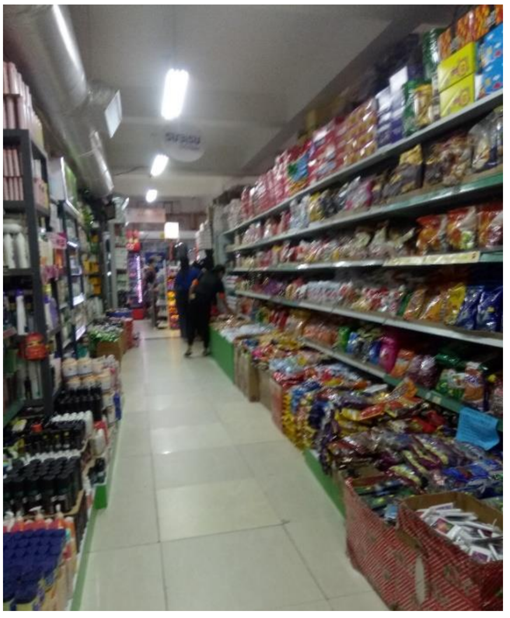


Figure 5-10: Photos of Energy consumption (lighting)

5.8. Building description

5.8.1. Zoning of the building

Both horizontally and vertically, every supermarket is divided in terms of different commodities. Parking is in basement, the ground floor is always used for the daily basic commodities i.e. groceries, food stall is in outer space. It is always a good idea to put food stalls outside the market because the shopping tires people down.

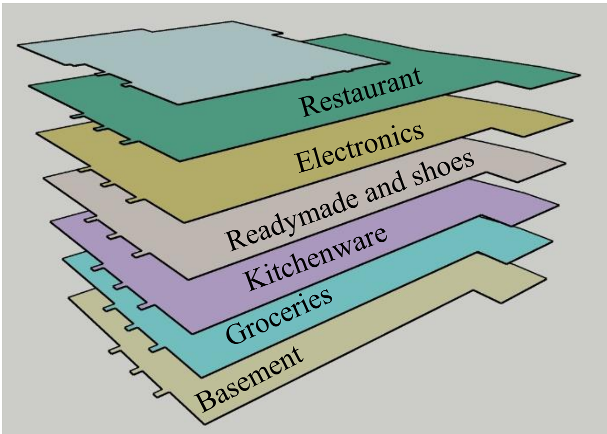


Figure 5-11: Vertical zoning

The first floor displays kitchen wares and other household items, second floor displays the fashion and accessories with variety of choices. Similarly, the third floor consists of least purchase but with high profit electronics items. Small portion of the top floor is used as restaurant and a service for HVAC chillers, motors, and water tanks and larger portion for terrace.

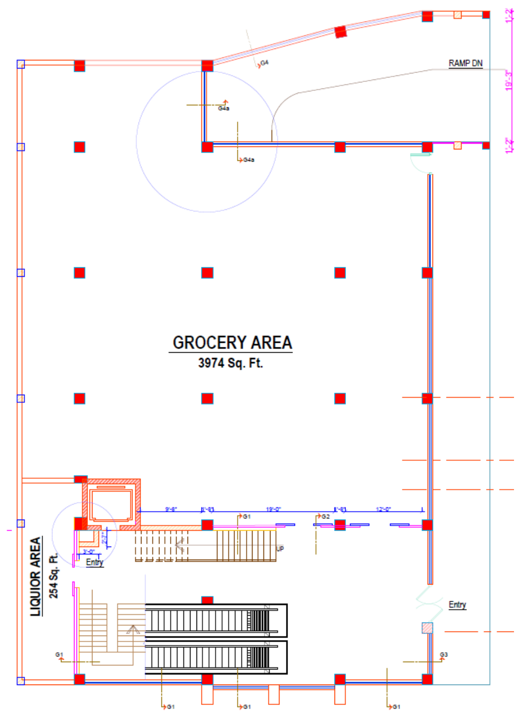


Figure 5-12: Ground Floor Plan

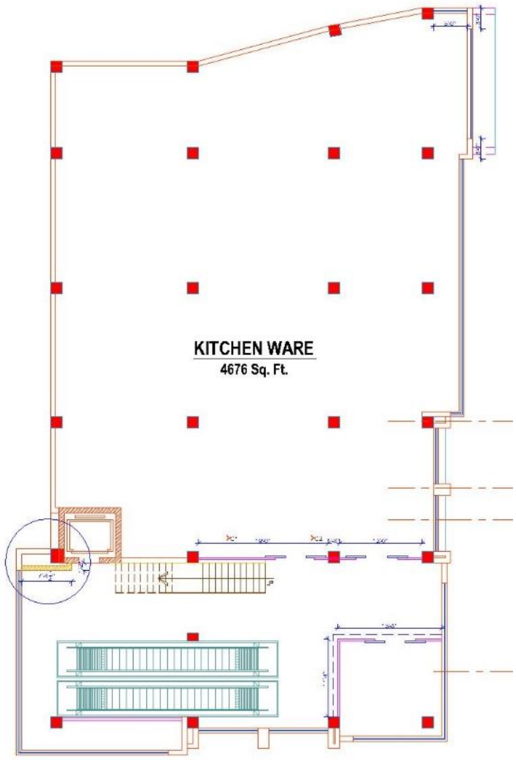


Figure 5-13: First Floor Plan

All floor have similar layout with display area toward north and escalator towards south. The two zones are separated by the central lobby space. The west portion contains a service area with elevator, staircase and toilet.

5.8.2. Building Envelope

Bhatbhateni Supermarket and Departmental store is one of the fastest growing chain recognized by a blue facade in Nepal, which is same in all building envelope throughout the country. The glazing is done mostly on the northern sides to admit ample light and exposure to heat is low on the north side.

Figure 5-12: View from Surface parking (East side)

ACPs are laid on the 9 inch thick walls that helps reducing the heat transfer into the building considerably. One of the greatest essential variables to address when analyzing the structure envelope's performance characteristics is window size.

Table 7: Description of the building envelope

Description	East	West	North	South	Total
Window area	2652.71 sq.ft.	498 sq.ft.	151.11 sq.ft.	2218.628 sq.ft.	5520.446 sq.ft.
Wall area	2670.58 sq.ft.	4799.09 sq.ft.	3365.95 sq.ft.	1404.75 sq.ft.	12240.4 sq.ft.
Gross Window-wall Ratio	49.83 %	9.4 %	4.29 %	61.23 %	31.08 %

For energy retrofitting with BIPV in the façade, the area of the window and wall should be well known. So, the above table is calculated with the help of drawings available from the Bhatbhateni. We can clearly see that south façade have large window and north has less. To gain maximum amount of sunlight, there is maximum glazing at east and south façade.

5.8.3. **Energy Load**

The energy load calculation of the building determines the consumption of energy of the building Overall energy can be evaluated by gathering the data relating to energy system and component specifications. Various types of loads is due to energy consumption by lighting, computer, Central AC, service devices (lift, escalator), security systems, grocery freezer, etc. about 600 lights are used here.

Lighting is the major component for the electricity consumption as the glazing in the east is blocked by the stack racks for showcasing the inside products. Lights are in operation from opening to closing of the building, only the lobby space lighting are partially offed in the day.

HVAC system is the major consumer for the load. Centralized AC is installed in the building which consists of cooler plants, AHU, fan cooling, etc.

Electrical load of the building is due to the escalator, lifts, motor, refrigerators, computer, power sockets, etc.

5.8.4. **Utility bills**

Electricity bill of 12 months i.e. last year (2020) was collected to calibrate the building energy model.

From the chart, we can see that maximum units is used in summer i.e. July and August and less in February and March. Maximum unit is about 28000 units per month seen in the month of August.

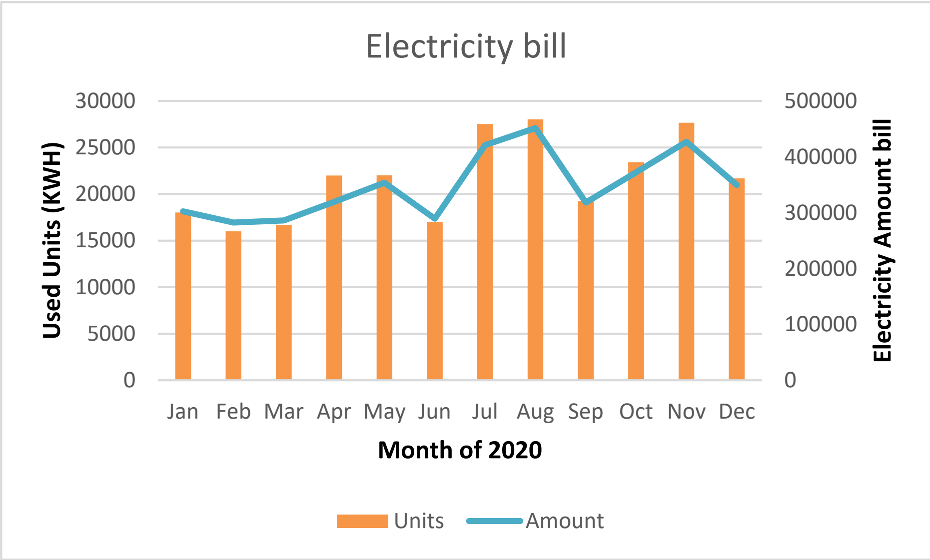


Figure 5-13: Electricity bill of Year 2020

As BIPV will be used for the electricity generation, overall power consumption units is very necessary for the energy simulation of the façade. This units will later be used in the simulation process in Ladybug. To calculate the number of solar panels from the equations provided, these units are equally important. Also, the amount paid is also necessary to calculate the payback period after the installation of BIPV. The bill helps us to see the real scenario of the electricity consumed throughout the year and potential offset to be done by the power generated by the BIPVs. And, also help us how much cost savings can be done in reality

5.9. Climatic Study

Kathmandu Valley's Climate

Kathmandu is Nepal's capital city, situated in latitude 27.7° and longitude 86.366°, somewhat in the heart of the country at an elevation of 1, 337 meters above sea level. The Warmer Temperate Zone encompasses this valley. Summer air temperatures from 28 to 30 degrees Celsius, while winter temperatures from 3 to 10.1 degrees Celsius (DHM/GoN). The annual precipitation ranges from 1,205 mm to 1871 mm. The Kathmandu Valley's air quality is decreasing. The vision level is decreasing at a pace of 1.2 kilometers each year. This clearly demonstrates that the Valley's fine particle level has risen at an alarming rate (Regmi & Adhikary, 2016).

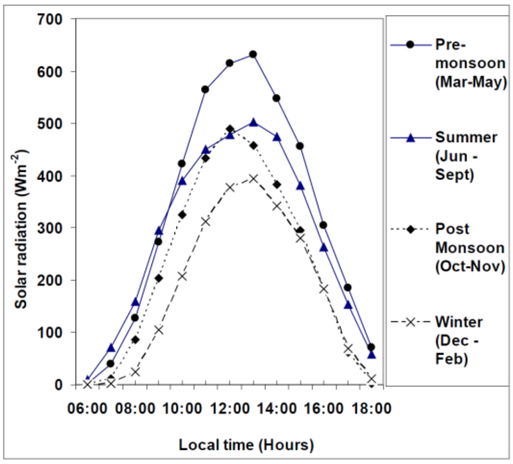


Figure 5-15: Diurnal variations of solar radiation in Kathmandu Valley

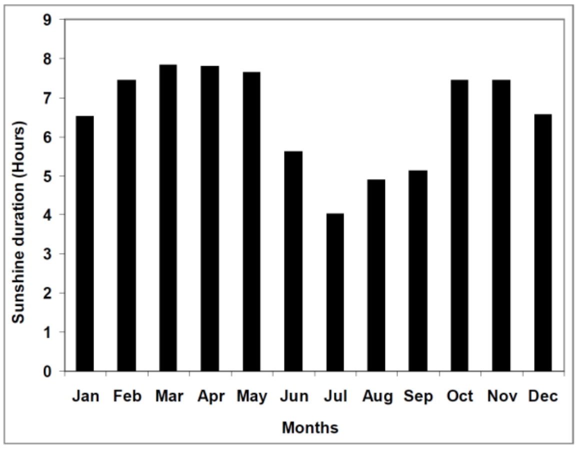


Figure 5-15: Mean monthly sunshine duration over KV

Above diagram shows the monthly mean values for solar radiation and sunshine diurnal variations of solar radiation in Kathmandu Valley. The average monthly sunlight duration across Kathmandu Valley is depicted in figure 5-15. Pre-monsoon (Mar-May) and post-monsoon (Oct-Nov) months have greater sunshine exposure (about 8 hours per day) than summers (Jun-Sept) (approximately 5 hours per day) and winters (Dec-Feb) (approximately 7 hours per day).(Nepal, 2020)

5.9.1. **Temperature**

The average temperature of Kathmandu is shown below. It shows the greatest average temperature of 29.8 degrees Celsius in August and the lowest average temperature of 12.2 degrees Celsius in December. In addition, the months of June through September have the highest temperatures, with temperatures exceeding 29 degrees Celsius.

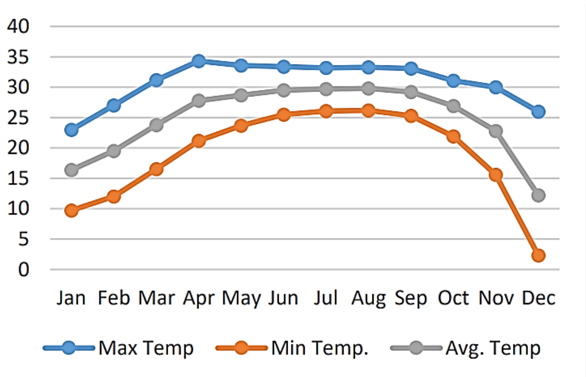


Figure 5-16: Monthly temperature of Kathmandu *Source:* (Nepal, 2020)

Temperatures in January and December are below 10 degrees Celsius. Kathmandu has a temperate climate as a result.

5.9.2. Solar Radiation

The moderate exposure to solar radiation is depicted in chart. For virtually the entire year, Kathmandu is exposed to sun radiation. In April, the maximum sun radiation was 4868 Wh/m2/day, while in July, the minimum solar radiation was 2040 Wh/m2/day. As a result, solar gain would be substantially higher throughout the year. Finally, there is the possibility of using solar energy.

