NEAR EAST UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

BUILDING INTEGRATED PHOTOVOLTAIC, A CASE STUDY FOR NEAR EAST UNIVERSITY CAMPUS

M.Sc. THESIS

ALEXANDER SAA BUNDOO

Nicosia

May, 2023

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Approval

We certify that we have read the thesis submitted by Alexander Saa Bundoo titled **"Building Integrated Photovoltaic, A Case Study for Near East University Campus"** and that in our combined opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master in Electrical and Electronic Engineering.

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Declaration

I hereby declare that all information, documents, analysis and results in this thesis have been collected and presented according to the academic rules and ethical guidelines of Institute of Graduate Studies, Near East University. I also declare that as required by these rules and conduct, I have fully cited and referenced information and data that are not original to this study.

Alexander Saa Bundoo

…../…../2023

Day/Month/Year

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Alexander Saa Bundoo

Abstract

Building Integrated Photovoltaic, A Case Study for Near East University Campus

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Building integrated photovoltaic (BIPV) is a solar PV energy technology that is incorporated into the structure of buildings that performs energy generation and building envelope functions. This technology is gaining popularity due to the growing concern for environmental sustainability and energy conservation in building design. BIPV systems may be mounted on windows, roofs, facades, and other surfaces of a building that receive enough sunlight. This technique's incorporation into the building envelope may lead to fewer greenhouse gas emissions and better indoor air quality. The aim of this thesis is to investigate BIPV and a grid-connected PV system (PV powerplant) potential on Near East University campus using HelioScope software. PV panels are installed on some selected buildings and simulated to determine their monthly and annual output energy. For example, 311 panels with rated capacity of 76.4kW (DC power) were installed on the rooftop of the innovation building, the simulated annual grid injected energy is 125.1MWh. Furthermore, the grid-connected PV plant for the NEU campus is sited behind the faculty of veterinary medicine building occupying an area of 1581.9 m^2. The rated capacity of the plant is 1.5235MW using a total of 6348 solar panels and 51 inverters, each panel and inverter are rated at 240W and 30kW respectively. Simulated yearly output energy of the PV plant is 2.078GWh with a performance ratio of 78.8%. The results of this investigation show that, more than 3GWh of solar electric energy are left to waste annually on NEU campus because the requisite investments have not been made to harvest these resources.

Keywords: Building Integrated Photovoltaics, PV Power Plant, Payback Period, Performance Ratio, Solar Energy.

Özet

Yakın Doğu Üniversitesi Kampüs Binası Entegre Fotovoltaik Vaka Çalışması

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Yüksek Lisans, Elektrik-Elektronik Mühendisliği Bölümü

Mayıs, 2023, 93 Sayfa

Binaya entegre fotovoltaik (BIPV), enerji üretimi ve bina kabuğu işlevlerini yerine getiren binaların yapısına dahil edilen bir Fotovoltaik güneş enerjisi teknolojisidir. Bu teknoloji, bina tasarımında çevresel sürdürülebilirlik ve enerji tasarrufuna yönelik artan ilgi nedeniyle popülerlik kazanmıştır. BIPV sistemleri, yeterli güneş ışığı alan bir binanın pencerelerine, çatılarına, cephelerine ve diğer yüzeylerine monte edilebilir. Bu tekniğin bina kabuğuna dahil edilmesi, daha az sera gazı emisyonuna ve daha iyi iç hava kalitesine yol açabilir. Bu tezin amacı, HelioScope yazılımı kullanılarak Yakın Doğu Üniversitesi kampüsünde BIPV ve şebekeye bağlı bir Fotovoltaik sistemi (PV santral) potansiyelini incelemektir. Fotovoltaik paneller seçilen bazı binalara kurulmuştur ve aylık ve yıllık çıkış enerjilerini belirlemek için simüle edilmiştir. Örneğin, inovasyon ve bilişim teknolojileri binasının çatısına 76,4kW (DC gücü) nominal kapasiteye sahip 311 panel kurulmuş olup, simüle edilen yıllık şebeke enjekte edilen enerji 125,1MWh olarak belirlenmiştir. Ayrıca, YDÜ yerleşkesi için şebeke bağlantılı Fotovoltaik santrali, 1581,9 m^2'lik bir alanı kaplayan Veteriner Fakültesi binasının arkasında yer almaktadır. Santralin nominal kapasitesi 1.5235 MW olup, toplam 6348 güneş paneli ve 51 inverter kullanılmıştır, her bir panel ve inverter sırasıyla 240W ve 30kW olarak derecelendirilmiştir. Fotovoltaik tesisinin simüle edilmiş yıllık çıkış enerjisi, %78,8 performans oranıyla 2,078 GWh'dir. Bu araştırmanın sonuçlarına göre, YDÜ kampüsünde yılda 3 GWh'den fazla güneş enerjisinin, bu kaynakların kullanılması için gerekli yatırımların yapılmaması nedeniyle boşa gittiğini göstermektedir.

Anahtar Kelimeler: Bina Entegre Fotovoltaik, PV Enerji Santrali, Geri Ödeme Süresi, Performans Oranı, Güneş Enerjisi.

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List of Abbreviations

AC:	Alternating Current
BIPV:	Building Integrated Photovoltaic
CO_2:	Carbon dioxide
CSP:	Concentrated Solar Power Technologies
DC:	Direct Current
HS:	HelioScope
I_{sc}:	Short circuit current
kWh:	Kilowatt hour
MW:	Megawatt
NEC:	Near East College
NEU:	Near East University
PR:	Performance Ratio
PV:	Photovoltaic
SLD:	Single Line Diagram
SWOT:	Strength Weak Opportunities Threats
V_{oc}:	Open circuit voltage
WPT:	Wireless Power Transfer

CHAPTER I
Introduction

1.1 Overview of the Research

It is troubling that the world's use of fossil fuels is increasing at an alarming rate. As a result, an excessive amount of demand is being placed on these finite resources (Kanters, 2016). It is estimated that buildings consume more than 40% of all the energy that is utilized on the globe (Heinstein, 2013). This includes the amount of power used by residences, commercial establishments, and manufacturing facilities alike (Zogou & Stapountzis, 2011). Research shows that buildings in the European Union are responsible for 30% of the total carbon dioxide (CO_2) emissions. 57% of all these energy are used in the heating of residential structures, per the European Parliament and Council of 2002 (Filippini, 2014). Because more and more people are becoming aware of these challenges, there has been an increased focus all over the world on efficient building design and the use of renewable energy sources.

The world is paying a lot of attention to renewable energy production in order to combat climate change and other pressing issues such as the steady depletion of conventional energy supplies, pollution of the environment, increased power demand, and the need for sustainable rural electrification (Pillai et al., 2022). Building integrated photovoltaic (BIPV) technology is a fresh and alternative option that makes use of extensive roof and façade areas of buildings for PV deployment due to its adaptability in comparison to traditional methods of solar power conversion (Mehravaran et al., 2019). In order to cut down on carbon dioxide emissions and fossil fuel use, several governments, with the help of the United Nations, are now implementing green energy initiatives. The United States government has allocated the majority of its solar energy research financies to PV projects over the last decade in order to lower cooling load and energy consumption (Funk,C.,& Hefferon,M. 2019).

There has been a consistent increase in solar energy's use and adoption since it is the most popular and most advanced kind of renewable energy (Ofori & Duke Energy 2020). As a consequence of the looming threat of climate change and the energy problem, an increasing number of people are interested in incorporating renewable energy sources, such as solar power solutions, especially photovoltaic, into their homes and businesses. Because of solar and photovoltaics' rising popularity, new innovations are always being developed to improve efficiency and reduce prices. However, building integrated photovoltaic, a novel photovoltaic technology, has just entered the solar energy industry. Essentially, energy conversion components would replace more conventional building materials and components like roof tiles, windows, and facades in buildings that use building integrated photovoltaic technology (M. Nassereddine, 2016).

In recent years, there has been a speedy rise in the amount of effort put into the investigation and development of alternate forms of energy. Certain industries have made significant strides toward the broad use of renewable energy technologies (Hussain, A, 2017). Solar technology, one of the most well-known and generally implemented types of renewable energy sources. The term "photovoltaic technology" comes from the "photovoltaic effect," which describes the process by which light is converted into usable energy. PV technology is also known as "photovoltaic technology" (NERL, 2019). The effect makes a reference to the possibility that electrons existing at this energy level may be stimulated to a higher energy level by a photon of light. They act as channels for the flow of electricity (Bhatia, S. C., 2017). Modern photovoltaic (PV) technology makes use of this process to generate power from solar panels that include solar cells made of photovoltaic materials. The PV technology available today may perform a broad variety of functions. For example, the International Space Station, which is considered to be the most significant man-made object currently orbiting the Earth, utilizes solar photovoltaic panels (Garcia, M., 2017). In addition to photovoltaics' applications in outer space, significant breakthroughs have been made in the field of alternative sources for powering vehicles and ships. On the other hand, research also indicates that, an electric car of average size could cover up to fifty percent of a person's daily distance in the United States on the electricity provided by its on-board solar panels alone(Abdelhamid, M. et al., 2015).

Photovoltaic (PV) systems, which convert light from the sun into usable electrical energy, have quickly become one of the most prominent forms of renewable energy production technology. According to the International Energy Agency's (IEA) Snapshot of Global PV Markets 2023, the photovoltaic (PV) market has expanded roughly to 240 GW, a boom ignored for years and mostly driven by China, the United States, and Europe. This is a significant increase in market side. The International Energy Agency (IEA) says that there has been a steady increase in the number of PV installations worldwide over the past several years, despite the fact that there have been a number of obstacles. This is due to developments in production, decreases in prices, and a greater awareness of the significance of maintaining a sustainable environment ("Snapshot of Global PV Markets 2022").

In addition, The International Energy Agency (IEA) has noticed that the price of PV systems has significantly decreased over the past few years (to as low as $0.02 USD/kWh in very sunny places), and that this development is now becoming obvious enough to influence the decisions that are made regarding energy policy (Ogbeba &

Hoskara, 2019). Research from the International Energy Agency (IEA) in 2018 says that solar photovoltaic (PV) power will be the cheapest source of energy, including electricity, as the cost of PV power drops to $0.02 USD per kilowatt hour in particularly sunny places.

There is also the issue of whether power should be generated centrally or decentralized in light of the rise in popularity of photovoltaic (PV) systems. There are benefits and drawbacks to using both centralized and decentralized power systems. Decentralized energy is energy that is made closer to where it will be used. This is different from the traditional model of electricity distribution, in which energy is made at a huge facility somewhere else and then sent across the national grid to different end users (Fig. 1.).

Table 1.

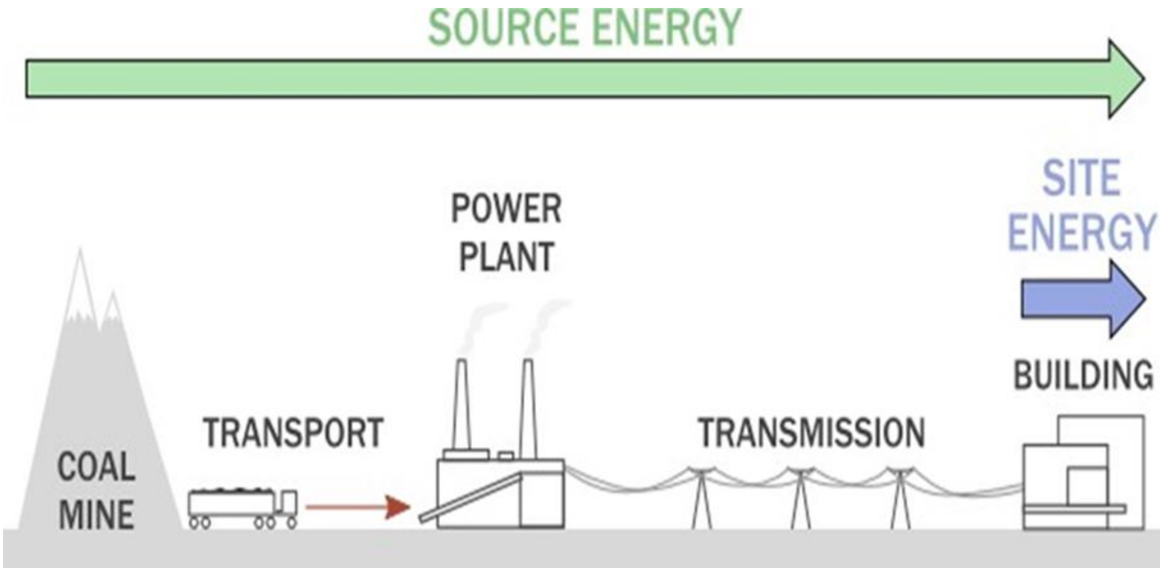
Advantages and Disadvantages of Decentralized and Centralized Energy System.

Advantages	Disadvantages
Efficiency: Due to the fact that decentralized energy systems produce power closer to the point of consumption, which lowers transmission losses, they may be more effective than centralized energy systems.	Cost: Installing and maintaining decentralized energy systems might be more costly than doing so with centralized ones, especially for single-family homes and small enterprises.
Environmental impact: Since decentralized energy systems often employ renewable energy sources like solar or wind power, they may be more ecologically friendly than centralized energy systems.	Decentralized energy systems may need new connectivity standards and infrastructure in order to be properly linked with the main power grid.
Reliability: Centralized energy systems are designed to provide a steady supply of power to a large number of users.	Transport: large transmission lines are needed in centralized energy systems to move power across great distances, which may result in energy waste and excessive prices.

To provide cheaper and greener energy, a decentralized power grid seems to be the best option. The annoying noises and air pollution that other systems create make them unsuitable for use as dispersed systems. While decentralized energy generation has many advantages, there is growing worry about how the solar PV component can alter the built environment. There is a significant obstacle to finding a way to attach PV panels without damaging the architectural or aesthetic aspects of the building or the urban pattern, whether they are used as independent energy producers or integrated into the outside surfaces of buildings.

Figure 1.

Centralized Energy System



This way of making electricity makes it easier to use PV parts as a shade device, roof covering, glazing, or facade cladding.

Today, building accounts for 70% of Northern Cyprus' total power consumption 40% of that 70% is used by houses and apartments (Ogbeba & Hoskara, 2019). The vast majority of generated energy is used in private residences for purposes including heating and cooling, running appliances, and providing lighting. The consumption rate in the industrial sector is low (JE Ogbeba, 2019). Many homes in Northern Cyprus are built without considering bio-climatic factors, leading to an excessive reliance on mechanical cooling and heating systems. Indoor temperatures are more unpleasant as a result of the structures.

The average daily solar radiation on a horizontal façade in Cyprus is roughly 5.4 kWh/m^2, as stated by (Petrakis et al., 1998). About 300 sunny days per year may be expected in Cyprus. The mean low and high temperatures in January are a chilly 4°C and 19 °C, making it the chilliest month of the year. The warmest month, August, with mean lows of approximately 23°C and highs of around 38°C, according to data compiled by (Petrakis et al., 1998). Since North Cyprus has no natural gas or oil reserves, all of its oil and gasoline must be imported. Cyprus Turkish Electricity Authority (KIB-TEK), which is owned by the government, and AKSA, which is owned by a private group, are in charge of distributing , and selling, electricity across the country (Elinwa et al., 2017).

Without a doubt, Northern Cyprus possesses the requisite climatic elements to rely solely on solar energy for its electrical needs. Using Near East University as a case study, which was founded in 1988 and is located in Nicosia, the capital city of North Cyprus.

Most of the power that is consumed on the campus of Near East University is devoted to the heating, cooling and lighting of buildings. This research aims to establish that Near East University could benefit from the integration of solar systems (also known as Building Integrated Photovoltaic) as a way of producing power that is clean, affordable, and cheap. This study is to develop an idea that will enable photovoltaic (PV) panels to be install on existing buildings on the campus of NEU without negatively impacting either the surrounding environment. This research will also use Northern Cyprus in it study to come up with ideas to how PV could be used in Near East University built environment.

1.2 Solar Energy Potential in Northern Cyprus

There are roughly 382,230 people living in Northern Cyprus, which occupies an area of 3,355 square kilometers and features a Mediterranean climate. Four power plants account for the vast majority of Northern Cyprus' electrical output, which is derived from non-renewable energy sources. There are eleven solar PV plants in Northern Cyprus, with capacities of 1 MW (2015) at the Middle East Technical University Northern Cyprus Campus, 1.3 MW (2016) at Cyprus International University, 50 kW (2017) at the KKTCell Main Building, 120 kW (2017) at Levent College (2018), 3 MW at Kaya Artemis Hotel Solar Power Station, 0.9 MW at Turkcell Solar Power, 1.1 MW at Döveç Group Solar Power Station, 1 MW at Eziç Solar Power Station, 3 MW no injection at Concord Hotel, 3 MW no injection at Limak Hotel Solar Power and the Serhatköy PV power plant 1.275 MW located in Guzelyurt (S.N.Tackie et al.,2022) .

The potential for solar energy in northern Cyprus is enormous. Northern Cyprus is predicted to get an average of 1800 kWh/m^2 of global horizontal irradiation every year, with maximum values of 2000 kWh/m^2. Based on these numbers, the solar resource is rated as good (class 4) or exceptional (class 5) by (Kassem et al., 2016) and (Prăvălie et al., 2019) As an added bonus, the maximum and minimum values of direct normal irradiation are around 2230 kWh/m^2 and 1710 kWh/m^2, respectively. Based on these estimates, Northern Cyprus has good, excellent, and extraordinary solar energy potential. At the end of the day, it's clear that all of Northern Cyprus's areas have a great deal of untapped potential for using solar energy generation techniques like flat-plate PV and concentrating PV systems.

It is also important to remember that solar radiation varies in strength from location to location. Furthermore, it was determined by (lkan et al., 2019) that solar energy systems might stand to be alternate sources to provide necessary electrical energy and lessen the country’s carbon dioxide (CO_2) emissions. After analyzing the situation, Pathirana and Muhtaroglu came to the conclusion that Northern Cyprus may benefit from harnessing solar energy to generate electricity and become less reliant on fossil fuels. (Radmehr et al., 2020) discovered that building-integrated PV systems are very well suited to providing residential energy needs in Northern Cyprus. Ultimately, Agboola and Egelioglu came to the conclusion that solar energy might be viewed as a potential alternative option to lower Northern Cyprus's energy consumption and alleviate the region's severe water shortage.

1.3 Statement of the Problem

The world at large is now exploring alternatives to fossil fuels for power generation. Stakeholders and academics are investing into renewable energy sources like solar energy as a way to combat pollution, extreme energy usage, and the declining supply of fossil fuels (B. Jelle, 2015). The increasing population and economic activity in Northern Cyprus have required the continued use of polluting fossil fuels to generate power (Kassem et al., 2021). As a result, using renewable energy, especially solar energy, might be an answer to lessening the problem of using fossil fuels.

Near East University which is located in North Cyprus is heavily dependent on the fossil fuel based electric power generating system. 94% of the electric power generated in North Cyprus is from the use of fossil fuel based power plant (S.N.Tackie et al., 2022). Unlike other Universities in North Cyprus which have PV power plant on campus, Near East University is 100% depending on the fossil fuel source ie there is no renewable energy source in the generation mix used on NEU campus. Also, each faculties has a standby generator which uses fossil fuel to generate electric power when there is a power outage from the grid (KIB-TEK). To address this issue in an environmentally and economically sound way, renewable energy (RE) appears to be the best option. This research investigates whether or not it would be possible to use the building surfaces on Near East university campus to create the necessary energy needed instead of the centralized method of power generation, since the energy can be generated using a decentralized energy method.

In recent years, photovoltaic systems have been progressively introduced on the building exterior as a decentralized solar systems which seen as the most encouraging sustainable power source for building applications in many countries (Schweizer, 2017). On the other hand, during the last few years, a new photovoltaic technology has entered the market for solar electricity. It is becoming increasingly common practice to power buildings using solar panels that may be included in the framework of the building itself. Using this method, the outside parts of the building that hold it up were made to be able to produce solar energy. Traditional building components and materials, such as roof tiles, windows, and facades, may be replaced with energy conversion components using building integrated photovoltaic technology, this is the fundamental concept of the technology (Jelle B., 2015). Traditional photovoltaics is referred to as building applied photovoltaics before the arrival of building integrated photovoltaics in the solar power market. Building integrated photovoltaics has an advancement over traditional photovoltaics in which it is integrated on the façade and roof top of buildings.

It is the standard operating procedure in Northern Cyprus at the present time to have the architect design the building and have a separate team of specialists handle the integration and attachment of the PV systems to the building (Kosorić et al. 2018). When architects are not members of the integration team for a project, the visual quality of the building is typically compromised. Installers of solar systems often pay little attention to the aesthetics or design of the building, preferring, instead, to concentrate on the efficiency and output of the system in terms of energy production. Carelessness on the part of those installing PV systems can be partially blamed for the damage done to the natural environment. The installation of solar photovoltaic panels, solar collectors, and thermal water storage tanks on the rooftops of modern buildings is becoming increasingly common and ugly. This study aims to address this growing concern of energy in Cyprus using NEU campus as a case study.

1.4 Purpose of the Study

Near East University, a private institution in north Cyprus founded in 1988 by Suat Gunsel, currently has 16 faculties and 98 departments (MastersPortal.eu. 2020).The goal of this thesis is to integrate the potential power output when BIPV is implemented on some selected faculties on the campus of NEU. Also, this thesis present the potential of a grid connected solar, PV power plant for the generation of electric energy on NEU campus. The aim is that BIPV and a grid connected may be used as a distributed power source to provide energy that is both cleaner and less expensive.

