USE OF PHOTOVOLTAIC SYSTEMS IN BUILDINGS - SAMPLE DESIGN ON THE OFFICE BUILDING ROOF IN DÖRTYOL DISTRICT OF HATAY

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
ÜLKER BURCU FİLİTOĞLU

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Architecture

NICOSIA, 2021

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NEU 2021

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ÜLKER BURCU FİLİTOĞLU
20186543

SUPERVISED BY: PROF. DR. ZEYNEP ONUR

CO SUPERVISED BY: PROF. DR. HÜSEYİN GÖKÇEKUŞ

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Appro, al of Director of lnslitut e of Graduate Studies

Prof.Or. K. Hiisno Can Baier

We certify this thesis in satisfactory for the award of the degree of Master of Science in Architecture

Examinin g Co1111nil1ee in C harge

Prof. Dr. Kabir Sadeghi — CommitteeClulirman, Department of Civil Engineering, NEU

Prof. Dr. Zeynep Onur — Supervis or, De partmenl of Architecture, NEU

Assoc. Prof Dr. R,far Re!atoglu — Department of Civil Engineering, NEU

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name: Ülker Burcu Filitoğlu

Signature: 

Date: 04.08.2020

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To my parents…

ABSTRACT

In this study, the use of solar energy, which is the most abundant renewable energy resource in the world, in the production of electricity and meeting the need for electricity by applying this technology on buildings is discussed. Examined the solar energy potential in Turkey within the scope of the study, the structure of photovoltaic panels, working principle, by considering the types, design principles of photovoltaic systems were examined. In addition, applications on buildings, design criteria and system dimensions of these applications are examined. The current standards and regulations regarding the use of photovoltaic systems in buildings are examined, and the problems and recommendations regarding the use of these systems are discussed. As a result of the research, a sample PV system was designed for an office building roof in Dörtyol district of Hatay. When the sample application is examined in terms of cost, it is still possible to perceive PV systems as an expensive electricity generation method today, but when the return percentage is calculated, it turned out that there is a prospective investment. Considering the increase in electricity needs in the world, possible electricity prices in the future and the decrease in PV system costs, it has emerged that PV systems will be economically usable in the near future.

Keywords: Renewable; energy; solar energy; photovoltaic (PV); building industry

ÖZET

Bu çalışmada sonsuz enerji kaynağı olan güneş enerjisinin elektrik enerjisi üretiminde kullanımı ve bu sistemin binalara uygulanmasıyla elektrik ihtiyacının karşılanması konusu ele alınmıştır. Çalışma dahilinde Türkiye'deki güneş enerjisi potansiyeli incelenmiş, fotovoltaik panellerin yapısı, çalışma prensibi, çeşitleri ele alınarak, fotovoltaik sistemlerin tasarım esasları incelenmiştir. Ayrıca binalar üzerindeki uygulamalar, bu uygulamaların tasarım ölçütleri ve sistem boyutlandırmaları irdelenmiştir . Fotovoltaik sistemlerin binalarda kullanımıyla ilgili mevcut standartlar ve yönetmelikler incelenip, bu sistemlerin kullanımına ilişkin ortaya çıkan sorunlar ve önerilere değinilmiştir. Araştırmaların sonucunda Hatay'ın Dörtyol ilçesinde bir ofis binası çatısına örnek bir FV sistem tasarlanmıştır. Örnek uygulama maliyet açısından incelendiğinde FV sistemlerin günümüzde halen pahalı bir elektrik üretim yöntemi olarak algılanması mümkündür fakat geri dönüş yüzdesi hesaplandığında ileriye dönük yatırım olduğu ortaya çıkmıştır. Dünyadaki elektrik ihtiyacı artışı, gelecekte artması muhtemel elektrik fiyatları ve FV sistem maliyetlerindeki azalma göz önünde bulundurulduğunda yakın bir gelecekte FV sistemlerin ekonomik anlamda kullanılabilir olacağı ortaya çıkmıştır.

Anahtar Kelimeler: Yenilenebilir; enerji; güneş enerjisi; fotovoltaik (FV); yapı sektörü

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LIST OF ABBREVIATIONS

A:	Ampere
A-si:	Amorphous Silicon
AC:	Alternating Current
AR-GE:	Research and Development
BAPV:	Building Applied Photovoltaics
BIPV:	Building Integrated Photovoltaics
° C:	Celsius Degree
Cds:	Cadmium Selenide
CdTe:	Cadmium Tellerium
CIS:	Copper Indium Diselenide
Cu2S:	Copper Sulfide
DC:	Direct Current
EU:	European Union
Ga:	Gallium
GaAs:	Gallium Arsenide
GW:	Gigawatt
I:	Current
IEC:	International Electrotechnical Commission
ISO:	International Standardization Organization
J:	Joule
° K:	Kelvin Degress
Kcal:	Kilocalories
Kw:	Kilowatt
KWh:	Kilowatt-hour
BC:	Before Christ
MTEP:	Million Tons of Equivalent Oil
MW:	Megawatt

N2O: Nitrous Oxide

NiCd: Nickel Cadmium

PV: Photovoltaic

Si: Silicium

TEDAŞ: Turkey Electricity Distribution Company

TSE: Turkish Standards Institute

TUBİTAK: The Scientific and Technological Research Council of Turkey

USA: United States of America

V: Volt

W: Watt

CHAPTER 1
INTRODUCTION

Most of the energies we use today are fossil-based energy systems, and they are rapidly depleted sources that, due to their use, harm the environment to a great extent. The most important of these energy sources are coal, oil and natural gas. The CO2 released by the burning of fossil sources leads to the warming of the atmosphere, increasing the greenhouse gas, and thus climate change. In addition, it has impacts such as Global warming, pollution of water and soil, damage of vegetation, acid rains, desertification and biological diversity. Accordingly, human health is negatively affected. It is an inevitable fact that these energies are not endlessly sourced, but they will be consumed in the near future. Industrial systems based on fossil-based technologies will also become inoperable. The results of this may be big enough to affect the whole world economy (Yücel, 2016).

The need for energy in the world increases every year. However, the fossil fuel reserve that meets this need is decreasing much faster. Even the most positive views suggest that oil reserves will be drastically depleted and will not meet needs between 2030 and 2050 at the latest. A similar situation exists for coal and natural gas. (Yücel, 2016).

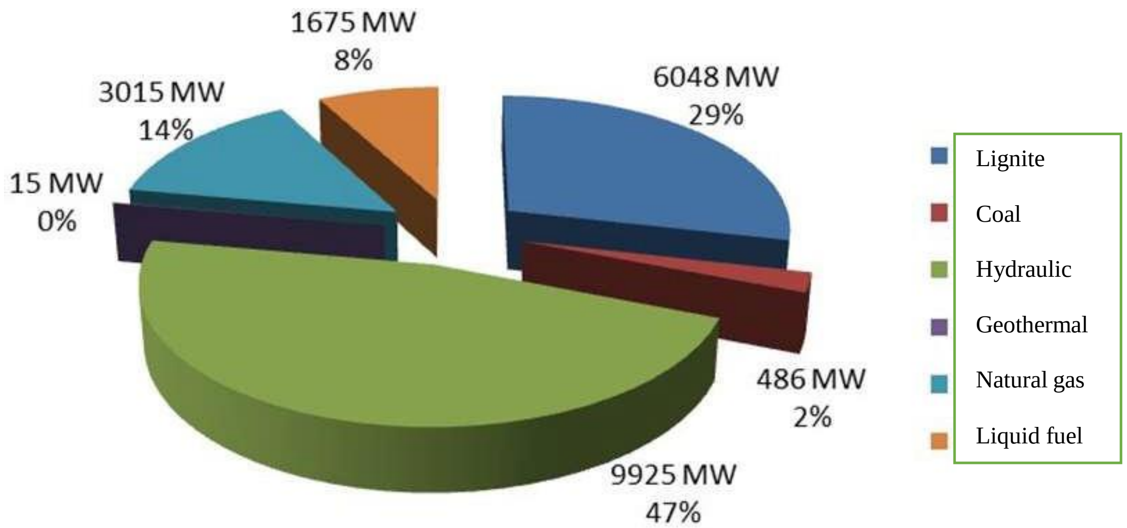

Figure 1.1: World fossil fuel reserve ratios (Yücel, 2016)

This has resulted in an obvious increase in natural disasters such as floods and storms that cause millions of dollars of damage outside of intense air pollution. In many islands of the world that are already at sea level, settlements have been evacuated due to melting glaciers and rising water levels. If no action is taken as soon as possible, this will cause even more serious damage in the near future. Therefore, one has to turn to clean energy resources without waiting for the end of fossil fuel reserves (Yücel, 2016).

Water, wind, solar, liquid fuels and hydrogen technologies, which we can count among renewable energy sources, have become more important day by day. Solar energy is considered to be extremely important among these energy sources. In the past two decades, solar technology has developed rapidly, both the thermal applications of solar energy and the applications for obtaining electricity have accelerated promising for the future. Turkey's used in a very high level, domestic, renewable "Clean Energy" has potential. When this energy potential is used correctly, foreign dependency in energy and the use of energy types that pollute the air and produce emissions will cease (Yücel, 2016).

Considering the current environmental and energy problems, an effective way to utilize natural energy sources other than fossil sources is to use renewable energy sources. Solar energy is the first source that comes to mind as a renewable energy source. Photovoltaic (PV) systems that utilize solar energy are among the most promising renewable energy sources in the world. We need to make maximum use of solar energy, which we can call continuous energy.

In this thesis, the integration of solar and solar energy, solar cell structure, photovoltaic systems and their features, photovoltaic systems, which we can also use as a design tool in architecture, to architectural elements (roof, facade and building elements) are examined. A sample design has been made for roof application in Dörtyol district of Hatay. Standards, regulations and regulations related to the subject have been researched. With this study, it was aimed to draw attention to the possibilities of using solar energy in our country, especially in the field of architecture, and to make a contribution not to ignore this information in the new building designs to be made. It is aimed to develop suggestions on the subject.

1.1. The Aim of The Study

Today, energy is consumed in every action that takes place in the world. Most of these energies come from finite (irreversible, consumable) energies. The extent of the damage caused by the burning of consumable energies has reached levels that threaten human health. It is known that the energies that are the alternative of this situation exist in nature. It is now compulsory to take advantage of these energies, the harm of which is negligible.

While buildings use 50% of the energy consumed in the world, it is unacceptable that architecture remains insensitive to it. Developed countries are continuing their efforts to benefit from renewable energies within this sensitivity. Turkey has a very high level of utilization of solar energy facilities due to geographical location. However, in order to benefit from this situation, studies are limited only to the studies of the relevant departments of universities and some state institutions (AR-GE).

In this thesis, pv systems that are of great importance in terms of energy efficiency; It is aimed to develop an approach for use in buildings. In the renovation of the roof systems of existing buildings as photovoltaic roof systems and in the design of photovoltaic roof systems in new buildings; is to develop a model proposal that can guide architects, roof system and roofing material manufacturers and contractors.

1.2. Scope of The Study

Architecture has a mission that guides societies. Therefore, the duties of architects are increasing day by day against environmental problems. Recognition and dissemination of ecological buildings and the efficient use of energy in the design and production of these buildings; It will integrate society with the natural environment, and will bring a permanent solution to environmental and resource consumption problems.

Within the scope of the thesis study prepared, in the first part; By giving an overview of the subject, Global energy problem, fossil energies and environmental effects are explained. referring to the importance of energy, it is emphasized that the solar energy from renewable energy sources and PV systems have great potential for Turkey.

In the second part; the structure of the sun, solar energy, solar energy transformations and the usage areas of this energy have been investigated. And historicial development of solar energy potential in Turkey is examined.

In the third part; definition of photovoltaic systems, their historical development and their place in renewable energy, their components, importance, advantages and disadvantages. Then, the structure, types and working principle of solar cells are examined.

In the fourth part; usage possibilities of photovoltaic systems in buildings are examined and the design criteria of the system are examined.

In the fifth part; current standards, regulations and regulations regarding the use of photovoltaics have been investigated.

In the sixth part; problems encountered in applications and suggestions regarding the use of photovoltaic systems in buildings are explained.

In the seventh part; application methods for add-on photovoltaic systems to buildings have been investigated.

In the eighth part; an example photovoltaic system was designed, analyzed and presented on the roof of an office building in Dörtyol district of Hatay.

In the conclusion part, by evaluating all the information put forward, utilizing solar energy in buildings; especially in terms of Turkey, it emphasized the importance and necessity.

1.3. Working Method and Plan

First of all, after a general research and literature review, the studies of the researchers related to the subject were examined and the subject and scope of the thesis study were determined.

After determining the subject of the thesis; Books, theses, symposium papers, scientific articles and information on the internet about fossil energy sources, renewable energy sources and types, the amount of energy consumed in the building sector or the possibilities of using solar energy in buildings were examined in detail.

In order to provide the necessary information, data and statistics for the sample design, Energy Systems Engineer Aydın Danacı (Solar-El Enerji) and Electrical-Electronics Engineer Selahattin Akay (Rant Enerji) were interviewed and the documents were collected. By gathering information from all these sources, the thesis is divided into certain sections and arranged. Using the numerical data, tables, pictures are used in a certain order and the possibilities of using solar energy in the structures are explained with examples.

CHAPTER 2
SOLAR AND SOLAR ENERGY

2.1. Structure of the Sun

The sun is a mass of gasand emits heat and light. Its temperature is quite high. The sun is approximately 150 million kilometers from our earth (Muhtaroğlu, 2012). The sun, which is compulsory for the continuity of live life, is the world's main energy source. It started to shine approximately 4 600 000 000 years ago (Akgün, 2006).

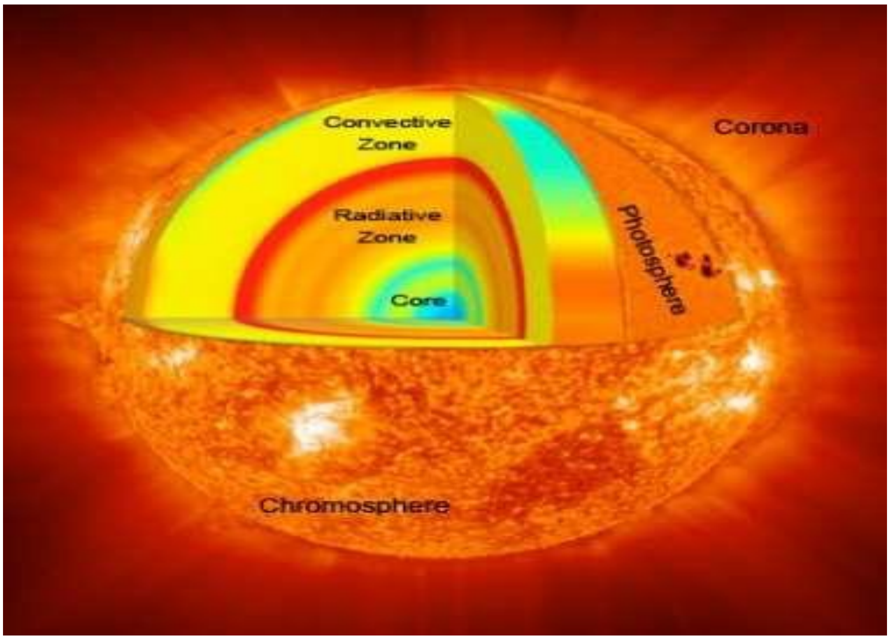

Figure 2.1: Structure of the Sun (UCAR, 2012)

The Sun is one of about one hundred billion stars in the galaxy, called the Milky Way, which has a radius of 7x105 km and a mass of 2x1030 kg, and is 110 times the size of the world with high temperature and high pressure. (Figure 2.1) Like every Star, the sun is formed as a result of the gravity of the substances that make up it. The surface temperature of the sun is about 6000 ^{o} K and the temperature in the inner regions varies between 8x106 ^{o} K and 40x106 ^{o} K (Yücel, 2016).

Table 2.1: Structural thermal and position properties of the sun (Yücel, 2016)

	Specifications	Value
Structural Features	Mass (kg)	19.891×10^{a} (a=26)
	Volume (km³)	1.412×10^{a} (a=15)
	Equatorial radius (km)	695.000
	Volumetric average radius (km)	696.000
	Ellipticity	0.00005
	Average density (kg / m³)	1408
	Gravity on the surface (m / s²)	274
Chemical Properties	Hydrogen (%)	92.1
	Helium (%)	7.8
	Oxygen (%)	0.061
	Carbon (%)	0.030
	Nitrogen (%)	0.0084
	Neon (%)	0.0076
	Iron (%)	0.0037
	Silicon (%)	0.0031
	Magnesium (%)	0.0024
	Sulfur (%)	0.0015
	Others (62 different elements) (%) 92.1	0.0015
Thermal Properties	Center temperature (ºK)	16.000.000
	Surface temperature (ºK)	6.000
	Total beam power (MW)	3.8×10^{a} (a=20)
Location and Movement Features	Slope relative to ground orbit (º)	7.25
	Speed relative to nearby stars (km / h)	19.4
	Rotation period around its axis (hours)	1609.12

2.2. Solar Energy

The radiant energy released by the fusion process in the core of the sun is called solar energy. The source of this energy is the fusion reaction that occurs as the hydrogen gas in the sun turns into helium. As a result of the conversion of 4 hydrogen atoms of 4.032 unit weight to 1 helium atom of 4.003 unit weight; According to the item energy relation, 0.029 unit mass turns into energy. Accordingly, 564 million tons of hydrogen turns into 560 million tons of helium every second in the sun and the mass difference creates 3.86x1026 J energy. Outside the earth's atmosphere, the intensity of solar energy varies depending on the distance between the sun and the earth and ranges from 1325 to 1412 W / m². The average value, called the solar constant, is 1367 W / m² (Varınca, 2006).

Table 2.2: Some solar dimensions (Yücel, 2016)

Diameter	1.391.980 Km (109 World Wide)
Mass	1.989.100x1024 Kg (333.000 Worlds)
Volume	1.412.000x1012 Km3 (1.304.000 Worlds)
Distance From Earth	Minimum: 147.100.000 Km Average: 149.600.000 Km Maximum: 152.100.000 Km
Central Pressure	2,477x1011 Bar
Center Temperature	1,571x10^7 K
Center Density	1,622x10^5 Kg/M^3
Center Composition	%35h, %63 He, %2 C,N.O…
Age	4,57X10^9 Years

All the energies we use on earth are fossil originated and are consumable energy sources and have reached the point of exhaustion today. The reserve of fossil resources such as coal, oil and natural gas on earth is only 20 days of solar energy reaching the world. The amount of energy emitted to the world in 40 minutes from the sun is as much as the amount of energy that human beings consume in a year. Energy reaching the earth in one day is equal to the total energy consumed in the world for 27 years. The energy that reaches the world from the sun by way of radiation is 10,000 times the energy consumed in the world in a year (Yücel, 2016).

Everywhere on earth does not receive the same amount of sun. The region that receives the sun's rays on the earth for the longest time and at a near-angle angle is the part between the Tropic of Capricorn shown in Figure 2. 2. and Tropic of Cancer. Energy coming from the sun to the Earth changes both daily and throughout the year. As the world rotates around itself and around the sun, solar energy is in different amounts in different regions (Muhtaroğlu, 2012).

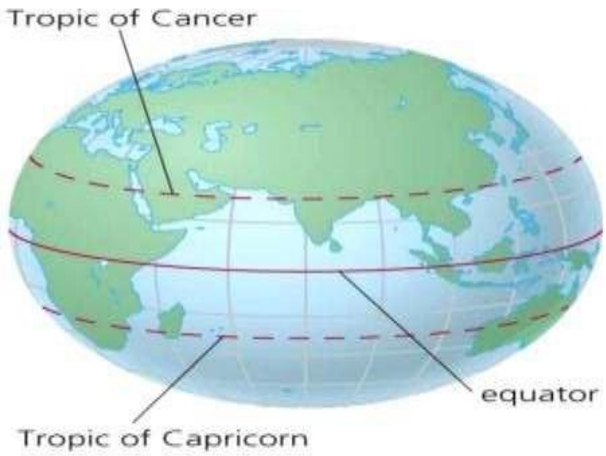

Figure 2.2: The shape of the earth and the circles (SuttaNews, 2018)

In order to make the best use of solar energy, it is necessary to be located in the region called "Solar Belt", between 45º north-south latitudes (Karamanav, 2007). The use of solar energy means using light, a form of electromagnetic radiation. Electromagnetic radiation is a kind of wave that transfers energy from place to place, not only light, but radiation that creates forms of microwaves, X-rays and gamma rays. The only feature that distinguishes these forms from each other is the different wavelengths (Keleş, 2008).

Studies on solar energy utilization have gained momentum especially after the 1970s, solar energy systems have shown a technological progress and a decrease in cost, and have established themselves as an environmentally clean energy source. Although solar energy technologies vary widely in terms of method, material and technological level, they can be divided into two main groups:

Thermal Solar Technologies: In these systems, heat is obtained primarily from solar energy. This heat can be used directly or in electricity generation.

Photovoltaic Solar Technology: Semiconductor materials called photovoltaic cells convert sunlight directly into electricity (Makine Mühendisleri Odası).

Solar energy is mostly used for heating, cooling and hot water in buildings. Use to obtain hot water is the most common form of use. Use for heating will become more efficient with the development of heat storage techniques. Cooling, on the other hand, is efficient in regions where annual sunshine time is long (Karamanav, 2007).

A second type of application is photovoltaic applications using solar cells. Solar cells that directly convert the solar radiation falling on it into electrical energy produce direct current. By connecting these batteries in series or in parallel, the current and voltage values they produce can be increased. An accumulator is required to store the current produced. Solar cells started to be developed for space programs; However, in the following years, it was started to be used in places such as lighthouses, forest observation towers, farm houses, chalets, which are difficult to generate electricity by known ways, or are far away (Karamanav, 2007)

Features of solar energy: Research aimed at replacing increasingly depleted energy sources accelerated especially in the second half of the 20th century. While seeking utopian exit points, such as the equal distribution of existing resources to the world population, on the one hand, ways and methods are developed to replace the natural and organic resources with artificial ones. This second starting point has forced technology to force man to explore the natural resources of other planets. Searching for exhausted resources has resurfaced solar energy response in environmental design. We can list the features of solar energy as follows; Solar energy is a pure energy type. It has no harmful substances such as gas, smoke, dust, carbon or sulfur.

- Sun is an energy source that all countries of the world can benefit from. In this way, countries' energy dependencies will disappear.
- Solar energy is a type of energy that will be used continuously, which does not require any payment to the resource other than the facility and maintenance costs.
- The biggest feature of solar energy is that it is decentralized, in other words, it can be provided anywhere without any transportation expenditure. Although there is a little difference in efficiency in places that see the sun more or less, it is possible to benefit from this energy in the valleys or plains on the hills of the mountains.

- Solar energy is excluded from the effects of any crisis that may arise. For example, a bottleneck that may arise in transportation networks and a change in the defense strategies of countries will not affect this type of energy.
- Solar energy does not require any complicated technology. Almost all countries can easily reach this energy thanks to local industrial organizations. (Keleş, 2008).

Solar cells started to be developed for space programs; However, in the following years, it was started to be used in places such as lighthouses, forest observation towers, farm houses,) chalets, which are difficult to generate electricity by known ways, or are far away (Karamanav, 2007.

2.3. Solar Energy Transformations

Approximately 30% of the energy coming from the sun goes back into space with reflection and scattering. Approximately 20% of the air is absorbed in the sphere. The remaining 50% of the incoming energy is absorbed on the earth. Solar energy reaching the earth is used with natural and artificial transformations (Yücel, 2016).

Natural transformations;

- Soil and water warming
- Photosynthesis
- Water cycle
- Wind and wave formation
- It is listed as natural fires.

As a result of the evaporation of water, the water cycle in the world is provided, this event is very important for all living things. Plants do photosynthesis using solar energy. As mentioned earlier, temperature differences resulting from different dispersion of solar energy cause pressure differences. This creates the wind. Sea waves and ocean currents also occur under the influence of the wind (Muhtaroğlu, 2012).

Artificial transformations;

- Solar radiation (heat - collectors)
- Solar radiation (electricity - solar cells)
- Water power (electricity-dams)
- Wind (electricity - turbines)
- Biomass (heat, gas and liquid fuel)
- Fossil fuel (electricity and heat)
- It is diversified as solar architecture applications.

Artificial transformations are developed by human beings (Muhtaroğlu, 2012).

Table 2.3: Solar energy transformations (Yücel, 2016)

Natural Transformations	**Artificial Transformations**
• Soil and water heating • Photosynthesis • Water cycle • Wind and wave formation • Natural fires	• Solar radiation- heat (collectors) • Solar radiation - electricity (solar cells) • Water power - mechanical - electricity (dams) Wind - electric - mechanical (turbines) • Biomass - heat - gas and liquid fuel (biological, chemical and thermal chemical transformation) • Fossil fuel - heat – electricity (electricity and heat production centers) • Solar architecture applications

2.4. Uses of Solar Energy

Today, the areas of use of solar energy start from residences during daily life, they are used in communication, agriculture, industrial sector, power plants, military field and space. Solar technology is mainly based on low temperature and high temperature applications, thermal and solar thermal applications, photo synthetic and photochemical processes (Sağlam, 2000).

We use solar energy in many areas today. It is used for heating, cooling and lighting of houses, from cooking to providing hot water, heating pools and agricultural technologies, heating greenhouses and drying agricultural products. In industry, salt and fresh water production from sea water, solar pumps, solar pools, heat pipe applications; It is widely used in transportation and communication tools, signalization and automation, aerospace industry and many other fields (Yücel, 2016).

2.5. Turkey's Solar Energy Potential

Turkey, the opportunity to use depending on the angle of incidence of solar radiation on Earth is quite high, is located on the sun belt. Our country, which provides a significant part of its energy need by import, needs to utilize the solar energy that is inexhaustible, free, has no transportation problems, does not create environmental problems and air pollution. For this, there is a need for economic systems that will convert the radiation from the sun into the most efficient type of energy available (Sağlam, 2000).

Turkey location as solar intensity and duration of sunshine is among the highest countries. Especially Southeast, Central Anatolia, Aegean and Mediterranean regions are rich in solar energy potential. Turkey's solar map in Figure 2.3 shows. Orange colors show the provinces with the highest solar energy density. The Black Sea region is the weakest settlements in terms of solar yield (Makina Mühendisleri Odası).