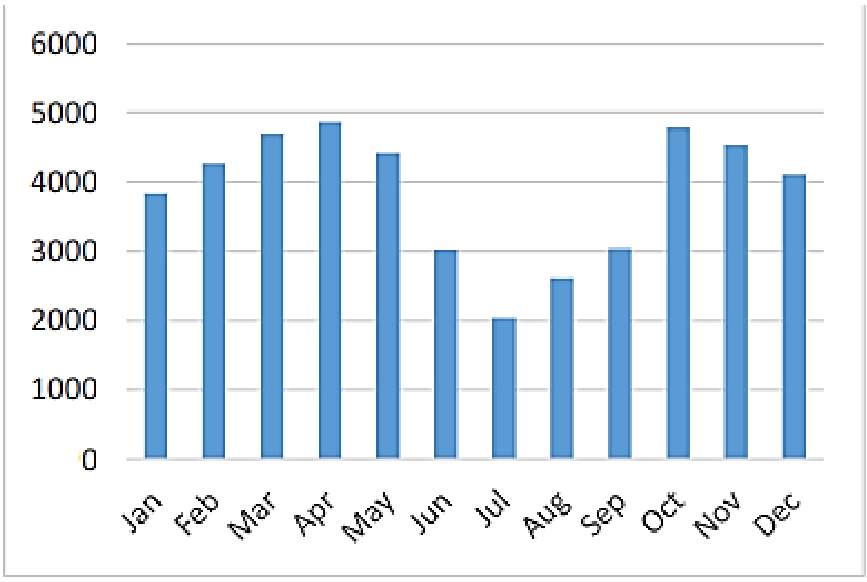


Figure 5-17: Monthly average solar radiation of Kathmandu

Source: (Nepal, 2020)

5.10. Calculation for sizing of solar panels

For the calculation of components of solar system, energy consumption of the whole building should be well known. The average consumption is 20000 Kwh per month and 666.67 Kwh per day. Now, as the energy from PV from façade alone is not sufficient for the entire building, so for 60% of the total consumption (400 Kwh), BIPV is designed for south and east façade of the building.

The important thing for the calculation is the type of solar panel for the building. After the market survey, from pienergy solar technology, PNG500-96M solar module is used for the further calculation below.

5.10.1. **Selection of Solar PV module**

Here, The system voltage is **24V.**

1st step: Now, expressing load in ampere hour (Ahr)= total load/system voltage

= 400000/24

= **16666.67 Ahr**@24V

2nd step: $I_{array} = \frac{\text{Total average daily load in Ahr@system voltage}}{\text{Peak sun X De-rating factor X Columbic efficiency}}$

Where, Columbic efficiency= 0.9

De-rating factor= 0.9

Peak sun= 4.5

Now, $I_{array} = \frac{16666.67}{4.5X0.9X0.9} =$ **4572.47**

3rd step: number of strings required, $N_s = \frac{\text{Nominal system voltage}}{\text{Nominal module voltage}}$

Ns= 24/48 =**0.5**

4th step: Number of required module, Np = Iarray/ Imp(Current of maximum power of module)

Np = 4572.47/10.28= 444.79

(**Used PNG500-96M Imp=10.28**)

Now, total number of modules, Nt = Np X Ns = 444.79 X0.5= 222.40 ~**223**

5.10.2. **Selection of Battery**

For calculation of battery capacity:

Capacity of battery, $C = \frac{Dah \text{ X } DOA}{DOD \text{ X } EFF}$

Dah = load in ampere hour

DOA= days of autonomy = 2

DOD = Depth of discharge= 80%=0.8

EFF = efficiency of battery= 60%=0.6

Now, Capacity of battery, $C = \frac{16666.67 \text{ X } 2}{0.8 \text{ X } 0.6} =$ **69444.44Ah**

Battery of size **70000 Ah** should be used for the storage**.**

5.10.3. **Selection of DC/AC Inverter**

The inverter's waveform must be pure sine wave, although the value of this sort of inverter is slightly more than that of a square wave inverter. The below calculation is used to compute the necessary inverter's rated power,

$$P_{inverter} = \frac{P\ load}{PF * Efficiency}$$

where,

$P_{inverter}$	=	Power rating of inverter (VA)
P_{load}	=	Load power (Watt)
PF	=	Load Power factor
Efficiency	=	Inverter Efficiency

Total power = 500*222.4 = 111198.29 W

$$P_{inverter} = \frac{total\ power}{0.8*0.8}$$

=**173747.33 VA**

Ths surge power should be provided by the inverter. As a result, the chosen inverter's total power should be two to three times the projected power .

In order to achieve the aforementioned, an inverter with a power of 173747.33*2= 347494.66 VA =**350000 VA (350KVA)** should be selected.

From the above calculation, it is found that **223 solar PV** each module with 96 cells, 500 W of size 1956mm*1300mm*50mm should be used. If the energy generated is not connected to the grid, then the battery of capacity 70000 Ah should be used. And the inverter size is 350KVA.

These panels are placed according in the south and east façade of the case building. Out of 223 solar panels, 103 panels (area- 2369 sq.ft) are placed in south and 120 (area-2760) in east façade as shown in the figure . Placement of solar PV is according to the area of the façade, so east have higher number than south.

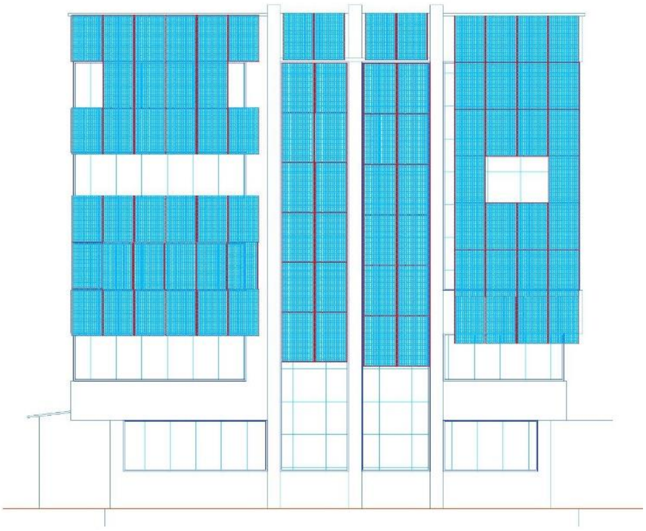


Figure 5-18: South elevation with solar panels

Figure 5-19: East elevation with solar panels

Chapter 6. Data Analysis

6.1. Energy Modelling and Simulation

Energy modelling was performed to calculate the solar radiation radiated on the building envelope as only the hand calculation is not enough for the accurate results. To calculate the type, size, and orientation of the solar PV, this simulation is important.

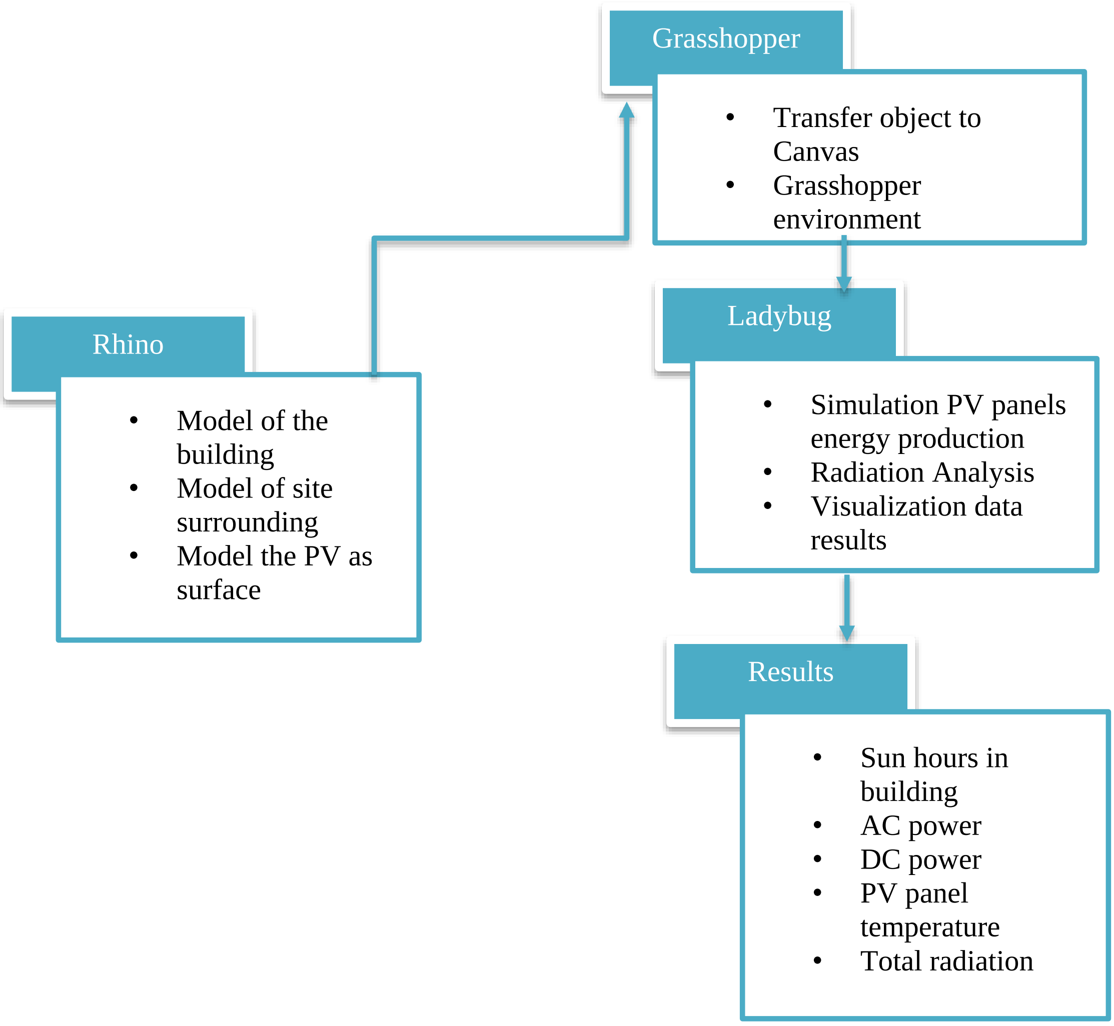


Figure 6-1: Flow chart for the simulation process

The energy consumption surveyed were used here. The software used for the simulation is Rhino with grasshopper plugin with ladybug plugin. This software is widely used in other countries for different type of simulation. For the energy modelling. First, the model was modelled in the rhino software and then the other essential plugins were used. Grasshopper is the plugin tool for rhino software, but it alone cannot perform the necessary simulation for BIPV, so Ladybug plugin for grasshopper is used further for energy simulation.

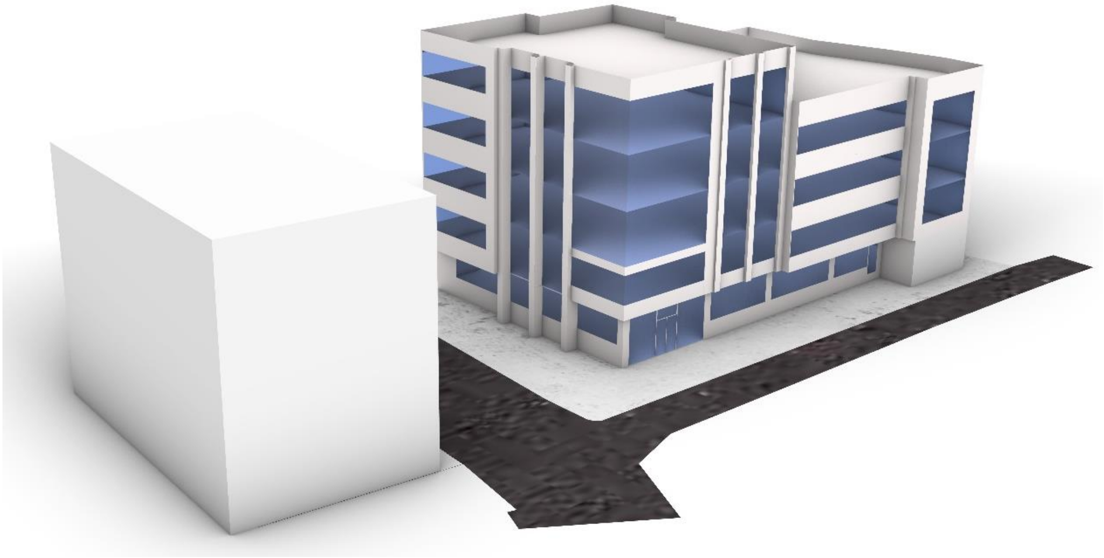


Figure 6-2: Case building modelled in rhino software

After the modelling of the building in the rhino software, grasshopper plugin was used further. Grasshopper environment was used with the ladybug plugin. The main thing here in ladybug is the accurate connection between different parameters as shown below.

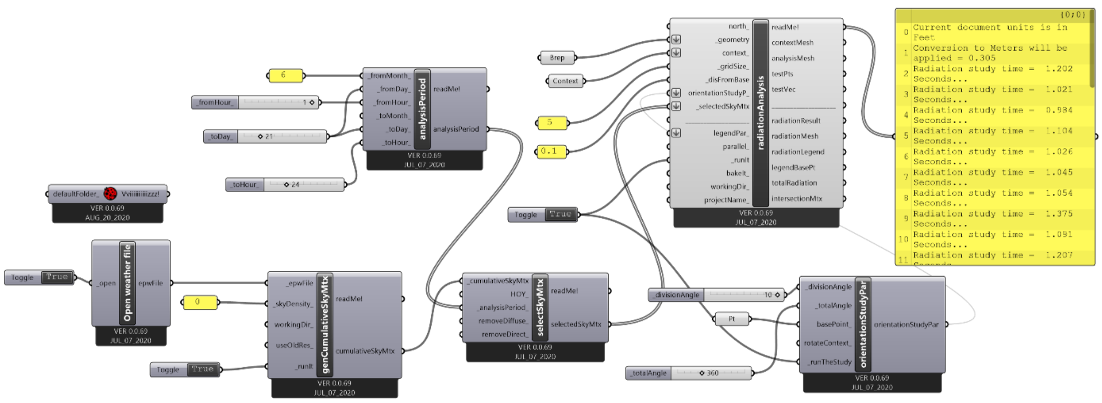


Figure 6-3: Logical sequence of ladybug with grasshopper environment (Radiation Analysis)

First, in the environment of grasshopper, ladybug is added from the toolbar so that analysis can be done later**.** The Kathmandu international Airport EPW file, the evaluation duration, a vector being used as a true North direction, and the average size of a grid cell for radiation assessment on the checking surfaces have been the input parameters and information necessary to undertake the solar insolation experiments after the buildings and their 3D urban environment were simulated(roofs and façades).

