Solar Energy Potential of Building Envelopes in EMU-Campus/Famagusta for the Energy Demand by Means of Efficient PV Application

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ABSTRACT

Climate change becomes more and more an important issue for the sustainable development of the countries. One of the reasons for the increasing climate change is the use of fossil fuels for heating, cooling, and lighting in buildings which should be replaced by renewable energy sources such as solar energy.

Educational institutions play an important role in the climate change discussions. Eastern Mediterranean University (EMU) in Famagusta, which is an important educational institution in Northern Cyprus, needs a renewable energy source for the energy supply of the campus.

The aim of the study is to investigate the solar energy potential of building roofs and exterior walls of the EMU campus buildings for PV application. First of all, a database about building height, floor number, roof type, vertical building surfaces areas and roof areas and their orientation as well as the obstacles which are blocking the solar radiation were established. It has been found that according to their building heights 43 out of 44 buildings in the EMU campus do not shade each other and are suitable for an efficient PV application.

Hereupon, the monthly solar energy yields and the annual total solar energy yields were calculated based on the appropriate roof areas and vertical building surface areas with the help of the PVsyst Simulation program and compared with the total energy consumption in 2019. Because of the global pandemic and lockdown, the monthly and annual energy consumption of EMU in 2019 were used as statistics instead of 2020. It was found out that on a monthly basis, the calculated energy yields between October and February (Fall and Winter season) are not meeting the energy demands for the same time period.

Three different scenarios were applied to increase the solar power generation between October and February (Fall and Winter season) with the same vertical building surfaces and roof areas, but with different PV tilt angles (scenario 1: 28°, scenario 2: 55°, scenario 3: 28° and 55°). The best results were achieved in scenario 3, where a flexible PV installation with a moveable tilt angle system on the total roof areas of the EMU campus was suggested as an option. On the total roof areas, the PV tilt angle 28° was applied between March and September (Spring and Summer season) and 55° between October and February (Fall and Winter season). In all scenarios (including scenario 3) the monthly solar energy yields between October and February (Fall and Winter season) generated by PVs are lower than the energy demand of the EMU campus of the same time period. Although an annual energy surplus of 68,052 kWh was achieved in scenario 3 in comparison to the EMU energy consumption in 2019.
As a conclusion it can be noticed that seasonal asynchronicity between solar power generation and electricity consumption can be solved either by efficient seasonal solar power storage systems or by applying hybrid systems beside PVs.

For the future development of the EMU campus, the consideration of solar energy technology must be integrated early in the design process and applied in the construction process of new smart buildings with the aim to increase the degree of self-sufficiency of the EMU campus in terms of energy use generated by fossil fuels.

Keywords: EMU Campus, Energy Demand, Solar Energy Potential, Building Surfaces, Photovoltaics

ÖZ

İklim değişikliği, ülkelerin sürdürülebilir olarak kalkınması için giderek daha önemli bir konu haline gelmektedir. Artan iklim değişikliğinin nedenlerinden biri binalarda ısınma, soğutma ve aydınlatma için fosil yakıtların kullanılmasıdır. Bu tüketim güneş enerjisi gibi yenilenebilir enerji kaynakları ile değiştirilmelidir.

İklim değişikliği hususunda eğitim kurumları önemli bir rol oynamaktadır. Kuzey Kıbrıs'ta önemli bir eğitim kurumu olan Gazimağusa'daki Doğu Akdeniz Üniversitesi (DAÜ), kampüsün enerji temini için yenilenebilir bir enerji kaynağına ihtiyaç duymaktadır.

Çalışmanın amacı, DAÜ kampüs binalarının PV uygulaması için bina çatılarının ve dış duvarlarının güneş enerjisi potansiyelini araştırmaktır. Öncelikle bina yüksekliği, kat sayısı, çatı tipi, düşey bina yüzey alanları ve çatı alanları ve bunların yönelimleri ile güneş ışınımına mani olan engeller hakkında bir veri tabanı oluşturulmuştur. DAÜ yerleşkesinde bulunan 44 binadan 43'ünün bina yüksekliklerine göre birbirini gölgelemediği ve verimli bir PV uygulaması için uygun olduğu tespit edilmiştir.

Bunun üzerine, uygun çatı alanları ve dikey bina yüzey alanları baz alınarak aylık güneş enerjisi ve yıllık toplam güneş enerjisi verimleri PVsyst Simülasyon programı yardımıyla hesaplanmıştır ve 2019 yılı toplam enerji tüketimi ile karşılaştırılmıştır. Küresel pandemi ve karantina nedeniyle 2020 yılı yerine DAÜ'nün 2019 yılındaki aylık ve yıllık enerji tüketimi istatistik olarak kullanılmıştır. Aylık olarak hesaplanan enerji verimlerinin aynı zaman dilimi içerisinde Ekim-Şubat (Güz ve Kış sezonu) enerji taleplerini karşılamadığı belirlenmiştir.

Farklı PV eğim açılarıyla aynı dikey bina yüzeyleri ve çatı alanları ile Ekim ve Şubat ayları arasında (sonbahar ve kış mevsimi) güneş enerjisi üretimini artırmak için üç farklı senaryo uygulanmıştır (senaryo 1: 28°, senaryo 2: 55°, senaryo 3: 28°-55°). En iyi sonuçlar, DAÜ kampüsünün toplam çatı alanlarında hareketli bir eğim açısı sistemine sahip esnek bir PV kurulumunun bir seçenek olarak önerildiği senaryo 3'te elde edilmiştir. Toplam çatı alanlarında, Mart ve Eylül ayları arasında (ilkbahar ve yaz mevsimi) 28° ve ekim ve Şubat ayları arasında (sonbahar ve kış mevsimi) 55° PV eğim açısı uygulanmıştır. Tüm senaryolarda (senaryo 3 dahil), Ekim ve Şubat ayları (sonbahar ve kış mevsimi) arasındaki aylık Fotovoltaikler tarafından üretilen güneş enerjisi verimi, aynı zaman dilimindeki DAÜ kampüsünün enerji tüketiminden daha düşüktür. Buna ragmen Senaryo 3'te, 2019 yılında EMU enerji tüketimine kıyasla yıllık 68.052 kWh enerji fazlası elde edilmiştir. Sonuç olarak, güneş enerjisi üretimi ve elektrik tüketimi arasındaki mevsimsel eşzamansızlığın, verimli mevsimsel güneş enerjisi depolama sistemleri veya PVlerin yanında hibrit sistemler uygulanarak çözülebileceği fark edilebilir.

DAÜ kampüsünün ilerideki gelişimi için, güneş enerjisi teknolojisi dikkate alınmalı, tasarım sürecinde erken entegre edilmeli ve DAÜ kampüsünün fosil yakıtların ürettiği enerji kullanımından ziyade kendi kendine yeterlilik derecesini artırmak amacıyla yeni akıllı binaların yapımı sürecinde uygulanmalıdır.

Anahtar Kelimeler: DAÜ Kampüs, Enerji İhtiyacı, Güneş Enerjisi Potansiyeli, Bina Yüzeyleri, Fotovoltaikler

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LIST OF ABBREVIATIONS

A-Si	Amorphous Silicon
BAPV	Building Applied Photovoltaic
BIPV	Building Integrated Photovoltaic
CdTe	Cadmium telluride
CI (G) S	Copper Indium Gallium Selenide Solar Cells
CIS	Copper Indium Diselenide
E	East
EMU	Eastern Mediterranean University
GaAs	Gallium Arsenide
kWh/m^2	Kilowatt per Square Meter
kWh	Kilowatt-hour
Mono	Monocrystalline
N	North
Poly	Polycrystalline
PV	Photovoltaic
SE	Southeast
Si	Silicon
SW	Southwest
TRNC	Turkish Republic of Northern Cyprus
UV	Ultraviolet
Volt	Voltage

Chapter 1

INTRODUCTION

1.1 Problem Statement

The main problem is that the world is at the stage of global climate change. The use of fossil resources rapidly accelerates climate change. Climate change causes many disasters in the world such as seasonal irregularity, temperature instability, extinction of animal generations, decrease in soil fertility and health problems of humans and animals. Therefore, fossil fuels should be replaced by renewable energy sources. The use of renewable sources is very beneficial, because it does not lead to any carbon dioxide emissions. While the energy demand increased, the importance of renewable energy became significant. Educational institutions play an important role in the climate change discussions. Considering that an educational institution will become an example for people in terms of behavior and thinking, academies can shape the mentality of peoples in ecological manner. However, photovoltaic panel applications based on renewable technologies are not common in university campus. In this context, Eastern Mediterranean University, which is a large educational institution, needs a renewable energy source that can supply the energy demands. The energy requirement of EMU buildings was not taken into consideration during the design phase, but they are quite suitable for using active solar technology such as photovoltaic integrated system through to climate conditions and existing unused roof areas. EMU is located in Famagusta city of Cyprus, while Cyprus has a high potential for solar energy due to its location. It is a big problem that this potential cannot be utilized throughout in Cyprus. Incentives are required for the widespread use of solar energy.

1.2 Research Aim and Objectives

The aim of the research is to find out solar energy potential of EMU-Campus by analyzing the surface areas. The aims of the study are:

- To understand how to make PV Panel applications available in educational institutions.
- To analyze and determine suitable PV Panel areas and available PV Panel types according to regional climatic aspects and existing building surface areas of the facilities in Emu/Famagusta. Along with environmental concerns in long term the renewable energy systems that provide economic growth has to be understood by the society.
- To ensure that the energy demands of the buildings in Main and South Campus are covered as self-sufficient energy zones.
- To measure solar energy potential of building surfaces such as roofs and exterior walls located in EMU Main and South Campus for optimum surface areas for PV Panel installations and the calculation of the energy demand of the EMU and the prospective electricity production by the installed PV Panels.

1.3 Research Questions

Following research questions will be analyzed in the thesis:

1.What are the conditions on-site to successfully use photovoltaics for power generations?

2.What is the energy demand for heating, cooling, and lighting of the EMU Campus?

3.What is the potential of the building surfaces in the EMU-Campus to generate power by photovoltaics?

1.4 Research Methodology

The methodology of the research is a mix method. Documentary Research covered by qualitative research technique. Field Study method was used for collection of statistics and survey of energy demand and analysis of roof areas and vertical surfaces areas to achieve optimum energy yield by solar panels.

As a quantitative research technique, the data findings as a statistic after the field study should demonstrate if the energy yield generated by the PVs is sufficient to cover the energy demand of the EMU-Campus.

Auto-Cad, GIS Map, Revit and PVsyst will be used as supporting software programs, while the data findings can be used for energy simulation. The criteria for PV installation to generate a high energy yield will be analyzed according to the site conditions. While determining the site conditions; suitable photovoltaic installation (integrative or additive), climatic features and the characteristic of the existing buildings will be analyzed accordingly. The EMU campus will be examined in two research areas as so-called Main Campus and South Campus. The current energy demand of the university in 2019 year will be presented in a table form to give an overview.

In addition to that, the optimum integrated PV installation area for a high energy yield will be analyzed according to the aesthetical needs. Hereby, air conditioning pipes and vertical circulation elements on the roofs and vertical building surfaces will be removed from the total square meter. Beside the roof areas, the south orientation of the facades will be determined as suitable areas.

These areas will be illustrated by Auto-Cad program and modeled to find out the amount of solar radiation by using the Revit Solar Simulation. A campus simulation will be developed to define the solar energy potential. The PVsyst program will be used to calculate the energy production potential of the campus. It is an easy applicable energy simulation program with an easy interface to specifically define and select Area, Module Type, Mounting Disposition, Technology-Cell Type, Ventilation Property, Tilt Angle and Azimuth. Due to these features of the program, it was found suitable to be used in energy generation simulation calculations in comparison to other existing simulation programs. Then the drawn and defined areas (vertical surfaces and roofs) will be calculated together with the selected PV panel type and the average sun duration. Based on these calculations the produced energy yield will be compared with the current energy demand to understand if the PVs are sufficient to cover the energy demand by integrating them successfully to roof and vertical surface areas.

1.5 Research Limitation

This study was conducted within the boundaries of the Eastern Mediterranean University which is located in Famagusta city. Field research is limited to educational and administrative buildings and dormitories administered by EMU.

The impact of photovoltaics on roof areas and vertical building surfaces (additive / integrative PV installation) according to the architecturally aesthetic values as well as energy conservation strategies are not researched in the thesis.

This thesis is limited to power generation by photovoltaics to cover the energy demand for heating, cooling, and lighting demands of the EMU buildings.

1.6 Research Structure

This thesis aims to determine the solar energy potential of the building surface areas of EMU-Campus according to climatic conditions and to create a PV panel integration model with aesthetic values. In this way, a model will be formed in EMU-Campus to provide a sustainable energy generation for heating, cooling, and illumination.

- In the first chapter, the purpose of the thesis, the problem statement, the research questions to be answered by the study, the methodology and limits of the study are explained as introduction part of the thesis.
- The second part provides a theoretical background as literature review. This theoretical background provides information about active solar energy use, photovoltaics as an active solar system, description, and history of photovoltaics, working principle, equipment, types, application types and usage criteria.
- The third section is the analysis part of the study. The climatic characteristics of Famagusta are examined. Afterwards, information about the historical development of the EMU-Campus will be described, which will be analyzed as case study area. In the light of this information, the total area of the roof and south-facing facades and the criteria affecting of the sunlight potential will be examined. Solar energy potential was determined by simulating the determined areas through the program.
- In the fourth chapter, the energy yield of the PV panels based on the available vertical building surfaces and roof areas will be compared and discussed with the energy demand of the university for heating, cooling, and illumination.

In the conclusion part, an overview will be given about the research process of the thesis based on the aim of the study and the research questions. Recommendation will be given about future research possibilities related to the research subject.

Chapter 2

THE USE OF SOLAR ENERGY AS RENEWABLE ENERGY SOURCE AND ITS ADAPTABILITY IN BUILDINGS

Solar energy is defined as radiant energy produced by the sun. The sun, 150 million km from the earth, sends about 10 thousand times the total energy used in the world in a year. The sun is a huge mass of hydrogen and helium atoms (NGS, National Geographic Society Encyclopaedia.)

Every day, a large amount of energy is sent to the earth by the sun. The sun is the source of life. Solar energy, with its potential and ease of use, has an opportunity to spread more easily than other renewable energy sources. Solar energy, which is the origin of many natural energy resources, is directly used for purposes such as heating and electricity generation (Kabir, E., Kumar, P., Kumar, S., Adelodun, A. A., & Kim, K. H., 2018).

According to Dikmen, Gültekin (2011) the renewable technologies have safe solutions to many serious environmental and social problems on a large scale. Renewable energy sources have enormous environmental benefits when compared with conventional energy sources. The biggest advantages are air emissions and the absence or scarcity of waste products. The use of renewable energy sources will help preserve air, water and soil quality and maintain the natural balance.

Sun provides a large part of the natural system energy. It can be said that solar energy is the most used renewable energy source for heating, cooling, lighting, and electricity generation in buildings as a passive and active system (Twidell, J., & Weir, T. ,2015).

One of the most important reasons is that solar energy has versatile benefits. Its greatest advantage is its easy availability, the ability to use simple technologies in general, to be available all over the world and at any time, to be renewable and not to pollute the environment in any way. Therefore, it is the only type of energy that has all the qualities required for humanity (Twidell, J., & Weir, T. ,2015).

Solar energy is both an abundant and free and a continuous and renewable energy source. In addition, it does not pollute the environment, can be applied locally, is easy to operate, does not depend on the outside, does not require complex technology, and has low operating costs. Due to these advantages, renewable energy sources are used to reduce environmental ethics from fossil fuels in recent years (Twidell, J., & Weir, T. ,2015).

In addition to these Lakatos et al. (2011) argues that the negativities of solar energy can be listed as follows. Since the solar radiation coming to the unit plane is less, it needs large surfaces, it requires storage because the solar radiation is not stable and continuous, the storage facilities are limited, the solar radiation is low in the winter months when the energy need is high and there is no at night, it is necessary to have an open environment.

The use of solar energy in buildings is classified as passive and active solar systems. Using solar energy as "passive solar systems" to heat the spaces during the design phase of the buildings; Every technological product added to the design is defined as "active solar systems". These systems are energy efficient and forbid environmental damage (Dikmen, Ç., & Gültekin, A., 2011).

2.1 Brief History About the Use of Solar Radiation/Energy

In the history of humanity, the cult of the sun has been found since prehistoric times. As an object worshiped, the sun has become a symbolic concept by being abstracted in religious systems that develop over time. In ancient civilizations the sun was a religious symbol for people. They considered the sun sacred and worshiped. (Michalec, A. - Solar Activity and Human History).

According to L. Szabó (2017), the sun was called and worshiped by names such as Ra in Egyptian civilization, Apollo in Ancient Greece, Amaterasu in Japanese mythology, and Surya in Hindus. Observation of the sun has led to many inn0ovations in ancient times. The best known of these inventions is the solar calendar that we still use in this era. The forms of the pyramids built were seen as stairs reaching out to the sun. As the first example of passive solar energy, house windows were positioned on the south façade found in the Neolithic period/ China. The Greeks and Romans used the sun's rays through the mirror to light the torches. With the same logic, Archimedes developed a defense tactic by burning the sails of enemy ships with reflective mirrors. This defensive tactic is called “heat-ray” or “death-ray” (L. Szabó, 2017).

Figure 2.1: Archimedes Solar Defense Tactic as Called a "heat-ray" (L. Szabó, 2017)

In later centuries, Leonardo Da Vinci discovered that the concave form collects the sun's rays and used to heat the water. Thus, for the first time, solar radiation has been used to heat water. The hot box designed by Saussure in 1767 is the first prototype of the thermal solar collectors. The system consists of two nested boxes and a glass panel on top. Solar radiation hits the glass and the water inside heats up. After the industrial revolution, solar collectors were invented by using iron and steel together. Respectively, scientists such as Antoine Lavoiser (1743-1794), August Monchot (1825-1911), John Ericsson (1803-1889) and Abel Pifre (1852-1928) developed solar collectors with the technologies (L. Szabó, 2017).

In 1883, Charles Edgar Fritts produced the first selenium solar cell with an efficiency as low as 1-2%, closest to the technology used today (Zaytsev, 2014). Albert Einstein was awarded the Nobel Prize for his photoelectric effect theorems in 1905 (Yajnik, 2017).

Becquerel discovered that the electrolyte cell transforms into electric current with the effect of photovoltaic (Ramakumar, R., & Bigger, J. E., 1993) in 1918, the first solar cell was produced from silicon. The first crystal cell was produced in 1954. The use of the produced crystal cells was initially limited in devices such as toys and calculators. Used in satellites sent to space in 1958 (El-Shimy, M., & Abdo, T., 2014).

With the 1973 oil crisis, the interest of the electricity industry in PV technology began to increase. Then it established scientific institutes interested in PV. However, with the effects of the oil crisis in the 1980s, interest in PVs increased. In the 90's, large companies started to be PV producers. (El-Shimy, M., & Abdo, T., 2014).

2.2 The Use of Active Solar Technology in Building

Active solar systems are defined by supporting applications with mechanical equipment and additional heat storage measures, automatic control of heat distribution, application of water-air collectors, and the use of high efficiency collectors and solar cells to benefit from solar energy in buildings. (Ç. B. Dikmen ve A. B. Gültekin, 2011).

In active systems that are not used for direct indoor heating, solar energy is generally collected through collectors, the collected energy is stored in water tanks or gravel areas located adjacent to the building or in the lower elevation, and the stored energy is distributed with equipment such as pumps and pipes and the interior spaces are heated by hot water (Ç. B. Dikmen ve A. B. Gültekin, 2011).

Active solar systems are allowing the effective use of solar energy in buildings and convert the sun rays received into electrical and heat energy and are the whole of various mechanical and electronic systems (Ç. B. Dikmen ve A. B. Gültekin, 2011).

2.2.1 Solar Collectors for Hot-Water Supply and Space-Heating

Solar collectors are used to meet the hot water needs of the buildings. Solar collectors, which provide the heating of the cold water supplied to the systems are work with the logic of collecting and concentrating the radiation emitted from the sun. As seen from

Figure 2.2, solar water heating systems basically have a collector panel that absorbs solar energy and converts it into heat energy and an insulating tank to store hot water to which the generated heat is transferred. Solar water heating systems are divided into two categories:

- Flat Plate Collector
- Evacuated Tube Collector. (Tian, Y., & Zhao, C. Y. ,2013).

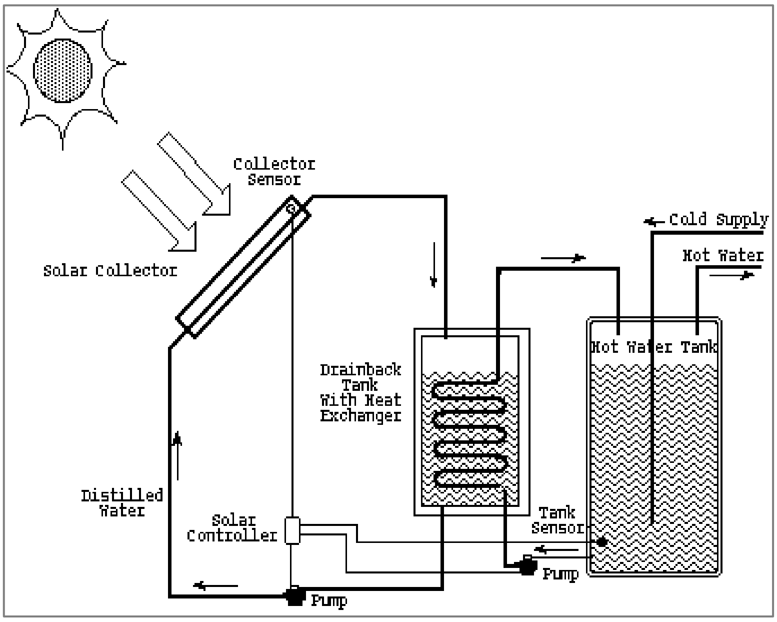


Figure 2.2: Solar Collector Working Principle Source: http://www.esru.strath.ac.uk/EandE/Web_sites/02-03/zero_emission_bldgs/descripsolarcollectors.htm

2.2.1.1 Flat Plate Collector

Flat plate collectors are the most common and traditional type of solar collectors. The flat plate collector basically consists of an insulated metal box with a glass or plastic lid (glass) and a dark colored absorbent plate (Tang, R., & Li, G., 2018). As shown in Figure 2.3, solar radiation is absorbed by the absorber plate and transferred from the collectors to tank. Provides the collector distribution function with natural convection.

Natural convection provides water circulation in the system with the rise of the heated water. thus, water is circulated without the need for extra power (Sen, Z., 2008).

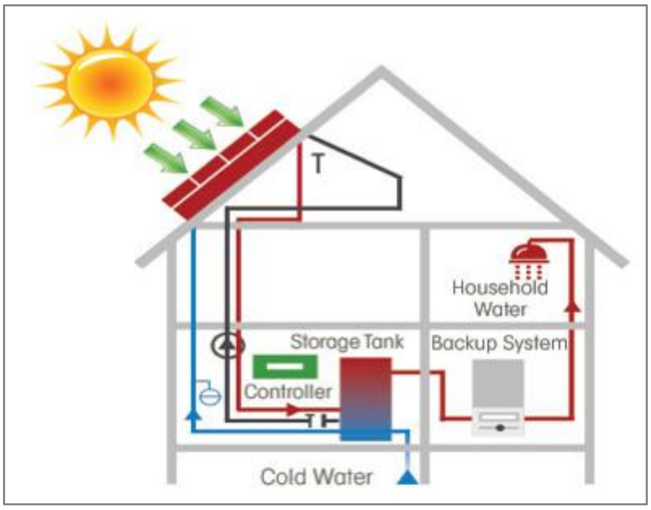


Figure 2.3: Working Principle of Flat Plate Collector Source: https://www.plumbconst.com/newsletters/harnessing-the-heat-of-the-sun/

2.2.1.2 Evacuated Tube Collector

Glass tubes in the collector create pressure with the effect of vacuum. Water circulation occurs with pressure difference. Thus, it does not need an extra power for water circulation like a flat plate collector. The collector reaches high temperatures. Thus, this collector is preferred in many countries which has cold climates. However, to prevent overheating from damaging the system, tempering valve is needed. This valve prevents the system from being damaged by overheating and balances the temperature (Bainbridge, D., & Haggard, K., 2011).