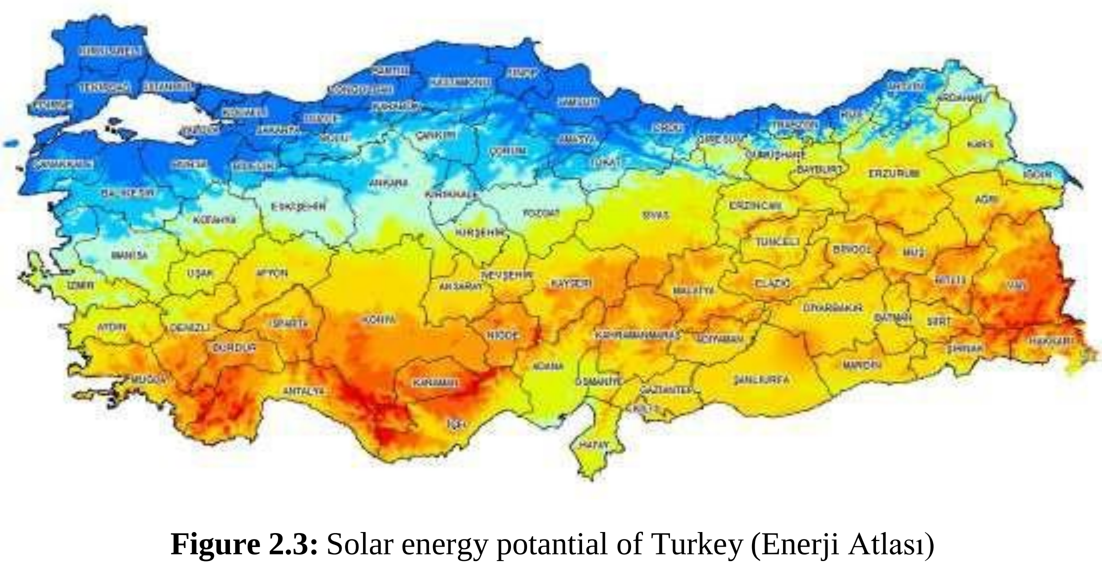

Figure 2.3: Solar energy potantial of Turkey (Enerji Atlası)

Our country is fortunate compared to many countries in terms of its solar energy potential due to its geographical location. According to the study conducted by General Directorate of Electrical Affairs; Turkey's average annual sunshine time of 2640 hours (7.2 hours per day total) average total solar radiation is 1311 kWh / m^2-year (daily total of 3.6 kWh / m^2) has determined that it is (Yucel, 2016).

Solar energy potential of Turkey and sunshine duration values by months is given in table 2.4.

Table 2.4: Breakdown of Turkey's total solar energy potential of the moon (Yucel, 2016)

Months	Sunbathing Time (hours / month)	Monthly Total Solar Energy	
		(KWh / m2 month)	(Kcal / cm2 month)
January	103,0	51,75	4,45
February	115,0	63,27	5,44
March	165,0	96,65	8,31
April	197,0	122,23	10,51
May	273,0	153,86	13,23
June	325,0	168,75	14,51
July	365,0	175,38	15,08
August	343,0	158,40	13,62
September	280,0	123,28	10,60
October	214,0	89,90	7,73
November	157,0	60,82	5,23
December	103,0	46,87	4,03
Total	2640,0	1311	112,74
Average	7,2 hour / day	3,6 KWh / m^2 day	308,0 cal / cm^2 day

Turkey's biggest area of solar energy is the South East Anatolia Region, followed by the Mediterranean Coast. The distribution of solar potential and sunshine duration values by region is also given in Table 2.5.

Table 2.5: Total annual Turkey's regional distribution of solar energy potential (Yucel, 2016)

Regıon	Total Solar Energy (Kwh/M2-Year)	Solar Tıme (H / Year)
South-East Anatolıa	1460	2993
Medıterranean	1390	2956
Eastern Anatolıa	1365	2664
Central Anatolıa	1314	2628
Aegean	1304	2738
Marmara	1168	2409
Black Sea	1120	1971

Accordingly, Turkey as well as the overall most and the least solar energy will be produced in the months of June and December is. Southeastern Anatolia and Mediterranean coasts are among the regions. Except for the Black Sea region, where solar energy production is almost non-existent, 1,100 kWh of energy can be produced per square meter per year and the total amount of sunny hours is 2,640 hours (Özsoy and Acar, 2017)

However, these values are lower than Turkey's real potential, it was later found by studies. Since 1992, General Directorate of Electrical Affairs and General Directorate of State Meteorology Affairs, have been taking solar energy measurements for the purpose of measuring solar energy values in a healthier manner. As a result of ongoing measurement studies, 20-25% of the former value of Turkey's solar energy potential is expected to rise further (Yücel, 2016).

Looking at the country by country in the world solar power installed capacity ratio, although more sunny days number compared to other countries, Turkey, in November 2017 as as installed capacity has a potential of 2,246 MW and is located in 15.sıra. Countries that attach importance to the use of solar energy such as China, Japan and Germany share the top 3 in terms of installed power potential (Yılmaz and Öziç, 2018).

Turkey is located at 42- 36 degrees North latitude. The amount of solar energy falling on its surface is 977 x 1012 kWh. Its technical potential is estimated as 500 MTEP / year and its economic potential as 25 MTEP / year. However, the solar energy potential of the country is not used effectively and widely enough in electricity production (Tuncay, 2003).

However, despite working on solar energy in Turkey is quite a long time. Efforts are underway to utilize solar energy in public institutions and foundations and in some universities and related foundations and associations. TSE has started to raise the standards regarding solar energy. In addition, the first solar car race organized by TÜBİTAK was held in 2007 and it is planned that these competitions will be repeated. Regarding the subject, the first law was enacted on 10.05.2005 with the number 5346 as “Law on the Use of Renewable Energy Sources for the Purpose of Generating Electric Energy”. The Electrical Works Survey Administration continues to determine where the systems developed on solar energy can be applied and the potential determination studies it has initiated to determine the energy that can be obtained (Özek, 2009).

2.6. Historical Development of Solar Energy

2.6.1. History of solar energy use

We can say that the use of the sun as an energy and consciously dates back to 400 BC. Socrates encouraged the houses to look at the sun fronts and made use of heat and light. In 1600's, when Galile found the lens, a different point was reached in the use of the sun. In 1725, a solar powered water pump was invented by Belidor. In this way, a vehicle has been produced depending on solar energy (Ekolojist, 2017).

With the increasing importance of oil, the studies on solar energy decreased considerably during the first world war. Although the researches accelerated again after 1930, the researches did not go out of their institutions. With the advent of the oil crisis until 1960, people turned to work on alternative energy sources. These studies focused mainly on solar energy (Yücel, 2016).

2.6.2. History of solar energy use in Turkey

In our country in the early 1960s, solar energy was understood as an alternative energy source for the first time, and some studies were started on this subject with the theses given at universities and the theses. In the mid-1970s, in parallel with the developments in solar energy technologies in the world, the thermal applications of solar energy gained importance in our country and the studies in this field increased (Yücel, 2016).

Solar energy for use in the invention and has gained importance in Turkey. Since it is an independent energy source, it is important for countries to benefit from this energy. The first national congress of solar energy in Turkey took place in 1975. Prior to this, it was in 1960 that this energy was accepted as an alternative energy source. Since then, studies have increased and the knowledge and activities in this field have increased with the studies of experts and universities. The increasing importance of solar energy in terms of government and industry have increased interest in this field in Turkey (Ekolojist, 2017).

On the other hand, the electrical works survey office also provides studies on solar energy water heating, active and passive heating, condensing collectors and solar cells. This organization is responsible for the development of solar and wind energy, which is a renewable energy source (Kapluhan, 2014).

CHAPTER 3
PHOTOVOLTAIC SYSTEM AND ITS CHARACTERISTICS

3.1. The Place of Photovoltaic Applications in Renewable Energy

Because of the fact that fossil fuel reserves are going to run out in near future and it gives unatoned damage to the environment; wind, solar, biomass, wave, hydrogen etc. sources of energy which are eco-friendly renewable energy sources should be at the forefront of every country's policy.

The solar energy technology which is the most suitable in terms of scalability and fuel obtainment became the first preference of people with 70.5 % according to the energy trendy research in the research of KONDA Research and Consulting firm in January, 2018 (KONDA, 2018).

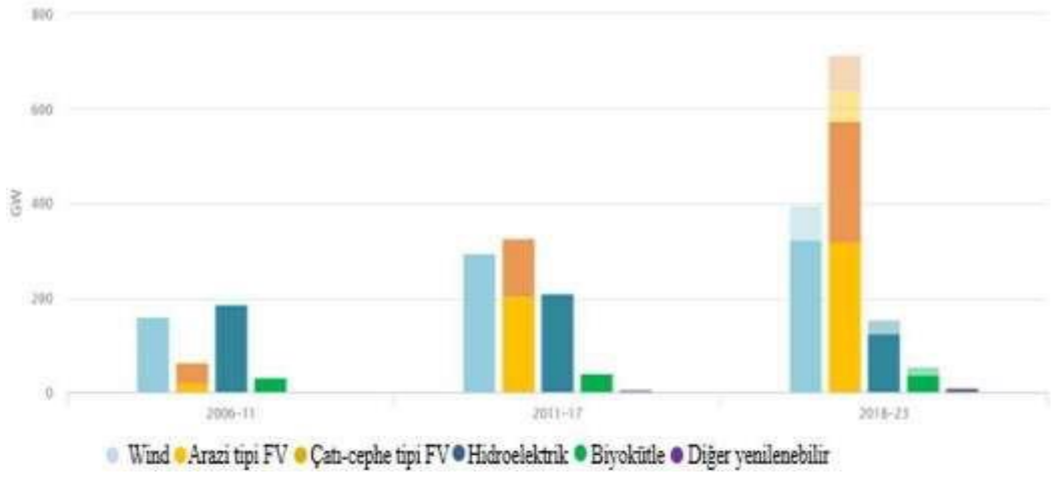

Figure 3.1: Renewable energy capacity status and prediction (KONDA, 2018)

3.2. Historical Development of Photovoltaic Systems

Solar cell is manufactured with semiconductors which are used in computer operators. Solar cells are the systems that produce direct electicity by the absorption of the sun ray in the surface of board. In a nutshell, electric manufacture is that the photons are creating an electric current by striking the material in the solar battery and snatching the electrons which are attached weakly to the materials, from its orbit. Photovoltaic effect (the physical case which lets the light to turn into electric energy) was discovered by French physicist Alexandre Edmund Becquerel in 1839 (Mutlu,2010).

Becqerel found the photovoltaic case as a result of his researches in 1839.In consequence of the voltage that electrodes produce, the voltage on electrolyte decreases. Correspondingly its effect to the light is examined. The productivity of photovoltaics were %1.In 1954 for the first time its productivity increased to %6.Afterwards solar cells are began to be used in aviation and space sector (Durgut 2014).

Due to the decrease of the effects of the oil shock and traditional energy-producing system's being economic, the interest on photovoltaics decreased. In time cells' productivities were increased. Several institutions were encouraged by the government's support about the useage of photovoltaics. The first photovoltaic power plant was built in Pellworm island in 1983.Renewable energy sources became a currents issue with the incident in Chernobly nuclear power plant in 1986 in terms of its positive environmental impact. In 1986 ARCO Solar firm relaased the first thin-film photovoltaic cell. In 90's full-scale companies started to become the producer of photovoltaic.

Photovoltaic systems, are used suitable in terms of economy especially in the settlements that haven't got grid circuit. Thats why implementations like signalization, rural electric need's providing are quite coomon. Besides photovoltaic useage is on the front burner for the buildings which makes photovoltaic useage more economic. Because in this implementations an additional land, construction foundation and load-bearing system aren't needed consequently it reduces the cost. The firm in building sector, especially glass industry, supports coalescing photovoltaics with the buildings. Framework industry also develops particular photovoltaic components and systems. As the photovoltaic compenents thar can be used in buildings diversifies, oppurtunities of use and consequently its systems diversifies. Photovoltaic installed capacity reached to 1 MW mostly in Ministery of forestry forest observation towers, Türk Telekom, lighthouses and highway lighting, general directorate of electrical power resources survey and development administratition, Muğla university, Ege university on the purpose of supplying tiny powers and research (Mutlu,2010).

Chronogıcal Development;

- In 1839, Alexander Edmond Becquerel who is applied physics professor in Paris museum of natural history discovered photovoltaic incident by observing the voltage between electrodes that are submerged within electrolytes.
- In 1873 with the help of Becquerel's practices Willoughby Smith produced the first simple solar cell(photovoltaic).
- In 1876 a similar incident observed for the first time on selenium crystal by G.W. Adams and R.E.Day.
- In 1887 Heinrich Rudolf Hertz ultraviolet light's effect on photovoltaic was analyzed.
- In 1904 Alberst Einstein published an article about power generation by sun's effect.

In the later years the studies were about phoiodiode that are based on copper oxide and selenium's useage of light meters mostly in photography field. The prominent name in these years is Wilhelm Hallwachs.

- In 1914 the productivity of photovoltaic diode's reached to %1.
- In 1932 Audobert and Stora discovered a method in photovoltaic by using Cdmium-Selenedi(CdS)
- In 1954 Pearson and Fuller discovered silicium's effect on phorovoltaic. Thus photovoltaic diode that converts solar energy to electric energy with %6 productivity. That year has been accepted as a milestone for photovoltaic power systems.

In the later years researches and the first designs were made for the power systems that were going to be used in spacecrafts.

- In 1958 photovoltaic were used in a space craft named Vanguard 1 for the first time.
- In 1961 United-nations "Solar energy conference" was held.
- In 1967 photovoltaics were used for SOYUZ I satellite to provide energy.

- In 1973 the researches about photovoltaic's being used as electical power system were put on the fast track by giving the importance to search alternative sources in the following years of 1.Petroleum crisis.
- In 1980 Cu2S/CdS technology that works with %10 productivity was developed.
- In 1988 uni-junction photovoltaic was developed wit %17 productivity by solar energy implementing agency in USA.
- The productivities of photovoltaics increased to %24 in 2000 , %26 in 2002 ,%27 in 2005 and %30 in 2007.
- In 2009 the productivity of photovoltaics broke the world record by rising to %43 with the research made by New South Wales university's photovoltaic reseachers (Muhtaroğlu, 2012).

The mission of researching and developing simple, eco-friendly photovoltaic systems and converting solar energy into electrical energy has been a task that universities have been loaded and executed for many years and therefore remained as a work that remains in the laboratory in the public. However, due to the increase in environmental awareness in the world over the past decades, public pressure has forced large multinational companies to work on new and renewable energy sources that are not fosil-based.

With the introduction of large companies, technological advances in photovoltaic batteries and the increasing demand for power system, and the growing production capacity accordingly, brought a rapid decrease in costs. Photovoltaic power systems which are consider as a very expensive system when using conventional electrical energy production methods until recently are now considered as systems that can contribute to power generation in the near future. Photovoltaic systems can be evaluated more economically that fosil-based systems, especially considering the social cost that can be considered as an invisible cost that is not taken into account in the electrical energy production (Karamanav, 2007).

3.3. Defining Photovoltaic Systems

“ PV” is the abbrevation of the world photovoltaic.”Photo” means light and “voltaic” means electricity. The term photovoltaic; is used to convert sunlight into electrical energy by solar cells. A properly designed phtovoltaic system can generate megawatts of electricity with little light. It does not require any operating fee, energy source, noisy machines and generates electicity only by sunlight without air pollution (Gemicioğlu, 2011). Photovoltaics produce DC (direct current).This electricity;

- Devices operating directly with DC power
- DC is stored for later use
- AC (alternating current) is converted and used in devices working with this current.

Photovoltaic systems are tools used to provide electrical energy directly from sunlight. Photovoltaic panels, the most important element of photovoltaic systems, consist of cells. Cells are the elements that convert solar energy into electrical energy through the photovoltaic effect (İdman, 2018).

Photovoltaic (PV) effect; It is the electrical potential that occurs between the common junction of two different materials exposed to solar radiation (buffer zone between the electronic and p and n type doped materials side by side). This effect was found by the French physicist Becquerel in 1839 (Özek, 2009).

Photovoltaic systems are silent and vibration-free, with no moving parts. They do not require cooling or tall towers. Each cell placed facing the sun first consumes a few kWh of energy and then starts generating kWh. The first applications of photovoltaic cells began with the use of power for satellites and other spacecraft, and many applications were later developed for small home appliances (İdman, 2018).

Photovoltaic panels can generate electricity at the targeted power value depending on the power of the installed system. The panels have an average commercial efficiency of 5% 20% in today's conditions. In addition, a record yield of 46% was achieved as a result of the work in the last laboratory environments (Durak, 2016).

3.4. Solar Cells

Photovoltaic is the name given to technology that can generate electrical energy directly from special semiconductor assemblies illuminated by photons. The devices designed to obtain direct electricity from solar energy with photovoltaic technology are called solar cells. Today, solar cells have wide usage areas (Karakan and Oğuz, 2015).

The trent towards renewable energy sources is increasing day by day. One of the most important reasons for this is the ability to generate electrical energy without harming the environment. Solar energy is also a renewable energy source and has been used in most applications recently. The main element that forms solar energy systems are solar cells, also called photovoltaic (PV) batteries. PV batteries are highly preferred for their longevity, easy electrical power generation and environmental protection (Okumuş, 2016).

In order to increase the power output, a large number of solar cells are mounted on a surface by connecting them in parallel or in series, this structure is called solar cell / module or photovoltaic module. Depending on the power demand, the modules are connected to each other in series or in parallel and a system is created to generate power from a few Watt to Megawatts (İdman, 2018).

Solar cells are the most basic unit of PV systems. These cells are connected in series and in parallel, forming PV modules, modules joining panels and panels joining sequences (Çelebi, 2002). Figure 3.2 shows schematically PV cell, module, panel and array.

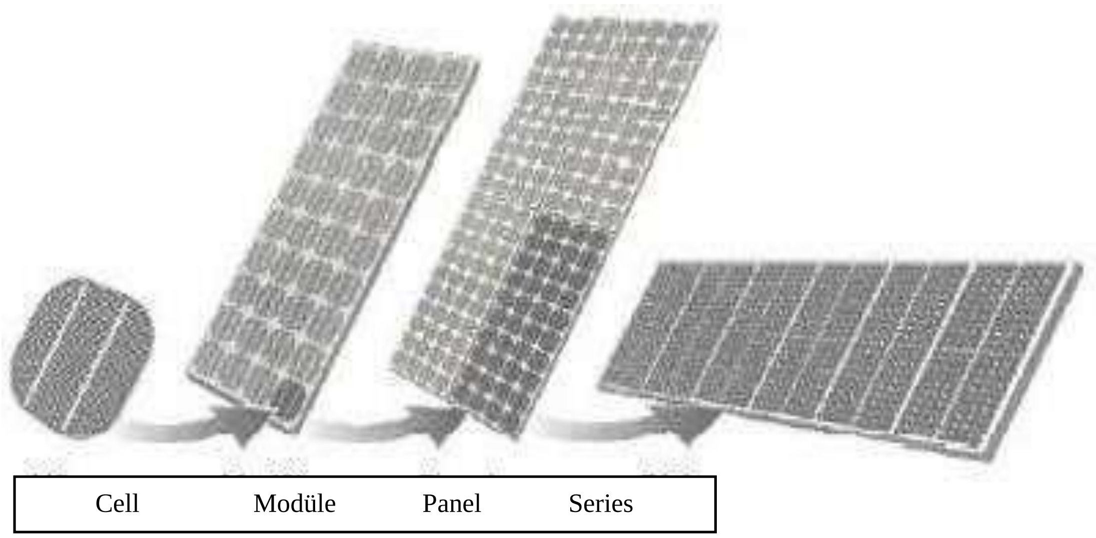

Figure 3.2: Cell, module, panel and array used in pv systems (Çelebi, 2002)

Today, solar cells have wide uses. Especially, the electricity needs of telephone transmitters, lightings and illuminated warning signs in areas remote to the main electricity grid can be met from photovoltaic panels, as well as domestic or industrial energy needs. Today, the establishment of solar power plants with photovoltaic panels and the generation of power plants is becoming widespread (Çolak, 2010).

3.4.1. Structure of solar cells

Solar cells (photovoltaic cells) are semiconductor materials that directly convert the sunlight (photon) coming to their surface into electricity. The solar cells, whose surfaces are shaped as square, rectangular, and circle, are generally around 1m2 and their thickness is between 0.20.4mm. Solar cells operate on the basis of photovoltaic principle, that is, when the light falls on them, electric voltage is created at the ends. Depending on the structure of the solar cell, solar energy can be converted into electrical energy in an efficiency of 5% to 20% (Özek, 2009).

Solar cells are electronic devices that convert sunlight directly into electricity. It consists of materials of electrical nature between a metal such as semiconductor copper and insulating material such as glass. Those working on these semiconductor materials; crystalline silicon is CuInSe2 (CIS) (copper indium diselenide), CdTe, GaAs and Amorphous silicon oxygen. Effectively converting solar energy into electrical energy requires quality semi-permeable layers and a perfect structure in crystal. Crystal surface defects are passivated with high quality coating layers (Bubenzer and Luther, 2003).

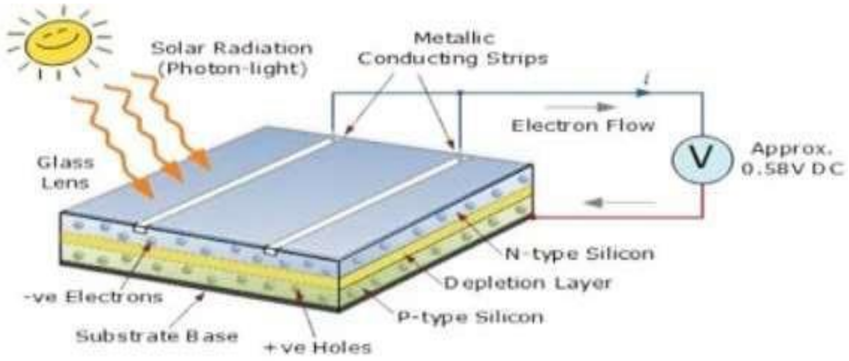

Figure 3.3: Structure of photovoltaic cell (Electrical Engineering 123, 2019)

Solar cells, or solar cells, are a structure made of silicon and semiconductor materials. The upper layer of the solar cell is covered with a layer called ARC that minimizes reflection and absorbs incoming light. After that, there is a protective front contact part. Below that is the n-type layer. This layer was added with a small amount of phosphorus. In this way, a displacement occurs between silicon atoms and phosphorus atoms. This creates negative charges, which is why it is called the n-type. The lower layer contains a p-type silicone layer added with a small amount of boron. The displacement of the silicon and boron atoms also creates positive charges in this layer. The last layer is the back contact made of metal, which increases the cell's durability and closes its back (Leblebicioğlu, 2018).

3.4.2. Working principle of solar cells

Solar cells operate on the basis of photovoltaic principle, that is, when light falls on them, electric voltage is generated at their ends. The source of the electrical energy supplied by the batteries is the solar energy coming to its surface. The radiation intensity at sea level on a bright cloudless day is around 1000 W / M2 maximum. Depending on the region, the amount of solar energy per 1m2 varies between 800-2600 KWh per year. This energy can be converted into electrical energy with a efficiency of 5% -70% depending on the structure of the solar cell (Karamanav, 2007).

Sunlight consists of small energy packets called photons. The photons coming from the sun every minute deliver enough energy to the world for one year's energy consumption. Solar panels, in other words, photovoltaic panels are used to generate electricity using this energy from the sun (Elektrikport, 2013).

Solar cells consist of two layers, positive and negative. These layers consist of N type and P type semiconductor materials. Of these substances, the P-type semiconductor material has one more electron and the N-type semiconductor material has one less electron. The atom of the top layer, which has an excess of electrons in its atomic structure, is stimulated by photons of the sun rays, and the atomic structure in the lower layer tends to advance to an electron-missing layer. When electrons flowing from this upper layer to the lower layer are collected with appropriate circuits, an electric current is created (Duran, 2014).

3.4.3. Types of solar cells

There are many types and types of materials in solar cell making. As technology develops, material derivatives are produced in solar cell production and more and more materials will be produced in the market day by day (Durgut, 2014).

Today, the most used technology in the PV industry is crystal silicon technologies with a share of approximately 90%. While thin film technology dominated 16% of the industry in 2009 and its share in the industry is expected to grow, today this rate has decreased to 10%. Although condensing PV cells, which are within the scope of third generation technologies, are developing rapidly, they have a share of less than 1% in the sector (Özkök, 2015).

The properties of PV panels change according to the material they are made of. Although the efficiency of PV panels varies according to the material used in laboratory conditions, PV panels made of crystalline silicon are preferred in our country. PV panel types and properties are given below (Duran, 2014).

1) ***Crystal silicon solar cell:*** It is a material that is typically semiconductor and is frequently used in solar cell production. Although there are other materials with higher photovoltaic properties, silicon is preferred both for its technological superiority and for economic

reasons. There are different types such as single-crystal, semi-crystal, ribbon and multi-crystal (Okyay, 2010).

a) ***Single-crystalline silicon solar cells:*** In the first commercial solar cells, single crystalline silicon was used, which was enlarged by the "chrozalski crystal drawing technique". In this technique, which is still the most widely used method in the photovoltaic industry, pure silicon is obtained by passing through various chemical and thermal reactions in arc furnaces. Then, a single crystalline silicon part, called the nucleus, is immersed in the silicon solution. After this nucleus is removed from the melt, the cooled silicon melt is stacked in nuggets on the nucleus. This silicon in-ingot is cut into slices with a diamond chisel. It consists of two stages. First, the ingot is cut into rectangular blocks, then these blocks are divided into slices and processed as batteries. Their efficiency is around 15%. The disadvantages of these batteries are the high loss of material during construction (Okyay, 2010).

b) ***Semi-crystalline silicon solar cells:*** This type of battery, also called semi-crystalline, consists of clustered small silicon crystals obtained by cooling the liquid silicon. The efficiency of these batteries is around 14%, due to losses on the borders of the clustered silicon particles (Okyay, 2010).

c) ***Strip silicon solar cells:*** These types of batteries are made from silicon layers in sheet form in order to reduce material loss. These batteries, which are obtained by various methods, are still under development. The efficiency of strip silicon solar cells varies between 13 and 16% in laboratory conditions (Okyay, 2010).

d) ***Multi-crystalline silicon solar cells:*** Although these batteries are also made with ribbon silicon technology, their structures show very crystalline properties. The efficiency of these batteries, which are still in the laboratory stage, is around 10% (Okyay, 2010).

2) ***Thin film solar cells***: In this technique, solar cells with less thickness (1-500 of single crystal thickness) are made using substances with better absorbent properties. For example, the absorption coefficient of amorphous silicon solar cells is higher than the

coefficient of crystalline silicon solar cells. While the wavelength coefficient can be absorbed with an amorphous silicon of 1 micron thickness in a region smaller than 0.7 micron, it is necessary to use 500 micron thick material in crystalline silicon to absorb the same radiation. Therefore, less material is used in amorphous solar cells and provides an advantage due to the ease of assembly (Karamanav, 2007).

Thin film solar cells are formed by using 1-2 micrometers thick semiconductor material placed on top of the layers (Figure 3.4). As a result, solar cell production costs can be reduced. It is also a commercially widespread technology due to its advantages, such as its tendency to mass production, simpler electrical connections between cells, and its tendency to manufacture in large sizes (Koç et al., 2007).

It is generally polycrystalline. However, it is quite thin compared to silicon batteries. Thus, it is easy and convenient to use. In itself; Amorphous Silicon Solar Cell, Cadmium Tellurium Solar Cell, Copper Indium Diseleneid Solar Cell are divided into three (Muhtaroğlu, 2012).