EPW file was used which was downloaded from epwmap of required area. EPW file is used in open weather file tool loaded in the grasshopper environment as shown below with the toggle tool. The toggle tool has two options i.e., true and false. Double click changes the option in the toggle bar, true loads the EPW file. This file is then connected with the cumulative sky matrix which have different sky density. Again, this is connected to select sky matrix with analysis period. This analysis period helps to calculate the solar radiation from specific period of the day of the year to another time.

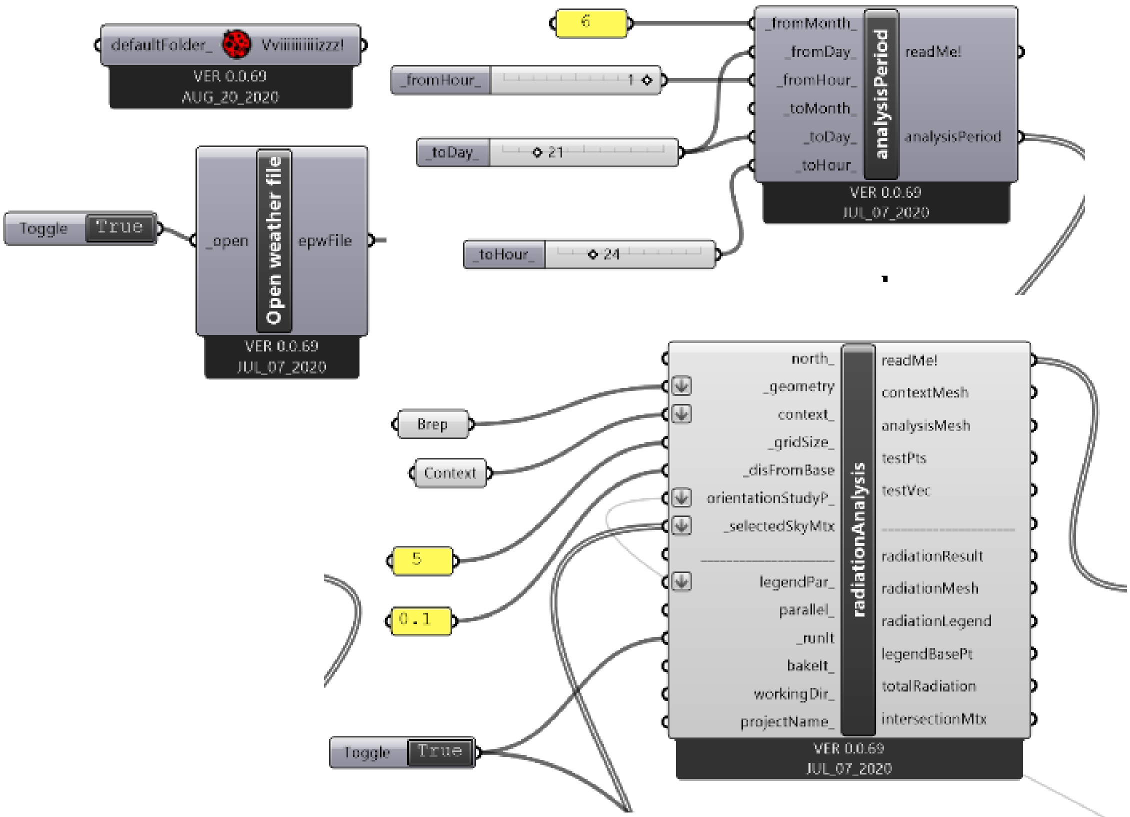


Figure 6-4:a) Weather file b) Analysis period for the surface c) Radiation Analysis with the building surface and with its necessary parameters

The connections of these parameters should be done very carefully as a small mistake will not give the result in the analysis process later. Now comes the major tool i.e., radiation analysis, here, geometry for the analysis is connected by the brep command, context is also added i.e., the surroundings around the building. Selected matrix used before is connected here. The grid size used here is 5 and Distance from the base is given 0.1. This varies according to the site conditions.

After all the parameters are put and interconnected with each other, then run it is toggled true for the simulation process. If the inputs are right then the boxes of different parameters will turn grey as shown but if the colour is orange then one should check the inputs. After the analysis is completed successfully, right side gives the expected results which can be seen if connected with the panel as shown by the yellow box in the above figure 6-3.

The total irradiation in kWh for every surface and the quantity of irradiation in kWh/m2.year which penetrated the experimental geometries depicted by a colour mesh really are the results.

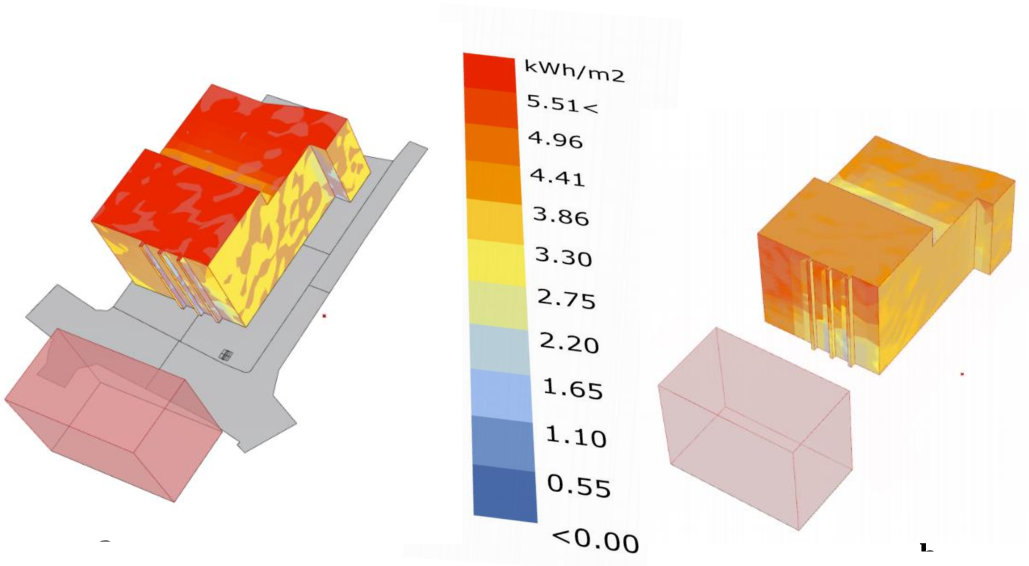


Figure 6-5: Radiation on building a) 21st June b) 21st December

The irradiance analysis was used to determine the best façade for solar implementation was used which can be seen in the figure above. Radiation analysis for the 21st June and in 21st December was done as it is the longest and shortest day throughout the year. It is found that maximum solar radiation is on roof and then in south and east façade. Due to the space limitation and functional space on roof, BIPV on south and east façade is preferred here as it gains more sunlight than other orientation of the building.

6.2. Scenario Cases

For the simulation process, a total of six scenarios were developed regarding the type, efficiency, orientation, placement and tilt angle. Scenario 1 deals with the monocrystalline BIPV in south façade with 15 % and 12% efficiency. Similarly, scenario 2 deals with the intervention in east façade and south façade both with same efficiencies as in scenario 2. In scenario 3, the BIPV were divided into segments which were retrofitted in the window of both south and east façade.

BIPV was placed on the building's front using a grasshopper with a ladybug plug-in because the building was modelled using rhino. Other attributes, such as the inclination angle of the PV surface, the azimuth angle of the PV surface, the module installation configuration, and the area proportion of the active module (the percentage of the module surface without the gap between Module frame and battery), are required in addition to the characteristic simulation of PV modules.

The ladybug component that calculates PV system loss and DC to AC conversion is the "DC-AC derating factor".

Table 8: List of Scenario cases

Cases	Description
Scenario 1	**Mono- crystalline BIPV in South facade**
Scenario 1a	With efficiency 15%
Scenario 1b	With efficiency 20%
Scenario 2	**Mono- crystalline BIPV in South and East facade**
Scenario 2a	With efficiency 15%
Scenario 2b	With efficiency 20%
Scenario 3	**BIPV in segments in South and East facade**
Scenario 3a	30^{O} Tilt angle with 14 % efficiency thin-film PV in window and 20% efficiency BIPV in wall of facade

Scenario 3b	60^{O} Tilt angle with 14 % efficiency thin-film PV in window and 20% efficiency BIPV in wall of facade

6.3. Scenario 1: BIPV in south façade

As the building was already modelled in rhino, now BIPV was placed in the south façade of the building in the grasshopper with ladybug plugin.

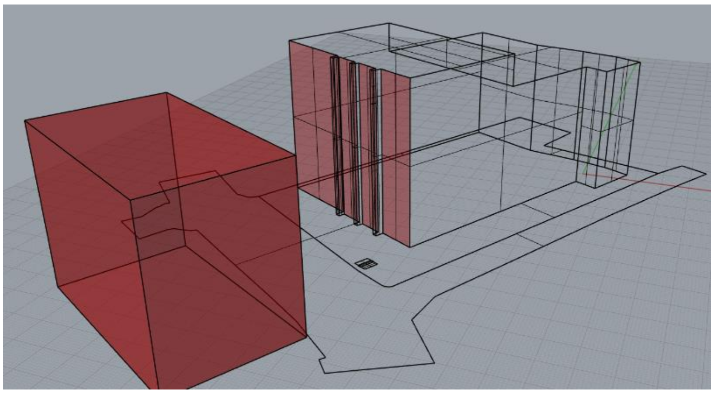


Figure 6-6: Solar PV in south facade

After the EPW file was added in the grasshopper environment, it was connected to PV surface added from the tool bar for further process. In PV surface, different inputs were put to different parameters. PV surface was added from the model with brep command, PV surface percent was 90 as some space is occupied by the connections between the panels.

PV module setting was connected to the another simplified PV module with **the configuration used mount type** Ground mount arrays, tilted flat/sloped roof arrays, pole-mount photovoltaic arrays, solar canopy, and BIPV systems with appropriate back

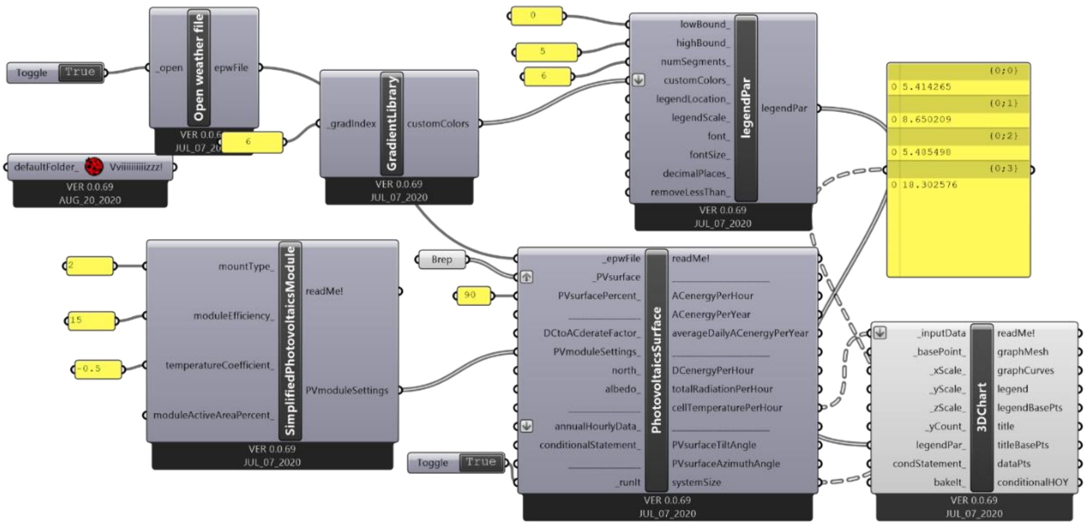


Figure 6-7: Logical sequence of ladybug with solar PV setting with different parameters

ventilation all were utilized in this arrangement.as shown above with mount type number 2. Temperature coefficient used was -0.5 and the percentage of active module area used was 90%. Hourly AC energy created for a year, total yearly AC energy output, and daily average AC energy output for a year, hourly DC energy output of the PV array for a year, hourly solar energy irradiation, hourly cell temperature for a year, and system size were among the information obtained.

For the 3d charts of the results, legend parameters helps to visualize with more than 20 colour schemes, number of segments, high bound to low bound.

6.3.1. **Scenario 1 a): Module efficiency with 15%**

As all the parameters are same except the efficiency of solar PV used in the south façade of the building. With the module efficiency of 15%, following results were found.

Hourly total solar irradiation

It is the overall incidence POA (Plane of array) irradiation expressed in kWh/m2 for every hour of year. It can be dipcted that the maximum solar radiation on the surface falls on winter season on 12 pm to 6 pm and as we know that at night we have zero solar radiation.

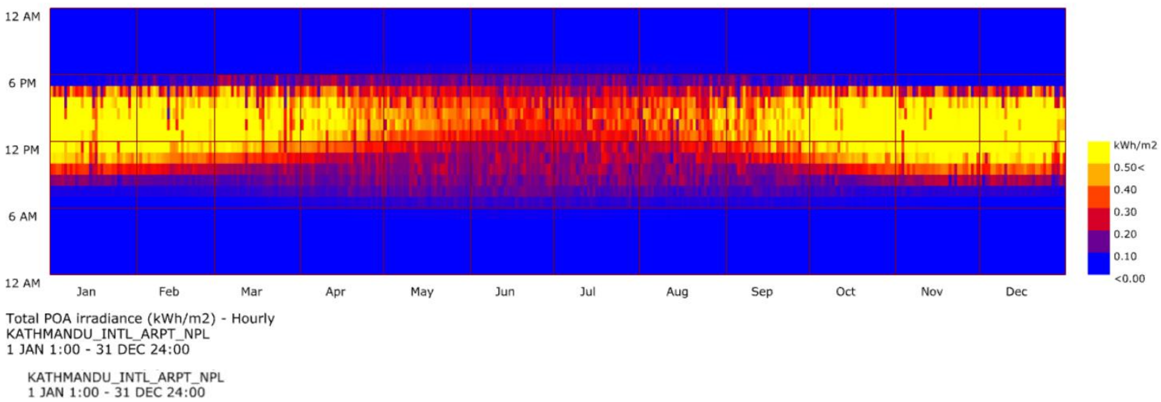


Figure 6-8: Hourly total solar irradiation

Cell temperature

It is the Cell temperature for each hour during year measured in Celsius.