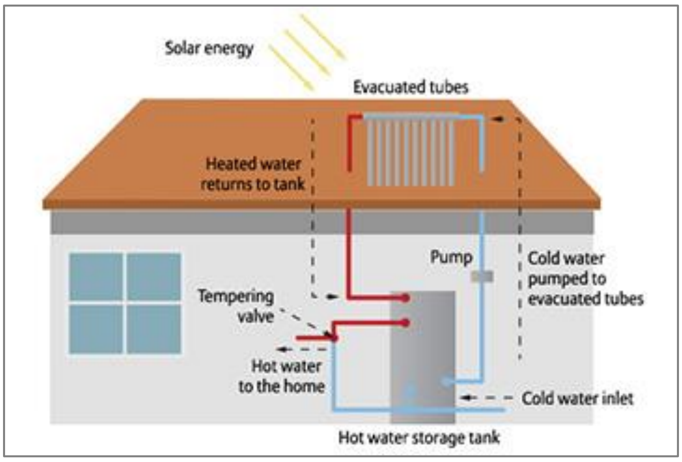


Figure 2.4: Working Principle of Evacuated Tube Collector Source: https://environmentalscience2017.wordpress.com/2017/05/11/solar-water-heaters-the-basics/

2.3 The Use of Photovoltaics and Its Adaptability on Buildings

2.3.1 Definition of Photovoltaic

The purpose of photovoltaics is to generate electric current from sunlight with the principle of photovoltaic effect. Photovoltaic consists of in terms of two main meanings. The meaning of the photo is light, voltaic is voltage. The origin of the photo comes from Greek language. Voltaic was inspired by Alessandra Volt, who invented the machine to redound electric current. The abbreviation is PV (Prasad, D., & Snow, M. ,2014).

Photovoltaic systems are semiconductor devices that convert solar radiation directly into electrical energy, benefit from renewable energy sources and do not pollute the nature. Photovoltaics provide energy gain in many areas. There are wide areas of use from items used in daily life to buildings (Sick, F., Erge, T., 1998).

PV cells are semiconductor materials that directly transform the solar radiation that reaches the surface into electrical energy. Cells are mostly produced from materials such as silicon (Si), cadmium telluride (CdTe), gallium arsenide (GaAs). In order for semiconductor materials to be used in solar cell production, they must be treated with materials such as phosphorus, aluminum, indium, boron and transformed into N or P type semiconductor materials. The adding process is carried out by adding the preferred additives into the pure semiconductor melt. Whether the semiconductor is N or P depends on the substance added. These produced PV cells have different efficiencies, appearances, and costs. Their efficiency varies according to the rate at which the solar energy falling on the cell can be converted into electrical energy. The smallest unit of the system is the solar cells. Cells consist of semiconductor materials. The shapes can be square, rectangular, and circular. (Prasad, D., & Snow, M. ,2014).

2.3.2 Working Principle and Structure of Photovoltaics

2.3.2.1 Working Principle of Photovoltaics

According to Mosiori photovoltaic cells are the systems that convert to solar energy into electrical energy with photovoltaic effect on surfaces that are square, rectangular, or circular. As shown in Figure 2.5, photons are formed when sunlight hits the semiconductor surface, releasing electrons inside the atom. Photons contain a different amount of energy for each wavelength in the solar radiation spectrum. When the photons land on the solar cell, some are reflected exactly, some are absorbed by the solar cell, and some pass through the solar cell. Photons absorbed by the solar cell produce electricity. (Mosiori, C. O. THE SOLAR CELL).

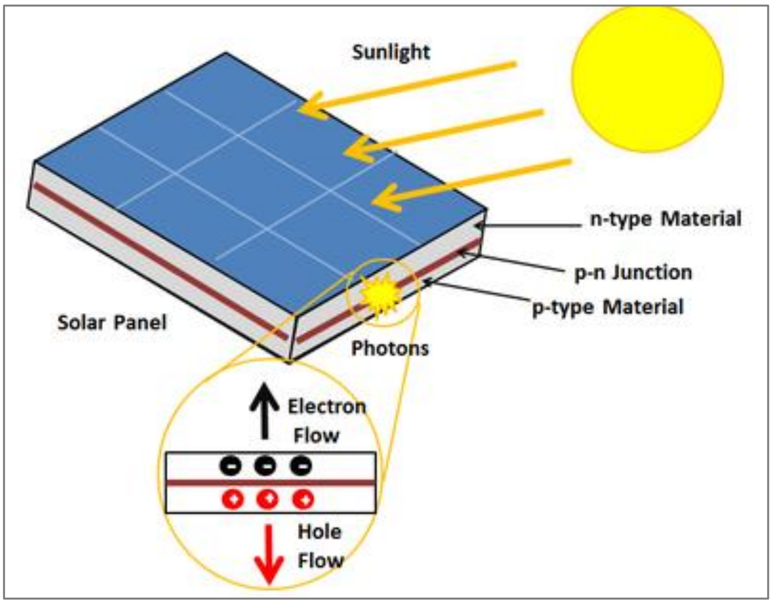


Figure 2.5: Figure 2.12: Layers and Working Principle of PV Panel Source: https://energyeducation.ca/encyclopedia/Photovoltaic_cell

Prasad (2014) explained that output voltage of a cell is approximately 0.5 volt. For increase the power output, multiple cells are connected in series or in parallel. As seen in Figure 2.6 the connected cells consist of module. Combining modules creates panels. Combining panels create an array.

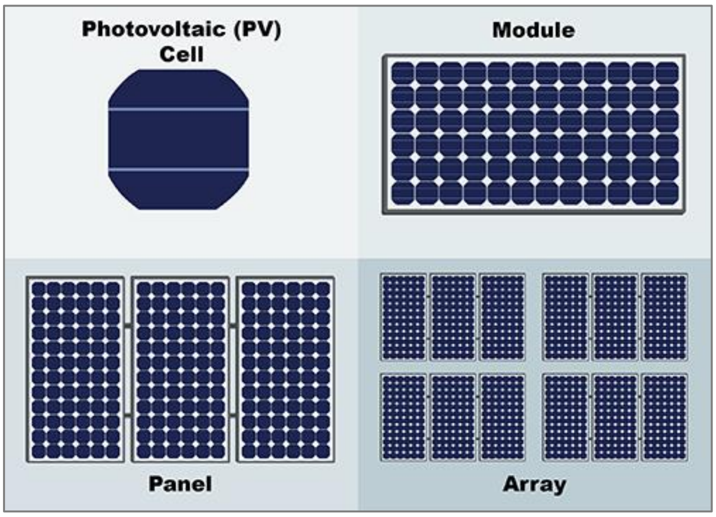


Figure 2.6: Combination of PV Cell, Module, Array, Panel (Poudel, R. C., Manwell, J. F., & McGowan, J. G., 2020).

2.3.2.2 Components of Photovoltaics

There are negative electrons in the front of the solar cell and positive electrons in the back. The photovoltaic system consists of a thin N type material and two layers of silicon on a P-type layer. In the joint area in the middle of these materials, with the external circuit. There are copper contacts that provide the connection. The most important factor in determining the efficiency of a solar cell is the conversion rate of radiation from the sun into electrical energy. Certain wavelengths in the beam of light coming to cells can be converted into electrical energy. The remainder of the incoming beam is absorbed or reflected by the cell. (Eiffert, P., Kiss, G.J., 2000).

2.3.2.3 Equipment

The equipment's of photovoltaics are:

Batteries are stores energy in off grid solar system. Batteries are necessary to power photovoltaic systems when there is no sun. The size of the battery depends on the electrical charge it will use. Batteries should be placed in an area not exposed to excessive heat and ventilation. Batteries can be adjusted in parallel for more capacity **(**Handbook, A. S. H. R. A. E., 2004).

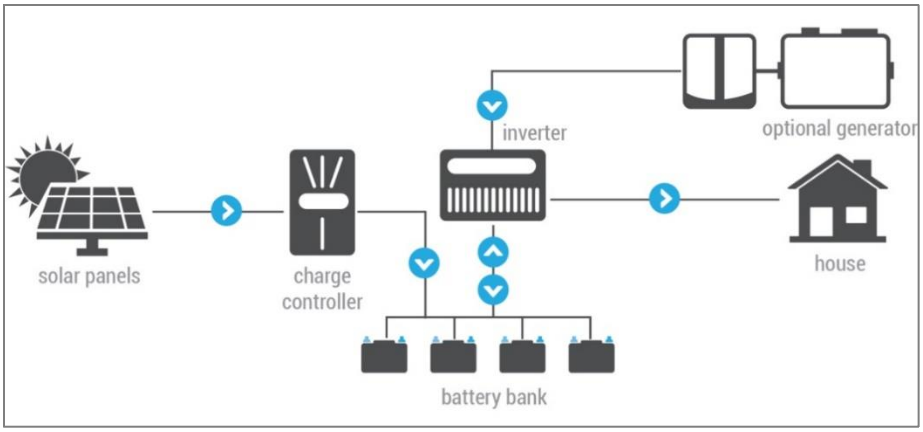


Figure 2.7: The Use of Battery in Off-Grid Systems Source: https://kharafi-solar.com/off-grid-back-up-system/

- Smart meters (net meters) are devices that record electrical input-output values in grid-dependent systems (on-grid). The excess energy produced can be sold to the grid and profit can be obtained (Kumar, N. M., Subathra, M. P., & Moses, J. E., 2018, February).

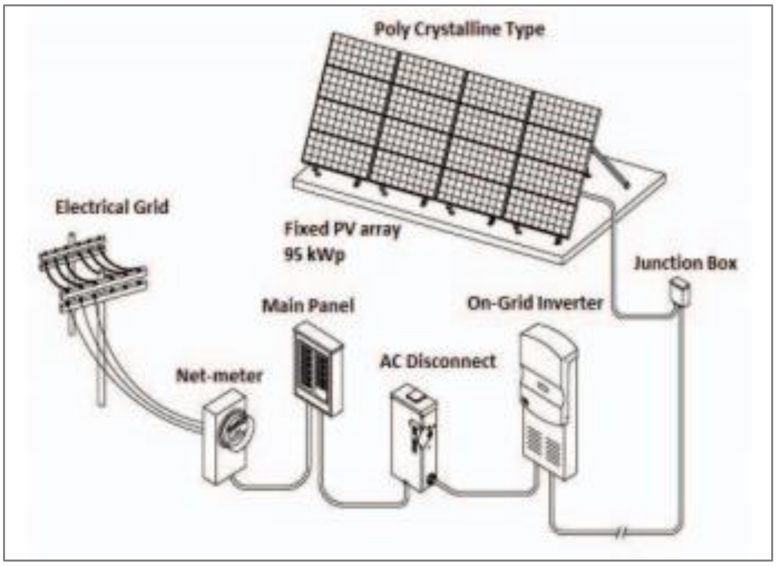


Figure 2.8: The Use of Smart Meter in On-Grid Systems (Kumar, N. M., Subathra, M. P., & Moses, J. E., 2018, February)

- Inverters are used to convert direct current to alternating current and convert it into electricity.
- Block diodes (blocking diodes) block reverse current.
- Fuses protect cables from excessive current. This protection is used if more than 4 strings connected in parallel.
- Cables are double insulated and resistant to UV rays. Overvoltage and lightning protection devices temporarily keep the voltage out of the system. **(**Handbook, A. S. H. R. A. E., 2004)

2.3.3 Types of Photovoltaics

Sick, F., Erge, T. (1998) explained that solar cells are made of silicon (Si) and silicon is abundant in nature. According to the type of material produced, PV cells can be divided into three groups as crystalline silicon, thin film and multilayer solar cells. PV cells are semiconductor materials that convert the solar radiation falling on them directly into electrical energy. Cells are mostly produced from materials such as gallium arsenide (GaAs), silicon (Si), cadmium telluride (CdTe), For semiconductor materials to be used in solar cell production, they must be treated with materials such as phosphorus, aluminum, indium, boron and converted into N or P type semiconductor materials. Whether the semiconductor is N or P depends on the substance added. These produced PV cells have different efficiencies, appearances, and costs. Their efficiency varies according to the rate at which the solar energy falling on the cell can be converted into electrical energy.

The variety of PV cells provides application in different functions. Each module has different performances because it is encapsulated differently. Commonly known and used types are Mono-Crystalline Cell, Poly-crystalline Cell and Thin-Film (Sick, F., Erge, T., 1998).

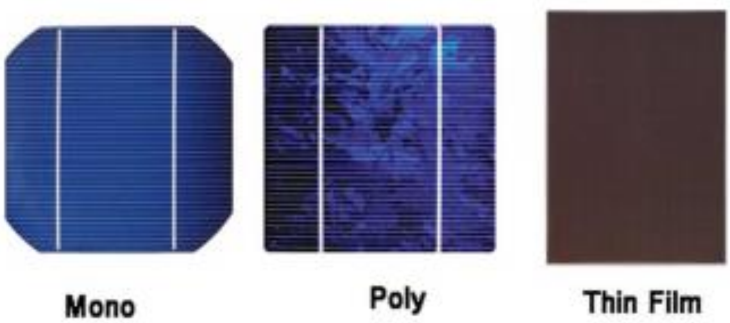


Figure 2.9: PV Cell Types (Bagher, A. M., Vahid, M. M. A., & Mohsen, M., 2015).

The first generation, conventionally counted, includes mono and poly silicon. These are made of crystalline silicon. The second-generation cells are thin cells made from materials such as amorphous silicon, CdTe. It is generally used for integrated photovoltaics. Their surface is thinner so it can be used comfortably on facades. This is less efficient than the first generation. More surface area is required to produce the same strength. (Bagher, A. M., Vahid, M. M. A., & Mohsen, M., 2015).

Table 2.1: Advantages and Disadvantages of Three Main Solar Cell Types Comparison Source: https://www.energysage.com/solar/101/types-solar-panels/

Solar panel type	Advantages	Disadvantages
Monocrystalline	• High efficiency/performance • Aesthetics	• Higher costs
Polycrystalline	• Low cost	• Lower efficiency/performance
Thin-film	• Portable and flexible • Lightweight • Aesthetics	• Lowest efficiency/performance

Table 2.1 above, shows the advantages and disadvantages of pv types. Solar cells should be selected according to the usage conditions and purpose of use.

Table 2.2: Efficiency Differences in Main types of Solar cells and modules (Thomas, R., Fordham, M., 2001).

Type	Approximate cell efficiency[a] %	Approximate module efficiency[a] %
1. Monocrystalline silicon	13–17 (1)	12–15 (2)
2. Polycrystalline silicon	12–15 (1)	11–14 (2)
3. Thin-film silicon (using amorphous silicon)	5 (3)	4.5–4.9 (2)

Table 2.2 above, clearly seen that efficiency differences of main solar cell types. The efficiency rate from high to low is as follows: Monocrystalline silicon cell, polycrystalline silicon cell and thin film silicon cell. The efficiency rates of cells and modules depends on the conditions.

2.3.3.1 Monocrystalline Solar Cell

According to Thomas, R., Fordham, M., (2001) The efficiency rate of monocrystalline solar cells varies between 13-17%. Bagher, A. M., Vahid, M. M. A., & Mohsen, M., (2015) supports, monocrystalline solar cells have the most efficiency. It is seen that the characteristic of this material is that it is homogeneous in structural and electrical properties and that it maintains its properties for a long time. For these reasons, they are the most efficient but costly cells. Its colors are between dark blue and black.

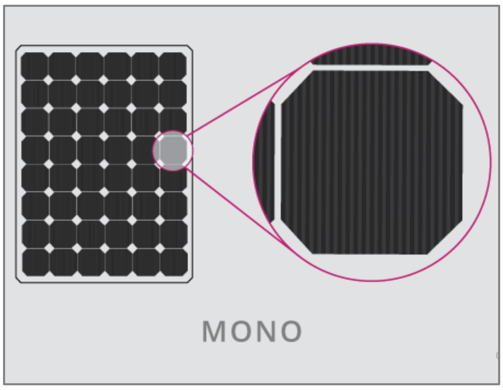


Figure 2.10: Monocrystalline Solar Cell Source:
https://www.energysage.com/solar/101/types-solar-panels/

2.3.3.2 Polycrystalline Solar Cell

These gray-blue polycrystalline cells are easier to produce than monocrystalline silicon solar cells, and their costs are lower. A disadvantage of polycrystalline cells is that their efficiency is lower than monocrystalline cells. The reason for this is that the purity level is less than monocrystalline solar cells. (Bagher, A. M., Vahid, M. M. A.,

& Mohsen, M., 2015). According to Thomas, R., Fordham, M., (2001) the efficiency rate of polycrystalline solar cells is around 12-15%.

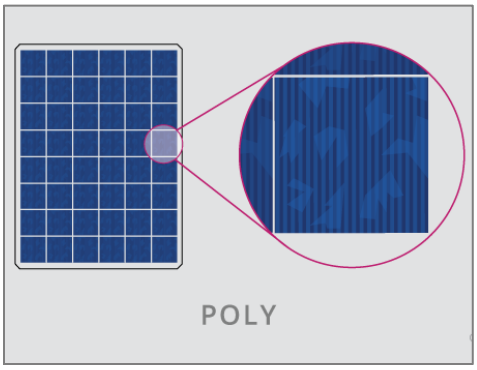


Figure 2.11: Polycrystalline Solar Cell Source:
https://www.energysage.com/solar/101/types-solar-panels/

2.3.3.3 Thin-Film Solar Cell

The system in which the semiconductor silicon atom element is used as the basic building block in converting solar rays into electrical energy. They are smaller in size than silicon-based solar cells. (Bagher, A. M., Vahid, M. M. A., & Mohsen, M., 2015).

According to Thomas, R., Fordham, M., (2001) The efficiency of thin-film solar cells is approximately 5 %. In addition, it is used in a much wider area than silicon based traditional glass panels. It also enables PV material applications on free-form, curvilinear surfaces. The lightness of the material contributes to the reduction of the building load. Since to their flexible, light, and unbreakable structure, they eliminate the aesthetic disadvantages of traditional solar cells. (Bagher, A. M., Vahid, M. M. A., & Mohsen, M., 2015).

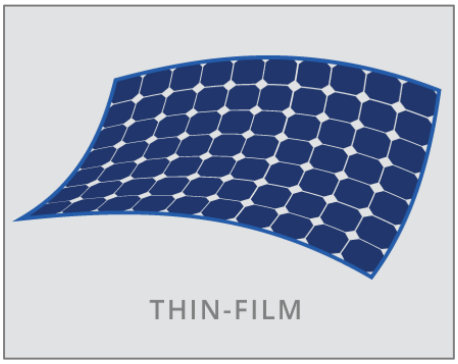


Figure 2.12: Thin-Film Solar Cell Source:
https://www.energysage.com/solar/101/types-solar-panels/

2.3.3.4 Amorphous Silicon Solar Cell (A-Si)

The structure of amorphous silicon does not have a regular arrangement as in single crystalline and polycrystalline ones. Amorphous silicon does not contain crystalline. Color of amorphous silicon is dark brown. The most preferred type among thin film types is amorphous silicon. It is widely used in calculators. The thickness of this type is 1 micron, the efficiency is 7%, the production cost is low (Bagher, A. M., Vahid, M. M. A., & Mohsen, M., 2015).

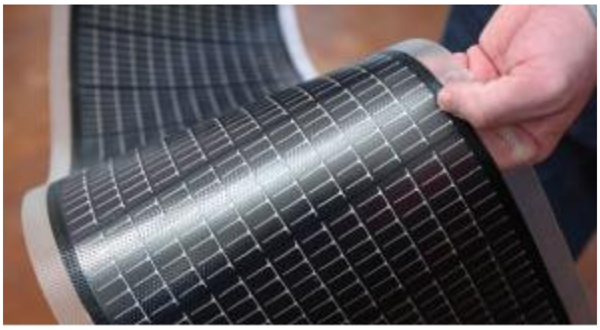


Figure 2.13: Amorphous Silicon Solar Cell (A-Si) Source:
https://aplussolarsolutions.ca/what-are-thin-film-solar-panels/

2.3.3.5 Cadmium Telluride Solar Cell (CdTe)

Cadmium Telluride is high absorption and coefficient. That’s the reason why CaTe is preferred in solar cell production because it allows easy production with many thin film growth technologies. It is estimated that the cost of solar cells will be lowered with CdTe, which is a polycrystalline material. (Bagher, A. M., Vahid, M. M. A., & Mohsen, M., 2015). An efficiency of 16% is achieved in laboratory type small cells and around 7% in commercial type modules (Luther, J., & Bubenzer, A. (Eds.)., 2003).

Figure 2.14: Cadmium Telluride Solar Cell (CdTe) Source: https://aplussolarsolutions.ca/what-are-thin-film-solar-panels/

2.3.3.6 Copper Indium Gallium Selenide Solar Cells (CI (G) S)

Copper Indium Diselenide (CIS) is a semiconductor material and has a high absorption coefficient. The efficiency of electronic properties is critically dependent on the copper/indium ratio. This multi-crystal battery has achieved an efficiency of 17.7% under laboratory conditions and 10.2% in a prototype module developed for energy generation. The production process is not expensive. Its efficiency is higher than amorphous silicon (Prasad, D.K., Snow, M., 2005).

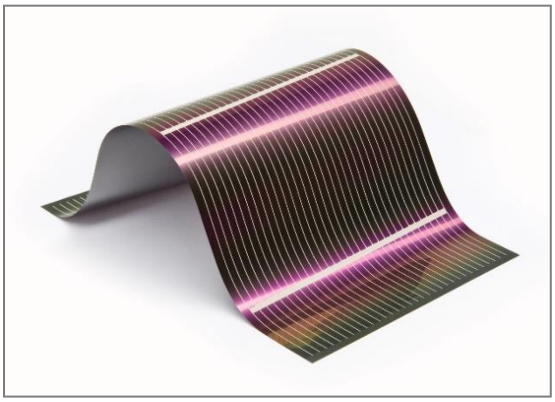


Figure 2.15: Copper Indium Gallium Selenide Solar Cells (CI (G) S) Source: https://aplussolarsolutions.ca/what-are-thin-film-solar-panels/

2.3.3.7 Gallium Arsenide (GaAs), GaInP / GaInAs

It is the second most important semiconductor material after crystalline silicon. It is used in LEDs and lasers. It can be combined with the 3rd and 5th group elements of the periodic table (for example: A1, In, N, P). Solar cell efficiency is around 25% and is expensive to manufacture. (Luther, J., & Bubenzer, A. (Eds.)., 2003).

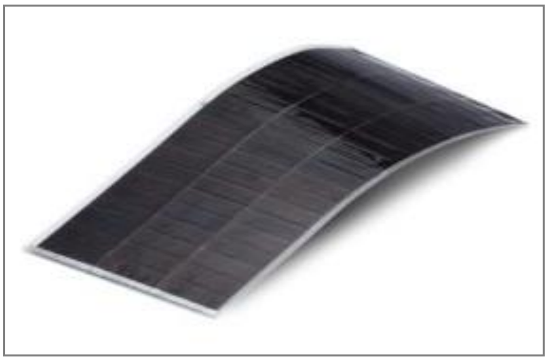


Figure 2.16: Gallium Arsenide (GaAs), GaInP / GaInAs Source: https://aplussolarsolutions.ca/what-are-thin-film-solar-panels/

2.4 Building Integrated/Applied Photovoltaic Systems

Buildings are known to play a big role in energy consumption. Therefore, the use of solar-based renewable energy systems in buildings is of great importance. According to the design of the building where PV panels will be used; It can be used in facade systems, curtain walls, roofs, shading elements, roof lighting systems or together with building elements such as parapets and eaves. (Eiffert, P., Kiss, G.J., 2000)

PV systems can be designed in buildings as integrated (BIPV) or post-added (BAPV). Building-integrated photovoltaic (BiPV) are considered as part of the building as well as power generation. (Eiffert, P., Kiss, G.J., 2000) Both types have different advantages and disadvantages compared to each other. BIPV systems prolong the useful life of the building by protecting the building from unwanted heat, noise, radiation, and water effects. In BAPV systems are fixed to the building later can be examined in two groups as panels fixed to the roof or outer wall. The advantage of this system over BIPV system is that it can be added to an existing building as needed. Common advantages of BIPV and BAPV; It covers all or a part of the electricity need of the building in which it is established, reduces energy losses and the load of the electricity network. (Dos Santos, Í. P., & Rüther, R. ,2012).

In addition to generating energy, PV elements play an important and decisive role in the formation of the building form, in the shaping of the building shell (facade and roof) by acting as a building element and in the building construction phase. (Eiffert, P., Kiss, G.J., 2000)

Building integrated photovoltaic systems (BIPV) provides benefits in terms of efficiency, economic, environmental, aesthetic, etc. Therefore, BIPV has become more preferred with the developing technology with an inclusive approach. BIPV systems should be in harmony with energy efficiency, aesthetic values, and technological developments. This system can be integrated with roof, facade, and external devices (Maturi, L., & Adami, J., 2018).

2.5 The Criteria for The Efficient Use of Photovoltaics

Most of the factors that affect photovoltaic system performance led to losses in energy generation. PV panels can be combined with the building exterior wall vertically (on the facade) or horizontally (on the roof). Module sizes, forms and colors are the features that affect the design in the use of PV panels in buildings. Factors such as location, orientation and surface inclination angle, shading, panel type, maintenance and cleaning, temperature behind the modules affect the performance / efficiency to be obtained from PV panels (Roberts, S., Guariento, N., 2009).

2.5.1 Location

Sun rays are different in every location and energy production values differ. This is due to the geoid shape of the Earth. The annual insolation values and temperature of the area where a PV panel application will be made on the roof or outer wall of a building, directly affects the energy to be obtained from the panel (Thomas, R., Fordham, M., 2001).