Figure 3.4: Thin film solar cell (Muhtaroğlu, 2012)

a) ***Amorphous silicon solar cell:*** It is a combined semiconductor. It consists of amorphous and silicon crystals. Today, it is a preferred substance for devices with low power requirements and is widely used. Amorphous silicon alloys; It is made using carbon, germanium, nitrogen and tin to change the band gap and material properties and develop highly functional devices. Amorphous silicon absorbs the sun's rays 40 times more effectively than monocrystalline silicones. The film is about 1µm thick. Despite this thin structure, it can absorb 90% of the necessary solar rays. It is economical to make amorphous silicon solar cells because it can be produced at low temperatures, it can be deposited on low cost materials and it can absorb the sun rays in high amounts (Muhtaroğlu, 2012).

b) ***Cadmium tellurium solar cell:*** Cadmium telluride, which is a very absorbent element, can be used as an alloy in photovoltaic devices or it can be used by alloys with elements such as zinc and mercury to change its properties. Different technologies are used in CdTe thin film production. One of these is the sublimation method. In this method, the source on which the temperature differences and the film on which the film grows are kept very close to each other and thus the material grows by sublimation. Another method is electro-precipitation method. CdTe semiconductor grows on the cathode by passing current through the electrolyte carrying cadmium and wires ions. Although this method is quite cheap, the control of the growing material is not as easy as sublimation (Muhtaroğlu, 2012).

c) ***Copper ındium diseleneid solar cell:*** The triple compound consisting of copper, indium and selenium consists of semiconductor material. Two technologies are available for CIS solar cell manufacturing. The first is the vacuum evaporation method. The elements are evaporated in vacuo by pairing. Another method is the method of celination. In this method, the enlarged CIS thin film alloy is reacted with a suitable selection selenium. CIS solar cell has very high absorption. In its layer of 1µm thickness, 99% of incoming light is absorbed. Their efficiency is approximately 14%. Higher efficiency can be achieved by folding the Ga element into these batteries. However, the element increases; It will increase the Cost by making the necessary materials and control complex. It is the basic condition under optimum conditions (Muhtaroğlu, 2012).

Figure 3.5: Copper indium diseleneid solar cell (Muhtaroğlu, 2012)

3) Other cell technologies under development

a) Gallium arsenide (GaAs): Gallium Arsenide is a high cost semiconductor material, but research in this direction has gained momentum as it can convert more than one third of the solar energy to the earth. In the experiments conducted in the early 1990s, the efficiency of the "multiple-junction" device was found to be 30%. In subsequent studies, cell efficiency reached 40% and system efficiency reached around 30-35%. These systems, which are very costly, are currently used in space applications (Koç, et al., 2007).

b) Dye-Sensitized (DSC) cells: Dye-sensitised (DSC) solar technology is a good technology considered with artificial photosynthesis. It performs best with indirect radiation in cloudy weather, temporary or permanent regional shading. Titanium dioxide (TiO2) element is common in DSC technology. The titanium dioxide particles are coated with photosensitive paint and suspended between two electrodes in the solution of iodine ions. Electron passes through titanium dioxide through the paint exposed to light. Along with this, iodine electrons flow to the place emptied in the paint. Thus, an electron current is formed. Its efficiency is around 10%, it is active in different daylight conditions (Keleş, 2008).

c) ***Organic and nano crystalline solar cell:*** Besides dye-sensitized cells, there are also organic / inorganic hybrid cells. It is possible to roughly separate them as molecular and polymer. Very low light absorption of these materials, which have very high light absorption, is sufficient. There is a great competition between organic cells and inorganic cells for use in areas larger than the energy recycling time shorter in organic cells. Organic cells have significant advantages such as low cost, different material options, thin layer thickness compared to inorganic materials. However, in studies conducted since 1999, the efficiency of these cells could only be increased to 3.3% (Yücel, 2016).

3.5. Photovoltaic Systems and Components

Photovoltaic modules are manufactured for outdoor use and are resistant to conditions such as sea conditions, tropical conditions, desert conditions. A photovoltaic module system is created by combining PV panels and complementary equipment to provide the desired current and voltage. The diagram showing the basic working principle of photovoltaic systems is shown in Figure 3.6 (Çolak, 2010).

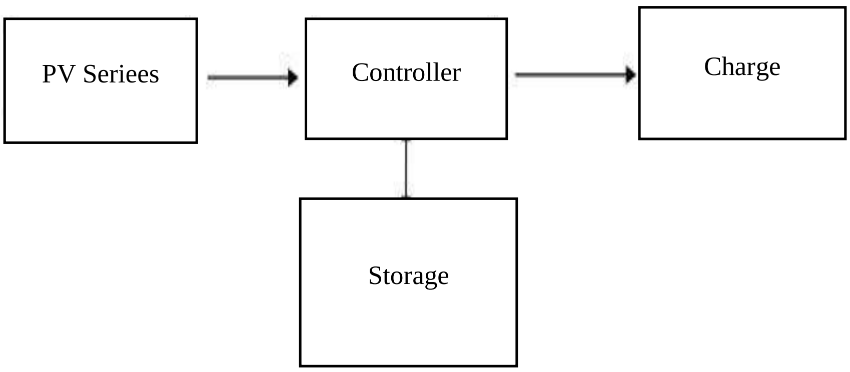

Figure 3.6: Basic working principle of photovoltaic systems (Çolak, 2010)

As previously described, all units and subsystems that generate electricity from sunlight and meet the load are called Photovoltaic (PV) Systems. For a PV system to operate effectively, in addition to PV collectors, many devices must work together in a balanced manner to make the generated electricity available to the load and to distribute this energy. PV systems can be created in many different ways, depending on the characteristics of the energy requirement, economic conditions and network conditions. Regardless of its structure, PV systems, which are expected to provide an optimum efficiency with cost, efficiency, life, repayment, environmental issues and reliability, are basically composed of three sub-systems:

- Collector series where energy generation takes place,
- Area, load, where the generated energy is used,
- Balance system formed by the devices that connect these two systems, that is, to transfer the produced energy to the load (Sakınç, 2006).

Components that make up the photovoltaic system;

1. Solar Panels
2. Batteries
3. Charge Control Units (Regulator)
4. Inverters (Inverters)
5. Other System Components

The solar panel converts the solar energy falling on it into electrical energy as DC. There are batteries that store electricity to be used in situations where the user wants a constant voltage electrical energy or for use in sunless moments. *Charge controllers* are available to balance the input-output voltage values in order to prolong the life of the batteries. These prevent the *battery* from overcharging or discharging. If the user needs electrical energy with AC characteristics, the inverter must use the *inverter*. If DC electrical energy is required, there is no need for an *inverter* (Muhtaroğlu, 2012).

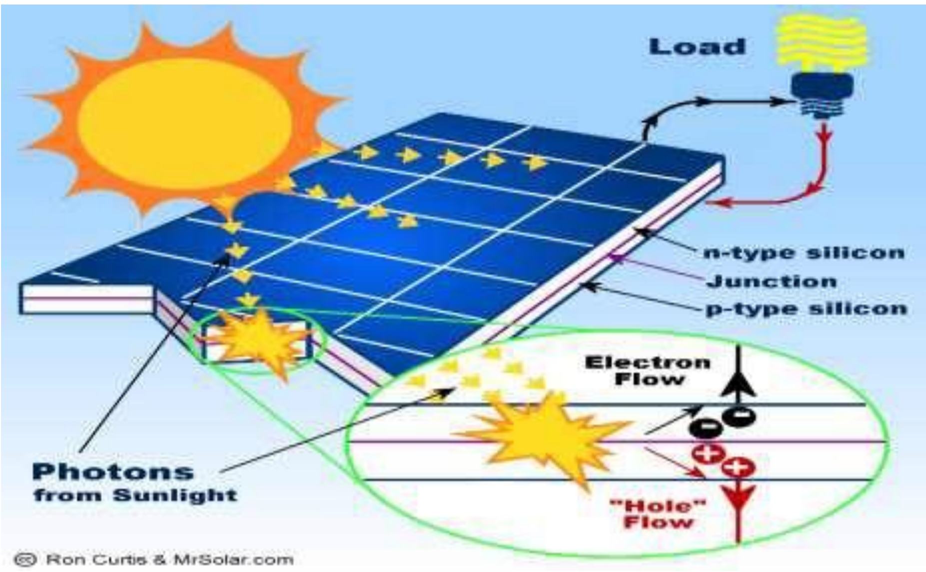

Figure 3.7: Working principle of solar cells (MrSolar, 2020)

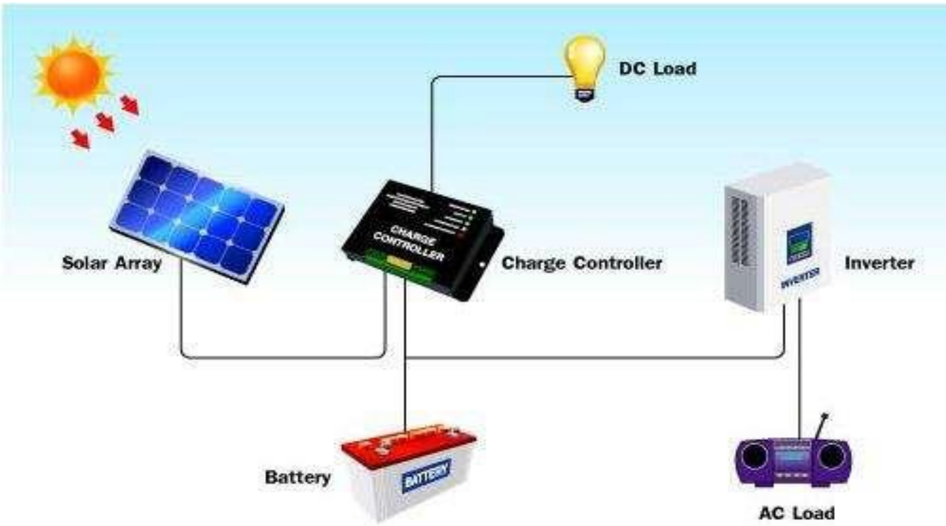

Figure 3.8: Photovoltaic system elements (LEONICS, 2013)

3.5.1. Solar panels

Photovoltaic plates (solar panels), the most important part of a photovoltaic system, convert solar energy directly into electrical energy. The form of converted energy is the correct voltage. Modules are formed with the combination of solar cells, and photovoltaic plates are formed with the combination of modules. The boards can be connected in series to increase the voltage obtained and in parallel to increase the current. In general, several photovoltaicplates are used in small applications. A system of 10-20 panels meets all the electricity needs of a normal house (Kaçar, 2010).

Figure 3.9: Photovoltaic sheets (Kaçar, 2010)

3.5.2. Batteries

Solar energy is not equal at all hours of the day. It depends on the weather and the position of the sun. For this reason, it is necessary to store the energy produced by solar panels for use at night when the sun is insufficient. Photovoltaic systems have batteries to perform this function. Batteries can have two main purposes: short-term and long-term storage, and the storage capacity of the batteries is determined accordingly. Short term storage systems are batteries that store an hourly or daily amount of energy to be used in bad weather conditions. Long-term storage systems are the batteries that store solar energy in the summer period to support solar energy in the winter period. These systems have the energy capacity to be used for several months and their costs are high (Keçel, 2007). In photovoltaic systems, lead acid and NiCd batteries are generally used. Dry type batteries are preferred. Wet batteries have a low cost, but their maintenance requirements are high. Gel type batteries have low efficiency as their loading is slow (Muhatroğlu, 2012).

3.5.3. Charge control units (regulators)

The charge control units (regulator) are between the solar panel and the battery and regulate the voltage. The aim is to protect the batteries from overcharging and discharging. That is, it cuts the current coming from solar cells or the current drawn by the load according to the battery's fullness. Batteries can be damaged when charging with less current. For this reason, it stops loading the batteries until the current rises to the required level. 80% of the batteries are easy to charge. The 20% portion gets harder and harder (Muhatroğlu, 2012). Charge control units are varied according to the desired amount of protection. Circuits providing only protection against overload are low. Some units have temperature sensors and if the temperature of the battery rises above a certain value, it lowers the voltage value. Thus, it prevents damage to the battery (Keçel, 2007).

Main functions of the charge controller;

- Charging and discharging the batteries under the most suitable conditions
- Temperature settings.
- Lightning control, different protection-insurance systems.
- It saves the data from solar panels and sends it to the center with a modem if requested.
- Working efficiently in the range of 5A-150A with minimum power consumption.

3.5.4. Converters (inverters)

PV cells produce direct current energy. This energy needs to be converted to alternating current for use in instruments. Inverters that act as energy converters should be used as low voltage (12-48V) for grid-independent systems, and high voltage (110V and above) for grid-connected systems (Sayın and Koç, 2011).

Solar cells convert solar energy into electrical energy with DC characteristics. Since most of the electronic devices used work with AC, converters (inverters) that convert direct current electricity to alternating current electricity should be added to photovoltaic systems. The converters convert the DC voltage in the accumulator to a sine wave of 220 V and 50 Hz or a square wave. The efficiency and costs of those with square waves are low. Sine wave ones are suitable for grid-connected systems. The costs are high. The cable thickness that makes the connection between the inverter and the battery should be in the range of 5-10 cm. Because a high amount of current passes between these two elements (Muhtaroğlu, 2012).

3.5.5. Other system components

PV systems module, battery etc. it needs other components to produce electricity other than components. These are diodes, wiring, disconnectors, fuses, grounding elements, overcurrent protection elements and mounting parts. The blocking diode is a component that is used to prevent the discharge of the batteries by returning to the system by electricity that goes to the battery during the day (Oluklulu, 2001).

3.6. Photovoltaic System Types

Photovoltaic systems can be constructed independently from the local electricity grid to feed the electrical loads located at distant locations from the residential area, and photovoltaic systems located near the local power grid can also be designed to transfer energy to the grid (Özek, 2009).

Solar cells can be used in any application that requires electricity. For this reason, they are used away from residential areas, where there is no electricity grid, or if a renewable energy source is preferred, even though it is a grid. Basically, grid-connected systems are divided into three main groups: grid-independent systems and hybrid systems (Muhtaroğlu, 2012).

3.6.1. Grid connected systems (on-grid)

In solar cell systems connected to the grid, the solar energy is converted into electricity with the help of panels, it is given to the city grid with the help of converters. In these systems, PV plants are divided into two as domestic systems

1) ***Grid connected PV power plants:*** These systems produce electricity by themselves and sell it to the network (Figure 3.10). The powers produced by these power generation centers vary between 100 kW and 10 MW. It is generally established for places that cannot reach electricity and its cost is quite high. The plant, which produces 1 MW of energy, costs about 4 million € (Grozdev, 2010).

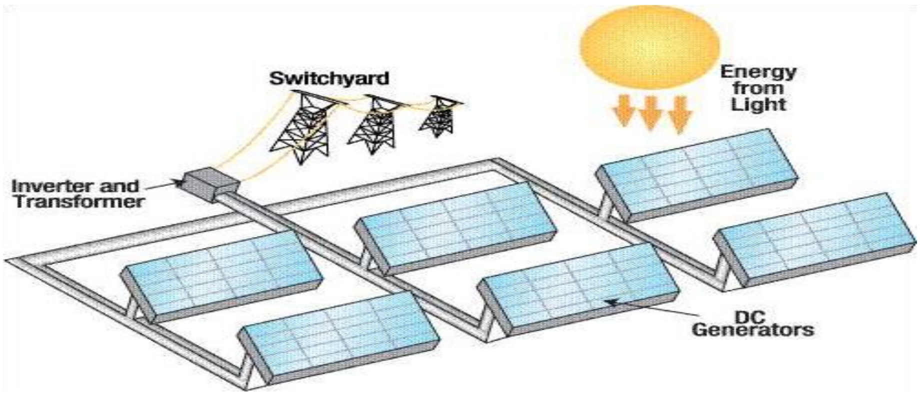

Figure 3.10: Grid connected PV power plant (Mande Blog, 2014)

2) ***Domestic PV systems:*** These systems, whose main purpose is to meet the electrical needs of a dwelling, can sell the excess electricity they produce to the city grid. In cases where sufficient energy is not produced, they receive energy from the grid. DC electricity produced from panels is converted to AC electricity. There is no need for energy storage because it can send the excess energy directly to the city grid. The power of these systems varies between 150 kW. The structures forming the domestic PV power systems are as follows; (Muhtaroğlu, 2012).
    - Solar panels arranged according to the required power,
    - Converter (DC / AC conversion),
    - Electronic control devices,
    - Counter

    Meters are two for measuring the electricity drawn from the network and the electricitysupplied to the network. Electronic devices, on the other hand, stop the system in case of any malfunction of the system and thus ensure that other subscribers connected to the network are not affected (Muhtaroğlu, 2012).

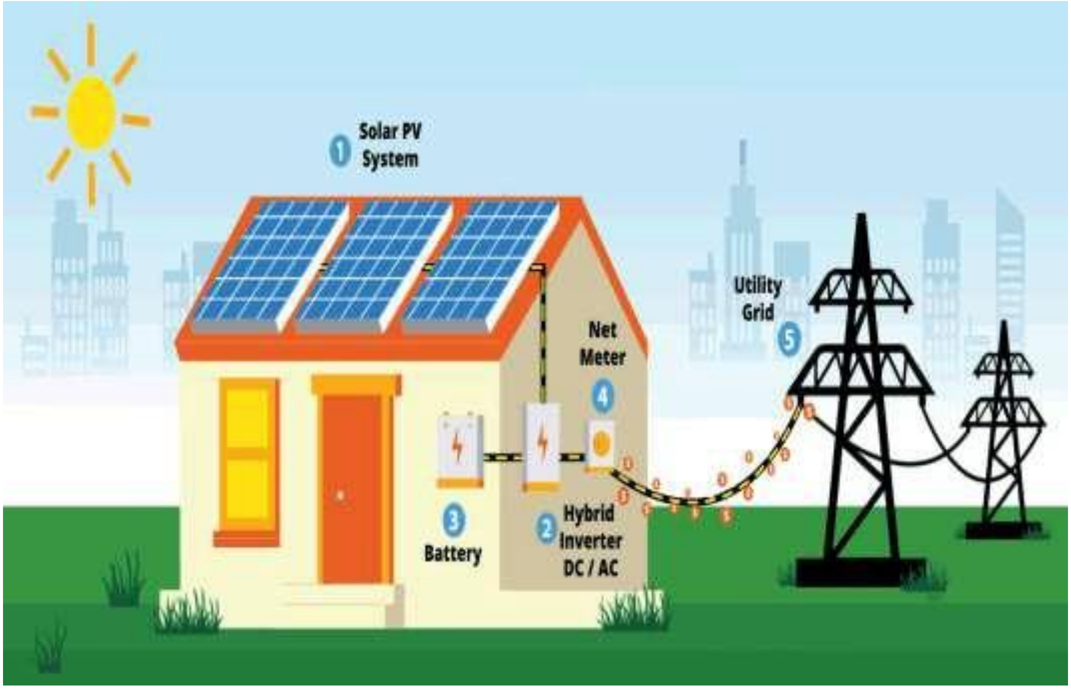

Figure 3.11: Grid connected domestic PV systems (TOBA ENERGI, 2020)

The most important issue in such systems is the establishment of energy quality compatibility and power balance between the network and the system. In order to ensure that the energy produced by the PV system is compatible with the grid energy, the cycle process must be performed and controlled with special electronic tools. Issues such as the qualities and numbers of DC - AC inverters used in the system, planning features of the system, wiring, connection features, network features determine the system efficiency. In such systems, device selection and configuration of the balance system are of great importance for system efficiency (Sakınç, 2006).

Grid-connected systems also have three end uses in different markets. These;

- PV systems applied in residences are systems with an installed power of up to 20 kW, usually located in single buildings or detached houses.
- PV systems applied in commercial buildings are systems with installed power between 20 kW and 1 MW, and commercial office buildings, hospitals, schools can be examples of these applications.
- Large-scale PV systems are systems that have a capacity above 1 MW installed power and are mounted on the ground.

In PV systems (roof type PV systems) applied in residences and commercial buildings, if the production and consumption are in the same place, connection is provided to the network with a duplex meter, and a double meter is used in different places. In large-scale systems (floor-mounted systems), they are connected to medium and high voltage lines with transformers. In 2013, more than 40 percent of the Global installed PV capacity was commercialized PV systems, 37 percent were large-scale PV systems, 20 percent were residential PV systems, and the remaining 1 percent were non-networked systems (Cebeci, 2017).

The steps listed below are followed for grid connected PV system design;

- The power of the system is not limited to the need, but the size of the area where PV panels can be installed, or the budget allocated for the installation of this system. Since the produced electricity will be sold with a high price tariff, a large system is tried to be established as much as possible.
- Selection of PV module technology: Efficiencies, temperature losses and low radiation conditions of different PV technologies are different. All variables must be evaluated.
- Selection of the installation place of the system and the appropriate installation construction Determining and calculating the shade amount of buildings that are likely to shade around the assembly area during the day and the relevant hours of the day
- Determination of the inverter (inverter) concept
- Calculation of inverter power
- Calculation of inverter voltage
- Determination of the number of parallel PV array groups
- Creation of cabling infrastructure (Gemicioğlu, 2011).

3.6.2. Off-grid systems

Grid-independent systems are often used in areas with high energy requirements away from the city grid. The energy range produced by the systems is very wide and can reach from 1 W to 100 kW (Grozdev, 2010).

Independent PV systems seen in Figure 3.12 generally consist of solar panels, charge control unit, battery and converter if necessary. The electricity produced in the system is stored in the battery to be used when the sunlight is insufficient. There is a charge control unit to prevent the battery from being overcharged or discharged. The inverters convert the DC electricity produced by the panels into AC for use where necessary. Thus, both direct current and alternating current can be us (Muhtaroğlu, 2012).

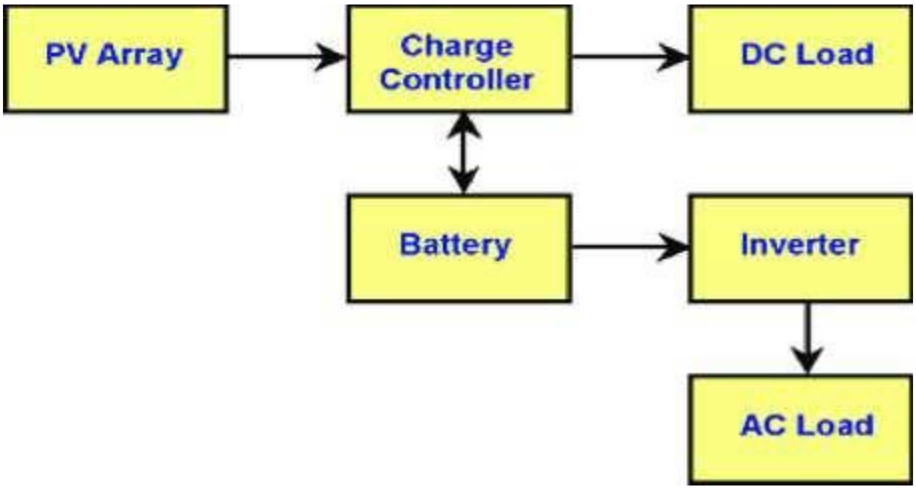

Figure 3.12: Off-grid PV system (Asovata et al., 2014)

Network independent systems have many application areas. We can list some of them as follows:

- Indoor and outdoor lighting,
- Rural radio, telephone, radio systems,
- Communication stations,
- Cathodic protection of oil pipelines,
- Telemetric measurements made in electricity and water distribution systems,
- Meteorological observation station,
- Agricultural irrigation pumping systems,
- Forest watchtowers,
- Medicine and vaccine cooling,
- Earthquake and weather observation stations,
- Lighthouses,

- Operating electrical devices in remote areas from settlements,
- First Aid, alarm and security systems,
- Traffic warning systems, ed at the same time.
- Military systems,
- Cars,
- Space studies (Akgün, 2006).

In self-sufficient systems, the quality, number, maintenance and repair, the number of DC - AC transducer qualities, the configuration of the system, the wiring and connection features are effective on the system efficiency (Sakınç, 2006).

The following steps are followed for grid independent PV system design;

- Calculation of daily consumption, consumption values of existing electrical appliances in Wh units, taking into account the units of Watt (W) and hours used.
- Determining the annual effective sunbathing time and solar panel capacity at the location where the system will be installed.
- Selection of the installation place of the system and the appropriate installation construction
- Determination and calculation of the structures likely to shade during the day and the amount of shade at the relevant hours of the day,
- If there are other renewable resources in the location where the system will be installed and a hybrid system is planned to be determined, determining these systems
- Calculation of inverter capacity
- Creation of cabling infrastructure
- Determining the type and capacity of the battery group where the energy will be stored for later use in the system to be designed (Gemicioğlu, 2011).

3.6.3. Mıxed systems

These systems, also called Hybrid Connected Systems, have other systems that generate electricity outside of the panels (Figure 3.13). Primary electricity generators are panels, in addition, they can be a system that uses a renewable energy source such as a wind turbine or a diesel generator that generates secondary energy to the system (Çolak, 2010).

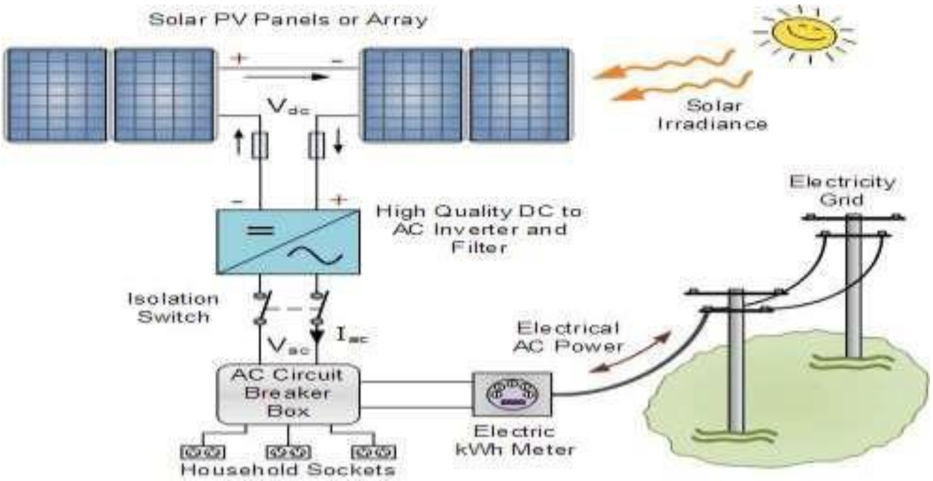

Figure 3.13: Mixed PV system (Alternative Energy Tutorial, 2019)

In addition to the storage system, in mixed systems, there are conventional electricity generation systems with solid fuel or natural gas that will supply energy to the system and fill the storage devices (batteries) in case of extra power requirement. Mixed systems require more complex control systems, but are more reliable than other systems (Sakınç, 2006).