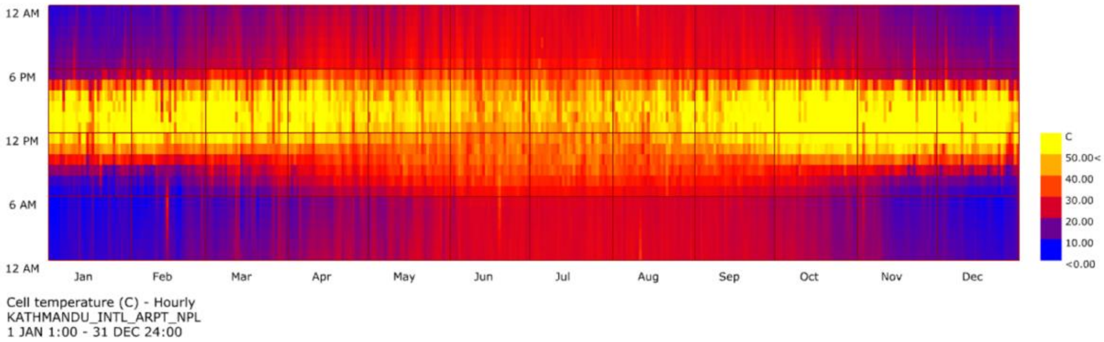


Figure 6-9: Cell temperature generated for a year

Hourly AC generated for a year

It is the AC power output for each hour during a year measured in kWh.

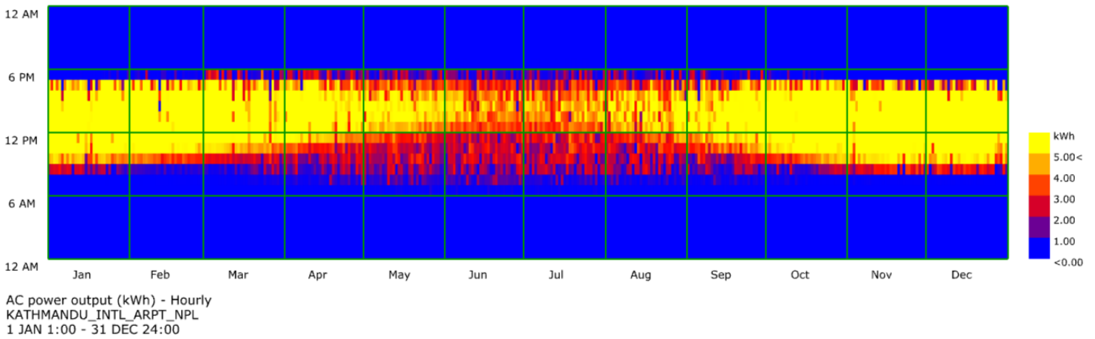


Figure 6-10: Hourly AC generated for a year

DC energy output

It is the DC power output for each hour during a year measured in kWh.

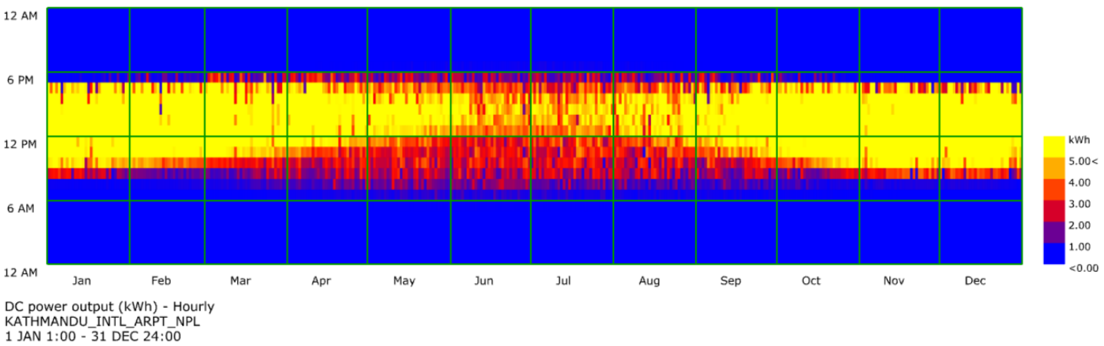


Figure 6-11: DC energy output

Yearly AC energy output

It is the total AC power output for a whole year measured in kWh. Total AC power obtained is 31607.76 kWh.

Daily average AC energy

It is the average daily AC power output per day for a whole year measured in kWh /day. Daily average AC power is 92.98 Kwh/day.

6.3.3. **Scenario 1 b): Module efficiency with 20%**

The outputs received hourly total solar irradiation and hourly cell temperature for a year were same as 15 % efficiency as the position of the sun i.e. the azimuth angle of the sun was same as above.

Hourly AC energy output for a year, total yearly AC energy output, daily average AC energy output for a year, hourly DC energy output of the PV array for a year, and system size were the differences.

Hourly AC generated for a year

It is the AC power output for each hour during a year measured in kWh.

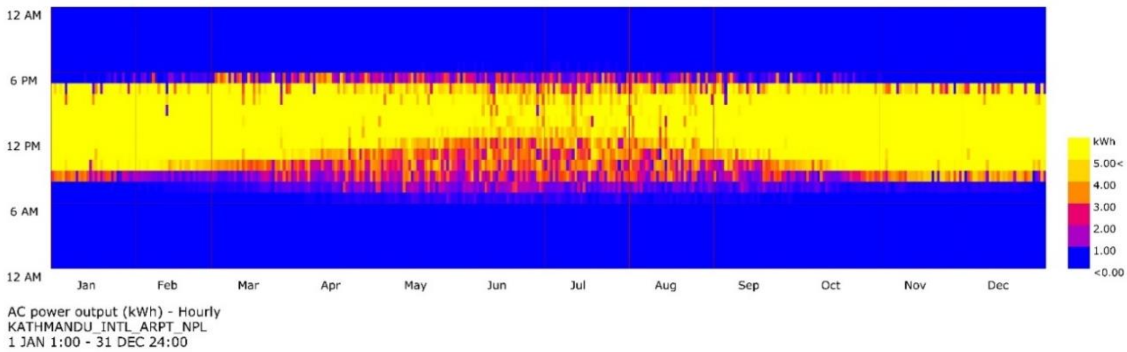


Figure 6-12: Hourly AC generated for a year

Yearly AC energy output

It is the total AC power output for a whole year measured in kWh. Total AC power obtained is 45210.67 kWh.

Daily average AC energy

It is the average daily AC power output per day for a whole year measured in kWh /day. Daily average AC power is 123.86 Kwh/day.

DC energy output

It is the DC power output for each hour during a year measured in kWh.

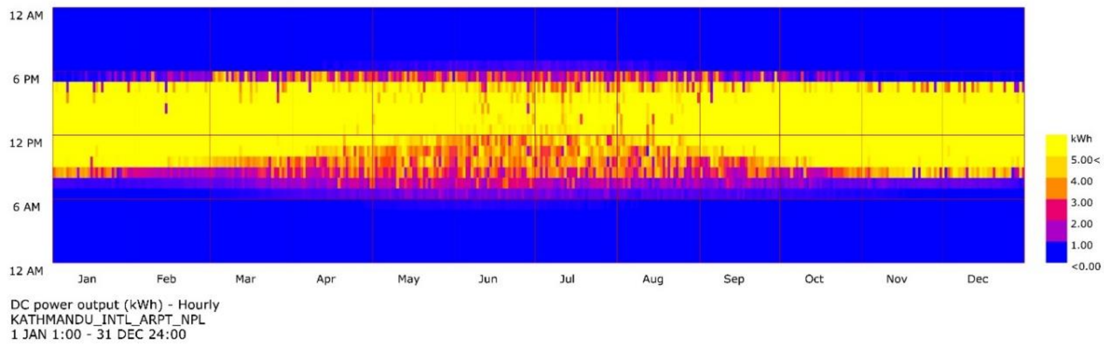


Figure 6-13: DC energy output

System size

It is the DC rating of the PV system measured in kW. The system size of this PV was found 50.47 kW.

6.4. Scenario 2: BIPV in South and East façade

All the parameters were assigned same in the scenario 1, the difference is the addition of BIPV in east façade. The total area of the façade in which the PV was placed is 717 sq.m. (South- 280 sq.m., East- 437 sq.m) as shown in the adjacent figure.

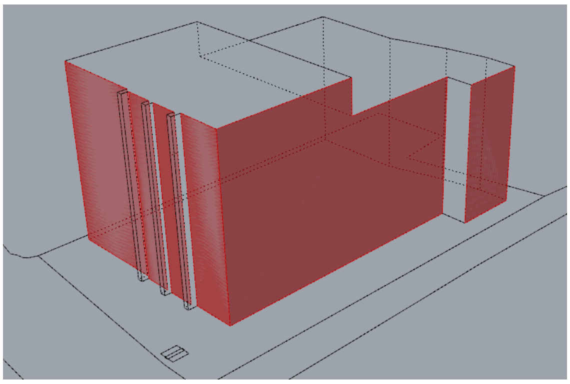


Figure 6-14: Solar PV in south and east

Like scenario 1, here also two scenario cases were simulated.

6.4.1. Scenario 2 a): Module efficiency with 15%

Here, the azimuth angle for south is same as scenario 1, i.e. 208.29^{O} and for east, it is 118.29^{O}. These parameter is different other than the placement of BIPV. The outputs after the simulation is shown below:

Hourly total solar irradiation

It is the total Incident POA (Plane of array) irradiance for each hour during a year measured in kWh/m2. It can be dipcted that the maximum solar radiation on the surface falls on winter season on 12 pm to 6 pm and as we know that at night we have zero solar radiation.

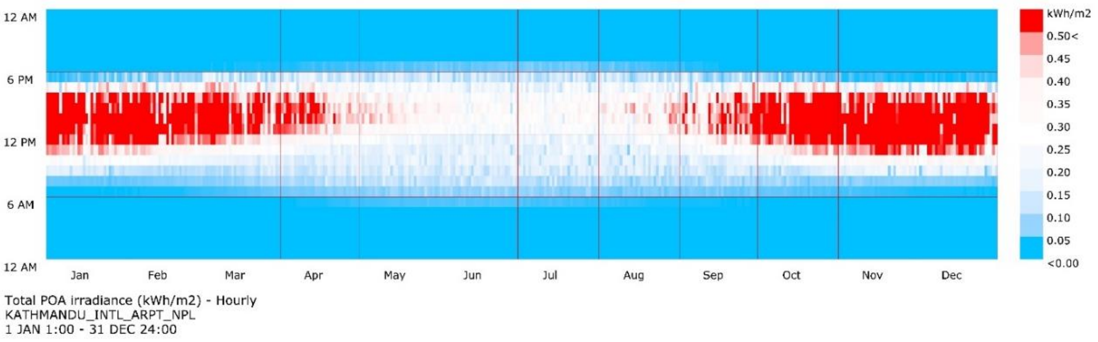
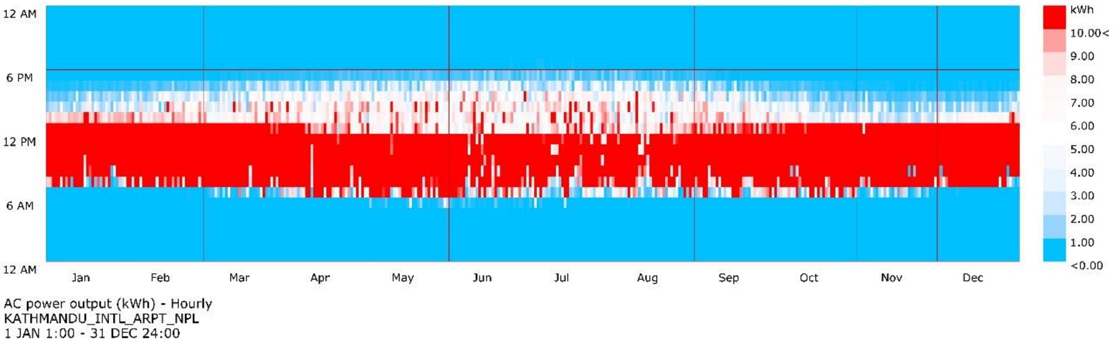


Figure 6-15: Hourly total solar irradiation in both south and east facade

Hourly AC generated for a year

It is the AC power output for each hour during a year measured in kWh.



Yearly AC energy output

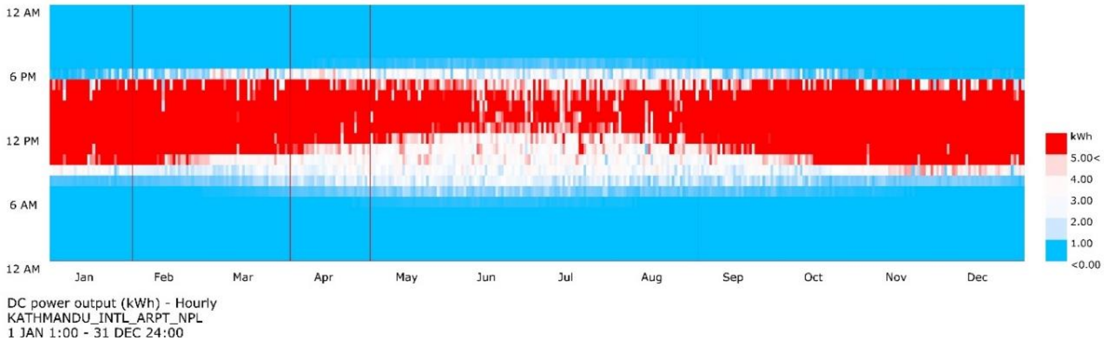
It is the total AC power output for a whole year measured in kWh. Total AC power obtained is 83344.58 kWh.

Daily average AC energy

It is the average daily AC power output per day for a whole year measured in kWh /day. Daily average AC power is 228.34 Kwh/day.

DC energy output

It is the DC power output for each hour during a year measured in kWh.



System size

It is the DC rating of the PV system measured in kW. The total system size of this PV is found 97.05 kW.

6.4.2. Scenario 2 b): Module efficiency with 20%

All other parameters are as mentioned above and the efficiency of the module is change from 15 to 20 %. As greater efficiency panels are good for long run.

The outputs received hourly total solar irradiation and hourly cell temperature for a year were same as 15 % efficiency as the position of the sun i.e. the azimuth angle of the sun was same as above.

The other differences are shown below:

Yearly AC energy output

It is the total AC power output for a whole year measured in kWh. Total AC power obtained is 111126.1 kWh.