This will be accomplished by a PV system software called Helioscope for designing a solar power system for the NEU campus. Using PV system software eliminate the need for capital intensive practical research. PV system software are widely accepted for research in academic and industry. Another goal of this thesis is to provide an advantageous approach to producing electrical power, mainly; photovoltaic energy.

The benefits of this approach to producing electricity are as follow:

- Environmentally safe
- Reduced or eliminated fuel costs.
- Maintenance at a reasonable cost.
- Installable in a wide range of environments.

1.5 Significance of the Study

The importance of this study is to demonstrate the viability of Photovoltaic systems for generating electricity at Near East University, both for stand-alone (BIPV), and grid-connected systems. The negative impacts of using generators, which include noise pollution and environmental air pollution (CO_2) are eliminated when photovoltaic systems are used to generate electric power. Additionally, since there is no fuel expense involved, the cost of photovoltaic system to produce electricity is much lower than that of generators and grid-tied electricity (non-renewable based sources). For Near East University, solar energy investment may result in long-term cost reduction. While there can be an upfront capital expenditure involved in constructing a PV plant, solar energy has the potential to eventually replace or lower electricity prices.

1.6 Limitations of the Study

For a first time user, photovoltaic (PV) systems software are more complicated and sometimes include many technologies. HelioScope is one of the most useful PV software that can be challenging for a first time user because of the elaborate setups involve. When it comes to assessing performance and designing a solar system, renewable energy professionals have access to a wide variety of software tools (Rima & Khan, 2018). The newly released HelioScope tool from Folsom Labs incorporates all the characteristics of PV systems plus the design capability of AutoCad, enabling designers to make a full design in one package.

Even though simulation-based research hardly has drawbacks, but a high-quality simulation model may be quite expensive because software designers charge for the use these software. Although simulation may be time-consuming for a first time user due to the prolonged hours spent on understanding the software, it ultimately provides a means of assessing potential computational solutions. Designers can accomplish a full job with the

Helioscope software since it combines the functionality of a PV system with that of AutoCAD’s design tools. The hardest part of solar PV-based software is figuring out how to set up the panels to make an array and how to choose the right inverter, combiner box, and other parts.

In addition, this study will take a wide perspective in PV integration on Near East University campus to find the most effective ways of incorporating PV surfaces into the built environment.

1.7 Overview of the Thesis

This thesis consists of four (4) chapters and below are these chapters.

Chapter 1: This first chapter provides a Scope of the research, which includes, the introduction, a statement of the problem, the thesis's aims, the thesis's significance, the study's limitations, and an overall overview of this thesis.

Chapter 2: A literature review that include photovoltaic modules, with their respective properties and Building Integrated Photovoltaic (BIPV) System which is explained in depth with the incorporation into the building envelope.

Chapter 3: BIPV simulation results of this research.

Chapter 4: Consist of the Conclusion and References

CHAPTER 2
LITERATURE REVIEW

2.1 Photovoltaics (PV)

The word "photovoltaics" (PV) refers to a technique that works with semiconductors and other electrical components in order to generate electricity (DC) from solar radiation. An inverter is required to change the DC voltage into alternating current that can be used by AC loads. This method is amazing not only because it has such a wide range of potential uses, but also because it generates energy in a way that is both noiseless and environmentally friendly. Researchers, however, claim that, half of the typical American's daily driving mileage could be covered by the electricity generated by an onboard solar system installed on a vehicle of average size (Abdelhamid, M. et al., 2015). When most people think of the photovoltaic system, there are two thought that often come to mind first, the Traditional photovoltaic systems, such as those used in building applied photovoltaics (BAPV) and building integrated photovoltaics (BIPV) (Tripathy, M., et al., 2016), which are the main ways this technology is used. The sun is a massive source of energy, which travels in the form of electromagnetic radiation. Depending on the wavelength of the radiations released, these radiations may be classified as light, radio waves, etc. Visible light makes up a relatively small portion of the sun's radiations which enter the atmosphere of the planet. This visible light creates electrons in solar cells. Different solar cells utilize light with different wavelengths. Semiconductor components, including silicon, are utilized in solar cells to generate power. Electric current is the term for the flow of microscopic particles known as electrons that represent electricity. Electric currents may flow in one of two directions: DC (direct current), where the direction of flow is constant, or AC (alternating current), where the direction of flow can change. The two layers of silicon in a typical solar cell are n-type at the top and p-type at the bottom. When sunlight hits the solar cell, the electrons are absorbed by the silicon, travel across the n and p layers to create an electric current, and then exit the cell via the metal contact. The power produced is of the DC type.

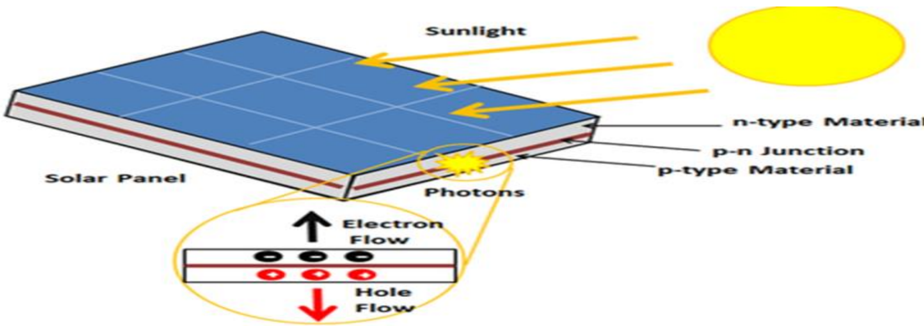
2.2 Types of PV Cells

A solar cell is an apparatus that absorbs solar light and transforms it into usable electrical energy (Sark, 2012). Due to the photovoltaic effect, a photoelectric cell has the potential to directly transform the energy in light into electricity.

There are three primary varieties of solar photovoltaic cells. The primary component of PV cells is silicon, which may be found in sand. Solar photovoltaic (PV) cells made from silicon may be divided into three groups.

Figure 2.

Basic PV Cell (Goodrich et al., 2012)

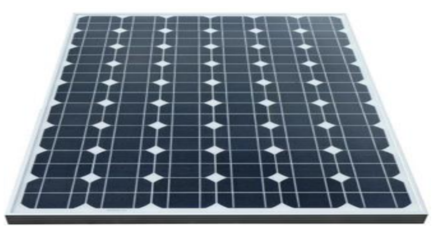


2.2.1 Monocrystalline Silicon Panel

Monocrystalline solar panels have been shown to have an efficiency level of around 20% on average with a diameter of 12.5 or 15 cm. Monocrystalline solar panels have the ability to deliver a high electrical output, and they are typically more durable owing to their tolerance to high heat. However, they tend to be more costly than polycrystalline solar panels because of their higher heat tolerance (Ray G et al., 2018).

Figure 3.

Monocrystalline Silicon Panel (Ray G et al., 2018).

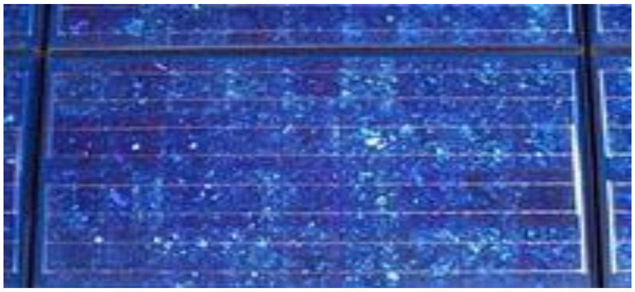


2.2.2 Polycrystalline Silicon Panel

Different names for polycrystalline silicon cells include poly-Si, polysilicon, and multi crystalline. Compared to monocrystalline, it has a lesser efficiency of 15% and is less expensive to produce. For the same amount of electricity generated, more room is needed. With an area of 1000W/m^2 of solar irradiation, a polycrystalline silicon cell generates 130W of electric power. Life expectancy is just 20–25 years (Ray G et al., 2018).

Figure 4.

Polycrystalline Silicon Panel (Ray G et al., 2018).



2.2.3 Thin Film Silicon

Thin film silicon PV cells are solar panels that are lightweight, flexible, and required less amount of resources and less energy to manufacture it. When compared to mono cells, thin film cells are more cost effective. With an average efficiency of about 10%, it is the least efficient option. Thin film silicon is often produced from non-crystalline silicon, which means it may perform quite well at lower irradiance.

Figure 5.

Thin film Silicon Panel (Guda and Aliyu, 2015)

The improvement in solar cell efficiency over time is encouraging for the progress of PV system technology.In 1954, researchers at Bell Telephone Laboratories produced a silicon solar cell that had an efficiency of 4%. (Fraas, L. M., 2014). In light of the fact that the National Renewable Energy Laboratory just established a new record for solar cell efficiency by achieving 47.1% efficiency with their six-junction solar cell as shown by Fig. 7 (NREL, 2020). This demonstrates the unquestionable progress of technology, as the solar cell with six connections can only attain an efficiency of 47.1% in a lab.According to the findings of recent studies, the overall efficiency of crystalline solar cells has improved by around 0.4% per year on average over the course of the preceding decade (Vartiainen, E. et al., 2019). Crystalline solar cells, which had an average efficiency of

17.2% in 2018, would have an average efficiency of 30% by the year 2050 if present trends in technological improvement continue.

Table 2.

Pros and Cons Characteristics of Difference Solar Panel Types

Solar Panel Type	Advantage	Disadvantage	Efficiency
Monocrystalline solar panel	Highest efficiency rate Durable Resistance to high	High Cost	20%
Polycrystalline solar panel	Lesser price than Mono c-Si Same energy output as Mono c-Si	Lesser efficiency rate than Mono c-Si	15%
Thin Film Solar cell	Light heaviness, flexible Aesthetically pleasing	Lowest Efficiency rate	10%

2.3 Photovoltaic System Component

The components that make up a PV system differ depending on the kind of system or the needs of the design. Solar panels, a charge controller, an inverter, and a storage device are all necessary parts (along with the battery). Since they use direct current (DC) electricity, solar water pumps made for irrigation do not need inverters. Other parts, including transformers, are needed for commercial or grid-connected PV systems. All of the above-mentioned parts may be found in PV systems that operate independently to provide electricity to households and small businesses.

Figure 6.

Photovoltaic Component (Guda and Aliyu, 2015)

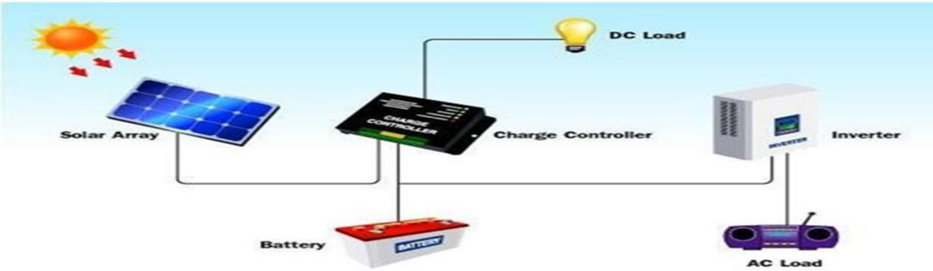
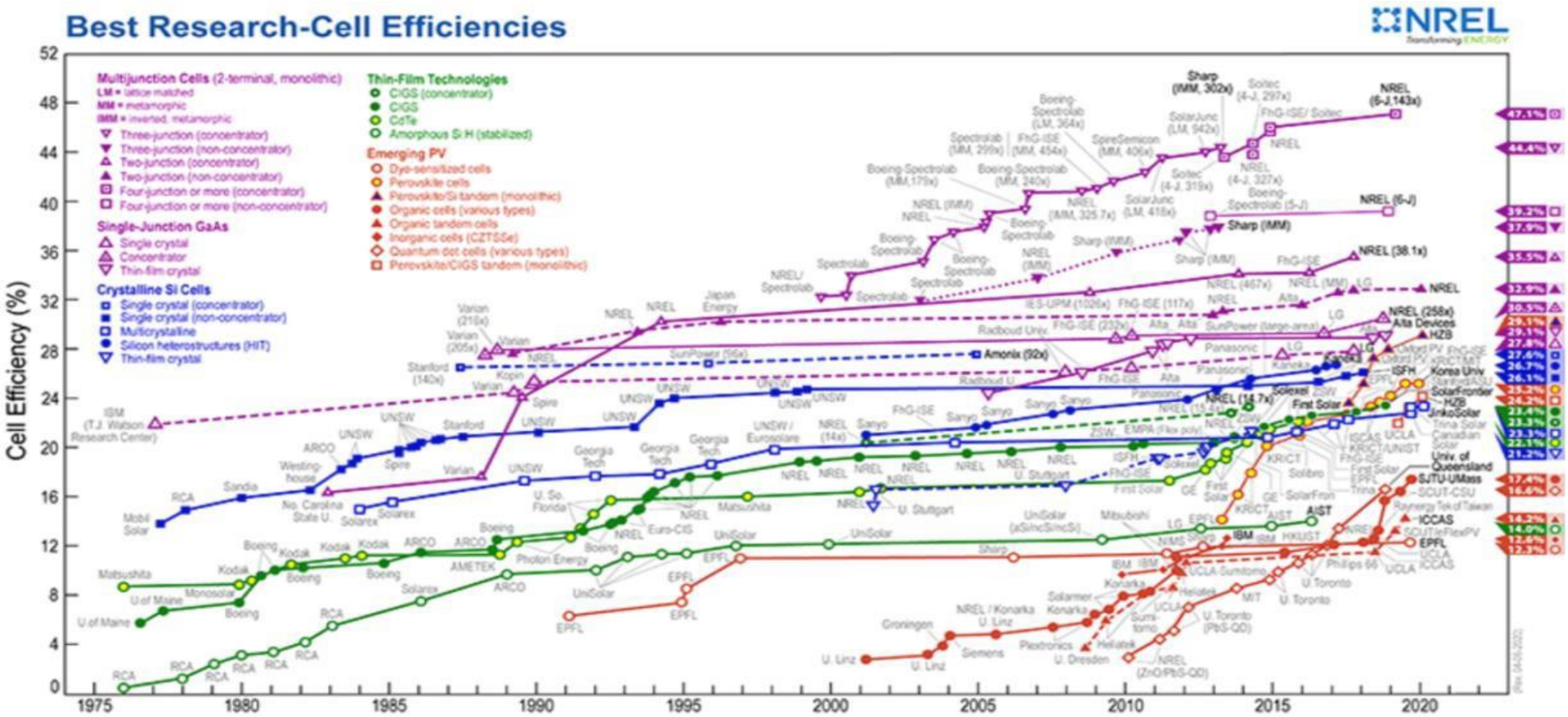


Figure 7.

(National Renewable Energy Laboratory (Alta, 2020)



2.3.1 Photovoltaic module

The photovoltaic panel's primary function is to transform sunlight into electricity (DC). The PV cells that make up the panel are joined together to produce the final product. Modules are linked in an array in one of the two ways: in series and in parallel, with the choice determined by the desired output characteristics. Most solar panels can be operated at voltages higher than 12 volts (Guda and Aliyu, 2015). The PV array can produce anywhere from a few hundred watts to thousands of kilowatts of electric power. Larger systems usually have more than one sub-array, and each sub-array is connected to its own power conditioning system. Both the module and the cell are at risk of being destroyed if they become too hot as a result of the electrical current flowing through the module. The construction of a PV module must adhere to a number of regulations. The electrical output (and hence the number of cells and the nature of their electrical connections), light transfer, cell temperature (which should be kept as low as possible), and cell protection all have a role. The module's electrical output is evaluated using the Standard Test Procedure.

2.3.3 Photovoltaic Module Selection

There is a wide variety of photovoltaic (PV) modules available on the market, including mono-crystalline, poly-crystalline, and thin film silicon panels. In order to choose the right PV module, it is important to consider factors such as cell type, system cost, warranty, module size/wattage, and so on (El-Shimy and M.; Abdelraheem 2015). In addition, Balo and Abanşua found that the power rating and material type of solar panels were key factors in the PV USA Test Conditions (Rehman et al., 2017). Using equation (2.1), we may choose an optimal PV module for the planned PV installation (Kassem et al., 2021).

$$\text{Panel selection} = \frac{\text{PV module capacity} \times \text{ Module efficiency}}{\text{Module price} \times \text{Frams area of the module}} \qquad (2.1)$$

2.3.4 Charge Controller

A charge controller's principal goal is to prevent the batteries from being overcharged or regulate their discharge to safe levels. Overcharging may destroy a battery by evaporating the electrolyte. If the battery is allowed to drain too much, the battery could fail prematurely and the load might be damaged. As with any PV system, the controller plays a vital role. The "state-of-charge" of a battery is used by the controller to determine how the system is operated (SOC). When the battery state-of-charge (SOC) is getting close to 100%, the controller will either redirect the current or turn off the array entirely. If the controller has low voltage disconnect (LVD) functionality, part or all of the load will be cut off when the battery voltage drops below a certain point. The majority of controllers calculate the remaining charge in a battery by measuring its voltage. Many controllers are equipped with a temperature sensor specifically for the purpose of improving SOC estimation by measuring battery temperature.

2.3.5 Inverter

The panels provide DC electricity; therefore, an inverter converts it to AC current that may be utilized by more equipment throughout the house. Manufacturers of photovoltaic inverters typically specify the inverter's nominal power under standard test conditions. More energy is lost as a result of an oversized inverter's. Oversized inverters increased the conversion of energy at lower power ranges, and more energy is also lost as a result of an undersized inverter's which increased conversion of energy at higher power ranges. A sizeable amount of the capital cost of a PV system goes toward the inverter. The inverter's input rating must be higher than the sum of all appliance wattages. For proper operation, the inverter's nominal voltage must match that of the battery. The inverter for a standalone system has to be powerful enough to provide however many watts the system will need at once. The wattage of the inverter should be 25–30 percent more than the total wattage of the appliances. If the appliance in question is a motor or compressor, the inverter's capacity must be increased by at least three times in order to accommodate the additional starting surge current. The input rating of the inverter for grid-tied or grid-linked systems should match the rating of the PV array for safe and efficient operation.

2.3.6 Optimal Sizing of Inverter

The sizing ratio (Rs) in PV systems is the ratio of the nominal power of the inverter (rated) over the nominal power of the PV array (rated) at the STC. To deliver the best possible PV array-inverter combination, this technique, however, chooses the PV module and the inverter via an optimisation procedure. Equation (2.2) contains the size ratio (Rs).

$$R_s = \frac{P_{pv}(\text{rated}),}{P_i(\text{rated}),} \tag{2.2}$$

The nominal power rating of the PV array $P_{pv(rated)}$ can be calculated using the formula outlined below.

$$P_{pv_{(\text{rated})}} = P_{mpp,stc}\ N_s . N_p \tag{2.3}$$

Where (Ns) and (Np) are the numbers of PV modules connected in series and parallel, respectively, and $P_{mpp,stc}$ is the nominal maximum power of the PV module under standard test circumstances. Design parameters (Ns) and (Np) have optimal values that are determined through the optimisation procedure.

2.3.7 Types of PV Inverters

There are three types of PV inverters, and they are as follows: stand-alone inverters, grid-tied inverters, and battery backup inverters.

- Stand-alone inverters: These are inverters that are design for a stand-alone systems. These inverter receives DC power from batteries that are recharged by PV panels and then outputs AC power for building usage.
- Grid-connected inverters: When the electricity goes out, grid-connected inverters won't save the day. For safety purposes, they are programmed to shut down immediately if the power goes out. They must be in phase with a sine wave provided by the power company.
- Battery backup inverters: These are specialized inverters that can take power from a battery, control the charging process using an on-board charger, and send any surplus power back to the mains grid. These inverters are required to include anti-islanding protection and can deliver AC power to specified loads during a utility outage.

2.3.8 Storage unit/Batteries

The primary function of the batteries that comprise the storage unit is to store any excess electrical energy. You may keep charging and discharging these batteries over and over again since they are deep-cycle batteries. They are different from car or vehicle batteries. Since the power output of a solar system fluctuates throughout the day in response to changes in sunlight, the battery storage system may maintain a typically consistent power supply even when the photovoltaic system is unplugged for maintenance or only provides a modest quantity of energy during periods of low sunlight.

2.3.9 PV Battery Sizing and Types

It is suggested that deep-cycle batteries be used in solar photovoltaic systems. A deep-cycle battery is a rechargeable battery that can be repeatedly charged and discharged for an extended period of time. In order for the battery to be able to keep the appliances operating through the night and on cloudy days, it has to have sufficient storage capacity. Formula (2.4) is used to determine the size of a PV battery (Leonics et al., 2020).

$$\text{Battery Capacity(Ah)} = \frac{\text{Total Watt−hours per day used by appliances} \times \text{Days of autonomy}}{(0.85 \times 0.6 \times \text{nominal battery voltage})} \qquad (2.4)$$

These include the two distinct types of batteries that are often used in a PV system: lead-acid batteries and alkaline batteries.

- Lead-acid batteries: These are PV system batteries with a low price, high durability, and high energy storage density. Two lead plates are submerged in diluted sulfuric acid to produce a voltage of roughly 2 volts in a lead battery cell. After that, a series connection is made between the cells to create 12V batteries.

- Alkaline batteries: Although they provide benefits over lead-acid batteries, alkaline batteries are more expensive and are only used in environments where very low temperatures (-50 °F or less) are expected or in certain commercial or industrial applications. A few examples of these benefits include being able to withstand extreme temperatures (be they low or hot), requiring little in the way of upkeep, and being safe to use even after being completely drained or overcharged.