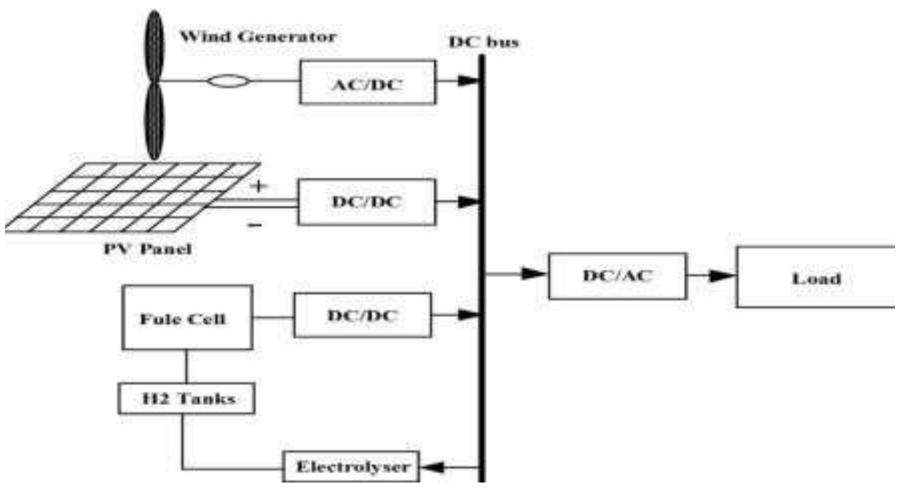

Figure 3.14: Mixed PV system schemes (Maleki and Askarzadeh, 2014)

Since conventional systems or utility electricity are also used in these types of systems, less PV collector areas may be sufficient. Mixed systems using additional resources such as generators are generally used in applications where power grid access is difficult, such as remote residential areas, or applications requiring uninterrupted energy such as small health units (Sakınç, 2006).

3.7. Advantages and Disadvantages of Photovoltaic Systems

As with any system, photovoltaic systems have their advantages and disadvantages. These cases should be evaluated very well and what system should be determined according to the need.

3.7.1. Advantages of photovoltaic (PV) systems

- The life of PV systems is long enough to pay for its cost.
- They are easy to maintain and very low maintenance costs.
- Since it uses solar energy as fuel, there is no fuel purchase and transportation cost. In addition, since it is not dependent on the fuel market, it is not affected by cost changes.
- They do not leave any harmful waste to the environment and they work silently.
- Many of the system components have a portable structure.
- It can be applied in a wide power range from 1 watt to several kilowatts, and the system can be expanded if desired.
- It is possible to use it as small units on buildings, cars and yachts in areas where the electricity network is not available, such as rural areas.
- It has less malfunction than a generator since it has no moving parts. If a module or battery in a medium-sized system fails, the entire system is not affected and continues to operate.
- Although the initial investment cost is high compared to generators, it is less costly in long-term use due to fuel and maintenance costs.
- Since the produced electricity is stored in batteries, it has the freedom to be used at any time and in quantity, whereas a generator must be operated even for a single bulb requirement.

- As PV systems do not have to comply with the electrical laws of installation and wiring, their costs are low.
- Since there is no long distance between the place where the energy is produced and the place where it is consumed, the amount of loss that may occur during the transportation of energy is very low.
- The system gives the opportunity to be removed and removed if desired (Oluklulu, 2001 - Sayın, 2006).

3.7.2. Disadvantages of photovoltaic (PV) systems

- They are affected by weather conditions and their efficiency is variable.
- They convert the solar radiation coming to the unit surface to electricity with low efficiency, so the required panel surface increases according to the requirement.
- In situations such as low or no solar radiation, they cannot produce enough electricity and they need batteries. Battery requirement increases cost.
- Panels produce direct current. Most electronic devices operate on alternating current. For this reason they need inverters.
- They are expensive systems. They only pay for themselves in a few years (Keçel, 2007 - Yerebakan, 2010 - Muhtaroğlu, 2012).

3.8. The Importance of Photovoltaic Systems in Solar Electricity Production

It is aimed that photovoltaic technology will reach an important point after 2020 with conventional energy options. The researches of the International Energy Agency indicate that the world average target share of electricity generation from the sun will be 0.1% in 2010 and 1% in 2020. Although these rates are extremely low, in the case take place in Turkey;

- The market volume of solar cells is 170 million in 2010 and 1,185 million in 2020.
- By 2010, 25,000 people will be given jobs, and by 2020, 175,000 people will be given jobs.
- 6500 people will work in the solar cell industry in 2010 and 30,000 in 2020.

- CO_2 emissions of 111 thousand tons until 2010 and 3,271 thousand tons by 2020 will not be thrown into the atmosphere (Keleş, 2008).

Since it can compete with other energy sources in terms of both the settlement of the solar cell industry and the price after 2020, its use is expected to increase rapidly and reach 10% and higher in 2030 (Özek, 2009).

Although photovoltaics emit indirect CO_2 emissions throughout their life cycle, at stages such as production, these values are far below the avoided emission values. As a proof of this, in a study conducted in Japan examining the CO_2 emissions of photovoltaic systems, various calculations have been made by considering the lifetimes of the systems, module productions and plant installations according to the production capacity in kWh, developing technologies and cell production size. According to these calculations; 1 kWh energy produced in the solar power plant, approximately 600 gr emission is prevented. By 2030, there can be a decrease of 1.6 billion tons in annual Global emissions thanks to PV systems. This reduction is equivalent to the emission of 450 thermal power plants operating on coal, with an average installed capacity of 750 MW. Between 2005 and 2030, 9 billion tons of CO_2 emission can be prevented (Özek, 2009).

Social Cost; It is the financial equivalent of human, animal and vegetation damage suffered by the use of fossil fuel power plants (floods, hurricanes, diseases, environmental pollution, cancer and other diseases, acid rains, etc.) and this cost is ignored in power plants projects or invoicing the electricity cost. Photovoltaic systems can be considered more economical than fossil-based systems, especially considering the “social cost” that can be considered as an invisible cost that is not taken into account in electricity production. Also, 0.60- 0.85kg with 1 kWh energy production from solar panels. CO_2 emission is prevented (Özek, 2009).

CHAPTER 4
USAGE OF PHOTOVOLTAIC SYSTEMS IN BUILDINGS

Since the fossil-sourced energy sources that we use today are being used up day by day and causing great damage to the environment and the atmosphere, there has been a tendency towards renewable energy sources. The most promising and inexhaustible energy source is the sun, which is the most renewable energy source. Most of the energies we use are used in buildings. For this reason, the use of solar energy systems in buildings is of great importance (Yücel, 2016).

The most common solar energy systems used in buildings are thermal and photovoltaic systems. Thermal systems can be used independently for space heating and domestic hot water or in combination with other fossil fuel-operated boilers. These systems can only meet the needs of the building they are established in and it is not always possible to use them efficiently throughout the year due to the seasonal change of the building need.

Photovoltaic systems are composed of modules used in solar power generation and are in the category of distributed electricity generation system. This means that these systems used in buildings work in parallel with the electricity grid to load the function of a small scale power plant and supply electricity to the nearest demand point. If there is a need for electricity in the building where they are installed, they can meet this, and if there is more than this need, they can meet the needs of other buildings by giving the energy they produce to the network. Such distributed electricity generation systems not only work with zero CO2 emissions, but also prevent losses of 40% caused by central production and transmission (Yücel, 2016).

4.1. Building Types in Using Photovoltaic Systems

The use of PV systems has a wide range from hotels to hospitals, from industrial buildings to residences. Office buildings have great potential for PV use. It can meet its own electricity needs between 9.00 am and 5.00 am in the morning when the network is at its peak. Commercial and industrial buildings provide large possibilities for PV systems with large roof areas. Residential structures are suitable for the use of PV to meet the energy needs of both day and night seven days a week. However, these are singular uses in terms of PV usage potential (Keleş, 2008).

4.2. Advantages of Using Photovoltaics in Buildings

- It meets all or part of the electricity need of the building in question
- No extra land is required
- No need for extra transmission line, foundation and carrier system
- Energy losses during transmission and distribution of electrical energy are reduced
- Reduces the burden of the electricity grid
- Causes a decrease in electricity bills
- When used instead of building materials, material consumption and the total cost of the building are reduced
- Provides a visually innovative image
- Shows the environmental awareness of building owners
- Increases the availability of electrical energy in rural areas
- Offers new jobs in the construction industry (Mutlu, 2010).

4.3. Factors Affecting Energy Inputs of Photovoltaic Systems

The power that can be obtained from photovoltaic generators in photovoltaic systems installed in buildings is not a fixed value. We can list the main factors that affect the power we can obtain from generators as follows (Koryürek, 2008).

- The position of the world relative to the sun
- Solar radiation intensity received by the neighborhood
- Location of panels
  - Tilt of panels relative to the floor (Tilt angle)
  - Panels orientation to the south (Azimuth angle)

- Shading factor
- Temperature

There are some criteria set to standardize photovoltaic generators worldwide. The produced photovoltaic generators are labeled with the power they produce under 25^{o}C ambient temperature and 1000 W / m2 solar radiation. For example, 15% efficient single crystal silicon panel with 1 m2 surface area produces 150 Kwp power under these conditions. Although the labeling of the products is done in this way, in many places, solar cells will not be able to deliver the maximum power indicated on their labels (Koryürek, 2008).

With a simple calculation, the annual power output that can be obtained from the photovoltaic module is calculated as follows;

S = Module Area * Solar Radiation * Module Efficiency * Directional Efficiency)

The power to be obtained from the system can be roughly calculated by multiplying the total module area by solar radiation, module efficiency and directivity efficiency (Koryürek, 2008).

The annual average electrical efficiency of PV systems, which was initially very roughly estimated, can be calculated with the formula below;

$$QPV = \eta \times I\ tot, rad \times APV \qquad (1.1)$$

QPV = the annual energy produced by the PV system [kWh]
η = Average efficiency of PV system
I tot, rad = average solar radiation per year on PV surface [kWh \ m2]
APV = PV system surface area [m2] (Keles, 2008).

4.4. Design Criteria of Photovoltaic Systems Used in Buildings

The design of the PV systems on the building depends on many parameters such as the area where the building is located, its location, the area it occupies, the architectural plan and for what purpose it is built. While designing my site, the most suitable project is prepared by considering the design of the architect and the functionality of the engineer. One of the most important advantages of using photovoltaic systems in buildings is that there is no need for an additional space to place the system (Koryürek, 2008).

PV panels can be combined with the building envelope vertically (on the facade) or horizontally (on the roof). Module sizes, forms and colors are features that affect the design when using PV panels in buildings. Factors such as location, orientation and angle of inclination, shading, panel type, maintenance and cleaning, and temperature occurring behind the modules affect the performance / efficiency to be provided from PV panels (Baş, 2016).

4.4.1. External climate conditions

The ability of PV systems to operate at maximum performance largely depends on the external climatic temperature values. The heat generated behind the PV panels as a result of high temperature reduces the efficiency of the system. Therefore, in hot regions, wind is a desired condition to dissipate the heat formed behind the panels and to realize a partial cooling. In cold climates, as the accumulation of the abdominal panels on the panels prevents the sunlight from coming to the solar cell, the efficiency decreases (Keles, 2008).

4.4.2. Location

Solar data is very important as the PV system is based on solar use. The amount of sunbathing depends on the latitude of the building and the regional climate. The place where the PV application will be performed should be investigated for the annual solar exposure time and intensity. Design calculations should be made according to the values found (Özdoğan, 2005).

Location is important for the effects of both climate and topography elements. The latitude of the building affects the solar radiation intensity and therefore the production of the system.

Local wind regimes are important in terms of reducing the temperature of photovoltaic components, especially in summer. In a place where there is a lot of snow in winter, a design should be realized in order to ensure that no snow accumulates on the system. The topography of the land is also a situation that needs to be studied. An elevation in the topography (mountain, etc.) can prevent the system from taking the sun (Mutlu, 2010).

4.4.3. External barriers and building ranges (shading)

The performance of PV panels can be affected by many factors, but one of the most important is shading. Factors that can cause shading; neighboring buildings, trees and shrubs can be counted as telephone poles. Especially in the city and city centers, the buildings cast a shadow over them because they are close to each other. Or sometimes it is possible for the building to self-shade due to the design. Since such situations will decrease the performance of the panel, correct decisions must be made during the design and the PV panel system must be designed correctly. Another factor that can cause shading is trees. During the design, the surrounding trees should be analyzed well and even deciduous trees should be preferred in winter. Thus, it is easier to drop the sun rays coming at a lower angle in winter onto the panel (Baş, 2016).

During the architectural design, it is necessary to avoid any obstructions that will cause shading. These are telephone poles, chimneys, trees, other buildings and shadows that the PV series will do to each other. The following items should be considered during the design.

- Put elements such as chimney and ventilation shaft in the north direction
- Position the elevator room, water tank and machine rooms to the north
- Ensure that the stairs do not shade the PVs
- if there is a tree to shade; Roof should be preferred instead of facade.
- Shading distances of neighboring buildings should be taken into consideration, and if there is not enough distance, the location of PVs should be analyzed (Keles, 2008).

Potential barriers that need to be placed on the roof should be placed on the north side (tanks, chimneys and ventilation shafts). In Figure 4.1, the advantages of positioning structures that will cause shade to the north are shown (Güneş, 2019).

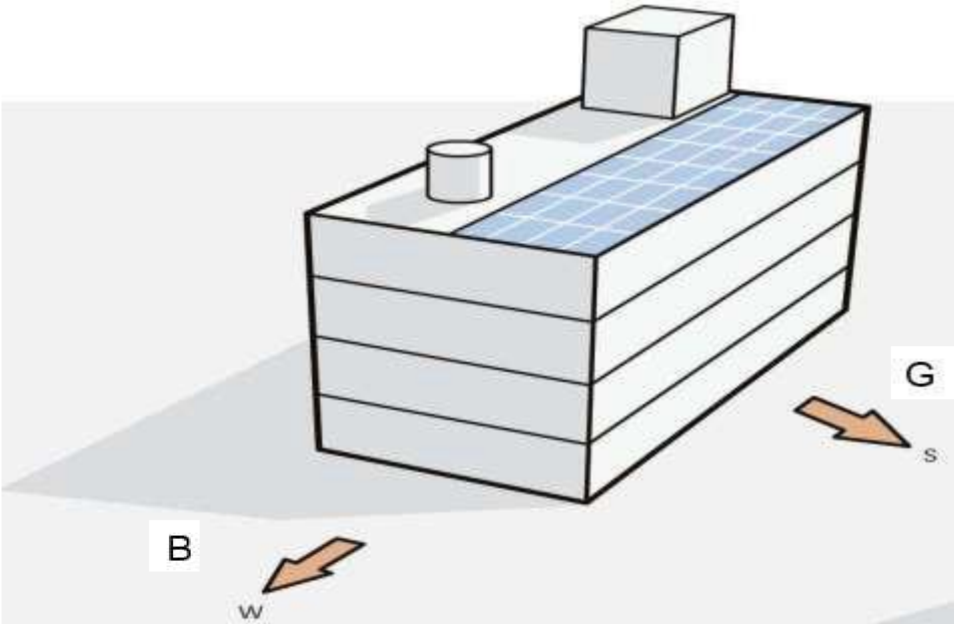

Figure 4.1: Locating structure that will cause shadow to the north (Güneş, 2019)

Facade balconies and stairs should be placed in the north. In Figure 4.2, an example of the facade, balcony and stairs application is given.

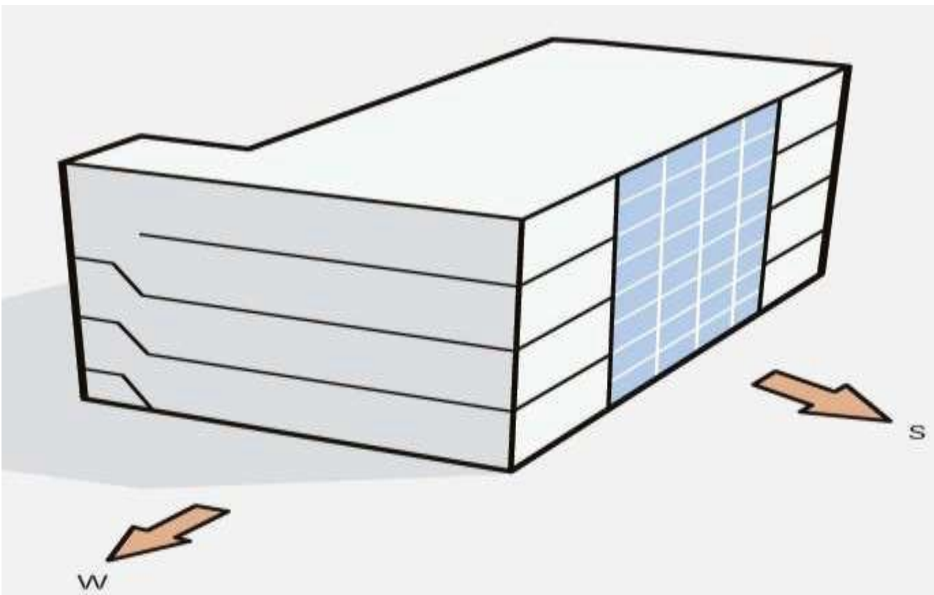

Figure 4.2: An example of facade, balcony and stair application (Güneş, 2019)

4.4.4. Direction and surface slope angle

Photovoltaic materials are materials that convert radiation directly into electricity. Therefore, the intensity and arrival angle of the radiation, which is the first parameter required for a PV system to generate electricity, is very important. As part of the design process, we can accept the slope and orientation of facades that will contain FV modules as the project start. To understand the importance of slope and orientation, we must observe how the radiation reaches the building surfaces. Radiation; It is divided into two as diffuse radiation and direct radiation. Direct radiation depends on the position of the sun and the path the sun takes. Diffusive radiation reaches a surface by being reflected from clouds and haze. Solar radiation components are shown in Figure 4.3 (Güneş, 2019).

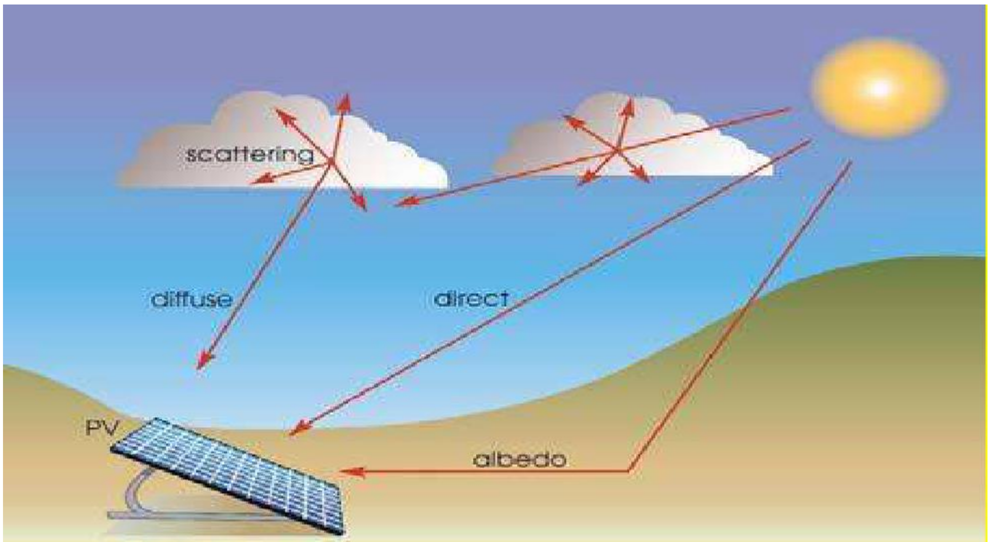

Figure 4.3: Solar radiation components (Gevers et al., 2015)

The amount of energy we can obtain from the panel; It changes according to the latitude of the building and the angle of inclination of the panel with the surface. The direction to which the panels should be applied is south. However, considering the low performance, it can be applied in South-East and South-West directions. According to the terms of optimal placement of PV panels summer and winter average 30 degrees in Turkey 'dir. The performance degradation in PV panels placed in different directions and angles differs according to the module type. annual performance difference between 30 degrees and 10 degrees conditions in Turkey will exceed 15% (Baş, 2016).

On the earth, the most important features of radiation are determined by the earth rotating around its own axis and the elliptical orbit around the sun. Certain angles are formed between the rays from the sun and the surfaces on the earth (Yücel, 2016). These angles are;

1) ***Declination angle:*** It is the angle of sun rays coming to the world according to the months and seasons. Another definition is the angle of the sun's rays with the equatorial plane. Declination angle; It is indicated by the "δ" icon. The declination angle results from the 23 ° degree 27 minute angle that the world makes with its own axis and orbital plane. To explain in more detail; This angle between the orbital plane and the equatorial plane of the world is the highest (23.45 °) in mid-summer (June 21) and the lowest (-23.45 °) angular in mid-winter (December 21). In the equinox points (March 21 spring equinox, September 22 autumn equinox), the declination angle becomes "zero" (Yücel, 2016).

2) ***Hour angle:*** It is the angle between the longitude (sun longitude) where the sun rays are located and the longitude of the place considered. It is indicated by the “ω” symbol. At noon, the hour angle indicates "zero" at noon, as the sundial is 12. It is negative (-) before noon and positive (+) in the afternoon (Yücel, 2016).

3) ***Latitude angle:*** The latitude angle “Φ” is the angle between the equatorial plane and the point under consideration. In other words, it is the angle between the direct beam and the horizontal. It is used to calculate the solar elevation angle. In the northern hemisphere (+) it is considered (-) in the southern hemisphere. The latitude degree can be read from an atlas per region. Turkey, located between latitudes 36-42 ° (Yücel, 2016).

4) ***Zenit angle:*** The Zenit angle is the angle between direct solar radiation and the normal of the horizontal plane. It is indicated by the “Ψ” symbol. While the Zenit angle is 90^{O} at sunrise and sunset, it is 0^{O} when the rays are perpendicular. Air mass (m): It is the ratio of the path that the direct solar radiation passes through the atmosphere and the path that the sun takes in its position at the zenith point (Yücel, 2016).

5) ***Sun height angle:*** The solar elevation angle is the angle between the direct solar beam

and the horizontal plane. It is indicated by the "α" symbol. The sun elevation angle complements the zenith angle to 90 degrees. The sun elevation angle takes its highest value at noon in all seasons, the sun elevation angle is zero during sunrise and sunset (Yücel, 2016).

6) ***Azimuth angle:*** It is the angle made by the projection of the sun-earth direction in the horizontal plane with the north-south. The sun azimuth angle is indicated by “Ys”. It is the angle between north-south direction and direct solar radiation. It is also the angle that shows the deviation of the sunbeams clockwise relative to the north. If the length of the day is more than 12 hours, the azimuth angle will be more than 90 ° at some times of the day. It is considered negative (-) from south to east and positive (+) from west. At 12 o'clock, Ys = 180 °. Solar radiation calculations are made according to solar time. The clock system in which the solar azimuth angle is 0 °, in other words, when the solar elevation angle is highest is taken as 12 o'clock, is called the sundial (local time). The standard time used by a country is different from the sundial. The longitude difference between the standard longitude and the local longitude of the current region and the time correction factor that changes according to the days are taken into consideration for the conversion of the standard time into solar hours (Yücel, 2016).

a) ***Surface azimuth angle:*** It is the angle in the south direction with the projection of the normal of the surface in the horizontal plane. The surface azimuth angle is zero in the south, negative (-) towards the east and positive (+) towards the west. -180 ° ≤ Y ≤ 180 ° (Yücel, 2016).

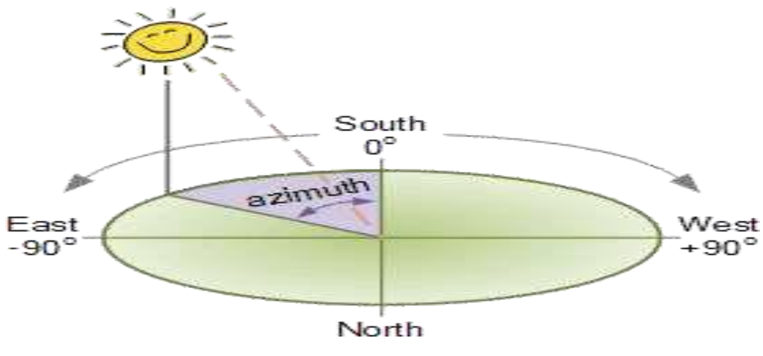

Figure 4.4: Surface azimuth angle (Yücel, 2016)

b) Angle of incidence: The angle of incidence of sun is the angle between the direct solar radiation coming to the surface and the normal surface. The solar incidence angle is indicated by the "Ѳ" symbol. If the surface is perpendicular to the sun's rays, the angle of incidence is zero (Ѳ = 0) and 90 ° (Ѳ = 90 °) if parallel. The angle of incidence is used in the design of solar energy systems (Yücel, 2016).

4.4.5. Temperature occurring behind the modules

PV performance decreases with increasing temperature. This decrease is higher in crystalline silicon than amorphous silicon. Considering this situation at the beginning of the integration into the building, the modules should pass air through the back and be allowed to maintain high performance. This also prevents the unwanted heat generated in the modules from passing into the interior. Thus, comfort conditions are maintained and the cooling load is not increased (Keles, 2008).

BIPV (PV integrated with building) modules can exceed 20-40 ° C in high radiation. Every 1 ° C increase in the cell causes an energy reduction of 0.4-0.5% above 25 ° C (Gemicioğlu, 2011).

Table 4.1: Average temperature values behind the photovoltaıc panel (Yücel, 2016)

Ventılatıon Status	**Roof**	**Facade**
Good Ventılatıon	%2.1 (290°C)	%3.9 (350°C)
Weak Ventılatıon	%2.6 (320°C)	%4.8 (390°C)
Unventilated	%5.4 (430°C)	%8.9 (550c)

4.4.6. Converters (inverters)

It converts direct current (DC) produced by PVs into alternating current (AC) used by the network. Areas are needed to protect and secure these transducers within the structure. There are junction boxes connected to converters on the back of PV modules. It is possible to increase the efficiency by putting the converters next to the modules. In converters, the alternating current cable feeds to the mains counter. The effectiveness of crystalline silicon cells decreases when the temperature increases, so the back of the modules must be ventilated. There is already a need for space for the junction box behind the modules. Depending on its size, a gap of 2-5cm is needed for the junction box on the back of the module. This space becomes important both by hosting the junction box and by acting as a ventilation. In addition, the switches must be close to the inverters for the safe operation of PV systems (Keles, 2008).

4.4.7. Landscape

After the integration of building construction and PVs, trees can grow in size depending on the type and become undesirable in a few years. For this, the following parameters should be applied during design (Keles, 2008).