Daily average AC energy

It is the average daily AC power output per day for a whole year measured in kWh /day. Daily average AC power is 304.45 Kwh/day.

System size

It is the DC rating of the PV system measured in kW. The total system size of this PV was found 129.39 kW.

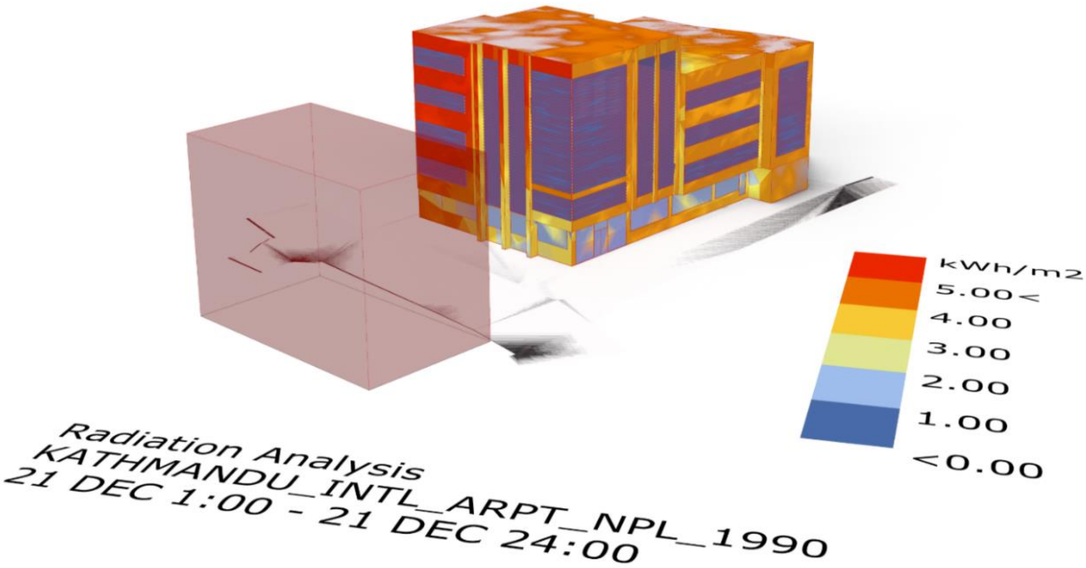


Figure 6-16: Result of Radiation Analysis of 21st December

6.5. Scenario 3: BIPV in both south and east façade

In this scenario, a total of 345 smaller segments (0.3 m width and length varies) of thin-film were retrofitted in the glazing of the south and east façade as shown in the adjacent figure. Rest of the façade with ACPs were retrofitted with mono-crystalline BIPV in both south and east façade.

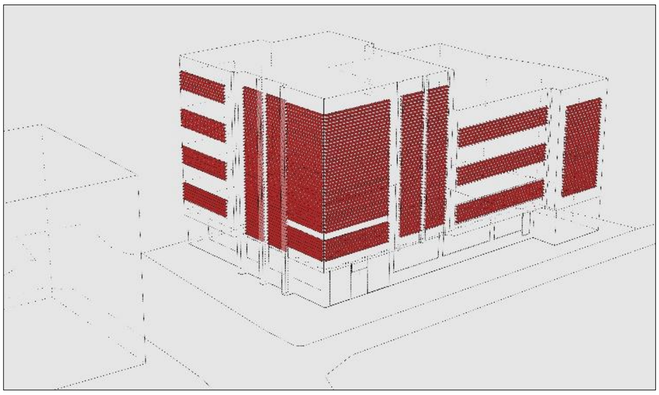


Figure 6-17: Thin-film solar segments retrofitted in glazing

Thin- film solar PVs are used for its light weight, transparency and due to aesthetic purposes.

Solar radiation analysis was done for 21st December and maximum radiation can be seen in the south façade of the building as shown in the figure below.

For the thin-film PV retrofitted in the glazing of the façade, 14% efficiency was used and for the ACPs area, 20% efficiency mono-crystalline was used in the south and east façade of the case building. The results of the 3rd scenario are as follows:

6.5.1. **Scenario 3: (20% efficiency in rest of façade)**

It is same for both scenarios 3a and 3b, the result obtained here were later added to the results for different tilt angle obtained separately in the further process. The results are as follows:

Yearly AC energy output

It is the total AC power output for a whole year measured in kWh. Total AC power obtained is 11101.47 kWh.

Daily average AC energy

It is the average daily AC power output per day for a whole year measured in kWh /day. Daily average AC power is 78.01 Kwh/day.

System size

It is the DC rating of the PV system measured in kW. The system size of the thin-film PV is found to be 51.58 kW.

6.5.2. **Scenario 3 a): Module with 30 degree tilt angle**

6.5.3. **Scenario 3 b): Module with 60 degree tilt angle**

The results from the both the scenario 3a and 3b with 14% efficiency thin-film solar panels are shown below with the addition of the scenario 3 to both for total solar in south and east façade.

Parameter	Unit	Scenario-3a			Scenario-3b		
		30 ^{O}	20%	Total	60 ^{O}	20%	Total
Yearly AC	kWh	28474.8	11101.43	39576.3	14637.3	11101	25739
Average daily AC	Kwh/day	30.415	78.01	108.425	21.415	78.01	99.43
DC system size	kW	37.34	51.58	88.92	37.34	51.58	88.92

From the table, it can be seen that the when the 14% efficiency thin-film transparent solar tilted at 30 degree from the ground gives better result than that of 60 degree tilted from the ground. The other remaining façade is treated with the 20% efficiency mono-crystalline solar PV, which is same for both the scenario. So, different analysis for the tilt angle was done and later added with the remaining façade as shown above.

6.6. Comparison of different cases

The yearly AC generated, daily average AC energy and the system sizing from above scenarios are compared with each other. The comparison is shown in the table below.

Table 9: Comparison of different parameters of different scenarios

Parameter	Unit	Scenario-1a	Scenario-1b	Scenario-2a	Scenario-2b	Scenario-3a)	Scenario-3b)
Yearly AC	kWh	31607.76	45210.67	83344.58	111126.1	39576.30	25739
Average daily AC	Kwh /day	92.98	123.86	228.34	304.45	108.428269	99.43
DC system size	kW	37.85	50.47	97.05	129.39	88.92	88.92

Yearly AC energy output

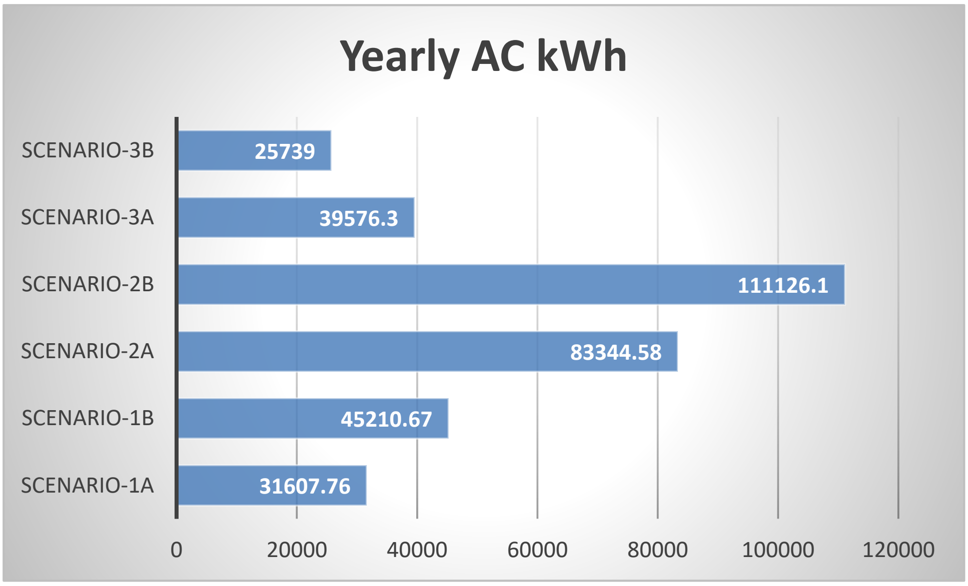


Figure 6-18: Comparison of yearly AC energy output of different scenarios

In the chart shown above, it can be depicted that the maximum AC generation for a year is for scenario 2b that is the BIPV used in both south and east façade with 20% efficiency and the least can be seen in the scenario 1a, i.e., the BIPV in south façade with 15% efficiency.

Daily Average AC energy output

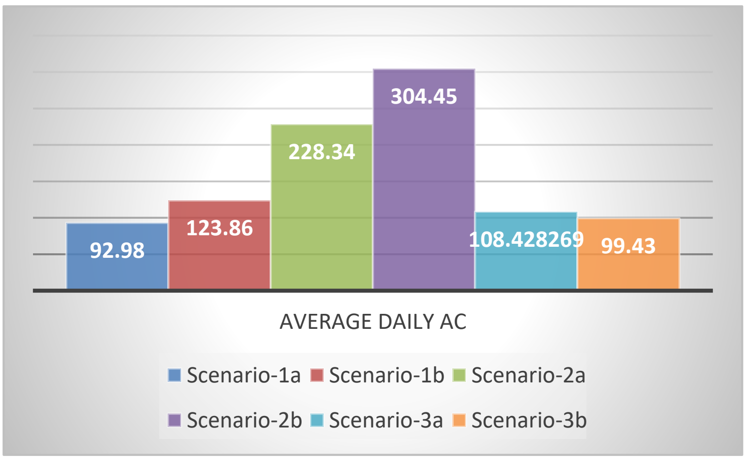


Figure 6-19: Comparison of daily average AC of different scenarios

As the AC power for a year is maximum in scenario 2b, so the average daily AC is also same. .

DC system size

The DC system sizing of the solar panel is also maximum for scenario 2, as the area of BIPV is more in this scenario.

Comparison of DC system size of solar panel with that of surface area:

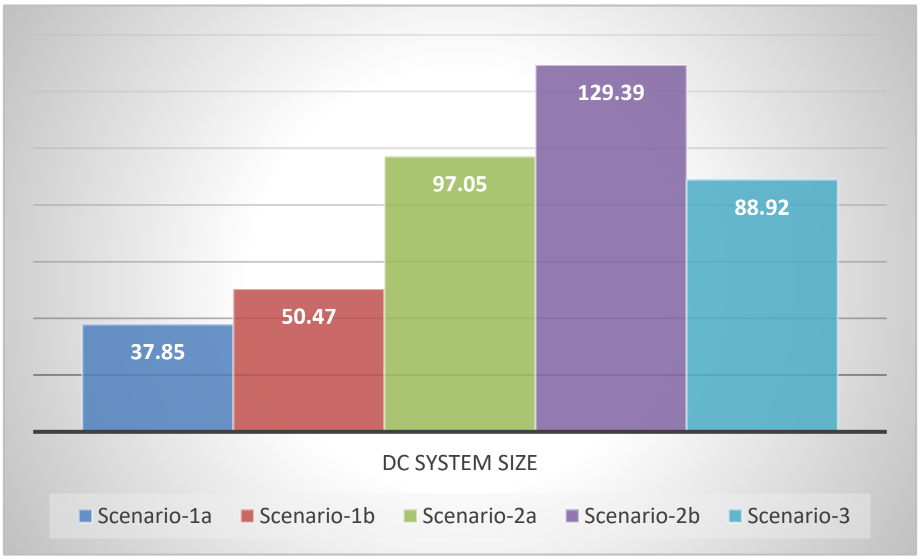


Figure 6-20: Comparison of DC system size of different scenarios

Here comparing DC system size with that of surface area placed in the façade of the building, maximum can be seen in scenario 1b with 20% efficiency PV panels in the south façade and minimum in the scenario 1a with 15% efficiency PVs.

Comparison of Yearly AC output of solar panel with that of surface area :

By comparison of yearly AC output of Solar PVs with the surface area, it can be depicted that scenario 1b gives maximum i.e. 13.5 kWh/sq.ft. and scenario 3a showed the poor performance with just 5.52 kWh/sq.ft.

Table 10: Comparison of Yearly AC output of solar panel with surface area

Parameter	Unit	Scenario-1a	Scenario-1b	Scenario-2a	Scenario-2b	Scenario-3a	Scenario-3b
Yearly AC	kWh	31607.8	45210.7	83344.6	111126	39576.3	25739
Area	sq.	3349.02	3349.02	8586.43	8586.43	7164.778	7164.778
Yearly AC per area	kWh/sq.	9.437913	13.49967	9.706546	12.94206	5.52373	3.592435

Comparison of Yearly AC output of solar panel with that of total energy consumption:

By comparison of yearly AC output of Solar PVs with the surface area, it can be depicted that scenario 2b gives maximum i.e. 46.3% of total energy consumption of the building and scenario 3b with the thin-film with 60 degree tilt angle showed poor performance.

Table 11: Comparison of Yearly AC output with total energy consumption

Parameter	Unit	Scenario-1a	Scenario-1b	Scenario-2a	Scenario-2b	Scenario-3a	Scenario-3b
Yearly AC	kWh	31607.8	45210.7	83344.6	111126	39576.3	25739
Area	sq.ft.	3349.02	3349.02	8586.43	8586.43	7164.778	7164.778
monthly	kWh	2633.98	3767.556	6945.38	9260.50	3298.02	2144.917
% energy solar PV		13.1699	18.83778	34.72691	**46.3025**	16.49013	10.72458

6.7. Financial Analysis

The PV components used for the solar installations should be chosen wisely so that initial investments are low. Despite the wide variety of BIPV, from market analysis, it was found that crystalline silicon PV modules are widely used by the public as they are cheap and easy in installation process.

For cost analysis, the DC system size and annual AC output from the above analysis are used. From the market analysis, it was known that price of PV module varies from smaller to larger units installation. As it is in larger quantity, the cost of mono-crystalline solar PV is Fifty rupees. This cost is multiplied by the system size so that we can obtain the initial cost of module. In addition, the electricity cost saved by installation of solar system is calculated by multiplying the cost of unit electricity to that of the annual AC generation from the solar panels.

