Comparison of Photovoltaic (PV) Panel Usage in Different Climates

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Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the Degree of

Master of Science
in
Architecture

Eastern Mediterranean University
August, 2013
Gazimağusa, North Cyprus

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ABSTRACT

In this thesis, PV panel usages will be analyzed in variable climates. By the way, during the research several case studies selected from both hot and cold climates will be observed, researched and calculated in order to find the best design principles for PV panel designs. So, comparative design method is selected to compare cold climate PV panel designs with hot climate PV panel designs. According to the findings, before designing the PV panel to the roof or facade or to the site, it is the most important to know the latitude of the place. The reason is to find the correct optimum tilt angle. According to the investigations, tilt angle that is known as inclined angle of the photovoltaic (PV) panel, is changeable due to the location of place, climatic conditions and the solar radiation. In Cyprus, tilt angle is 20° in summer and 50° in winter. On the other hand, if the panels designed fixed in North Cyprus, optimum tilt angle will be taken between 28° and 30°. Secondly, optimum tilt angle of England is 65° in winter and 35° in summer periods. By the way, due to variable tilt angles during a year, sun trackers can be given as a suggestion. On the other hand, orientation of the PV panel is the second important aspect to consider. This is because; PV panels should be oriented to south direction in Northern Hemisphere and to the north direction if the location is in Southern Hemisphere. Solar radiation should be considered to know the countries solar radiation amount to select the correct PV panel type and size. At the same time, electricity usage of the building should be calculated in order to find panel numbers to install.

Keywords: PV Panels, Climates, Tilt Angle, Orientation, Sun-Tracker

ÖZ

Bu tezde değişik iklimlerdeki fotovoltaik panel kullanımı analiz edilecektir. Bu yüzden araştırma sırasında sıcak ve soğuk iklimlerden çeşitli örnekler; araştırmak, hesaplamak ve gözlemlemek üzere en iyi fotovoltaik panel tasarım ilkelerini bulmak için seçilmiştir. Karşılaştırmalı tasarım yöntemi, sıcak iklim fotovoltaik tasarımlarını ve soğuk iklim fotovoltaik tasarımlarını karşılaştırmak üzere seçilmiştir. Elde edilen sonuçlara göre; panellerin çatıya, cepheye ve zemin alana tasarlanmadan önce ilk olarak bölgenin enleminin (paralelinin) bilinmesi gerekir. Bunun sebebi ise fotovoltaik panelin en uygun eğim açısını bulmak içindir. Araştırmalara göre, panelin eğim açısı bölgenin konumuna, iklim koşullarına ve güneş ışınımına(radyasyonuna) göre değişiklikler göstermektedir. Kıbrıs'ta eğim açısı yazda 20° ve kışta 50° olmalıdır. Eğer paneller sabit tasarlanacak ise eğim açısı 28° ve 30° Aralığında olması gerekmektedir. Diğer bir yandan İngiltere'nin kış ayları için olması gereken açı 65° ve yaz ayları için 35° olmalıdır. Görüldüğü üzere yaz ve kış ayları için iki farklı açı önerilmiştir. Bu yüzden, güneş takipçi sistemleri açı ve yön ayarlı olduğundan ötürü daha verimli sonuçlar verebilir. Dikkate alınması gereken bir diğer önemli kural ise panellerin yönlendirilmesidir. Bölge kuzey yarım kürede ise paneller güneye bakmalı; güney yarım kürede ise kuzeye bakmalıdır. Ayrıca doğru panel (hücre tipi) seçimi yapabilmek içinse, bölgenin güneş ışınım miktarına da bakılmalıdır. Paneller sayısı, binanın elektrik kullanım miktarına göre ayarlanmalıdır.

Anahtar Kelimeler: Fotovoltaik Panel, İklim, Eğim açısı, Yönlendirme, Güneş-takipçisi

To my family

ACKNOWLEDGMENTS

I would like to thank to my supervisor Asst. Prof. Dr. Halil Zafer Alibaba for his positive guidance, supports and his great role in the development of this research.

I would like to thank to my whole family members Tezcan Kayalar, Eren Kayalar and Ulfet Kayalar who give their supports in this challenging and enjoyable process.

Finally, I would like to thank to my friends for their support during the visits in North Cyprus.

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INTRODUCTION

1.1 Problem Statement

Photovoltaic (PV) panel usage in the world is evolving day by day. Therefore, photovoltaic (PV) installations were started to be used especially in recent years in Northern Cyprus like other developed countries such as England, Germany and America. However during the installation of the photovoltaic (PV) panels, significant errors are done by companies. These errors are wrong PV cell selection, not appropriate tilt angle, wrong installation spaces and orientation of the PV panels.

1.2 Aim (Scope of Thesis)

Because of the certain problems that are done during the installation, case studies are selected from hot and cold climate regions will be compared in order to find correct solutions for photovoltaic (PV) panel usage. Aim of the thesis is to create a "design aid" for architects, engineers, users and all participants that want to install and design PV panels.

1.3 Methodology

The methodology of the research is to compare case studies selected from hot climate and cold climate. Building projects will be evaluated according to the criteria's. Due to the hot climate of Cyprus; most of the case studies were selected from Turkish Republic of Northern Cyprus (TRNC). Case studies will be analyzed by measuring;

taking photos, drawings**,** calculations and interviews will be done with users. Panel dimensions, supporting elements, distance between the panels were measured by meter. On the other hand, tilt angle of the panels were calculated by using right triangle trigonometric calculations. Total investment cost, total size of the system and intended use of the system was found out with the interviews of the building owner's in TRNC. By the way, twelve different interviews were done at the hot climate case studies. Lastly, one case study was selected from America because of the successful installation and America is on the same latitude with Cyprus.

On the other hand, cold climate case studies were selected randomly around the world. Various cold climate countries selected from Serbia, Germany, and Canada and mostly from UK to understand the installations. Case studies will be evaluated according to the collected data and suggestions will be given.

Interviews will be done with the specialized peoples like mechanical engineers and contractors and users on PV panel technologies in TRNC. (Turkish Republic of Northern Cyprus) Results that will be obtained at the end of the research will be discussed.

In the conclusion, suggestions will be given to the selected cases in order to understand how PV panels can be designed correctly. Design suggestions should be given to achieve these problems during PV panel designs and increase the energy efficiency to get the best yield. In order to get the best efficiency in such cases like panels designed at the site of the buildings, sun-trackers preferred to change the direction of panel according to the direction of the sun. On the other hand, for the integrated PV panels to the facade or the roof of building and secondly, for additive

PV panels at the roof of the buildings; new design solutions and suggestions should be given. As a result of this research will be helpful to design, orient and mount panels in a most accurate way according to the climatic conditions.

1.4 Limitation of the Research

During the usage of PV panels in different climates; it is important to do correct orientation and organization of the panels, select the most efficient cell type and calculate the correct tilt angle according to the location's latitude. According to the previous researchers that panels should be oriented to south direction in the northern hemisphere. This research suggests that future researchers can study deeply on the positives and negatives about the installation to south direction

Secondly, panels are overheated by the lack of gap between the roof surface and the panels. For this reason, what will be the exact gap between the roof surface and the panels should be researched. Hybrid Solar Panels (HIT Solar Cells) are said that are the most efficient cell type. The efficiency and the cost of the panels should be researched. Lastly, efficiency differences between the roof installation and façade installation can be researched.

1.5 Research Questions

1. Is it possible to use in hot climates the same PV CELLS that is used in cold climates? Photovoltaic (PV) cell type panels can be used at both hot and cold climatic regions. However, mono-crystalline cell type panels loose efficiency under too much solar irradiation. On the other, amorphous thin-film cell type panels are not loose efficiency under high solar irradiation.

2. Is it possible to get the same efficiency in hot climates like in the cold climates? As solar irradiation increases, the efficiency will increase.

1.6 Literature Review

According to Barkaszi and Dunlop (2001), When PV arrays designed directly and integrated to the roof, heat transfer can be increased between the roof surface and conditioned spaces. By the way, this can be used as an advantage in the cold climates. But, another type of design solutions should be applied for the hot climates.

Welch (2013) argues that photovoltaic panels should be placed before taking environment in consider. Because, if they are located where photosynthesizing plants would normally grow, they simply substitute one potentially renewable resource (biomass) for another. It should be noted, however, that the biomass cycle converts solar radiation energy to chemical energy (with significantly less efficiency than photovoltaic cells alone).

According to Beyit and Dervişoğulları (2009) in order to produce 1kWp, 7-9m² panel modules needed at mono-crystalline silicon to provide 11-16% energy efficiency. Secondly, 8-9m² panel modules needed at poly-crystalline silicon (EFG) to be 10-14% energy efficient. Thirdly, 11-13m² panel modules needed at thin-film copper-indium-dieseline to be 6-8% energy efficient. Thin film is less efficient than mono-crystalline and poly-crystalline. But thin film is both suitable for high temperature environments (hot climatic regions) and shade shadow conditions. Accordingly; energy production is increase when solar radiation is high. By the way, if the solar radiation is higher, maximum energy production is occurred. So, peak power is the maximum produced power energy by a single module. Before, installing the photovoltaic modules; the location of the house and the availability of solar energy should be investigated (peak power). Peak power of Cyprus can be considered as an average of 5 hours. Additionally, angle of the photovoltaic (PV) modules must be found. These angles can be found by using graphics that is showing solar panel angles for various northern latitudes. For instance Karpaz is located in 35°N latitude of North Cyprus. So panels should face south. For better efficiency; between months April and October, inclined angle must be between 10° and 25°. On the other hand, between months November and March, inclined angle should be between 25° and 55°. For Cyprus, orientation of the inclined angle can be 45°. As a solution, angles can be designed moveable according to the direction of the sun (Angle can be 35° and 45°).

Kumar, Thakur, Makade and Shivhare (2011) argue that photovoltaic arrays needed to be tilted at the correct angle to maximize the performance of the system. This can be known as the inclined angle of the photovoltaic modules. In order to find the tilted angle several calculations needed. Monthly average daily solar irradiation components should be noted. Khatkar Kalan (Punjab) that is a location in Indian State of Punjab. It is found that the optimum tilt angle changes between 60.5◦ (January) and 62.5◦ (December) throughout the year. In winter (December, January, and February) the tilt should be 57.48◦, in spring (March, April, and May) 18.16◦, in summer (June, July, and August) 2.83◦, and in autumn (September, October, and November) 43.67◦. The yearly average of this value was found to be 30.61◦ which is nearly equal to the angle selected at Khatkar Kalan. Latitude and Longitude of Punjab is noted as 30°4’N, 75°5’E.

Mousazadeh, Keyhani, Javadi, Mobli and Abrinia (2009) studied on the sun trackers devices. Accordingly sun trackers are such devices for increasing the energy efficiency and efficiency improvement. Seasonal movements of earth and day time affect the energy efficiency. (Solar radiation increases the energy production). It is important to know that sun trackers keeping the best orientation relative to the sun. Additionally, solar trackers not recommended using for small solar panels because of high energy losses. The most efficient and popular sun tracing device was founded to be in the form of polar axis and azimuth/elevation types.

According to Rakovec, Zaksek, Brecl, Kastelec and Topic (2011), climatic, topographical and geographical varieties can cause changes in the photovoltaic (PV) potential. Slovenia is selected as a case study in order to understand the changes. At the orientation of the panel, in winter, large tilt and south facing orientation is needed on the other hand, in summer times, flat installation of panel is preferred. Slovenia has 45.5°N and 47°N latitude. Average latitude is noted as 46°N. By the way, on 21th March and 21th September tilt angle of PV panel will be 44°. On 21th of June (summer) tilt angle will be 20.5° and on the 21th of December, tilt angle calculated as 67.5° (winter). Different climate characteristics have a huge influence on the optimal tilt. (Incline angle) "It is important to stress those optimal orientations and tilts are strongly affected by local weather and climatic conditions."

Makrides, Georghiou, Zinsser and Werner (2007) studied that temperature is a great factor that affects daily and seasonal performance of PV panels. For instance, module temperature of PV panels reach to 70°C in Cyprus especially at midday hours in summer times. Two cities are compared in order to understand which panels are more efficient. Cyprus and Germany is selected as a case study. Different types of mono-crystalline, poly-crystalline and thin-film installed at both Nicosia and Stuttgart. As a result, Mono c-Si and thin-film technologies have best performance for both countries.

Kelly and Gibson (2011) studied on four identical photovoltaic arrays in order to increase the solar photovoltaic energy capture at different seasons including cloudy, cloud-free and sunny weathers. Several measurements were done within a defined time line in order to find which kind of tilt angle is suitable for sunny and cloudy days. By the way, it is more efficient to design DTS configuration (flat-plate solar device pointed directly towards the sun) during the sunny days because sun light is captured twice compared to the H configuration (Solar array with a horizontal tilt, 0° pointed towards the zenith). Secondly, H configuration (Solar array with a horizontal tilt, 0° pointed towards the zenith) increases the solar energy capture by nearly 40% at cloudy days. During the longitudinal comparison method period, 4 type of identical PV arrays designed facing to south. Multi-crystalline (mono-crystalline) cells that are known as the most efficient cell type were used. Arrays created by 10 modules. According to Kelly and Gibson (2011); tilt angle is set equal to the site latitude. Survey is done at Milford which has 42°N latitude. During the survey 57° tilt angle given to first array, 42° tilt angle to second array, 27° to third array and lastly 0° given to the fourth array. At the end of the survey, it is understood that tilt angle would be 18.9° in the season June (summer) and 64.2° in December (winter). By the way, tilt angle 27° that is given to number 3 array is the closest array to DTS condition (flat-plate solar device pointed directly towards the sun) near solar noon on 21th June. The array with a tilt angle of 57° that is given to number 1 array is closest to the DTS condition near solar noon on December 1. At the conclusion, solar tracking systems with current technology can increase the solar energy capture by 30% versus a fixed south facing latitude tilt installation in the US. Additionally, solar tracking systems increase energy capture on cloudy days.