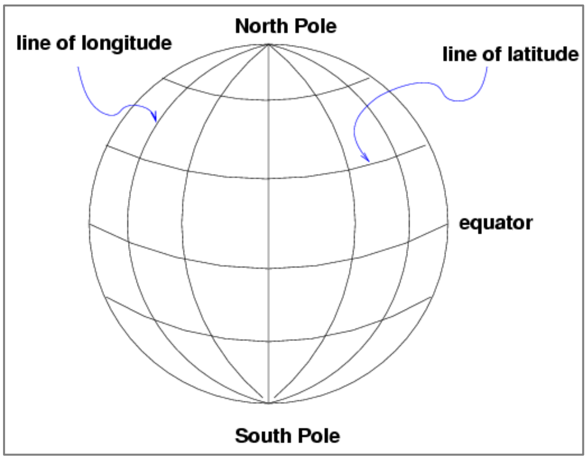


Figure 2.17: Earth Shape and Coordinate System Source:
http://spiff.rit.edu/classes/phys445/lectures/radec/radec.html

According to Thomas, R., Fordham, M. (2001), one of the factors most affected by photovoltaic panels due to location is temperature. Examining the temperature values and choosing a panel type that causes less efficiency loss in the temperature range depending on this temperature value will increase the efficiency of the system. When the temperature is high, electrons can be damaged. This reduces the voltage of the panel and negatively affects its efficiency. In other words, the efficiency of the panel decreases in summer days when the temperature was high.

2.5.2 Orientation and Surface Inclination Angle

The amount of energy obtained from the panel, the latitude of the building and the angle of inclination of the panel with the surface. The most efficient angle of the panel varies according to the location. The panel, which is positioned at an appropriate angle according to the sun angle of the location, shows the most efficient effect. The direction in which the panels should be applied to South direction. However, if there is a decrease in performance depending on the location, additional application can be made in the South-East and South-West directions. (Roberts, S., Guariento, N., 2009).

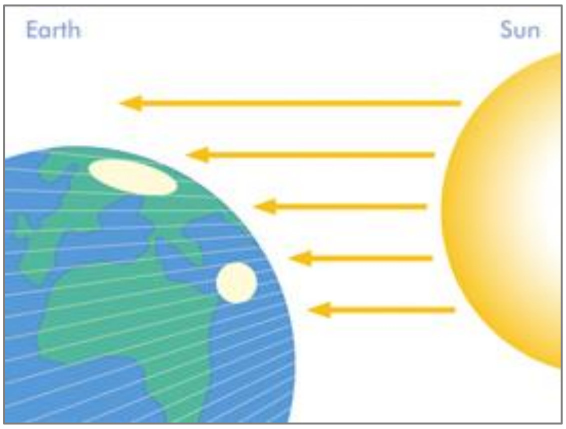


Figure 2.18: Orientation and Surface Inclination Angle of Earth Source: https://www.kippzonen.com/Knowledge-Center/Theoretical-info/Solar-Radiation/Introduction

2.5.3 Shading

Another factor that affects energy production the most is shading. In cases that cause shadow, shading analysis can be performed and positioning can be made. These analyzes are usually done by identifying the items that will prevent getting sun. Factors that can cause shadowing; neighbor buildings, trees and bushes can be counted as telephone poles. They overshadow each other, especially due to their close location in cities and city centers. Or sometimes it is possible for the building to shade itself due to the design. Since such situations will reduce the performance of the panel, correct decisions should be made during design and the PV panel system should be designed correctly (Roberts, S., Guariento, N., 2009).

Figure 2.19: Shading of solar collectors Source: https://news.energysage.com/what-is-a-solar-easement/

2.5.4 Panel Type

The material used in cell construction is one of the important factors affecting performance. As mentioned in 2.4.3 Types of Photovoltaics, the efficiency of the panel types varies according to the material purity ratio. The most efficient material is the monocrystalline cell with 16-19% efficiency. However, this material varies according to usage types. Therefore, considering the climatic conditions of the location to be used, the selected material type will help to affect the efficiency positively (Prasad, D.K., Snow, M., 2005).

Chapter 3

ANALYSIS OF SOLAR ENERGY POTENTIAL BY PV PANEL APPLICATION IN EMU-CAMPUS/FAMAGUSTA

3.1 Location and Climatic Features of Famagusta

Cyprus is in the northern hemisphere and is at latitude 35 ° N and longitude 34 ° E of the equator. Cyprus is the third largest island in the Mediterranean Sea. The climatic feature of the island is hot-dry in summer and rainy in winter. The most frequent months of rainfall are December, January, February, and March. The prevailing wind blows from the west. The island is affected by the climatic changes of the surrounding continents. The north and west zones of Cyprus are affected by the climate changes of Europe. The south and east zones of the island affected Africa and the Arabian Peninsula by the climatic changes. There are two important mountains in Cyprus. First one is Beşparmak mountains which is in north part of the island. Second one is Trodos mountains which is in the middle of the Cyprus (Ozay, 2005).

Figure 3.1: Location Map of Cyprus Source:
https://www.britannica.com/place/Cyprus

Famagusta City is in the eastern part of Cyprus and is 25 meters above sea level. The city's latitude and longitude settlement between in 35.1 ° N and 33.9 ° E. The climatic characteristic of the city is Mediterranean climate. Due to its location, the humidity is high, so the temperature in summer is felt higher than it is (Ouria, M., & Sevinc, H., 2018).

Figure 3.2: Location of Famagusta in Cyprus Source:
https://www.justaboutcyprus.com/map-cyprus/

3.1.1 Temperature Assessment of Famagusta

According to Figure 3.3 below, the minimum temperature of the year is 10° C in February. The maximum temperature of the year is 31° C in August. Generally, the coldest months of the year are January, February, and March. The months of the year with the highest temperatures are July, August, and September. According to the annually temperature table, the difference is 21 degrees.

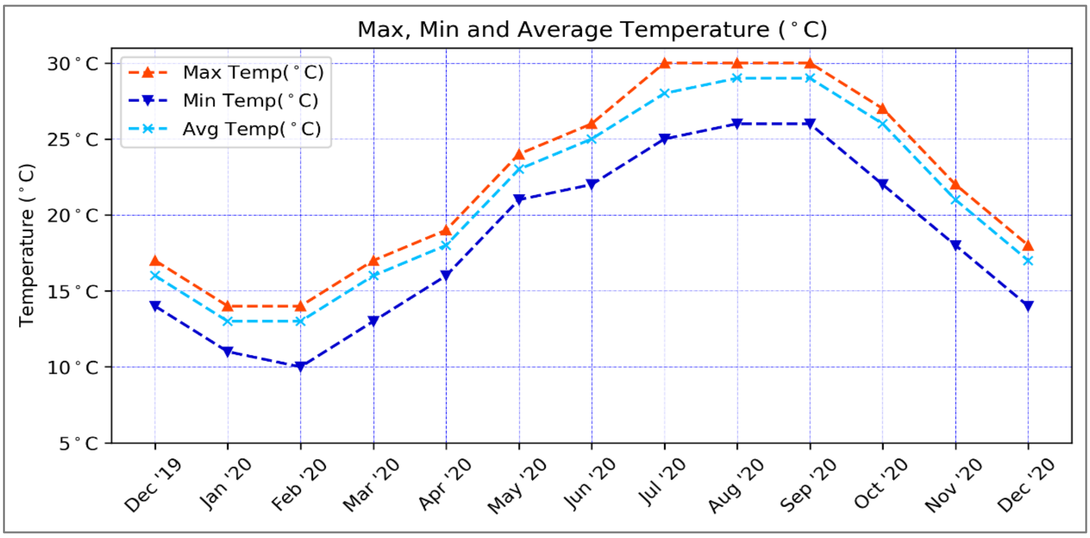


Figure 3.3: Annual Temperature Assessment of Famagusta (December,2019-December,2020) Figure Drawn by Author - Data taken from: https://www.worldweatheronline.com/famagusta-weather-averages/famagusta/cy.asp

As seen in the 10-year temperature graph in Figure 3.4, the minimum temperature ranges between 10-14 degrees. The lowest temperature is 10 degrees in February 2020. The maximum temperature varies between 30-34 degrees. In the last 10 years, the maximum temperature was observed as 34 degrees in August 2010.

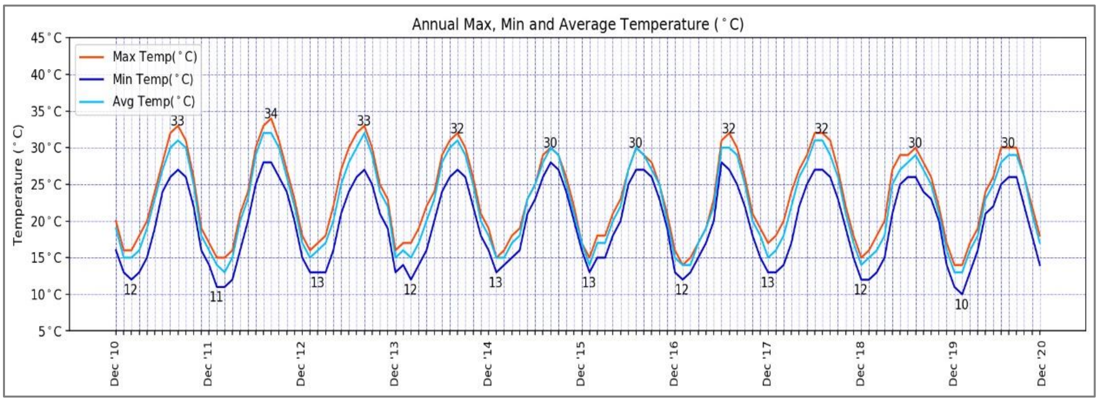


Figure 3.4: 10 Year Temperature Assessment of Famagusta (2010, December - 2020, December) Figure Drawn by Author - Data taken from: https://www.worldweatheronline.com/famagusta-weather-averages/famagusta/cy.aspx

3.1.2 Rain Fall Assessment of Famagusta

According to Figure 3.5 January receives 25 days of rain although, the total amount of precipitation in December is more than January with a 53 mm rainfall amount. There is no rain in June, July, and September. It only rained for 1 day in August. Based on these data, the Famagusta city usually receives rainfall during the winter and early spring months.

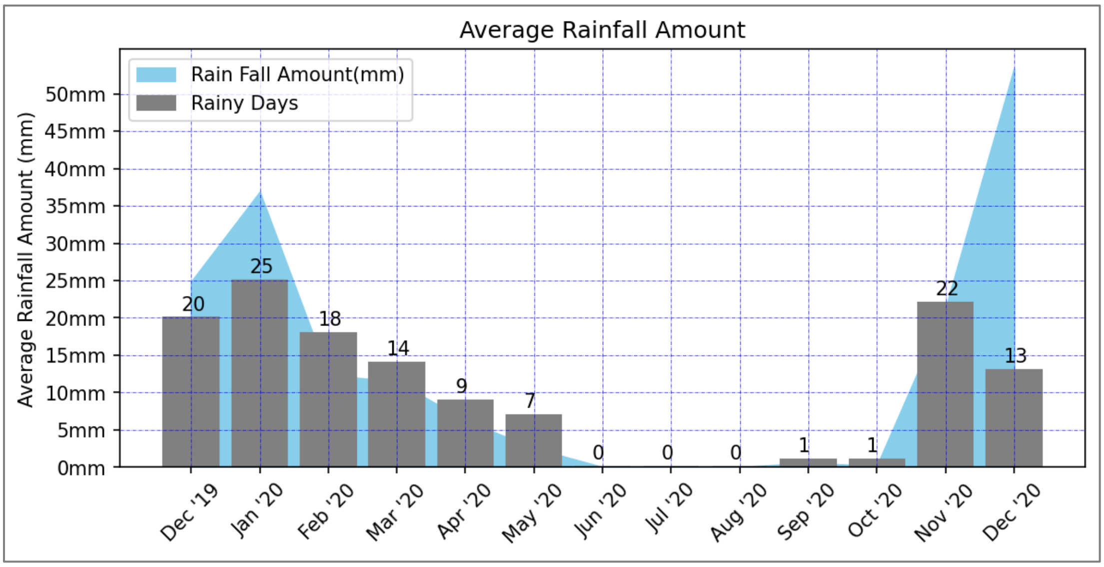


Figure 3.5: Rainfall and Rain Amount Assessment of Famagusta (December,2019 - December, 2020) Figure Drawn by Author - Data taken from: https://www.worldweatheronline.com/famagusta-weather-averages/famagusta/cy.aspx

According to Figure 3.6 and Figure 3.7 below, in the last 10 years, the most rainfall days and amount occurred in January 2020 with 24 days and December 2020 with 53mm rainfall amount. In the last 2 years, the amount of rainfall has increased significantly and reached the peak level. Based on the maximum amount of rainfall amount and days, the least rainfall happened in 2018 (13,68 mm, 7 days). The difference in ratio-quantity between the two tables can be clearly observed. The reason for this rainfall periods and rates are low while rain days are often. In winter, it is usually sunny or cloudy after a short rainfall.

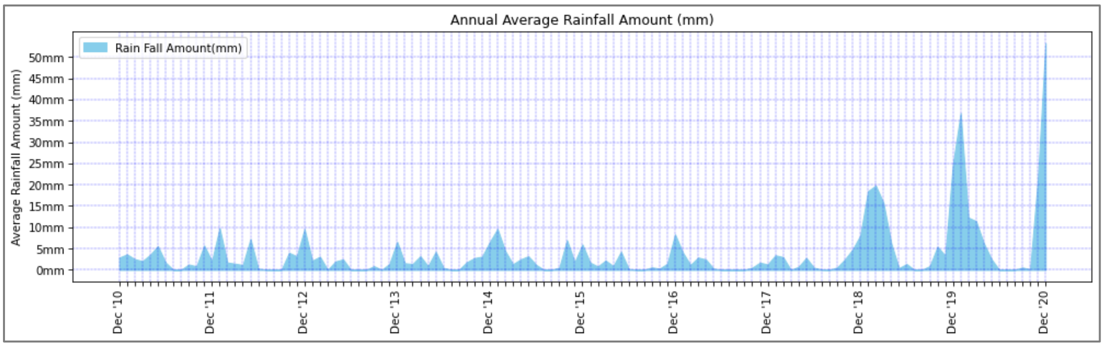


Figure 3.6: Annually Rainfall Amount Assessment of Famagusta (2010, December - 2020, December) Figure Drawn by Author - Data taken from: https://www.worldweatheronline.com/famagusta-weather-averages/famagusta/cy.aspx

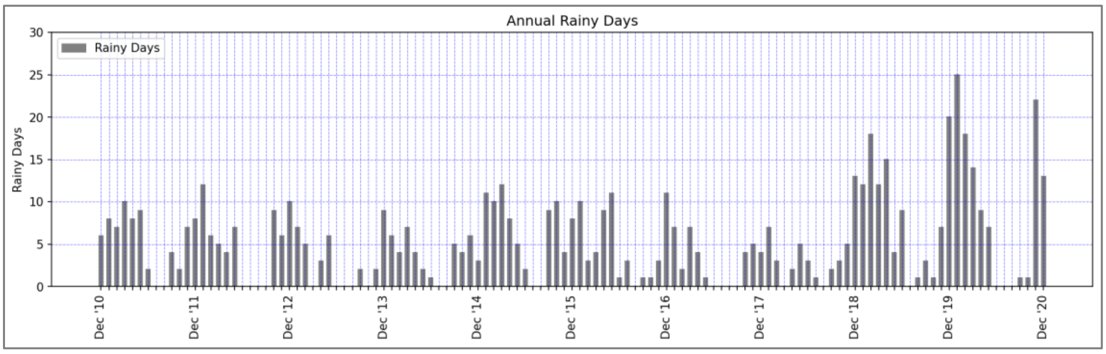


Figure 3.7: Annually Rainy Days Assessment of Famagusta (2010, December - 2020, December) Figure Drawn by Author - Data taken from: https://www.worldweatheronline.com/famagusta-weather-averages/famagusta/cy.aspx

3.1.3 Sunshine Duration of Famagusta

As seen in Figure 3.8 below, maximum sunlight reaches in July with 444 sun hours. Based on these data, the average sunshine duration is approximately 14 hours in July. Sunshine reaches a minimum level in February with 205 hours. Average sunshine duration is approximately 6 hours 30 minutes in December. According to Ouria, M., & Sevinc, H., (2018) the differences of sunshine duration time between the shortest (21 June) and longest days (21 December) is 4 hours 44 minutes.

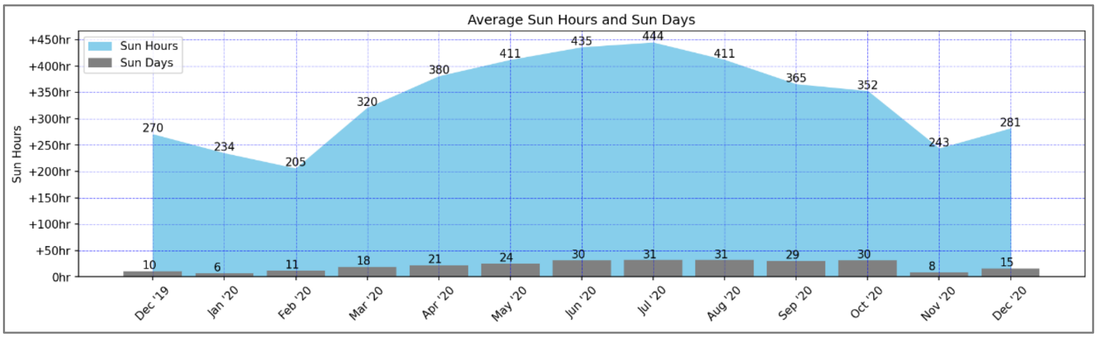


Figure 3.8: Sunshine Duration of Famagusta (December, 2019- December, 2020)
Figure Drawn by Author - Data taken from:
https://www.worldweatheronline.com/famagusta-weather-averages/famagusta/cy.aspx

Due to Figure 3.9 and Figure 3.10, the sunshine duration data of the last decade are close to each other, while the daily sunshine duration increases in the summer months and decreases in the winter months.

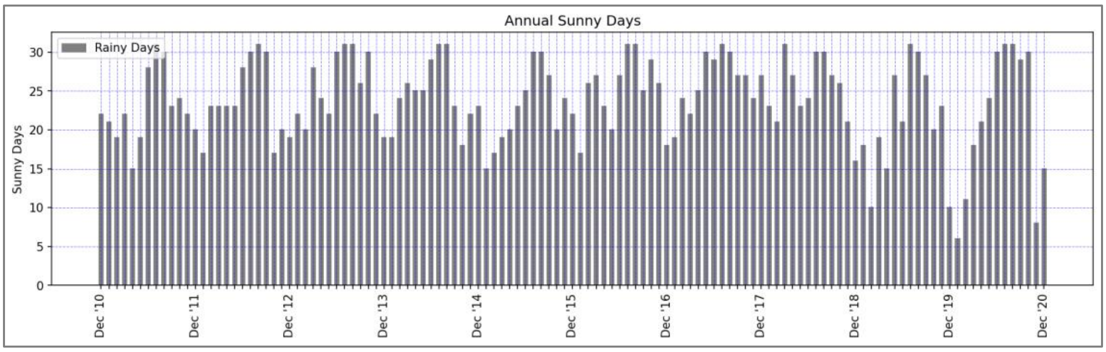


Figure 3.9: Sunny Days of Famagusta of the last decade (2010, December - 2020, December) Figure Drawn by Author - Data taken from: https://www.worldweatheronline.com/famagusta-weather-averages/famagusta/cy.aspx

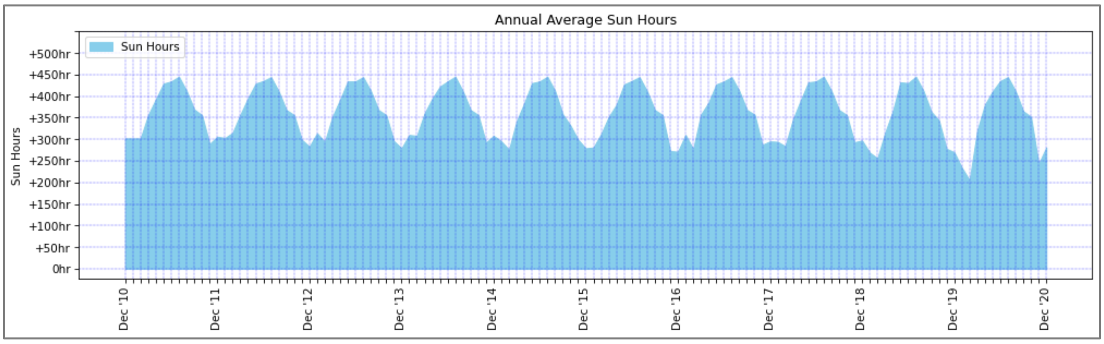


Figure 3.10: Sun Hours of Famagusta of the last decade (2010, December - 2020, December) Figure Drawn by Author - Data taken from: https://www.worldweatheronline.com/famagusta-weather-averages/famagusta/cy.aspx

3.1.4 Solar Energy Potential of Famagusta

Solar energy values vary according to location and climatic values. Famagusta city has a high level of solar energy potential due to its location and climatic characteristics (Ouria, M., & Sevinc, H., 2018).

According to Figure 3.11 below, Famagusta solar radiation values approximately 1935 kWh/m². That means Famagusta has a high solar energy potential.

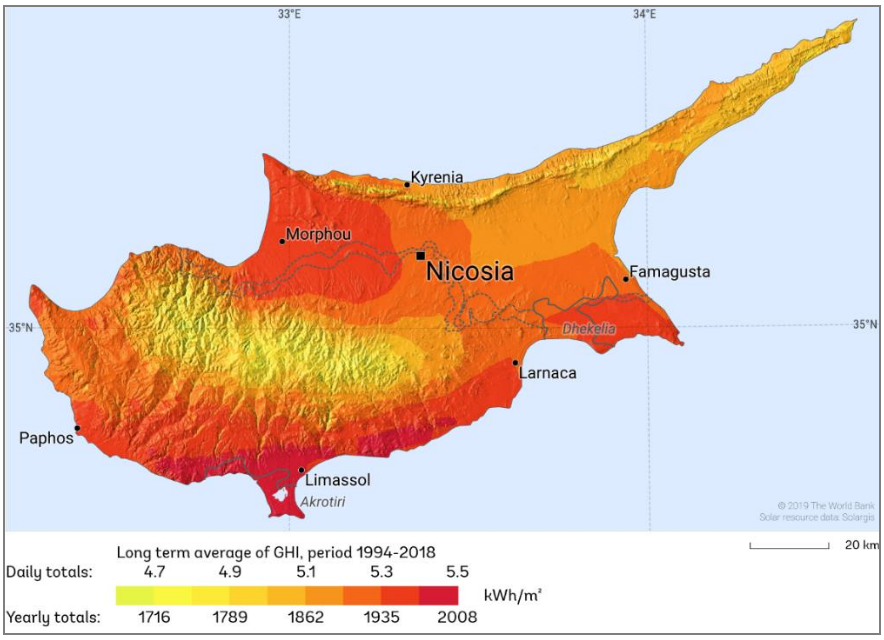


Figure 3.11: Solar Energy Potential of Famagusta Source: https://solargis.com/maps-and-gis-data/download/cyprus

3.2 Historical Development of the EMU

EMU is a multicultural university with 17.500 students are enrolled from 110 countries and 1.100 faculty member and academic staff from 35 different countries are working at the EMU. EMU has 12 faculties and 4 schools with 108 associate and undergraduate programs, 96 master and doctoral programs (EMU Official Web Page-I).

Figure 3.12: Campus of Eastern Mediterranean University Source: https://www.emu.edu.tr/en/campus/photo-gallery/681

The EMU-Campus is located on 3.000.000 meter-square of land with a main campus and south campus. In addition to the education buildings library, health center, sports hall, outdoor sports areas, activity spaces and dormitories are also located on the campus (EMU Official Website-I).

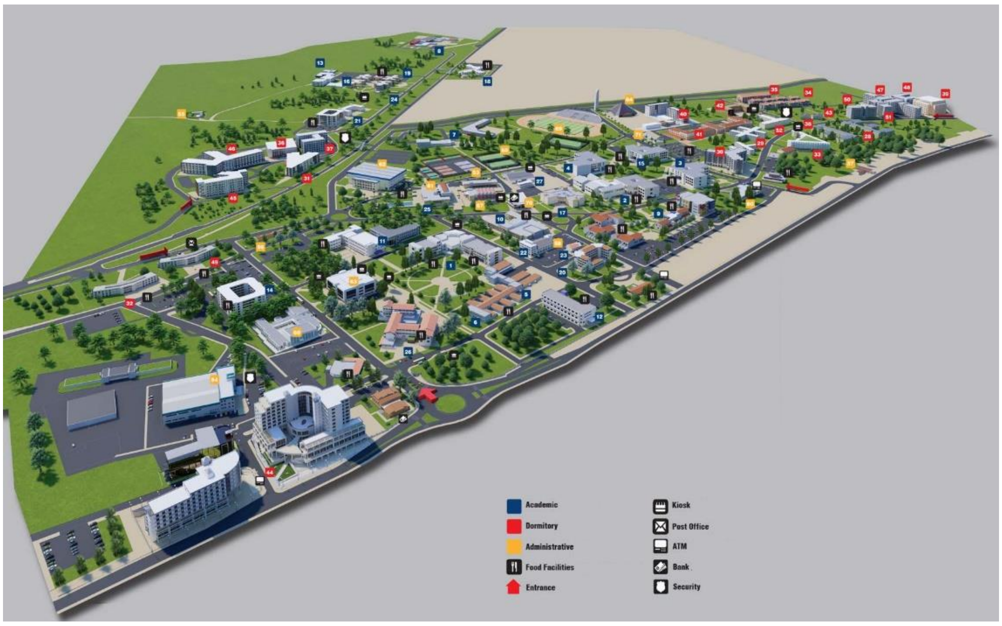


Figure 3.13: 3D Map of Eastern Mediterranean University Campus(2020) Source: https://www.emu.edu.tr/campusmap

The Eastern Mediterranean University (EMU) started its educational activities as the High Technology Institute in 1979. The goal of this program was to provide technician education. In 1984, the associate degree program was transformed into engineering education. According to decision of Turkish Republic of Northern Cyprus (TRNC) and the Republic of Turkey, the institute became a university in 1986. (EMU Official Website-II).