Table 12: Cost comparison of different scenarios

Parameter	Unit	Scenario -1a	Scenario-1b	Scenario-2a	Scenario-2b	Scenario-3a	Scenario -3b
DC system size	kW	37.85	50.47	97.05	129.39	88.92	88.92
Cost of PV	Rs.	1892500	2523500	4852500	6469500	4446000	4446000
Yearly AC	kWh	31607.76	45210.7	83344.6	111126	39576.3	25739
Annual Electricity savings	Rs	537331.92	768581.4	1416858	1889144	672797.1	437563
Expenditure	Rs	53733.192	76858.14	141685.8	188914.4	67279.71	43756.3
Payback period	Years	3.9133684	**3.64814**	3.80537	**3.80507**	7.34248	**11.2898**

From the above table we found that the payback period of the scenario 1b is less than other scenario. Likewise, scenario 3b takes maximum time to recover the initial investment of the solar panel. Initial cost has a major role to play in setting up with BIPVs. As it is well known that the initial investment for BIPVs are high but the façade could reimburse not only the initial costs but also be a source of income in the long run. The life of the BIPVs are up to 25 years so the payback period helps to calculate the benefit for the future. From the above calculations, scenario 1a and 2b with a payback period of 3-4 years will justify the investment by the owner. After these years, there will be benefit to the owner for next 15-20 years.

Chapter 7. Findings and Discussions

This research was done with the aim to provide an appropriate BIPV to Bhatbhateni building at Anamnagar so that it can tackle future crisis. The energy consumption of the building was studied and energy modelling was performed to visualize parameters. The energy consumption charges for the summer season is double than that of the winter season. The building is dependent fully upon mechanical and artificial system for operation.

Different findings were obtained for the six scenarios developed earlier. AC energy generated for a year, overall AC, and daily average AC, hourly DC energy, hourly total solar radiation, hourly cell temperature, and DC system were among the information obtained. The findings recommend that maximum energy generation from BIPV used in both south and east façade of the building PV efficiency 20%, temperature coefficient -0.5 was found in scenario 2b when compared with other scenario developed during the simulation process. In addition, scenario 1b was considered good with the comparison of yearly AC output with the surface area. From the financial analysis, it can be depicted that the minimum payback period for the BIPVs were of scenarios 1a and 2b with 3.6 and 3.8 years respectively.

From the comparison of manual calculation to that of the simulated results, it can be depicted that the area of solar PV is less than simulated results. Also, manual calculation gave more energy generation than that of scenario2b which was considered good from the simulation process. This can be due to the consideration of solar radiation in the building in the simulation process in different time, month and year from the EPW file loaded in ladybug software. In manual calculation no such factors were considered. Also, the placement of the solar panel impacts the power generation as in the simulation process, the surrounding were also present and BIPV were placed in the building facade.

Chapter 8. Conclusion and Recommendation

The main objective of this research is to find out the possibility of BIPV in the façade of the commercial building of Kathmandu that has been achieved by the calculation and simulation results of different scenario cases. The energy generated by BIPVs is mainly dictated by daily average AC and yearly AC output placed in the building facade. Basically, performance of the solar PVs mainly depend upon the orientation, tilt angle, shading, placement, solar radiation from the sun, etc. which should be taken into consideration while placing these BIPVs.

The comparison between different scenario cases concluded that the BIPV with 20% efficiency retrofitted in both south and east façade can give maximum power output. Hence, energy retrofit with BIPV in the existing façade of the building can reduce the dependency in fossil fuel that ultimately helps in the reduction of GHGs that creates clean environment. BIPV can also be used as the mix energy with other resources.

BIPVs can play a significant role in buildings in tapping the solar energy potential especially in country like Nepal where there is a good amount of sunshine throughout the year. Use of BIPVs in the buildings helps in reducing the use of fossil fuels which are non-renewables. As these are clean source and energy efficient, use of BIPVs should be encouraged.

Some recommendation on further studies such as orientation as the above study have not done research on all the orientation, building types, climate to the impact of the BIPVs.

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Annex-I: Checklist for the survey

Type of the building

Working hours

Working days/week

Building occupancy

Flow of the people

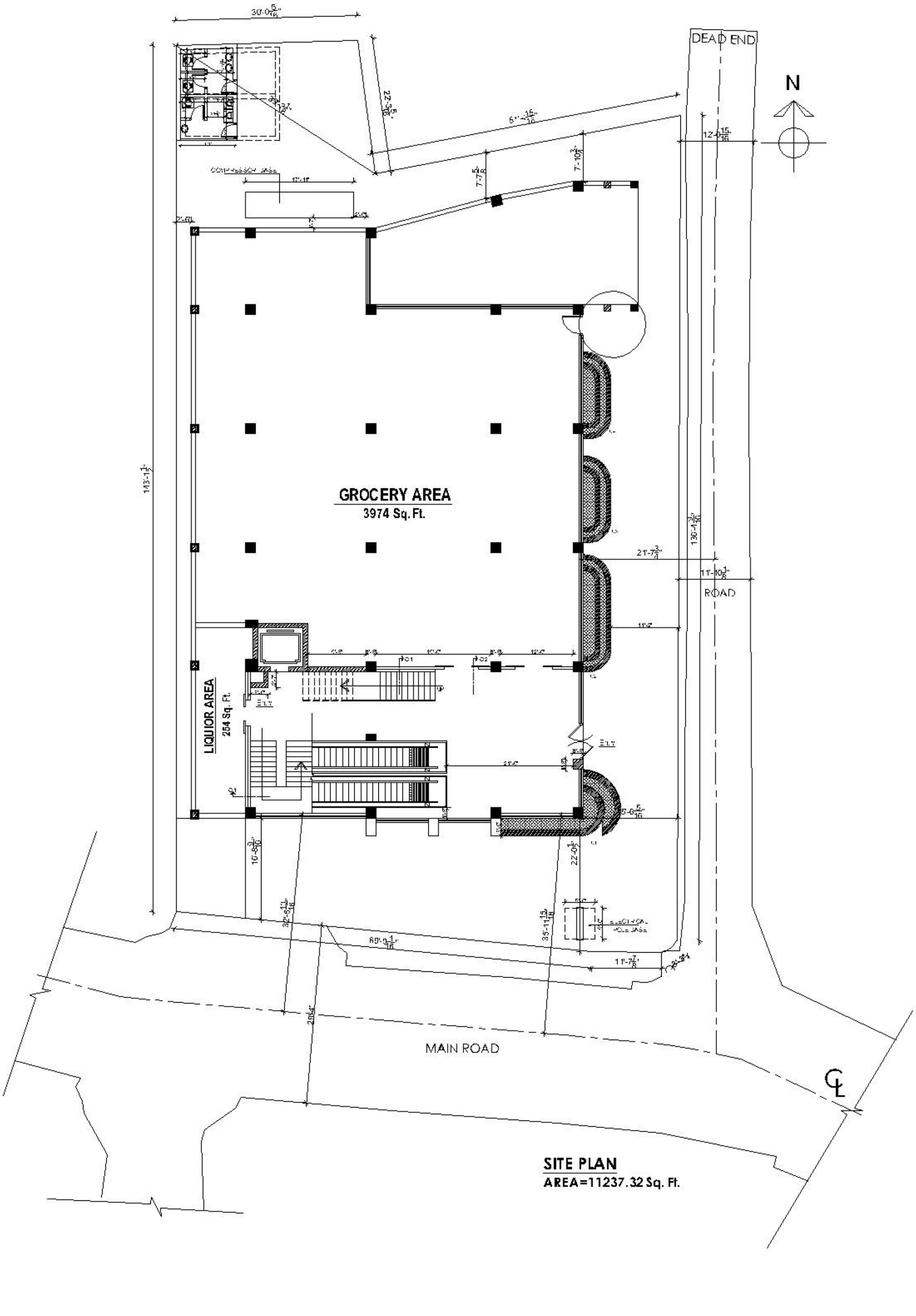
Area of the building

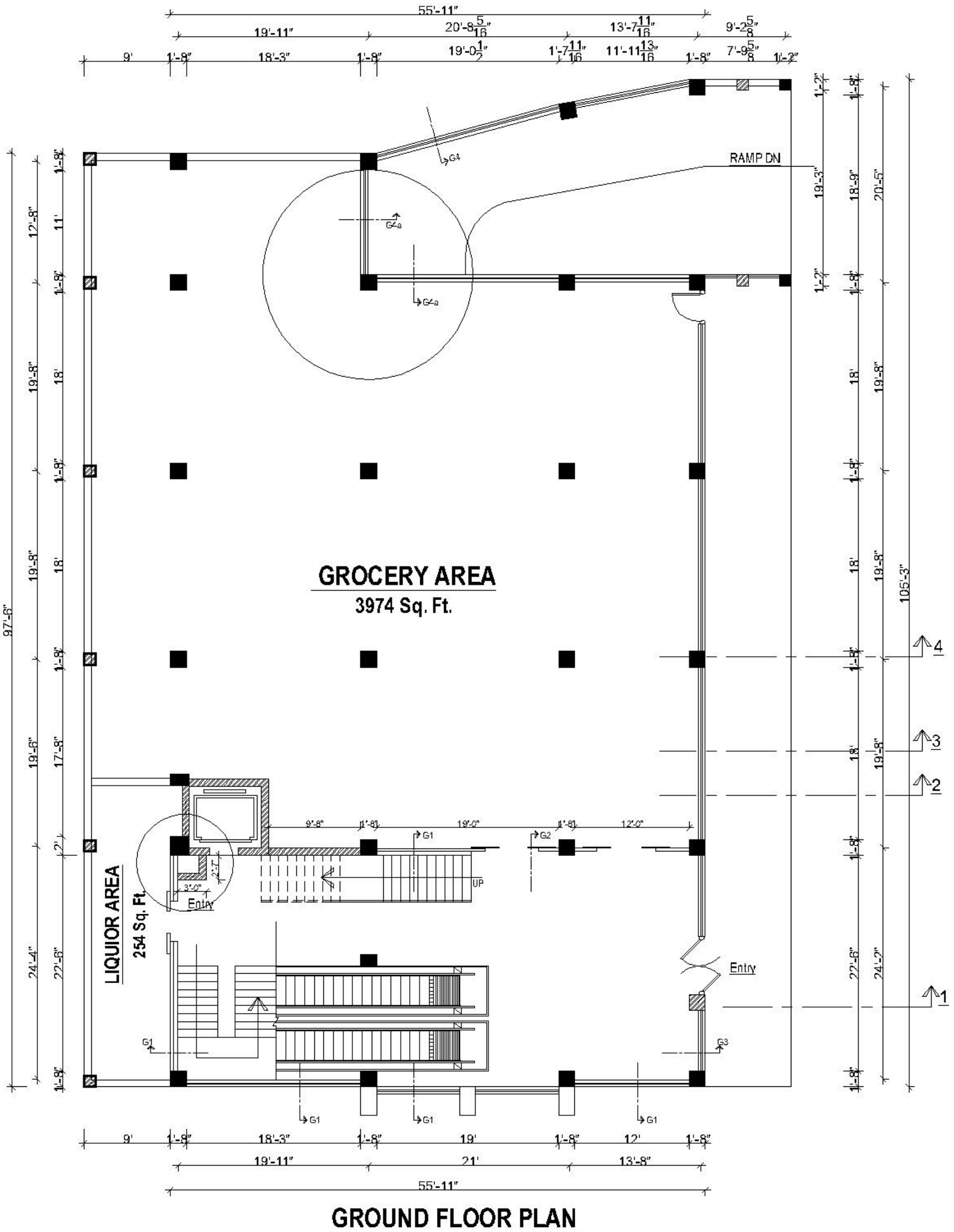
Orientation of the building

Architectural drawings of the building

Electricity bill of last year

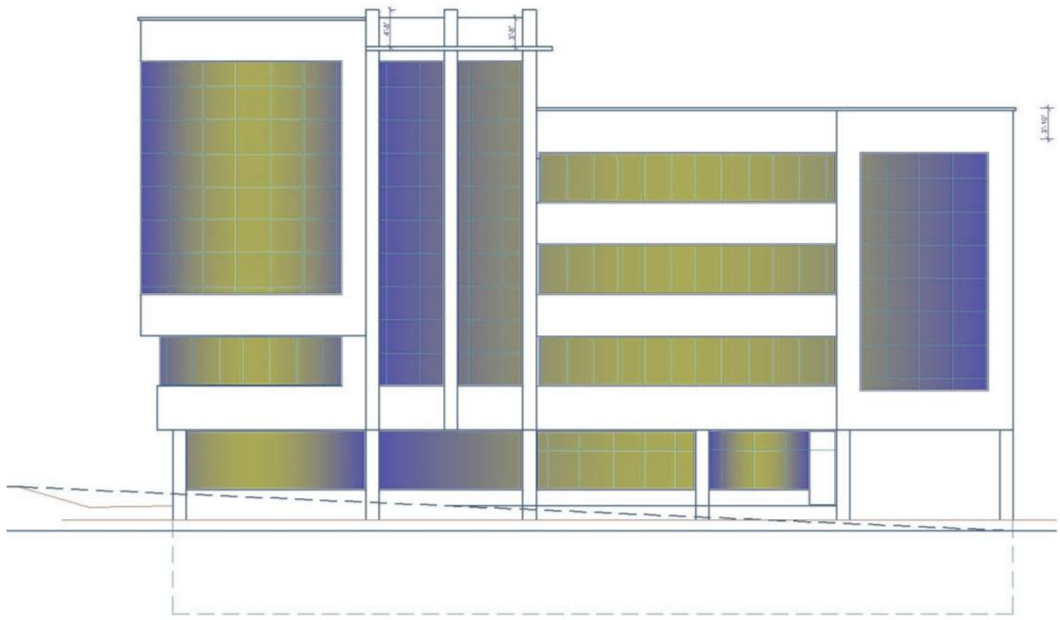
Annex-II: Building drawings of selected building