Chang (2010) studied on different seven sites of Taiwan in order to find suitable the annual optimal angles. Mono-crystalline silicon type PV panels used and additionally, computer subprogram is used to account climatic conditions and latitude of each site. Chang (2010) argues that the optimal annual tilt angle is approximately equal to the latitude of the location. At the end of the survey, annual optimal tilt angle for Taipei is 18.16°, Taichung is 17.3°, Tainan is 16.15°, Koosiung is 15.79°, Hengchung is 15.17°, Hualian is 17.16° and Taitung is 15.94°. The lowest optimal tilt angle is noted as 15.17° for Hengchung but the highest electrical energy (kWh/m^2) is 233.81.

According to Mieke (1998), tropical climate (like Malaysia) has high ambient temperature and humidity during wet seasons. So, during wet seasons A-si (Amorphous) array produces up to 20% more energy than P-si (Poly-crystalline) array.

At the same time according to Akhmad et al. (1997), A-si (Amorphous) modules may be more suited to tropical climates.

Amin et al (2009) argues that amorphous silicon, Copper Indium Diselenide (CIS) have better performance ratio than mono and multi-crystalline silicon solar cells in Malaysia climate conditions.

According to Azhar et al (2012), poly-crystalline (P-si) cell type has higher power output efficiency compare to mono-crystalline (M-si) and amorphous (A-si) in high level of average solar radiation. (Hot climates) On the other hand, poly-crystalline has low power output compared to M-si and A-si photovoltaic modules. Secondly, mono-crystalline power output is better in high average solar radiation. However power output of cells drop as the module temperature reaches high values. As it can be compared with P-si and A-si, Mono-crystalline produces more heat than the other modules. Thirdly, amorphous power output is better in low intensity of solar radiation than poly-crystalline and mono-crystalline. But in high average solar radiation, energy output of amorphous is lower compared to P-si and M-si. Amorphous has a cooler module temperature than pol-crystalline and mono-crystalline.

At the end of the literature review; no one compared the usage of PV panels in hot and cold climates. By the way; “Comparison of Photovoltaic (PV) Panel Usage in Different Climates” is selected as thesis subject.

1.7 Research Principles

In order to do a systematic research; significant rules are needed. First of all, hemisphere of the location should be known for orienting photovoltaic (PV) panels direction correctly. Secondly, climate type and panel type is important to select the most efficient cell type according to the climatic conditions of the location. Thirdly, latitude and longitude is important for finding the optimum tilt angle of the location. Subsequently, location of the panel must be mounted correct to get the most solar radiation and avoid from shading. Lastly, panels should be supported correct to avoid from external factors and to be ventilated well.

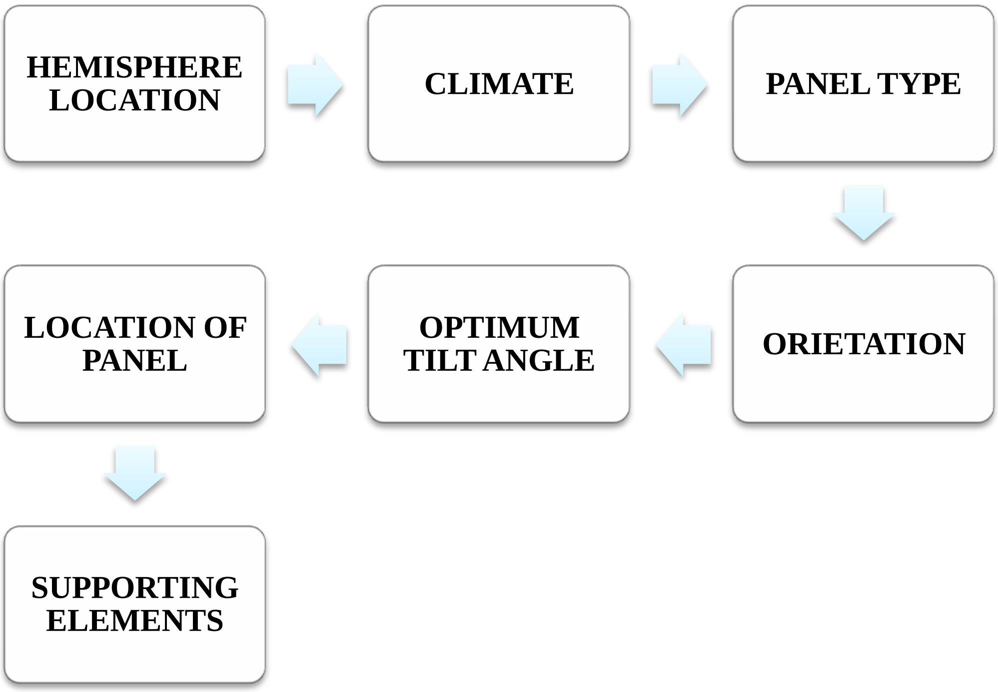


Figure 1.1: Principles for PV Panel Design (Drawn by author)

Chapter 2

THEORITICAL BACKGROUND

2.1 General Information About Photovoltaic(PV) Panels

When viewed from the past, the photovoltaic effect was discovered by Alexander Becquerel in 1839. At the following years, this trend began to develop each passing day. First solar collectors installed on rooftops in the mid-1970s. (Zauscher, 2006)

Photovoltaic (PV) are solar cell systems that convert sunlight directly into electricity. Photovoltaic systems are mainly divided into two. Sunshine is converted to electricity by PV cells (Aysan, 2011). Photovoltaic word comes from the Greek language. Photo means “light” and voltaic means “producing electricity”. (Hegger et al, 2009). Additionally, photons of sunlight are transferred to the electrons of the photovoltaic module elements by photovoltaic. The smallest part of the photovoltaic is named as cell. A single PV cell has a capacity to produce energy between 1 and 2 Watts. When 36 numbers of cells are combined together, a module/panel is created. An array can be created with the combination of several modules and panels. PV cell shape can be seen rectangular, circular and square. Each cell’s dimension can be 10x10 cm (Sev, 2009)

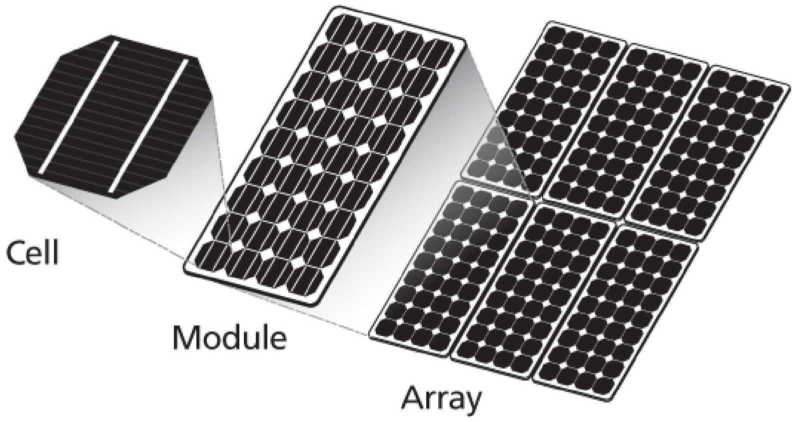


Figure 2.1: PV Cell, Module and Array (Samlex Solar, 2009)

According to Kazek (2012), photovoltaic (PV) module can be framed with aluminum and without any frame. At the same time, base of PV module can be plastic, metal or double surface.

2.2 Different Climate types

According to Ozdeniz and Alibaba (2009), there are thousands of climates on the earth but it can be classified for architectural purposes like that:

1. Cool climate
2. Temperate dry climate
3. Temperate climate
4. Temperate humid climate
5. Hot-dry climate(arid)
6. Hot humid climate
7. Composite climate

2.3 Classification of Photovoltaic Cells

There are three main types of photovoltaic cell types. These are mono-crystal (mono-crystalline) that has 16-19% cell efficiency capacity; second type is poly-crystal (multi-crystalline or poly-crystalline) that has 14-15% cell efficiency capacity and lastly, thin-film amorphous silicon (A-si) panel type that has 5-7% efficiency. Area requirements of various cell type panels can be changeable. Approximately 8m² is needed for poly-crystalline, 7m² is required for mono-crystalline and 15m² is needed for thin-film amorphous silicon per kilowatt (kW). These percentage rates are taken under 25°C and 1000W/m² solar irradiation standard testing conditions (Welch, 2010). On the other hand, a panel with a new cell type has recently started to be used which is named as HIT photovoltaic module. According Mishima et al (2010), HIT was certified as highest conversion efficiency of 23% for practical size crystalline silicon solar cell.

1. Mono-crystalline (single-crystalline) silicon
2. Poly-crystalline (multi-crystalline) silicon
3. Thin-film amorphous silicon
4. HIT (Hetero Junctin with Intrinsic Thin Layer) (Mixture of Ultra-thin Amorphous silicon and Mono-crystalline silicon)

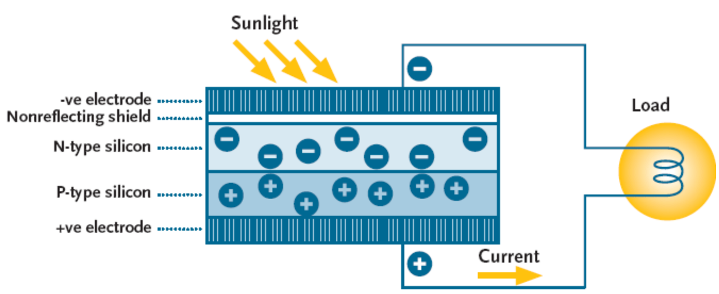


Figure 2.2: Principles of Operation for PV Cell (Welch, 2010)

Table 1: Mono-crystalline Cell Type Characteristics (Drawn by author)

MONO-CRYSTALLINE CELL TYPE	
Number of Cells	**72**
Power class	**190Wp**
Maximum Power Rating P max [Wp]	**190**
Tolerance of Pmax P [Wp]	**-0/+5**
Number of Cells (Matrix)	**72 (6 x 12)**
Solar Cell Size (mm)	**125 x 125**
Dimensions [L x W x D mm] :	**1580 x 808 x 45**
Weight [kg]	**15.50**
Cell Efficiency [%]	**17.80**
Module Efficiency [%]	**15.27**

Table 2: Poly-crystalline Cell Type Characteristics (Drawn by author)

POLY-CRYSTALLINE CELL TYPE	
Number of Cells	**60**
Power class	**235Wp**
Maximum Power Rating P max [Wp]	**235**
Tolerance of Pmax P [Wp]	**-0/+5**
Number of Cells (Matrix)	**60 (6 x 10)**
Solar Cell Size (mm)	**156 x 156**
Dimensions [L x W x D mm] :	**1650 x 992 x 50**
Weight [kg]	**19.50**
Cell Efficiency [%]	**16.50%**
Module Efficiency [%]	**14.79%**

Table 3: Thin-film Amorphous Silicon Cell Characteristics (Drawn by author)

THIN-FILM AMORPHOUS SILICON	
Number of Cells	**72**
Power class	**100Wp**
Maximum Power Rating P max [Wp]	**100**
Number of Cells (Matrix)	**72 (3x24)**
Dimensions [L x W x D mm] :	**1,308 x 1,308 X 35**
Weight [kg]	**20.8**
Module Efficiency [%]	**6.9%**

Table 4: HIT Cell Characteristics (Sanyo, 2009)

HYBRID (HIT) CELL TYPE	
Number of Cells	**72 (6x12)**
Power class	**235Wp**
Dimensions [L x W x D mm] :	**1,610 x 861 x 35**
Weight [kg]	**16.5**
Cell Efficiency [%]	**19.6%**
Module Efficiency [%]	**17.0%**

Hybrid (HIT) cell type panel is the best performer compared to the other cell types. Because Hybrid cell type is the mixture of amorphous and crystalline cells. “Honeycomb Design” cell type is used for hybrid cell type panels. Additionally, generates more electricity in lower lights. By the way, Hybrid panels can be used at lower solar irradiation countries. This means that, hybrid panels can be used at high latitude and colder countries.

Table 5: PV Cell Type Classifications (Drawn by author)

Characteristics	PV Cell Types		
	Mono-crystalline	Poly-crystalline	Amorphous
Power class	190Wp	235Wp	100Wp
Number of cells	72 (6x12)	60 (6x10)	72 (3x24)
Dimensions [LxWxD]mm	1580x808x45	1650x992x50	1308x1308x35
Module efficiency	15.27%	14.79%	6.9%
Weight[kg]	15.5kg	19.5kg	20.8kg

Table 6: Comparison of the PV Cells (Kazek, 2012)

<table>
<tr><th>Type of PV</th><th>Degree of Module Efficiency</th><th>Market Share</th><th>Area Requirements</th><th>Energy Payback Period</th><th>Cell color availability</th><th>Cell diameters</th><th>Cell thickness</th></tr>
<tr><td>Mono-crystalline Silicon Cell</td><td>15 – 17 %</td><td>approx. 30%</td><td>7 – 9 m²/kWp</td><td>approx. 5 years</td><td>Blue
Black
Violet
Turquoise
Dark and light grey
Yellow</td><td>100 mm
125mm
150 mm</td><td rowspan="2">between 0,2 - 0,4 mm</td></tr>
<tr><td>Poly-crystalline Silicon Cell</td><td>13 – 15 %</td><td>approx. 60%</td><td>7 – 10 m²/kWp</td><td>approx. 3 years</td><td>Blue
Violet
Brown
Green
Gold
Silver</td><td>100 mm
125 mm
150 mm</td></tr>
<tr><td>Thin-film Amorphous Silicon</td><td>6 – 10 %</td><td>approx. 10%</td><td>14 – 20 m²/kWp</td><td>approx. 2 to 4 years</td><td>Black - brown</td><td>Variable</td><td rowspan="3">approx 0,004 mm</td></tr>
<tr><td>Thin-Film (CIS)</td><td>8 – 12 %</td><td>< 1%</td><td>9 – 11 m²/kWp</td><td>approx. 1 to 2 years</td><td>Black - grey</td><td>Variable</td></tr>
<tr><td>Thin-Film (CdTe)</td><td>8 – 10 %</td><td>< 1%</td><td>12 – 17 m²/kWp</td><td>approx. 1 to 3 years</td><td>Black - green</td><td>Variable</td></tr>
</table>

2.4 Orientation and Optimum Tilt Angle of PV Panels

World is divided into two by equator. Part that stays at the northern planet is known as northern hemisphere and south part of the world is known as southern hemisphere.