- Afforestation should be done only in the northern direction in the northern hemisphere and only in the southern direction in the southern hemisphere.
- Only trees that can grow to the height of the roof should be selected.
- Branches that will cause shading should be cut every year.
- In order to benefit from the natural landscape, different types of applications should be made in different climate types.
  - In the cold climate regions, afforestation, which remains green in summer and winter in the northeast and southwest directions, especially in the dominant wind direction, is useful.
  - In temperate climatic zones, natural wind breakers should be positioned in the northwest direction. However, trees should not cut south-southwest winds in order to benefit from the cooling effect in summer. In periods that require shading, deciduous trees should be preferred for the purpose of solar control, especially in the west direction, which will not interfere with the solar radiation in winter. Trees that are constantly green are useful as an element that reduces heat loss due to being wind breaker. Creating green vegetation in the close vicinity of the building is beneficial

- in terms of preventing excessive rise of the ambient temperature as a result of absorption and evaporation.
- In warm and dry climatic regions, afforestation and green tissue absorption of sunlight are important because of their cooling and moisturizing properties. In hot - humid climate regions, high and dense branches that give shade and do not interrupt the air flow should be preferred. Stunted trees and shrubs should not be located near the building as they block the air flow (Özçiftçi, 2010).

Trees should be strategically placed to ensure effective shading. In the morning and late afternoon, when the sun passes with a low angle of rise, the trees form the most productive shade in the west-southwest and east-southeast directions. In this case, when the angle of rise of the sun is low, trees and all kinds of objects make a long shadow. For this reason, they can be used effectively next to the building. Otherwise, it becomes difficult to be protected from solar radiation. However, in the middle of the day, radiation can be easily cut with shading elements in the building.

Large trees should be placed either north of the building or south of the road, park or industrial area. Areas that are not suitable for climate settlement or with a high slope are good for large tree groups. Small tree groups should be placed so as not to coincide with the sun entrance. Generally, it is appropriate to place high and low tree groups first (Özçiftçi, 2010).

4.4.8. Glare

Glare is an undesirable effect, although it is not a major problem. We usually see this problem in low-rise buildings. It interferes with the reflection of sunlight when multi-storey buildings in mixed campuses cast shadow on each other's facades. The size of this glitter; It arises from the textural properties of PVs, mounting systems, the position of the sun and the beam intensity, and occurs at some time of the year. By leaving sufficient distances between the buildings, this glare problem disappears. More sunlight, a more even distribution will increase the effectiveness of PVs (Keles, 2008).

4.4.9. Color

The rise in temperature on sun-exposed surfaces is not only dependent on the temperature of the outside air and the heat transfer coefficient of the surface. It also depends on the clarity of air, the angle of incidence of radiation, the type and color of the surface. According to the climate regions; The colors to be used in the buildings are summarized as follows:

- In hot-dry climate; generally white and close to white colors should be chosen. The aim should be to reflect the overheating and excess radiation that occurs in the summer.
- In cold climate regions; dark, black colors should be preferred. The aim is to absorb solar radiation coming into the building, street squares, creating a more temperate and warm environment (Özçiftçi, 2010).

4.4.10. Form

One of the design parameters that are effective in conservation of heating and air-conditioning energy is the form of the building. Building form; building shape, building height, roof type, slope, and slope of the facade surface can be defined through geometric variables related to the building. The ratio of the size of the building envelope surface, which protects the spaces from external factors, and the volume of the building plays an important role in energy losses and gains. The buildings with this high value are in more interaction with the climate and external environment conditions (Figure 4.5) (Özçiftçi, 2010).

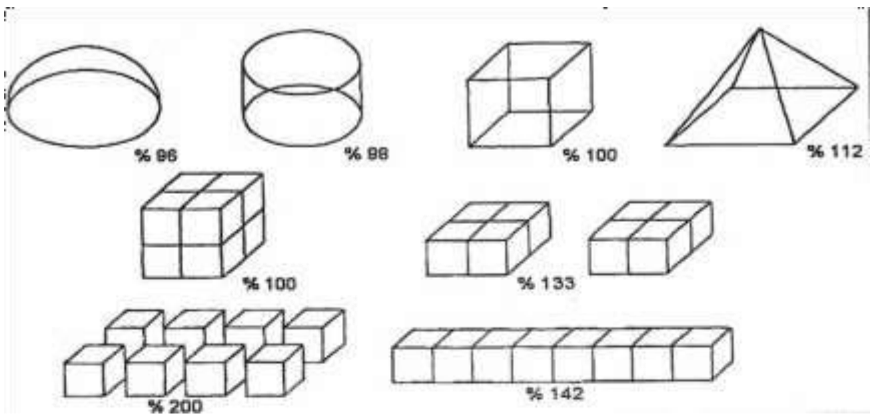

Figure 4.5: Building form-surface relation (Özçiftçi, 2010)

Since the heat losses increase as the shell area increases, the heat loss decreases when the surface and volume ratio increases, while the heat loss is minimal in the simplest, geometric shapes that cover the same volume. Since the compact building form has less outer surface than others, it provides important advantages in heat losses and control of gains. If the surface areas of different forms are compared, the order from the lowest surface area to the highest surface area, provided that they have the same volume; sphere, cylinder, cube and rectangles are prisms. The deep-plan, open office system building form, which has been used frequently in office designs since the late 1970s, is important in terms of energy relations. For reasons arising from the form it does not allow natural ventilation and offers a better working environment despite the need for artificial lighting. The fact that the city does not spoil the appearance, as well as bringing many advantages in energy conservation, can be counted among the positive aspects of such structures (Özçiftçi, 2010).

4.5. Forms of Use of Photovoltaic Systems in Buildings

The application of photovoltaic systems to buildings can be in two different ways. The first of these; designing and installing a photovoltaic system for a built building; The second is to consider the photovoltaic system from the beginning of the project when designing the building and to use the photovoltaic panels as an integral building element of the building. (Koryürek, 2008).

The design of the PV systems on the building depends on many parameters such as the area where the building is located, its orientation, the area it occupies, the architectural plan and for what purpose it is built. While designing my site, the most suitable project is prepared by considering the design of the architect and the functionality of the engineer. One of the most important advantages of using photovoltaic systems in buildings is that there is no need for an additional space to place the system. Systems can be applied to the roof or the facade in two ways (Koryürek, 2008).

PV modules are often used in building envelope. The building envelope is composed of elements that separate the internal and external environment. Building envelope users control the changing physical environmental conditions outside and provide comfort conditions for users inside (Keles, 2008).

The functions of the building envelope are versatile. The shell, called a building element, creates spaces within the building that provide livable comfort conditions. The basic principle of the formation of outdoor and indoor concepts is that there is a separator. The shell has to perform many functions besides being a separating surface (Sayın, 2006).

These functions are:

- Weather requirement
  - Protection against rain, snow and moisture,
  - Providing heat conservation and transition,
  - Protection against cold winds,
  - Allowing wind passage for cooling in the summer,
  - Providing solar control.
- Structural requirements
  - Providing structural stability,
  - Resistance to internal and external loads,
  - Resistance to mechanical and chemical damage,
  - To be solid,
  - It is easy to maintain,
  - Ensuring fire safety,
  - Don't allow an emergency exit.
- User requirements
  - Allowing relationships and communication with the outside,
  - Privacy-privacy inside
- Requirements for urban planning and design
  - Allowing dialogue with the environment,
  - Aesthetic look,
  - Environmentally compatible materials and forms,
  - Integrated identity delivery.
- Environmental requirements

- Providing noise control,
- Protection from waste gases in the environment,
- Protection from radiation effects,
- Protection from dust and pollen,
- Protection from pests (Sayın, 2006).

The use of PV systems in buildings is examined under 3 main headings.

1. Use on roofs
2. Use on facades
3. Use in different building sections

Table 4.2: Use of PV Systems in Buildings (Gemicioğlu, 2011)

Usage on Roofs	**Use on Facades**	**Usage in Different Building Sections**
Flat roof	Curtain PV wall	Patio
Inclined roof	Rain-screen facade PV	Sun shutter
Curved roof	Shading element	Entrance fringe
Set roof (saw tooth)		Balcony railing
Atrium		

4.5.1. Use of photovoltaic systems on roofs

One of the most suitable places for placing PV modules in buildings is roofs. The required slope and orientation can be achieved more easily on the roof. In addition, the structures required during the application are cheaper than the facade. In addition, it is easy to integrate and provides an aesthetically pleasing advantage in terms of easy shading, which is generally not shaded. We can generally divide the use of PVs on the roof to 5.

1. Use in Flat Roofs
2. Use in Inclined Roofs

3. Use in Curved Roofs
4. Use of Saw Toothed Roofs
5. Use in Atrium Roofs

Ventilation of unwanted heat in roof systems is easier than in the facade. Installation of a subframe on pitched roofs facilitates the application of PV modules. Thus, while the necessary space and ventilation is provided under the module, windows opening to the north in saw toothed roofs provide this ventilation (Keles, 2008).

1) ***Usage in flat roofs:*** The flat roof PV installation can be applied in the optimal position, at the desired angle of inclination with the supporting structures and at the desired location. We can collect different systems in 3 categories for assembly;
    - Mechanically fixed to the roof structure
    - Built on the source (roof) with its weight
    - Integrated solutions

    The equipment, which is mechanically fixed on the roof structure, provides the application of PVs with screws and bolts. Modules can be adjusted from 10 ° to 60 ° and can withstand 200km / h wind load. Examples are shown in Figure 4.6 (Keles, 2008).

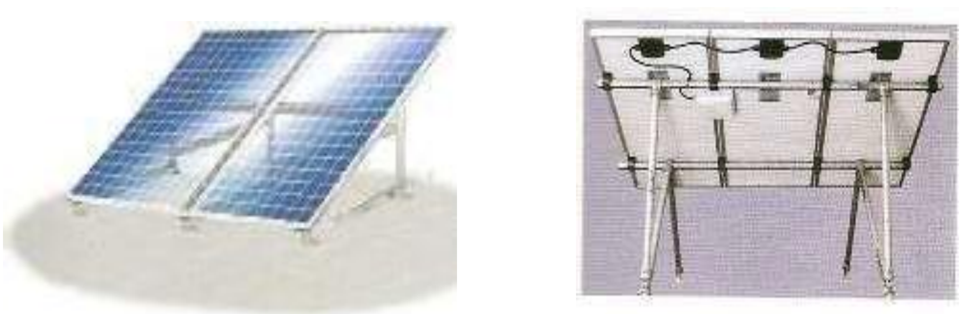

Figure 4.6: Application based on roof structure (Keles, 2008)

In systems built on the source (roof) with its weight, designers used fixed systems that sit on the roof with their own weight, which requires less support structure. Although it does not always look aesthetic, it puts an extra load on the roof. These systems are preferred when it is desired to obtain cheaper and hundreds of kilowatts. Concrete elements are used for weighting. Horizontal elements are fixed to the ground, while remaining attached to the slope. The weight-driven design can be placed almost anywhere and can provide modular expansion. Figure 4.7 shows the independent support structure design (Keles, 2008).

Figure 4.7: Independent support structure design (Keles, 2008)

As seen in Figure 4.8, PV modules used on flat roofs are independent of the building envelope. They are no different from an independent PV plant and are the easiest to implement. Since they can be adjusted at the desired slopes, maximum efficiency can be achieved. However, it should be noted that other elements on the roof should not be shaded. The system offers the opportunity to be disassembled and re-attached at any time (Sayın, 2006).

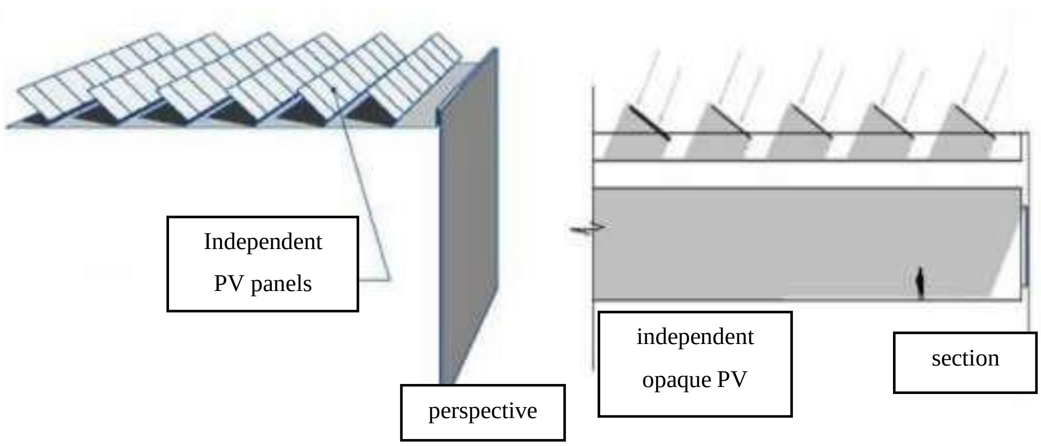

Figure 4.8: Independent PV module usage in flat roofs (Sayın, 2006)

Integrated solution systems are systems used in cooperation with the feature of the roof element (such as an airtight barrier and insulation). These products put a little load on the roof. It is more expensive but aesthetic compared to standard flat roof solutions. However, it is a very practical solution. It uses both PV production and isolation of the roof.

The sandwich construction detail in Figure 4.9 is a practical solution with electricity generation while protecting the roof and providing insulation. Each piece is easily connected to each other and does not fit into the roofing material, it can be applied to the existing roof. Elements are mechanically attached or made of adhesive membranes (Keles, 2008).

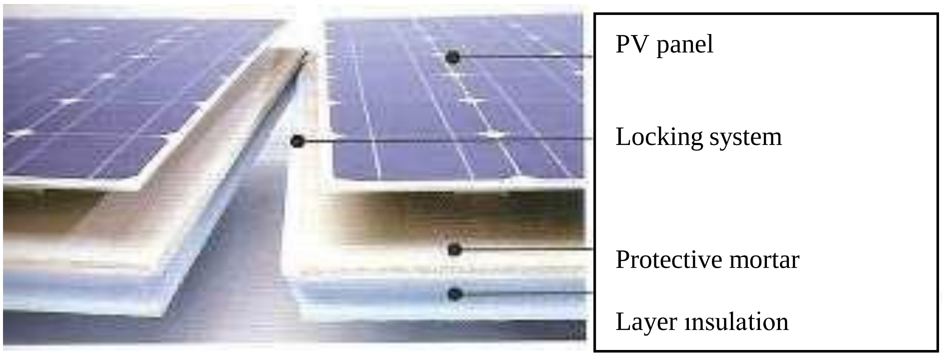

Figure 4.9: Sandwich construction detail (Keles, 2008)

2) ***Use in inclined roofs:*** Pitched roof constructions are generally very suitable for the use of PVs in residential buildings. PV panels can be placed directly on the roof as well as can be used as a roofing material instead of the roof to provide protection from weather conditions. Thus, while the roof generates electricity, it will be more economical in the long term as it will also perform the coating function (Gemicioğlu, 2011).

The use of PV in pitched roofs;

a) With an additional structure on the roof cover
b) Integrated with roof cover

a) The use of PV with an additional structure on the roof covering is one of the cheapest systems, it is provided by mounting the profiles on the roof covering. The common plumbing approach is to fix special roof pieces onto the wedges. Vertical pieces are placed on horizontal aluminum pieces while forming the foundation. PVs are fixed on them with screws or gaskets (Figure 4.10). The most important advantage in these mounting systems is that the space formed between the existing roof and the panel leaves an air gap to provide the necessary cooling without any additional payment and Effort (Gemicioğlu, 2011).

Figure 4.10: Using PV with an additional structure on the roof cover (Gemicioğlu, 2011)

b) In the use of PV integrated with roofing, PVs replace the normal roofing. Thus, PVs fulfill two tasks at once. They are used both as roofing materials and by reducing electricity, they reduce the energy costs of buildings (Gemicioğlu, 2011).

Integrated systems are more aesthetic than mounting systems applied on the roof with an additional structure. But there are disadvantages to ventilating the back of the modules. Figure 4.11 shows the use of PV integrated with roof cover (Gemicioğlu, 2011).

Figure 4.11: Use of PV ıntegrated with roof cover (Gemicioğlu, 2011)

In integrated systems, special sun tiles (tiles or shingles) can also be used on the roof. These modules are just a few Wp regular roof tiles. The use of these tiles; It is more problem-free than the integration of PVs with the classical roof. At the same time, they are easy to apply and are installed in a short time. Figure 4.12 shows the use of shingle PV on the roof (Gemicioğlu, 2011).

Figure 4.12: Shingle PV on the roof (Gemicioğlu, 2011)

3) Use in curved roofs: The use of PVs is also possible in curved roofs. Curved roofs use amorphous silicon, thin film or curvaceous opaque, translucent solar cell modules applied to metal sheet or synthetic flexible material (Uğur, 2006).

The variety depends on the roof dimensions. The roof is made of aluminum cages that carry its own weight, and the modules are placed between the two cage segments and screwed. Figure 4.13 shows the curved roof overlay detail (Keles, 2008).

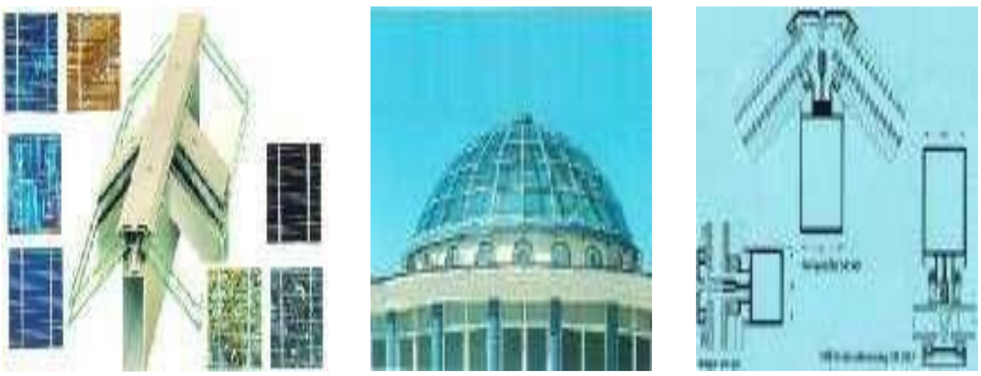

Figure 4.13: Curved roof overlay detail (Keles, 2008)

In Figure 4.14, the application of amorphous silicon based PVs in free style is given (Keles, 2008).

Figure 4.14: Free style PV application (Keles, 2008)

Roofs to which PVs will be applied are formed from aluminum frames and the modules are screwed by placing them between the frames. Figure 4.15 shows the use of monocrystalline PVs in the curved roof of the office and research-laboratory building in the Netherlands (Gemicioğlu, 2011).

Figure 4.15: PV usage in curvilinear roof (Gemicioğlu, 2011)

4) Use of saw tooth in roofs: Saw toothed roofs are roofs made to get more daylight into the building. The use of translucent or transparent optic solar panels on the north-facing skylights and opaque solar cell panels on the south-facing slopes is the best method to obtain the highest level of efficiency (Uğur, 2006). Figure 4.16 shows the example of using PV in embankments.

Figure 4.16: PV usage on set roof (Keles, 2008)

In the figure, PV modules were integrated into a very large glass roof construction at 4.17. Here, PV modules have undertaken the isolation, daylight and sun protection functions. Therefore, the solar cells here are combined with a glass module and glass is used on its outer surface to provide insulation. In order to protect this insulated glass, two glasses that are glued together are used on the inner surface. In building regulations, the glasses used on the hill should be made of laminated or tempered glasses (Keles, 2008).

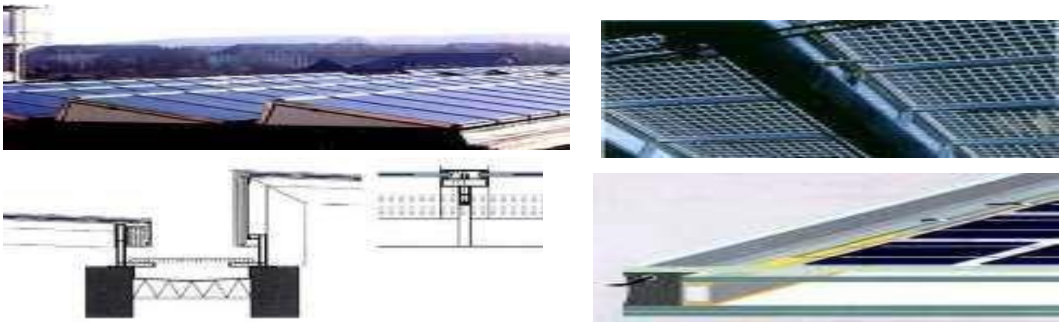

Figure 4.17: Glass roof application with PV modules (Keles, 2008)

5) ***Usage in atrium roofs:*** Atrium areas, which are frequently applied in large shopping malls and hotels, are usually covered with glass. PV modules are the most suitable systems that can be used instead of glass. Using the semi-permeable PV module, both electricity is produced and solar control can be provided inside. Generally, atrium where steel structures are used, the snow load should be calculated and the waterproofing details should be solved correctly (Figure 4.18) (Sayın, 2006).

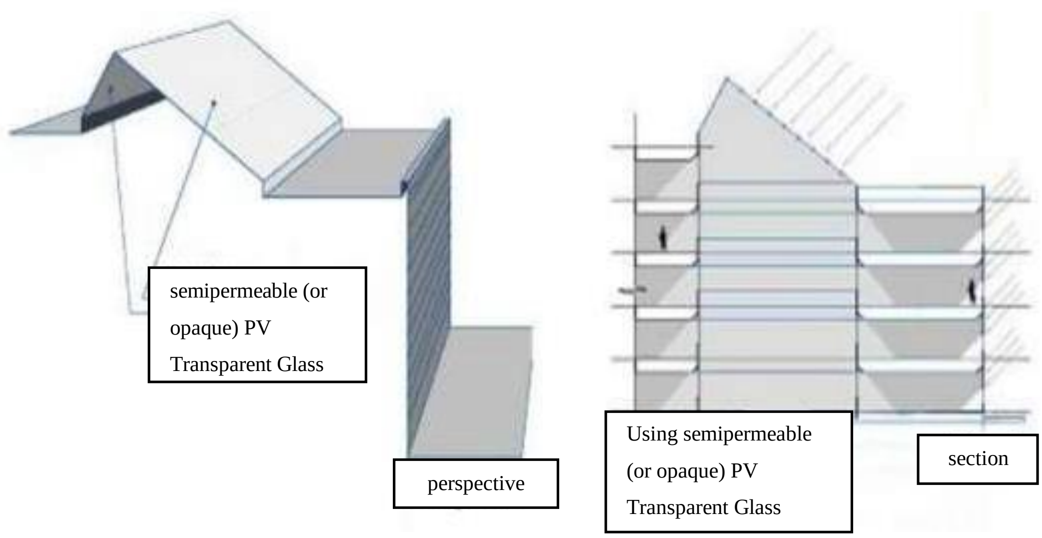

Figure 4.18: PV module usage in atrium spaces (Sayın, 2006**)**

The use of PVs in the atrium as roof lighting is an exhilarating and most detailed use of architecture. These areas constitute reference points for PV use in terms of design. In these glass-covered areas, sun protection is required when heating is not desired. Transparent PV modules are more expensive than standard modules. However, integration possibilities, multiple use (daylighting, shading, passive cooling) and mechanical cooling reduce system costs reduce the total building cost. The distance between solar cells is 520mm and this distance can be adjusted according to the light value desired to be taken inside. Figure 4.19 shows an example of PV atrium at Nottingham University (Gemicioğlu, 2011).

Figure 4.19: PV use in the atrium, UK (Gemicioğlu, 2011)

4.5.2. Use of photovoltaic systems on facade

Building facades are the outer layer that emphasizes the visuality of the building and protects the building from external factors. The facades are divided into different categories according to the construction technique used, the material and the structural features of its subcomponents. Photovoltaic systems used in building facades are more difficult and important than the systems used in roofs. Because the structure's visuality and aesthetics are in question (Yücel, 2016).

Photovoltaic panels used on the facades are generally used vertically. Since the building facades are exposed to shading, shading models should be made during the layout plan and photovoltaics should be applied to the facades in the most efficient way. The temperature of the air formed behind the photovoltaic modules integrated into the facade surfaces is important for the facade. It is suitable to use heat-sensitive crystalline silicon photovoltaic modules in terms of efficiency in the ventilated facade. In non-ventilated façade systems, amorphous silicon photovoltaic modules should be preferred, which may contain more temperate environmental conditions (Yücel, 2016).

PVs, which are often used in large façade areas, are used vertically. The width is beneficial in the use of PVs depending on the latitude found, especially the vertical use of the facade between east and west requires protection from the sun in the morning and afternoon. However, since the facades tend to be shaded, it is necessary to define the solar radiation as an input during the layout and in the construction of the shading models. It is possible to divide the façade constructions into two as ventilated and non-ventilated. It is important whether it is ventilated due to the heat generated behind the PV modules. Ventilated facades, efficiency events are suitable for the integration of heat sensitive crystalline silicon PV modules. The technology required by non-ventilated facades, amorphous silicon PV modules that can tolerate more temperate environmental conditions when ventilation is not possible should be preferred (Keles, 2008).

A building that explores daylight and is built to the south away from shading; It is very suitable for photovoltaic application. The fact that the building facade is large and long provides an advantage for photovoltaic use and energy production (Yücel, 2016).

The application of photovoltaic modules to be integrated into the facade surface may require complex details. The following criteria should be taken into consideration in order to find maximum solutions and reduce the cost in the sizing of the modules, the installation of the electrical system and its integration into the facade; (Sayın, 2006).

The load that the photovoltaic modules will bring to the structure must be calculated in advance and suitable designs must be made accordingly.

- In order not to decrease the efficiency of photovoltaic modules, the facade to be designed must be suitable for this.
- Waterproofing must be applied to photovoltaic modules that are in direct contact with the external environment, this insulation layer should not affect the efficiency of the module.
- Shading on the facade surfaces is higher than on roofs. This is important in the design of the building so that the efficiency of the photovoltaic module does not decrease.
- Different module materials have different advantages. For example, larger openings can be covered with thin film cells and the structure of the module is flexible. In cases where it is difficult to ventilate the module, amorphous silicon cells are recommended. Considering such criteria, materials suitable for the structure should be selected.
- The module materials to be used in the facades that form the appearance of the building must be in an aesthetic integrity. The modules that will determine the image of the building also reflect the prestige of a building.

The facades form the largest outer surface of the buildings. It is the facade that gives the first effect when looking at the building from the outside. Architects express their wishes and expectations of the users with the form and color alternatives of the facade. PVs are the section where aesthetic concerns are experienced for building facades. PVs used in large facade areas are mostly used vertically. However, considering that the facades are shaded, solar radiation should be defined as input during the layout plan and shading models. It is possible to separate the use of PVs on facades to 3 (Gemicioğlu, 2011).

1. Curtain PV wall
2. Rain-screen facade PV
3. Shading element

1) Curtain PV wall: Curtain walls created with the integration of PV elements are often used to improve existing structures (Akgün, 2006).

It is the usage where PV panels directly form the building envelope. Stylistically varying wall types (planar, inclined, fractured, etc.) can be created. PV modules that make up these walls are attached to metal grids and the load of the metal grid is carried to the structural system of the building. In such applications, sealing problems can be solved with the details and methods used in traditional curtain wall technology (Çelebi, 2002).

Curtain wall systems consist of pre-produced panels that are connected to the structure carrier system and a carrier grid. The fact that the facade consists of pre-manufactured panels makes it possible to control the physical conditions of the interior and exterior environment and to load various safety or comfort functions on the building envelope. Curtain wall systems are applied on the filled surfaces as well as the spaces on the building and continuity is provided on the building facade. Heat and steam insulation is provided by leaving a ventilation gap between the covering layer and the building. Elements such as security, ventilation, solar control can be easily integrated into these systems (Yücel, 2016).