Figure 3.14: The EMU-Campus in 1975. Source: Map taken from EMU Project Management

According to Figure 3.14, there were only two buildings on the EMU-Campus land. These buildings are used today as Faculty of Communication and Media Studies(I) and the School of Computing Technology (II).

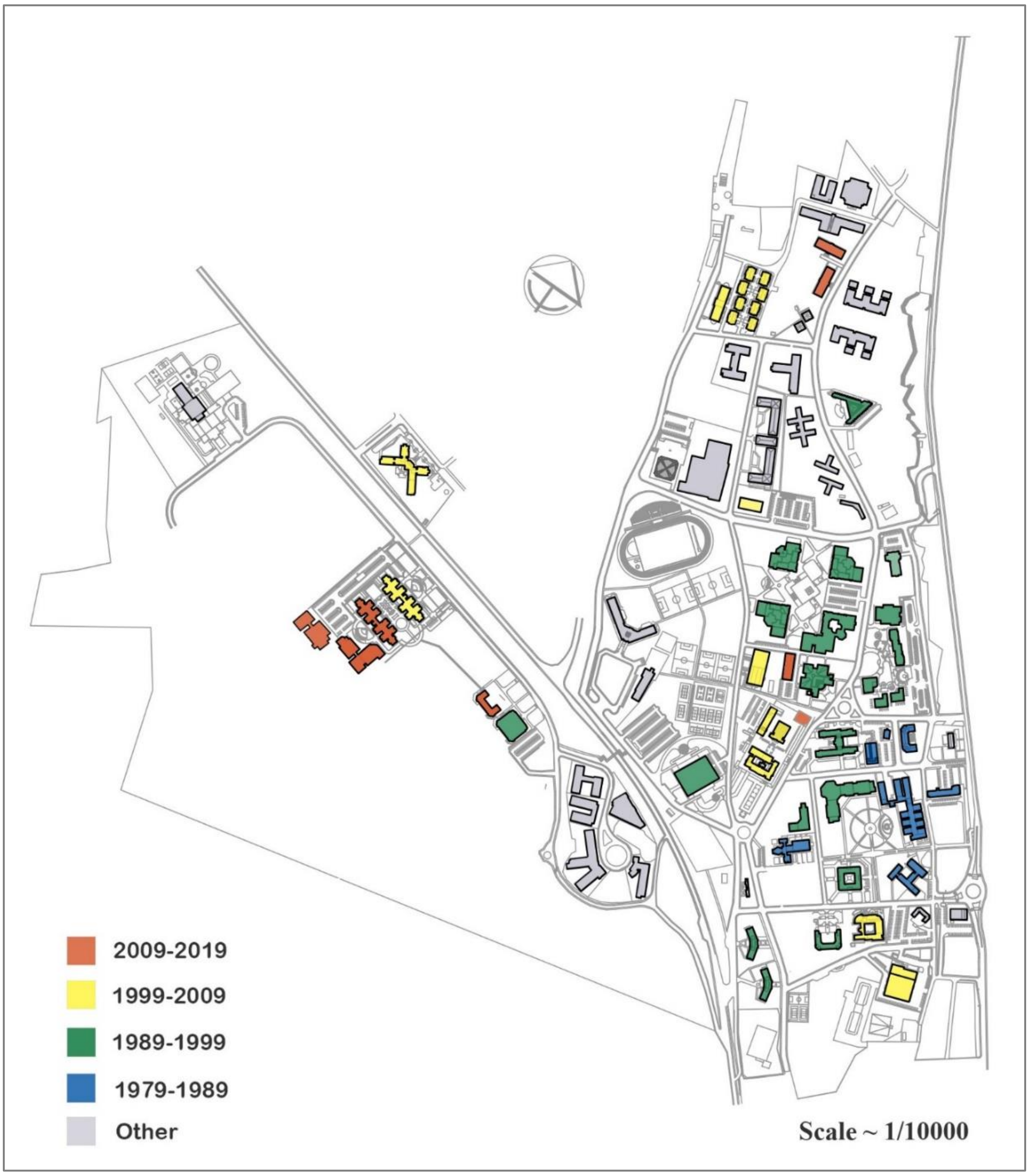


Figure 3.15: Historical Development of the EMU-Campus between 1979-2019
Source: Map taken from EMU Project Management, edited by Author

As shown in Figure 3.15, the current map of the campus is categorized in 10-year periods according to the construction years of buildings. Other buildings which are not administrated by EMU (the buildings marked with gray). For this reason, these buildings are not included in the research study.

Table 3.1: Construction years of the education, administrative and other service buildings in the campus.

Building	Construction Year	Period
School of Computing and Technology(Existed)	1979	
Faculty of Communication and Media Studies	1979	
Computer Center	1979	
Institute of Graduate Studies and Research	1979	
Business and Economy Faculty	1988	
Faculty of Tourism	1989	
Faculty of Education	1990	
Arch Studios	1990	
Sabancı (EMU 1) Dormitory	1990	
Faculty of Arts and Sciences	1994	
Özay Oral Library	1994	
Civil Engineering	1996	
Central Lecture Halls Building	1996	
Faculty of Architecture	1996	
Health Center	1996	
Business and Economy Faculty Block B	1997	
Foreign Languages and English Preparatory School	1997	
Industrial Engineering	1997	
Electrical and Electronic Engineering	1998	
EMU 2 Dormitory	1998	
Administrative Building of Faculty of Architecture	1998	
Lala Mustafa Paşa Sports Complex	1998	
Computer Engineering	1998	
Faculty of Law	1999	
Administrative Services Building	2000	
Faculty of Pharmacy	2001	
Activity Center	2003	
Faculty of Medicine-TechnoPark	2004	
Technical Affairs and Project Management	2005	
Visual Arts and Visual Communication Design	2005	
EMU 3 Dormitory	2005	
EMU 4 Dormitory	2007	
Registrars Office	2008	
Personnel and Financial Affairs	2008	
Rectorate Building	2008	
Faculty of Health Sciences	2010	
Student Service Building	2011	
Visual Arts and Visual Communication Design Block B	2013	
Foreign Languages and English Preparatory School Block B	2014	
Faculty of Health Sciences Block B	2017	
Faculty of Dentistry	2020	

According to Figure 3.15 and Table 3.1; EMU had 6 buildings together with the existing buildings limited to small area in the first ten-year period. Between 1989-1999 period, the campus accelerated in construction. As can be seen from the construction years of the buildings, the buildings in the EMU-Campus were mostly developed between 1990-1999. The South-Campus was also added to the land. Thus, the campus consists of two large areas, the Main- and the South-Campus. EMU land has almost formed its current borders. Finally, the current situation of the EMU Campus was completed after the construction of the Faculty of Dentistry in 2020.

The development of EMU between 1979 - 2020 is going to be analyzed to find out its solar energy potential capacities. Because of the limited construction area, the planning and design of new buildings in the future will focus on the South-Campus. It is undeniable that as the campus grows, the need for heating-cooling-equipment energy will gradually increase. To meet the increased energy demand of the EMU Campus the solar energy technology will be applied on building roofs and vertical surfaces and not on vacant sites, because it will contribute to the sustainable development of the university.

3.3 Energy Demand of the Buildings in the EMU-Campus

EMU has a large campus with education-administrative buildings, dormitories, and various activity areas. All these spaces need electricity for heating, cooling, lighting and for electronical devices. EMU consumed 11.596.693 kW/h total energy in 2019. Data is based on 2019 because of pandemic and lockdown situation in 2020. It is assumed that the energy consumption might not be realistic in 2020 because of lack of students who left the country after March 2020 and staff’s working conditions (home office) outside of the EMU Campus.

Table 3.2: Annual Total Energy Consumption Report of EMU (2019)

ANNUAL TOTAL ENERGY CONSUMPTION REPORT OF EMU	
JANUARY 2019	1.140.224
FEBRUARY 2019	772.386
MARCH 2019	795.568
APRIL 2019	804.054
MAY 2019	924.254
JUNE 2019	1.069.644
JULY 2019	1.267.248
AUGUST 2019	841.814
SEPTEMBER 2019	1.057.062
OCTOBER 2019	1.328.334
NOVEMBER 2019	774.625
DECEMBER 2019	821.480
Total kWh	**11.596.693**

Smart meters are measuring total electricity consumption data. They are used regionally depending on the surrounding buildings. Each smart meter calculates the total electricity consumption of their region. The data of the smart meters are collected in total. Therefore, the electrical energy consumed by buildings cannot be calculated precisely. According to the smart meter system that measures zonal data, it is possible to get an average data based on the square meter of the buildings.

3.4 PV Panel Application on Building Surfaces in the EMU-Campus/Famagusta

Photovoltaics are technical devices as well as they are architectural elements of buildings. There must be a “functional, constructive and formal” approach to combine architecture and technique. In other words, there should be architectural integrity as well as technical conditions and details in integrations (Farkas, K. et al., 2013).

3.4.1 Analysis About the Building Surfaces of EMU Campus

In this chapter EMU-Campus building roofs and facades have been evaluated and tabulated for PV Panel integration. The evaluations are based on the following criteria: building height-floor, south facing areas, shadow potential around the building

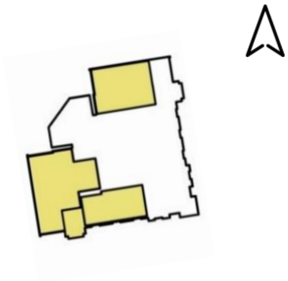
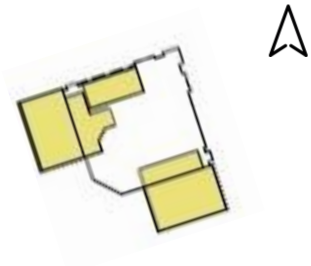
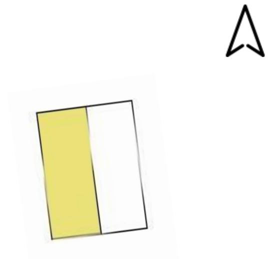
(building or tree), air conditioning components and vertical circulation areas for roofs are not include. As a result of these criteria, unsuitable buildings and areas were excluded. The areas for PV panel integration have been determined.

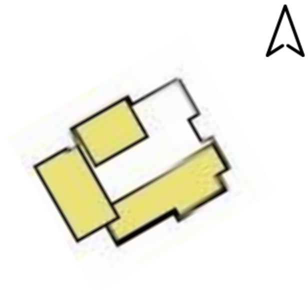
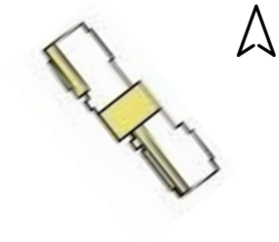
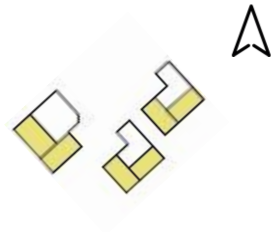
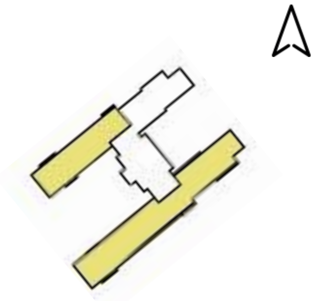
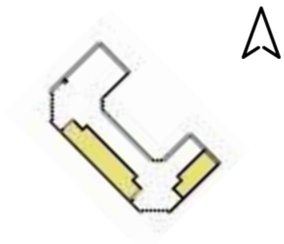
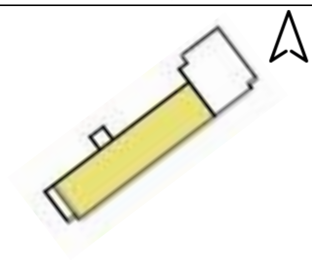
3.4.1.1 Available Roof Areas and Roof Inclination

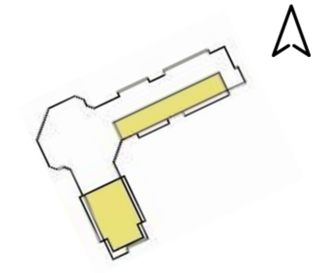
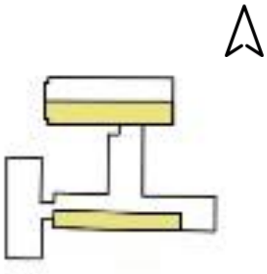
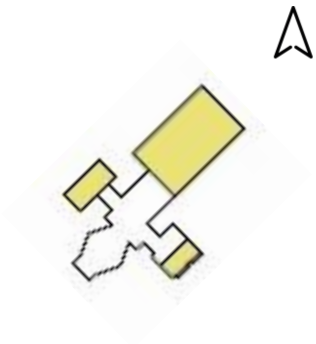
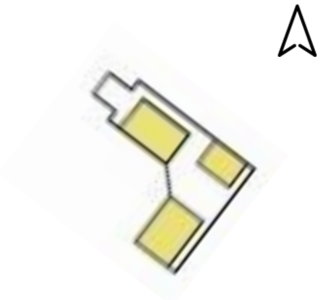
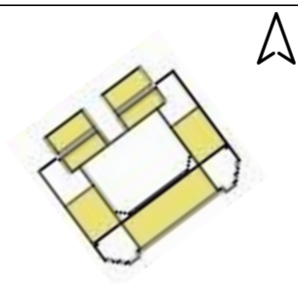
EMU Campus have 44 buildings for the integration of Photovoltaic Panel. These are education, administrative buildings, and dormitories. Most of the buildings located close to each other are the same in height. The location distances of the buildings are wide, so there is no shadowing on the roofs. The surrounding trees are approximately 4-6 meters height. For this reason, the building roofs have not been shadowed.

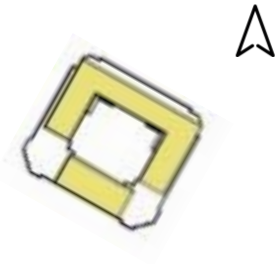
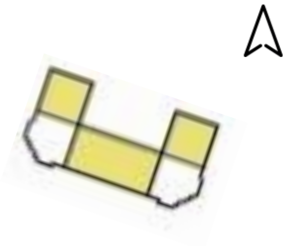
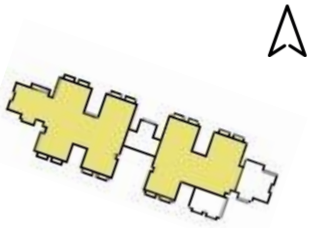
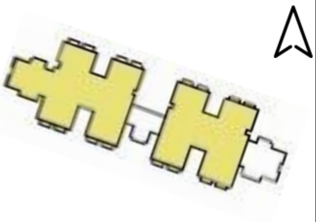
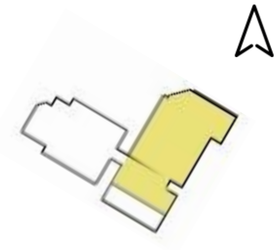
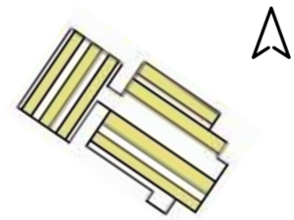
As a result of investigations Mechanical Engineering is not suitable for PV panel integration. The mechanical engineering building has 2 floors and is located at a lower code due to the topography. The building is not suitable for integration due to the high trees around it. According to these evaluations, 43 of 44 buildings are suitable for integration.

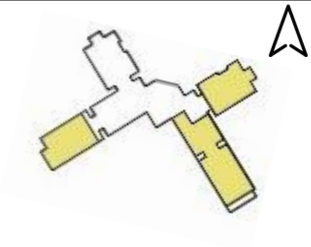
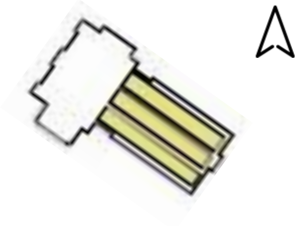
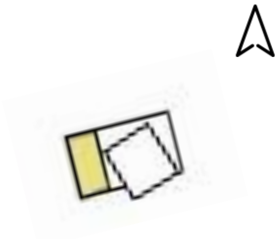
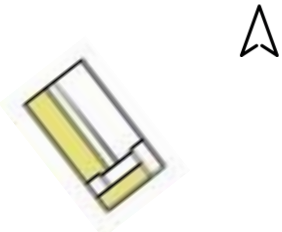
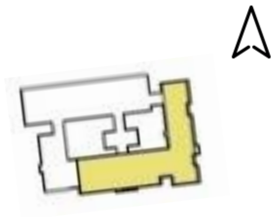
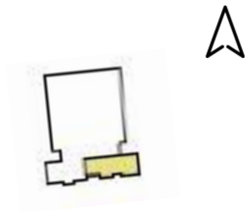
Table 3.3: Available Roof Areas of EMU-Campus

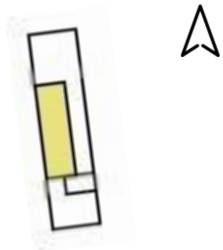
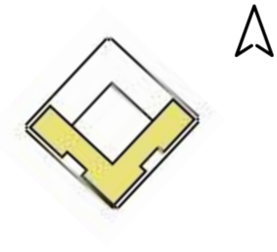
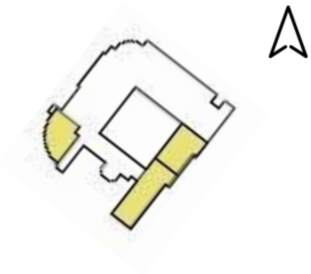
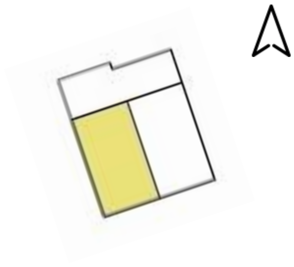
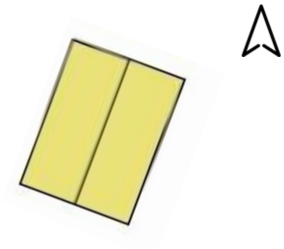
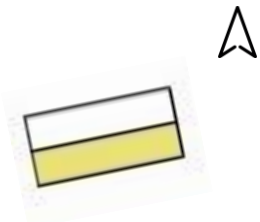
Name of the Building	Available Roof Areas for PV Installation	Photos
1-Industrial Engineering Floor Number: 3 Height: 12 m Roof Type: Flat Available Area :913 m²		
2-Computer Engineering Floor Number: 3 Height: 12 m Roof Type: Flat Available Area:1191 m²		
3-Electrical and Electronic Engineering Floor Number: 3 Height: 12 m Roof Type: Flat Available Area: 1418 m²		
4-Civil Engineering Floor Number: 3 Height: 12 m Roof Type: Flat-Slopy Available Area: 1688 m²		
5-Visual Arts and Visual Communication Design Floor Number: 1 Height: 5 m Roof Type: Slopy Available Area: 487 m²		
6-Faculty of Law Floor Number: 3 Height: 12 m Roof Type: Flat Available Area: 1093 m²		

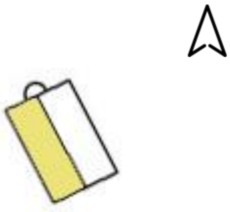
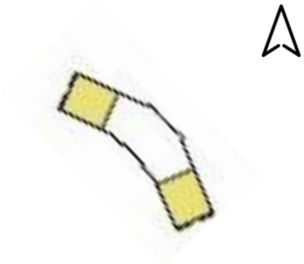
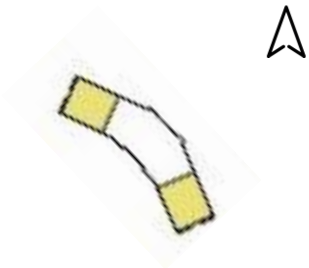
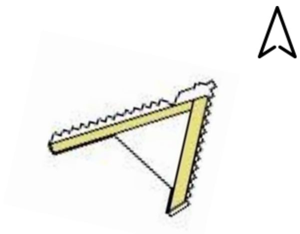
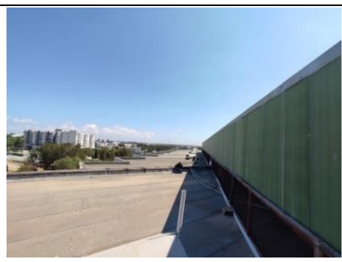
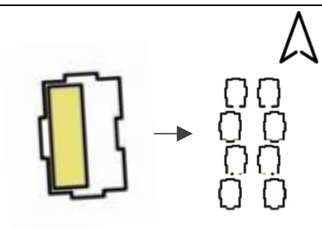
Name of the Building	Available Roof Areas for PV Installation	Photos
7-Faculty of Architecture Floor Number: 3 Height: 12 m Roof Type: Flat Available Area: 955 m²		
8-Faculty of Architecture Administrative Building Floor Number: 3 Height: 12 m Roof Type: Slopy Available Area: 344 m²		
9-Faculty of Architecture Studios Floor Number: 1 Height: 5 Roof Type: Flat Available Area: 892 m²		
10-Faculty of Arts and Sciences Floor Number: 3 Height: 12 Roof Type: Flat Available Area: 1311 m²		
11-Faculty of Tourism Floor Number: 4 Height: 16 m Roof Type: Slopy Available Area: 345 m²		
12-Faculty of Communication and Media Studies Floor Number: 3 Height: 12 m Roof Type: Flat Available Area: 512 m²		

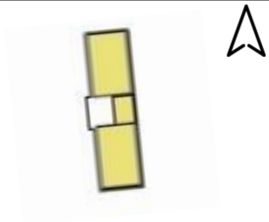
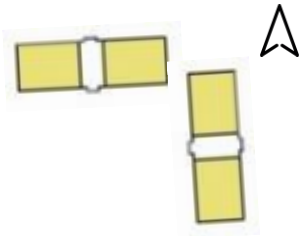
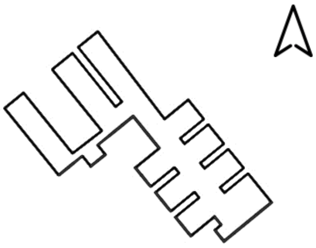
Name of the Building	Available Roof Areas for PV Installation	Photos
13-Central Lecture Hall Floor Number: 4 Height: 16 m Roof Type: Flat-Slopy Available Area: 1157 m²		
14-School of Computing and Technology Floor Number: 3 Height: 12 m Roof Type: Flat Available Area: 485 m²		
15-Faculty of Business and Economics Block A Floor Number: 3 Height: 12 m Roof Type: Flat Available Area: 812 m²		
16-Faculty of Business and Economics Block B Floor Number: 3 Height: 12 m Roof Type: Flat Available Area: 504 m²		
17-Faculty of Education Floor Number: 4 Height: 16 m Roof Type: Flat Available Area: 853 m²		

Name of the Building	Available Roof Areas for PV Installation	Photos
18-Foreign Languages and English Preparatory School Block A Floor Number: 4 Height: 16 m Roof Type: Flat Available Area: 941 m²		
19-Foreign Languages and English Preparatory School Block B Floor Number: 3 Height: 12 m Roof Type: Flat Available Area: 568 m²		
20-Faculty of Pharmacy Floor Number: 3 Height: 12 m Roof Type: Flat Available Area: 1883 m²		
21-Faculty of Health and Sciences Floor Number: 3 Height: 12 m Roof Type: Flat Available Area: 1974 m²		
22-Faculty of Health and Sciences Block B Floor Number: 1 Height: 5 m Roof Type: Flat Available Area: 1357 m²		
23-Faculty of Dentistry Floor Number: 1 Height: 5 m Roof Type: Available Area: 1351 m²		

Name of the Building	Available Roof Areas for PV Installation	Photos
24-Faculty of Medicine Floor Number: 2 Height: 8 m Roof Type: Flat Available Area: 1201 m²		
25-Health Center Floor Number: 2 Height: 8 m Roof Type: Flat Available Area: 324 m²		
26-Student Service Building Floor Number: 2 Height: 10 m Roof Type: Flat Available Area: 120 m²		
27-Computer Center Floor Number: 4 Height: 16 m Roof Type: Flat-Slopy Available Area: 311 m²		
28-Rectors Office Floor Number: 2 Height: 10 Roof Type: Flat-Curve Available Area: 744 m²		
29-Registrar's Office Floor Number: 2 Height: 10 m Roof Type: Flat-Curve Available Area: 102 m²		

Name of the Building	Available Roof Areas for PV Installation	Photos
30-Personnel Affairs and Financial Affairs Floor Number: 2 Height: 8 m Roof Type: Flat Available Area: 234 m²		
31-Özay Oral Library Floor Number: 4 Height: 20 m Roof Type: Flat Available Area: 670 m²		
32-Social and Cultural Activities Center Floor Number: 1 Height: 5 m Roof Type: Flat Available Area: 498 m²		
33-Administrative Services Floor Number: 4 Height: 16 m Roof Type: Flat Available Area: 1080 m²		
34-LMP Sports Complex Floor Number: 3 Height: 20 m Roof Type: Flat Available Area: 3496 m²		
35-Technical Affairs Floor Number: 2 Height: 8 m Roof Type: Slopy Available Area: 442 m²		

Name of the Building	Available Roof Areas for PV Installation	Photos
36-Cooperative Building Floor Number: 1 Height: 4 m Roof Type: Slopy Available Area: 158 m²		
37-Institute of Graduate Studies and Research Floor Number: 1 Height: 5 m Roof Type: Slopy Available Area: 80 m²		
38-Sabancı Dormitory (EMU 1) Block A Floor Number: 4 Height: 16 m Roof Type: Flat Available Area: 379 m²		
39-Sabancı Dormitory (EMU 1) Block B Floor Number: 4 Height: 16 m Roof Type: Flat Available Area: 404 m²		
40-EMU 2 Dormitory Floor Number: 4 Height: 16 m Roof Type: Slopy-Flat Available Area: 554 m²		
41-EMU 3 Dormitory Floor Number: 2 Height: 8 Roof Type: Slopy Available Area: 1208 m²		

Name of the Building	Available Roof Areas for PV Installation	Photos
42-EMU 4 Dormitory Floor Number: 3 Height: 12 m Roof Type: Slopy Available Area: 963 m²		
43-KYK Dormitory Floor Number: 7 Height: 28 m Roof Type: Flat Available Area: 1581 m²		
44-Mechanical Engineering Floor Number: 2 Height: 8 m Roof Type: Slopy-Flat Available Area: -		

As seen in Figure 3.16 below, avaible roof areas determined are marked on the campus map. Suitable PV Panel integration areas of buildings are marked with yellow, unsuitable buildings are indicated with purple and other buildings that cannot be inspected are indicated with gray color.