Northern Hemisphere is the half of the planet that is north of the equator. Coordinates of Northern hemisphere is shown with 45° 0′ 0″ N, 0° 0′ 0″ E. Secondly, southern hemisphere is the other half of the world that lies south of the equator. Coordinates of Southern hemisphere is shown with 45° 0′ 0″ S, 0° 0′ 0″ E. (Wikipedia, 2013) Duffie and Beckman (1991) said that, “For solar energy applications in the northern hemisphere, optimum orientation is considered to be that of due south. In most cases, PV panels are placed according to this general rule”.

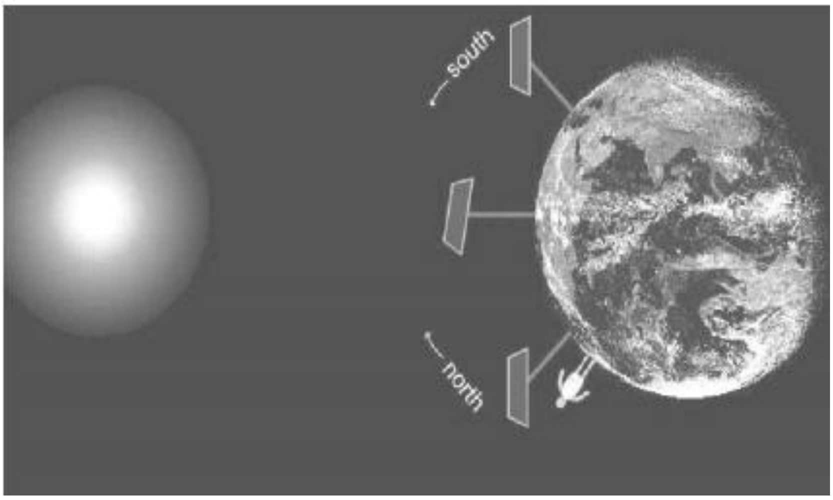


Figure 2.3: Orientation in Northern and Southern Hemisphere (Sundaya, 2013)

The installation of a PV module is determined location with respect to the equator. If the location is at the north of the equator (northern hemisphere) PV panels should be oriented to the south direction. If the location is at the south of the equator (southern hemisphere) PV panels should be oriented to the north direction.

On the other hand, optimum tilt angle is the required angle of panels for receiving the best solar irradiation. Optimum tilt angle is changeable according to the latitude of the regions. Mikell (2008) argued that in order to derive maximum amount of electricity from a photovoltaic panel, it is necessary to make sure that the panel is optimally oriented. There are many ideas about how should be the optimum tilt angle of the panels. So; Hottel (1954) argues that optimum tilt angle should be plus 20 degree (+20°). Kern and Harris (1975) suggested that optimum tilt angle should be plus 10 degree (+10°). Hyewood (1971) said that tilt angle must be minus 10 degree (-10°). Yellot (1973) argued that optimum tilt angle can be two angles. One angle is for summer (-) and one for winter times (+). By the way, optimum tilt angle should be plus and minus 20 degree (±20°). Lewis (1987) suggested that optimum tilt angle can be minus 8 degrees in summer periods and plus 8 degrees in winter periods. So optimum tilt angle is noted ±8°. *"As a rule of thumb, photovoltaic are usually positioned at a* ***tilt angle*** *approximately* ***equal to the latitude*** *of the site and facing south."* (Mehleri, Zervas, Sarimveis, Palyvos, Markatos, 2010).

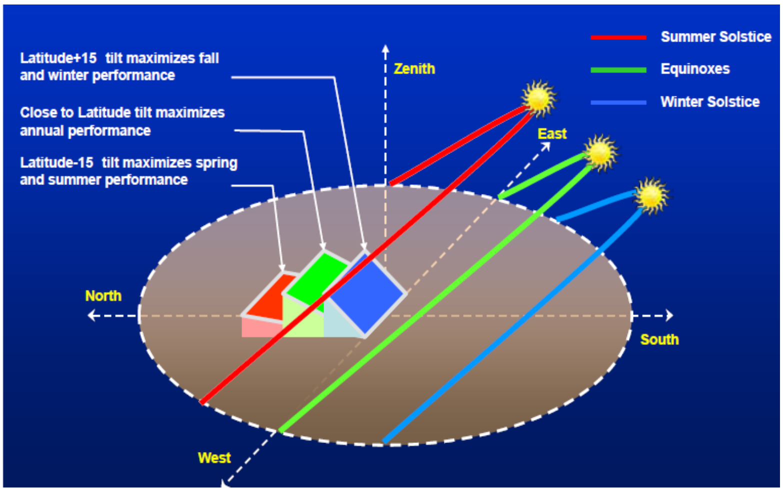


Figure 2.4: Array Tilt Angle Affects Seasonal Performance (Brooks, Dunlop, 2012)

As seen from Figure 2.4, sun is lower in winter according to summer times. By the way, tilt angle for winter should be +15 degrees and -15 degrees in summer times. According to Mehleri et al (2010), optimal tilt angle for cold period should be larger compared to the hot periods. This change in tilt angle would improve the quantity and uniformity of the produced power.

In order to find the tilt angle of the current installations that was done on the roof surface, right triangle trigonometric calculation can be used.

2.4.1 Optimum Tilt Angle for Turkish Republic of Northern Cyprus (TRNC)

Cyprus' latitude is noted as 35°N. According to the Ibrahim (1995) optimum tilt angle should be +15° of latitude in winter and -15° of latitude in summer times. So, tilt angle of Cyprus should be 50° for winter and 20° for summer. By the way, the average of two angles is found 35°. So, the solution is equal to the local latitude.

Garp and Gupta (1978) argued that; in order to find the yearly average tilt angle, modules tilt angle should be equal to the local latitude.

On the other hand 9 months pass like summer and 3 months are pass winter. So;

$$\frac{\text{(Number of Summer Months x Summer Tilt Angle) + (Number of Winter Months x Winter Tilt Angle)}}{\text{Total Months}}$$

$$\frac{(\#SM \times STA) + (\#WM \times WTA)}{12}$$

$$((9x20) + (3x50)) / 12 = 27,5° \approx 28°$$

Figure 2.5: Formula for finding fixed tilt angle for TRNC (created by author)

2.5 Latitude and Longitude

Latitude is the lines that run horizontally on the world. These horizontal lines are also known as parallels. Each degree of latitude is approximately 69 miles (111km) apart and degrees of latitude are numbered from 0° to 90° north and south. Lastly, 90° north is the North Pole and 90° south is the South Pole.

Vertical lines of the world is known as longitude and at the same time known as meridians. They converge at the poles and are widest at the equator (about 69 miles or 111 km apart). Zero degrees longitude is located at Greenwich, England (0°). The degrees continue 180° east and 180° west. (Rosenberg, 2013)

2.6 Sun Position Defined by Azimuth and Altitude Angle

Solar azimuth angle can be defined as the direction of the sun's horizontal projection relative to a point on earth and symbolized by the Greek letter psi.

Solar altitude angle can be defined as the sun's elevation above the horizon and symbolized by the Greek letter alpha (α)

2.7 Solar Irradiation

Solar irradiation or insolation is a measure of solar radiation energy received on a given surface area and recorded during a given time. It is also called solar irradiation and expressed as "hourly irradiation" if recorded during an hour or "daily irradiation" if recorded during a day.

2.7.1 Global Horizontal Irradiation of Europe

It can be seen from the table that when latitude lowers, solar radiation increases at the locations. At the same time, it is observed that there is decline at angles and latitudes and increase at temperature and solar radiation from north to south latitudes. For example as it can be seen from the table that solar irradiation of Cyprus is 1800-2000 kWh/m². Additionally, Cyprus is in Zone 4 at solar electricity potential/ solar radiation. By the way, solar radiation is greater than 1250 kWh/kWp (> 1250 kWh/kWp). Cyprus' latitude and longitude is 35°00"N and 33°E.

Table 7: Optimum Tilt Angle for Summer and Winter Times at Europe Countries (University of Strathclyde Glasgow, 2013)

EUROPEAN COUNTRIES				
	Solar Radiation	**Latitude**	**O.T. A. Summer**	**O. T. A. Winter**
ZONE 1	**<750 kWh /kWp**			
Northern UK Scotland		57ºN	42º	72º
Northern Germany		54ºN	39º	69º
Netherlands		52º23N	37º	67º
Belgium		50º50N	35º	65º
Scandinavia		ºN	º	º
ZONE 2	**750- 1000 kWh /kWp**			
Southern UK Plymouth		50º22N	35º	65º
North-East France Strasburg		48º58N	33º	63º
Germany		51ºN	36º	66º
Austria		47º20N	32º	62º
Hungary		47ºN	32º	62º
ZONE 3	**1000-1250 kWh /kWp**			
Southern France Perpigan		46ºN	31º	61º
Northern Greece Orestias		41ºN	26º	56º
Bulgary		43ºN	28º	58º
Northern Spain A Coruna		43º20N	28º	58º
Northern Italy Trento		46º4N	31º	61º
Portugal Porto Lisbon		39º5N 41 º09N 38 º42N	24º	54º
ZONE 4	**>1250 kWh /kWp**			
Southern Spain Malaga		36ºN	21º	51º
Souhern Italy Palermo		38ºN	23º	53º
Southern Greece		31ºN	16º	46º
Cyprus		35ºN	20º	50º

2.8 Support Types of Photovoltaic Panels

2.8.1 Plastic tubs

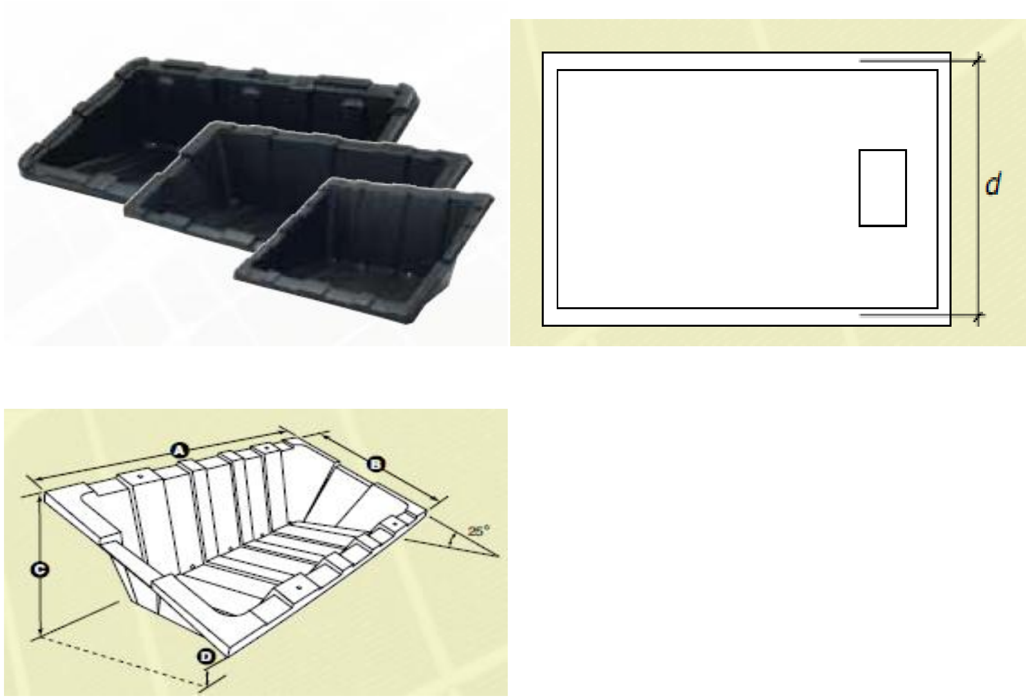


Figure 2.6: Plastic Tubs Image, Top View and 3D View (Antaris Solar Germany, 2012)

Plastic tubs can be placed on the flat roof surface and on the ground (free standing). Dimensions of the plastic tubs can be changed according the size of the selected panels. Plastic tub dimensions can be 135x73cm, 144x67cm, 125x86cm, 160x80cm, 120x105cm and 168x105cm. Optimum tilt angle of the panel is fixed manufactured.