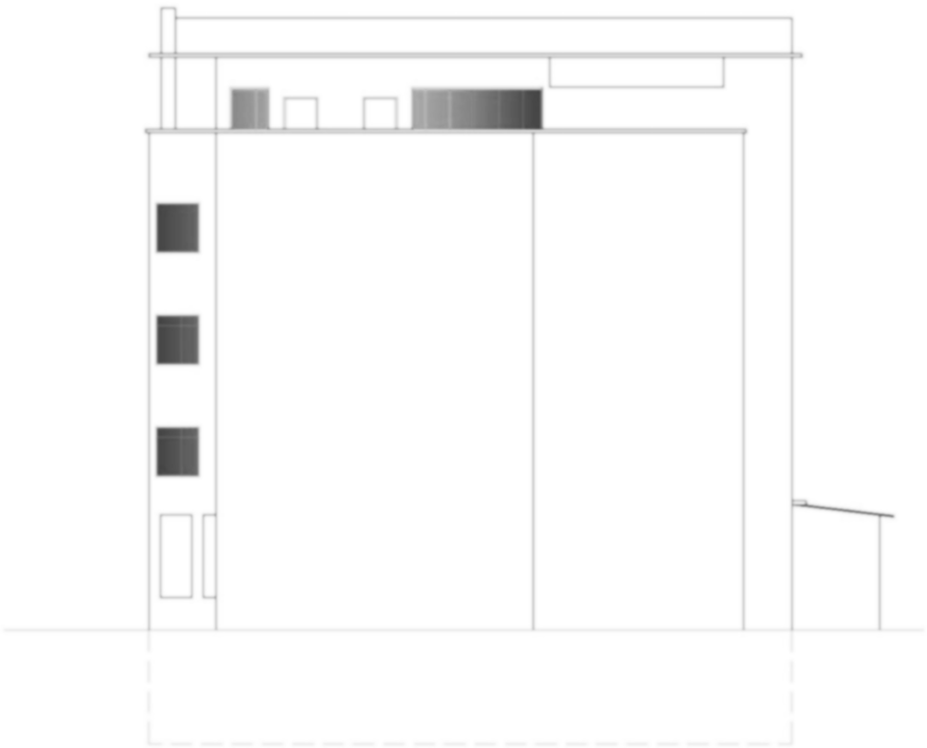


GROUND FLOOR PLAN

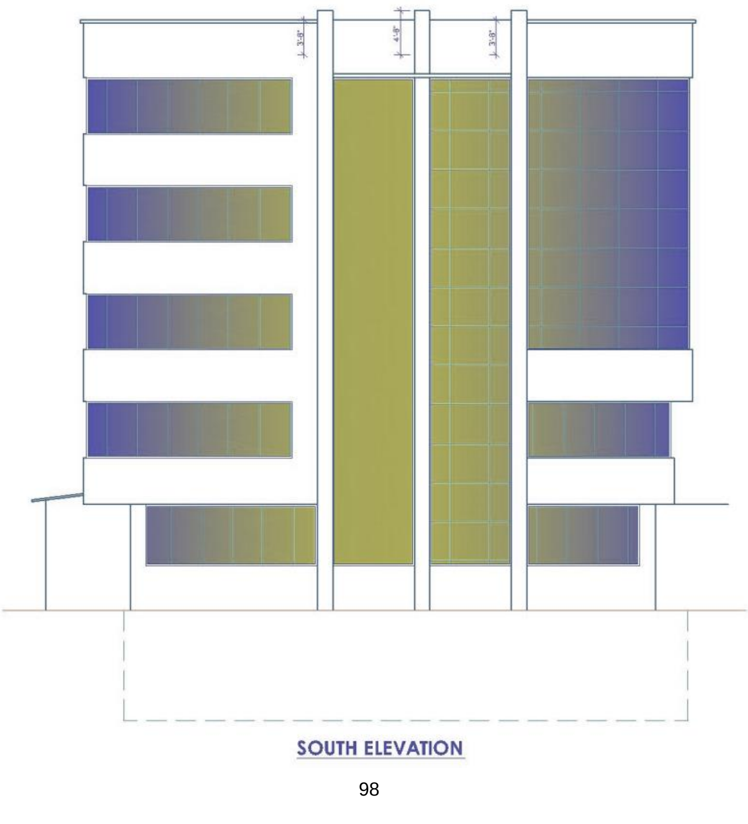
AREA=6479 Sq. Ft.



WEST ELEVATION



NORTH ELEVATION



SOUTH ELEVATION

Annex-III: Electricity bill of the case building

Electricity bill of Anamnagar			
Month	Unit	Khapat units	Amount
Jan	Kw per unit	18016	302406.4
Feb		16000	282356
Mar		16692	286055
Apr		21986	319253
May		22000	353619
Jun		17000	289300
Jul		27524	420736.6
Aug		28005	451557.1
Sep		19235	318131.5
Oct		23417	372079.3
Nov		27654	426736.6
Dec		21678	349646.2
Total		259207	4171877

Annex-IV: Article –IOEGC

IOE Graduate Conference
[Placeholder for Publication Information]

Energy retrofitting of façade: Curtaining with Building Integrated Photovoltaics

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Abstract

The use of renewable resources helps to reduce dependence of fossil fuels, improve global energy security and tackle environmental problems like climate change. Building integrated Photovoltaics (BIPV) are on the rise as they serve the dual purpose of regulating indoor environment as well as generating electricity. This study presents the analysis of the energy retrofitting of façade with BIPV in the building of Kathmandu Valley. The research focuses on the comparison analysis of placement and type of BIPV in the façade for maximum generation of energy. For this purpose, various type of BIPV were studied and suitable type was used for further calculation. Manual calculation for the sizing of PVs was done for the case building and for the comparison, computer based energy simulation was also carried out using various software i.e. rhino for 3d modelling and grasshopper and ladybug tool for the further analysis of solar radiation and PV. The results illustrates that the placement of BIPV with maximum efficiency in south and east façade of the case building reduces 46.3% of the total consumed units per month. Energy retrofit of façade with BIPV could significantly reduce the monthly bill of the building and can be used as energy mix for the future

Keywords

Building Integrated Photovoltaics, Energy Retrofit, Solar energy, Building facade.

1. Introduction

Successful use of renewable energy resources and related technologies can offset a part or entire building's electrical load and thermal energy load [1].

"According to the International Energy Agency's New Policies Scenario, the electricity demand of the world will rise by almost 80 percent during the period of 2012-2040"[2]. The IEA believes that the clean energy revolution is necessary to break the world's dependency on fossil fuels. Today, more than half of the world population lives in city areas and by 2050, it is estimated to nearly double to a total of 6.4 billion. Most of the growth in urban population is expected be in middle- and lower-income countries, which have limited capacity to address the new risks emerging and existing risks being intensified by the global urban shift [3]. Such a rebellion would improve global energy security, encourage the continuance of economic growth and help minimize environmental challenges like climate change.

Buildings are among major contributors of greenhouse gases and consuming more than 40% of total primary energy [4]. Façade of the building contains large glass openings, which absorbs solar radiation from the sun, which degrades the indoor air quality. Considering present skills and market scenario, the most promising renewable energy technology to produce electrical energy from buildings is photovoltaics inclination [5]. The use of BIPV is widely recognized for the popularization and acceptance of PV. PV avoids the use of land for energy systems and reduces the cost of capital of the system by providing various purposes for multiple functions of PV components, for instance double use of the outer surface of the building.

Building envelopes to which the BIPV module can be applied mostly depends upon the building façade; with the increase in area of the façade, the building height also increases [6]. PV alleviates the need to use the land for energy systems (double use of the building envelope surfaces), and reduces the capital costs of the systems as it serves several purposes due to the multi-functionality of the PV components [7].

They are becoming "Energy flexible Buildings" by producing, storing, supplying, and consuming energy [8].

The benefits of integrating PV system into national grids are decrease in transmission and distribution line losses, increase in grid resilience, lower generation costs, and reduction in requirements to invest in new utility generation capacity. This will help policy makers in municipal to province level to in different sectors [9].

This technology can be used by the public easily and benefited financially by the government with different incentives and schemes. More energy production will increase energy self-reliance for the public. Solar energy is the source with least negative environmental impact compared to any other energy source. It does not produce greenhouse gases, nor does it pollute the water. As it is renewable source of energy, promotes healthy environment and minimizes the use of non-renewable sources like petroleum products, gas, etc. which ultimately helps the atmosphere to be clean.

2. Methodology

In this research, the study of types of BIPV that can be used in the building of Kathmandu valley was reviewed and energy generation from BIPV retrofitted in the façade of the building was reviewed using research paradigm like post positivism. In addition, the research approach will be inductive research approach as it starts with observations and theories which are proposed later at the end of the research process because of observations and analysis.

To address the key research objectives, this research has used both quantitative and qualitative methods, and also a combination of primary and secondary sources as shown in the figure 1. The qualitative data backs up the quantitative data analysis and results. The study comprises a site survey of case building. The survey was based on direct observations and using questionnaires. The result obtained was triangulated since there is application of the quantitative and qualitative data types in the data analysis.

Interpretation of data analysis, simulation, and literature review results were discussed along with other dimensions that affected the results in order to achieve the goals of the study. Achieving the goal led to subsequent conclusions.

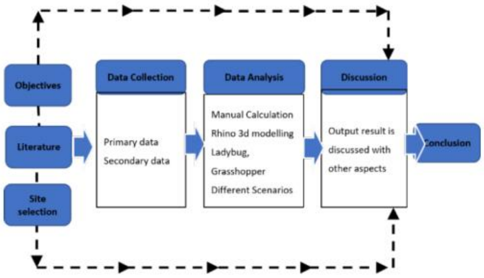

Figure 1: Methodology

3. Literature review

In this research, the study of types of BIPV that can be used in the building of Kathmandu valley was reviewed and energy generation from BIPV retrofitted in the façade of the building was reviewed using research paradigm like post positivism. In addition, the research approach will be inductive research approach as it starts with observations and theories which are proposed later at the end of the research process because of observations and analysis.

3.1 Historical Background

The Sun has been the ultimate source of energy since the beginning of life on Earth. The solar panels were first discovered by Becquerel's discovery in 1839. BIPV's first appearance worldwide was as roof integration in Germany in 1985 [10]. Again, in Germany, the first facade integration took place in 1991. Many countries have already centralized solar energy in their energy policy and have committed to fulfill a significant portion of their energy demand via solar power.

3.2 Energy retrofit and Building integrated Photovoltaics

Energy retrofit involves modifying existing commercial buildings which may improve energy efficiency or decrease the energy demand. In addition, retrofits are often used as opportune time to install distributed generation to a building. Among photovoltaic technologies, building-integrated photovoltaic (BIPV) technology integrates the functions of building exterior materials and photovoltaic (PV) modules into building envelopes.

3.3 Type of Solar Photovoltaics

There are three major types of solar PVs: monocrystalline, polycrystalline and thin-film solar panels. Characteristics for the same are shown in the table 1 below.

Table 1: Major types of Solar PV

Solar panel Type	Material	Efficiency	Cost	Appearance
Mono-crystalline	Pure, single silicon crystal	High (18 % or slightly higher)	Highest	Black or dark blue cells with rounded corners
Poly-crystalline	Silicon fragments	Medium (15-17 %)	High	Blue rectangular cells
Thin-film	Various	Low (11%, but may attain 15%)	Lowest	Black or blue uniform surface

Thin film solar panels can further be classified based on the flexibility, transparency and other characteristics. For the aesthetics purposes also, different experiments are done for new types of solar panels in whole world.

3.4 Benefits of Solar PVs

Continual advancements are being made in solar panel technology that are increasing the efficiency and at the same time lowering the production cost, thus making it even more cost effective. Solar energy can be an alternative in remote areas where it is too expensive to extend the electricity power grid. BIPV is one of the most promising and elegant ways of directly producing on-site electricity from the sun without any environmental harm, pollution, or depletion of natural resources [11].

3.5 Factors affecting performance of PVs

Like everything else that deteriorates when left in the sun, solar panels will also deteriorate from ultra-violet rays. The outdoor performance of a PV module is influenced by many factors. Few of these major factors are: i. Degradation of PV Module ii. Variation in Solar Radiation iii. Module Temperature iv. Fill-Factor v. Parasitic Resistances vi. Shading vii. Soiling viii. PV Module Orientation and Tilt Angle

3.6 Research findings on BIPV

Building shape characteristics were determinant to overall energy results smaller façade-to-roof and larger surface-to-volume ratios were more favorable. Grasshopper/Ladybug enable fast energy and visual simulations with acceptable grade of accuracy and time investment, Rhinoceros BIM [12]. [13] found that significant deviation (to the tune of 50 percent) has been observed between individual panel efficiency and year-round system (array) efficiency. Optimization of the system is more important than efficiency of the PV module. Semi-transparent PV scan effectively save energy, provide cost reduction and also environmental benefits [14].

4. Research Context

Bhat- Bhateni is considered as one of the leading supermarket and departmental store chain spreading in Kathmandu valley as well as in major cities around the country. Bhat-Bhateni is one of Nepal's most trusted and famous brand. Public-oriented bhatbhateni building contains a large variety of products used in people's daily use. The building is identical and architectural uniformity maintained providing typical façade color, material, fenestration designs and plane geometry. Bhatbhateni supermarket and departmental

Figure 2: Bhatbhateni east façade (Anamnagar)

store depend mainly on electricity, HVAC system, and refrigeration. It is necessary to carry out the energy calculation from BIPV from the façade by simulation through different soft wares for energy savings.

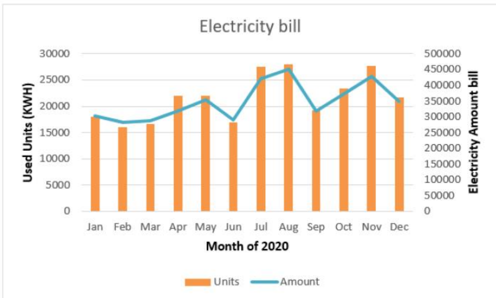

Figure 3: Electricity bill of the year 2020

As BIPV will be used for the electricity generation, total energy consumption units of the building is very necessary for the energy simulation of the façade. These units will later be used in the simulation process in Ladybug. To calculate the number of solar panels from the equations provided, these units are equally important. It is found that July- August have the maximum consumption units as shown in the figure 3 above. Major load present are HVAC load, equipment loads, lightings and electricity loads.

5. Modelling and Simulation

Energy modelling was performed to calculate the solar radiation radiated on the building envelope. To calculate the type, size, and orientation of the solar PV, this simulation is important. First, the model was

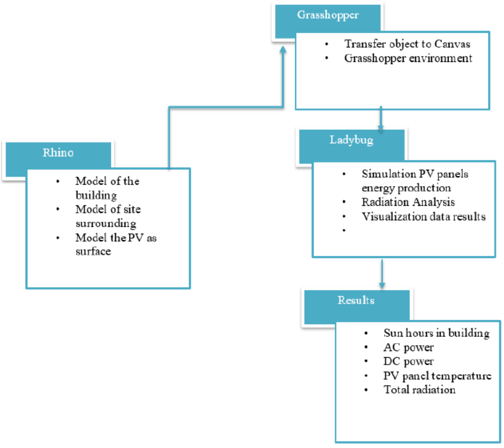

Figure 4: Flow chart for the simulation

modelled in the rhino were used. Grasshopper provides the environment canvas for the building modelled in rhino, which the plugin tool, but it alone cannot perform the necessary simulation for BIPV, so Ladybug plugin for grasshopper is used further for energy simulation as shown in the above figure 4. Ladybug is used for energy simulation that relies on several Energy Plus validated models with the climate file Energy Plus Weather file (EPW) of the target location.