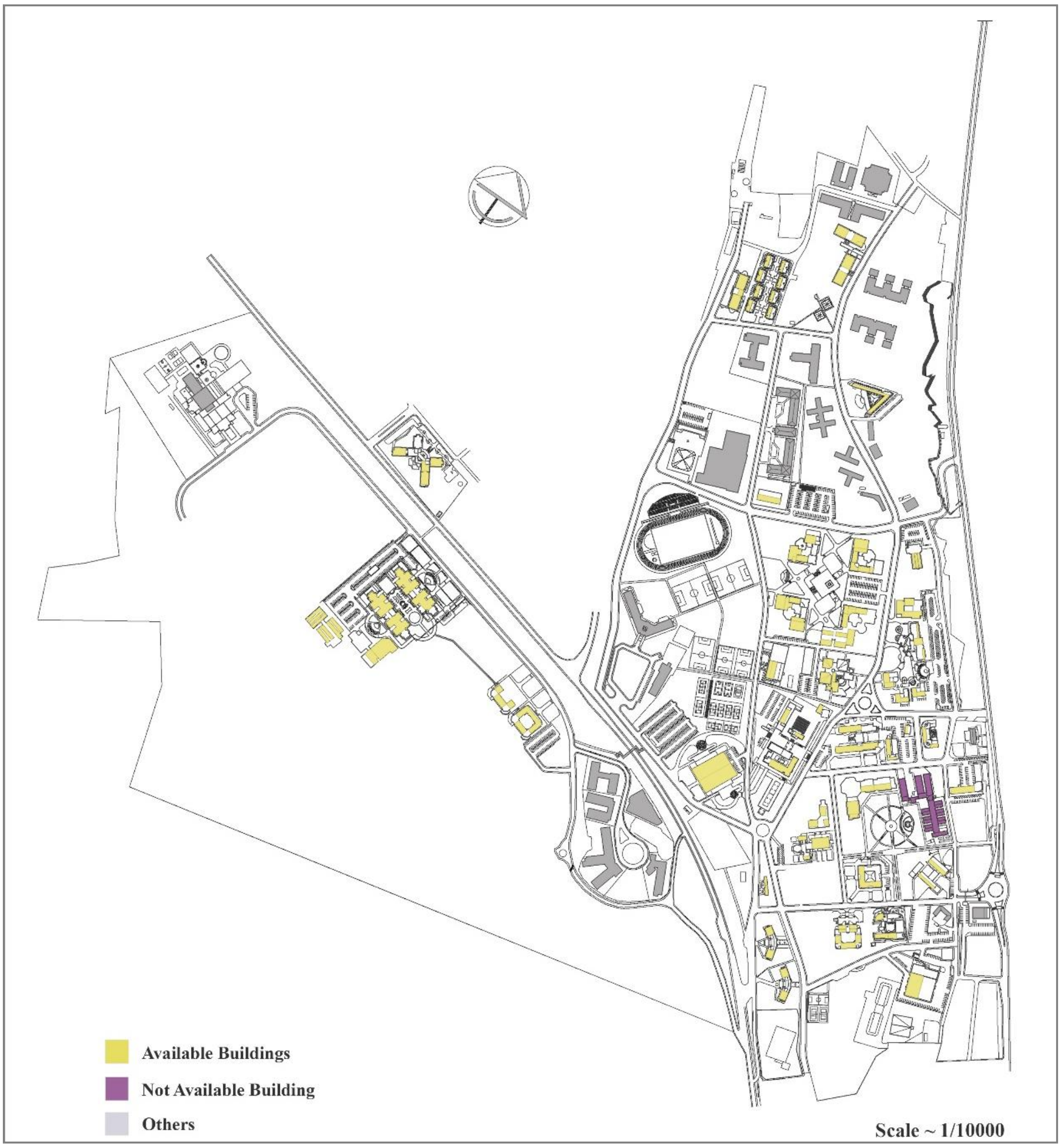


Figure 3.16: Map of Available Roof Areas in the Emu-Campus

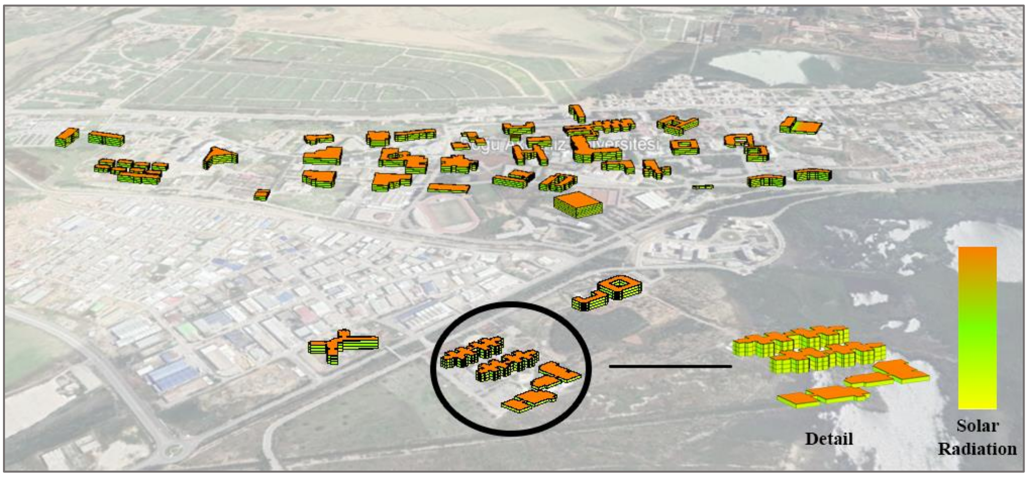


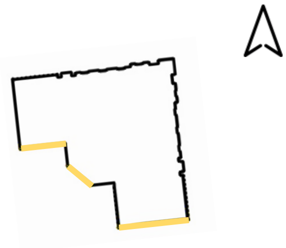
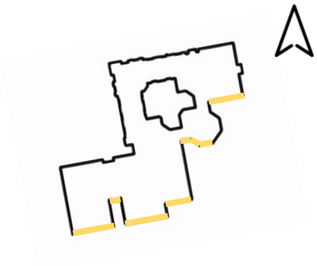
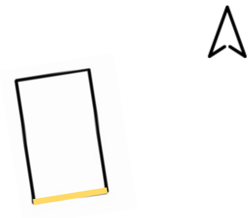
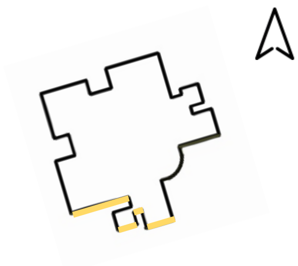
Figure 3.17: Solar Radiation Simulation of EMU-Campus from South Direction (Model analyzing with Revit Software)

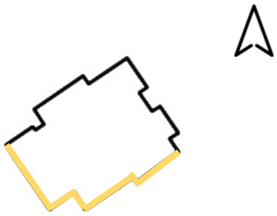
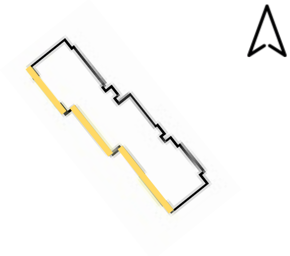
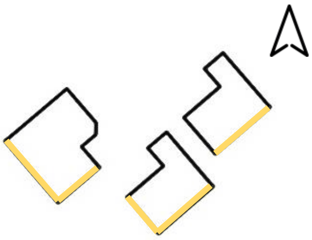
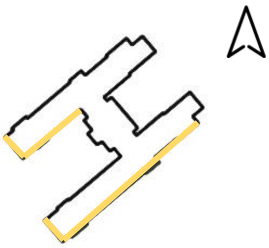
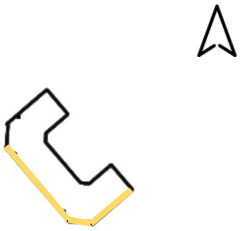
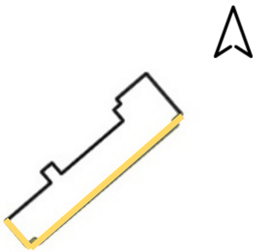
As seen in Figure 3.17, the solar energy radiation potential of EMU-Campus buildings was simulated. According to this radiation graphic, roof areas are more efficient than facades and it is clearly understood that campus buildings have high solar energy potential.

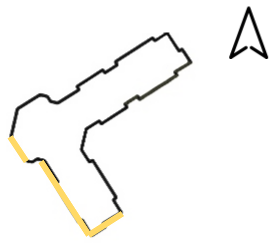
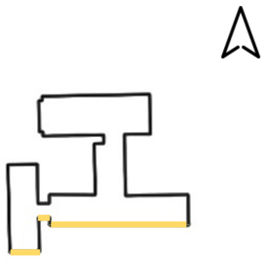
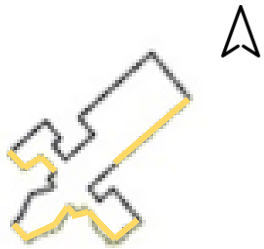
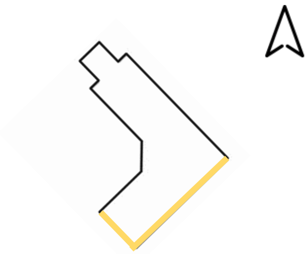
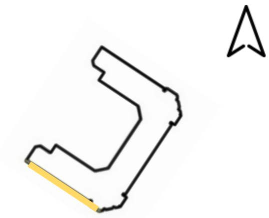
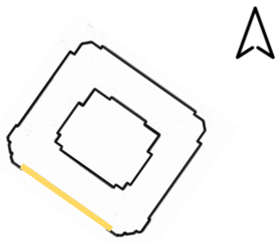
3.4.1.2 Appropriate Exterior Walls

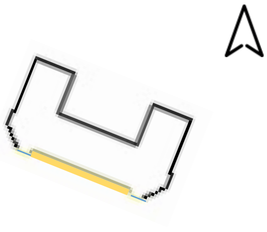
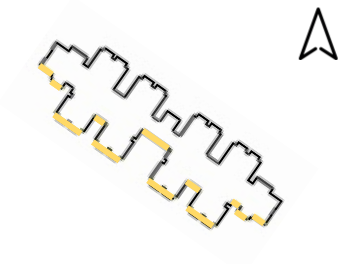
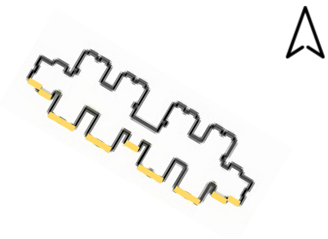
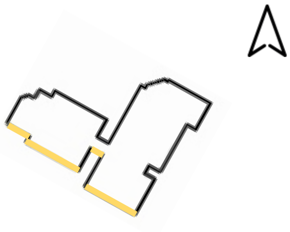
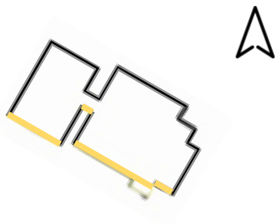
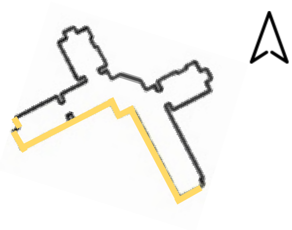
The appropriate exterior walls play an important role for power generation by BIPVs. The south façades of total surface areas are measured as appropriate orientation for solar energy gain. The areas where sunlight is blocked due to shading of the building have been identified. During the investigation, 3 types of shading were detected. Some building facades are shaded partially by tree/greenery, level differences or shading elements. One building is completely in shadow which is the Mechanical Engineering building. The reason for this, building heights are approximately 5 meters, trees are located on the south facade and the buildings height is lower in comparison to the surrounding building. Azimuth angles are given in the table. Southeast and Southwest directions are abbreviated as a SE and SW.

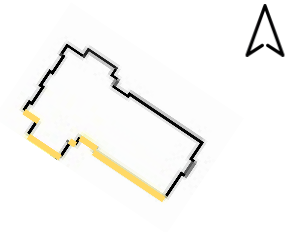
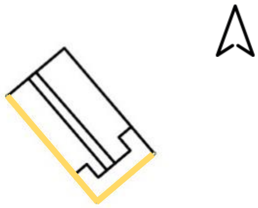
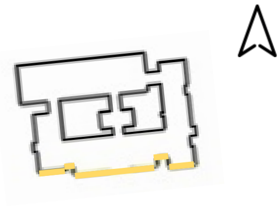
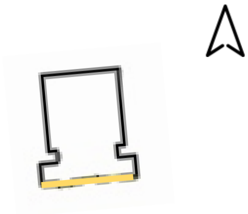
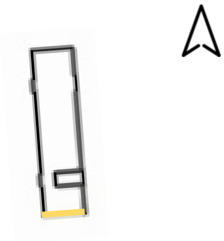
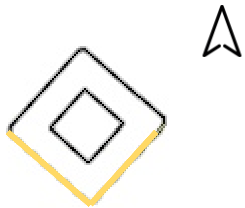
Table 3.4: Appropriate Exterior Wall surfaces of EMU-Campus

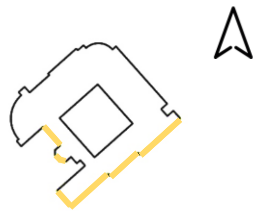
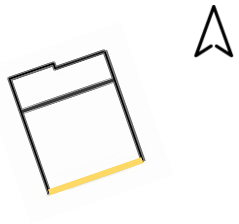
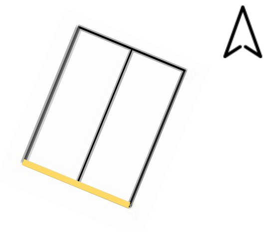
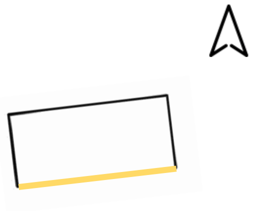
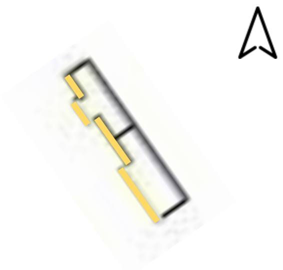
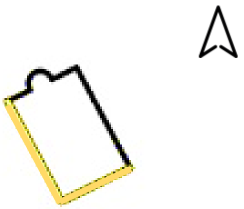
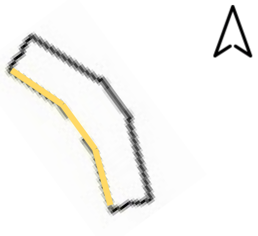
Name of the Building	South-facing Exterior Walls	Photos of the Exterior Walls
1-Industrial Engineering Height: 12 m Surface Area: 636 m² Shadow: Partially Blocked (Tree) Azimuth: SW 339°, SE 67°		
2-Computer Engineering Height: 12 m Surface Area: 732 m² Shadow: Partially Blocked (Tree) Azimuth: SW 339°, SE 67°		
3-Electrical and Electronic Engineering Height: 12 m Surface Area: 624 m² Shadow: - Azimuth: SW 339°, SE 67°		
4-Civil Engineering Height: 12 m Surface Area: 1044 m² Shadow: Partially Blocked (Tree) Azimuth: SW 339°, SE 67°		
5-Visual Arts and Visual Communication Design Height: 5 m Surface Area: 145 m² Shadow: - Azimuth: SW346°, SE 75°		
6-Faculty of Law Height: 12 m Surface Area: 432 m² Shadow: - Azimuth: SW 340°, SE 69°		

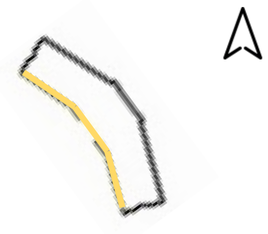
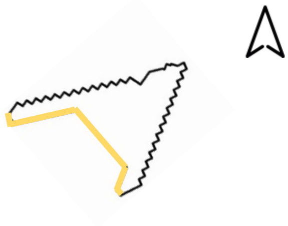
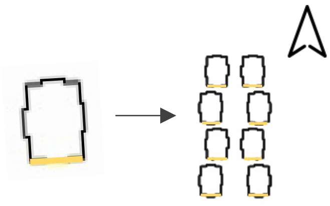
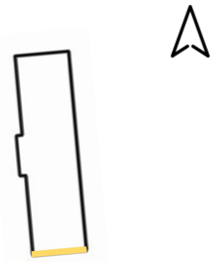
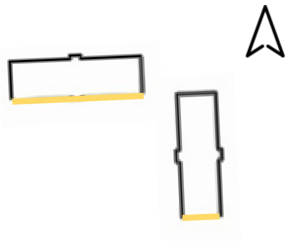
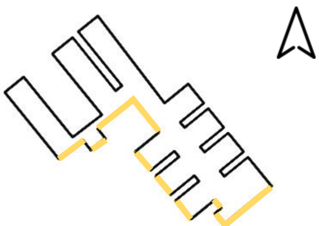
7-Faculty of Architecture Height: 12 m Surface Area: 828 m² Shadow: - Azimuth: SW 330°, SE 61°		
8-Faculty of Architecture Administrative Building Height: 12 m Surface Area: 840 m² Shadow: Partially Blocked (Tree) Azimuth: SW 322°, SE 59°		
9-Faculty of Architecture Studios Height: 5 Surface Area: 545 m² Shadow: - Azimuth: SW 323°, SE 55°		
10-Faculty of Arts and Sciences Height: 12 Surface Area: 941 m² Shadow: - Azimuth: SW 324°, SE 52°		
11-Faculty of Tourism Height: 16 m Surface Area: 1040 m² Shadow: Partially Blocked (Tree) Azimuth: SW 324°, SE 52°		
12-Faculty of Communication and Media Studies Height: 12 m Surface Area: 804 m² Shadow: Partially Blocked (Tree) Azimuth: SW 324°, SE 56°		

13-Central Lecture Hall Height: 16 m Surface Area: 1536 m² Shadow: Partially Blocked (Tree) Azimuth: SW 322°, SE 50°		
14-School of Computing and Technology Height: 12 m Surface Area: 708 m² Shadow: Partially Blocked (Tree) Azimuth: South 90-91°		
15-Faculty of Business and Economics Block A Height: 12 m Surface Area: 1200 m² Shadow: Partially Blocked (Tree) Azimuth: SW 322°, SE 53°		
16-Faculty of Business and Economics Block B Height: 12 m Surface Area: 636 m² Shadow: Partially Blocked (Tree) Azimuth: SW 322°, SE 53°		
17-Faculty of Education Height: 16 m Surface Area: 496 m² Shadow: - Azimuth: SW 323°, SE 53°		
18-Foreign Languages and English Preparatory School Block A Height: 16 m Surface Area: 640 m² Shadow: - Azimuth: SW 290°, SE 18°		

19-Foreign Languages and English Preparatory School Block B Height: 12 m Surface Area: 360 m² Shadow: - Azimuth: SW 307°, SE 36°		
20-Faculty of Pharmacy Height: 12 m Surface Area: 1236 m² Shadow: - Azimuth: SW 290°, SE 18°		
21-Faculty of Health and Sciences Height: 12 m Surface Area: 1224 m² Shadow: Partially Blocked (Tree) Azimuth: SW 290°, SE 18°		
22-Faculty of Health and Sciences Block B Height: 5 m Surface Area: 335 m² Shadow: - Azimuth: SW 290°, SE 18°		
23-Faculty of Dentistry Height: 5 Surface Area: 350 m² Shadow: - Azimuth: SW 290°, SE 18°		
24-Faculty of Medicine Height: 8 m Surface Area: 1008 m² Shadow: - Azimuth: SW 333°, SE 60°		

25-Health Center Height: 8 m (South E. 4m) Surface Area: 180 m² Shadow: Partially Blocked (Tree) Azimuth: SW 323°, SE 50°		
26-Student Service Building Height: 10 m Surface Area: 240 m² Shadow: Partially Blocked (Shading Element) Azimuth: SW 349°, SE 79°		
27-Computer Center Height: 16 m Surface Area: 960 m² Shadow: Partially Blocked (Tree) Azimuth: SW 324°, SE 56°		
28-Rectors Office Height: 10 Surface Area: 550 m² Shadow: - Azimuth: SW 353°, SE 85°		
29-Registrar's Office Height: 10 m Surface Area: 300 m² Shadow: Partially Blocked (Shading Element) Azimuth: SW 353°, SE 85°		
30-Personnel Affairs and Financial Affairs Height: 8 m (South E.4m) Surface Area: 52 m² Shadow: Partially Blocked (Level Differences) Azimuth: SW 353°, SE 85°		
31-Özay Oral Library Height: 20 m Surface Area: 1600 m² Shadow: - Azimuth: SW 326°, SE 55°		

32-Social and Cultural Activities Center Height: 5 m Surface Area: 325 m² Shadow: Partially Blocked (Tree) Azimuth: SW 328°, SE 55°		
33-Administrative Services Height: 16 m (South E.8m) Surface Area: 392 m² Shadow: - Azimuth: SW 345°, SE 77°		
34-LMP Sports Complex Height: 20 m Surface Area: 1060m² Shadow:- Azimuth: SW 298°, SE 26°		
35-Technical Affairs Height: 8 m Surface Area: 344 m² Shadow: Partially Blocked (Tree) Azimuth: SW 346°, SE 75°		
36-Cooperative Building Height: 4 m Surface Area: 132 m² Shadow: Partially Blocked (Tree) Azimuth: SW 332°, SE 67°		
37-Institute of Graduate Studies and Research Height: 5 m Surface Area: 125 m² Shadow: - Azimuth: SW 340°, SE 73°		
38-Sabancı Dormitory (EMU 1) Block A Height: 16 m Surface Area: 864 m² Shadow: Partially Blocked Azimuth: SW 350°, SE 77°		

39-Sabancı Dormitory (EMU 1) Block B Height: 16 m Surface Area: 864 m² Shadow: - Azimuth: SW 350°, SE 77°		
40-EMU 2 Dormitory Height: 16 m Surface Area: 1248 m² Shadow: Partially Blocked (Tree) Azimuth: SW 321°, SE 28°		
41-EMU 3 Dormitory Height: 8 m Surface Area: 1024 m² Shadow: Partially Blocked (Tree) Azimuth: SW 345°, SE 75°		
42-EMU 4 Dormitory Height: 12 Surface Area: 216 m² Shadow: Partially Blocked (Tree) Azimuth: SW 345°, SE 75°		
43-KYK Dormitory Height: 28 m (South E.16m) Surface Area: 1184 m² Shadow: Partially Blocked (Tree) Azimuth: SW 357°, SE 85°		
44-Mechanical Engineering Height: 8 m Surface Area: 2752 m² Shadow: Blocked Azimuth: SW 320°, SE 51°		

According to Table 3.4, the south façades of 44 buildings were examined. Nineteen of them are completely facing to the sun, twenty-four of them are partially shaded by neighbor buildings and vegetation, one of them is completely shaded. These are:

- Buildings without obstacles: Electrical and Electronic Engineering, Visual Arts and Visual Communication Design, Faculty of Law, Faculty of Architecture, Studios of the Faculty of Architecture, Faculty of Arts and Sciences, Faculty of Education, Foreign Languages and English Preparatory School Block A, Foreign Languages and English Preparatory School Block B, Faculty of Pharmacy, Faculty of Health and Sciences Block B, Faculty of Dentistry, Faculty of Medicine, Rectors Office, Özay Oral Library, Administrative Services, LMP Sports Complex, Institute of Graduate Studies and Research, Sabancı Dormitory (EMU 1) Block B
- Partially Shaded Buildings: Industrial Engineering, Computer Engineering, Civil Engineering, Faculty of Architecture Administrative Building, Faculty of Tourism, Faculty of Communication and Media Studies, Central Lecture Hall School of Computing and Technology, Faculty of Business and Economics Block A, Faculty of Business and Economics Block B, Faculty of Health and Sciences, Health Center, Student Service Building, Computer Center, Registrar's Office, Personnel Affairs and Financial Affairs, Social and Cultural Activities Center, Technical Affairs, Cooperative Building, Sabancı Dormitory (EMU 1) Block A, EMU 2 Dormitory, EMU 3 Dormitory, EMU 4 Dormitory, KYK Dormitory
- Shaded Building: Mechanical Engineering

3.5 Calculation of the Energy Yield by Software Simulations

The PVsyst program was used to measure the total solar energy potential of the roof area and exterior surfaces of the EMU campus (Latitude 35.12 N, Longitude 33.94 E, Altitude 14m for Famagusta / EMU location).