There are a few different kinds of alkaline batteries used in PV systems, but nickel-cadmium batteries are by far the most popular. Nickel-cadmium (NiCd) batteries are suitable for use in standalone PV systems because they are secondary or rechargeable batteries with significant benefits over lead-acid batteries. Some of the benefits include an extended service life with few maintenance and repair needs, non-critical voltage control requirements, and excellent low-temperature capacity retention. As opposed to lead-acid batteries, nickel-cadmium batteries have a higher price tag and a smaller supply.

2.4 Types of Photovoltaics System

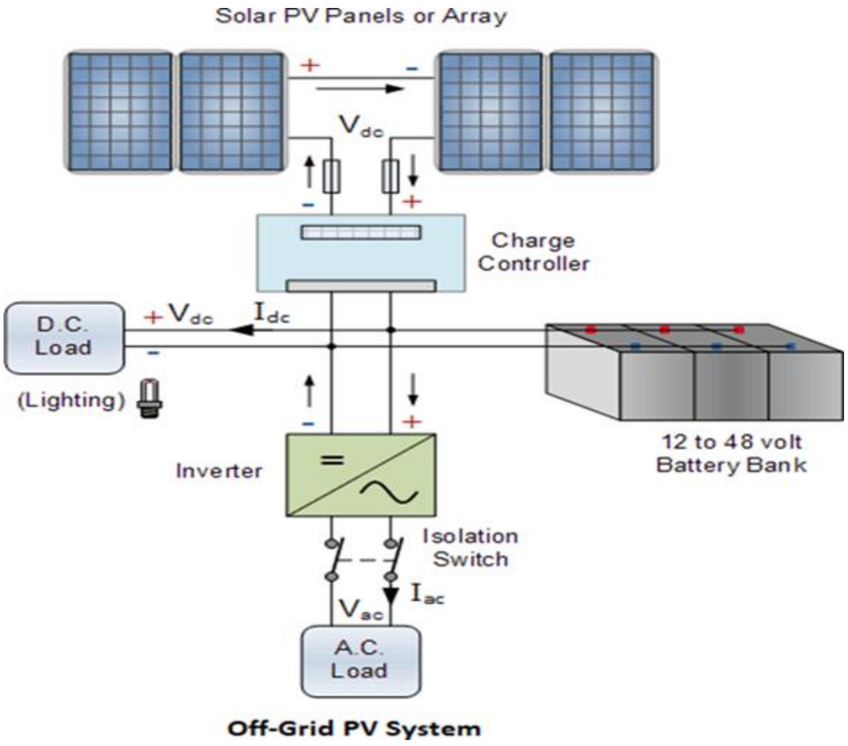
Photovoltaic systems are categorized in terms of their construction method and their intended use. Generally speaking, there are three types of photovoltaic systems: standalone, grid-connected, and hybrid PV systems. Other forms of PV systems exist, such as the inverter-free direct PV system.

2.4.1 Standalone PV System

The solar panels of a standalone PV system are not connected to any larger source of electricity. A basic standalone PV system is an automated solar setup that generates electricity throughout the day to charge batteries for use after the sun goes down. PV panels collect energy from the sun, which is then stored in deep-cycle lead-acid batteries and utilized as needed. Rechargeable deep-cycle batteries may be drained nearly to zero several times without losing their capacity to hold a charge.

Figure 8.

Standalone PV System (Bhatia, 2018)



2.4.2 Grid-connected PV System

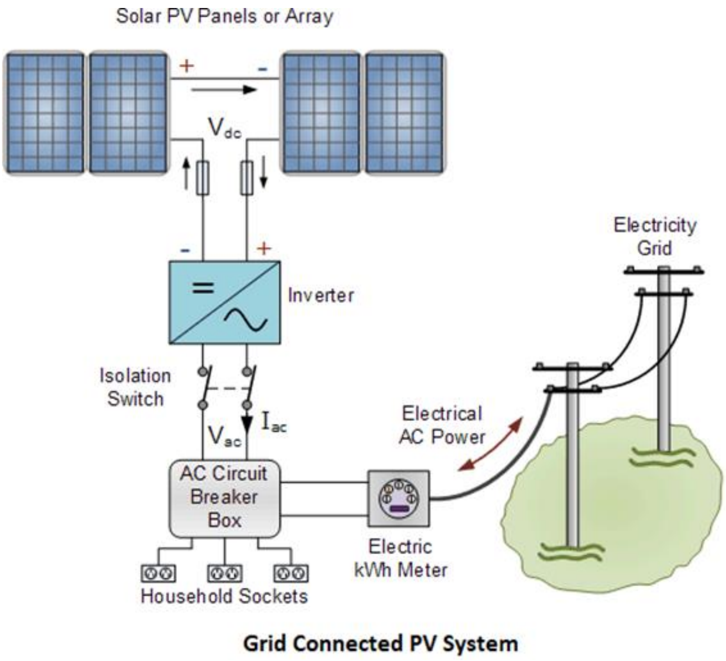
A storage battery is not necessary in a grid-connected PV system since the PV array is linked directly to the grid-connected inverter. You won't need to use the grid at all if your PV system is producing enough electricity. Your system's excess energy output will be sent back into the power grid, thereby reversing the direction of your meter. The power grid will meet all of the building's demand when the PV system is not generating energy, such as during the night. Instead, the utility company will compensate service providers with energy credits equal to the amount of electricity generated by the solar panels. Net metering is the term for this setup. One meter records both the input and output of energy throughout this procedure.

2.4.3 Hybrid PV Systems

The hybrid PV system integrates solar panels with other power sources like wind or hydro turbines or even diesel or gas engines. These auxiliary systems are meant to back up the PV setup when the sun isn't shining or when the sun goes down.

Figure 9.

Grid Connected PV System (Bhatia, 2018)

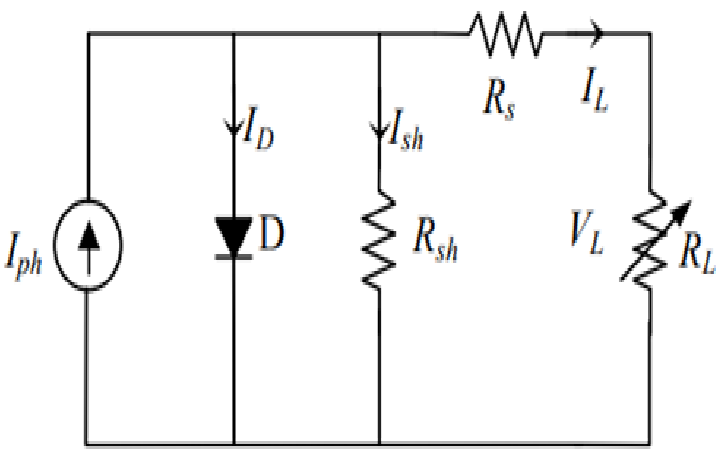


2.5 PV Cell Equivalent Circuits

In Fig 10, we see the simplest possible comparable depiction of the solar cell. This circuit has a current source Iph, a diode D in parallel, a shunt resistance Rsh, and a series resistance Rs. With regard to the solar flux that it is exposed to, the ideal current source supplies current in a linear manner.

Figure 10.

PV cell Equivalent Circuit (El-Dein et al., 2013)



2.6 PV Module Connection

Series, parallel, and hybrid series-parallel connections may all be used to successfully install solar modules. The need to use one type of connection over another is based on various specifications for array output. Modules may be connected in series to boost voltage while maintaining current or in parallel to keep voltage constant while increasing current as seen in Fig 11. and 12. Array power output, inverter capacity, power conditioning component ratings, and other considerations all influence which parallel and series combinations are optimal (El-Dein et al., 2013).

2.7 Concentrated Solar Power Technologies

The history of concentrated solar energy dates back to at least 200 BC, when Archimedes utilized a curved mirror to focus the sun's rays. This concept was utilized to spark wildfires. The Greek mathematician Diocles, who lived in the second century BC, described the optical feature of the parabolic trough. Comte de Buffon mapped out the evolution of the heliostat in 1746. In 1878, Augustin Mouchot brought a dish powered by a steam engine system to the Universal Exposition in Paris. In Egypt in 1913, Frank Schuman successfully constructed a parabolic trough-driven pumping system, which was a major advance in CSP technology development.

Figure 11.

PV Module Connected in Series (Bhatia, 2018)

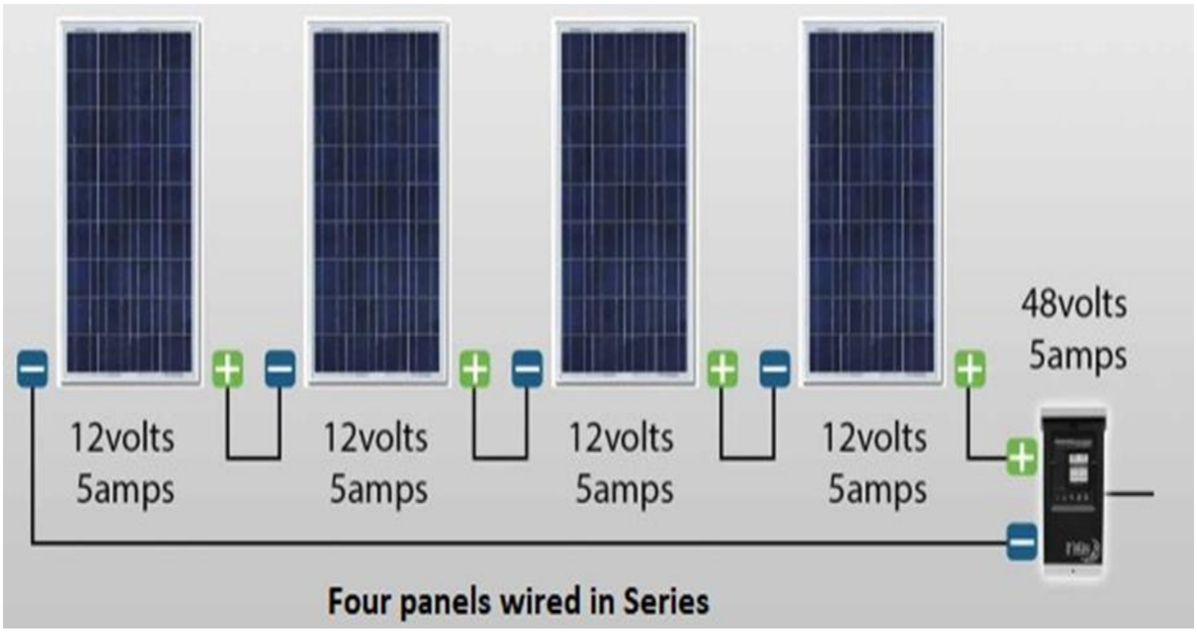
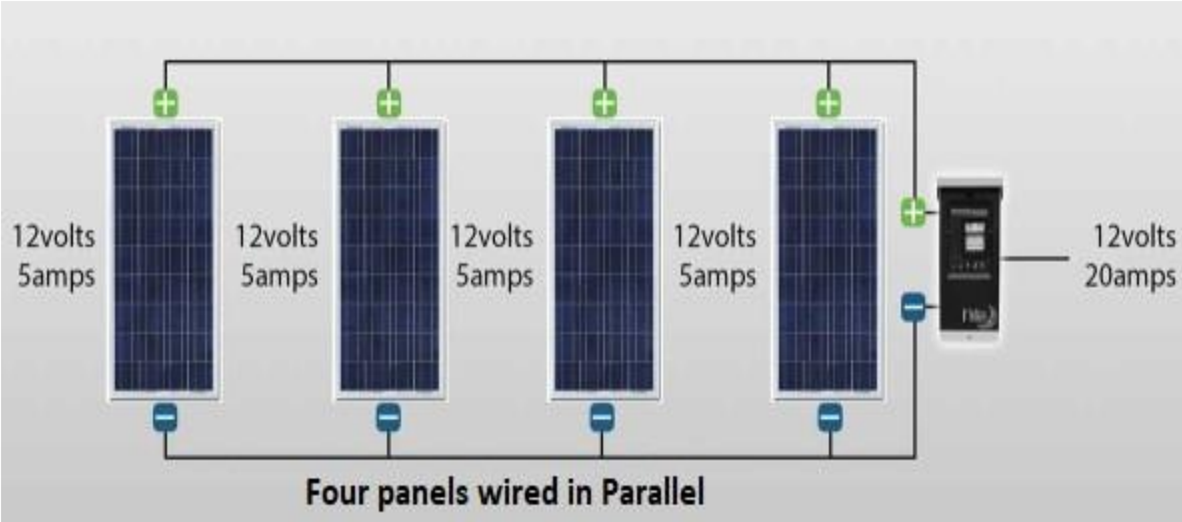


Figure 12.

PV Module Connected in Parallel (Bhatia, 2018)



However, the concentrated solar power (CSP) business had its start in the 1980s in California, USA, when 9 SEGS (Solar Electric Generating Systems) with a combined capacity of 354 MW were constructed and are still operational today (Lovegrove, 2012).

The concept of concentrated solar power relies on focusing the sun's rays in one location to generate enough heat to drive a steam turbine, which in turn generates electricity. Concentrating the sun's rays requires either a mirror or a lens. Concentrated photovoltaic is a similar technique, but instead of using single-junction solar cells, it employs multiple-junction solar panels to generate electricity (El-Dein et al., 2013). Power plants that use fossil fuels or nuclear reactors to create electricity are environmentally detrimental, but CSP is a sustainable energy source, therefore it eliminates that risk. In comparison to photovoltaic systems, CSP's capacity factor is much higher due to the technology's ability to generate electricity even when the sun isn't shining, thanks to the installation of a thermal storage system. Both line-focusing systems (LFS) and point-focusing systems (PFS) are examples of CSP technology (PFS). While the Fresnel plants and parabolic trough that make up LFS employ a single-axis tracking network, the solar tower and solar dish plants that make up PFS make use of a double-axis tracking system (Lovegrove, 2012).

2.7.1 Parabolic Trough

The parabolic trough uses mirrors or lenses with parabolic forms to increase light focus. The tube's length is proportional to the mirrors; hence, it may be found in the mirror's center. In order to convert solar thermal energy into usable electricity, the fluid in the tube is heated to a high enough temperature to turn a steam turbine. The thermal receiver, solar collector (lenses, mirror, or highly reflective surface), storage unit, and generator system are the basic components of parabolic trough technology. The parabolic reflectors and tubes housing the thermal receivers are seen in Fig 13. Since the sun's location is always changing due to Earth's rotation, a solar tracking system is integrated with a parabolic trough system to provide maximum output at all times of the day (Lovegrove, 2012).

Figure 13.

Parabolic Trough (Lovegrove, 2012)

2.7.2 Solar Tower Technology

A central receiver is another name for solar tower technology. There are five main parts: heliostats, thermal storage, heat and exchange, receivers, and controllers. By using a system of mirrors known as heliostats, solar radiation may be focused on a single receiver at the very top of a very tall tower. The primary receiver acts as a conduit for solar energy to reach the power plant. Steam generators are powered by the steam created from water using the heat collected by the receiver. The molten salt may be used as a kind of heat bank. To further understand the central receiver technology, see Fig 14.

2.7.3 Linear Fresnel

The construction and operation of a linear Fresnel are similar to those of a parabolic reflector, with the key differences being the use of flat mirrors or slightly curved reflectors (mostly at the edges) and the elevation and inversion of the tube housing the thermal receiver. Using a linear Fresnel lens, as shown in Fig 15, its advantages over parabolic trough technology include a small land area and lower cost (Jacobson and Delucchi, 2011).

Figure 14

Solar Tower Technology (Lovegrove, 2012)

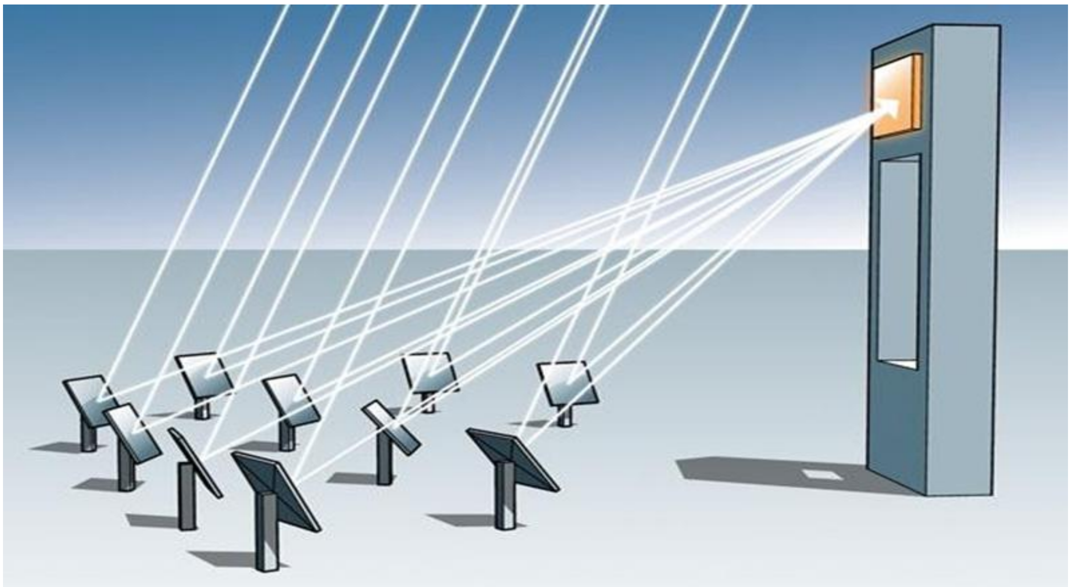


Figure 15

Linear Fresnel Reflector (Jacobson and Delucchi, 2011)

2.7.4 Dish Technology

The dish combines elements of the parabolic trough and the solar tower. The dish is physically shaped like a satellite receiver. The core elements of the dish system are the collector, the receiver, and the power station. Fig 16 shows the design of a satellite dish made from mirrors and the location of the receiver and engine. The energy from the sun is collected by the collector (mirror), transferred to the receiver, and then used to power the engine.

Figure 16.

Dish Technology (Azoumah et al., 2010)

These are key indicators for evaluating the four CSP technologies which include:

- Total annual energy output
- Capacity Factor
- Land needed
- Water Requirements

2.7.5 Total Annual Energy Output of CSP

The total annual energy output is an efficiency of collecting solar energy and converting it into electricity over a year. It is expressed as a percentage of the total solar energy that falls over the collector array each year. Below, we compare the various technologies in terms of their effectiveness.

Table 3.

Four Primary CSP Technologies and their Average Annual Solar-to-Electricity Conversion Efficiency(Alalewi, 2014).

CSP Technologies	Annual Efficiency
Parabolic Trough	15%
Solar Tower Technology	17-35%
Linear Fresnel	8-11%
Dish Technology	25-30%

The total annual energy output of a CSP plant can be calculated use this equation:

$$E_{annual} = n_{annual} \times DNI_{annual} \times A \qquad (2.5)$$

Where

E_{annual} is power output of the plant per year in MWh/A

n_{annual} is the efficiency of converting solar energy into electricity on a yearly basis;

DNI_{annual} is yearly Direct Normal Irradiance in MWh/ m^2A

A is the collector field's area in m^2

2.7.6 Capacity Factor

The annual capacity factor may be determined using equation (2.6): The annual capacity factor is the ratio of the energy generated during a certain time period to the energy that might have been produced if the plant had functioned continuously at maximum output.

$$\text{Annual CF} = \frac{\text{actual enegry generated (MWh)}}{\text{365days} \times \text{24hours} \times \text{nominal power out (MW)}} \qquad (2.6)$$

Table 4 below shows the yearly capacity ratio of CSP plants. Including thermal storage that has the ability to significantly increase the capacity ratio of all the systems. With thermal storage in place, the plant can utilize the sun's energy from the collector field more efficiently and continue producing power even when the sun goes down. If successful, this might increase the capacity factor to almost 75%.

Table 4.

Capacity Factor for the Four Main CSP Technologies (Alalewi, 2014).

CSP Technologies	Capacity Ratio
Parabolic Trough	25%
Solar Tower Technology	24 -25%
Linear Fresnel	17%
Dish Technology	50%

2.7.7 Land Needed for CSP System

The collector field takes up most of the space required for a CSP plant. To get the most of the sun at all times of the day and year, the collectors in each of these technologies are arranged in a certain manner. Space must be allotted between collectors to prevent or reduce the possibility of one collector being obscured by another. A measurement of land use efficiency is either the ratio of collector area to total plant area or the ratio of total plant area to electrical power generation. The land use efficiency of the four CSP systems is summarized in Table 5 and the equations below are used in calculating the land use efficiency.

$$\text{Land use efficiency} = \frac{\text{Collector Area } M^2}{\text{Total Plant Area } M^2} \qquad (2.7)$$

Or

$$\text{Land use efficiency, ha/MV} = \frac{\text{Total Plant Area,ha}}{\text{Output power,MV}} \qquad (2.8)$$

Table 5.

The Efficiency with which four Different CSP Systems use Land (Alalewi, 2014).

Technologies	Land use efficiency (collector area/total plant area, m^2 / m^2)	Land use efficiency (total plant area/output power, ha/MW)
Parabolic Trough	0.26	3.9
Solar Tower Technology	0.12-0.22	5.4
Linear Fresnel	0.62	0.8-1
Dish Technology	0.36-0.48	1.2-1.6

2.7.8 Water Requirement CSP System

Large quantities of water are needed for cooling purposes in CSP systems. More water is needed for cooling if the power block's efficiency is low since more heat is lost. The water consumption of various technologies is outlined in Table 6. CSP technology can be seen to demand far more water for cooling than a typical modern fossil fuel power station. This is due to its increased efficiency in operation. Since the energy is produced on-site at the dish and the waste heat is vented to the air, cooling water is not necessary for dish technology.