2.8.2 Roof Hooks and Profile Carriers

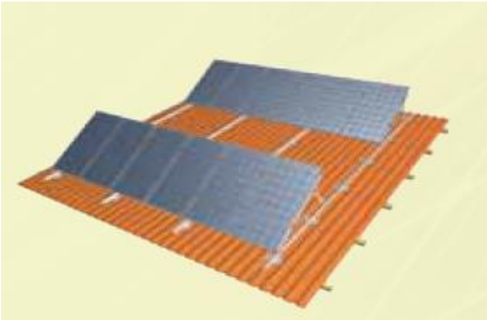


Figure 2.7: Roof Hooks and Profile Carriers (Antaris Solar Germany, 2012)

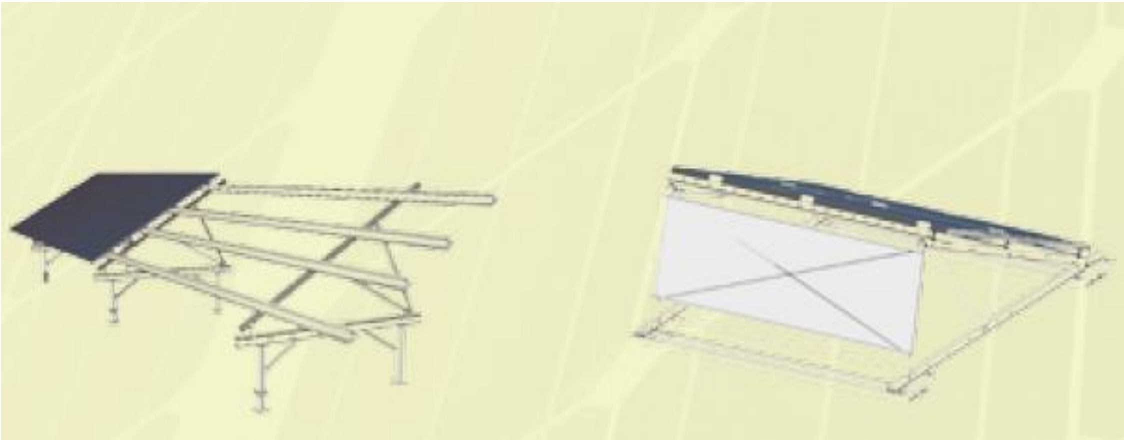


Figure 2.8: Profile Carriers for Roof (Antaris Solar Germany, 2012)

As seen from Figures that, panels are supported by profiles and mounted on the roof structure and optimum tilt angle can be given by profile carriers. According to weight and number of panels, thickness of profile carriers increases for strong supporting. Profile carriers can be mounting on the existing roof surface and on the flat roofs. Additionally, carriers can be used at roof integrated (in-roof) designs. Profiles mounted inside the roof for supporting the panels and cannot be seen from the outside of the building.

2.8.3 Profile Carriers at Ground Mounts

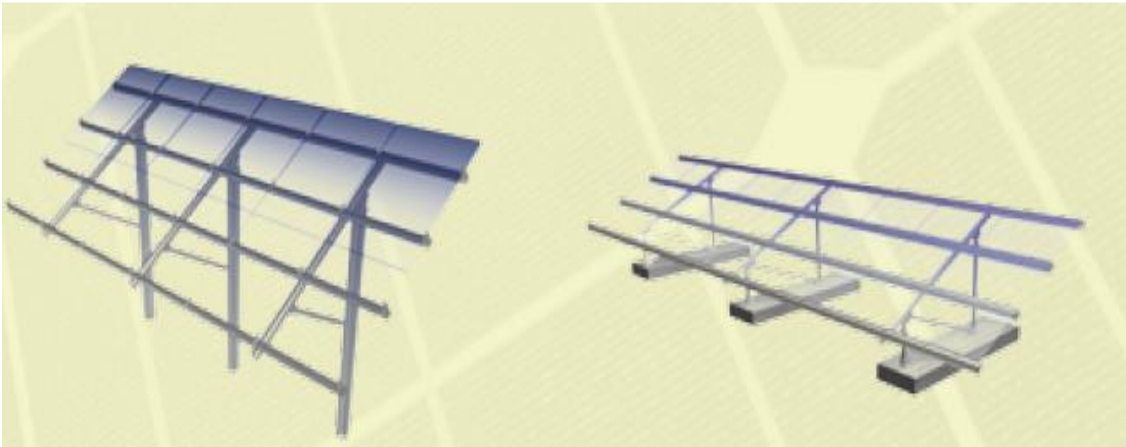


Figure 2.9: Profile Carriers for Ground Mount (Antaris Solar Germany, 2012)

As seen from Figures, optimum tilt angle can be given by the profile carriers. (On the facade, roof and ground mounts)

2.9 Location/Position of Photovoltaic Panel

Application of the PV panels can be generally done on roof and facade surface. Thirdly panels can be installed freestanding on the ground.

PV Panel application types can be listed below;

2.9.1 Roof Integration

Roof integration is the integration of photovoltaic (PV) panels to the roof structure. Roof integration can be divided into three. These are on-roof, in-roof (building integrated PV) and on flat roof.

2.9.1.1 On-roof (Additive roof)

As understood from the description that panels are mounted on the roof surface subsequently. Roof mounted photovoltaic systems are suitable for any pitched roof and can be installed on any type of roof surface such as slate, tile, composite panel, and corregated metal sheet roof.

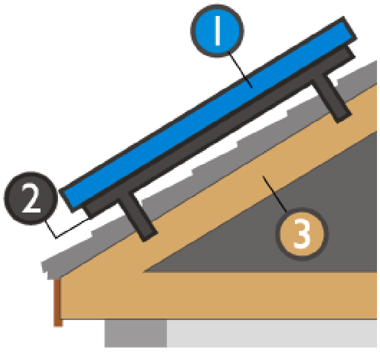


Figure 2.10: On-roof Installation (Horizon Renewables, 2013)

Number 1 is the photovoltaic panel on the roof surface attached to a profile frame and number 2 is the profile support that is fixed to the building's roof structure and thirdly, number 3 is showing the roof structure. (Rafters and perlins)

Figure 2.11: On-roof Location Type Applications (Horizon Renewables, 2013)

2.9.1.2 In-roof (building integrated PV)

In roof type of application is suitable for new buildings or re-roofing. This kind of application is done directly on the roof surface. These kinds of applications can be done in two ways, First application type of in-roof integration can be done by waterproof membrane and second type of roof integration can be done by photovoltaic (PV) tiles.

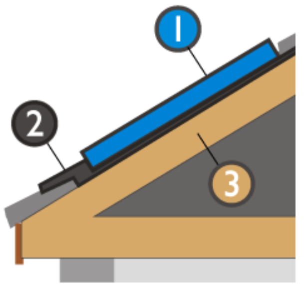


Figure 2.12: In-roof Application (Horizon Renewables, 2013)

Number 1 is photovoltaic (PV) panels that are laid over and attached to a waterproof membrane (Number 2) and Number 3 is representing the roof structure that water proof membrane is fixed on it. Figure shows the first group of in-roof application. PV panels were attached to the waterproof membrane.

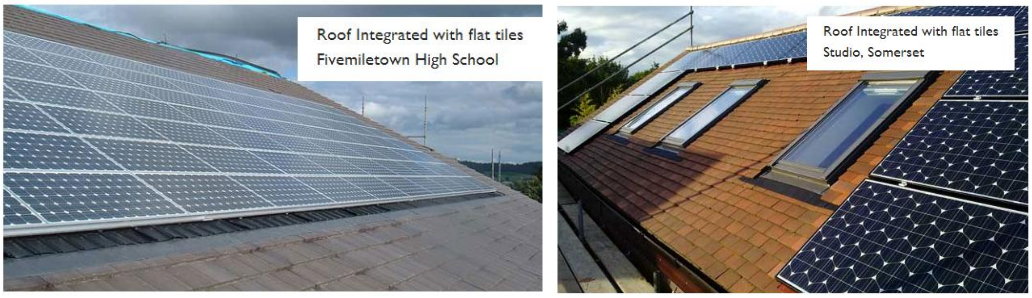


Figure 2.13: In-roof Location Type Applications (Horizon Renewables, 2013)

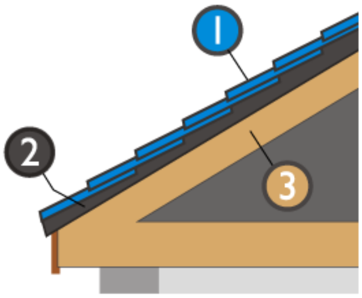


Figure 2.14: Photovoltaic Tile Installation (Horizon Renewables, 2013)

Number 1 is photovoltaic (PV) tiles that are attached to standard timber roofing tile that is Number 2. Timber roofing lathe is fixed to the rafters (Number 3).

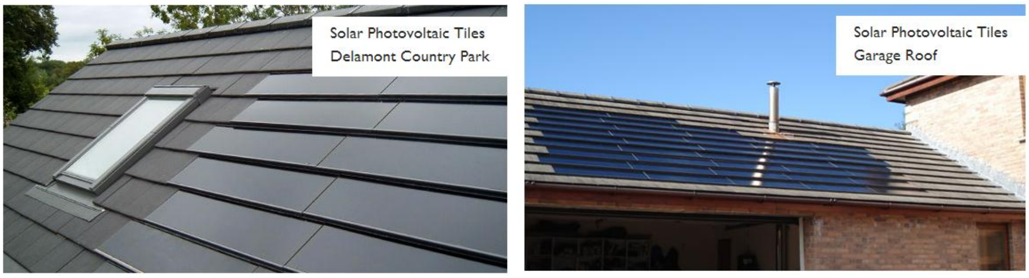


Figure 2.15: Photovoltaic Tiles were attached to the Standard Timber Roofing Lathe (Horizon Renewables, 2013)

2.9.1.3 Flat roof

Roof type of the building is designed flat, photovoltaic panels can be supported with plastic tubs and profile carriers like free standing location type.

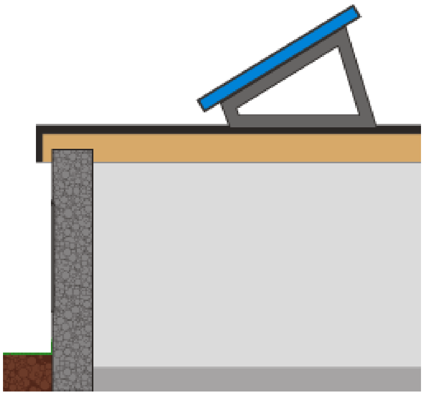


Figure 2.16: Flat Roof Installation (Horizon Renewables, 2013)

Figure 2.17: Photo shows the Flat Roof PV Application Supported with Plastic Tubs (Horizon Renewables, 2013)

2.9.2 Facade Integration

Photovoltaic panels can be attached to the building surface (facade) and supported with profile carriers and optimum tilt angle of the panels can be adjusted by profile carriers. As panels are attached to the facade surface with an adjusted tilt angle, energy efficiency of the panels will increase. Panels that are applied parallel to the building facade, panels optimum tilt angle will be 90°. So efficiency will be lower because panels will not be parallel to the sun.

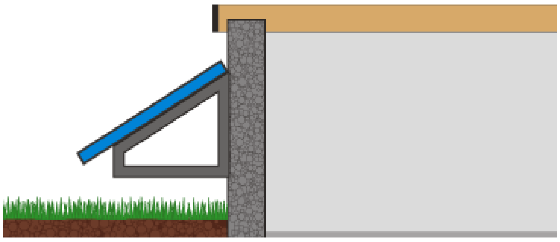


Figure 2.18: Facade Installation (Horizon Renewables, 2013)

2.9.3 Freestanding/Ground Mount Installation

Freestanding/ground mount installation can be done individual, separated from the building. If there is not enough space on the roof, or the orientation of the roof is not looking to the south direction in northern hemisphere and if panels will shaded from the outside factors and there is enough space at the site of the building; panels can be installed by using freestanding design method.

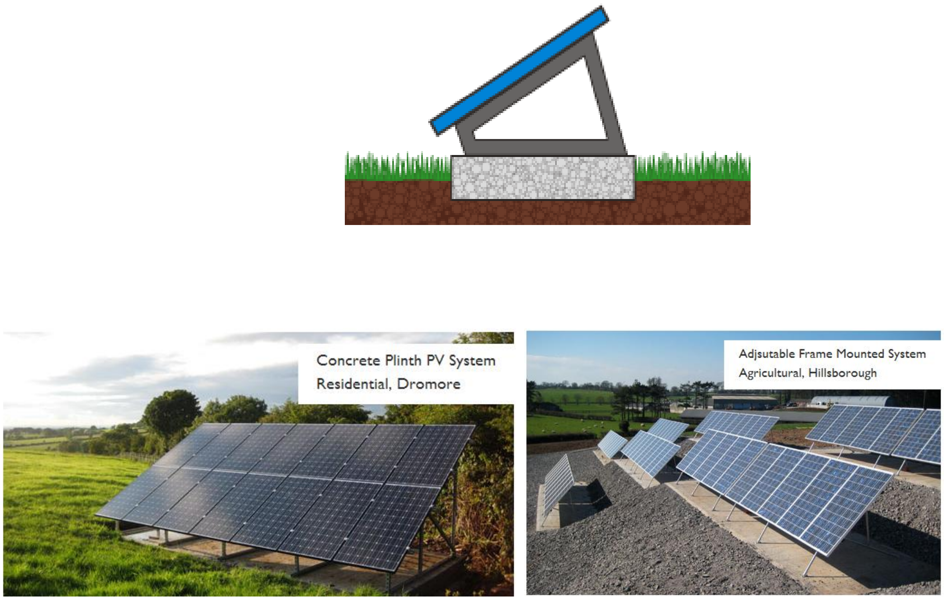


Figure 2.19: Photos show the Freestanding Examples Supported by Profile Carriers (Horizon Renewables, 2013)

2.9.4 PV Integration as a Balustrade

Photovoltaic panels can be designed to the balustrade of the facade. However, panels will be perpendicular to the facade. Therefore, panels will not be parallel to the sun all the time.