Total available roof areas of EMU campus buildings are 37.583 m². In addition, the sum of the usable exterior surface areas are 29.998 m². The total solar energy potential of each building has been calculated separately. There are some parameters to determine the potential of suitable roof and exterior surface areas which are defined as Module Type, Mounting Disposition, Technology-Cell Type, Ventilation Property, Tilt Angle and Azimuth according to the used software simulation program.

3.5.1 Calculation Parameters of EMU Campus Roofs

- Module Type: Standard
- Mounting Disposition: Flat Roof-Façade or Tilt Roof

  Most of EMU Campus buildings are flat roofs, but some buildings have sloped roofs. Therefore, each building has been evaluated for the calculation according to the roof type.
- Technology/Cell Type: Monocrystalline Cells

  Monocrystalline cells are the most efficient cell type as mentioned under the heading 2.4.3 (Bagher, A. M., Vahid, M. M. A., & Mohsen, M., 2015) which will be proposed as efficient and suitable PV cell type for the roof areas.
- Ventilation Property: Ventilated

  Famagusta has high outdoor temperatures due to its location (Ouria, M., & Sevinc, H., 2018) which might overheat the PVs in hot-summer season and adversely affects the performance of PV panels (Roberts, S., Guariento, N., 2009). Therefore, the ventilation of the PV panels is very important for the PV efficiency to generate electricity.

- Tilt Angle: 28°-55°
- Azimuth: South Direction

3.5.2 Calculation Parameters of EMU Campus Exterior Surfaces

- Module Type: Standard
- Mounting Disposition: Façade or Tilt Roof
- Technology/Cell Type: Polycrystalline Cells

  As mentioned under the headings 2.4.3.2 and 2.4.3.3, the efficiency of polycrystalline cells is between 12-15%. The efficiency of Thin Film cells is much lower than Polycrystalline Cells (Thomas, R., Fordham, M., 2001).
- Ventilation Property: Ventilated
- Tilt Angle: 90°
- Azimuth: Positioning of each building is different in EMU-Campus. Therefore, the azimuth of each building has been determined separately one by one.

The PV Syst software is used to perform the necessary calculations and to obtain the annual results based on the above-mentioned parameters. Firstly, the exterior surfaces are calculated based on the azimuth of each building. The solar energy potential of the south facades of the buildings are 3.541.101 kWh. The results of the 28° and 55° tilt angles on building roofs were obtained through the Software Simulation Program. The annual solar energy yield (28° tilt angle) is 7.926.897 kWh while the annual solar energy yield (55° tilt angle) is 7.280.273 kWh. The total annual solar energy yield of the EMU Campus is calculated according to the PV Syst Simulation Program and listed separately based on different combinations between exterior surface areas and roofs areas with 28° tilt angle or 55° tilt angle (Table 3.5).

Table 3.5: Annual Solar Energy Yields of the EMU Campus based on the PV Syst Simulation Program

Appropriate Vertical Exterior Surface Areas and Roof Areas with different tilt angles for maximum active solar energy gain	Annual Results kWh (PV Syst Simulation Program)
Energy Generation of Vertical Exterior Surfaces	3,541,101
Energy Generation of Roofs with 28° Tilt Angle	7,926,897
Energy Generation of Roofs with 55° Tilt Angle	7,280,273
Energy Generation of Roofs with 28°-55° Combination	8,123,644
Energy Generation of Roofs (28°) + Vertical Exterior Surface	11,467,998
Energy Generation of Roofs (55°) + Vertical Exterior Surface	10,821,374
Energy Generation of Roofs(28°-55°)+ Vertical Exterior Surface	11,664,745

In Chapter 4, the total annual and monthly solar energy yield of the EMU Campus will be analyzed and discussed in comparison to the annual and monthly energy use in 2019 in detail respectively with the aim to understand if the calculated solar energy yields are covering annually and monthly the energy demand of the EMU Campus.

Chapter 4

RESULTS AND DISCUSSIONS

The use of energy is essential for lighting, heating, cooling and ventilation systems, and other technical equipment which are used in the EMU campus. The energy demand of the EMU campus is increasing in daytime during the working hours of the staff and students from 8 am to 5 pm because of the high number of users. After the working hours, all buildings are closed except the colored building and studios of the Faculty of Architecture which are used in nighttime by students. Hence, the use of energy after working hours (8 am to 5 pm) is less and limited only to the Faculty of Architecture, dormitories and for street lighting in the campus area.

The monthly energy consumption of the administrative and academic staff during the working hours are approximately constant. Therefore, it has no effect on the evaluations of monthly electricity consumption. However, the student number varies according to the lecturing period and time between terms during the Academic Year since there is a linear growth or decrease between the student number and energy demand. Furthermore, the energy consumption especially for heating, cooling and ventilation is depending to a great extent on varying seasonal air-temperatures and humidity values.

In this study, the energy consumption data of the EMU campus in 2019 is used as essential prerequisite for the quantitative research method since the energy consumption in 2020 was not useful because of the pandemic situation, online education, and lockdown of the university. During the Covid-19 pandemic the majority of the students left the EMU campus and the administrative and academic staff worked from home office.

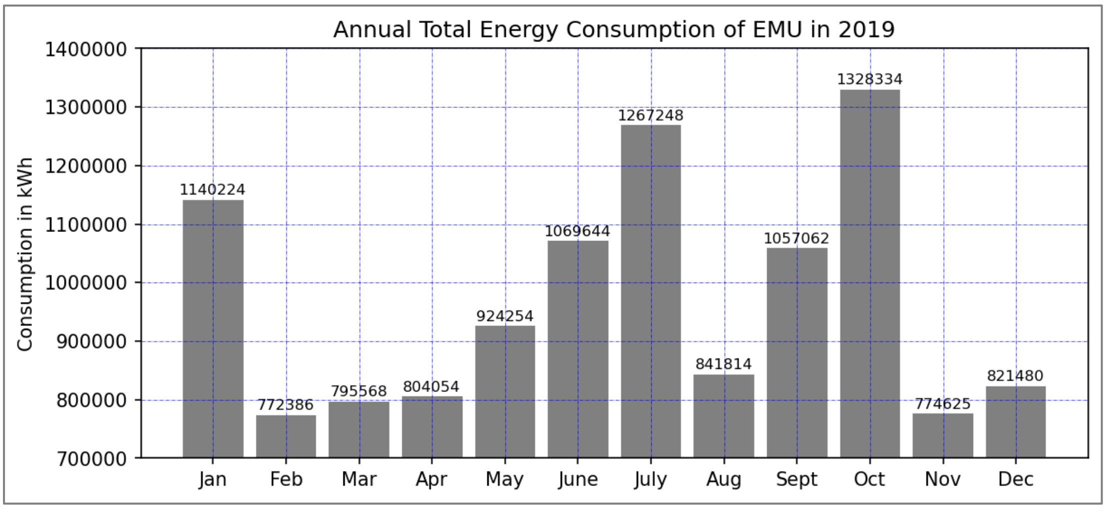


Figure 4.1: Annual Total Energy Consumption of the EMU campus in 2019

According to Figure 4.1 (Annual Total Energy Consumption of the EMU campus in 2019), the amounts of monthly energy consumption in January, June, July, September, and October seems relatively high in comparison to all other months.

Consequently, the monthly energy consumptions in 2019 of the EMU campus will be evaluated as follows:

- January (1,140,224 kWh): It shows the highest energy consumption in winter particularly for heating demand, because there is a significant decrease in air temperature compared to December. Because of the Final Exam Period, the number of students and their energy demand for heating and lighting is increasing because of low air-temperatures and the use of artificial lighting (short daytime).

- February (772,386 kWh): In comparison to January the energy consumption is relatively low, because it is the time between terms and the number of students is suddenly decreasing after the Final Exam Period even if the air-temperatures are lower than January. Additionally, most of the students are not on the campus during the semester break. Thus, the electricity usage of the dormitories and buildings decreases noticeably. Only administrative buildings and administrative areas of educational buildings are used in the time between the terms.
- March (795,568 kWh): The student number is increasing rapidly in March because of the Spring Semester start which is the main reason for the slightly increase of the energy consumption. The heating demand of the interior spaces is slightly decreasing because of the slightly increase of the seasonal air-temperatures.
- April (804,054 kWh): The number of students in April is constant during the lecture period, while in comparison to March the air-temperatures are higher. Hence, the energy demand for the air-conditioning systems is slightly increasing.
- May (924,254 kWh): The air-temperatures and the use of air-conditioning systems for cooling are increasing in comparison to April. The number of students and university staff are constant.
- June (1,069,644 kWh): At the beginning of the summer season, the air-temperatures have increased rapidly which have directly increased the energy consumption for cooling.

- July (1,267,248 kWh): The need for cooling increases as the temperature increases, Hence, the highest energy consumption of the summer months in 2019 was in July.
- August (841,814 kWh): The monthly mean air-temperature in August achieves the maximum value of the whole year, but the number of students and staff and their energy consumption is lower than July. A small number of students are visiting the Summer School after the lecture period (March – July) and a small number of university staff is working during the vacation time.
- September (1,057,062 kWh): September is the Fall Semester registration period and continues until the end of September (Add/Drop day). The student number is slowly increasing during the registration period and the vacation time of the university staff is ending latest on 15th of September. Although the air-temperatures are lower than August, the energy demand of the air-conditioning systems for cooling is increasing because of the increasing number of students and university staff in comparison to August.
- October (1,328,334 kWh): The student number is increasing rapidly in October because of the Fall Semester start and the lecture period which is the main reason for the slightly increase of the energy consumption in comparison to September. The air-temperatures are still high and at the same time the energy use for cooling of interior spaces is high because of the high number of students.
- November (774,625 kWh): The number of students in November is constant during the lecture period, while in comparison to October the air-temperatures are comfortable. Hence, the energy demand for the air-conditioning systems is lower than October.

- December (821,480 kWh): Low air-temperatures and the use of air-conditioning systems for heating are increasing in comparison to November (EMU Official Website-III). The number of students and university staff are constant.

4.1 Energy Yield Generated by BIPV According to Available Building Surfaces

4.1.1 Solar Energy Potential of Appropriate Vertical Building Exterior Surfaces

The monthly solar energy potential of south-facing facades (43 EMU buildings) was obtained according to each building's azimuth from the south direction. The annual total solar energy potential of the vertical exterior surfaces is calculated as 3,541,101 kWh (Table 4.1), which varies from month to month. The results are calculated and presented as follows:

Table 4.1: Monthly Solar Energy Potential of the Vertical Exterior Surfaces

Month	Results/kWh
January	201,686
February	204,559
March	266,613
April	329,145
May	338,146
June	358,267
July	383,438
August	378,004
September	332,356
October	275,799
November	239,847
December	233,241
Total kWh	**3,541,101**

4.1.2 Solar Energy Potential of Appropriate Building Roof Areas

The solar energy potential of building roofs is depending on roof areas as well as on appropriate PV tilt angles based on the location. To determine the most efficient PV tilt angle, results were obtained by 5° intervals starting from 20° to 55°.

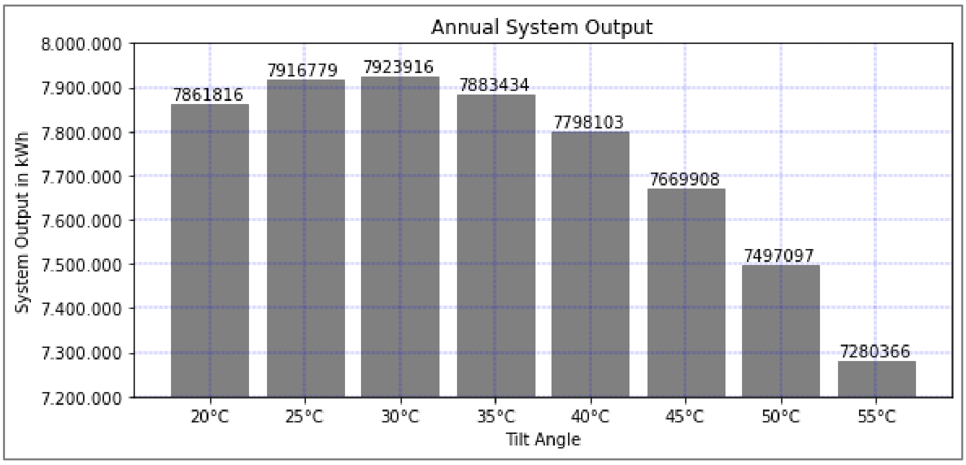


Figure 4.2: The annual solar energy potential of the total roof areas depending on different PV tilt angles

According to Figure 4.2, the highest energy yields were generated for the total roof by the application of PV tilt angles between 25° and 30°. To determine the optimum PV tilt angle, every tilt angle value between 25° and 30° was used for the calculation of the highest annual energy yield with the result that 28° is the optimum PV tilt angle for the highest annual energy yield.

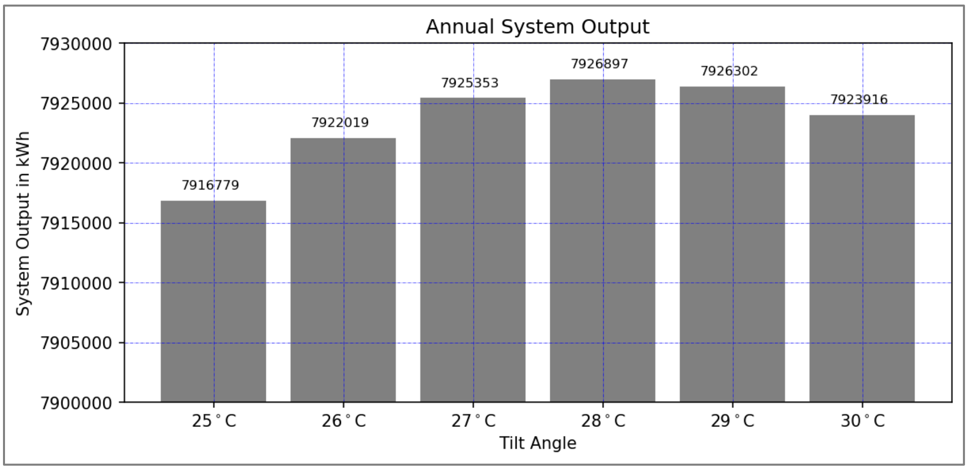


Figure 4.3: The annual energy yield of the total roof areas depending on the PV tilt angles between 25°-30°

The comparison between the annual energy consumption (2019: 11,596,693 kWh) of the whole EMU campus and the generated solar energy by using the appropriate vertical surfaces areas and roof areas (28° PV tilt angle) is showing that the annual solar energy yield (11,467,998 kWh) is insufficient to cover the energy demand of the EMU campus (Table 4.2).

Table 4.2: Monthly solar energy yield based on the total roof areas (tilt angle 28°) and vertical building surfaces in comparison with the EMU Consumption (2019)

Month	Total Roof Areas (PV Tilt Angle 28°) + Vertical Building Surfaces	EMU Consumption (2019)	Difference
January	584,246	1,140,224	**-555,978**
February	625,630	772,386	**-146,756**
March	843,670	795,568	+48,102
April	1,081,632	804,054	+277,578
May	1,147,025	924,254	+222,771
June	1,265,514	1,069,644	+195,870
July	1,347,905	1,267,248	+80,657
August	1,293,112	841,814	+451,298
September	1,062,601	1,057,062	+5,539
October	842,781	1,328,334	**-485,553**
November	703,942	774,625	**-70,683**
December	669,940	821,480	**-151,540**
Total kWh	**11,467,998**	**11,596,693**	**-128,665**

On a monthly basis the energy demand between March and September (Spring and Summer season) is covered by the generated solar energy, while the generated solar energy between October and February (Fall and Winter season) is insufficient.

According to the results in table 4.2 the seasonal disparity can be neutralized by finding out the efficient PV tilt angle on the roof areas to maximize the solar energy yield for the affected time period between October and February.

For this reason, the PV tilt angles on the roof were analyzed by 5° intervals starting from 20° to 60° to find out the most efficient PV tilt angle for the Fall and Winter months.

According to figure 4.4 it has been determined that the efficient PV tilt angle for the affected time period is between 50° and 60° degrees after checking the monthly solar energy potential results for October, November, December, January and February.

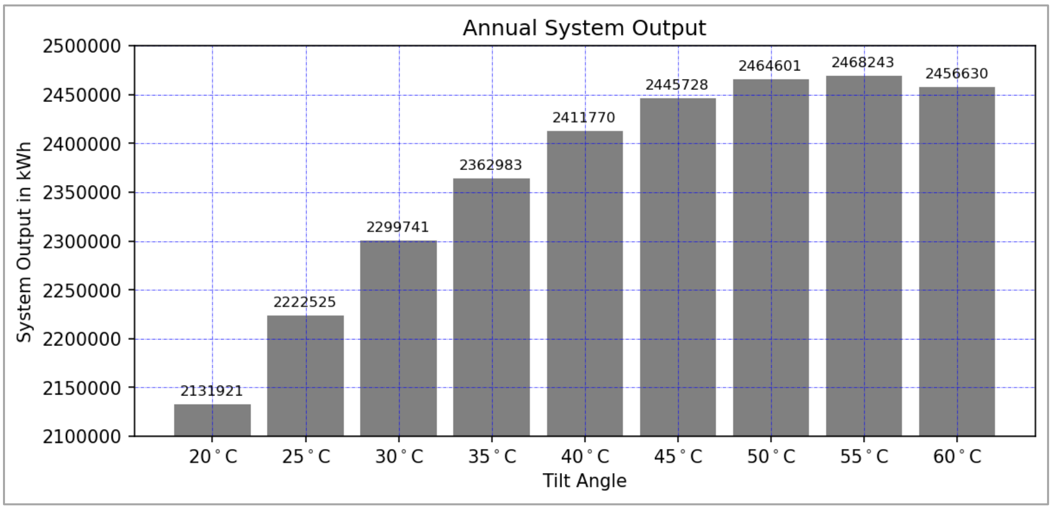


Figure 4.4: The energy yield of the total roof areas between October and February (Fall and Winter Season) depending on the PV tilt angles between 20°-60°

The highest energy yield of the total roof areas is in the range of 54° and 55° PV tilt angles for the Fall and Winter months which are approximate values based on the PVsyt Simulation Program (Figure 4.5).

According to Ouria, M. & Sevinç, H. (2018), the PV tilt angle in winter season for the location Famagusta / Cyprus to achieve the highest amount of solar energy has been calculated as 55°.

Therefore, 55° has been selected as the efficient PV tilt angle to understand if the energy yield of the total roof areas can be increased and subsequently cover the energy demand of the affected time period between October and February (Fall and Winter Season).

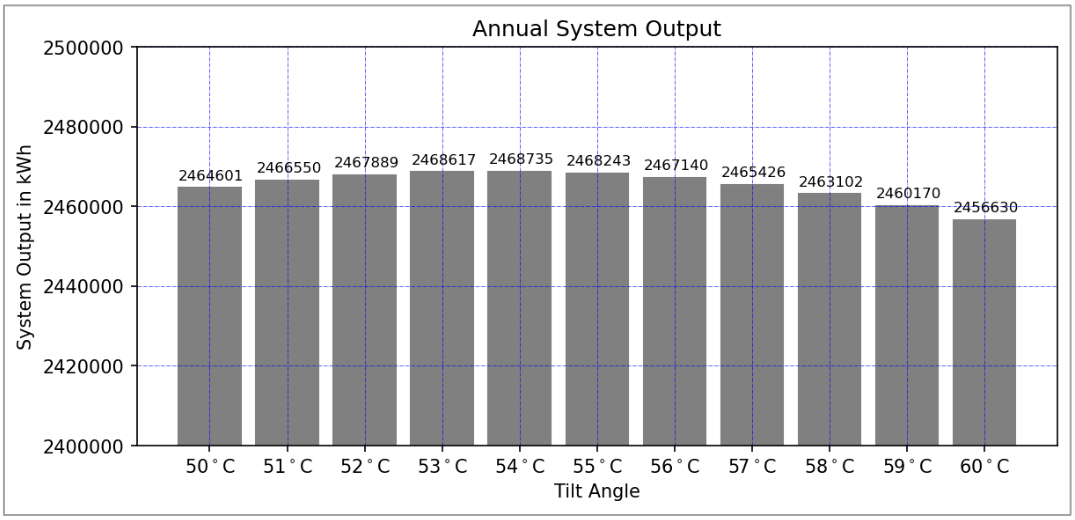


Figure 4.5: The energy yield of the total roof areas between October and February (Fall and Winter Season) depending on the PV tilt angles between 50°-60°

The comparison between the annual energy consumption (2019: 11,596,693 kWh) of the whole EMU campus and the generated solar energy by using the appropriate vertical surfaces areas and roof areas (28° PV tilt angle and 55° PV tilt angle separately) is showing that the generated solar energy between October and February cannot cover the energy demand of the EMU campus for the same time period (Table 4.3). In addition to that, the use of 55° PV tilt angle on the total roof areas is decreasing the solar energy yield between March and September and consequently the annual solar energy yield. The use of 55° PV tilt angle on the total roof areas is not suitable for the Spring and Summer months.

Table 4.3: Monthly solar energy yield based on the total roof areas (tilt angle 28° and 55°) and vertical building surfaces in comparison with the EMU Consumption (2019)

Month	Total Roof Areas (PV Tilt Angle 28°) + Vertical Building Surfaces	Total Roof Areas (PV Tilt Angle 55°) + Vertical Building Surfaces	EMU Consumption (2019)
January	584,246	**633,295**	**1,140,224**
February	625,630	**640,128**	**772,386**
March	843,670	827,062	795,568
April	1,081,632	997,011	804,054
May	1,147,025	999,194	924,254
June	1,265,514	1,059,052	1,069,644
July	1,347,905	1,141,340	1,267,248
August	1,293,112	1,154,780	841,814
September	1,062,601	1,019,649	1,057,062
October	842,781	**857,150**	**1,328,334**
November	703,942	**751,472**	**774,625**
December	669,940	**741,241**	**821,480**
Total kWh	**11,467,998**	**10,821,374**	**11,596,693**

Based on the Table 4.3 results, the use of two different PV tilt angles (28° and 55°) for the total roof areas might be helpful method to cover the monthly energy demand of the EMU campus. A flexible PV installation with a moveable tilt angle system can be applied on the total roof areas of the EMU campus.

The use of 28° PV tilt angle is appropriate for Spring and Summer months with high temperatures and high amount of solar radiation, while 55° PV tilt angle is appropriate for Fall and Winter months with low temperatures and low amount of solar radiation as follows:

- 28° PV tilt angle: March, April, May, June, July, August, September
- 55° PV tilt angle: October, November, December, January, February

Table 4.4: Selection of the PV tilt angles according to the maximum monthly solar energy yield

Month	Total Roof Areas (PV Tilt Angle 28°) + Vertical Building Surfaces	Total Roof Areas (PV Tilt Angle 55°) + Vertical Building Surfaces	Maximum solar energy yield and the selected PV tilt angle
January	584,246	**633,295**	**633,295 (55°)**
February	625,630	**640,128**	**640,128 (55°)**
March	**843,670**	827,062	**843,670 (28°)**
April	**1,081,632**	997,011	**1,081,632 (28°)**
May	**1,147,025**	999,194	**1,147,025 (28°)**
June	**1,265,514**	1,059,052	**1,265,514 (28°)**
July	**1,347,905**	1,141,340	**1,347,905 (28°)**
August	**1,293,112**	1,154,780	**1,293,112 (28°)**
September	**1,062,601**	1,019,649	**1,062,601 (28°)**
October	842,781	**857,150**	**857,150 (55°)**
November	703,942	**751,472**	**751,472 (55°)**
December	669,940	**741,241**	**741,241 (55°)**
Total kWh	**11,467,98**	**10,821,374**	**11,664,745**

According to the table 4.4, the use of two different PV tilt angles on the total roof areas (28° and 55°) together with the use of vertical surfaces has increased the annual solar energy yield to 11,664,745 kWh and is covering the annual EMU energy consumption in 2019 which was 11,596,693 kWh.