Table 6.

Water used for Cleaning Purposes of CSP Technology. Cooling Doesn't Involve the use of Water (Alalewi, 2014).

Technology	Water cooling (Liters/MWh)
Fossil fuel power plant	800
Parabolic trough	3000
Solar tower	2000
Linear Fresnel reflector	3000
Dish	80

2.8 Building Integrated Photovoltaics (BIPV)

BIPV is the primary subject of this thesis, it is necessary to have an in-depth understanding of the concept in contexts. There is no generally accepted definition of what precisely constitutes BIPV since it is currently considered a specialized product.

According to what (Agentschap, 2011) has said, "BIPV is a component of the building envelope; it serves a "structural" construction function, such as water proofing. Building Integrated Photovoltaic has been planned and built as an essential component of the building's capacity to save energy and to function well in its relationship to the surrounding environment. It may serve as an acceptable replacement for more traditional building materials. According to findings of other piece of research, BIPV modules provide at least one other function inside the building envelope in addition to the generation of electrical power it protect us (From the weather, from the brightness of the sun, from the cold or the heat, from the noise) protection integration of the aesthetic insulation and soundproofing (Folkerts, 2013).

The term "BIPV" was used by (Ferrara et al. 2012) to describe a building component that serves several purposes, including "electricity production, shading systems, weather protection, noise protection, heat insulation, and sunlight modification." Several researchers (Ferrara et al., 2012) came to this conclusion. British government agency defines BIPV as "photovoltaic systems that produce power and act as part of the building." (2013) Architects may use BIPV (building-integrated photovoltaic) products such as solar shingles or tiles to combine form and function in a building's windows, walls, façades, and roofs.

As it can be seen from the above definitions, there is no general agreement as to what minimum standards a system must achieve in order to be considered BIPV. Although all researchers agree that it must be weatherproof, not all also agree that it must also add to the building's aesthetic value.

2.9 Parameters used in Building Integrated Photovoltaic

The variables that are connected to solar systems that have been installed in buildings are specified. In this situation, the following groups are used to describe how different BIPV products work:

- Short Circuit Current: is the current flowing through the solar cell when the voltage across the solar cell is zero (V=0) and is given as follows:

$$I_{sc} = {}_{q}G(L_n + L_P) \quad (2.9)$$

- Open Circuit Voltage: The open circuit voltage is the highest voltage that can be measured between the terminals of a solar cell. It is defined as follows:

$$V_{oc} = \frac{nkT}{q} 1n(\frac{I_L}{I_0} + 1) \quad (2.10)$$

- Peak power (P max): A solar cell or module that makes the most energy possible at any given temperature and amount of sunlight.

$$P_{max} = V_{max} \times I_{max} \quad (2.11)$$

- Solar cell efficiency (n_{cell}): It is the effectiveness of a solar cell in transforming the light energy it absorbs into useable electricity and is measured by its power conversion efficiency. Solar cell efficiency decreases in response to both a reduction in the amount of light that is incident on the cells and an increase in the ambient temperature.

$$n_{cell} \frac{P_{max}}{E \times A} \quad (2.12)$$

P_{max} represents the maximum power output in watts (W), "E" input luminous flux measured in watts/m2 and "A" dimensions of the solar cell's active surface in m^2.

- Solar module efficiency (n_m): The ratio of a solar panel's peak power to the radiation power reaching over the whole area of the module, including the area of the frame, is the definition of the module efficiency of a solar panel. n_m is always less than n_{cell}.

$$n_m = n_{cell} \times PF \quad (2.13)$$

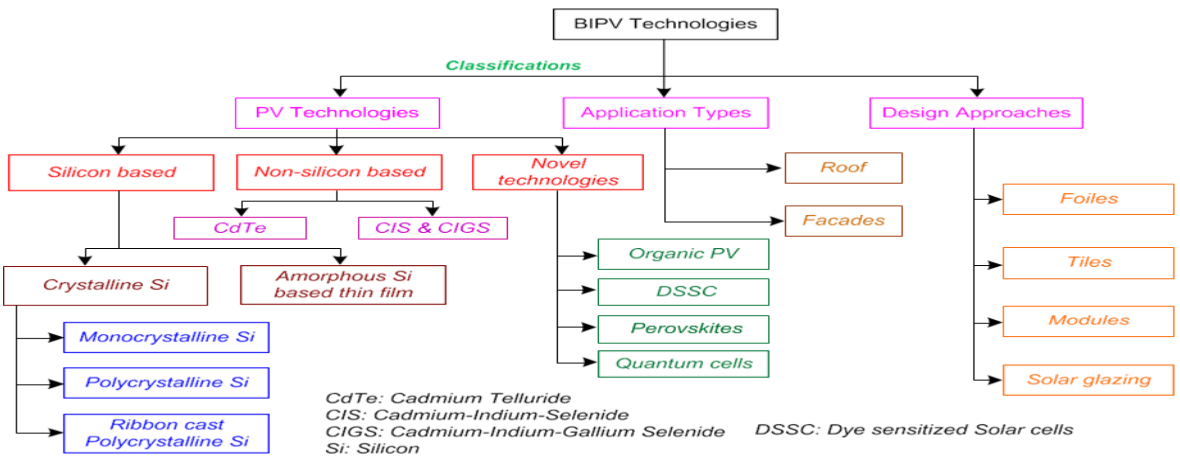
2.10 BIPV Technological Advancements and Growth Impediments

Various academic disciplines have played a part in the expansion and development of the BIPV industry, which has finally resulted in the creation of innovative tools and machinery. To provide a concise overview of these technological advancements, many product categories within the BIPV sector are analyzed below. In general, building-integrated photovoltaic (BIPV) systems may be divided into three separate categories, which are influenced by the following factors: The first, which is referred to as PV technology, describes the components and their properties that are used in the production of BIPV modules. The second, which is referred to as an application type, describes how these modules are incorporated into buildings. The third, which is referred to as a design approach, explains the applicability of BIPV products. The classification of BIPV technology is shown in an informative tree diagram that is provided in Fig 17. There are typically two approaches used for incorporating solar photovoltaics (PV) into structures. Photovoltaic (PV) systems that are connected to or incorporated into a building are referred to as "building integrated PV," or "BIPV," as are PV systems that are building attached photovoltaic (BAPV). The real concept of BIPV, however, is misunderstood in the construction sector, and this misunderstanding extends into the PV sector.Canopies, balconies, and glass balustrades are all examples of BIPVs, which are multipurpose solar products that also generate electricity through photovoltaics and can be used in construction, while BPAVs are more traditional forms of photovoltaics that are simply mounted to the building and have no effect on its structural function. Before solar PV systems can be successfully built into a structure, many factors must be carefully looked at. These include how easy it is to build, how it looks, how long it lasts, how it affects the environment, how it is maintained, how safe it is to use, and how it meets standards.

The two types of solar modules that are now the most widespread on the market, these modules include silicon and those that do not contain silicon. Silicon-based modules composed of silicon wafers that have undergone a number of chemical processes to produce a semiconductor material. An electric current is produced when sunlight strikes a semiconductor substance, releasing electrons. Semiconductors, is a component of solar cells, that act as a key to silent and undetectable power transformations. Such materials act as insulators at room temperature and only become electrically conductive when subjected to heat or light. (Weller et al. 2010) say that a solar cell is made up of two layers, each of which has had its conductivity changed in some way. To create a surplus of negative charge carriers, the sunlight-facing layer of crystalline silicon is negatively (n-) doped with phosphorus. Other than silicon, materials such as cadmium telluride (CdTe), and copper indium gallium selenide (CIGS), are used to create non-silicon-based PV modules. The performance of the PV module may be impacted by the fact that these materials' characteristics vary from those of silicon.

Figure 17

Classification of BIPV Technologies (Pillai et al., 2022)



2.11 Application Type BIPV Technologies

The purpose of this section is to provide an overview of PV from a construction and design perspective. It is possible to design unique solutions that incorporate PV modules into various areas of the building's exterior. Here, we'll delve into the many BIPV system application types, such as photovoltaic roofs, photovoltaic façades, photovoltaic windows and skylights, and photovoltaic shading devices. Different ways of putting PV envelopes together mean that different PV components and materials have to be chosen for each category.

Aristizabal et al. (2018) define Building Integrated Photovoltaics (BIPVs) as "the incorporation of solar panels into the building skin to serve as both power producers and structural elements" (Assoa et al., 2017; Shukla et al., 2017). It's not a new phenomenon that buildings are increasingly being retrofitted to convert from pure energy consumers to producers. Since PVs first reached the market, people have been trying to figure out how to incorporate them into buildings structural.

"The concept of employing PV for decentralized energy collection via the "smart grid' was conceived after the first initiative ('Megawatt') was launched by the Swiss engineer Real (1986), which urged Zurich homeowners to put PV panels on their roofs. A number of experts have concluded that BIPV systems are a viable technology that might be used in buildings to enhance their power performance and reduce their environmental impacts.

2.12 Roofs for BIPV Technologies

Solar photovoltaic (PV) panels should ideally be installed on roofs. There are a few different methods for incorporating a PV system onto a roof. When looking at energy production over a year, in Central Europe, the best results come from modules set at an angle of 30 degrees facing south (Emrah et al. 2017) .Very small losses occur when deviating from this direction by a small amount, and adjusting the angle does not drastically alter the possible yields. A horizontal orientation and angle results in a 10% reduction in production when compared to a rooftop installation at the ideal orientation and angle.

A roof may provide a lot of ample space and have other design benefits (Reijenga and Kaan, 2011). Fig 18. Shows an image of PV modules mounted at a roof top. When photovoltaic panels are mounted on a flat roof, it is more difficult to get access to the roof in order to perform normal maintenance and repairs on the system. Before installing the photovoltaic system, it is necessary to be certain that the roof will be able to sustain it during the whole of its useful life. The free-standing system is the best option to go with when the roof has sufficient load-bearing reserves or when the PV installation has been included in the structural analysis. By using ballast in the form of concrete paving slabs, concrete sleepers, or loose gravel fill, this technique is able to strengthen the structure that is supporting the PV installation without causing any damage to the waterproofing layers. The fact that gravel is already present on the roof, where it helps to maintain the integrity of the waterproofing, makes this a suitable ballast (Weller et al., 2012).

When used as a counterbalance, gravel-filled trapezoidal profile sheeting or trough systems may reduce wind uplift. Using concrete plinths is the best option when the roof structure has a greater loadbearing capability along just one or two axes. Concrete paving slabs are recommended for use on flat roofs due to their increased capacity to withstand point loads. Protection sheeting must be put under the PV installation so that the structure that holds it doesn't damage the waterproofing materials. A fixed anchoring system is preferable if the freestanding approach cannot be used due to structural constraints. Often, a grid of members (typically some kind of grillage) is constructed in the field to provide support for each row of modules in such setups. These are then supported by a series of vertical posts that are connected to the structure below via the roof deck.

Both the freestanding and anchored configurations have the PV modules lined up in rows. In order to prevent a row of modules from casting a shadow on an adjacent row, sufficient space must be left between the rows. Module width, mounting angle, and zenith angle all have a role in determining how far apart the rows need to be. The so-called shadow angle, which is the angle that the sun will be at noon on the 21st of December and which varies in Germany from 12 degrees to 19 degrees depending on latitude, has been shown to be useful for planning purposes. To keep things simple, let's assume that the temperature is, on average, 15 degrees. As a consequence of this, the area of the roof has to be greater than the total area of the modules that are going to be placed on it. This is because the best mounting angle is thirty degrees, and the general guideline is to have the module spacing be three times the width of the module in Figure 19 (Weller et al., 2012).

2.13 Facades for BIPV Technologies

Solar panels that are integrated into a building's outside envelope are known as building-integrated photovoltaics (BIPV) façades. With this strategy, a building's façade may be used for both its aesthetic appeal and its capacity to produce energy. BIPV technology may be used on a variety of facades, including cladding, curtain walls, and window systems. One example of passive solar design is the use of transparent materials during the winter months with the goal of maximizing the advantages of solar radiation. However, with the development of photovoltaics, we are now able to switch from a passive approach to an active one and make use of the enormous energy potential that facade surfaces provide.

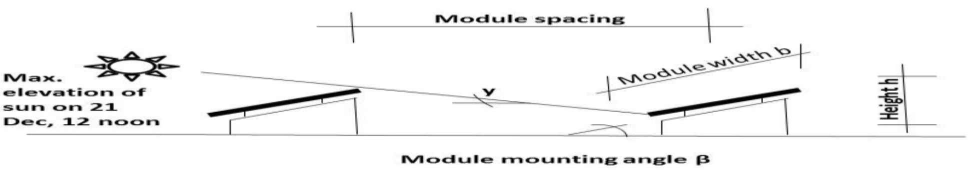
The basic methods through which PV is utilized on building facades include opaque and semi-transparent facades, according to the evaluation conducted by specialists of IEA Task 41 (IEA, 2012). The opaque facades are divided into two groups: "warm" facades and "cold" facades, depending on whether a back-ventilated layer or a non-back-ventilated layer provides the essential weather protection.

Figure 18.

Photovoltaic Modules Mounted on a Roof (Reijenga and Kaan, 2011).

Figure 19.

Weller et al. (2012) Describe How to Figure out How Far Apart PV Modules Should be on a Flat roof.



$$\text{Module spacing} = \frac{h}{\tan(21\ \text{Dec}, 12\text{noon})} h = \sin\beta \times b \qquad (2.14)$$

2.13.1 Opaque Cold Facades

An opaque cold façade are building envelops that are designed to help reduce energy costs by minimizing the amount of heat required to maintain a comfortable indoor temperature. These kinds of facades are especially helpful in cold areas where buildings need a lot of insulation to keep the inside at a suitable temperature. In most cases, PV panels are employed as cladding over opaque cold facades shown in Fig 20. The PV cladding is supported by a framework attached to the wall's bearing surface. Under these conditions, the PV's back-ventilation may be used to lower the system's internal temperature and improve performance. These systems often use solar cells (like Si-PERC) that are very efficient and have a unique layer of protection over them (e.g., printed on the glass). PV modules themselves serve as the weatherproofing and outside cladding.

Figure 20.

Thin-Film Modules on the Photovoltaic Facade (Aelenei et al., 2013).

2.13.2 Opaque Warm Facades

These façade types serve as sound insulators, which is especially helpful in hot, sunny areas where buildings need a lot of insulation and shading to maintain appropriate indoor temperatures (Sonnenenergie, 2007).

Curtain wall systems meet the criteria necessary to be considered as viable integration options for PV. In this situation, solar panels might be mounted either on the semi-transparent PV or on the spandrel (the opaque part). It is possible that it may be necessary to make preparations for a PV back-ventilation in the event that the sprandel is used. However, this will dependent on the PV technology that is utilized.

2.13.3 Photovoltaic Sun Shading Devices

When applied to the outside of a building, photovoltaics may be used as shading devices, movable shutters, louvres, canopies, parapets, balconies, and many other architectural features Fig 21. Components made of semi-transparent crystalline glass or thin-film glass are often used in manufacturing practices nowadays. On balconies, you'll often see the utilization of semi-transparent security glass modules. A common type of system that hides information from the user is an opaque system.

Figure 21.

The following are common forms of sun protection: (Pierre, 2003).

2.14 Market Design for Building Integrated Photovoltaics

BIPV system can be described in terms of the market names and subcategories under which it is sold. The following four categories—BIPV foil product, BIPV tile product, BIPV module product, and BIPV solar cell glazing—can be created from these market names and subcategories:

2.14.1 BIPV Tile Product

Building-integrated photovoltaic (BIPV) tiles are solar panels that are designed to look like traditional roofing tiles, making them a more appealing alternative for residential and commercial structures. BIPV tiles may be put on different surfaces, such as walls or facades, to produce energy while integrating with the architecture of the structure. One example of a BIPV tile product is the Tesla Solar Roof. The Tesla Solar Roof is a tough, tempered glass tile with the extra advantage of producing energy from the sun. It is designed to resemble a normal roof tile. (Shukla, A., and Sharma, A., 2018).

2.14.2 BIPV Foil Product

BIPV foil products are designed to be portable, simple to install, and very effective at converting solar power into electricity. The MiaSolé PowerFLEX+ is one type of BIPV foil product. Including metal roofs and facades, PowerFLEX+ is a lightweight, flexible BIPV foil that is simple to incorporate into a number of building materials. Compared to conventional solar panels, BIPV foil products provide a number of benefits, such as flexibility, ease of installation, and design integration. BIPV foils could need more specialized installation and maintenance, and their power production might be less than that of traditional solar panels. (Shukla, A., & Sharma, A., 2018).

2.14.3 BIPV Module Product

Building integrated Photovoltaics Modules' outside appearance might be confusing and mistaken for conventional PV Modules. Yet a key distinction between modern BIPV products and conventional PV modules is that BIPV modules are built using weather skin technologies (Shukla, A., & Sharma, A., 2018).

2.14.4 BIPV Solar Glazing

Building-integrated photovoltaic product known as BIPV solar glazing uses solar cells in place of traditional glazing materials to enable buildings to produce energy from sunlight while maintaining natural light and views. The solar cells are linked together to form an electrical circuit and are included in the glazing material as either thin film or crystalline silicon cells. BIPV solar glazing has a number of benefits over conventional glazing materials. It may act as a sizable source of clean energy, lowering the building's dependency on grid power. Reducing the quantity of heat passed through the windows may help increase the building's energy efficiency. (Shukla, A., & Sharma, A., 2018).

2.15 BIPV’s Barriers in the Current Market

BIPV have shown sustained expansion in the present decade. While BAPV has seen tremendous success and expansion, BIPV is just getting off the ground. As for where they stand in the modern PV market, they are still seen as somewhat of a niche product (Curtius, 2019). To really cement BIPV technology's position in the market, its creators and implementers must first identify the obstacles standing in the way of its widespread adoption and then work to eliminate those obstacles. Through research, we might be able to figure out what is causing these problems and put them into three categories: public perception barriers, institutional obstacles, and technical/product hurdles.

The first obstacle is how the general public perceives the issue. Consumers have some influence over the product's market. The development of the BIPV industry and its market success will be slowed as long as consumers and the general public believe that BIPV technology is not the answer. The general public's favorable view of BIPV technology may be attributed to their enthusiasm for renewable energy sources in general. In the United States, for instance, the political environment plays a big part in determining whether or not the general population will embrace renewable energy sources like PV and BIPV. Some people in the United States still support using fossil fuels and coal for electricity generation, despite the fact that public support for renewable energy continues to rise. It's encouraging that, according to a survey by the Pew Research Center (Funk, C., & Hefferon, M., 2019), the public continues to regard renewable energy as a viable norm and solution for society, and is less inclined to support conventional energy sources like mining coal and fracking. The United States government, if it wants this upward trend to continue, must work to fill the knowledge gap on the issue.

The second problem is of an institutional kind. Although feed-in tariff regulations are recognized to have played a significant role in the early growth of the photovoltaic system sector, only a limited number of nations now provide such a subsidy for the installation of building-integrated photovoltaics (BIPV) (IEA PVPS, 2019). Based on the findings of Fig 22 of the research conducted by the International Energy Agency, only Austria, China, Spain, and Switzerland have incentive programs for the BIPV system. Because of this, the feed-in tariff would be less of a concern in the adoption of BIPV systems because governments would let owners of photovoltaic systems use the power that was generated on-site by their systems.

Another institutional barrier are the rules and policies governing the construction industry. Permits must be applied for and obtained before installing the BIPV system in the building. However, this step may be more challenging to complete if the system was designed to be incorporated into the structure in the first place. It may be challenging to implement some technologies, such as BIPV modules that are put on the curtain wall or facade of a building, in regions where the local authority is concerned with maintaining the traditional architecture of the region. A comprehensive analysis of the technical and product barriers is required in order to get an understanding of the feasibility of BIPV technology.

On the product side of things, building integrated photovoltaics offers an aesthetic advantage over their counterpart, building applied photovoltaics. This makes the parts of the building that are built in look better than the parts that are added later, which is good for the product as a whole.

The original cost of the system will still be much difficult than the cost of a conventional PV or BAPV system when it is first installed. Depending on the scale of the project, the general contractor who is working on the building may provide the owner with a number of different bids. Some of these bids may or may not contain a BIPV system that is integrated into the structure. Even if the building's integrated photovoltaic (BIPV) system is not included in the design, the owner may still be convinced to go through with the project due to the price.

If homeowners decide against installing a BIPV system and instead purchase tiles or shingles, they may put the money that they would have spent on the BIPV system toward something else, such as renovating their kitchens. For example, if homeowners decide against installing a BIPV system and instead purchase tiles or shingles, they may use the money that they would have spent. Additionally, the BIPV system might eventually provide both electricity and revenue. Yet, these benefits of BIPV would be accompanied by two significant drawbacks and obstructions.