Curtain walls can be designed vertically or at an angle and horizontal or broken in themselves according to the horizontal plane (Uğur, 2006). Curtain walls;

a) Planar curtain walls
b) Vertical broken curtain walls
c) Accordion curtain walls
d) Horizontal broken curtain walls
e) Inclined planar curtain walls
f) Curved broken curtain walls

a) Planar curtain walls: Standard glass, curtain wall carrier grille can be used. Electricity generation is low compared to inclined facades due to the inconvenience of the angle to the sun rays (Uğur, 2006). It has the same structure as traditional glass curtain walls, which are widely used in large office buildings. PV modules are attached to the metal grid and their loads are transferred to the structural system of the building (Çelebi, 2002). There is no additional construction cost. By using opaque modules and semi-permeable modules together, solar control can be provided to create a comfortable environment within the structure (Sayın, 2006).

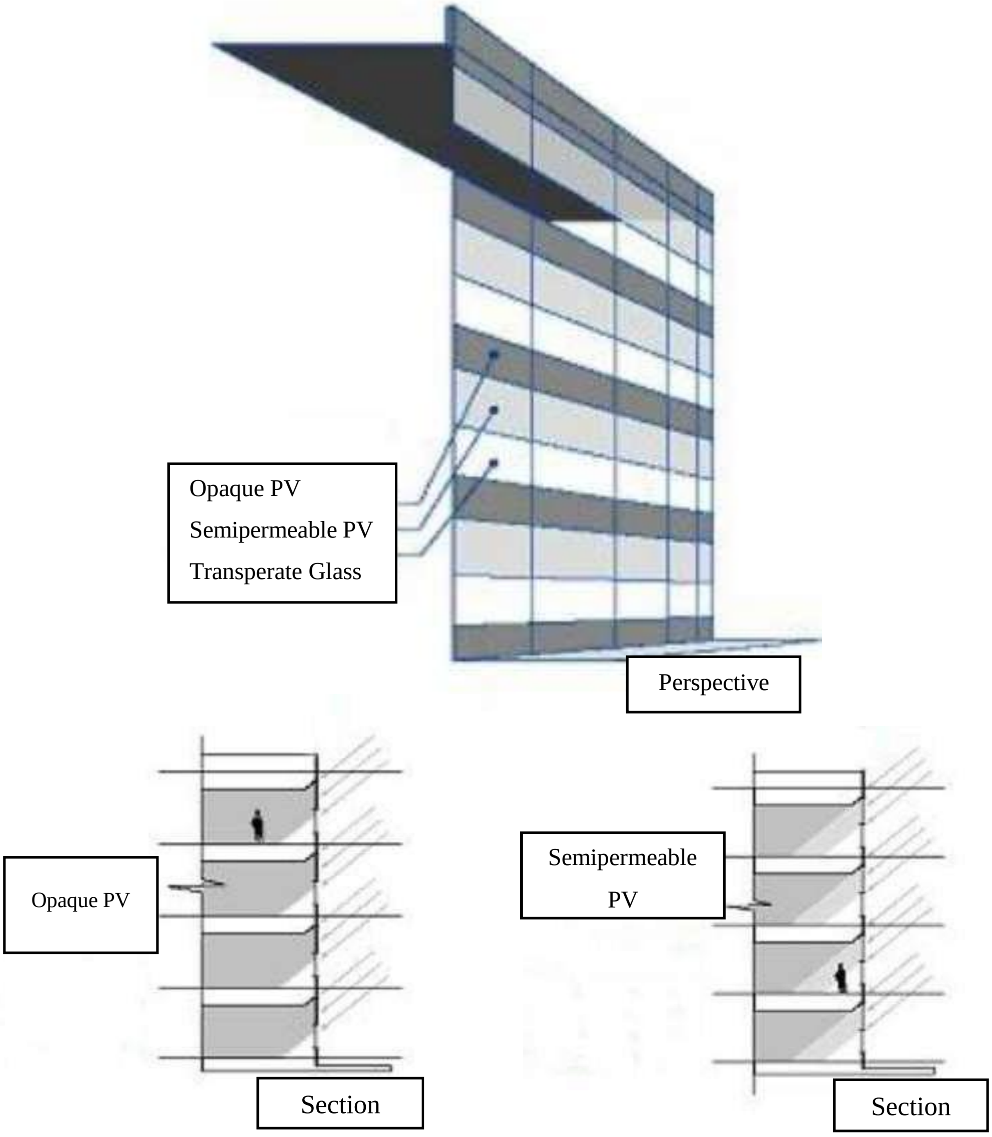

Figure 4.20: PV module use in planar curtain wall (Sayın, 2006)

b) Vertical broken curtain walls: Although it is a form that increases the surface of the facade, the additional carrier construction costs have negative effects on the system cost. It has good electricity generation potential when the sun is directed properly. It is possible to provide surface cleaning by opening a window from the corner points (Keles, 2008).

There is an extra cost incurred by an additional construction due to the faulty design of the facade. If the orientation is correct, good electricity generation performance can be obtained from PV modules. By designing the corner windows that can be opened, the facade can be cleaned. As seen in Figure 4.21, opaque PV modules and semi-permeable modules are used together with clear glasses (Sayın, 2006).

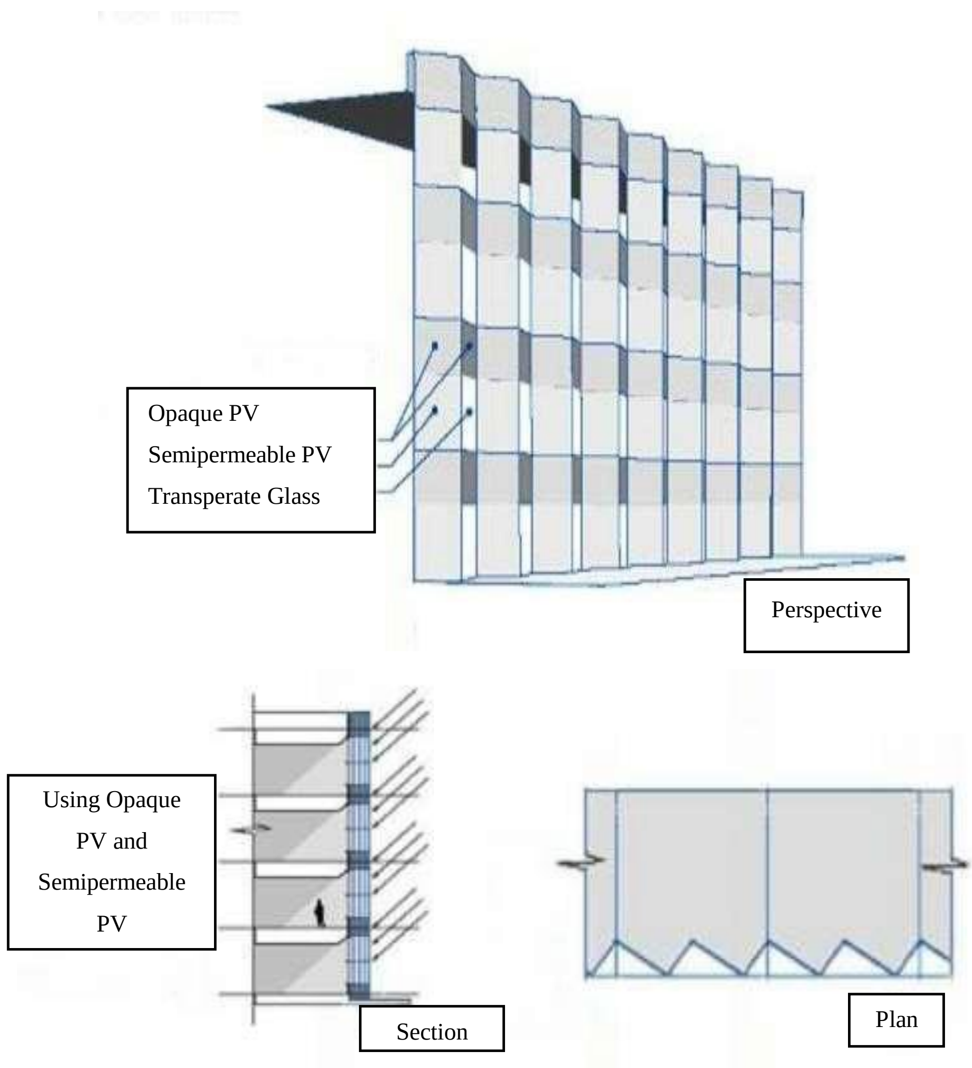

Figure 4.21: PV module usage in vertical fracture curtain wall (Sayın, 2006)

c) Accordion curtain walls: Accordion curtain walls, which have a complex construction structure, are also applied in the form of folded plate-folded plate combination. As it is difficult to apply, it is costly and difficult to clean. In addition, double wall application is made in this system. In this application, heat energy is obtained between the wall formed by the outer PV modules and the inner wall and this is given to the interior in a controlled manner (Figure 4.22). The performance of such walls is higher than other planar walls (Çelebi, 2002).

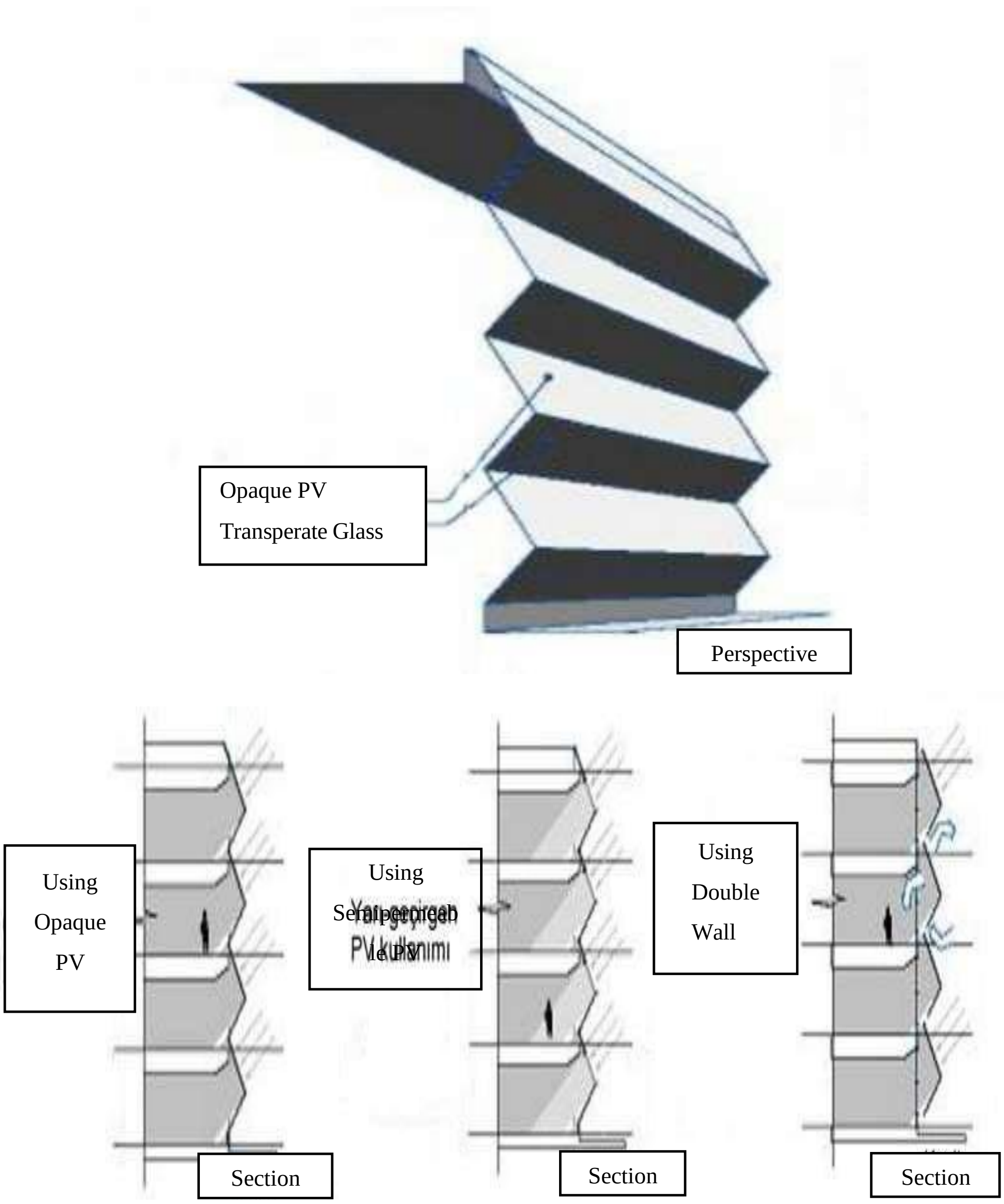

Figure 4.22: PV module usage in accordion curtain wall (Sayın, 2006)

Due to its form, it has a complex carrier construction. Additional carrier costs are high. On the other hand, its performance is quite high since it is more flexible in terms of angle adjustment than the sun. Cleaning can be done from the outside (Keles, 2008).

d) ***Horizontal broken curtain walls:*** There is an additional construction cost for the application of the cracked wall created using the PV panels horizontally. However, since the modules receive the sunlight both at an angle and at an angle, their performance is higher compared to the vertical broken walls. Horizontal modules create a passive shading effect and provide solar control in terms of application. Since the façade is a problem, module efficiency may decrease (Çelebi, 2002).

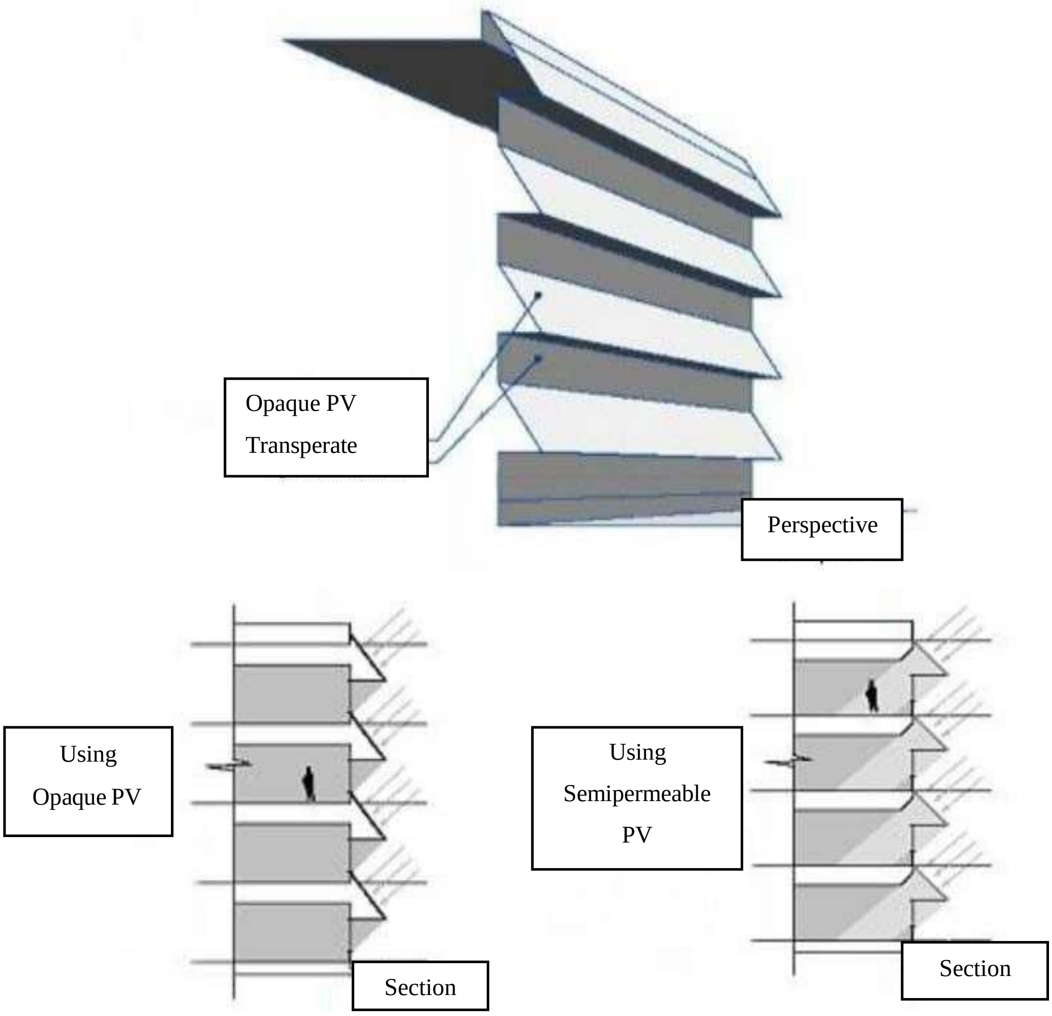

Figure 4.23: PV module usage in horizontally fractured curtain wall (Sayın, 2006)

e) Inclined planar curtain walls: It is the type of curtain wall where the highest performance can be achieved. 60 ° is recommended as the optimum angle. The effect created by different angles can be seen in the sections in Figure 4.24. Solar control can be achieved by using opaque PV, semi-permeable PV and glass together as in planar walls. Although it is not costly in terms of construction, facade cleaning is a problem (Çelebi, 2002).

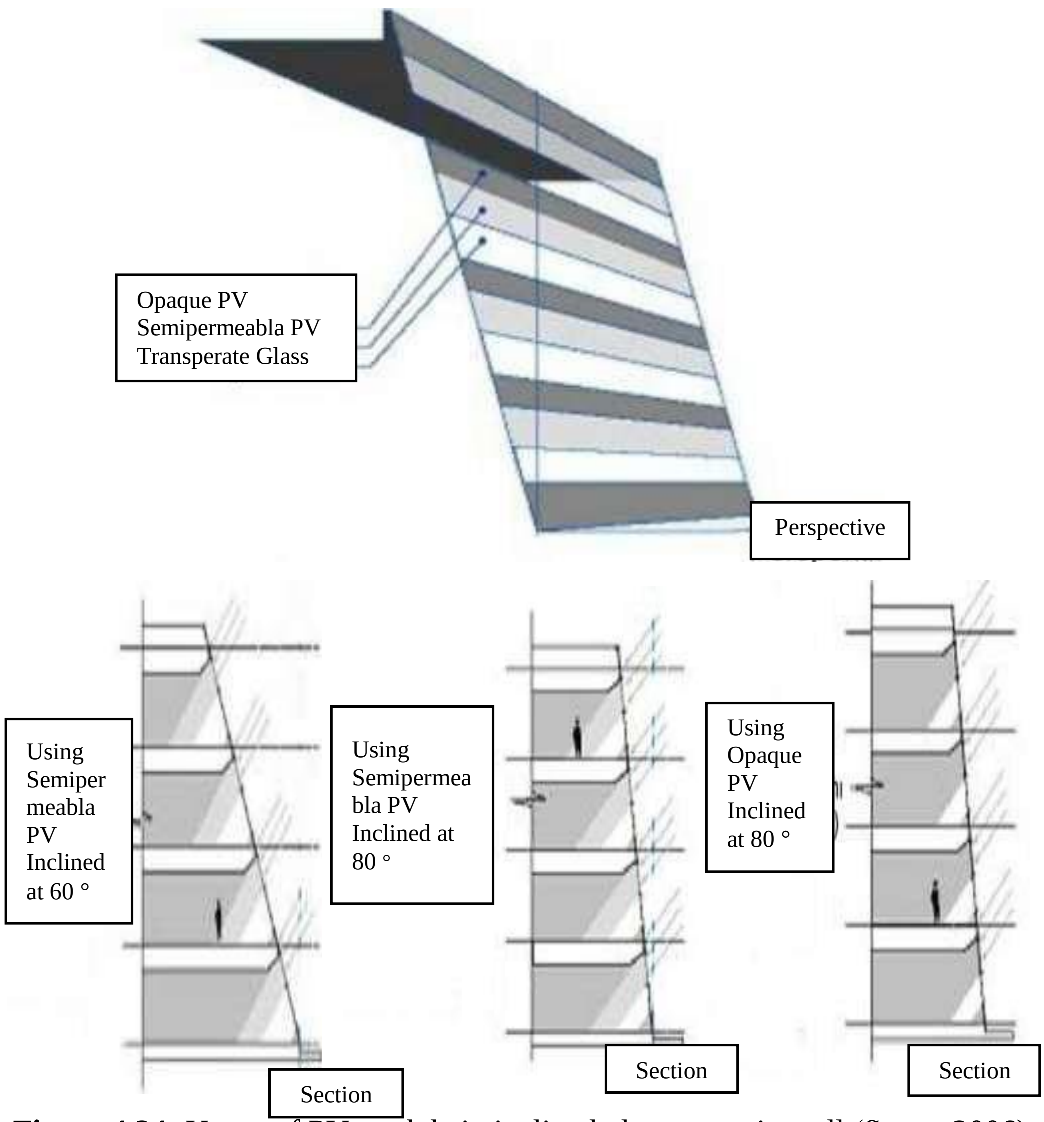

Figure 4.24: Usage of PV module in inclined planar curtain wall (Sayın, 2006)

It is the form of facade that provides the highest PV performance at angles between 40 ° and 60°. It is possible to obtain effective systems by using opaque and translucent panels and transparent or selective glass surfaces. There is a cleaning problem. Energy supply is also high performance (Uğur, 2006).

f) Curved broken curtain walls: Since the curtain wall is broken, its cost is high. Curved curtain walls have the same performance and have a cleaning problem like them. As can beseen in Figure 4.25, the PV module in the curved part and the vertical part both provide high performance and provide solar control by using glass. As with the sloping walls, uniqueness occurs between the floor plans and the building mostly rests on the land (Çelebi, 2002).

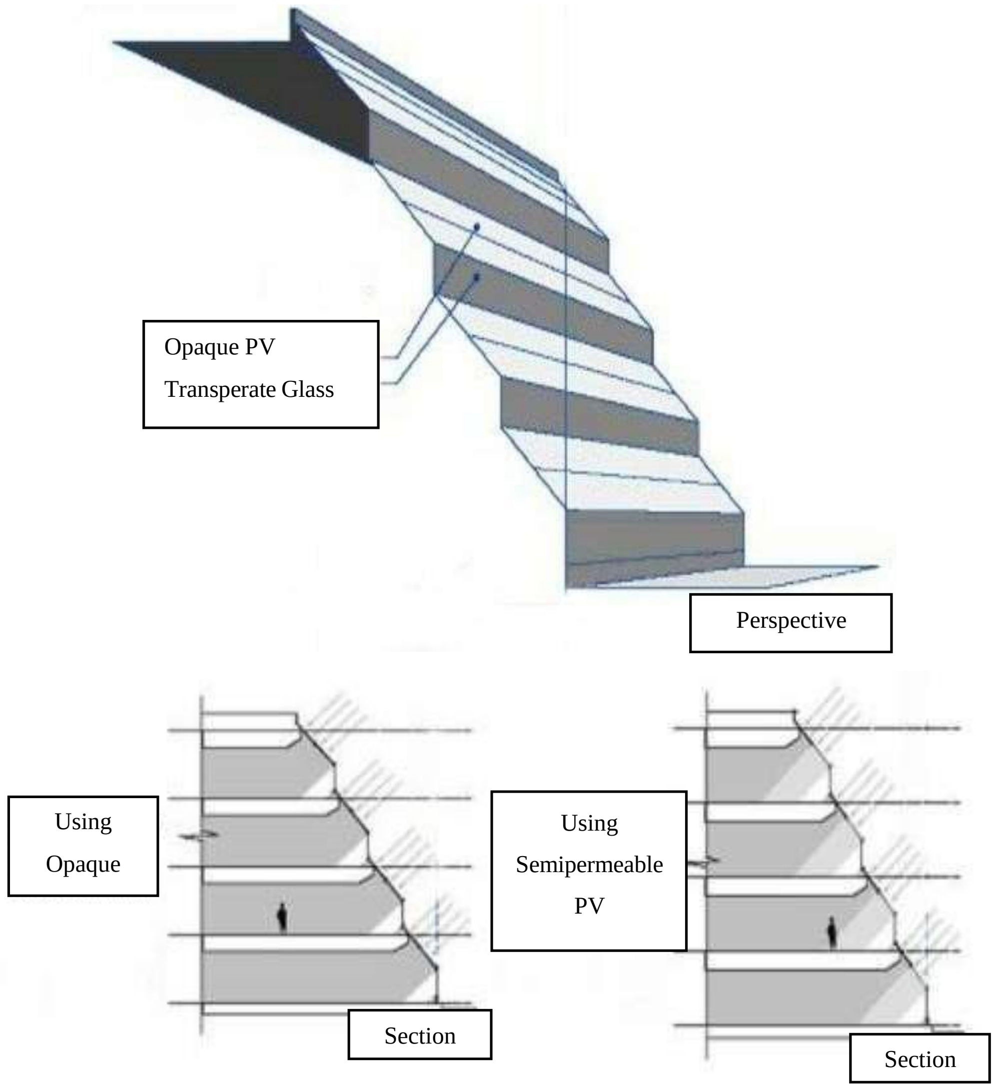

Figure 4.25: Usage of PV module in curved broken curtain wall (Sayın, 2006)

There are additional construction costs due to fractures. Opaque glass is used on the curved surface, and transparent glass is used on the vertical surface. It is considered to have almost the same performance as the inclined planar curtain wall (Keles, 2008).

2) *Rain-Screen facade PV:* Rain curtains are layers that protect the structure from the adverse effects of weather conditions, formed by carrier grids mounted on the structure or panels attached to the mounting rails, preferably with clips or claw fittings. In the creation of rain curtains, a minimum of 10 cm air gap should be left between the panels and the structure. The air gap not only provides ventilation and water discharge behind the panels, but also creates an ideal space for cable transits that must be installed between solar cell panels. Figure 5.18 shows the principle of creating rain curtains with solar cell panels (Uğur, 2006).