At the same time each monthly solar energy yields has been increased slightly, but it is still not covering the EMU energy consumption of the affected time period between October and February in 2019. On the other hand, the annual EMU electricity consumption in 2019 is covered by the use of flexible PV installation with a moveable tilt angle system which has generated a surplus of 68,052 kWh (Table 4.5). It can be concluded that the use of a flexible PV installation with a moveable tilt angle system on the total roof areas of the EMU campus has reduced the monthly difference between solar power generation and energy consumption for the affected time period.

Table 4.5: Comparison of maximum monthly solar energy yields and EMU Consumption (2019)

Month	Maximum solar energy yield: Vertical building surfaces + combined PV tilt angles (28° and 55°) for the total roof areas	EMU Energy Consumption (2019)	Difference
January	633,295 (55°)	1,140,224	**-506,929**
February	640,128 (55°)	772,386	**-132,258**
March	843,670 (28°)	795,568	+48,102
April	1,081,632 (28°)	804,054	+277,578
May	1,147,025 (28°)	924,254	+222,771
June	1,265,514 (28°)	1,069,644	+195,870
July	1,347,905 (28°)	1,267,248	+80,657
August	1,293,112 (28°)	841,814	+451,298
September	1,062,601 (28°)	1,057,062	+5,539
October	857,150 (55°)	1,328,334	**-471,184**
November	751,472 (55°)	774,625	**-23,153**
December	741,241 (55°)	821,480	**-80,239**
Total kWh	**11,664,745**	**11,596,693**	**+68,052**

Different scenarios were applied to cover the energy demand in Fall and Winter months (October – February) with same suitable vertical building surfaces and total roof areas of the EMU campus for solar power generation.

The scenario 1 (PV tilt angle 28°) was not efficient for the solar power generation between October and February (Fall and Winter season) because of the low inclined solar altitude in Fall and Winter.

The scenario 2 (PV tilt angle 55°) was not efficient for the solar power generation between March and September as scenario 1 (PV tilt angle 28°) because of the high inclined solar altitude in Spring and Summer season. In comparison to the results of the scenario 1 (PV tilt angle 28°) the solar power generation has been increased between October and February, but the total annual solar energy yield is lower.

The scenario 3 (PV tilt angle 28° between March and September) and (PV tilt angle 55° between October and February) was efficient and has increased in general the monthly and annual power solar generation but it is still not covering the energy demand of the EMU campus between October and February.

According to Figure 4.6 seasonal asynchronicity is the reason for the difference between solar power generation and electricity consumption (2019). After applying different scenarios, it is obvious that the difference between solar power generation and electricity consumption of the EMU campus (2019) cannot be annulled just by application of a flexible and movable PV tilt angles on the total roof areas.

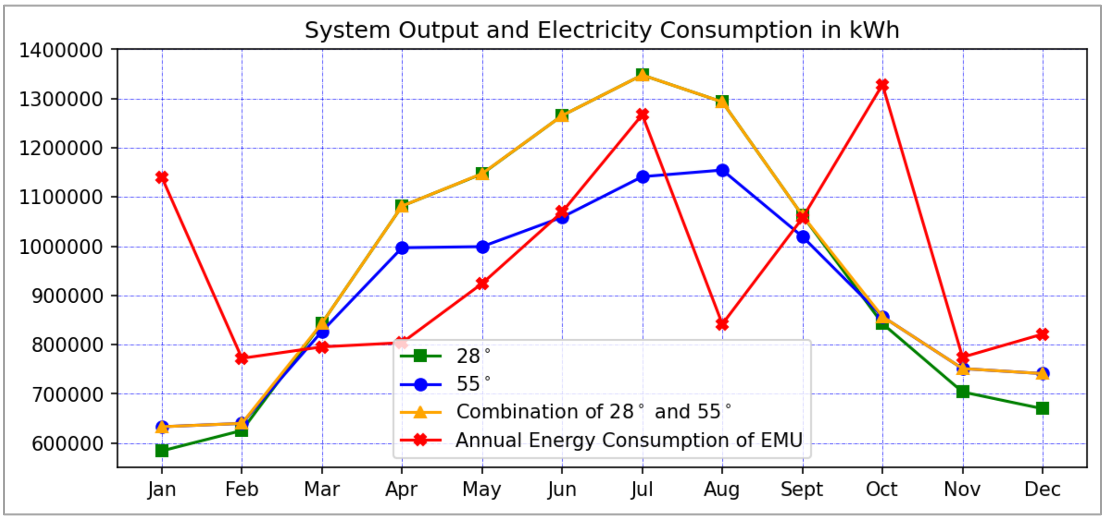


Figure 4.6: Seasonal asynchronicity between solar power generation and electricity consumption (2019)

Additional measures beside the use of PVs have to be taken to ensure the sustainable energy supply of the EMU campus by other renewable energy sources in Fall and Winter season.

Chapter 5

CONCLUSION

The thesis is a research about the solar energy potential of building roofs and exterior walls in the EMU - campus in Famagusta / North Cyprus to cover the energy demand by photovoltaics.

First of all, the conditions on-site for a successful application of photovoltaics were examined and analyzed for the whole EMU campus based on Main- and South-Campus as a case study. The location Famagusta / North Cyprus has a Mediterranean Climate (hot-dry summer season and rainy winter season). The monthly minimum average temperature is 10° C in February and maximum average temperature is 31° C in August. The solar radiation values of Famagusta region are approximately 1935 kWh/m². That means Famagusta has a high solar energy potential.

Furthermore, the suitability of the existing buildings in the Main- and South – campus were investigated for an efficient PV application as a database according to building height, floor number, roof type, vertical building surfaces areas and roof areas and their orientation as well as the obstacles which are blocking the solar radiation.

It has been found that according to their building heights 43 out of 44 buildings in the EMU Campus do not shade each other and are suitable for an efficient PV application.

It has been determined that the energy demand of the EMU campus is used for heating in cold winter season, cooling in hot summer season and lighting as well as for electrical gadgets, while at the same time the user profile, user behaviour and working conditions were analyzed. The greatest energy use in the EMU Campus takes place during the working hours in daytime, which is between 8 am morning and 5 pm afternoon. Because of the global pandemic, the Eastern Mediterranean University (EMU) shifted in March 2020 from face-to-face education to online education. The majority of the students left the EMU campus after March 2020. For this reason the annual and monthly energy consumption of EMU in 2019 were used as statistics instead of 2020. The annual energy consumption of EMU was 11,596.693 kWh. The statistics were obtained from the EMU Project Directorate.

The next step was to find out approximately the solar energy potential of building surfaces of EMU buildings (roof areas + vertical exterior surfaces) for maximum power generation by PVs to cover the energy consumption in 2019.

South-facing exterior surface areas for the location Famagusta in the Northern Hemisphere, building azimuths and shadows are three main evaluation parameters used in the PVsyst Simulation Program. The total energy generation of vertical exterior surfaces was calculated as 3,541,101 kWh.

Roof areas with the appropriate south orientation without any obstacles like mechanical devices in front of PVs and efficient PV tilt angle for the location Famagusta are significant parameters for the calculation of the solar energy potential of roof areas. After the determination of roof areas, the efficient PV tilt angle for the location Famagusta was defined as 28° based on the results of the PVsyst Simulation Program.

The annual power generation of the EMU campus by the selected roof areas (PV tilt angle 28°) and vertical surface areas was calculated as 11,467,998 kWh. Compared to the energy consumption (2019) 11,596,693 kWh, it is insufficient to cover the energy demand of the EMU campus. In addition to that, on a monthly basis the power generation in Fall and Winter season (October – February) is less than the monthly EMU energy consumption (2019) for the same time period. It can be explained that solar altitudes angles and sunshine duration is changing particularly in summer and winter seasons.

Three different scenarios were applied to cover the energy demand in Fall and Winter months (October – February) with same suitable vertical building surfaces and total roof areas of the EMU campus for solar power generation.

As above-mentioned the scenario 1 (PV tilt angle 28°) was not efficient for the solar power generation between October and February (Fall and Winter season) because of the low inclined solar altitude in Fall and Winter.

According to PVsyst Simulation Program, the maximum monthly solar energy yields between October and February (Fall and Winter season) were achieved by PV tilt angle 55°.

The scenario 2 (PV tilt angle 55°) increased the monthly solar energy yields between October and February (Fall and Winter season) but decreased the monthly solar energy yields between March and September (Spring and Summer season) in comparison to scenario 1.

The annual power generation of the EMU campus by the selected roof areas (PV tilt angle 55°) and vertical surface areas was calculated as 10.821.374 kWh which is lower than in scenario 1.

11,467,998 kWh and is not covering the annual EMU energy consumption (2019) 11,596,693 kWh.

In scenario 3 a flexible PV installation with a moveable tilt angle system on the total roof areas of the EMU campus was suggested as an option. The PV tilt angle 28° was applied between March and September (Spring and Summer season) and 55° between October and February (Fall and Winter season).

In scenario 3 the annual total energy yield reached 11,664,745 kWh after applying a flexible PV installation with a moveable tilt angle system. Monthly as well as the annual power generation have been increased in comparison to scenario 1 and scenario 2. There is an annual energy surplus of 68,052 kWh in comparison to the EMU energy consumption in 2019.

The energy demand of the EMU campus between October and February (Fall and Winter season) cannot be covered by applying a flexible PV installation with a moveable tilt angle system in different seasons. In all scenarios even in scenario 3 the energy demand of the EMU campus between October and February (Fall and Winter season) are higher than the monthly solar energy yields generated by PVs in the same time period.

As a conclusion it can be noticed that the solar energy potential of the existing building roofs and exterior walls in the EMU campus/ Famagusta cannot cover the energy demand between October and February (Fall and Winter season).

The implementation of energy conservation strategies in the EMU buildings is the most significant step to reduce the energy demand of the EMU campus particularly in Fall and Winter Season. Thermally insulated building surfaces by avoiding thermal bridges, energy efficient windows (minimum double pane windows, better triple pane windows) and external shading devices for sun control as well as conscious user behaviour are some important measures for energy saving.

The architecturally aesthetic values have to be considered by applying photovoltaics on roof areas and vertical surfaces areas. In the field analysis, the optimum PV Panel installation areas were determined in a way that the architecturally aesthetic quality would not be disturbed. Moreover, an integrative PV Panel application on roof areas is appropriate rather than additive to preserve the architecturally aesthetic quality.

From the feasibility point of view, it is expected that the efficiency of PVs will increase and accordingly the required PV installation area (sqm) will decrease, so that the investment in PV technology in the EMU campus will be cost-efficient in the future.

For a long time period it can be recommended that the seasonal asynchronicity between solar power generation and electricity consumption can be solved firstly by efficient seasonal solar power storage systems as an option. The second option is the use of hybrid systems beside PVs for instance heat pumps with immersion heater which can be installed in the Faculty buildings where the energy demand is very high in the Fall and Winter season.

For the future development of the EMU campus, the consideration of solar energy technology must be integrated early in the design process and applied in the construction process of new smart buildings. The aim is to increase the degree of self-sufficiency of the EMU campus in terms of energy use generated by fossil fuels.

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APPENDIX

Table. Number of Buildings

No	Building Name		
1	Industrial Engineering	23	Faculty of Dentistry
2	Computer Engineering	24	Faculty of Medicine
3	Electrical and Electronic Engineering	25	Health Center
4	Civil Engineering	26	Student Service Building
5	Visual Arts and Visual Communication Design	27	Computer Center
6	Faculty of Law	28	Rectors Office
7	Faculty of Architecture	29	Registrar’s Office
8	Faculty of Architecture Administrative Building	30	Personnel Affairs and Financial Affairs
9	Faculty of Architecture Studios	31	Özay Oral Library
10	Faculty of Architecture Studios	32	Social and Cultural Activities Center
11	Faculty of Tourism	33	Administrative Services
12	Faculty of Communication and Media Studies	34	LMP Sports Complex
13	Central Lecture Hall	35	Technical Affairs
14	School of Computing and Technology	36	Cooperative Building
15	Faculty of Business and Economics Block A	37	Institute of Graduate Studies and Research
16	Faculty of Business and Economics Block B	38	Sabancı Dormitory (EMU 1) Block A
17	Faculty of Education	39	Sabancı Dormitory (EMU 1) Block B
18	Foreign Lang. and English Prep. School A	40	EMU 2 Dormitory
19	Foreign Lang. and English Prep. School B	41	EMU 3 Dormitory
20	Faculty of Pharmacy	42	EMU 4 Dormitory
21	Faculty of Health and Sciences	43	KYK Dormitory
22	Faculty of Health and Sciences Block B		

Table. Solar Potential of The Exterior Surfaces

No	January	February	March	April	May	June	July	August	September	October	November	December
1	3769	4008	5450	7110	7604	8294	8819	8314	6969	5488	4539	4249
2	4338	4613	6272	8183	8752	9546	10150	9569	8021	6317	5224	4890
3	3698	3933	5347	6976	7461	8137	8653	8157	6838	5385	4454	4168
4	6187	6579	8946	11671	12482	13614	14476	13648	11440	9009	7451	6974
5	771	855	1193	1599	1755	1941	2055	1896	1537	1178	944	858
6	2491	2681	3669	4817	5186	5677	6030	5654	4703	3662	3021	2804
7	5269	5463	7303	9290	9740	10504	11201	10810	9207	7428	6302	6015
8	5466	5621	7467	9423	9821	10541	11252	10937	9411	7620	6511	6259
9	3694	3741	4910	6098	6288	6677	7140	7042	6157	5079	4401	4280
10	6596	6607	8586	10531	10731	11298	12145	12064	10677	8907	7818	7652
11	7290	7302	9489	11639	11860	12486	13423	13333	11800	9844	8641	8457
12	5397	5486	7221	9004	9310	9912	10596	10411	9067	7451	6434	6237
13	10973	10917	14104	17161	17366	18245	19583	19572	17461	14721	12989	12825
14	3020	3622	5275	7430	8531	9615	10107	8970	6924	5005	3777	3233
15	8329	8371	10911	13437	13741	14508	15579	15427	13599	11302	9857	9649
16	4414	4437	5783	7122	7283	7689	8257	8177	7207	5990	5224	5114
17	3442	3460	4510	5554	5679	5997	6439	6377	5621	4672	4074	3988
18	5840	5389	6316	6650	5876	5515	6089	7099	7372	7018	6761	7043
19	2926	2779	3432	3926	3769	3800	4108	4361	4147	3680	3407	3489
20	11279	10407	12197	12843	11348	10650	11759	13710	14238	13553	13056	13602
21	11170	10306	12079	12718	11238	10547	11644	13577	14099	13421	12930	13470
22	3057	2821	3306	3481	3076	2887	3187	3716	3859	3673	3539	3687
23	3194	2947	3454	3637	3214	3016	3330	3882	4032	3838	3697	3852

No	January	February	March	April	May	June	July	August	September	October	November	December
24	6487	6699	8926	11309	11819	12719	13571	13143	11228	9095	7743	7417
25	1286	1279	1653	2011	2035	2138	2295	2294	2046	1725	1522	1503
26	1213	1367	1925	2624	2912	3240	3424	3126	2504	1879	1492	1329
27	6444	6551	8622	10751	11116	11836	12651	12431	10827	8897	7682	7448
28	2544	2958	4250	5905	6663	7478	7877	7076	5567	4097	3157	2744
29	1387	1613	2318	3221	3635	4079	4296	3860	3036	2235	1722	1497
30	240	280	402	558	630	707	745	669	526	387	298	259
31	10845	10984	14414	17902	18461	19602	20963	20673	18077	14911	12919	12567
32	2203	2231	2928	3636	3750	3982	4258	4199	3672	3029	2624	2553
33	2034	2273	3178	4306	4753	5271	5576	5118	4124	3133	2496	2239
34	9277	8618	10315	11262	10338	10071	10975	12250	12223	11295	10751	11149
35	1830	2028	2830	3794	4164	4604	4876	4499	3647	2794	2240	2037
36	782	832	1131	1476	1578	1721	1830	1726	1446	1139	942	882
37	686	749	1040	1383	1510	1664	1764	1637	1340	1031	836	763
38	4483	5009	7004	9491	10475	11618	12290	11280	9090	6906	5500	4934
39	4483	5009	7004	9491	10475	11618	12290	11280	9090	6906	5500	4934
40	10780	10055	12103	13339	12364	12129	13203	14589	14397	13206	12500	12942
41	5447	6038	8424	11293	12397	13705	14514	13393	10856	8318	6669	6063
42	1149	1274	1777	2382	2615	2891	3062	2825	2290	1755	1407	1279
43	5476	6367	9149	12711	14345	16098	16956	15233	11984	8820	6796	5907
Total	201686	204559	266613	329145	338146	358267	383438	378004	332356	275799	239847	233241

Table. Finding the Most Efficient Tilt Angle -Scenario 1, Step 1

Angle	January	February	March	April	May	June	July	August	September	October	November	December	Total
20°	354176	402990	563186	753154	828411	942172	999488	925112	718371	543350	433562	397843	7861816
25°	372596	414995	572848	754091	817726	922016	980747	919717	727109	559112	453460	422362	7916779
30°	388737	424645	579197	750517	802049	896307	955999	908650	731454	571543	470623	444193	7923916
35°	402476	431867	582184	742461	781763	865240	925434	891995	731373	580549	484920	463171	7883434
40°	413708	436607	581787	729984	757022	829678	889763	871233	726866	586061	496244	479150	7798103
45°	422348	438827	578009	713181	728014	791399	850842	844768	717967	588037	504507	492009	7669908
50°	428330	438512	570878	692420	696333	748208	806712	813202	704744	586462	509647	501650	7497097
55°	431608	435663	560449	667865	661049	700786	757901	776775	687298	581349	511624	507999	7280366

Table. Finding the Most Efficient Tilt Angle -Scenario 1, Step 2

Angle	January	February	March	April	May	June	July	August	September	October	November	December	Total
25°	372596	414995	572848	754091	817726	922016	980747	919717	727109	559112	453460	422362	7916779
26°	376011	417116	574385	753736	814966	917313	976273	917956	728331	561868	457116	426949	7922019
27°	379333	419142	575788	753202	812017	912389	971559	915967	729377	564490	460661	431427	7925353
28°	**382562**	**382562**	**577059**	**752487**	**808880**	**907246**	**966608**	**913753**	**730246**	**566977**	**464095**	**435794**	**7926781**
29°	385697	422907	578195	751592	805558	901885	961421	911314	730939	569329	467416	440050	7926302
30°	388737	424645	579197	750517	802049	896307	955999	908650	731454	571543	470623	444193	7923916

Table. Solar Potential of The Available Roof Areas with 28° Tilt Angle (Scenario 1)

No	Jan 28°	Feb 28°	Mar 28°	Apr 28°	May 28°	June 28°	July 28°	Aug 28°	Sept 28°	Oct 28°	Nov 28°	Dec 28°	Roof Annual	Facade Annual
1-R	9294	10229	14018	18280	19650	22040	23482	22198	17740	13774	11274	10587	192564	
1-F	3769	4008	5450	7110	7604	8294	8819	8314	6969	5488	4539	4249		74614
2-R	12123	13344	18287	23846	25633	28750	30632	28957	23141	17967	14707	13810	251199	
2-F	4338	4613	6272	8183	8752	9546	10150	9569	8021	6317	5224	4890		85876
3-R	14434	15887	21772	28391	30519	34230	36470	34476	27552	21392	17510	16442	299076	
3-F	3698	3933	5347	6976	7461	8137	8653	8157	6838	5385	4454	4168		73206
4-R	17182	18912	25918	33797	36330	40748	43414	41040	32798	25465	20844	19573	356023	
4-F	6187	6579	8946	11671	12482	13614	14476	13648	11440	9009	7451	6974		122479
5-R	4957	5456	7478	9751	10481	11756	12525	11840	9463	7347	6014	5647	102715	
5-F	771	855	1193	1599	1755	1941	2055	1896	1537	1178	944	858		165584
6-R	11126	12246	16782	21884	23524	26385	28111	26574	21237	16489	13497	12674	230529	
6-F	2491	2681	3669	4817	5186	5677	6030	5654	4703	3662	3021	2804		50395
7-R	9721	10700	14663	19121	20554	23054	24562	23219	18556	14407	11793	11074	201423	
7-F	5269	5463	7303	9290	9740	10504	11201	10810	9207	7428	6302	6015		98531
8-R	3502	3854	5282	6888	7404	8304	8847	8364	6684	5190	4248	3989	72554	
8-F	5466	5621	7467	9423	9821	10541	11252	10937	9411	7620	6511	6259		100329
9-R	9080	9994	13696	17860	19198	21533	22942	21687	17332	13457	11015	10343	188135	
9-F	3694	3741	4910	6098	6288	6677	7140	7042	6157	5079	4401	4280		65508
10-R	13345	14688	20129	26249	28216	31647	33718	31874	25473	19778	16189	15202	276508	
10-F	6596	6607	8586	10531	10731	11298	12145	12064	10677	8907	7818	7652		113612
11-R	3512	3865	5297	6908	7425	8328	8873	8388	6703	5205	4260	4000	72765	
11-F	7290	7302	9489	11639	11860	12486	13423	13333	11800	9844	8641	8457		125565

No	Jan 28°	Feb 28°	Mar 28°	Apr 28°	May 28°	June 28°	July 28°	Aug 28°	Sept 28°	Oct 28°	Nov 28°	Dec 28°	Roof Annual	Facade Annual
12-R	5212	5736	7861	10251	11020	12360	13168	12448	9948	7724	6322	5937	107988	
12-F	5397	5486	7221	9004	9310	9912	10596	10411	9067	7451	6434	6237		96526
13-R	11777	12963	17765	23165	24902	27930	29757	28130	22481	17455	14287	13416	244027	
13-F	10973	10917	14104	17161	17366	18245	19583	19572	17461	14721	12989	12825		185917
14-R	4937	5434	7447	9711	10438	11708	12474	11792	9424	7317	5989	5624	102293	
14-F	3020	3622	5275	7430	8531	9615	10107	8970	6924	5005	3777	3233		75508
15-R	8265	9097	12468	16258	17476	19602	20884	19742	15777	12250	10027	9416	171262	
15-F	8329	8371	10911	13437	13741	14508	15579	15427	13599	11302	9857	9649		144709
16-R	5130	5647	7739	10091	10847	12166	12963	12254	9793	7603	6224	5844	106301	
16-F	4414	4437	5783	7122	7283	7689	8257	8177	7207	5990	5224	5114		76696
17-R	8683	9557	13097	17079	18359	20591	21939	20739	16574	12868	10533	9891	179910	
17-F	3442	3460	4510	5554	5679	5997	6439	6377	5621	4672	4074	3988		59813
18-R	9579	10543	14448	18841	20253	22716	24202	22878	18284	14196	11620	10911	198470	
18-F	5840	5389	6316	6650	5876	5515	6089	7099	7372	7018	6761	7043		76967
19-R	5782	6364	8721	11372	12225	13711	14609	13810	11036	8569	7014	6586	119799	
19-F	2926	2779	3432	3926	3769	3800	4108	4361	4147	3680	3407	3489		43824
20-R	19167	21097	28912	37701	40527	45455	48429	45781	36587	28407	23252	21834	397151	
20-F	11279	10407	12197	12843	11348	10650	11759	13710	14238	13553	13056	13602		148643
21-R	20094	22116	30309	39523	42485	47652	50770	47994	38355	29780	24376	22890	416344	
21-F	11170	10306	12079	12718	11238	10547	11644	13577	14099	13421	12930	13470		147200
22-R	13813	15204	20836	27170	29206	32758	32758	32993	26367	20472	16757	15735	286210	
22-F	3057	2821	3306	3481	3076	2887	3187	3716	3859	3673	3539	3687		40287
23-R	13752	15136	20744	27050	29077	32613	34747	32847	26250	20381	16683	15666	284945	