Figure 2.20: Example for PV Integration as a Balustrade

Source: http://www.bca.gov.sg/GreenMark/others/pv_guide.pdf

2.9.5 Shading Device

Figure 2.21: Shading Device (Facade) cases

Source: http://www.bca.gov.sg/GreenMark/others/pv_guide.pdf

2.10 Ventilation of PV Panel

Photovoltaic panel ventilation has importance in terms of efficiency in hot climatic regions. On the other hand, panels increase heat transfer at the building in cold climatic regions. Ventilation of PV panels can be divided into two; these are façade and roof ventilation.

2.10.1 Facade Ventilation of PV Panel

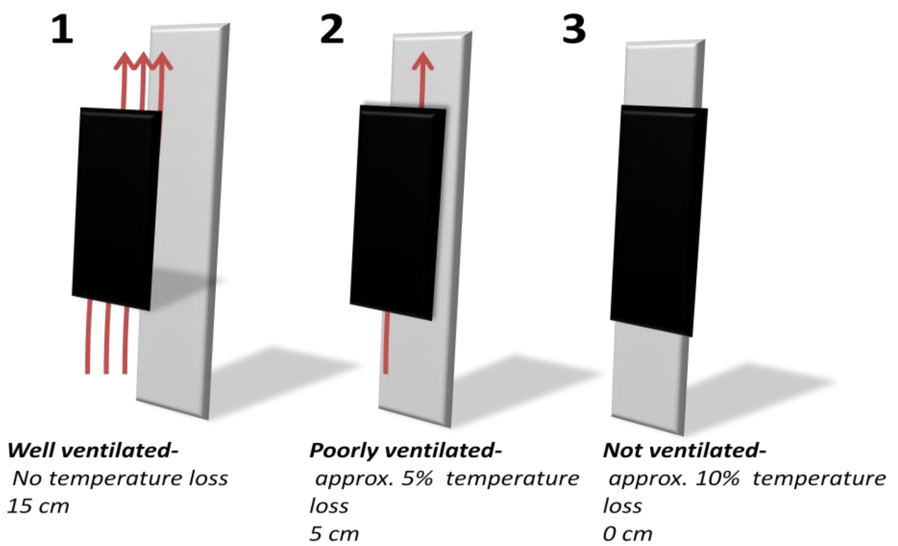


Figure 2.22: Change in Energy Production of PV Module due to Ventilation on Facade Surface (Ozdogan, 2005)

At warmer climates (hot climates), there should be at least 15cm space between facade and the panel for the good ventilation of the panel. On the other, in contrast at colder climates, space between the panel and the façade can provide insulation.

2.10.2 Roof Ventilation of PV Panel

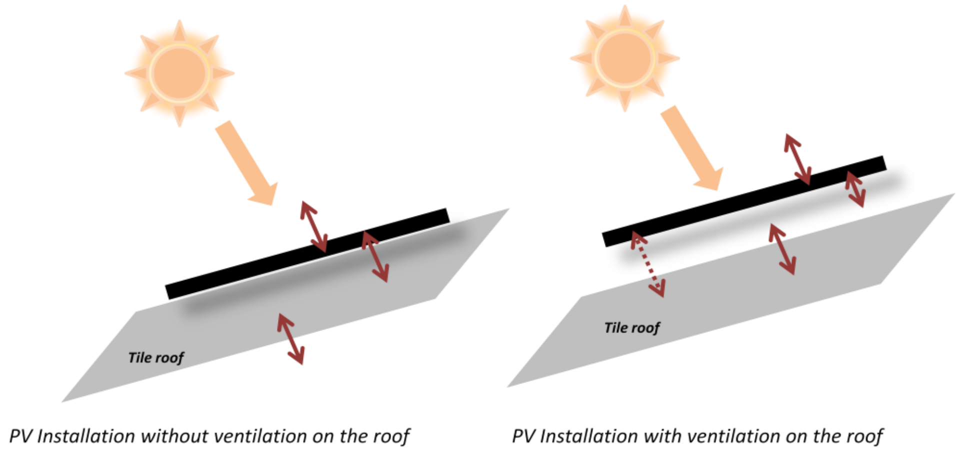


Figure 2.23: Panels on the Roof Surface (Pallardo, 2011)

If there is not enough gap between roof surface and the panel, panel cannot be ventilated in hot climates and this will help panels to be overheated more quickly. On the other hand Barkaszi and Dunlop (2001) argued that, when PV array designed directly on the roof surface, heat transfer can be increased between the roof surfaces. Accordingly, no gap between the panel and the roof surface is an advantage for cold climates.

2.11 Shading of PV panels (Explain the shading types and add pictures)

Distance between the two arrays should be far enough from each other in order to prevent shading. (Multiple rows of rock-mounted PV arrays must be separated for enough to prevent shading)

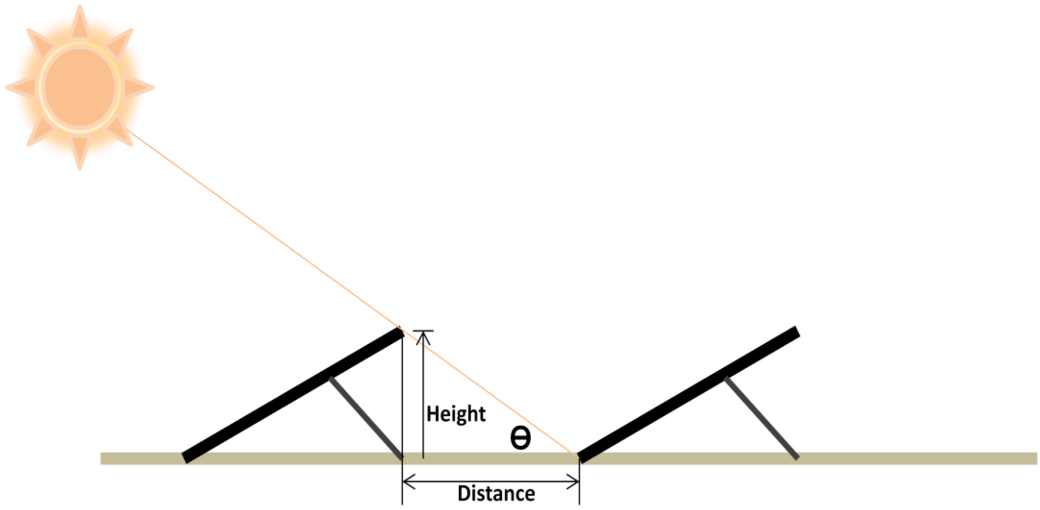


Figure 2.24: Distance between Two Arrays (Brooks, Dunlop, 2012)

Shading types can be divided into five. These are, temporary shading, shading resulting from the location, shading resulting from the building, self-shading and direct shading. (Powerway, 2012)

Figure 2.25: Shading from front panel (Self shading)

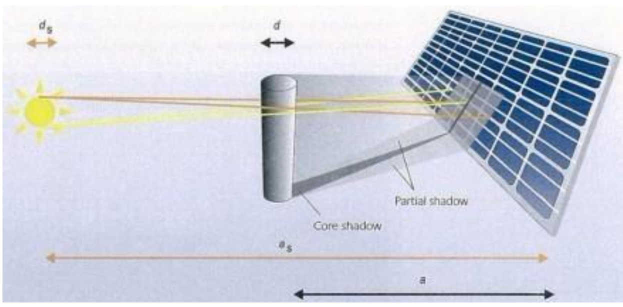


Figure 2.26: Direct shading (Powerway, 2012)

2.12 Sun-tracker Systems

First automatic solar tracking system was presented by McFee in 1975. (Semme and Imamura, 1980) Sun trackers are automatically follows sun from east to west. This following stage can increase yield %30. There are two kinds of tracker systems. These are;

1. Single-axis tracker

This kind of tracker sets the direction from east to west

2. Two-axis tracker (Dual Axis Sun tracker)

On the other hand, two way trackers sets both the direction (from east to west) and the inclined/tilt angles according to the direction of the sun. (Sets direction and angle)

Tracking systems increase gain %30 or more in summer and %15 or less is winter and Sungur (2009) was argued that, “In order to collect the maximum possible daily energy, one solution is to use tracking systems”. (Sungur, 2009)

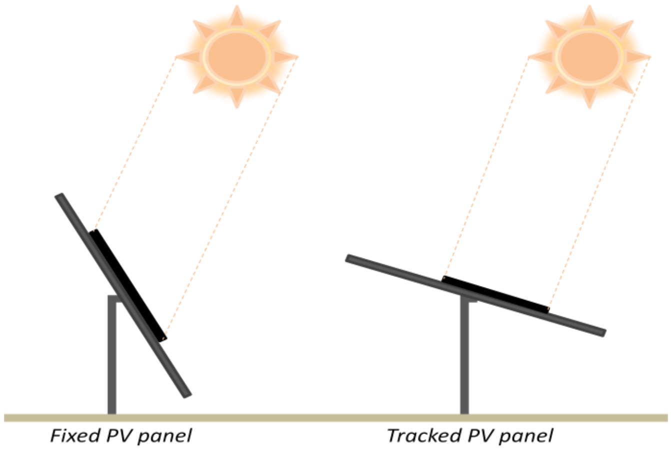


Figure 2.27: Difference of Fixed PV Panel and Tracked PV Panel (Amec, 2011)

On the other hand, according to Rhif (2011), in the locations that sunlight is weak and subsides are not expanded, sun tracker systems can be applied for solving the problems. (Rhif A., 2011) As it can be seen from the Figure 1.27 that at the fixed installation systems;

Sun is not followed from east to west direction. Additionally tilt angle of the panel is not changeable. By the way, energy efficiency will be lost. Sun is not perpendicular to the panel all the time.

Therefore sun-tracker systems increase the energy efficiency. Because tracker system follows the sun from east to west and tilt angle can be changeable. Panel is perpendicular to the sun during the day.

Trackers can be divided in to 2 groups. These are passive trackers and active trackers. Passive tracker systems are working by liquid moves. Liquid is heated by sun and used to move panels. On the other hand, active trackers are working with electric servo motors. Passive systems are cheaper than active systems. (Lee, 2013)

2.13 Organization of the Panels

2.13.1 Landscape Organization (Horizontal Organization)

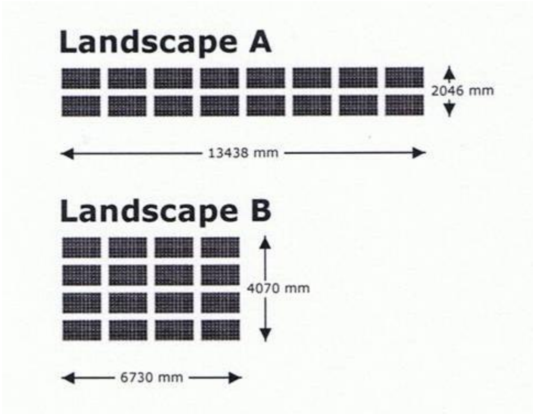


Figure 2.28: Landscape panel organization (Solar help, 2010)

As seen from Figure 2.28, photovoltaic panels are connected to each other horizontally.

2.13.2 Portrait Organization (Vertical Organization)

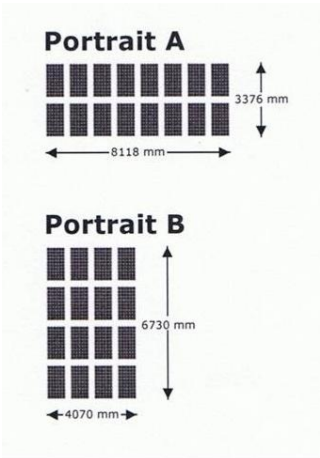


Figure 2.29: Portrait panel organization (Solar help, 2010)

On the other hand, when panels are connected to each other vertically, they are organized portrait.

2.14 Cost of Poly-crystalline and Mono-crystalline Panels in Turkish Republic of Northern Cyprus

An interview was done with Osman Zorba who is director at Neoaura Technologies and Energy Solutions Ltd. in Turkish Republic of Northern Cyprus. According to director's idea, poly-crystalline and mono-crystalline silicon panels are mostly preferred cell types in Northern Cyprus.

250Wp Poly-crystalline cell type 1 module/panel cost is 310 Euro. (60 cells)

255Wp Mono-crystalline cell type 1 module/panel cost is 335 Euro. (72 cells)

265Wp Mono-crystalline cell type 1 module/panel cost is 355 Euro. (72 cells)

Inverter: 4,600 Euro (10kWp Panels), 1kWp is 460 Euro

6 watery batteries: 1,100 dollar

At the Cyprus' climatic conditions, watery battery (deep cycle) is preferred. Gel battery is preferred at colder climates because gel retains the heat and heat changes more slowly.

Calculation for a house that spends 500 TL at each month:

16 poly-crystalline cell type panels needed.

250 Watt x 16 panels = 4,000 Watts (4 kWp)

16 panels x 310 Euro= 4,960 Euros (for 16 panels)

460 Euro x 4kW = 1,840 Euros (for 1 inverter)

24 battery = 4 x 1,100dollar = 4,400dollar = 3,344 Euros

Total price: 4,960 + 1,840 + 3,344 Euros = 10,144Euros =25,360TL

(Off-grid System)

Total price: 4,960 + 1,840= 6,800Euros = 17,000TL

(On-gird System)

Chapter 3

ANALYSIS OF PV PANELS IN HOT AND COLD REGIONS

3.1 Method of Analysis

At Chapter 3, case studies that were selected from both hot and cold climate regions which were installed before will be evaluated according to data collected in Chapter 2. Site visits were done to case studies selected from Turkish Republic of Northern Cyprus (TRNC). During the evaluation of the systems, measurements were performed in order to found out the required angles and dimensions, necessary information were learned from building owners and from companies that done the installations of the PV panels and photos are taken to support the evaluation of the case studies.