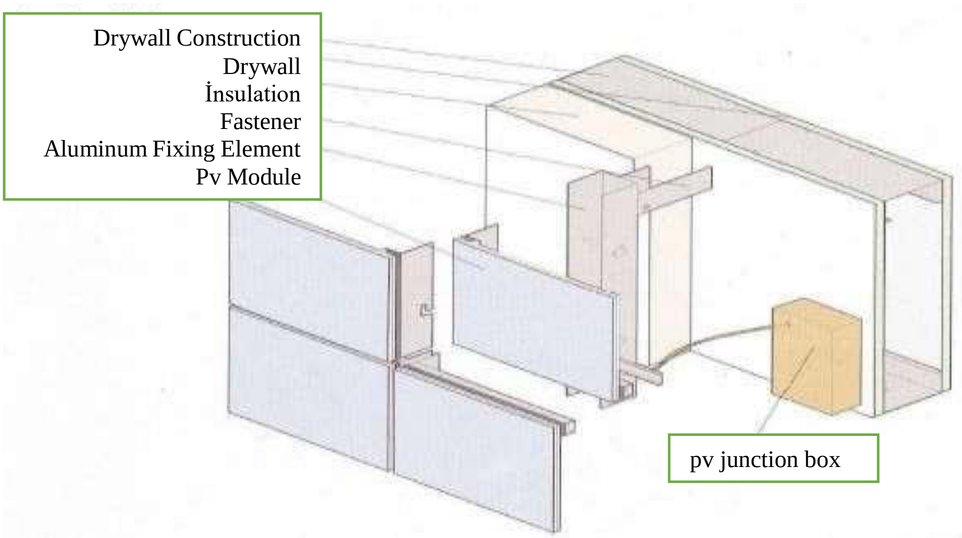

Figure 4.26: PV curtain wall system details (Gemicioğlu, 2011)

We can divide the rain wall framing system into 2; pressure plates system and structural silicone glazing system. In the pressure plates system, the glass unit is held mechanically from the front with a coated plate. In the structural silicone glazing system, the edges of the glass are glued to the frame system. In the pressure plates system, the frame system is formed by the combination of vertical and horizontal partitions. The depths of the partitions must be of a size that will not create shadow. In structural silicone glazing system, there is no problem such as shade formation, while air tightness problems arise (Keles, 2008).We can examine the rain walls in 3 groups;

a) Single wall facades
b) Double wall facades
c) Smart facade

a) Using PVs as single faced (cold facades); Single-wall facades are hollow wall elements. This application is the use of PVs by taking the functions and location of the wall element. PV modules are the wall itself. Since PV modules are only the elements that separate the internal and external environment, the insulation problems are solved behind the PV modules (Keleş, 2008).

b) Using PVs as double facades (warm facades); It is not possible for this application to replace and replace the functions of the PV element of the wall element. In this application, there is already a wall and PV modules are laid over this wall. There is a wall between the inner and outer surface, and the isolation problem is not solved on the PV module, and the necessary insulation measure is taken on the wall (Keles, 2008).

c) Using PVs as smart facades ; Smart facades are facades that use renewable energy sources, provide natural ventilation, protect the building from external influences and produce their own energy. Smart facades are divided into two walls, single wall and double wall. PVs integrated into the building are generally used in double-wall facades (Keles, 2008).

In this type of facade, in addition to the facade, a transparent glass shell is configured in front of the existing facade, providing thermal insulation and sound insulation. An unheated thermal buffer area between the interior and the exterior is a section that is ventilated if desired and includes solar shading systems. These facades are designed to adapt to environmental conditions and balance climatic fluctuations. Thus, heating, cooling, lighting and wind are adjusted to catch the optimum conditions without using complex technology or energy. PV integration on the exterior is very convenient and also takes on the role of solar shading (Keles, 2008).

3) Using as a shading element: In order to provide passive solar heating, solar radiation is an element that is desired in the building in winter and should be checked in summer. Providing control inside or outside the façade is optional. On the other hand, solar shades applied to the facade should be planned during the design phase, as controlling the sun's rays outside the facade, reducing the cooling loads of the interior and preventing excessive light level in the work spaces (Keles, 2008).

An additional construction is required for shade elements that can be integrated later in the building. They can be applied horizontally as well as vertically, inclined or mobile. Photovoltaic panel shading systems integrated into the structure provide both natural light control and sufficient use of natural light. (Figure 4.27) Waterproofing problems may arise in the integration of solar shading with the building envelope. The construction details must be solved well to ensure insulation (Oluklulu, 2001).

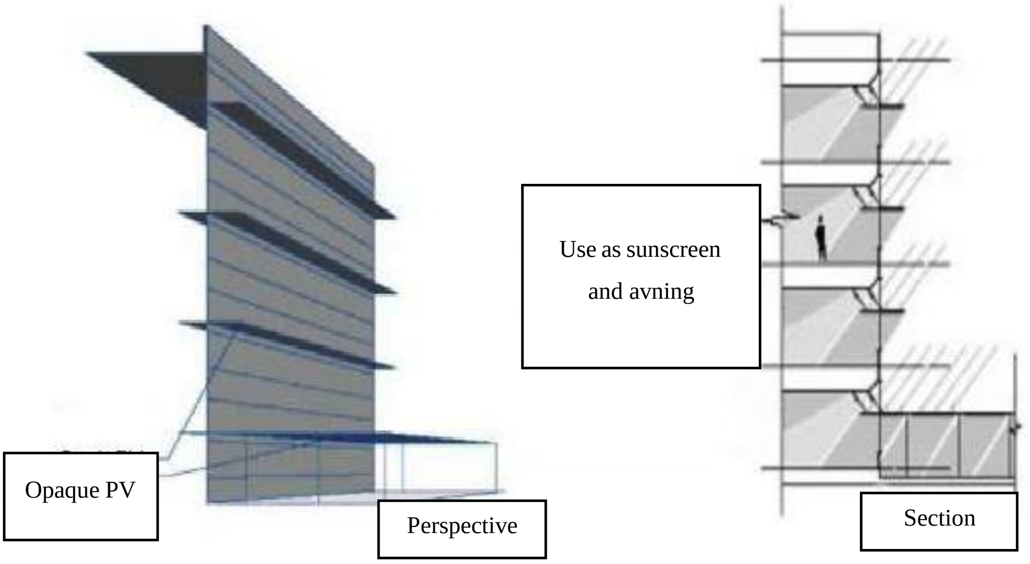

Figure 4.27: Using PV modules as solar shading (Sayın, 2006)

We can classify sunscreens in four different ways;

a) Horizontal solar shading
b) Vertical sun shading
c) Fixed solar shading
d) Movable sun shading

a) Horizontal solar shading; They are the elements designed for solar control in building shells facing south. They are used to cut the sun's rays in the summer, when the sun's rays come at right angles and direct rays negatively affect the interior comfort conditions.

In winter, they are used to absorb the slanting sun rays to the maximum extent and increase the indoor heat and brightness level (Uğur, 2006).

Figure 4.28: Horizontal solar shading (Yücel, 2016)

b) ***Vertical sun shading:*** They are used together with mixed sun shades to control the sun rays hitting the facade at a narrow angle on the east and west facades of the building envelope. Unlike horizontal solar shades that do not affect the viewing angle of the façade opening, vertical sunshades are façade elements that limit visibility (Keles, 2008).

Figure 4.29: Vertical sun breaker curtain wall example (Yücel, 2016)

c) ***Fixed solar shading:*** It is fixed to the structure directly. It is not possible to move or change its direction. Fixed solar shades are the simplest version of the sun shades on the front and can be very impressive if used properly. PV modules with laminated and safety glass are fixed to provide the necessary slope to the cantilever roof supports. While the correct size and depth protects against the sun in summer, it also allows the sunlight coming in the winter to penetrate the building (Keles, 2008).

Figure 4.30: Fixed sunbreak facades (Yücel, 2016)

d) ***Movable sun shading*****:** Includes blinds, sun visors, expandable canopy and sheds. It can be adjusted according to the intensity of sunlight coming vertically and horizontally and the need of sunlight. Usually it is directed on one axle according to the angle of rise of the sun on the vertical or horizontal axis (Keles, 2008).

Integration of solar cells with mobile solar shades is appropriate. In the louver systems lined up one on the front, each louver is not shaded by the upper louver. With translucent solar cells, outside weather conditions and sky can also be seen. The efficiency is high in these systems (Yücel, 2016).

Figure 4.31: Using PV as a moving shading element (Gemicioğlu, 2011)

4.5.3. Use of photovoltaic systems as other building elements

PVs can be integrated into building sections such as verandas, shutters, eaves, balustrades. While these integrations add mobility to the building, they can also reduce energy costs of buildings by generating energy. The use of PVs on the verandas is shown in Figure 4.32, the use of solar shutters is shown in Figure 4.33, the eaves are used in Figure 4.34 and the railing is shown in Figure 4.35 (Gemicioğlu, 2011).

Figure 4.32: Use of PV's on verandas, Australia (Gemicioğlu, 2011)

Figure 4.33: Use of PV in solar shutters, Germany (Gemicioğlu, 2011)

Figure 4.34: PV's in eaves, Spain (Gemicioğlu, 2011)

Figure 4.35: Using PV's in building railings, Finland (Gemicioğlu, 2011)

4.5.4. Advantages of using PV systems as facade or roof

- Apart from the traditional function of the building envelope, the fact that it has a system that can produce energy adds a new dimension to the building designs.
- Since PV modules can be produced in very variable sizes and structures, they can be designed in a variety of ways in appearance.
- In order to integrate PV modules into structures, there is no need for additional space and any mechanism to support the module.

- PV modules are designed as permeable or semi-permeable, providing solar control of the structure and contributing to the gain in terms of passive.
- Since they can be produced in color, their visual effects and their use will be widespread.
- Since the PV modules integrated into the structures are designed as a grid-connected system, there is no battery costs that require storage.
- Network electricity such as rural areas is considered as a system that can be an alternative in regions with high transportation cost (Sayın, 2006).

CHAPTER 5
PROBLEMS AND SUGGESTIONS IN APPLICATION RELATED TO THE USE OF PHOTOVOLTAIC SYSTEMS IN BUILDINGS

5.1. The Photovoltaic Sector

Solar energy is increasingly used because of its renewable and clean properties. In this regard, Germany, Japan, America, the Netherlands stand out as the most advanced examples. It is known that the mentioned states and European Union's public policies to increase the use of solar energy are the basis of their success in this field. It is remarkable that these policies are in harmony and in close relation with the environmental protection measures developed at the international, regional and state level. In order to use solar energy as a clean and renewable energy source and to expand its use, it is necessary to evaluate the necessary legal and administrative infrastructure, considering that our country is on the world solar belt. The Photovoltaic Sector consists of the following actors and its success depends on the realization of the works determined in the targeted periods:

- State: In the short term, it is necessary to establish legal regulations and incentive mechanisms, to implement promotional projects in public institutions, and to give appropriate interest and term loans. In the medium term, incentive mechanisms of production and exports should be established.
- Academy: First, short-term and certified courses for the sector should be organized, thin film technology should be researched and a national PV Ar-Ge center should be established. Simple laboratory experiments and PV projects should be created in secondary education institutions for PV energy, and participation in international Ar-Ge projects should be ensured. In the long term, the infrastructure and technical staff potential needed to develop existing PV technologies and to establish national technology should be created.
- Manufacturer: Market research should be done in the short term, a silicon module assembly line with an annual production capacity of 500 KWp should be installed.

In the medium term, a thin film production and assembly line with an annual production capacity of 5 MWp should be established, and the production cost should be at the same level as Europe. In addition, PVs should be developed as a structural element (brick, glass, tile, etc.). In the long term, a thin film PV panel facility with a capacity of> 30 MWp / year should be established, and technologies that will compete in global PV markets should be closely monitored.

- Distributor: PVs should be promoted and marketed first, and PV experiment kits should be distributed to secondary education institutions. Then, export research should be done gradually with the manufacturer.
- Practitioner: Standards should be determined together with the state and academia, and technical regulations and implementation details should be prepared. Then, ecological and economic architecture should be expanded, and necessary projects and application methods should be developed to meet all energy needs of a house with PV and other solar applications.
- Electricity Company: In the first place, the grid connected to the grid should be researched and developed, and then the small and large projects should be adapted to the grid. In the long term, a minimum of 1% of the total energy distributed must be met by incentives from solar energy. The steps taken in Turkey than in chess events described above and should limit the use of photovoltaic of the done very slowly in this case. There is Turkey's advantages in the development sector (İkinci Sarıgerme, 2001).

5.2. Support Points in the Creation of the Photovoltaic Sector

- Solar generation (an average of 1311 kWh / m2 per year)
- The industry is very open to development
- Overseas sectoral experiences are known
- Global development of PV
- International financial resources
- Prices of fossil fuel sources tend to be expensive
- PV prices are gradually falling

- Being environmentally friendly
- Production in having attractive conditions in Turkey
- Local PV inadequacy in electricity transmission distribution lines relief if used
- Unlike all other technologies, PV can be used anywhere (Keles, 2008).

In order for PV to become a competitive economic sector within the supply-demand balance, local, national, international financial incentives and supports should be provided as soon as possible, cooperation models should be created at every scale and pioneering practices should be initiated. Public buildings should be contacted to benefit from solar energy, modular fixed and mobile generators should be used in rural areas outside of the network, and exemplary applications should be applied in facade, roof and urban furniture in non-residential buildings (İkinci Sarıgerme, 2001).

The indispensable condition of being a fully developed country; In addition to achieving technological goals, it is to be a society that can evaluate social and socioeconomic results in an integrated manner, question, participate, and have a national environmental and energy consciousness. In order to speak of an integrated assessment, it is also necessary to internalize social costs that were previously ignored and not taken into account. Social costs associated with the destruction of ecosystems should also be included in the calculations as much as possible; The fact that the social costs to be calculated will constitute a minimum and the real costs are surely more than that should be known (İkinci Sarıgerme, 2001).

5.3. Problems Encountered in Application

The most important factors in the limited use of photovoltaic systems in buildings in our country,

1) The cost of the system is expensive,
2) In this context, the level of consciousness is not sufficiently developed,
3) Systems not recognized by designers and producers

1) High cost: Operation and maintenance costs of photovoltaic systems are low. In this regard, investment cost constitutes a significant part of the system cost. In the coming years, it is expected that investment costs will decrease as a result of realization of high efficiency batteries and development of module construction and design techniques depending on the development of production technology. Therefore, as a result of these developments, it is estimated that high power solar cells that take up less space will be produced and become more practical. According to the cost calculation, electricity production by using solar cells is expensive compared to other methods. It is a fact that the cost of electricity to be produced with photovoltaic panels will decrease in the future, as the prices of fossil fuels will increase due to the decrease in their lifespan and technological developments and efficiency increase. As a result of technological developments within 5-6 years, a 40-50% reduction in electricity generation costs is expected. Moreover, our country's orientation towards alternative energy sources is of vital importance both at the point of evaluating its potential and at the solution of the energy crisis we will face in the future (Keles, 2008).

2) ***Lack of education:*** It can be said that one of the most important factors in the limited use of PV systems and the insufficiency of these systems is the lack of education. For the establishment and development of social consciousness, it is recommended that environmental and energy education should be given within the formal education with the "Common Model" approach. The common model can be expressed as the preparation and presentation of the contents of all the basic, applied, social and vocational courses in the education programs with the awareness of environment and energy, instead of putting specific courses on environment and energy as a principle. The places where the common model approach can be implemented are listed below:

- In primary and secondary education, awareness should be raised on energy efficiency and PV systems in accordance with the common model within the scope of science and social studies.
- Environment, energy education, solar energy (PV systems) should be an integral part of the pedagogical formation to be provided to educators.
- Specialists and researchers should be trained in the fields of environment, energy and PV system at universities.

- Mass education programs should be prepared for all citizens. TV, radio, magazine, newspaper, internet, theater etc. institutions and organizations should lead this issue. In addition, groups such as professional chambers, military branches, local administrations, religious officials, political parties are mass educational areas where this function will be fulfilled (Keles, 2008).

3) ***Insufficient information:*** The photovoltaic sector in our country is predominantly an importer. There is no company in our country that produces panels in a commercial sense yet. There are several companies that do Ar-Ge studies with universities. However, they have not yet started mass production in commercial terms. All of the sector companies import panels from abroad. Panels imported due to high taxation have to be sold at high prices. This is; It causes the photovoltaic applications to be limited to a maximum of a few hundred kW applications, not MW. The same applies to the inverter, battery and charge control devices. Since these products are produced exclusively for photovoltaic systems, they are often imported together with panels (Keles, 2008).

5.4. Suggestions

It will be useful to lead the related government institutions, which are the most important actors in the implementation of photovoltaic systems in buildings, and the most important actor in disseminating the use of PV by realizing the suggestions on this matter. State institutions, researchers working at the university, designers, producers and decision makers in the sector should work together to achieve significant breakthroughs in solving problems. The regulations to be prepared on the subject should be a guideline that defines photovoltaic systems and energy efficient buildings, contains PV applications related to high-tech buildings, and provides technical information and criteria guiding architects / engineers and building users. With such a resource and appropriate structural arrangements, it can be possible to renew these buildings to use energy efficiently and to design and realize new buildings as energy efficient buildings by using PV in existing buildings.

CHAPTER 6
SPECIFICATION OF ELECTRICITY GENERATION FACILITIES BASED ON SOLAR ENERGY UP TO 50 kWe

TEDAŞ will open the way for small investors especially in the solar energy sector; He published the Type Specification of Solar Power Based Electricity Generation Plants Up to 50 kW.The projects to be prepared according to the specification; There will also be no fees for design conformity reviews and acceptance processes. Performing the same procedures for all projects in the solar energy sector, carrying out the same application process in every project without saying small or large, caused serious problems in the sector. Especially in small projects, the “project approval cost” was almost equal to the system cost, thus preventing the development of roof applications where such facilities were most frequently installed. All is a time to eliminate these problems and engaged in the work of the Specification TEDAŞ, which has contributed greatly to its implementation, has presented a road map on how to design and build small facilities with a Type Specification of up to 50 kW (Yenienerji, 2015)

In the announcement made by TEDAŞ, it is stated that the specification of the power plants and the power of small power plants based on solar energy is aimed and the following information is summarized

‘Unlicensed electricity generation process started with 2011 and 2012; With the publication of the Electricity Market Law No. 6446, it was revised and entered into force in 2013.

As a result of these regulations, it has created a vitality in the sector, and the number and capacities of applications for unlicensed electricity generation have increased rapidly and continue to increase. In addition, within the scope of the "Electrical Facilities Project Regulation" published in 2014, regarding the Electrical Facilities; Within the scope of the Approval of the Ministry Authority dated 2015 and numbered 58 of the Project Approval, Acceptance and Record Approval processes; Approval, acceptance and minutes approval authorization of Unlicensed Production Facility projects have been given to TEDAŞ General Directorate. Many production facility projects have been approved and put into operation at a power of approximately 200 MW (Yenienerji, 2015)

6.1. Purpose

The purpose of this specification includes conditions and information for the design, implementation and commissioning of power plants based on the PV system to generate electricity from solar radiation. The relevant legislation includes the necessary conditions for the plants operating in parallel with the network in accordance with the relevant technical legislation and national / international standards. This Specification has been prepared in order to determine the design, application and operation rules that will ensure safe and proper operation of photovoltaic plants based on solar energy with a voltage of up to 50 Hz, 1000 V AC or 1500 V DC voltage (including these values) (TEDAŞ, 2015).

6.2. Scope

This Specification; Within the scope of the Regulation on Unlicensed Electricity Generation in the Electricity Market (LÜY), a connection letter and / or a letter of call for the connection agreement has been given and the design suitability of the solar power plant (GES) facilities is positive;

- Regulation on Electricity Market Unlicensed Electricity Generation (Luy) under the photovoltaic-based technology to the production of electrical energy and installed capacity of 50 Kw (50 Kw included) network running in parallel with PV systems up,
- The energy obtained from the PV panel is stored and operated in parallel cordless network, power board 50 Kw (50 kW included) GES systems up it includes PV systems.

The following facilities are not covered by this Specification;

- Licensed power plants based on solar energy,
- PV plants connected from MV,

- Photovoltaic production facilities that work isolated from the network.

If an instability arises as to whether any facility will be covered by this Specification; The decision of the Ministry of Energy and Natural Resources on this matter is valid (TEDAŞ, 2015).

6.3. Basis

This Specification has been prepared based on the provisions of the Regulation on the Production of Unlicensed Electricity in the Electricity Market and the Communiqué on the Implementation of the Regulation on the Production of Unlicensed Electricity in the Electricity Market (TEDAŞ, 2015).

6.4. Standards

All equipment used in the design and installation of the PV system within the scope of this specification will be in accordance with the latest Turkish Standards (TS) International Electrotechnical Commission (IEC, EN, HD, ISO) Standards and the latest editions of other standards (TEDAŞ, 2015).

Table 6.1: PV system design Turkish standarts (TEDAŞ, 2015)

TS Standad Number	**IEC, EN, HD, ISO Standard Its Number**	**Standard Name**
TS HD 60364	IEC 60364 (All Sections)	Low voltage electrical installation
	IEC 60364-6	Low voltage electrical wiring - Part 6: Verification
	IEC 60364 7 712	Electrical installation in buildings - Part 7 712: Special installation and layout requirements - Photovoltaic (PV) power supply systems
TS IEC 60755	IEC 60755	Current-operated protective devices-General rules.
TS EN 61557	IEC 61557 (All Sections)	Electrical safety in low voltage distribution systems - up to 1000 V AC and 1500 V DC – Equipment for testing, measuring or monitoring protective devices.

TS EN 61730	IEC 61730 (All Divisions)	Photovoltaic (PV) module safety feature
TS EN 50438	IEC 50438	Rules for parallel connection of micro generators with low voltage distribution networks .
TSE K 191		Connection rules for generators with a phase current greater than 16 A. - AG to distribution system connecting from the level
TSE K 192		Connection rules for generators with a phase current greater than 16 A. - MV to the distribution system connecting from the level
TSE EN 62446	IEC 62446	Grid-connected photovoltaic systems-System documentation, commissioning experiments and minimum rules for inspection.
TSE EN 5021	IEC 50521	Binders for photovoltaic systems - Safety rules and experiments.
TSE EN 62305	IEC 62305	Year Protection
TS CLC / TS 50539-12		Protective device against sudden surges for low voltage - protective device against sudden surges for specific applications including DC voltage - - Part 12: Selection and use of ESAs - Photovoltaic to the installations connected to the SPD's.
	IEC 62548	PV Strings. Design requirements.

CHAPTER 7
APPLICATION METHODOLOGY FOR BAPV SYSTEMS

7.1. Building Analysis

7.1.1. Climate data analysis

The sunshine time, temperature, rainfall, humidity etc of the current location. It is necessary to have information about climate data. The temperature and radiation coefficients of each product are different. For this reason, this analysis will directly affect technology and product selection (Güneş, 2019).

7.1.2. Location and direction selection

The amount of radiation varies according to the angle of the system to be installed to the Sun. For this reason, it should be ensured that the radiation hits the FV module perpendicularly throughout the year. The location and direction selection is very important for us to use the areas deemed suitable in the building in the most optimum way (Güneş, 2019).

7.1.3. Shading analysis

After choosing the location and direction, shading analysis should be done. The shade has a direct and continuous negative effect on production. Although it is not possible to reduce this effect to 0 in building applications, it should be kept to a minimum (Güneş, 2019).

7.1.4. Consumption analysis

Thanks to the consumption analysis, we determine the amount of electricity we need and the power we need to set up. This analysis will help us find out whether the system to be installed will be financially viable as it constitutes our current cost item (Güneş, 2019).

7.2. Standards and Legislations

Each stage of the system planned to be installed should be planned and implemented in accordance with the relevant standards and regulations. For this reason, standards should be researched and related items should be applied (Güneş, 2019).

7.3. PV Design Analysis

7.3.1. Technology and product selection

After determining the size of the system to be installed with consumption analysis, climate data analysis, climate status, location selection and shading analysis, and the appropriate area, the most appropriate technology and products should be selected for these parameters. At this stage, simulation studies are of great importance. The most suitable products are selected according to the simulation result (Güneş, 2019).

7.3.2. Appropriate electrical design

The voltage value required for each inverter to reach its maximum power point is different. Electrical design is of great importance here. In order for the system to work at high efficiency, the most appropriate design must be made. Simulation studies are of great importance for this section (Güneş, 2019).

7.4. Production Analysis

Production analysis is required to construct a photovoltaic system that can meet consumption data based on climate data. In this way, it is determined how powerful a photovoltaic system will be installed in the existing building with the selected technologies and products (Güneş, 2019).

CHAPTER 8
A SAMPLE BIPV APPLICATION

As a case study; The two-storey office building of Filitoğlu Petrol located in Dörtyol District of Hatay Province has been selected. In the image below, the yellow area indicates the oil office. Below is the Google Earth image of the example building. The sample house is shown in Figure 8.1.

Figure 8.1: Google earth image of the sample building (Filitoğlu GO Petrol)

In the 2 floor building chosen as an example building; There are 4 rooms and a market on the ground floor and 6 rooms on the 1st floor. The second floor is used as a storage. Total building construction area is 756 m2. The roffice area of the building is 340 m2. In this building, where there is no elevator, the roof is triangular.

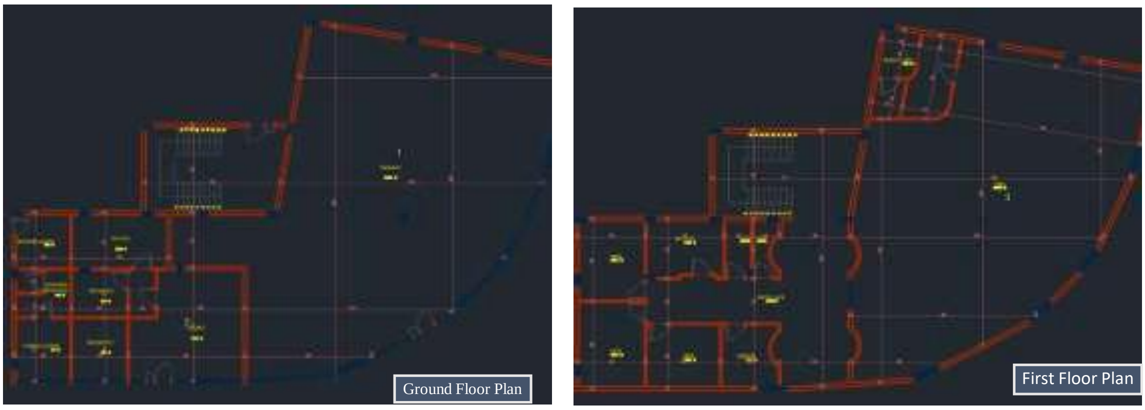

Figure 8.2: Floor plans of the sample building

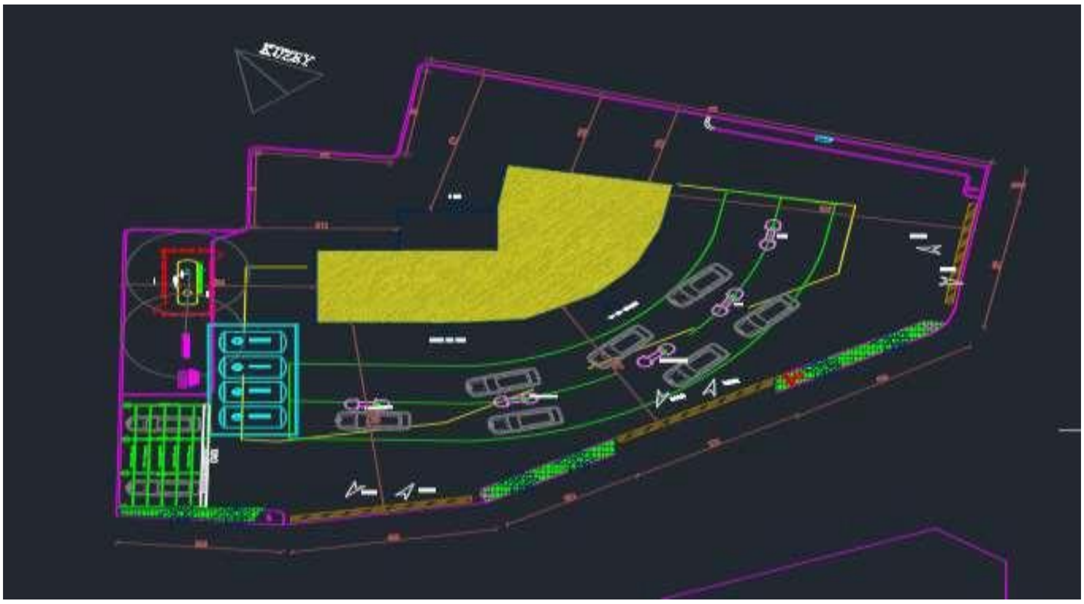

Figure 8.3: Site plan of the sample building

8.1. Building Analysis

8.1.1 Climate data analysis

Although Dörtyol's annual total solar energy varies depending on the aspect, it varies between 1450-1750 kWh / m². (Figure 8.4). Annual total sunshine duration is 2997 hours and annual total radiation amount is 1536 kWh / m².year (daily average 4.21 kWh / m².day). The reason why the amount of radiation is partially low compared to the duration of sunbathing is related to topography features and climatic conditions. In Dörtyol, where the

Mediterranean climate is dominant, the high amount of humidity and the number of foggy days and the higher altitude in terms of topography reduce the amount of radiation partially. Considering the time and the sun radiation values are above the average of Turkey is seen as a high solar energy potential. Average radiation values and sunshine times by months are given in Figure 8.5 (Geçen, 2019).