No	Jan 28°	Feb 28°	Mar 28°	Apr 28°	May 28°	June 28°	July 28°	Aug 28°	Sept 28°	Oct 28°	Nov 28°	Dec 28°	Roof Annual	Facade Annual
23-F	3194	2947	3454	3637	3214	3016	3330	3882	4032	3838	3697	3852		42091
24-R	12225	13456	18440	24046	25849	28992	30889	29200	23336	18118	14831	14831	253308	
24-F	6487	6699	8926	11309	11819	12719	13571	13143	11228	9095	7743	7417		120157
25-R	3298	3630	4975	6487	6973	7821	8333	7877	6295	4888	4001	3757	68336	
25-F	1286	1279	1653	2011	2035	2138	2295	2294	2046	1725	1522	1503		21787
26-R	1221	1344	1843	2403	2583	2897	3086	2918	2332	1810	1482	1391	25310	
26-F	1213	1367	1925	2624	2912	3240	3424	3126	2504	1879	1492	1329		27033
27-R	3166	3484	4775	6227	6693	7507	7999	7561	6043	4692	3840	3606	65594	
27-F	6444	6551	8622	10751	11116	11836	12651	12431	10827	8897	7682	7448		115255
28-R	7573	8336	11424	14896	16013	17960	19135	18089	14456	11224	9187	8627	156920	
28-F	2544	2958	4250	5905	6663	7478	7877	7076	5567	4097	3157	2744		60315
29-R	1038	1143	1566	2042	2195	2462	2623	2480	1982	1539	1260	1183	21513	
29-F	1387	1613	2318	3221	3635	4079	4296	3860	3036	2235	1722	1497		32899
30-R	2382	2622	3593	4685	5036	5649	6018	5689	4547	3530	2890	2713	49354	
30-F	240	280	402	558	630	707	745	669	526	387	298	259		5703
31-R	6820	7507	10287	13415	14420	16174	17232	16290	13018	10108	8274	7769	141312	
31-F	10845	10984	14414	17902	18461	19602	20963	20673	18077	14911	12919	12567		192318
32-R	5069	5579	7646	9971	10718	12022	12808	12108	9676	7513	6150	5775	105035	
32-F	2203	2231	2928	3636	3750	3982	4258	4199	3672	3029	2624	2553		39065
33-R	10993	12100	16583	21624	23244	26071	27777	26258	20985	16293	13336	12523	227787	
33-F	2034	2273	3178	4306	4753	5271	5576	5118	4124	3133	2496	2239		44500
34-R	35586	39168	53678	69997	75243	84393	89915	84998	67928	52741	43170	40538	737355	
34-F	9277	8618	10315	11262	10338	10071	10975	12250	12223	11295	10751	11149		128523

No	Jan 28°	Feb 28°	Mar 28°	Apr 28°	May 28°	June 28°	July 28°	Aug 28°	Sept 28°	Oct 28°	Nov 28°	Dec 28°	Roof Annual	Facade Annual
35-R	4499	4952	6787	8850	9513	10670	11368	10746	8588	6668	5458	5125	93224	
35-F	1830	2028	2830	3794	4164	4604	4876	4499	3647	2794	2240	2037		39344
36-R	1608	1770	2426	3163	3401	3814	4064	3841	3070	2384	1951	1832	33324	
36-F	782	832	1131	1476	1578	1721	1830	1726	1446	1139	942	882		15486
37-R	814	896	1228	1602	1722	1931	2058	1945	1554	1207	988	928	16873	
37-F	686	749	1040	1383	1510	1664	1764	1637	1340	1031	836	763		14403
38-R	3858	4246	5819	7588	8157	9149	9748	9215	7364	5718	4680	4395	79936	
38-F	4483	5009	7004	9491	10475	11618	12290	11280	9090	6906	5500	4934		98081
39-R	4112	4526	6203	8089	8695	9752	10391	9822	7850	6095	4989	4685	85209	
39-F	4483	5009	7004	9491	10475	11618	12290	11280	9090	6906	5500	4934		98081
40-R	5639	6207	8506	11092	11923	13373	14248	13469	10764	8358	6841	6424	116846	
40-F	10780	10055	12103	13339	12364	12129	13203	14589	14397	13206	12500	12942		151604
41-R	12296	13534	18548	24187	25999	29161	31069	29370	23472	18224	14917	14007	254784	
41-F	5447	6038	8424	11293	12397	13705	14514	13393	10856	8318	6669	6063		117117
42-R	9803	10789	14786	19281	20726	23247	24768	24768	18711	14528	11892	11166	203110	
42-F	1149	1274	1777	2382	2615	2891	3062	2825	2290	1755	1407	1279		24704
43-R	16093	17713	24275	31655	34027	38165	40662	38439	30719	23851	19523	18333	335455	
43-F	5476	6367	9149	12711	14345	16098	16956	15233	11984	8820	6796	5907		129843
Total	584246	625630	843670	1081632	1147025	1265514	1347905	1293112	1062601	842781	703942	669940	7926897	3541101

Table. Finding the Most Efficient Tilt Angle for Low Temperatures-Scenario 2, Step 1

Angle	January	February	October	November	December	Total
20	354176	402990	543350	433562	397843	2131921
25	372596	414995	559112	453460	422362	2222525
30	388737	424645	571543	470623	444193	2299741
35	402476	431867	580549	484920	463171	2362983
40	413708	436607	586061	496244	479150	2411770
45	422348	438827	588037	504507	492009	2445728
50	428330	438512	586462	509647	501650	2464601
55	431608	435663	581349	511624	507999	2468243
60	432158	430302	572735	510425	511010	2456630

Table . Finding the Most Efficient Tilt Angle for Low Temperatures Scenario 2, Step 2

Angle	January	February	October	November	December	Total
50	428330	438512	586462	509647	501650	2464601
51	429203	438144	585722	510296	503185	2466550
52	429967	437675	584840	510819	504588	2467889
53	430623	437105	583817	511214	505858	2468617
54	431170	436434	582653	511483	506995	2468735
55°	**431608**	**435663**	**581349**	**511624**	**507999**	**2468243**
56	431937	434790	579904	511639	508870	2467140
57	432156	433818	578320	511526	509606	2465426
58	432266	432745	576597	511286	510208	2463102
59	432267	431573	574735	510919	510676	2460170
60	432158	430302	572735	510425	511010	2456630

Table. Solar Potential of The Available Roof Areas with 55° Tilt Angle (Scenario 2)

No	Jan 55°	Feb 55°	Mar 55°	Apr 55°	May 55°	June 55°	July 55°	Aug 55°	Sept 55°	Oct 55°	Nov 55°	Dec 55°	Roof Annual	Facade Annual
1-R	10485	10584	13615	16224	16059	17024	18412	18870	16696	14123	12429	12341	176862	
1-F	3769	4008	5450	7110	7604	8294	8819	8314	6969	5488	4539	4249		74614
2-R	13678	13806	17761	21165	20949	22208	24018	24616	21780	18423	16213	16098	230715	
2-F	4338	4613	6272	8183	8752	9546	10150	9569	8021	6317	5224	4890		85876
3-R	16285	16437	21146	25198	24941	26441	28595	29308	25932	21934	19304	19167	274688	
3-F	3698	3933	5347	6976	7461	8137	8653	8157	6838	5385	4454	4168		73206
4-R	19385	19567	25172	29996	29690	31475	34040	34888	30869	26111	22979	22816	326988	
4-F	6187	6579	8946	11671	12482	13614	14476	13648	11440	9009	7451	6974		122479
5-R	5593	5645	7262	8654	8566	9081	9821	10065	8906	7533	6630	6583	94339	
5-F	771	855	1193	1599	1755	1941	2055	1896	1537	1178	944	858		165584
6-R	12552	12670	16299	19423	19225	20380	22041	22590	19988	16907	14879	14774	211728	
6-F	2491	2681	3669	4817	5186	5677	6030	5654	4703	3662	3021	2804		50395
7-R	10967	11070	14241	16971	16798	17807	19259	19738	17465	14772	13001	12908	184997	
7-F	5269	5463	7303	9290	9740	10504	11201	10810	9207	7428	6302	6015		98531
8-R	3951	3988	5130	6113	6051	6414	6937	7110	6291	5321	4683	4650	66639	
8-F	5466	5621	7467	9423	9821	10541	11252	10937	9411	7620	6511	6259		100329
9-R	10244	10340	13302	15851	15689	16633	17988	18436	16312	13798	12143	12057	172793	
9-F	3694	3741	4910	6098	6288	6677	7140	7042	6157	5079	4401	4280		65508
10-R	15056	15197	19550	23297	23059	24445	26438	27096	23975	20279	17847	17720	253959	
10-F	6596	6607	8586	10531	10731	11298	12145	12064	10677	8907	7818	7652		113612
11-R	3962	3999	5145	6131	6068	6433	6957	7131	6309	5337	4697	4663	66832	
11-F	7290	7302	9489	11639	11860	12486	13423	13333	11800	9844	8641	8457		125565

No	Jan 55°	Feb 55°	Mar 55°	Apr 55°	May 55°	June 55°	July 55°	Aug 55°	Sept 55°	Oct 55°	Nov 55°	Dec 55°	Roof Annual	Facade Annual
12-R	5880	5935	7635	9098	9006	9547	10325	10582	9363	7920	6970	6921	99182	
12-F	5397	5486	7221	9004	9310	9912	10596	10411	9067	7451	6434	6237		96526
13-R	13287	13412	17254	20560	20351	21574	23332	23913	21159	17897	15750	15639	224128	
13-F	10973	10917	14104	17161	17366	18245	19583	19572	17461	14721	12989	12825		185917
14-R	5570	5622	7232	8619	8531	9043	9781	10024	8869	7502	6602	6556	93951	
14-F	3020	3622	5275	7430	8531	9615	10107	8970	6924	5005	3777	3233		75508
15-R	9325	9413	12109	14430	14282	15141	16375	16783	14849	12560	11054	10976	157297	
15-F	8329	8371	10911	13437	13741	14508	15579	15427	13599	11302	9857	9649		144709
16-R	5788	5842	7516	8956	8865	9398	10164	10417	9217	7796	6861	6812	97632	
16-F	4414	4437	5783	7122	7283	7689	8257	8177	7207	5990	5224	5114		76696
17-R	9796	9796	12720	15158	15003	15905	17202	17630	15599	13195	11612	11530	165146	
17-F	3442	3460	4510	5554	5679	5997	6439	6377	5621	4672	4074	3988		59813
18-R	10807	10908	14032	16722	16551	17546	18976	19449	17209	14556	12810	12719	182285	
18-F	5840	5389	6316	6650	5876	5515	6089	7099	7372	7018	6761	7043		76967
19-R	6523	6584	8470	10094	9991	10591	11454	11740	10387	8786	7732	7678	110030	
19-F	2926	2779	3432	3926	3769	3800	4108	4361	4147	3680	3407	3489		43824
20-R	21625	21828	28080	33462	33120	35111	37973	38918	34435	29127	25634	25452	364765	
20-F	11279	10407	12197	12843	11348	10650	11759	13710	14238	13553	13056	13602		148643
21-R	22670	22883	29437	35079	34721	36808	39808	40799	36099	30535	26872	26682	382393	
21-F	11170	10306	12079	12718	11238	10547	11644	13577	14099	13421	12930	13470		147200
22-R	15584	15730	20236	24114	23868	25303	27365	28047	24816	20991	18473	18342	262869	
22-F	3057	2821	3306	3481	3076	2887	3187	3716	3859	3673	3539	3687		40287
23-R	15515	15661	20147	24008	23763	25191	27244	27923	24706	20898	18391	18261	261708	

No	Jan 55°	Feb 55°	Mar 55°	Apr 55°	May 55°	June 55°	July 55°	Aug 55°	Sept 55°	Oct 55°	Nov 55°	Dec 55°	Roof Annual	Facade Annual
23-F	3194	2947	3454	3637	3214	3016	3330	3882	4032	3838	3697	3852		42091
24-R	13792	13922	17910	21342	21124	22394	24219	24823	21963	18578	16349	16234	232650	
24-F	6487	6699	8926	11309	11819	12719	13571	13143	11228	9095	7743	7417		120157
25-R	3721	3756	4832	5758	5699	6041	6534	6697	5925	5012	4411	4379	62765	
25-F	1286	1279	1653	2011	2035	2138	2295	2294	2046	1725	1522	1503		21787
26-R	1378	1391	1789	2132	2111	2238	2420	2480	2194	1856	1634	1622	23245	
26-F	1213	1367	1925	2624	2912	3240	3424	3126	2504	1879	1492	1329		27033
27-R	3572	3605	4638	5527	5470	5799	6272	6428	5687	4811	4234	4204	60247	
27-F	6444	6551	8622	10751	11116	11836	12651	12431	10827	8897	7682	7448		115255
28-R	8544	8624	11095	13221	13086	13873	15004	15377	13606	11508	10128	10056	144122	
28-F	2544	2958	4250	5905	6663	7478	7877	7076	5567	4097	3157	2744		60315
29-R	1171	1182	1521	1813	1794	1902	2057	2108	1865	1578	1389	1379	19759	
29-F	1387	1613	2318	3221	3635	4079	4296	3860	3036	2235	1722	1497		32899
30-R	2687	2713	3489	4158	4116	4363	4719	4836	4279	3620	3185	3163	45328	
30-F	240	280	402	558	630	707	745	669	526	387	298	259		5703
31-R	7694	7767	9991	11906	11785	12493	13511	13848	12253	10364	9121	9056	129789	
31-F	10845	10984	14414	17902	18461	19602	20963	20673	18077	14911	12919	12567		192318
32-R	5719	5773	7426	8850	8759	9286	10043	10293	9107	7703	6779	6731	96469	
32-F	2203	2231	2928	3636	3750	3982	4258	4199	3672	3029	2624	2553		39065
33-R	12403	12519	16105	19192	18996	20138	21779	22322	19750	16706	14702	14598	209210	
33-F	2034	2273	3178	4306	4753	5271	5576	5118	4124	3133	2496	2239		44500
34-R	40149	40526	52133	62125	61491	65188	70501	72256	63933	54077	47592	47255	677226	
34-F	9277	8618	10315	11262	10338	10071	10975	12250	12223	11295	10751	11149		128523

No	Jan 55°	Feb 55°	Mar 55°	Apr 55°	May 55°	June 55°	July 55°	Aug 55°	Sept 55°	Oct 55°	Nov 55°	Dec 55°	Roof Annual	Facade Annual
35-R	5076	5124	6591	7855	7774	8242	8913	9135	8083	6837	6017	5974	85621	
35-F	1830	2028	2830	3794	4164	4604	4876	4499	3647	2794	2240	2037		39344
36-R	1814	1832	2356	2808	2779	2946	3186	3266	2889	2444	2151	2136	30607	
36-F	782	832	1131	1476	1578	1721	1830	1726	1446	1139	942	882		15486
37-R	919	927	1193	1422	1407	1492	1613	1653	1463	1237	1089	1081	15496	
37-F	686	749	1040	1383	1510	1664	1764	1637	1340	1031	836	763		14403
38-R	4352	4393	5652	6735	6666	7067	7643	7833	6931	5863	5159	5123	73417	
38-F	4483	5009	7004	9491	10475	11618	12290	11280	9090	6906	5500	4934		98081
39-R	4640	4683	6025	7179	7106	7533	8147	8350	7388	6249	5500	5461	78261	
39-F	4483	5009	7004	9491	10475	11618	12290	11280	9090	6906	5500	4934		98081
40-R	6362	6422	8261	9845	9744	10330	11172	11450	10131	8569	7542	7488	107316	
40-F	10780	10055	12103	13339	12364	12129	13203	14589	14397	13206	12500	12942		151604
41-R	13873	14003	18014	21467	21248	22525	24361	24967	22091	18686	16445	16328	234008	
41-F	5447	6038	8424	11293	12397	13705	14514	13393	10856	8318	6669	6063		117117
42-R	11059	11163	14361	17113	16938	17956	19420	19904	17611	14896	13110	13017	186548	
42-F	1149	1274	1777	2382	2615	2891	3062	2825	2290	1755	1407	1279		24704
43-R	18156	18327	23576	28095	27808	29480	31883	32677	28913	24456	21522	21370	306263	
43-F	5476	6367	9149	12711	14345	16098	16956	15233	11984	8820	6796	5907		129843
Total	633295	640128	827062	997011	999194	1059052	1141340	1154780	1019649	857150	751472	741241	7280273	3541101

Table. Solar Potential of The Available Roof Areas with 28-55 Tilt Angle Combination (Scenario 3)

No	Jan 55°	Feb 55°	Mar 28°	Apr 28°	May 28°	June 28°	July 28°	Aug 28°	Sept 28°	Oct 55°	Nov 55°	Dec 55°	Roof Annual	Facade Annual
1-R	10485	10584	14018	18280	19650	22040	23482	22198	17740	14123	12429	12341	197370	
1-F	3769	4008	5450	7110	7604	8294	8819	8314	6969	5488	4539	4249		74614
2-R	13678	13806	18287	23846	25633	28750	30632	28957	23141	18423	16213	16098	257464	
2-F	4338	4613	6272	8183	8752	9546	10150	9569	8021	6317	5224	4890		85876
3-R	16285	16437	21772	28391	30519	34230	36470	34476	27552	21934	19304	19167	306537	
3-F	3698	3933	5347	6976	7461	8137	8653	8157	6838	5385	4454	4168		73206
4-R	19385	19567	25918	33797	36330	40748	43414	41040	32798	26111	22979	22816	364903	
4-F	6187	6579	8946	11671	12482	13614	14476	13648	11440	9009	7451	6974		122479
5-R	5593	5645	7478	9751	10481	11756	12525	11840	9463	7533	6630	6583	105278	
5-F	771	855	1193	1599	1755	1941	2055	1896	1537	1178	944	858		165584
6-R	12552	12670	16782	21884	23524	26385	28111	26574	21237	16907	14879	14774	236279	
6-F	2491	2681	3669	4817	5186	5677	6030	5654	4703	3662	3021	2804		50395
7-R	10967	11070	14663	19121	20554	23054	24562	23219	18556	14772	13001	12908	206447	
7-F	5269	5463	7303	9290	9740	10504	11201	10810	9207	7428	6302	6015		98531
8-R	3951	3988	5282	6888	7404	8304	8847	8364	6684	5321	4683	4650	74366	
8-F	5466	5621	7467	9423	9821	10541	11252	10937	9411	7620	6511	6259		100329
9-R	10244	10340	13696	17860	19198	21533	22942	21687	17332	13798	12143	12057	192830	
9-F	3694	3741	4910	6098	6288	6677	7140	7042	6157	5079	4401	4280		65508
10-R	15056	15197	20129	26249	28216	31647	33718	31874	25473	20279	17847	17720	283405	
10-F	6596	6607	8586	10531	10731	11298	12145	12064	10677	8907	7818	7652		113612
11-R	3962	3999	5297	6908	7425	8328	8873	8388	6703	5337	4697	4663	74580	
11-F	7290	7302	9489	11639	11860	12486	13423	13333	11800	9844	8641	8457		125565

No	Jan 55°	Feb 55°	Mar 28°	Apr 28°	May 28°	June 28°	July 28°	Aug 28°	Sept 28°	Oct 55°	Nov 55°	Dec 55°	Roof Annual	Facade Annual
12-R	5880	5935	7861	10251	11020	12360	13168	12448	9948	7920	6970	6921	110682	
12-F	5397	5486	7221	9004	9310	9912	10596	10411	9067	7451	6434	6237		96526
13-R	13287	13412	17765	23165	24902	27930	29757	28130	22481	17897	15750	15639	250115	
13-F	10973	10917	14104	17161	17366	18245	19583	19572	17461	14721	12989	12825		185917
14-R	5570	5622	7447	9711	10438	11708	12474	11792	9424	7502	6602	6556	104846	
14-F	3020	3622	5275	7430	8531	9615	10107	8970	6924	5005	3777	3233		75508
15-R	9325	9413	12468	16258	17476	19602	20884	19742	15777	12560	11054	10976	175535	
15-F	8329	8371	10911	13437	13741	14508	15579	15427	13599	11302	9857	9649		144709
16-R	5788	5842	7739	10091	10847	12166	12963	12254	9793	7796	6861	6812	108952	
16-F	4414	4437	5783	7122	7283	7689	8257	8177	7207	5990	5224	5114		76696
17-R	9796	9796	13097	17079	18359	20591	21939	20739	16574	13195	11612	11530	184307	
17-F	3442	3460	4510	5554	5679	5997	6439	6377	5621	4672	4074	3988		59813
18-R	10807	10908	14448	18841	20253	22716	24202	22878	18284	14556	12810	12719	203422	
18-F	5840	5389	6316	6650	5876	5515	6089	7099	7372	7018	6761	7043		76967
19-R	6523	6584	8721	11372	12225	13711	14609	13810	11036	8786	7732	7678	122787	
19-F	2926	2779	3432	3926	3769	3800	4108	4361	4147	3680	3407	3489		43824
20-R	21625	21828	28912	37701	40527	45455	48429	45781	36587	29127	25634	25452	407058	
20-F	11279	10407	12197	12843	11348	10650	11759	13710	14238	13553	13056	13602		148643
21-R	22670	22883	30309	39523	42485	47652	50770	47994	38355	30535	26872	26682	426730	
21-F	11170	10306	12079	12718	11238	10547	11644	13577	14099	13421	12930	13470		147200
22-R	15584	15730	20836	27170	29206	32758	32758	32993	26367	20991	18473	18342	291208	
22-F	3057	2821	3306	3481	3076	2887	3187	3716	3859	3673	3539	3687		40287
23-R	15515	15661	20744	27050	29077	32613	34747	32847	26250	20898	18391	18261	292054	
23-F	3194	2947	3454	3637	3214	3016	3330	3882	4032	3838	3697	3852		42091

No	Jan 55°	Feb 55°	Mar 28°	Apr 28°	May 28°	June 28°	July 28°	Aug 28°	Sept 28°	Oct 55°	Nov 55°	Dec 55°	Roof Annual	Facade Annual
24-R	13792	13922	18440	24046	25849	28992	30889	29200	23336	18578	16349	16234	259627	
24-F	6487	6699	8926	11309	11819	12719	13571	13143	11228	9095	7743	7417		120157
25-R	3721	3756	4975	6487	6973	7821	8333	7877	6295	5012	4411	4379	70040	
25-F	1286	1279	1653	2011	2035	2138	2295	2294	2046	1725	1522	1503		21787
26-R	1378	1391	1843	2403	2583	2897	3086	2918	2332	1856	1634	1622	25943	
26-F	1213	1367	1925	2624	2912	3240	3424	3126	2504	1879	1492	1329		27033
27-R	3572	3605	4775	6227	6693	7507	7999	7561	6043	4811	4234	4204	67231	
27-F	6444	6551	8622	10751	11116	11836	12651	12431	10827	8897	7682	7448		115255
28-R	8544	8624	11424	14896	16013	17960	19135	18089	14456	11508	10128	10056	160833	
28-F	2544	2958	4250	5905	6663	7478	7877	7076	5567	4097	3157	2744		60315
29-R	1171	1182	1566	2042	2195	2462	2623	2480	1982	1578	1389	1379	22049	
29-F	1387	1613	2318	3221	3635	4079	4296	3860	3036	2235	1722	1497		32899
30-R	2687	2713	3593	4685	5036	5649	6018	5689	4547	3620	3185	3163	50585	
30-F	240	280	402	558	630	707	745	669	526	387	298	259		5703
31-R	7694	7767	10287	13415	14420	16174	17232	16290	13018	10364	9121	9056	144838	
31-F	10845	10984	14414	17902	18461	19602	20963	20673	18077	14911	12919	12567		192318
32-R	5719	5773	7646	9971	10718	12022	12808	12108	9676	7703	6779	6731	107654	
32-F	2203	2231	2928	3636	3750	3982	4258	4199	3672	3029	2624	2553		39065
33-R	12403	12519	16583	21624	23244	26071	27777	26258	20985	16706	14702	14598	233470	
33-F	2034	2273	3178	4306	4753	5271	5576	5118	4124	3133	2496	2239		44500
34-R	40149	40526	53678	69997	75243	84393	89915	84998	67928	54077	47592	47255	755751	
34-F	9277	8618	10315	11262	10338	10071	10975	12250	12223	11295	10751	11149		128523
35-R	5076	5124	6787	8850	9513	10670	11368	10746	8588	6837	6017	5974	95550	
35-F	1830	2028	2830	3794	4164	4604	4876	4499	3647	2794	2240	2037		39344

No	Jan 55°	Feb 55°	Mar 28°	Apr 28°	May 28°	June 28°	July 28°	Aug 28°	Sept 28°	Oct 55°	Nov 55°	Dec 55°	Roof Annual	Facade Annual
36-R	1814	1832	2426	3163	3401	3814	4064	3841	3070	2444	2151	2136	34156	
36-F	782	832	1131	1476	1578	1721	1830	1726	1446	1139	942	882		15486
37-R	919	927	1228	1602	1722	1931	2058	1945	1554	1237	1089	1081	17293	
37-F	686	749	1040	1383	1510	1664	1764	1637	1340	1031	836	763		14403
38-R	4352	4393	5819	7588	8157	9149	9748	9215	7364	5863	5159	5123	81930	
38-F	4483	5009	7004	9491	10475	11618	12290	11280	9090	6906	5500	4934		98081
39-R	4640	4683	6203	8089	8695	9752	10391	9822	7850	6249	5500	5461	87335	
39-F	4483	5009	7004	9491	10475	11618	12290	11280	9090	6906	5500	4934		98081
40-R	6362	6422	8506	11092	11923	13373	14248	13469	10764	8569	7542	7488	119758	
40-F	10780	10055	12103	13339	12364	12129	13203	14589	14397	13206	12500	12942		151604
41-R	13873	14003	18548	24187	25999	29161	31069	29370	23472	18686	16445	16328	261141	
41-F	5447	6038	8424	11293	12397	13705	14514	13393	10856	8318	6669	6063		117117
42-R	11059	11163	14786	19281	20726	23247	24768	24768	18711	14896	13110	13017	209532	
42-F	1149	1274	1777	2382	2615	2891	3062	2825	2290	1755	1407	1279		24704
43-R	18156	18327	24275	31655	34027	38165	40662	38439	30719	24456	21522	21370	341773	
43-F	5476	6367	9149	12711	14345	16098	16956	15233	11984	8820	6796	5907		129843
Total	633295	640128	843670	1081632	1147025	1265514	1347905	1293112	1062601	857150	751472	741241	8123644	3541101