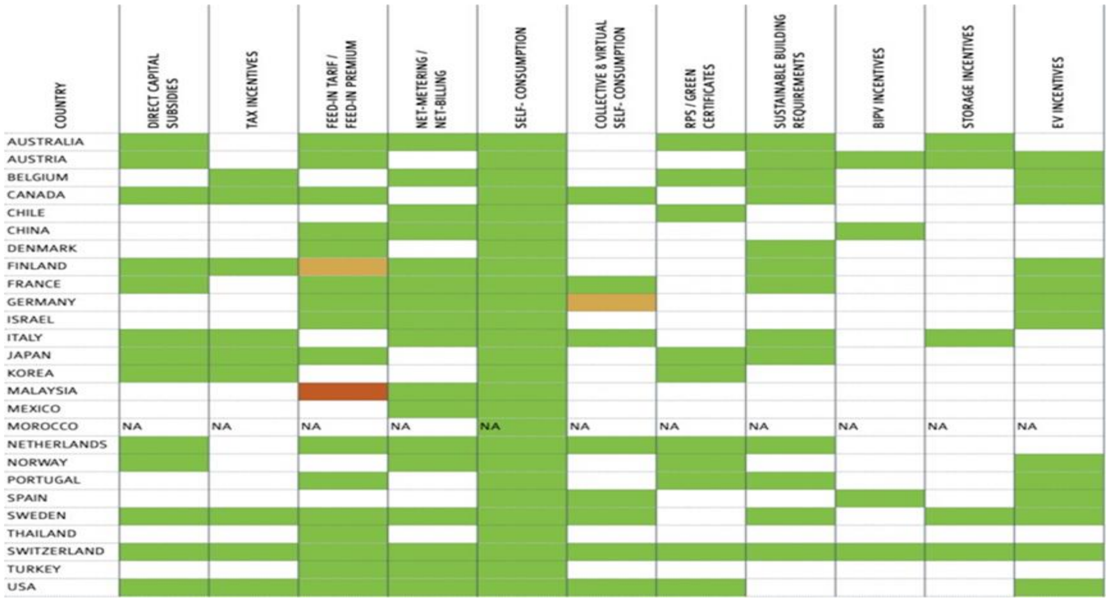
Firstly, the system's starting cost is still greater than that of a conventional PV or BAPV system. Depending on the owner's preferences, the construction contractor may provide many pricing options for the project, including one with the BIPV system integrated into the structure and others that do not. Owner acceptance of the design without the BIPV system may be contingent on financial considerations. Simultaneously, the proprietor may recognize that the BIPV system has an additional benefit to the structure; for example, in the case of BIPV tiles and shingle products, the proprietor may spend the cost of the BIPV system on other areas, such as kitchen renovation.

The product's second issue is that it is difficult to get installed in the building. This is something that is most likely only done for brand-new structures or for extremely extensive renovations. It is not in the owner's best interest to replace operable windows with BIPV glass windows since it would not be sustainable. Even if the owner of the building agrees to replace certain components with the BIPV system, the question of where to locate manufacturers who can make BIPV products of the correct size to be integrated into the building still arises. This is because the BIPV system requires specific components to be replaced.

As a result of this product barrier, the first technological aspects of the barrier would be diversity and BIPV adaptability. (Bonomo, P., et al., 2015) Because the BIPV industry is still young, a truly custom solution would either not be available or would cost too much for the system to be a good long-term investment.

Figure 22.

Review of Support Scheme of each Countries' Government (International energy agency (Alta, 2020)



The second technical issue is the power loss of BIPV, which is also a widespread difficulty. This is a problem with both technologies. It is essential to keep in mind that all photovoltaic (PV) systems are prone to issues with power loss. However, there are some places in which these issues would have an even bigger influence on the efficiency of BIPV. There are a number of potential causes of power losses in the BIPV and PV systems, including air pollution and shading (Azadian, F., & Radzi, M., 2013). Also, everyone knows that a lot of clouds in the sky could make it hard for the system to work.

According to a study that was conducted by Ikedi, Chukwuemeka, and colleagues in 2010, partial shading can lower the efficiency of the BIPV, which can result in a loss of 15–20% of the energy that is produced. Additionally, serious technical malfunctions, such as the formation of a hotspot on the system, can take place. In the event that a region of the system that would typically produce energy is prevented from doing so as a consequence of cloud cover, this might lead to hotspots, which are regions with an excess of power within the system. In the case of the fixed orientation system, problems with shading and power loss are more likely to occur. According to this theory, the building integrated photovoltaic system (BIPV) of a structure would be at its least effective during specific times of the day or during specific times of the year, when the cells and modules are serving as the envelope of the structure, along with windows and curtain walls. The direction of the system is of critical significance.

Thirdly, islanding represents a technological hurdle. The term "islanding" refers to the situation in which a portion of the BIPV system, while being cut off from the rest of the system's loads and resources, continues to function reliably. If the load kept getting power from the BIPV supply after a certain part of the system lost its connection to the main sources that would be a problem.

The problem with the inverters is the fourth and final technical obstacle that has to be conquered before a PV system can work well. Maximum Power Point Tracking, often known as MPPT, is a method that is frequently used in the process of evaluating the performance of inverters. Estimating and quantifying the effectiveness of MPPT is conceivable, but doing so would be difficult owing to the high possibility of shadow generation by the core of BIPV.

2.16 Wireless Power Transfer in Building-Integrated Photovoltaics

With a WPT system, it is possible to carry the power produced by solar panels wirelessly over the building envelope. This eliminates the need to drill any holes in the structure. By doing so, you will have a better chance of achieving near-perfect thermal, air, and water tightness, which will increase your ability to regulate the temperature inside, extend the life of your system, and save you money. Furthermore, BIPV systems with WPT may provide a simple "plug-and-play" installation procedure. There are now debates on whether the builder or the electrician should be held accountable for the BIPV building parts. Now, in the field, electricians and other construction personnel get training on how to properly handle the various WPT wiring designs. An easy-to-install system would be one that requires no configuration beyond plugging in the necessary components. WPT would help address the issue of decreased efficiency brought on by factors such as partial shadowing, in addition to its plug-and-play convenience and enhanced insulation.

2.17 BIPV Strength Weakness Opportunities Threats Analysis in Northern Cyprus

The SWOT analysis is use to performed or determine the positive and negative factors that might affect the effective implementation of PV in Northern Cyprus's building stock. This research used a SWOT analysis to examine the viability of solar technology in Northern Cyprus, as well as the possibilities and challenges that this analysis may provide**.** Table 7 details the findings of the SWOT analysis conducted.

2.18 Photovoltaics Trends

When seen from a global perspective, solar energy is a valuable resource that is available to us in vast amounts. Having the ability to exercise direct control over power would have a profound impact on the way our society is structured. According to scientists, the amount of solar energy that reaches the earth's surface for one hour is enough to power the entire world for an entire year. It is impossible to deny the appeal of getting better at making use of resources. Solar photovoltaics (PV) is an area that is expanding quickly and will only continue to do so in the future. In the final analysis, building integrated photovoltaics (BIPV) is a promising PV technology that will continue to gain prominence in the next few years. After taking into consideration and analyzing the demand for BIPV in 13 different locations across the globe, EC&M's 2018 research predicted that worldwide BIPV revenue would reach $5.7 billion by 2023, and that the revenue from the technology would reach $11.6 billion by the end of the ten-year prediction.

This estimate was based on the company's assessment of the demand for BIPV in each of the 13 different locations. In addition, the research highlighted the fact that the residential sector is seeing 15% quicker BIPV development, despite the fact that the majority of BIPV opportunities are still in the commercial sector. Because of the progressive mindset that pervades the nation as a whole, the United States of America, and more specifically the state of California, will emerge at the vanguard of BIPV technology (EC&M, 2018). As a result of extensive research into the past of photovoltaics (PV) and building integrated photovoltaics (BIPV), some features of the technology have become abundantly clear. The building-integrated photovoltaic, or BIPV, technology is an exciting new photovoltaic (PV) alternative that is now available on the market. This technology's revolutionary design makes it an essential element of a building rather than an afterthought. However, because of the recent boom in the photovoltaic technology sector, there is less information available for those who are looking to make an investment in the technology.

Table 7.

SWOT Analysis of Northern Cyprus (Kumar et al., 2018)

Strength	Weakness
More than 300 days per year with enough sunlight Installing photovoltaic panels in buildings is a great way to provide sustainable energy close to where it is needed. The surface area for PV integration is more than that of most other kinds of homes. There have been changes made to the building's architecture that have helped make it look better**.**	Improper installation methods and insufficient rules for integrating PV Lack of a decision-making framework for the integration of PV systems.
Opportunities	Threats
A rise in the cost of electricity, the construction has the potential to operate with zero net energy consumption. The market for photovoltaics is expanding.	Not enough regulations exist for the use of photovoltaics in homes.

2.19 Overview of North Cyprus Power System

The Cyprus Turkish Electricity Authority (KIB-TEK) is in charge of energy generation, transmission, and distribution in the northern part of the island. KIB-TEK has a 346.3 MW total generating capacity, and fossil fuels are its exclusive source of energy(Ozerdem & Biricik, 2011). Transmission lines in the TRNC are divided into three voltage levels. They have 132 kV and 66 kV, respectively. Low-voltage lines of 415/240 volts and medium-voltage lines of 11–22 kV make up the distribution system. There were 554 km of transmission lines overall as of the end of 2008. The total installed capacity began in the north of the island in March 1995 with 60 MW, increased to 120 MW in March 1996, and peaked in 2008 at 327.5 MW. Majority of the needed electric power is produced by four thermal power plants. The prolonged period of power rationing observed in the early and middle of 2022 is one of the main drawbacks of depending on fossil fuels. The mix of electric power production for Northern Cyprus is shown in Table 8 for 2021.

Table 8.

Generation mix in Northern Cyprus (S.N.Tackie et al., 2022).

Generating Unit	Output Power (MW)	Production Percentage (%)
Teknecik steam Turb.S.U. 1	191,765	11.67
Teknecik steam Turb.S.U. 2	196,278	11.95
Kalecik Diesel Generator	725,541	44.17
Teknecik Diesel Generator	435,794	26.53
Serhatköy PV power plant	1,686	0.10
Total installed PV (MV)	91,673	5.58
TRNC Total Production	1,642,737	100

2.20 Overview of South Cyprus Power System

There are three thermal power plants in South Cyprus that make up the country's power production system, which has a combined installed capacity of 1480 MW. The Dhekelia power plant, which has two 50-MW internal combustion engine blocks and six 60-MW steam turbines, is situated on Cyprus' southeast coast, east of Larnaca. The most modern power plant is Vasilikos, which is made up of 3x130 MW steam turbines, 2x220 MW combined cycle technology units, and a 38 MW gas turbine. It is situated on the southern coast between Limassol and Larnaca. The 4x37.5 MW Moni power plant, which serves as a backup, is situated on Cyprus's south coast, east of Limassol. The transmission network, which links the power stations to the distribution network, serves as the foundation of the Electricity Authority of Cyprus EAC’s electrical infrastructure. The 11 kV or 22 kV medium voltage switchgear in all other transmission substations, which are typically found inside the load centres, is reached via 132 kV or 66 kV overhead power lines or underground cables, in accordance with the Transmission and Distribution Rules of EAC’s.

CHAPTER 3
Simulation Results of BIPV and System Design

3.0 Introduction

This section gives a detailed description of the PV system used in this chapter; stimulation results are generated to confirm its working principles. This chapter comprises six HeliScope stimulation results. The first include a proposed grid connected photovoltaic plant, and the others include a standalone photovoltaic system designed on the roof tops of buildings around Near East University Campus. Fig. 23 and Fig. 24 shows the block diagrams for both a grid connected and stand-alone PV system. The photovoltaic plant, which is a grid-connected photovoltaic system mounted in an open field, located at the back of the faculty of veterinary medicine will generate electricity for campus usage and excess transmitted to the grid.

Figure 23

Block Diagram of a Grid Connected PV System

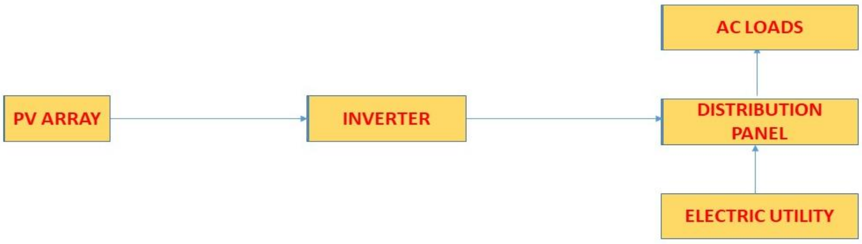
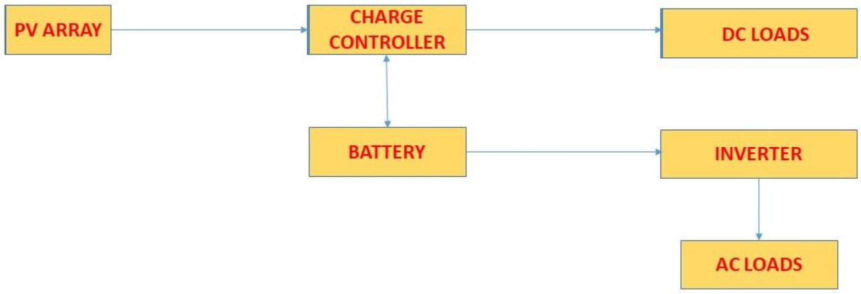


Figure 24

Block Diagram of a Stand-Alone PV System



3.1 Site Location

Figure 25 depicts the location of Near East University, which is in the Turkish Republic of North Cyprus (TRNC), a region of northern Cyprus with a total daily energy consumption of 3 MW and latitude and longitude of 35.2267° N and 33.3264° E, respectively. Suat Günsel, a Turkish Cypriot who owns the entire NEU, established it in North Nicosia in 1988. Cyprus is an island that may be found in the Mediterranean Sea's northeastern region, south of Turkey.

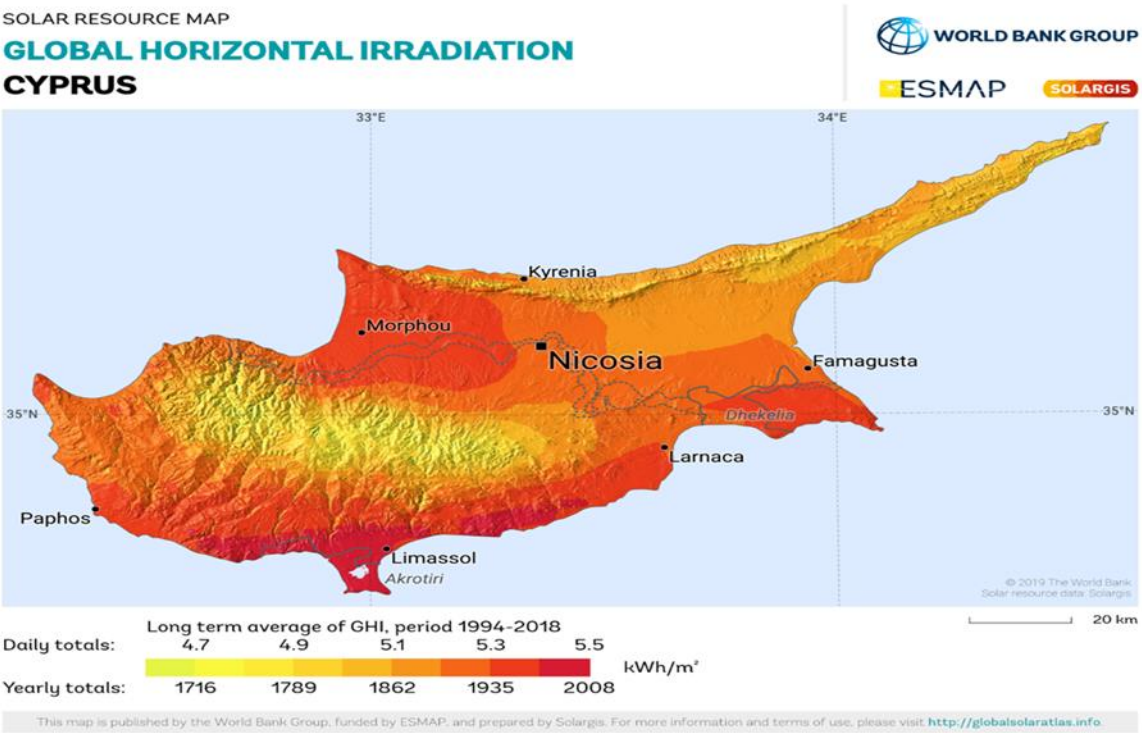
Despite being a de facto split island, Cyprus is a member of the EU, and all of Cyprus is EU territory (Tackie & Özerdem, 2022).

Figure 25.

Near East University Campus

Figure 26.

Photovoltaic Potential Map of Cyprus (Bamisile et al., 2021)



Because of its favourable climate and geographical location, as illustrated in Fig. 26, Cyprus has a high potential to domesticate solar energy (M. Michaelides et al. 2017). The island receives 5.4 kWh/m2 of daily solar radiation on average, which is fairly high. According to S.A. Kalogirou et al. (2003), the mean day-to-day solar energy ranges from 2.3 kWh/m2 in December and January, when it's cloudiest, to 7.2 kWh/m2 in July, when it's sunniest. Between 1600 kWh/m2 and 2000 kWh/m2 of horizontal solar radiation are received worldwide annually. According to M. Hastunç et al. (2018), the island is home to two republics, the Turkish Republic of North Cyprus and the Republic of Cyprus, with a combined population of around 1.2 million.Some snow falls in the Troodos Mountains during the mild winter, and there is often a chill in the air. January and February are the coldest months, with average highs of 15-16 degrees Celsius. Even at night, temperatures below the freezing point are unusual. There will probably be some wet days in February and March, but the summer months of May through September see hardly any precipitation. The warmest months in North Cyprus are July and August. Those who are easily overheated should plan their trip for the cooler months of September and October. Days average above 47 degrees Celsius in July and August, with temperatures dropping to about 20 degrees Celsius at night.

3.2 Photovoltaic Power Plant Design

Power plants are large electrical facilities that generate high and medium voltages for use in the electrical grid. Electricity at these facilities is typically produced by generators with a kilowatt or megawatt rating. While resembling this category, PV power plants do not rely on generators to provide electricity. Instead, hundreds or thousands of solar panels are linked together in arrays to produce a maximum amount of electricity. PV power plants use solar cells to convert photons (solar energy) into electric power at a dc voltage.

The total output power may fluctuate when weather conditions are unfavorable for photovoltaic applications since PV power plants rely on various components and elements, including the weather conditions at the plant site, the kind of PV module and inverter, and their unique efficiency. All PV modules' power output and efficiencies may be compared using the information provided on their nameplates, measuring using STC (standard test condition).

Modules (PV), inverter, distribution controller, and load are the components of a grid-connected PV system used in sizing a PV system. Battery-based systems are unnecessary for certain grid-connected setups. As such, it offers a potential benefit to the overall price of the system. The maximum power (P_{max}) of the designed plant can be derived from this using the following formula (loukarfi L. Missoum et al., 2017):

$$P_{max} = \frac{E_{AC} P_i}{G_{SR} F_{PVn\ ino}} \quad (3.1)$$

P_i is the solar energy at STC in KW/m^2

G_{SR} is the global solar energy ($kwh/m^2/d$)

F_{pv} is the PV derating factor

E_{AC} is the daily energy consumption in KWh/d

N_{inv} is the inverter yield.

The following are some examples of parameters used to characterize the operating features of PV power plants:

Specific Yield is referred to the total amount of energy produced (kWh) divided by panel capacity (kWp) for a period of time in a yea.

$$\text{Specific Yield (SF)} = \frac{\text{Produced energy (kWh)}}{\text{Panel capacity (kWh)}} \quad (3.2)$$

The nameplate capacity of the PV system is calculated by dividing the yearly net AC output of the system by the peak power of the installed PV array under standard test conditions (STC) at 100 W/m2 solar irradiances, 25 C0 cell temperatures, and 1.5 air masses. These settings are considered to be the system's "nameplate" conditions.

$$\text{Final energy yield (FEY)} = \frac{\text{Annual energy output E(kWh−AC)}}{\text{Nameplate power capacity P(kW−DC)}} \quad (3.3)$$

The reference yield equal to the difference between the irradiance of reference (1 kW/m^2) of the PV array and the panel solar irradiation. In addition, a measurement of the peak solar radiation is taken every hour. This measurement, which is subject to change due to factors such as the weather, the orientation of the array, and irradiance losses, is recorded in the logbook.

$$\text{Reference yield (RY)} = \frac{\text{Inplane irradiance H } (\frac{kWh}{m^2})}{\text{PV reference irradiance G } (\frac{kW}{m^2})} \quad (3.4)$$

The payback period is the length of time it takes for a plant to generate enough revenue from output to repay the cost of installation.

$$\text{Paybackperiod(PBP)} = \frac{\text{Total investment}}{\text{Generated Revenue}} \quad (3.5)$$

The ability of a PV system to lower end users' monthly power bills is measured by their net annual electricity savings. This yearly net savings is often used by third-party owners to assess the cost-saving potential of PV systems.

$$\text{Annual net saving (ANS)} = \text{cost without PV system } - \text{Cost with PV system} \quad (3.6)$$

The levelized cost of energy (LCOE) estimates the cost per kilowatt-hour ($kWh) throughout the course of a project. The cost per kWh of various power system technologies is compared using the LCOE. LCOE is calculated by separating the project's life-cycle cost by its anticipated energy production.

$$\text{Levelized cost of enegry (LCOE)} = \frac{\text{sum of cost over lifetime}}{\text{sum of electricity generated over the lifetime}} \quad (3.7)$$

3.3 Proposed PV Power Plant Using HelioScope (NEU)

The proposed PV plant (NEU) in Fig 27 shows the modules and inverter arrangement. It is located at the back of the faculty of veterinary Medicine and occupies a land area of 1581.9 m^2 for the solar panels/modules and inverters alone. Additional space has to be set aside in order to accommodate the installation of a mini-substation and the placement of signs that act as limits. This will allow the electricity to be adequately conditioned before it is transmitted. 6348 REC solar photovoltaic modules with 51 inverters power ratings of 30kW are required to produce 1.53 MW of electric power.