Totally, 26 case studies were selected for both hot and cold climate regions. Half of the total case studies were from hot climates. 12 of case studies were from Turkish Republic of Northern Cyprus and only 1 case study is from California, USA because of accurate project and latitude of the location is similar with Cyprus. Also, as a Turkish Cypriot, hot climate case studies were selected for giving contribution to TRNC for improve itself in this field.

On the other hand, 13 case studies were selected from several cold climatic regions. One case study is selected from Serbia, Canada and Germany and 10 of the projects were from UK.

During the evaluation of the whole cases installed in both hot and cold climate regions, systems were evaluated according to this analysis method; hemisphere (location) of the installed system, climate type of the region, panel cell type, orientation (direction), tilt angle, location/position of panels, supporting elements, shading, ventilation and panel organization.

3.2 Case Studies for Hot Climate

Hot climate case studies are selected both from Turkish Republic of Cyprus and America. Case studies are Cengiz Köy Water Pump System, Erson Hoca's Organic Farm, Ciftlik Evi, Ekrem Gunes Solar Ltd. Office, Cemsa Sporting Center, Aspava Restaurant, Dereli Student Dormitory, Development and Restructuring of the Energy Infrastructure Solar Power Plant, 1001 Cesit Shopping Center, Levent Dagasan's House, House from Gonyeli and Lakeside Dairy in Harford.

3.2.1 Evaluation of Cengiz Koy Water Pump System

Location of Cengiz Köy Water Pump System is located in Cengiz Köy. Aim of the installation of system is for water pumping (deep wheel system). Year of the installation is done in 2010. 23 tones of water is pumped per hour under from 35meters by deep wheel system. By the way, average 200 tones of water pumped up in 1 day. System power is 5,0kWp (Aciman, 2012) and 52 numbers of thin-film amorphous cell is used. 1 array is created with 52 panels. Installation location/position is done freestanding (on the site). Total space area is calculated as 60m². At the same time, current tilt angle of array is calculated as 29.25° by using right triangle trigonometric mathematical calculation. Array is oriented to South-East direction.

Table 8: Evaluation of Cengiz Koy Water Pump System

Characteristics	
Name of the Project	Cengiz Köy Water Pump System
Hemisphere (Location)	Northern Hemisphere
Climate Type	Hot climate
Panel Cell Type	Thin-film Amorphous silicon
Orientation	South-east direction
Tilt Angle	29.25°
Location/Position of Panels	Ground mount/freestanding
Supporting Elements	Profile carriers
Shading	A part shaded by tree
Ventilation	Sufficient
Panel Organization	Landscape

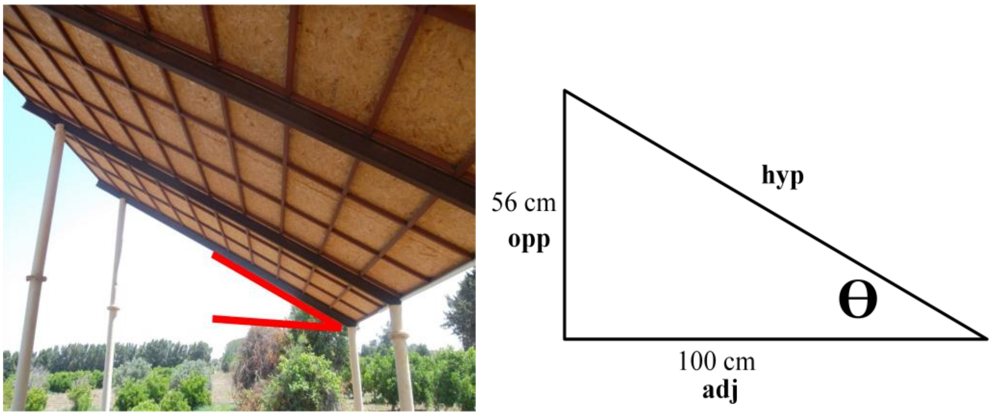


Figure 3.1: Photo Taken from South-West Direction and the Calculation of the Current Tilt Angle (Taken by author)

Angle = tan -1 (56/100)

Angle = tan -1 (0, 56)

Angle = 29.25°

Figure 3.2: Photos are Showing South-East View and South-West View (Taken by author)

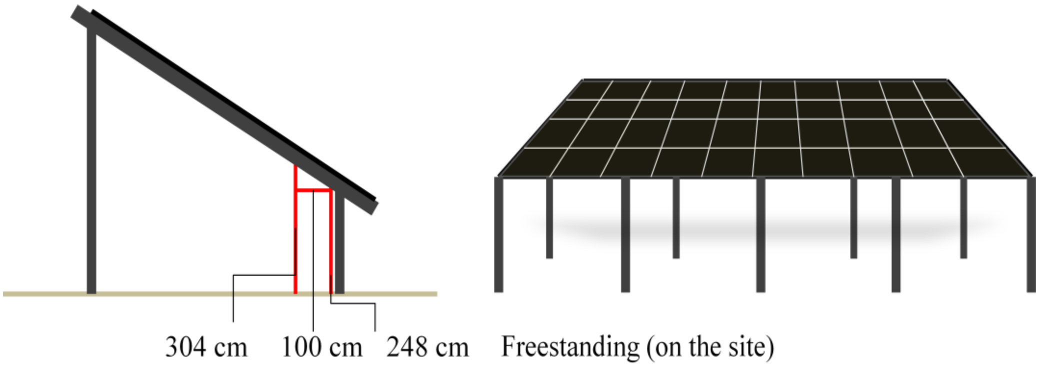


Figure 3.3: South-West Elevation and South-East Elevation of the Array (Drawn by author)

Figure 3.4: Trees Shading Panels (Photo Left) and the Space between the Panels and Supporting Element (Photo right) (Taken by author)

It can be seen from the Figure 3.4 that trees shading the left side of the panels. A shadow on the array can substantially cut power output. At the same time, the space between the panels and the supporting element is 4 cm.

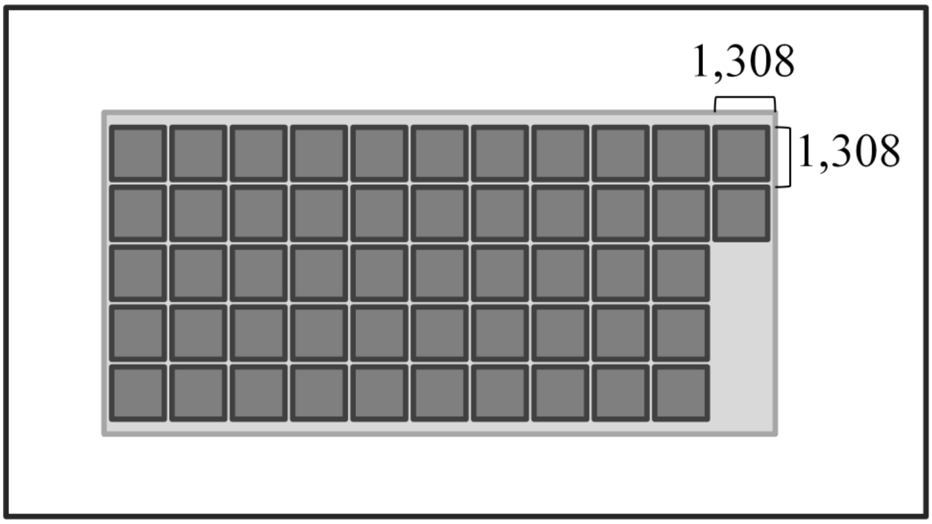


Figure 3.5: Top View of the Site and Orientation of the Panels (Drawn by author)

Horizontal organization of the panels can be observed from Figure 3.5. Therefore, type of organization is landscape organization.

3.2.1.1 Suggestions for the Current System

1. Distance between the panels and the supporting element is not enough for good ventilation because Cyprus is in the hot climate zone. By the way; distance between the panels and the supporting element should be minimum 10cm.

2. Array can be designed away from the trees because they cause nearby shade and this kind of shading can cause a decrease at energy efficiency.

3. Panels should be cleaned in order to increase the efficiency and for decreasing the temperature of the panels.

4. Panel’s orientation is not correct. (South-east). By the way there is enough space at the site so the direction of the array should look to the south direction.

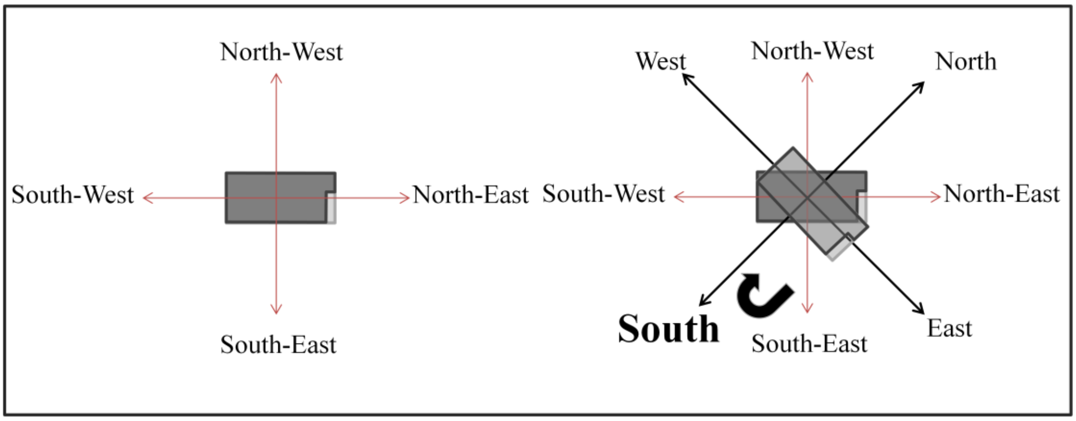


Figure 3.6: Current Orientation and the Correct Orientation of the Array. (Drawn by author)

Array should be rotated 45° from south-east to south direction that can be seen from Figure 3.6

5. Cell type and tilt angle selection is noted as correct. Amorphous thin film cell type has good efficiency in the hot climatic zones.

As an alternative suggestion for Cengiz Köy Water Pump system, single-axis sun tracker system can be used to increase the energy efficiency.

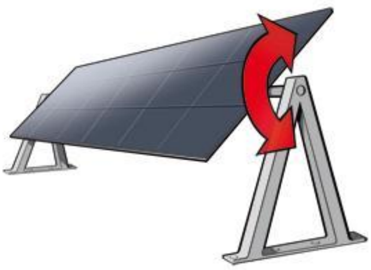


Figure 3.7: Single-axis Sun-tracker System (Solar choice, 2010)

There are 52 amorphous thin film panels at 1 array at the existing system. It can be suggested that there can be 18 amorphous thin film panels at 1 array. For this reason 3 arrays needed for the suggested system.

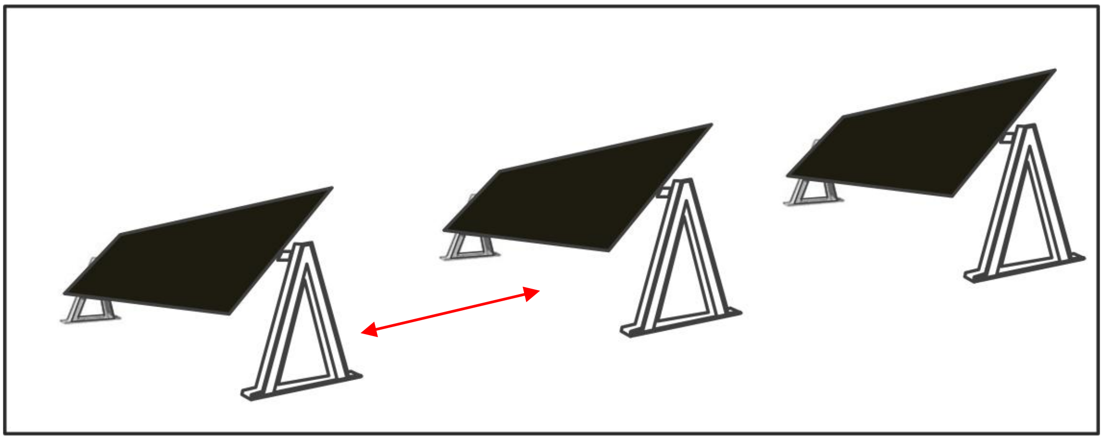


Figure 3.8: Horizontal Orientation of the Arrays (drawn by author)

It can be suggested that; arrays can be oriented horizontally on the site. (Figure 3.8) Each array can include 18 amorphous thin-film panels. There should be enough space between two arrays (5m) in order not be shaded both from each other and from the trees.