5.1 Scenario Cases

For the simulation process, six scenarios were developed regarding the type, efficiency,orientation, placement and tilt angle as presented in the table 2.

Figure 6 shows the logical sequence of the ladybug

Table 2: Scenario cases

Cases	Description
Scenario 1	Mono- crystalline BIPV in South facade
Scenario 1a	With efficiency 15%
Scenario 1b	With efficiency 20%
Scenario 2	Mono- crystalline BIPV in South and East facade
Scenario 2a	With efficiency 15%
Scenario 2b	With efficiency 20%
Scenario 3	BIPV in segments in South and East facade
Scenario 3a	30^0 Tilt angle
Scenario 3b	60^0 Tilt angle

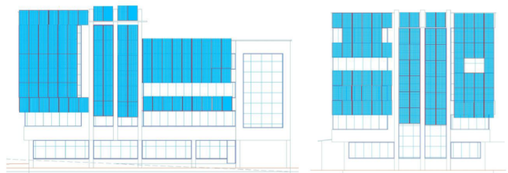

Figure 5: Placement of calculated BIPV in the east and south facade of case building

for the scenario cases developed, the process was same for all the cases but the input parameters are different. As the building was already modelled in rhino, BIPV were placed in façade of the building in the grasshopper with ladybug plugin. Besides PV modules' characteristics simulation required other attributes, like PV surface tilt angle, PV surface azimuth angle, mounting configuration of the modules and the percentage of area of active modules (percentage of the module's area excluding module framing and gaps between cells). These parameters are different for different scenario depicted in table 2.

6. Analysis and Results

6.1 Results from Manual Calculation

With the average units per month i.e. 20,000 kWh, calculation for the sizing of PV panels, batteries and inverter were done. As 100 percent was much higher, only 60 percent was taken into consideration. For the calculation, 500w solar pv with 19.5 percent efficiency from Pi-energy solar technology was used. The results from the calculation are 223 solar panels,70 kAh battery and 173 KVA inverter. BIPVs from the calculattion were curtained in the east and south facade as shown in the figure 5.

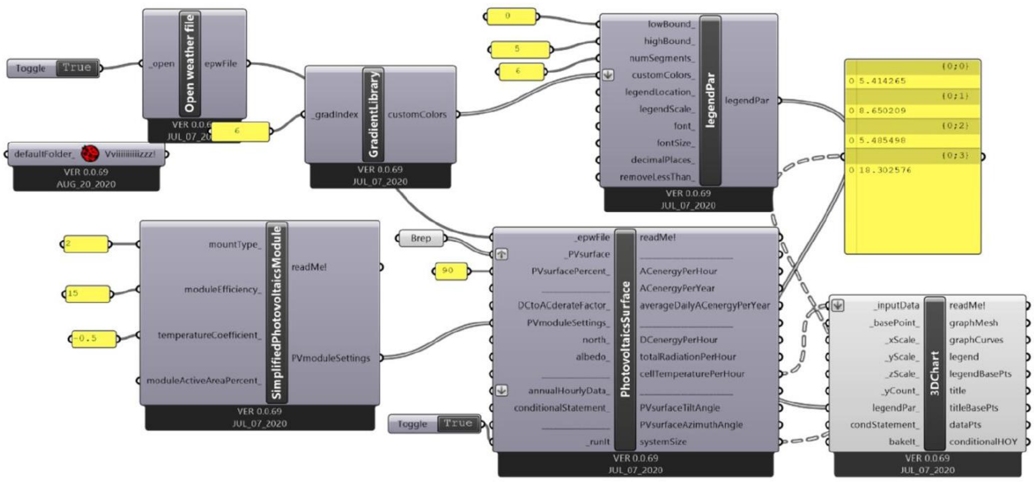

Figure 6: Logical sequence of ladybug with solar PV setting with different parameters

6.2 Radiation Analysis

To identify the most suitable façade for photovoltaic integration, the irradiation analysis was used which can be seen in the figure 7. Radiation analysis for the 21st June and in 21st December was done as it is the longest and shortest day throughout the year. It is found that maximum solar radiation is on roof and then in south and east façade. Due to the space limitation and functional space on roof, BIPV on south and east façade is preferred here as it gains more sunlight than other orientation of the building.

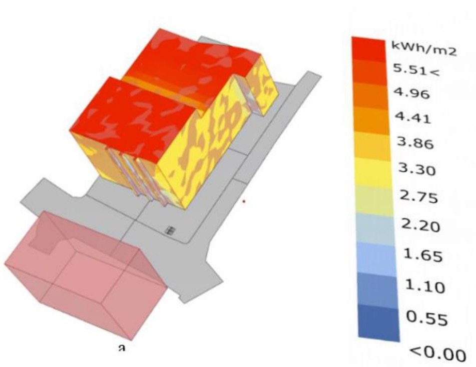

Figure 7: Radiation on building on 21 June

6.3 Results and Comparison of Scenario cases

6.3.1 Yearly AC Output

It is the AC power output for each hour during a year measured in kWh. In the figure 8, it can be depicted that the maximum AC generation for a year is for scenario 2b that is the BIPV used in both south and east façade with 20 percent efficiency and the least can be seen in the scenario 1a, i.e., the BIPV in south façade with 15 percent efficiency.

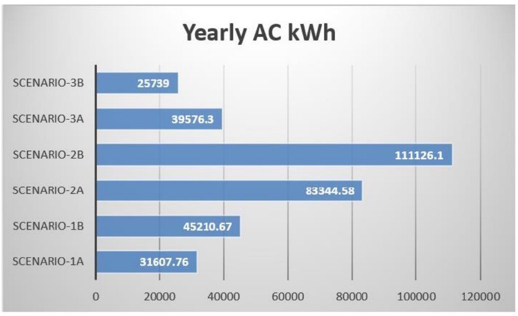

Figure 8: Comparison of yearly AC energy output of different scenarios

6.3.2 Daily Average AC energy output

It is the average daily AC power output per day for a whole year measured in kWh /day. As the AC power for a year is maximum in scenario 2b, so the average daily AC is also same presented in the figure 9.

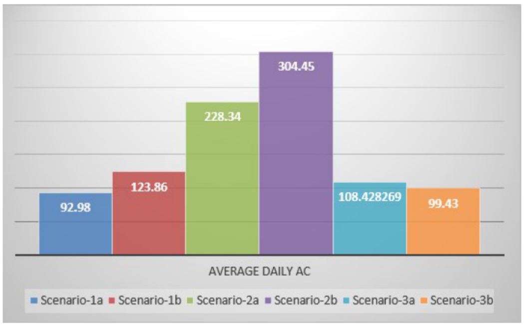

Figure 9: Comparison of daily AC energy output of different scenarios

6.3.3 DC System Sizing

It is the DC rating of the PV system measured in kW. The DC system sizing of the solar panel is also maximum for scenario 2, as the area of BIPV is more in this scenario as presented in the figure 10.

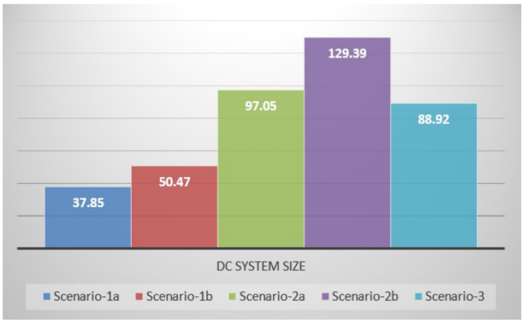

Figure 10: Comparison of DC system size of different scenarios

6.3.4 Comparison of DC system size of solar panel with surface area

In the table 3, comparing DC system size with that of surface area placed in the façade of the building, maximum can be seen in scenario 1b with 20 % efficiency PV panels in the south façade and minimum in the scenario 1a with 15 percent efficiency PVs.

6.3.5 Comparison of Yearly AC output of solar panel with surface area:

By comparison of yearly AC output of Solar PVs with the surface area shown in table 3, it can be depicted that scenario 1b gives maximum i.e. 13.5 kWh/sq.ft. and scenario 3a showed the poor performance with just 5.52 kWh/sq.ft

Table 3: Comparison of results of different scenario cases

Parameter	Unit	Scenario 1a	Scenario 1b	Scenario 2a	Scenario 2b	Scenario 3a	Scenario 3b
DC system size	kW	38.75	50.47	97.05	129.39	88.92	88.92
Area	sq.ft	3349.02	3349.02	8586.43	8586.43	7164.778	7164.778
System size/ area	kW/ sq.ft.	0.011	0.015	0.011	0.015	0.012	0.012
Yearly AC	kWh	31607.76	45210.67	83344.58	111126.1	39576.30	25739
Yearly AC/ area	kWh/ sq.ft.	9.43	13.50	9.70	12.94	5.52	3.59
Monthly energy	kWh	2633.98	3767.55	6945.38	9260.50	3298.02	2144.917
Energy by BIPV	%	13.17	18.83	34.72	46.3	16.49	10.72

6.3.6 Comparison of Yearly AC output of solar panel with building energy consumption:

By comparison of yearly AC output of Solar PVs with energy consumption, from the table 3 can be seen that 46.3%of total energy consumption of the building and scenario 3b with the thin-film with 60-degree tilt angle showed poor performance.

7. Findings and Discussions

This research was done with the aim to provide an appropriate BIPV to Bhatbhateni building at Anamnagar so that it can tackle future crisis. The energy consumption of the building was studied and energy modelling was performed to visualize parameters. The energy consumption charges for the summer season is double than that of the winter season. The building is dependent fully upon mechanical and artificial system for operation.

Different findings were obtained for the six scenarios developed earlier. The outputs obtained were, AC energy generated for a year, total yearly AC energy output, and daily average AC energy output for a year, hourly DC energy output of the PV array for a year, hourly total solar irradiation, hourly cell temperature for a year, and system size. The findings recommend that maximum energy generation from BIPV used in both south and east façade of the building PV efficiency 20%, temperature coefficient -0.5 was found in scenario 2b when compared with other scenario developed during the simulation process. In addition, scenario 1b was considered good with the comparison of yearly AC output with the surface area. From the financial analysis, it can be depicted that the minimum payback period for the BIPVs were of scenarios 1a and 2b with 3.6 and 3.8 years respectively.

From the comparison of manual calculation to that of the simulated results, it can be depicted that the area of solar PV is less than simulated results. Also, manual calculation gave more energy generation than that of scenario2b which was considered good from the simulation process. This can be due to the consideration of solar radiation in the building in the simulation process in different time, month and year from the EPW file loaded in ladybug software. In manual calculation no such factors were considered. Also, the placement of the solar panel impacts the power generation as in the simulation process, the surrounding were also present and BIPV were placed in the building façade.

8. Conclusion/Recommendation

The main objective of this research is to find out the possibility of BIPV in the façade of the commercial building of Kathmandu that has been achieved by the calculation and simulation results of different scenario cases. The energy generated by BIPVs is mainly dictated by daily average AC and yearly AC output placed in the building facade. Basically, performance of the solar PVs mainly depend upon the orientation, tilt angle, shading, placement, solar radiation from the sun, etc. which should be taken into consideration while placing these BIPVs.

The comparison between different scenario cases concluded that the BIPV with 20% efficiency retrofitted in both south and east façade can give maximum power output. Hence, energy retrofit with BIPV in the existing façade of the building can reduce the dependency in fossil fuel that ultimately helps in the reduction of GHGs that creates clean environment. BIPV can also be used as the mix energy with other resources.

BIPVs can play a significant role in buildings in tapping the solar energy potential especially in country like Nepal where there is a good amount of sunshine throughout the year. Use of BIPVs in the buildings helps in reducing the use of fossil fuels which are non-renewables. As these are clean source and energy efficient, use of BIPVs should be encouraged. Some recommendation on further studies such as orientation as the above study have not done research on all the orientation, building types, climate to the impact of the BIPVs.

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Annex-V: Comment/Questions from External Jury with explanation

1. As manual calculation was not so important to be done for the solar PV system. Why did you include in your study?

As the solar radiation from the sun was not incorporated in the manual calculation, so it did not give the correct number of solar panels. So. It is not that valuable to be included in this thesis project. This was included just to compare the solar PVs obtained from both manual and from simulation. In addition, to prove that from the simulation process as it includes solar radiation from the sun, it is more efficient to use the simulation software for the calculation.

2. How did you concluded scenario cases and the subdivisions for the simulation?

From the literature review and market study, I concluded that the BIPV of 20% efficiency is the highest range and incorporated in the simulation process further. Efficiency was subdivided into two groups as 15 and 20%. We already know that 20% efficiency PVs yields maximum energy but for cost and other comparisons 15%, efficiency was also considered in the simulation process. As we already know that east and south orientation gains maximum sunlight in Kathmandu valley, so the cases were according to the orientation of the building and the efficiencies of the BIPV. Third scenario case was for the thin-film solar PV in replacement of the windows of the building obtained from the literature review earlier.

3. Can you conclude that the scenario 2b i.e. BIPV (20% efficiency and south and east façade) can be used in other climatic zones?

As mentioned earlier, south and east orientation gains maximum sunlight in KV. Therefore, scenario 2b is best for this particular climatic zone. For other climatic zones, we can use 20% efficiency BIPV but the orientation varies according the sun angle in different regions. In general, we can use 20% efficiency BIPV with its best orientation in other buildings in other climatic zones as well.

4. Batteries used for the solar PV system is non-renewable, hazardous and not so cost efficient. What is your views on this?

Yes, the batteries are not efficient and causes environment degradation. When batteries run out, there are environmentally troublesome disposal issues. Conventional landfills must remove toxic waste from batteries. Therefore, in this thesis, I did not include the batteries in the solar system process as from the case study; I came to know about the net metering system incorporated in the building in association with the national grid. In this thesis, the power generation is not stored in the batteries instead excess amount of the generation is given to the national grid and in need building takes from the national grid. It is the to and fro process which is economically and environmentally favorable.

5. The result for this research is obvious that by using BIPV in the façade of the building is efficient. What is the newer findings from this thesis?

BIPV retrofitted in the curtain façade of the commercial building can serve dual purpose. The roof of the building is not included in this thesis as it can be used for different activities and instead façade can be used for energy generation. This thesis gives the energy generation per area in the façade, which will help the governmental and private sectors for more energy efficient techniques. The payback period results also help owners shift towards the use of BIPV.