The modules are at a fixed orientation with a plane tilt and azimuth angles of 25^0 and 87^0 respectively. These modules has a maximum input voltage of 1000 V and an open circuit voltage of 36.8 V. The string count and module details are illustrated in Fig 28, from the SLD details of the proposed PV plant, there are three groups of strings. The first group of strings are made up of 48 modules having a string count of 2(each string is made up of 24 modules). The second group of strings are made up of 76 modules having a string count of 4(each string is made up of 19 modules). Finally, the third group of 5 strings are made up of 125 modules having a string count of 5 (each string is made up of 25 modules). The first and second group of strings are connected to 27 inverters (CSI-30KTL-GS-FL), i.e. 2 strings of 48 modules and 4 strings of 76 modules are connected to one inverter. The third group of strings are connected to 24 inverters i.e. 5 strings of 125 modules are connected to one inverter. This system's PV modules are linked together using copper wire that is 10 AWG in diameter. These strings are attached to disconnect switches, and from the disconnect switches to the inverters. 51 circuit interconnects, each rated at 20.0 A, are used to aggregate the output power of all the inverters. The system employs two distinct types of disconnect switches: AC disconnects are placed between the utility grid and inverter, while DC disconnects are placed between the PV modules and the inverter.

The monthly and annual energy production are shown in Fig 30 and 29. Fig 31 displays all the losses in the system, including the inverter losses, wiring losses, shading losses, solar irradiance losses, soiling losses, and reflection losses. There are total losses of 24.3% and Fig 32 shows the system metric which include the module DC, Inverter AC nameplate, Annual Production, Performance Ratio etc. The grid recorded 247075.5 kWh in the month of July, which is the maximum production in summer, and the minimum of 88785.8 kWh in December, which is winter and is the lowest. The annual grid production is 2.078 GWh, and the system has a performance ratio of 79.1%. The performance ratio is used to evaluate the efficiency of PV systems. Performance ratio is independent of radiation levels, particular sites, or even module orientations. As a result, the performance ratio may be used to evaluate the same system over a certain period of time, the same system at a different site, or various PV system types. The performance ratio will, however, be lower in a colder climate because of the PR's significant temperature sensitivity. This formula is used to calculate the performance ratio of a given PV power system.

$$\text{Performance Ration (PR)} = \frac{\text{Produced power (kWh)}}{\text{Nominal plant output (kWh)}} \times 100\% \qquad (3.8)$$

The nominal output power of a PV system is determined by the formula below:

$$\text{Nominal Output Power} = \frac{\text{Incident irradiation on PV panels}}{\text{Panel efficiency} \times \text{Area} \times \text{ Irradiance}} \qquad (3.9)$$

The calculations below validate the results of the energy required from the PV system, i.e., the needed number of modules and inverters.

$$P_{ac} = P_{dc,STC} \times \text{Conversion efficiency} \quad (3.10)$$

$$P_{ac} = 1.524 \times 0.98 = 1.494 \text{ MW} \quad (3.11)$$

Note: The 98% conversion efficiency reported by Ghode and Pratiksha et al. (2018) takes into account the impact of factors such as inverter efficiency, dirt accumulation on the module surface, module mismatch, and the impact of environmental changes brought on by STC.This conversion efficiency (95%) is the minimum acceptable efficiency (Features, 2018).The selected Canadian solar inverter has the conversion efficiency 98%.

P_{dc}(STC): is the system's nameplate power rating accurate under standard test conditions. P_{ac}: AC power.

$$\text{The number of PV modules required} = \frac{\text{Estimated Plant Power}}{\text{Each Module Power}} \quad (3.12)$$

$$\text{The number of modules required} = \frac{1.524\text{MW}}{240 \text{ W}} = 6348 \text{ modules} \quad (3.13)$$

$$\text{The Inverter Quantity} = \frac{\text{Estimated Plant Power}}{\text{Inverter Power}} \quad (3.14)$$

$$\text{The Inverter Quantity} = \frac{1.524\text{MW}}{30 \text{ kW}} = 50.78 \cong 51 \text{ inverters} \quad (3.15)$$

Figure 27.

Proposed PV Plant Modules and Inverters

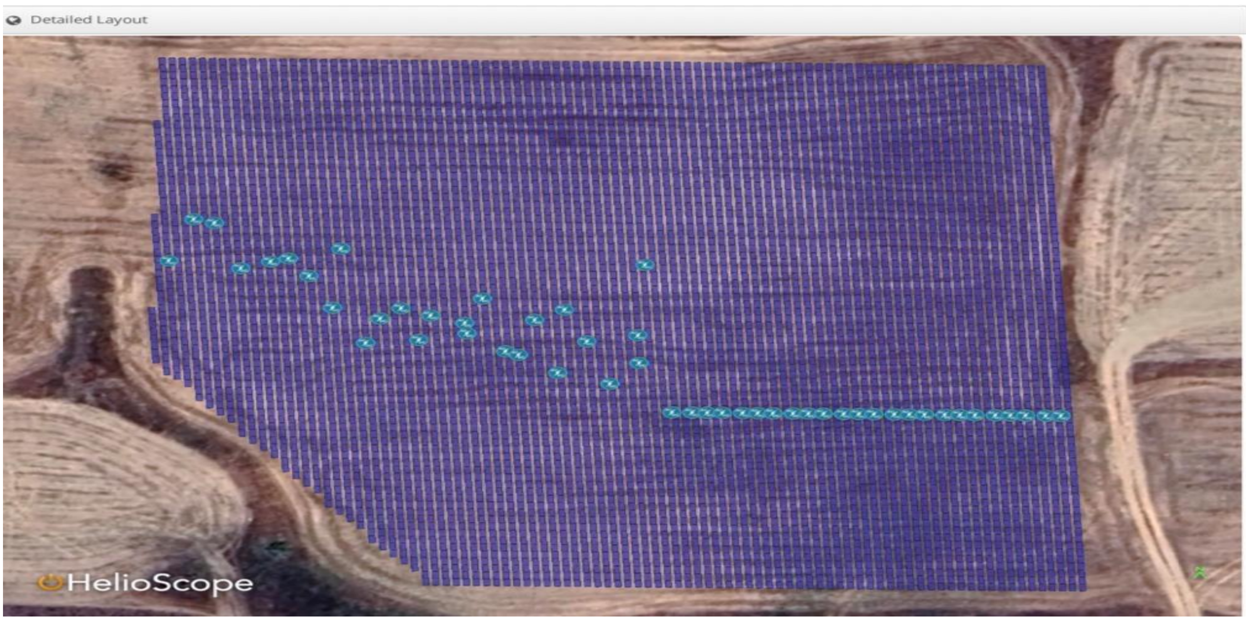
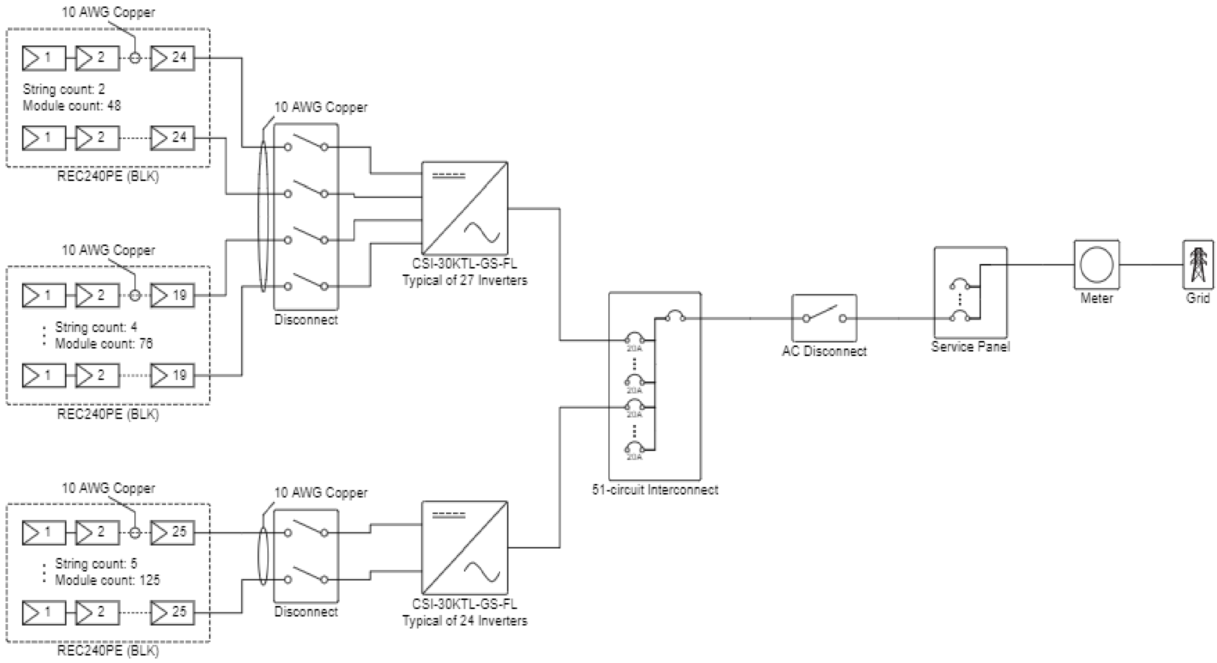


Figure 28.

Proposed PV Plant SLD Details



Module Specifications	
6348x REC Solar REC240PE (BLK)	
STC Rating	240 W
Vmp	29.5 V
Imp	8.23 A
Voc	36.8 V
Isc	8.75 A

Inverter Specifications	
51x Canadian Solar CSI-30KTL-GS-FL	
Max AC Power Rating	30 kW
Max Input Voltage	1,000 V
Min AC Power Rating	0 W
Min Input Voltage	200 V

Wire Schedule		
Tier	Wire	Length
String	282x 10 AWG	52226ft

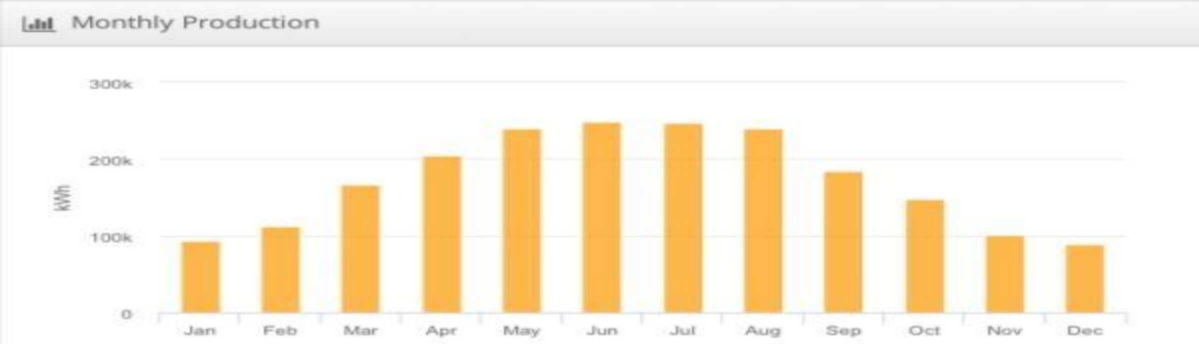
Figure 29

Proposed PV Plant Annual Energy Production

Annual Production			
	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	1,806.0	
	POA Irradiance	1,729.8	-4.2%
	Shaded Irradiance	1,607.7	-7.1%
	Irradiance after Reflection	1,552.6	-3.4%
	Irradiance after Soiling	1,521.5	-2.0%
	Total Collector Irradiance	**1,521.5**	**0.0%**
Energy (kWh)	Nameplate	2,344,958.7	
	Output at Irradiance Levels	2,326,597.4	-0.8%
	Output at Cell Temperature Derate	2,196,098.1	-5.6%
	Output After Mismatch	2,131,788.2	-2.9%
	Optimal DC Output	2,124,394.0	-0.3%
	Constrained DC Output	2,124,352.7	0.0%
	Inverter Output	2,088,238.7	-1.7%
	Energy to Grid	**2,077,797.5**	**-0.5%**
Temperature Metrics			
	Avg. Operating Ambient Temp		22.1 °C
	Avg. Operating Cell Temp		30.7 °C
Simulation Metrics			
		Operating Hours	4606
		Solved Hours	4606

Figure 30

Proposed PV Plant Monthly Energy Production



Month	GHI (kWh/m²)	POA (kWh/m²)	Shaded (kWh/m²)	Nameplate (kWh)	Grid (kWh)
January	79.7	76.0	70.5	100,761.9	94,143.6
February	94.8	90.1	82.8	119,780.8	112,015.0
March	143.6	133.6	125.2	182,078.6	167,231.8
April	171.6	166.1	154.8	227,053.5	205,134.5
May	205.4	198.7	185.5	272,328.8	240,533.5
June	217.5	210.7	196.2	288,079.5	249,207.1
July	217.2	210.6	196.9	289,180.7	247,075.5
August	217.3	205.1	191.5	281,536.5	240,245.8
September	162.1	156.8	145.1	211,951.6	184,733.5
October	129.5	123.3	114.7	166,268.5	147,627.2
November	91.5	84.9	77.6	110,682.5	101,064.2
December	75.9	73.7	67.0	95,255.9	88,785.8

Figure 31

Proposed PV Plant System Loses

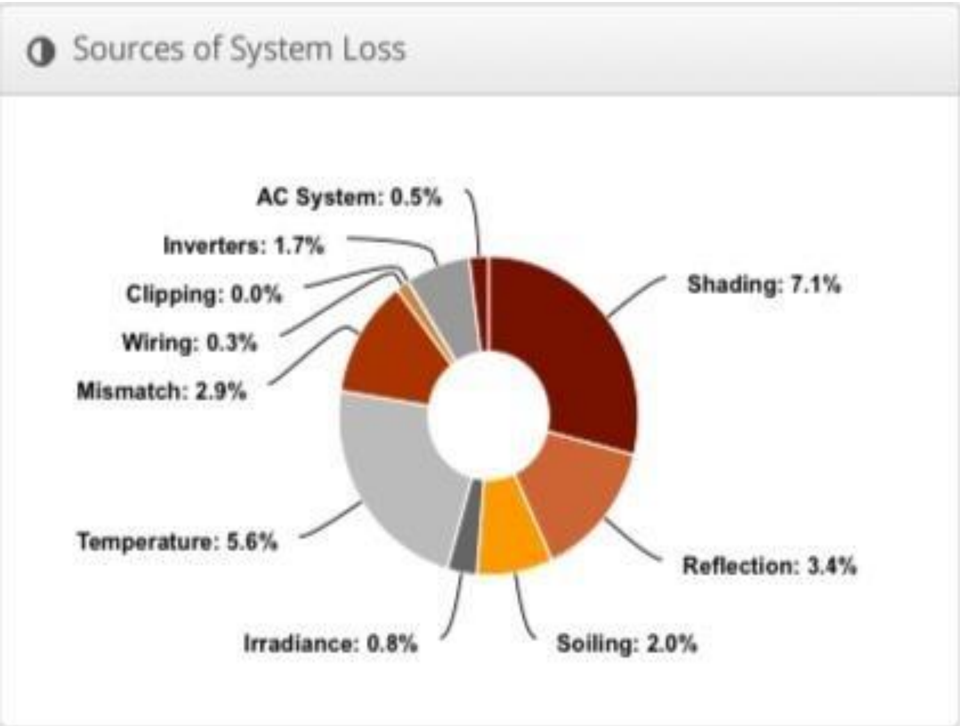


Figure 32

Proposed PV System Metrics

System Metrics	
Design	Design 1
Module DC Nameplate	1.52 MW
Inverter AC Nameplate	1.53 MW Load Ratio: 1.00
Annual Production	2.078 GWh
Performance Ratio	78.8%
kWh/kWp	1,363.8
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)
Simulator Version	bd726797e3-c6dc798c02-b135fa1d14-3ecbdc96a0

3.3.1 Varying the Module (Watt) Magnitude

In this section the magnitude of the PV modules in the power plant are varied to ascertain the effective change in the plant's output power. The size (1581.9 m^2) of the plant location is maintain for the various module sizes. Table 9 shows the various module sizes use in this analysis and the corresponding change in the plant's output power.

Table 9.

Varying the Module (Watt) Magnitude

Module Size (Watt)	Module DC Nameplate (MW)	InverterAC Nameplate (MW)	Annual production (GWh)	Performance Ratio (%)
240	1.52	1.53	2.078	78.8
270	1.75	2.00	2.315	76.8
300	1.65	2.00	2.195	77.5
350	1.89	2.00	2.494	76.8
390	2.18	2.00	2.895	77.1
400	2.24	2.00	2.995	77.8

3.4 Payback Period for the Proposed PV Plant

A power plant's payback period is the amount of time it needs to earn enough money to cover both its original installation and maintenance costs. If the payback period for a power plant is shorter than its lifetime, the plant is considered lucrative. The price of one kilowatt-hour (1 kWh) of electricity, the cost of plant construction, and the quantity of energy generated over time need to be evaluated in order to calculate a photovoltaic power plant's payback period.For the Proposed photovoltaic power plant of NEU, the below parameters are determined. The cost of the installation in 2023: 1500000 euros (30607117.50 million Lira) Amount of energy produced in (2023): 2078000 kW. Price of one kilowatt-hour of power: Price of one kilowatt-hour 0.46 TRY.

$$\text{Revenue generated of system per year} = \text{annual energy} \times \text{price of energy} \tag{3.16}$$

$$\text{Revenue generated of the system per year} = 2078000 \times 0.46 = 955{,}880 \text{ Euro} \tag{3.17}$$

$$\text{Payback period} = \frac{\text{The total investment}}{\text{Generated revenue}} \tag{3.18}$$

$$\text{Payback period} = \frac{1500000 \text{ Euro}}{955880 \text{ Euro}} = 2 \text{ years} \tag{3.19}$$

3.5 Innovation Centre Photovoltaic System (NEU)

There is always enough roof space in the departmental buildings on campus to install a PV system for powering the building. PV modules may be mounted at certain locations. If the root top space is not large enough for high voltage generation, ground mounted PV system can be used. The roofs of academic buildings are often accessible but not put to good use in some areas, Fig 33 shows the Innovation centre root top mounted with the PV modules/panels and inverters. These occupy a total area of 1209.4 m^2 with a total of 311 Canadian solar panels rated at 230W. The modules have a maximum input voltage of 29.6 and an open circuit voltage of 36.8. The system recorded 13512.4 kWh in the month of August in Fig. 35, which is the maximum, and have a performance ratio of 80% in Fig.38. Fig. 36 shows the losses in the system, with a total loss of 22%.The extra benefit of lowering the building's heat gain from the top is another benefit of installing PV modules on the rooftop. Yet, when the load demand cannot be satisfied by PV production due to unfavorable air conditions, the necessary energy may be pulled from the utility grid immediately. The roof top of the buildings is directly impacted by solar radiation. The design of the solar PV array is carefully designed to eliminate any potential shadow cast by the water tanks, sidewalls, columns, and neighbouring buildings

Figure 33.