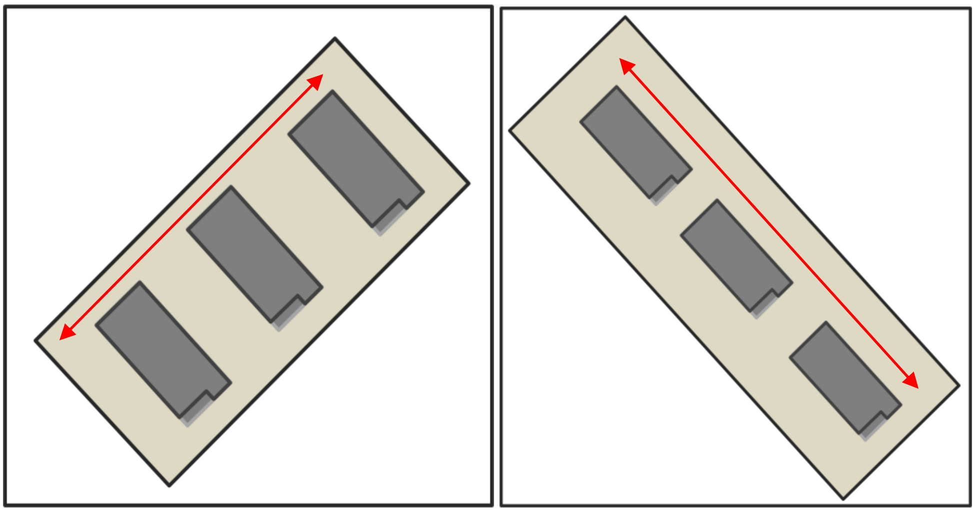


Figure 3.9: Vertical Orientation of the Arrays (left) and Horizontal Orientation of the Array (right) (Drawn by author)

3.2.2 Evaluation of the System Erson Hoca's Organic Farm

Location of Erson Hoca's Organic Farm is in Yesilırmak. Aim of the installation is to produce electricity. Reason of the installation is because of city electricity is not provided. By the way, off-grid system is installed. In the off-grid system, batteries are needed as an extra. System power is 12.20kWp and 65 mono-crystalline cell type panels installed. 65 mono-crystalline panels are mounted on 2 arrays. The array that is at the back includes 32 panels and the one that is at the front includes 33 panels. Installation location/position is done freestanding (on the site). Total space area is calculated as 165,11m². The back array is on 40,448m² and the front array is on 41,712m². The space between the two arrays is calculated as 82,95m². At the same time, current tilt angle of array is calculated as 31.14° by using right triangle trigonometric mathematical calculation. Array is oriented to South direction. 1 panel dimension is 80cmx158cm and panels were organized landscape.

Table 9: Evaluation of Erson Hoca's Organic Farm

Characteristics	
Name of the Project	Erson Hoca's Organic Farm
Hemisphere (Location)	Northern Hemisphere
Climate Type	Hot climate
Panel Cell Type	Mono-crystalline silicon
Orientation	South direction
Tilt Angle	31.14°
Location/Position of Panels	Ground mount/freestanding
Supporting Elements	Profile carriers for ground mount
Shading	No shade
Ventilation	Good
Panel Organization	Landscape

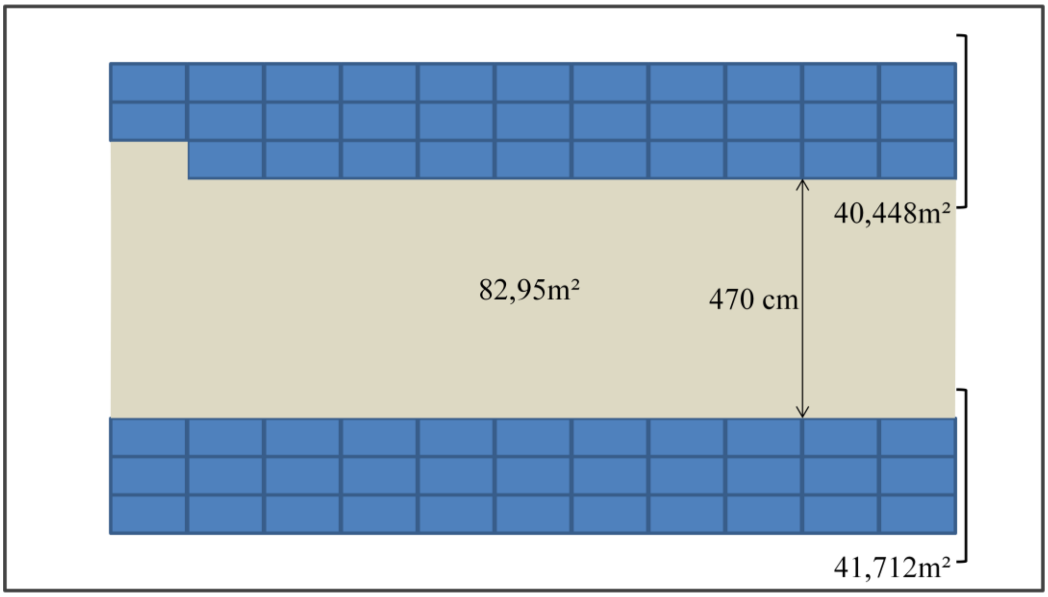


Figure 3.10: Top View of the Site (Drawn by author)

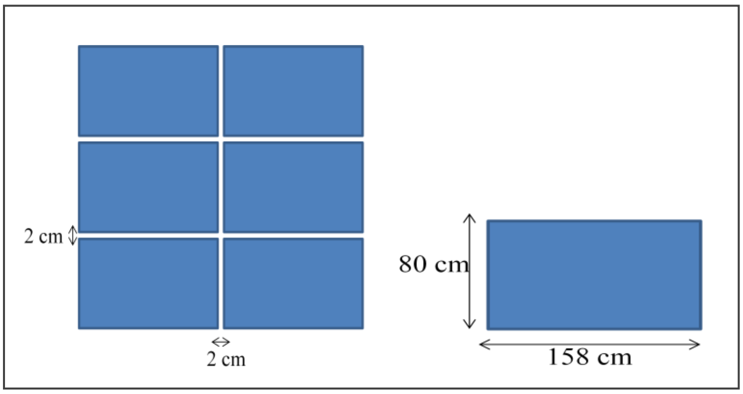


Figure 3.11: Distance between Two Panels and the Dimension of One Panel (Drawn by author)

Figure 3.12: Back Array and Side View of the Back Array (Taken by author)

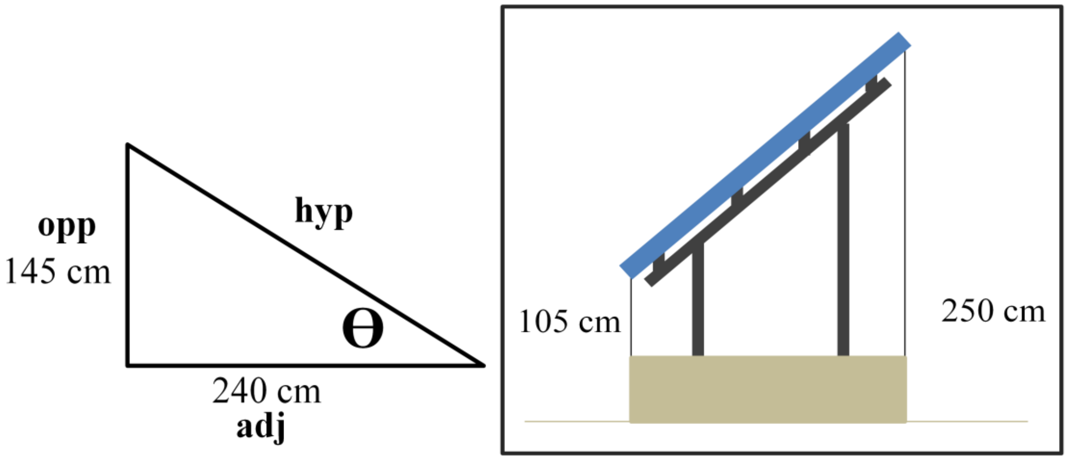


Figure 3.13: Calculation of Current Tilt Angle (Drawn by author)

Angle = tan -1 (145/240)

Angle = tan -1 (0,604)

Angle = 31.14°

Figure 3.14: Supporting Type of the System (Antaris Solar Germany, 2012)

Figure 3.15: Photo show 24 Numbers of Batteries (Taken by author)

Supporting type is ground mounted system. (Figure 3.14) By the way, profile carrier with reinforced concrete foots were selected.

3.2.2.1 Suggestions for the Current System

1. Tilt angle and ventilation of panels are designed correctly after making the calculations.

2. On the other hand, distance between two arrays is applied correct. No shading is observed from front panel like self shading. However tall trees can cause nearby shade that can be seen from Figure 3.12

3. Mono-crystalline silicon panel selection can decrease the efficiency at overheating conditions. However there has no more chance to install amorphous thin-film cell type panels because there is not enough space for thin-film installation.

If alternative suggestion is given, single-axis sun-tracker system selection can increase the energy efficiency.

3.2.3 Evaluation of Ciftlik Evi Restaurant

Location of System is in Gaziveren and aim is to provide electricity from PV panels system because electricity of building is provided from the house that is next to the restaurant. System power is 4,94kWp and 26 mono-crystalline cell type panels installed. Installation is done on the roof. Each panel is calculated as 1,28m². By the way; total installation space is calculate as 33, 28 m². Current tilt angle is calculated as 10° and the orientation is done to the south direction.

Table 10: Evaluation of Ciftlik Evi Restaurant

Characteristics	
Name of the Project	Ciftlik Evi Restaurant
Hemisphere (Location)	Northern Hemisphere
Climate Type	Hot climate
Panel Cell Type	Mono-crystalline silicon
Orientation	South direction
Tilt Angle	10°
Location/Position of Panels	On-roof
Supporting Elements	Profile carriers
Shading	Shade from trees
Ventilation	Not sufficient
Panel Organization	Portrait

Figure 3.16: Photos are taken from Over the Roof (taken by author)

Installation is not enough to provide all electricity (x10) ten times more panel system is needed to provide the all electricity of the building. Installation cost is provided by the grant program (%75) and %25 cost of the installation will be given by the owner. Direction is not exact south and there is not enough tilt angles to capture sun directly so there is 1kWh lost.

Figure 3.17: Outside View of Building (Taken by author)

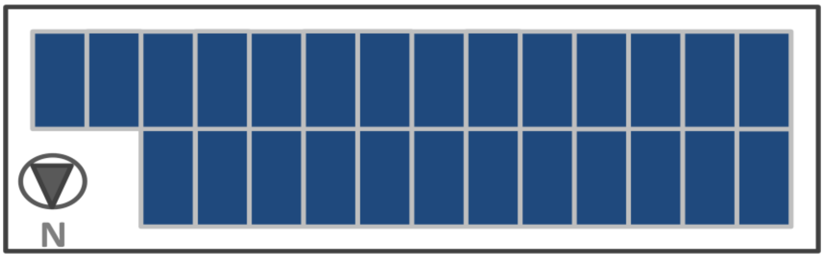


Figure 3.18: Top View of the Panels (Drawn by author)

3.2.3.1 Suggestions for the Current System

1. Gap between the panel and the roof should be minimum 10cm. But it is only 6-7cm. Panels are not well ventilated.

2. Tilt angle is not enough. Angle of the roof is calculated as 10. Slope of the roof is used as tilt angle. Extra 18° is needed to get the maximum efficiency.

3. Not enough space to install thin-film amorphous cell type panels. Mono-crystalline cell type panels installed on 33,28m². However 52,3m² is needed for amorphous thin-film.

4. Panels can be installed on the ground because there is enough space.

5. Orientation is done correct. (South direction)

As an alternative suggestion for Ciftlik Evi Restaurant; panels cannot be oriented on the facade surface of building because there are high trees planted to the south direction. Additionally, there are windows and doors. Therefore, high trees will cause shading to the panels. Secondly, there is enough space at the garden of restaurant. If owner of the restaurant wishes to install panels on the ground (by using free standing/ ground mount method) they will get more efficiency compared to the current system.

3.2.4 Evaluation of Ekrem Gunes Solar Ltd. Office

Location of the system is in Yenikent/Gonyeli. Aim of the installation is done for electricity production. System power is 4.32kWp. 24 numbers of mono-crystalline cell type panels were used with 2 numbers of single axis sun-tracker systems. Installation is done by using freestanding (on ground) design principle. Optimum tilt angle is adjusted to 30°. Because of the single axis sun-tracker system there is not a fixed tilt angle. By the way, tracker system follows sun's direction from east to west.

Table 11: Evaluation of Sun-tracker System (Ekrem Gunes Solar Ltd. Office)

Characteristics	
Name of the Project	Sun-tracker System (Ekrem Gunes Solar Ltd. Office)
Hemisphere (Location)	Northern Hemisphere
Climate Type	Hot climate
Panel Cell Type	Mono-crystalline silicon
Orientation	Single-axis sun tracker (sets direction)
Tilt Angle	30°
Location/Position of Panels	Ground mount/Freestanding
Supporting Elements	Profile carriers
Shading	No shade
Ventilation	Sufficient
Panel Organization	Landscape

Figure 3.19: Photos are showing 24 Mono-crystalline Cell Type Panels on 2 Single-axis Sun-tracker System (Ekrem Güneş Solar, 2013)

Sun-tracker provides to get %30 and %40 more efficiency. With the use of sun tracker; it can be observed 9 hours insolation but with the fixed used of installation 5 hours insolation is observed. In 1 hour, 3kWh is produced by the way with the use of sun-tracker system; 27kWh energy is produced in 9 hours. Lastly, this kind of design is sufficient so no need for extra suggestions.

3.2.5 Evaluation of Cemsa Sporting Center (Karting)

Cemsa Sporting Center is located in Nicosia. Installation of the system was completed at 22 March 2012. System power is calculated as 14, 82kWp. 78 numbers of mono-crystalline cell type panels installed on the flat roof. Panels are supported with plastic tubs. Each panel’s power is 190 Watts. Because of the standard degree of the plastic tub (Figure 3.21); tilt angle is calculated as 25°.

Table 12: Evaluation of Cemsa Sporting Center

Characteristics	
Name of the Project	Cemsa Sporting Center
Hemisphere (Location)	Northern Hemisphere
Climate Type	Hot climate
Panel Cell Type	Mono-crystalline silicon
Orientation	South-east
Tilt Angle	25°
Location/Position of Panels	Flat roof
Supporting Elements	Plastic tub
Shading	No shade
Ventilation	Insufficient
Panel Organization	Landscape

Figure 3.20: Photos show the Empty and Not Organized Plastic Tubs (Before) and Organized System (After) (Ekrem Güneş Solar, 2013)

Landscape panel organization was observed from the Figure 3.20 in order to use the current space well.