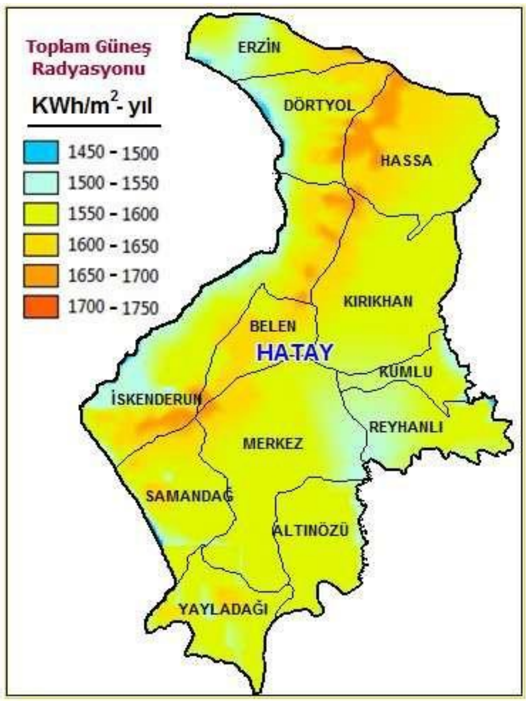

Figure 8.4: Hatay-Dörtyol solar energy potential (TC Enerji ve Tabi Kaynaklar Bakanlığı)

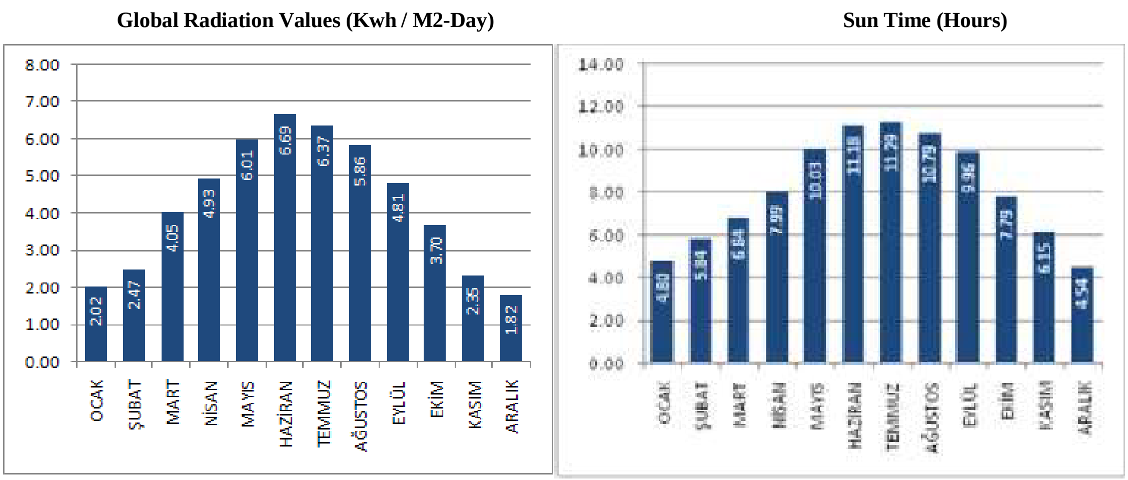

Figure 8.5: Radiation amount and sunbathing times by month in Hatay-Dörtyol (TC Enerji ve Tabi Kaynaklar Bakanlığı)

Dörtyol has a typical Mediterranean climate. 70 m altitude in the district, most rainfall in Rize province after centers in Turkey. The average humidity is 48.3 %. It receives the most precipitation in December, January, February and March, and the least in August. As of the end of 2013, the temperature was the highest 43.2 ° C and the lowest 2.00 ° C. The surface area of the district is 342 Km² (TC Dörtyol Kaymakamlığı, 2015).

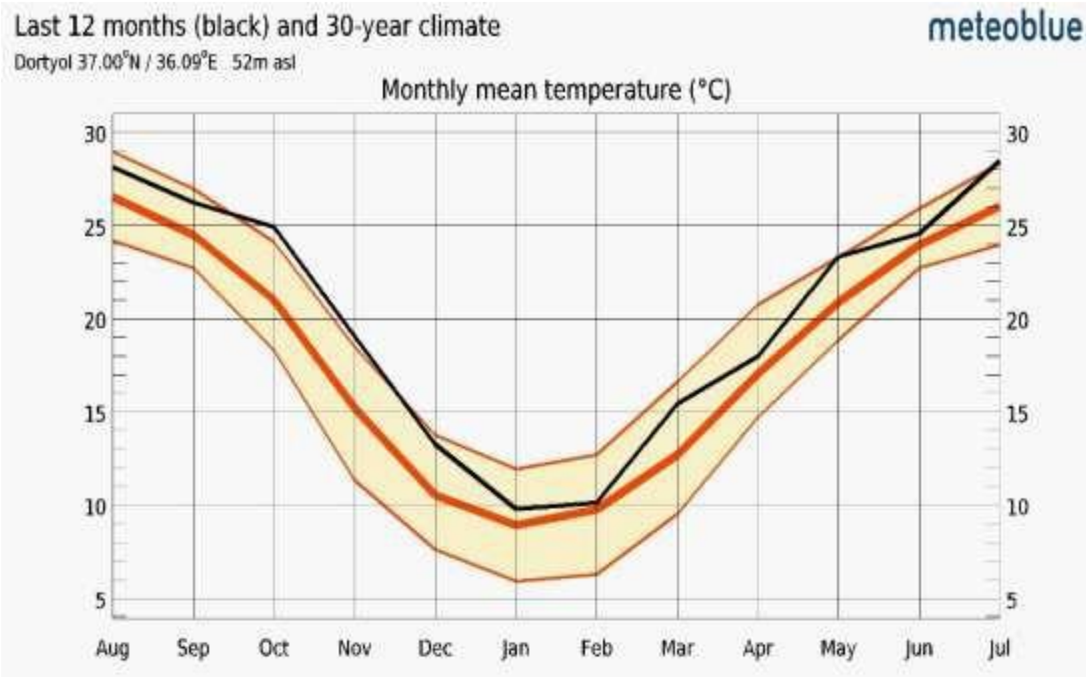

Figure 8.6: Monthly avarage temperature graph of 2019 (Meteoblue)

This diagram shows the current season compared to the average climate for Dörtyol. The diagram is labeled with temperature and months.

- The black line shows the mean temperature for every month of the last 12 months (current).
- The thick red line shows the calculated mean temperature of the last 30 years for every month (climate). This line denotes the exact mean of the temperatures but does not reveal fluctuations of the temperature from year to year.
- The orange buffer around the red line makes the fluctuations between the last 30 years more visible. It shows in what range the temperatures of the last 30 years are distributed. It shows the maximum monthly mean and the minimum monthly mean of the last 30 years (Meteoblue).

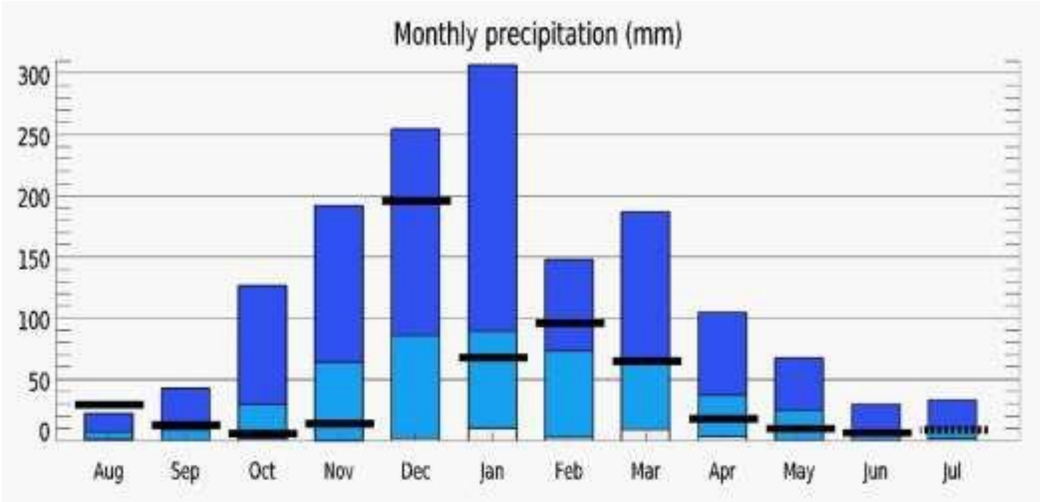

Figure 8.7: Average monthly precipitation graph for 2019 (Meteoblue)

The monthly precipitation diagram for Dörtyol shows the precipitation for every month of the last 12 months based on the precipitation of the last 30 years. The chart is labeled in millimeters and months.

- The black bars show the recorded precipitation for each current month.
- The dark blue bars show the maximum amount of precipitation during the last 30 years for each month. The light blue bars show the minimum amount of precipitation during the last 30 years.
- The boundary between dark blue and light blue is the monthly mean precipitation calculated from the last 30 years (Meteoblue).

8.1.2. Location and direction selection

Dörtyol, located between 36.925 0 - 36.805 0 North parallels and 36.075 0 - 36.300 0 East meridians. In the east of the Mediterranean Region; There are Amanos mountains and Hassa in the east, Payas in the south, İskenderun in the west and Erzin district in the north.

The roof of the existing building is the pitched roof. The south, south-west and south-east facades are suitable for use. We will use the south facade to get high performance from the panels. The degree of azimuth (angle to the south) of the southern facade is 0 °, and the slope of the roof is 32°. The usable area value of the roof for the solar panel is about 340 m2.

Figure 8.8: South view of existing building

8.1.3. Shading analysis

The location of the chimneys on the roof and the absence of other obstacles keep shadow losses at low values. As seen in Figure 8.9, the stairs and other equipment of the existing building are located on the north facade. The possibility of shading of the panels is very low.

Figure 8.9: East view of existing building

Another important issue is the change of the angle that the sun makes to the earth every day. Radiations that are perpendicular to the summer fall to the earth at a narrower angle in winter. When we calculate hourly production for the longest day, July 21 and the shortest night, December 21, we see the production values for the longest day of the western part and the shortest day of the year. This analysis gives us more detailed and concrete information about the production profile of the system. In addition, although we say that solar panels are negatively affected by temperature, we see the effect of clouding by examining hot and cold days.

8.1.4. Consumption analysis

When the consumption profile is examined, energy consumption in winter is higher than in summer. This situation shows us that a special care must be taken in production analysis. Because sunbathing hours differ in winter and summer. Studies should proceed based on winter consumption.

The annual electricity consumption value of the building is explained below.

Table 8.1: Annual electricity consumption chart of the sample building on a monthly basis

Months	The Amount of Electricity Consumed	Energy Consumption
January	5.921 tl	6,713 KWh
February	7.512 tl	8.493 KWh
March	7.347 tl	7.903 KWh
April	5.187 tl	5.660 KWh
May	5.913 tl	6.162 KWh
June	4.513 tl	4.715 KWh
July	4.963 tl	6.985 KWh
August	6.686 tl	8.506 KWh
September	8.296 tl	10.542 KWh
October	7.488 tl	9.365 KWh

November	6.062 tl	6.873 KWh
December	4.833 tl	5.479 KWh
Total	74.721TL	87.396 KWh
Average	6.226 TL	7.283 KWh

8.2.Standards and Regulations

In Turkey, 50 kW (50 kW included) features a rooftop legislation. The photovoltaic system we have established takes advantage of this legislation. All equipment used in the design and installation of the PV system under this legislation will comply with the latest editions of the Turkish Standards (TS), International Electrotechnical Commission (IEC, EN, HD, ISO) Standards and other standards.

8.3. PV Design Analysis

8.3.1. Technology and product selection

The selection criteria of solar panels and inverters, which are two important products that enable us to produce electricity and transmit it to the network, differ in each application. The points that we should be careful about in this application will be as follows for these two product groups.

1) ***Choosing of Solar panel:*** Since low air gaps in roof applications increase the temperature of the panels rapidly, temperature resistant solar panels should be chosen. This leads us to panel groups where the current temperature coefficient is low. Another issue is the use of solar panels consisting of efficient cells. In this way, a production facility with more capacity will be installed. The most efficient solar panel among PV panel types in this project, whose system size is designed as 50 kWp; monocrystal panel selected. This solar panel type generates great energy in a small space. The usage and electricity production life of these solar panels are longer. Monocrystalline solar panels can work more

efficiently in hot climates and the efficiency rate is around 24%. This rate is much higher than other solar panels on the market. Some of its advantages are as follows;

- High conversion efficiency
- Excellent strength capacity
- High efficiency in low beam
- Self-cleaning glass that reduces reflection
- Easy setup

2) ***Choosing of inverter:*** The inverter selected in this project is ABB On-Grid inverter Uno-Dm 50. A single 3-phase inverter will be used.

8.3.2. Appropriate electrical design

This design; It was created by considering that the building has a consumption counter of 50 kW. 157 pieces of 320w monocrystalline solar panel will be used. Shades will be calculated and placed in the required places on the roof. The inverter can be placed below if there is no space on the roof.

8.4. Production Analysis

The power generation capacity of the power plant per kW per year is estimated to be 1,422.4 kWh on average. Filitoğlu Petrol GES will contribute to the evaluation of domestic and renewable resources of our country. It is planned to meet 82% of the electricity to be taken from the network thanks to the on-site production in this amount to be realized at the consumption point. Approximately 71.118 kWh of energy will be prevented from polluting the environment annually and approximately 73.323 kg of CO2 emission will be prevented annually. The values given in the figures below are obtained from the numerical values SOLMART weri base (SOLMART, 2020).

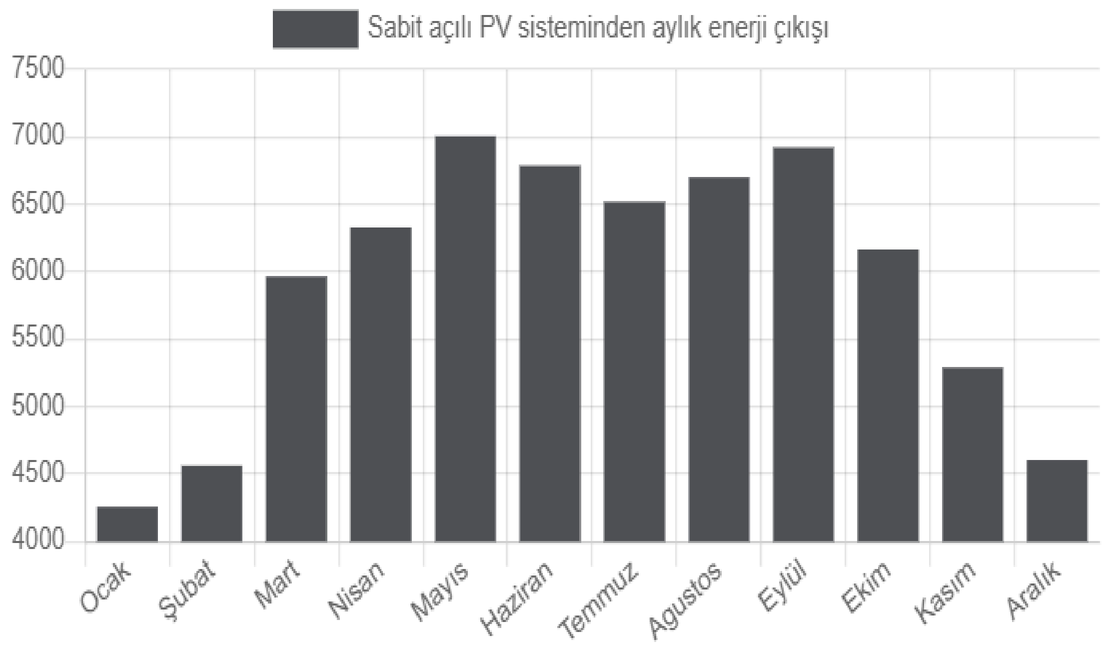

Figure 8.10: Expected monthly energy production data (SOLMART, 2020)

As seen in Figure 8.8, the most efficient months of photovoltaic batteries are May and September. Dörtyol is located in terms of location and climate; photovoltaic efficiency decreases in the summer months. Altitude and temperature affect the performance of the batteries.

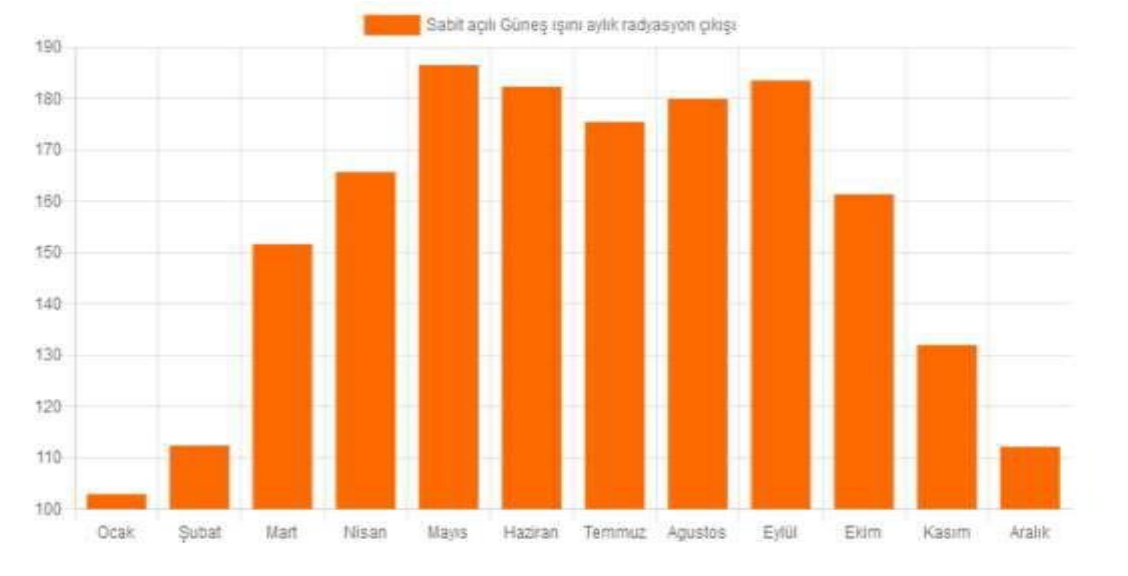

Figure 8.11: Monthly solar radiation data (SOLMART, 2020)

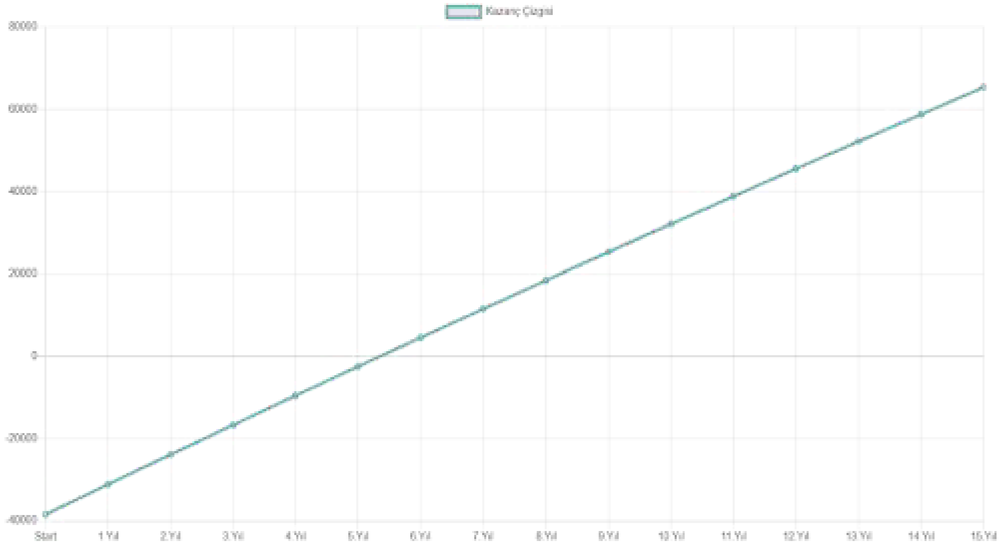

Figure 8.12: Expected annual earning gain curve (SOLMART, 2020)

CHAPTER 9
CONCLUSION

Most of the energy sources we use in the world are fossil based (such as coal, oil, natural gas) energy sources. Investments, developing technologies and industries are based on these energy sources. These sources are consumable energy sources. The CO2 gas released as a result of the burning of the fossil-based resources used as waste to the atmosphere pollutes our world and causes serious environmental disasters that cannot be prevented. The need for energy has increased day by day with the rapid growth of the world population, the increase of technological innovations and investments, and the progress of industry and industry.

As an infinite energy source, the sun is the most advantageous of alternative and renewable energy sources. Electricity generation from solar energy is possible with solar cells called photovoltaics. Photovltaic solar cells are converters that convert solar rays into direct current, and the raw material of photovoltaic solar cells is silicon, which is abundant in nature, like the sun. When the energies used in the world are analyzed, it is seen that the energy used in the buildings has a big share. Energy wastes consumed in the buildings harm the environment to a great extent and cause the exhaustion of fossil energies. For this reason, the use of renewable energy sources in buildings is of great importance. The use of solar energy systems in buildings is inevitable.

In the architecture, areas that are not used with photovoltaic systems applied on roofs are evaluated and energy production is provided. Photovoltaic systems used on the building facade are applied as curtain walls. On the facades where translucent and opaque photovoltaic glasses are used, the amount of energy consumed by reducing the comfort conditions of the space is reduced and energy is also produced.

The first year generation value of the BIPV system, which was planned as 50 kWp, was analyzed as 71.118 MWh. It is predicted that 209.440 MWh electricity will be produced by the end of 25 years. The daily electricity consumption of the building, whose daily electricity usage is 1.777.95 kWh, is calculated as 194.8 kWh. It is expected to provide 23.95% return in 5 years. Project information is given in Table 9.1.

Table 9.1: System production data

Location of Building	Dortyol / Hatay
Annual Irradiation	1845.4 kWh / m²
Annual Average Temperature Value	18.3 ° C
Azimuth Angle of the Roof	0 °
Suitable Space on the Roof	340 m²
Slope Angle of Roof	32 °
Annual Electricity Consumption Value	87.396 kWh
Production Facility Installed Capacity	50 kWp
Number of Panels	157
Panel Power	320 Watt
Panel Technology Used	Monocrystalline Solar Panel
Inverter Technology Used	3 phase
Annual PV Electricity Production Value	71.118 kWh
Arrival Angle Reflection Rate	-2.67%
Temperature And Low Irradiation Rate	-8.25%
Spectral Effect Rate	0.36% by
Total loss rate	-22.92%
Project Cost	$ 38,460,88
25-Year Energy Gain	$ 209,440,09

The cost of the sample project is approximately $ 38.460.000. In order to keep the return time of an investment with such a high cost to a minimum, much attention should be paid to the analysis work to be carried out during the design phase. In the approach developed in this project, the whole process from location selection to income chart has been explained. The method in the study; It is applicable to all consumers who want to produce their own electricity from the roof.

As a result, designs should be realized by integrating photovoltaic systems with the projects from the first design stages of the buildings, considering the most efficient orientation and surface slopes for these systems. When these developments are achieved, architects should be informed about the structural design of photovoltaics, and they should be able to design well-integrated systems compatible with the building. Since the model presented in the study was created by examining the detection systems used today, new systems may be designed in the future by making use of the alternatives and design inputs in the model. The model can be updated depending on the developments in photovoltaic technology.

Solar power plants are distributed facilities and generate electricity only during the daytime. As the number of these facilities increases, these plants, which exhibit variable production during the day, do not work at full capacity at noon, and in the evening will cause voltage changes in the network. For this reason, in future studies, an answer should be sought to the question of how distributed plants can sustain their assets without harming the network by researching the impact of distributed generation facilities on distributed networks. Thus, with the increase in the number of samples in this study, a damage to the network will be prevented.

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APPENDICES

Appendix 1: Similarity Report

Submit File

Online Grading Report | Edit assignment settings | Email non-submitters

AUTHOR	TITLE	SIMILARITY	GRADE	RESPONSE	FILE	PAPER ID	DATE
Ülker Azbay	CHAPTER 1	0%	--	--		1484033542	07-Jan-2021
Ülker Azbay	CHAPTER 7	0%	--	--		1484035260	07-Jan-2021
Ülker Azbay	CHAPTER 9	0%	--	--		1484035534	07-Jan-2021
Ülker Azbay	CHAPTER 5	1%	--	--		1484034936	07-Jan-2021
Ülker Azbay	CHAPTER 8	1%	--	--		1484035392	07-Jan-2021
Ülker Azbay	CHAPTER 4	3%	--	--		1484034429	07-Jan-2021
Ülker Azbay	CHAPTER 3	4%	--	--		1484033869	07-Jan-2021
Ülker Azbay	THESIS	8%	--	--		1484033408	07-Jan-2021
Ülker Azbay	CHAPTER 6	12%	--	--		1484035109	07-Jan-2021
Ülker Azbay	CHAPTER 2	14%	--	--		1484033688	07-Jan-2021

Appendix 2: Ethical Aproval Document

Date: 13/01/2021

To the **Graduate School of Applied Sciences**

The thesis titled “Use of Photovoltaic Systems in Buildings - Sample Design on the Office Building Roof in Dörtyol District of Hatay ’’ has been evaluated. Since the researcher will not collect primary data from humans, animals, plants or earth, this project does not need to go through the ethics committee.

Name Surname: Prof. Dr. Zeynep Onur

Signature: 

Role in the Thesis: Supervisor