Innovation Centre (NEU)

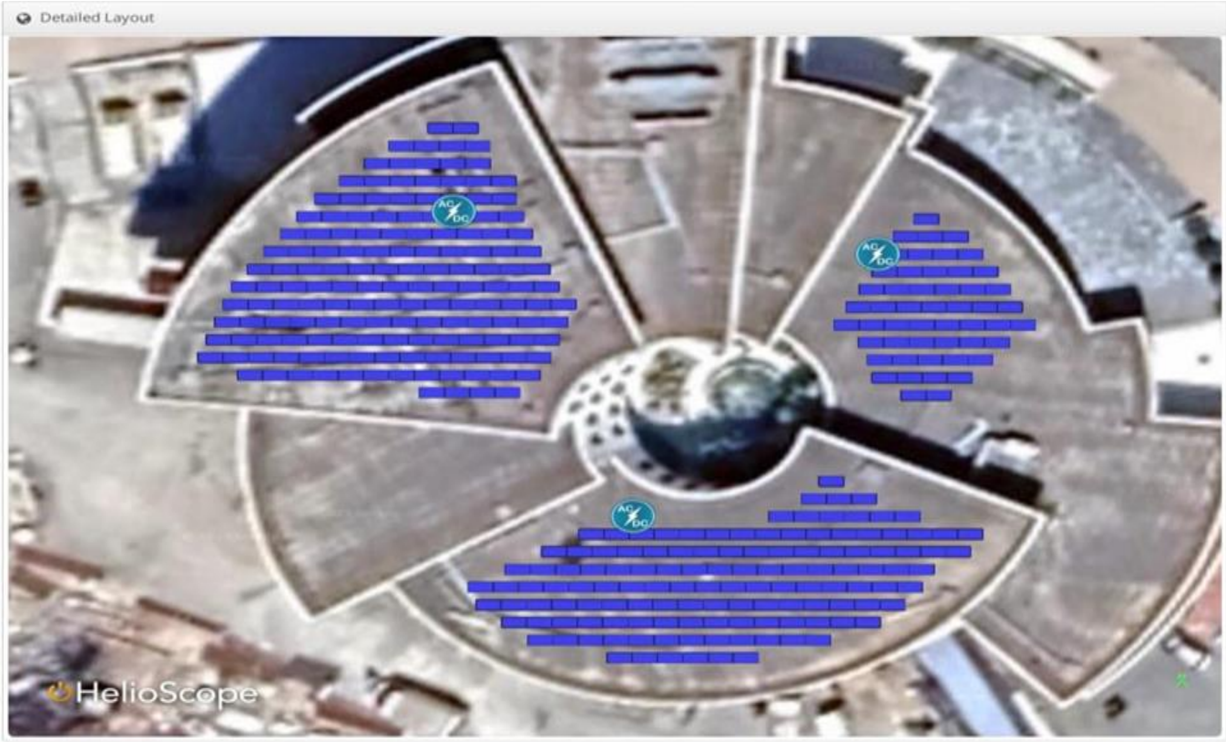
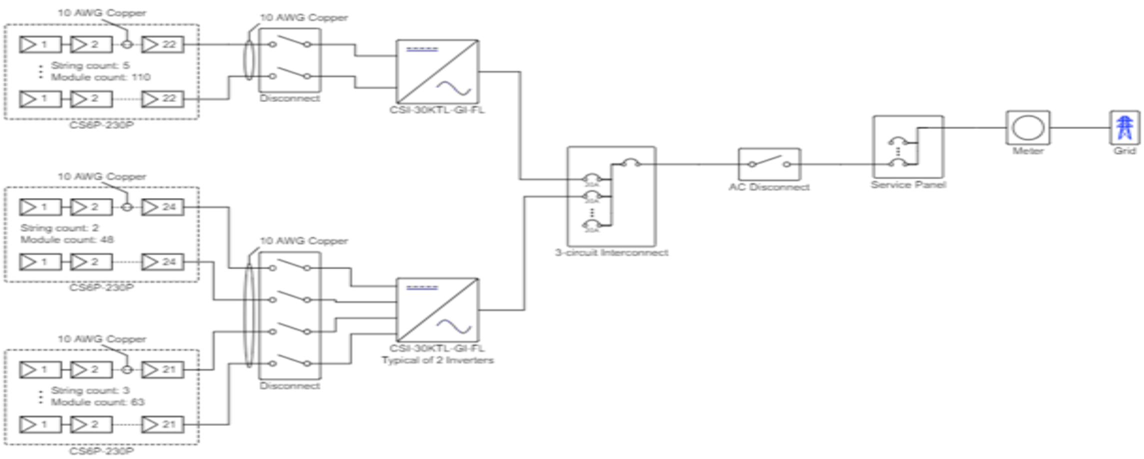


Figure 34.

SLD of Innovation Centre String and Module Details



Module Specifications	
332x Canadian Solar CS6P-230P	
STC Rating	230 W
Vmp	29.6 V
Imp	7.78 A
Voc	36.8 V
Isc	8.34 A

Inverter Specifications	
3x Canadian Solar CSI-30KTL-GI-FL	
Max AC Power Rating	30 kW
Max Input Voltage	1,000 V
Min AC Power Rating	0 W
Min Input Voltage	200 V

Wire Schedule		
Tier	Wire	Length
String	15x 10 AWG	1964ft

Figure 35.

Innovation Centre Monthly Energy Production

Figure 36.

Innovation Centre Annual Energy Production

Annual Production

	Description	Output	% Delta
Irradiance (kWh/m^2)	Annual Global Horizontal Irradiance	1,806.0	
	POA Irradiance	2,048.3	13.4%
	Shaded Irradiance	1,955.6	-4.5%
	Irradiance after Reflection	1,902.7	-2.7%
	Irradiance after Soiling	1,864.6	-2.0%
	Total Collector Irradiance	**1,864.6**	**0.0%**
Energy (kWh)	Nameplate	142,553.8	
	Output at Irradiance Levels	141,906.1	-0.5%
	Output at Cell Temperature Derate	132,342.4	-6.7%
	Output After Mismatch	128,290.2	-3.1%
	Optimal DC Output	127,906.1	-0.3%
	Constrained DC Output	127,903.5	0.0%
	Inverter Output	125,729.1	-1.7%
	Energy to Grid	**125,100.5**	**-0.5%**
Temperature Metrics			
	Avg. Operating Ambient Temp		22.1 °C
	Avg. Operating Cell Temp		32.5 °C
Simulation Metrics			
		Operating Hours	4606
		Solved Hours	4606

Figure 37.

System Loses Innovation Centre

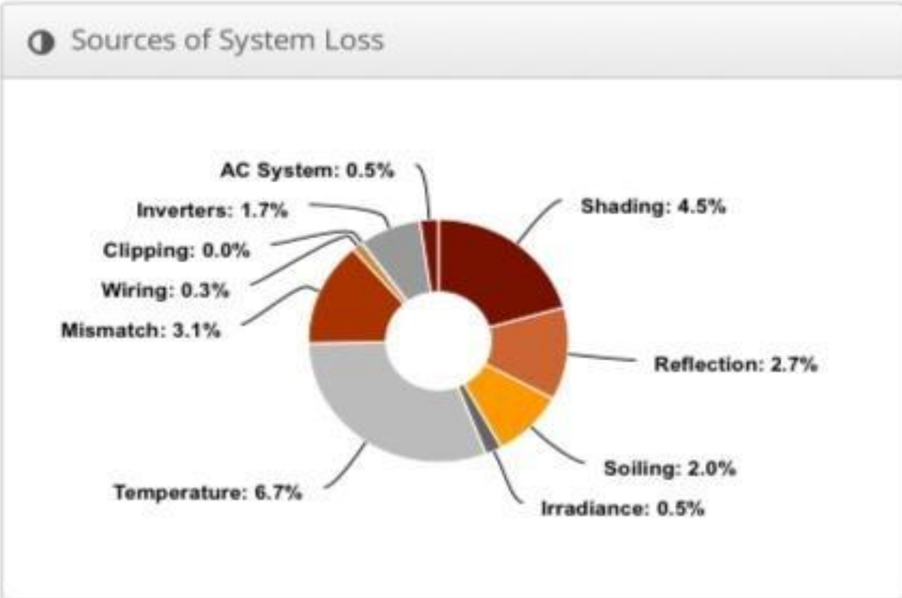


Figure 38.

Innovation Centre System Metrics

System Metrics	
Design	Engineering Faculty
Module DC Nameplate	76.4 kW
Inverter AC Nameplate	90.0 kW Load Ratio: 0.85
Annual Production	125.1 MWh
Performance Ratio	80.0%
kWh/kWp	1,638.3
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)
Simulator Version	7fcfed6b7f-c73bc584e3-60fabe3f4f-3e4a7ea9f7

3.6 NEU Library PV System

The NEU library building was stimulated using the HelioScope software. You may get an idea of the size of the NEU library from the fact that it has space for 1.5 million books. Built to international specifications, this cultural and information hub provides access to over 150 million electronic resources, 7.5 thousand DVDs, 17 movie closets, 12 study rooms for solo and small group study, a cafeteria with capacity for 600, and 600 study tables. The modern digital technology of the information centre allows you to access it online from the comfort of your own home.

The library has a larger rooftop area for the installation of PV panels. On the rooftop, 243modules of 230W Canadian solar modules were installed to fill the 888.9m^2 of available area. The PV system is rated at 90kW.The system needs three 30 kilowatt inverters. In August, the system produced 8434.3 kWh shown in Fig.40, with a 79% performance ratio in Fig. 44 of the system metrics. The rooftop modules and inverters of the NEU library are shown in Fig 39.

Figure 39.

NEU Library

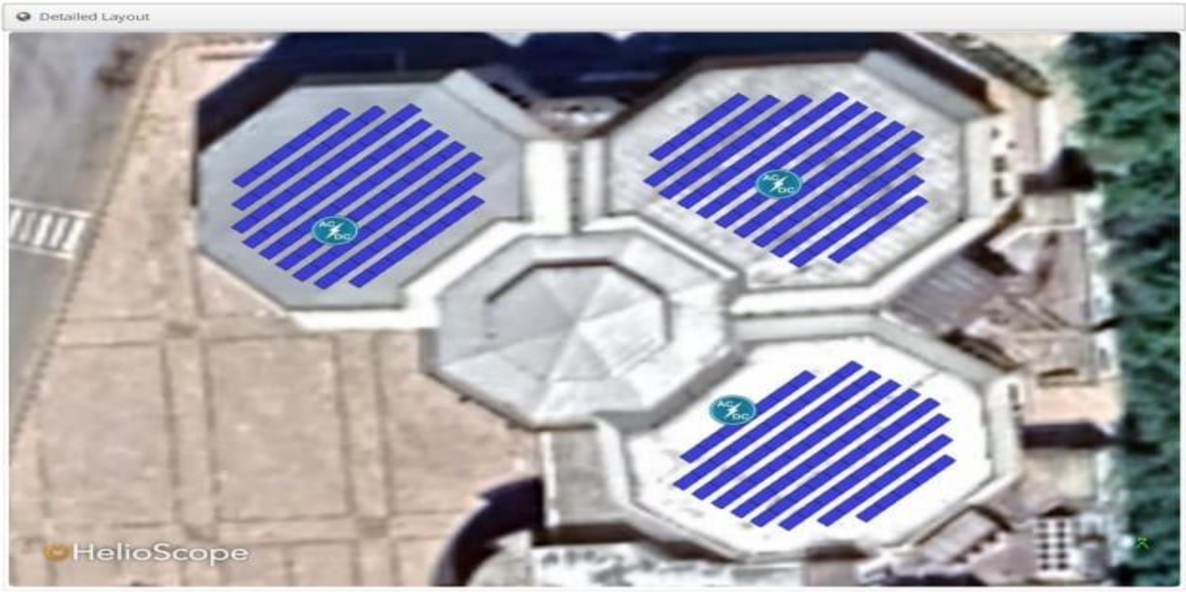
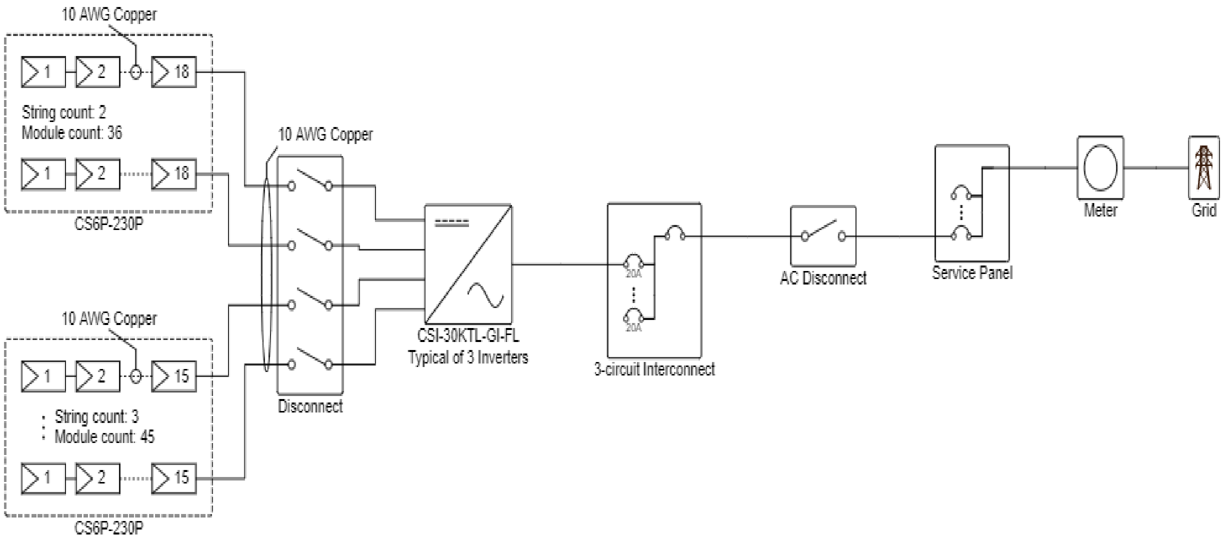


Figure 40.

NEU Library Monthly Energy Production

Figure 41.

SLD of NEU Library Module and String Details



Module Specifications	
243x Canadian Solar CS6P-230P	
STC Rating	230 W
Vmp	29.6 V
Imp	7.78 A
Voc	36.8 V
Isc	8.34 A

Inverter Specifications	
3x Canadian Solar CSI-30KTL-GI-FL	
Max AC Power Rating	30 kW
Max Input Voltage	1,000 V
Min AC Power Rating	0 W
Min Input Voltage	200 V

Wire Schedule		
Tier	Wire	Length
String	15x 10 AWG	898ft

Figure 42.

NEU Library Annual Energy Production

Annual Production

	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	1,806.0	
	POA Irradiance	1,956.9	8.4%
	Shaded Irradiance	1,844.5	-5.7%
	Irradiance after Reflection	1,791.7	-2.9%
	Irradiance after Soiling	1,755.8	-2.0%
	Total Collector Irradiance	**1,755.7**	**0.0%**
Energy (kWh)	Nameplate	98,246.4	
	Output at Irradiance Levels	97,699.0	-0.6%
	Output at Cell Temperature Derate	91,249.1	-6.6%
	Output After Mismatch	88,737.2	-2.8%
	Optimal DC Output	88,478.3	-0.3%
	Constrained DC Output	87,773.1	-0.8%
	Inverter Output	86,281.0	-1.7%
	Energy to Grid	**85,849.6**	**-0.5%**
Temperature Metrics			
	Avg. Operating Ambient Temp		22.1 °C
	Avg. Operating Cell Temp		32.0 °C
Simulation Metrics			
		Operating Hours	4606
		Solved Hours	4606

Figure 43.

System Loses for the Library

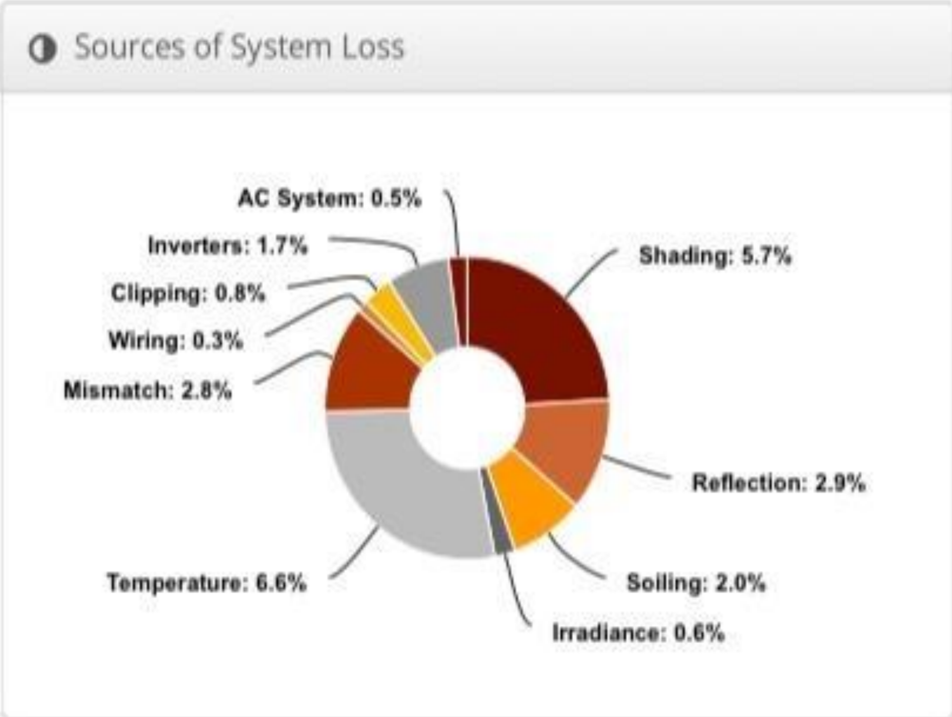


Figure 44.

System Metrics for the Library

System Metrics

Design	Library NEU
Module DC Nameplate	55.9 kW
Inverter AC Nameplate	90.0 kW Load Ratio: 0.62
Annual Production	85.85 MWh
Performance Ratio	78.5%
kWh/kWp	1,536.0
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)
Simulator Version	7fcfed6b7f-c73bc584e3-60fabe3f4f-3e4a7ea9f7

3.7 NEU High School

For NEU High School building in Fig 45, 90 kW from the HelioScope software was designed to supply electricity to the building. Depending on the location, a PV system installed at the school might result in considerable energy savings. This make the building an eco-friendly, self-sustainable from energy point of view. The area available on the building's rooftop occupied 365 Canadian solar panels rating 230W, and this system needed 3 inverter with a 30 kW rating. The PV system occupy an area of 1263.7 m^2 at the rooftop. In August, the system recorded 14831.8 kWh in Fig.49, and its performance ratio was 80% shown in Fig 50 of the system metrics. Fig. 46 show the total system loses of 22.1%.

Figure 45.

NEU High School

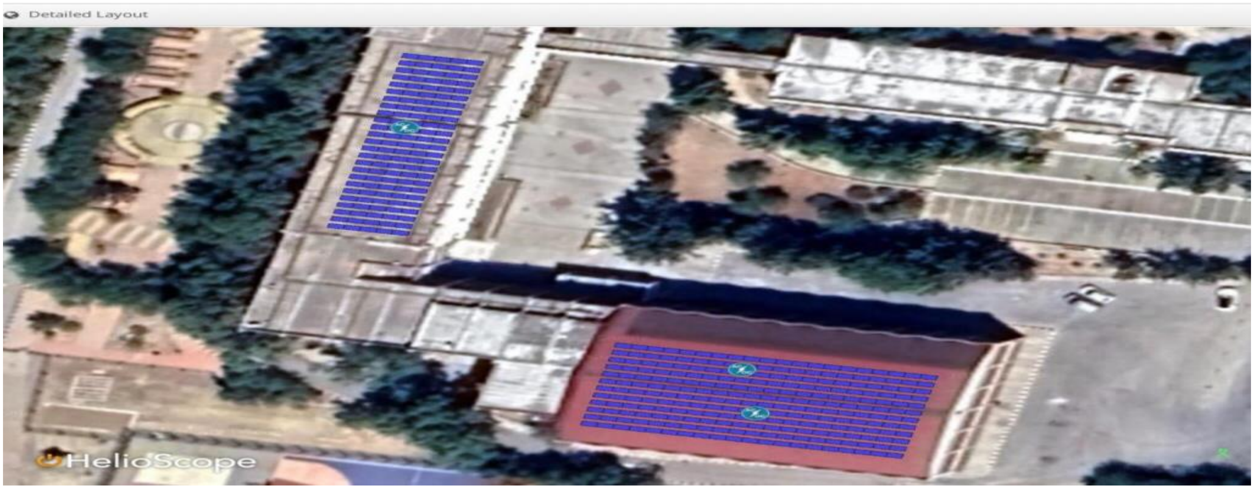


Figure 46.

NEU High School System Loses

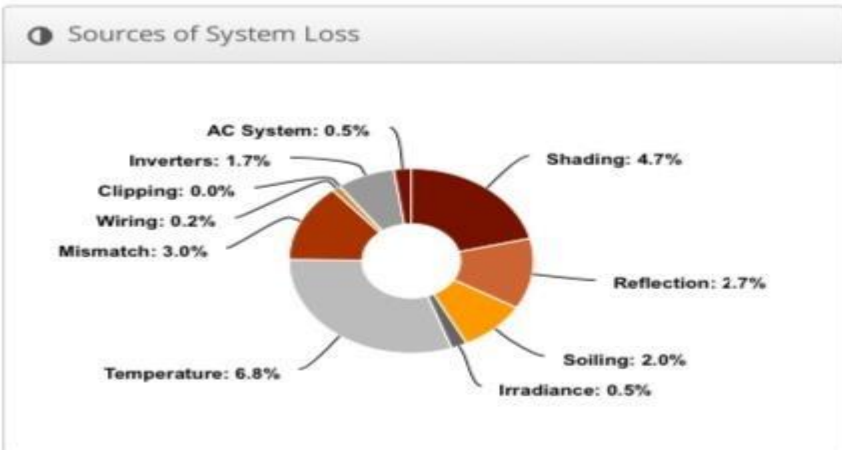
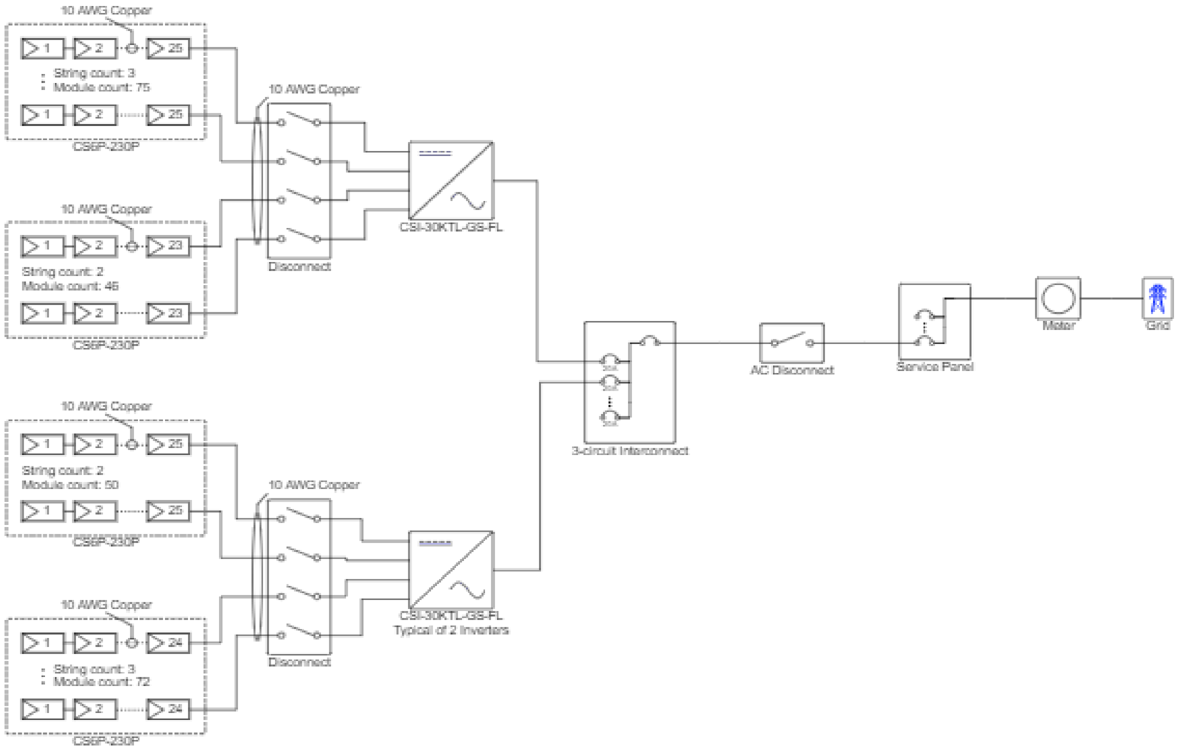


Figure 47.

SLD of NEU High School Module and String Details



Module Specifications	
365x Canadian Solar CS6P-230P	
STC Rating	230 W
Vmp	29.6 V
Imp	7.78 A
Voc	36.8 V
Isc	8.34 A

Inverter Specifications	
3x Canadian Solar CSI-30KTL-GS-FL	
Max AC Power Rating	30 kW
Max Input Voltage	1,000 V
Min AC Power Rating	0 W
Min Input Voltage	200 V

Wire Schedule		
Tier	Wire	Length
String	15x 10 AWG	1127ft

Figure 48.

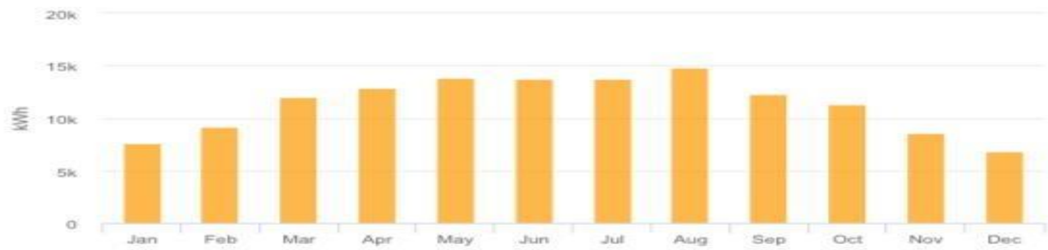
NEU High School Annual Energy Production

Annual Production			
	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	1,806.0	
	POA Irradiance	2,040.2	13.0%
	Shaded Irradiance	1,945.2	-4.7%
	Irradiance after Reflection	1,891.9	-2.7%
	Irradiance after Soiling	1,854.0	-2.0%
	Total Collector Irradiance	**1,854.1**	**0.0%**
Energy (kWh)	Nameplate	155,850.1	
	Output at Irradiance Levels	155,127.8	-0.5%
	Output at Cell Temperature Derate	144,645.7	-6.8%
	Output After Mismatch	140,288.0	-3.0%
	Optimal DC Output	139,939.2	-0.2%
	Constrained DC Output	139,936.7	0.0%
	Inverter Output	137,557.8	-1.7%
	Energy to Grid	**136,870.0**	**-0.5%**
Temperature Metrics			
	Avg. Operating Ambient Temp		22.1 °C
	Avg. Operating Cell Temp		32.5 °C
Simulation Metrics			
		Operating Hours	4606
		Solved Hours	4606

Figure 49.

NEU High School Monthly Energy Production

Monthly Production



Month	GHI (kWh/m²)	POA (kWh/m²)	Shaded (kWh/m²)	Nameplate (kWh)	Grid (kWh)
January	79.7	116.3	102.8	8,233.9	7,600.6
February	99.4	130.9	124.0	9,940.7	9,197.1
March	143.6	169.4	164.6	13,216.1	11,981.1
April	173.8	184.9	180.0	14,415.3	12,895.9
May	206.7	203.3	197.6	15,807.0	13,825.5
June	217.9	206.6	201.1	16,075.1	13,780.1
July	215.3	208.6	203.0	16,236.6	13,734.8
August	216.2	225.1	220.1	17,644.8	14,831.8
September	159.9	182.6	177.9	14,271.5	12,251.6
October	130.2	168.4	162.2	13,032.9	11,353.8
November	90.2	132.0	119.7	9,601.7	8,630.2
December	73.2	112.0	92.2	7,374.4	6,787.5

Figure 50

System Metrics NEU High School

System Metrics	
Design	NEU High School
Module DC Nameplate	84.0 kW
Inverter AC Nameplate	90.0 kW Load Ratio: 0.93
Annual Production	136.9 MWh
Performance Ratio	79.9%
kWh/kWp	1,630.4
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)
Simulator Version	bd726797e3-c6dc798c02-b135fa1d14-3ecbdc96a0

3.8 NEC Children Cafeteria

Due to the cafeteria's large rooftop surface, simulations run for the standalone system using HelioScope software for the Near East College Cafeteria building yielded 52 kW. The 733.2 m^2 of accessible rooftop area can house 220 Canadian photovoltaic modules rated at 230W.

Two inverters, each rated at 30 kW, are needed for the system. The placement of modules and inverters on the rooftop is shown in Fig 51.

Figure 51.

Near East College Cafeteria

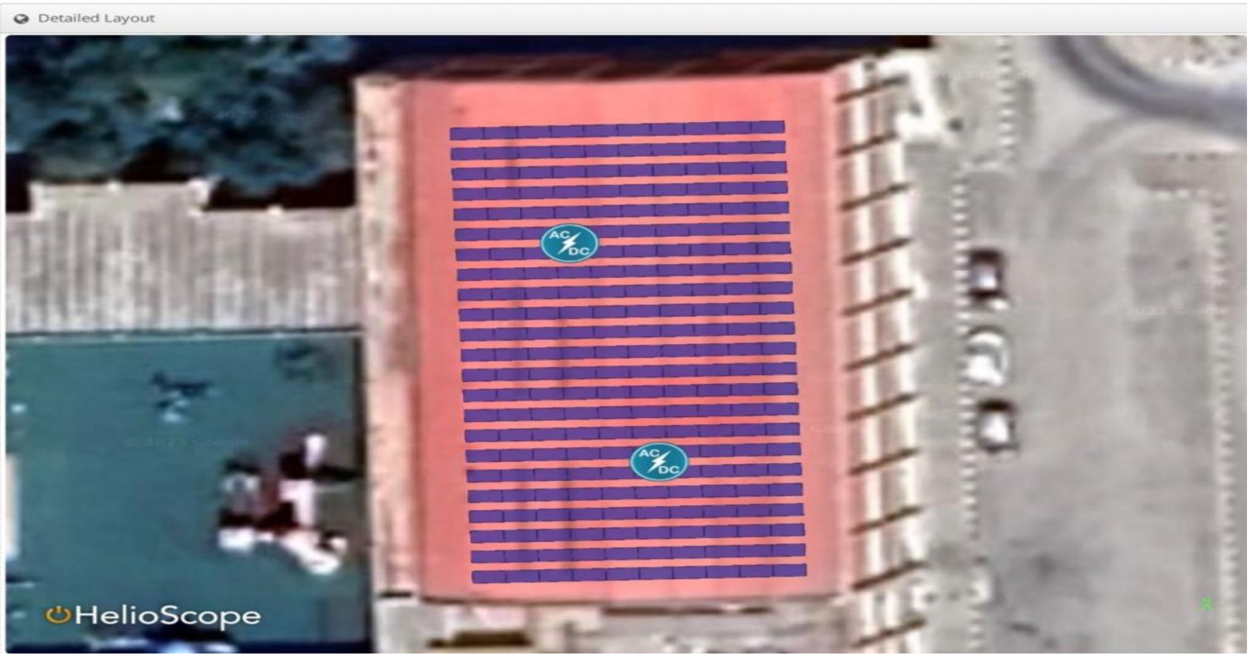
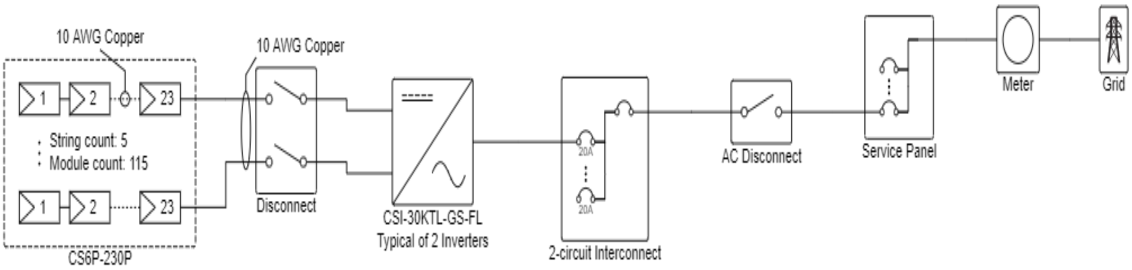


Figure 52

SLD of Module and String Details of NEC



Module Specifications	
230x Canadian Solar CS6P-230P	
STC Rating	230 W
Vmp	29.6 V
Imp	7.78 A
Voc	36.8 V
Isc	8.34 A

Inverter Specifications	
2x Canadian Solar CSI-30KTL-GS-FL	
Max AC Power Rating	30 kW
Max Input Voltage	1,000 V
Min AC Power Rating	0 W
Min Input Voltage	200 V

Wire Schedule		
Tier	Wire	Length
String	10x 10 AWG	587ft

Figure 53

Annual Energy Production of NEC

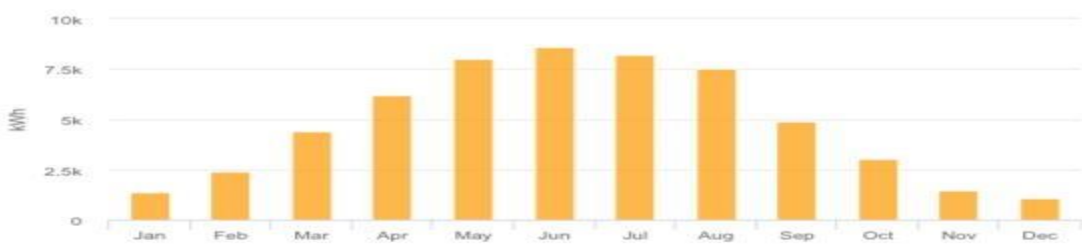
Annual Production

	Description	Output	% Delta
Irradiance (kWh/m^2)	Annual Global Horizontal Irradiance	1,806.0	
	POA Irradiance	1,365.3	-24.4%
	Shaded Irradiance	1,318.5	-3.4%
	Irradiance after Reflection	1,244.8	-5.6%
	Irradiance after Soiling	1,219.9	-2.0%
	Total Collector Irradiance	**1,219.9**	**0.0%**
Energy (kWh)	Nameplate	64,612.9	
	Output at Irradiance Levels	63,751.9	-1.3%
	Output at Cell Temperature Derate	60,308.1	-5.4%
	Output After Mismatch	58,468.6	-3.1%
	Optimal DC Output	58,380.7	-0.2%
	Constrained DC Output	58,379.1	0.0%
	Inverter Output	57,386.7	-1.7%
	Energy to Grid	**57,099.7**	**-0.5%**
Temperature Metrics			
	Avg. Operating Ambient Temp		22.1 °C
	Avg. Operating Cell Temp		28.9 °C
Simulation Metrics			
		Operating Hours	4606
		Solved Hours	4606

Figure 54.

Monthly Energy Production of NEC

Monthly Production



Month	GHI (kWh/m^2)	POA (kWh/m^2)	Shaded (kWh/m^2)	Nameplate (kWh)	Grid (kWh)
January	79.7	35.3	33.3	1,490.7	1,358.4
February	99.4	57.2	54.6	2,552.9	2,377.9
March	143.6	101.5	97.8	4,737.7	4,386.3
April	173.8	141.9	137.4	6,795.4	6,199.8
May	206.7	186.7	180.6	9,036.6	8,017.5
June	217.9	203.5	196.9	9,884.7	8,577.2
July	215.3	197.2	191.0	9,573.4	8,210.2
August	216.2	180.4	175.7	8,733.9	7,516.3
September	159.9	118.2	114.2	5,568.7	4,894.4
October	130.2	75.7	72.8	3,404.9	3,026.1
November	90.2	39.1	37.2	1,644.3	1,469.4
December	73.2	28.7	26.9	1,189.9	1,066.2

Figure 55.

System Loses of NEC

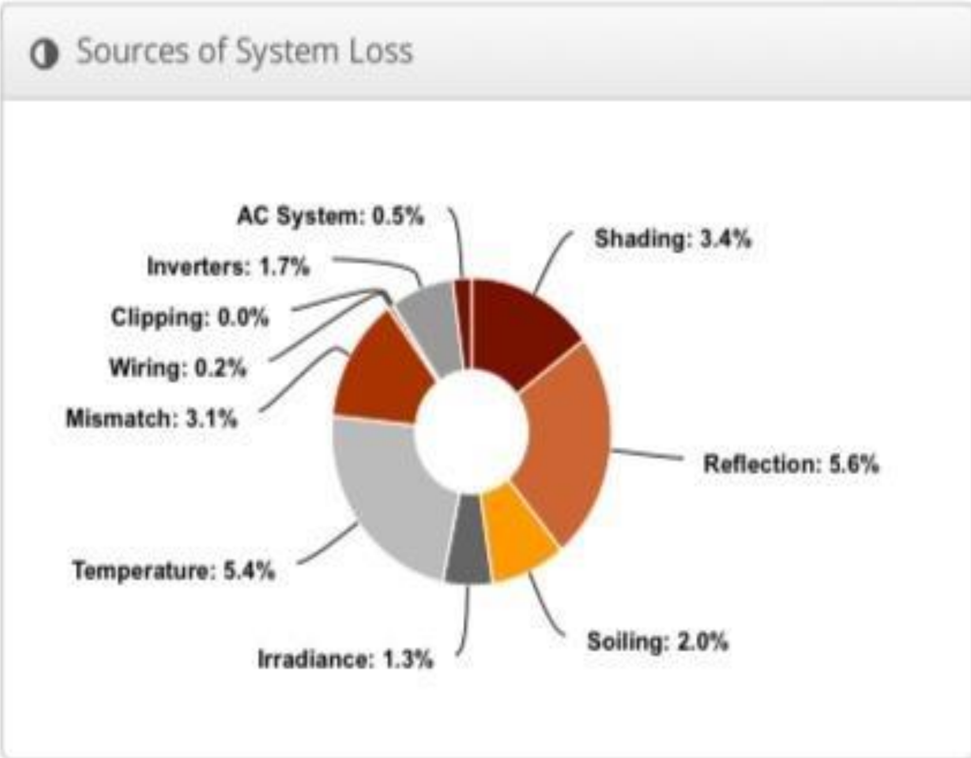


Figure 56.

System Metrics NEC

System Metrics	
Design	Design 1
Module DC Nameplate	52.9 kW
Inverter AC Nameplate	60.0 kW Load Ratio: 0.88
Annual Production	57.10 MWh
Performance Ratio	79.1%
kWh/kWp	1,079.4
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)
Simulator Version	bd726797e3-c6dc798c02-b135fa1d14-

3.9 Faculty of Veterinary Medicine NEU (Façade)

PV module installation in a building's envelope may be done on the roof or the façade. The quantity of solar energy captured in a façade installation will depend on the direction and inclination angle. When facing southeast or southwest in the northern part of the globe, a PV module will produce more electric energy than when facing northeast or northwest, and vice versa. The faculty of veterinary medicine's façade was fitted with 79 Canadian solar panels, each rated for 230 kW, and one inverter with a power rating of 30 W to produce 30 kW of electricity, with a performance ratio of 81% and a monthly energy output of 3,144.9 kWh for the structure. The veterinary medicine faculty can be seen in Fig. 57 along the PV modules attached to the building's façade.

Figure 57.

The faculty of veterinary medicine NEU (Façade)

CHAPTER IV

Conclusion and Recommendations

4.0 Conclusion

This research suggests an inexpensive, eco-friendly, and environmentally sustainable way to generate electricity for the campus of the Near East University. Throughout time, Photovoltaic (PV) systems, which convert light from the sun into usable electrical energy, have quickly become one of the most prominent forms of renewable energy technology. The photovoltaic (PV) market has expanded roughly to 240 GW, a boom ignored for years and mostly driven by China, the United States, and Europe (IEA, 2015). This is a significant increase in market side. The International Energy Agency (IEA) says that there has been a steady increase in the number of PV installations worldwide over the past several years, despite the fact that there have been a number of obstacles.

The goal of this thesis is to integrate the potential power output when BIPV is implemented on some selected faculties on the campus of NEU. Also, this thesis present the potential of a grid connected solar, PV power plant for the generation of electric energy on NEU campus. The aim is that BIPV and a grid connected may be used as a distributed power source to provide energy that is both cleaner and less expensive.

This will be accomplished by a PV system software called Helioscope for designing a solar power system for the NEU campus. Using PV system software eliminate the need for capital intensive practical research. PV system software are widely accepted for research in academic and industry. Another goal of this thesis is to provide an advantageous approach to producing electrical power, mainly; photovoltaic energy.

The proposed PV power plant will be situated behind the faculty of veterinary medicine. The following field data were used with the HelioScope software to generate the required energy. The grid-connected solar power plant produced 1.5 MW of electric power using 51 inverters rated at 30 kW and 6348 REC solar photovoltaic modules. The system has a performance ratio of 79.1, and the yearly grid output is 2.078 GWh. The results of this investigation show that, more than 3GWh of solar electric energy are left to waste annually on NEU campus because the requisite investments have not been made to harvest these resources.

Finally, the standalone PV system for five other buildings on the campus of the Near East University were created using the same HelioScope software. The largest rooftop on three of these five buildings generated 90 kW of electric power, whereas the smallest rooftop area chosen for simulation generated 30kW of electric power. The system with the largest rooftop area is rated at 90 kW and has 365 Canadian solar panels. Three inverters with a 30 kW rating were required for this system.

As HelioScope has been used extensively in research projects by the academic community and the photovoltaic sector, using it as a tool for simulating solar photovoltaic power plants is definitely a wise decision. I can draw the conclusion that building a PV power plant at NEU is technically and economically possible and won't endanger the environment based on the numerous simulation findings from the grid-connected and standalone systems of this study.

4.1 Recommendations

I propose carrying out the practical aspect of this study by utilizing the necessary PV module data recording equipment for at least one year.

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Appendix i

SolarDesignTool Features · Pricing SIGN UP · LOGIN

REC Solar REC-240PE (240W) Solar Panel

Generate a Solar Permit Package for a design using REC Solar REC-240PE (240W)

With SolarDesignTool, you can create a design from scratch and generate a full PV permit package in as little as 15 minutes.

Learn More Sign up

This page contains information about the REC Solar REC-240PE (240W) solar panel. To compare this to other PV modules, click here.

Manufacturer Data Sheet **Installation Manual**

DC Electrical Characteristics

STC Power Rating	240W
PTC Power Rating	218W [1]
STC Power per unit of area	147.7W/m^2 (13.7W/ft^2)
Peak Efficiency	14.77%
Power Tolerances	0%/+2%
Number of Cells	60
Nominal Voltage	not applicable
Imp	8.17A
Vmp	29.7V
Isc	8.75A
Voc	36.8V
NOCT	45.7°C
Temp. Coefficient of Isc	0.02%/K
Temp. Coefficient of Power	-0.4%/K
Temp. Coefficient of Voltage	-0.099V/K
Series Fuse Rating	15A
Maximum System Voltage	600V

Appendix ii

SolarDesignTool Features · Pricing SIGN UP · LOGIN

Canadian Solar CS6P-230P (230W) Solar Panel

Warning
This model has been discontinued by the manufacturer.

Generate a Solar Permit Package for a design using Canadian Solar CS6P-230P (230W)
With SolarDesignTool, you can create a design from scratch and generate a full PV permit package in as little as 15 minutes. Learn More Sign up

This page contains information about the Canadian Solar CS6P-230P (230W) solar panel. To compare this to other PV modules, click here.

DC Electrical Characteristics

STC Power Rating	230W
PTC Power Rating	211W [1]
STC Power per unit of area	143.0W/m^2 (13.3W/ft^2)
Peak Efficiency	14.3%
Power Tolerances	0%/+2%
Number of Cells	60
Nominal Voltage	not applicable
Imp	7.78A
Vmp	29.6V
Isc	8.34A
Voc	36.8V
NOCT	45°C
Temp. Coefficient of Power	-0.43%/K
Temp. Coefficient of Voltage	-0.125V/K
Series Fuse Rating	15A
Maximum System Voltage	600V

Appendix X

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☐	Alexander Bundoo	Chapter 3	3% 3%	3%	1%	N/A	--	--	download paper	2122884118	26-Jun-2023
☐	Alexander Bundoo	Chapter 4 (Conclusion)	0% 0%	0%	0%	N/A	--	--	download paper	2122884448	26-Jun-2023

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04/07/2023