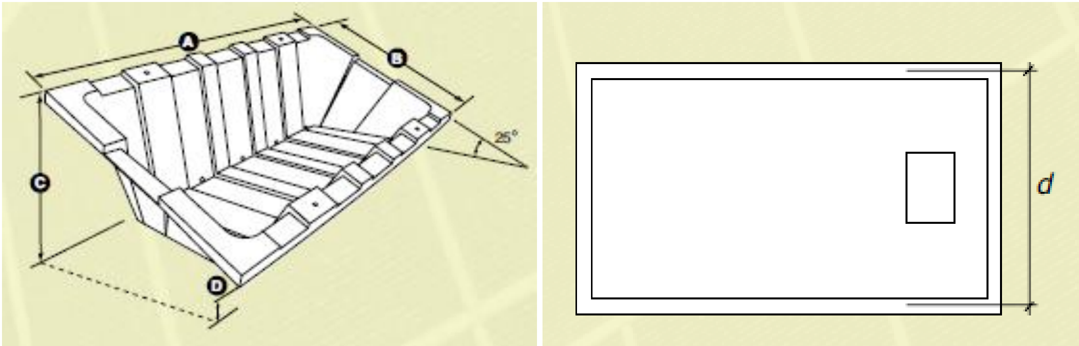


Figure 3.21: Dimensions of Plastic Tubs (Antaris Solar Germany, 2012)

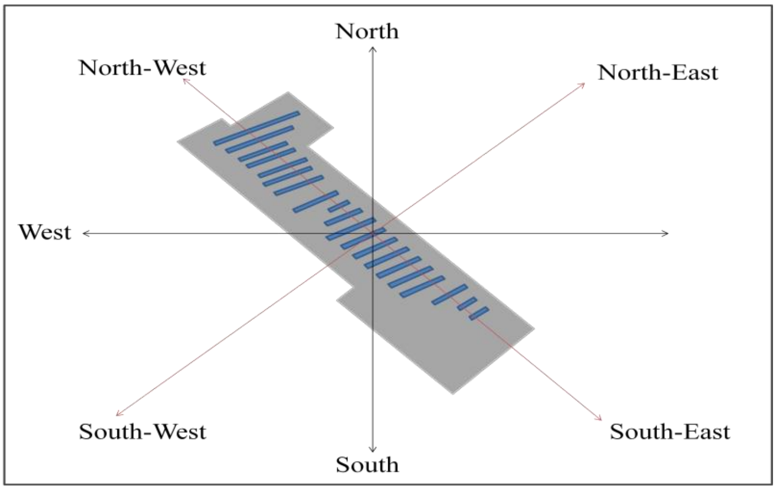


Figure 3.22: Current Orientation and Organization of Panels (Drawn by author)

It can be seen from Figure 3.22 that panels are oriented to the direction of south-east. There is not enough space to orient to the south direction because of the location of the existing building. Panels are designed as 20 rows. Each row is organized different. Certain row includes 2, 3 and 4 plastic tubs according to the available space.

3.2.8.1 Suggestions for the Current System

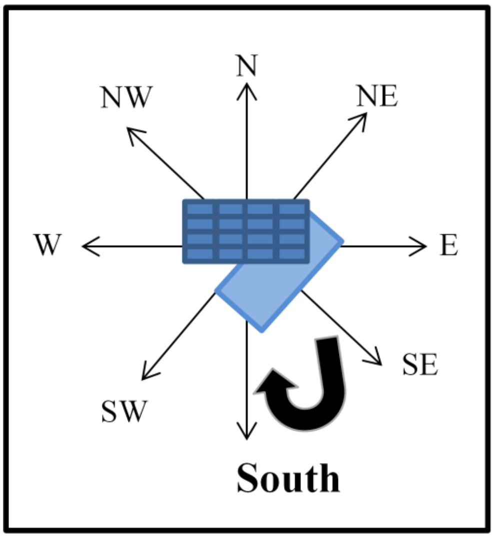


Figure 3.23: Panels are rotated from South-east Direction to South (Drawn by author)

1. Orientations of the panels are looking to the south-east direction. By the way, energy efficiency decreases. So, panels can be oriented the south direction. Panels should be rotated 45° to the left. (Figure 3.23) this kind of panel design can help to an increase at energy efficiency.

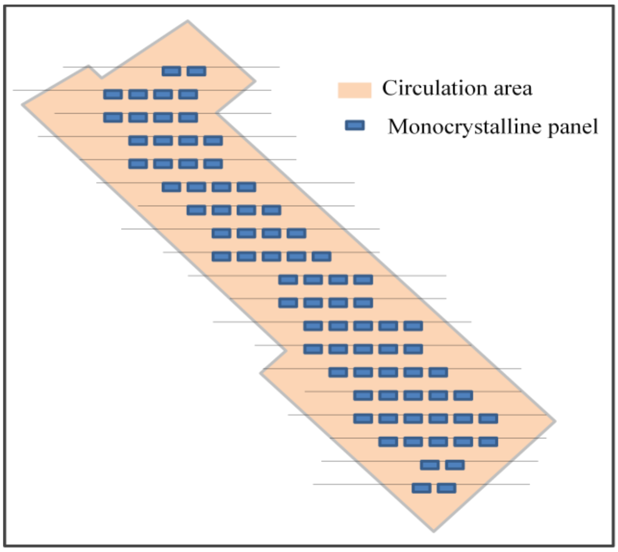


Figure 3.24: Arrays Oriented to the South Direction (Drawn by author)

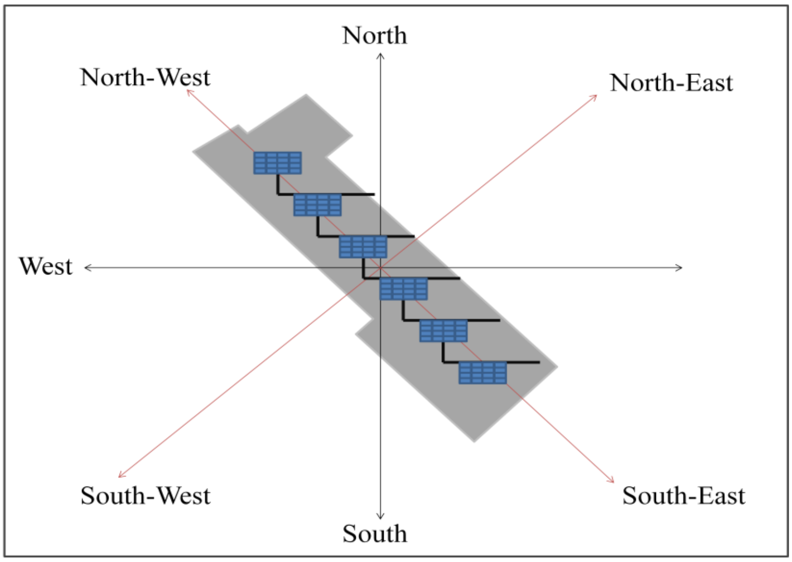


Figure 3.25: Top View of Alternative Suggestions both Single Sun-tracker and Fixed Arrays (Drawn by author)

1. Alternative single axis sun-tracker suggestion on the roof oriented to the south direction.
2. Alternative fixed arrays suggestion on the roof oriented to the south direction.

As a suggestion 16 panels are combined on 1 array. There is enough space for 6 arrays with 16 panels each. This means that there is enough space for 96 panels.

Each array is calculated as 25, 6 m^2. By the way, total meter square of arrays are calculated as 153,6m^2. While designing sun-tracker or fixed systems. It is important not to get shade from the front array. By the way, there should be enough space between the two arrays. This space is approximately equals to the meter square of 1 array. So, there should be 4m distance between the two arrays that can be seen from Figure 3.26.

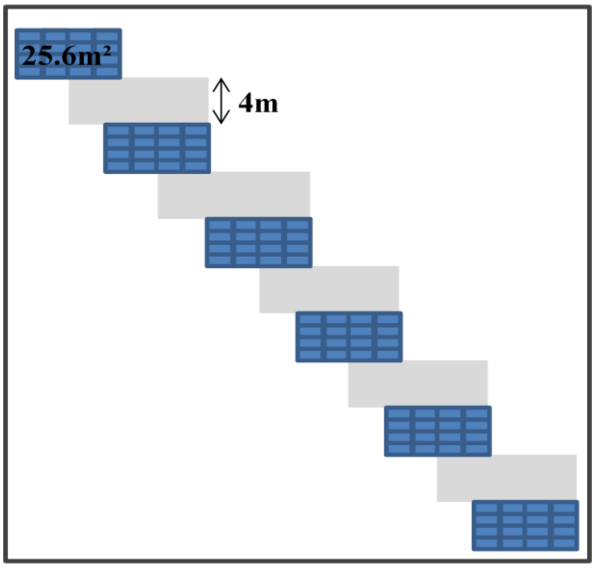


Figure 3.26: Distance between Two Arrays (Drawn by author)

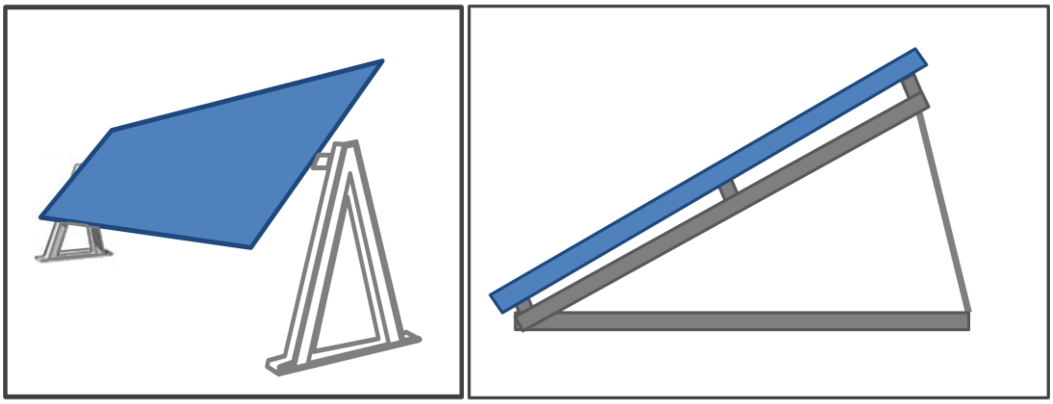


Figure 3.27: Single-axis Sun-tracker and Fixed Array (Drawn by author)

The location of the two types of suggestions will be on the roof space. Single-axis sun tracker and fixed array can be seen from Figure 3.27. Since there is not slope of roof, the appropriate tilt angle can be given by the support elements. (Profile carriers)

3.2.6 Evaluation of Aspava Restaurant

Aspava restaurant is located in Yedidalga. Aim of the installation is to produce one part of restaurants electricity need. System power is 5,04kWp and 21 numbers of poly-crystalline cell type panels are used. System is installed on the tile roof and oriented to the south direction. Space area is calculated as 34,65m². 1 panels meter square is 1,65m².Current tilt angle is calculated by using the right triangle trigonometric mathematical calculation. 13.39° is found at the end of the calculation. Installation cost is noted as 40,000 TL.

Table 13: Evaluation of Aspava Restaurant Organic Farm

Characteristics	
Name of the Project	Aspava Restaurant
Hemisphere (Location)	Northern Hemisphere
Climate Type	Hot climate
Panel Cell Type	Poly-crystalline silicon
Orientation	South direction
Tilt Angle	13.39°
Location/Position of Panels	On-roof
Supporting Elements	Profile carriers
Shading	No shade
Ventilation	Not sufficient
Panel Organization	Portrait

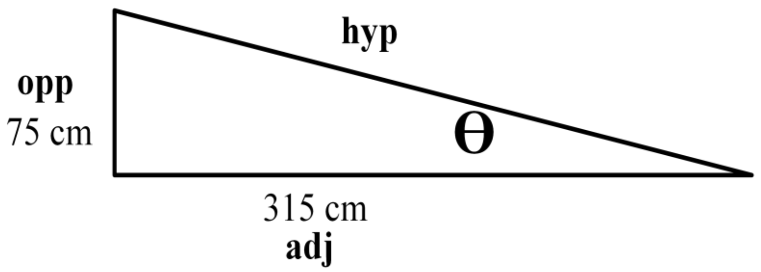


Figure 3.28: Calculation of Current Tilt Angle (Drawn by author)

Angle= tan -1 (75/315)

Angle= tan -1 (0,238)

Angle = 13.39°

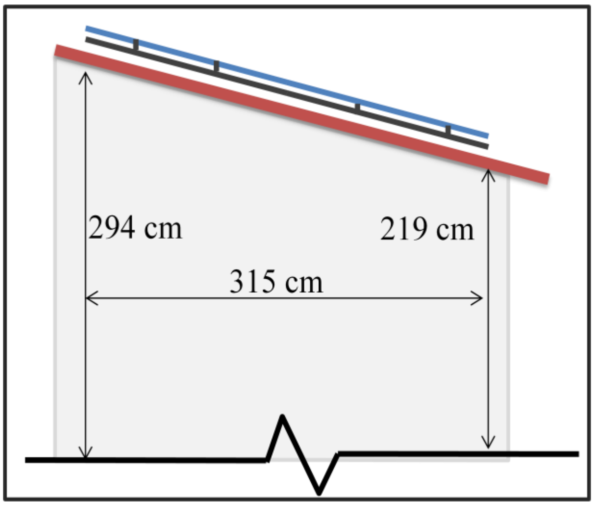


Figure 3.29: Panels at the Partial Part of the Building (Drawn by author)

Figure 3.30: Connection Detail of the Support (Brooks, Dunlop, 2012)

Panels are supported with the roof hooks and the profile carriers that can be seen from the Figure 3.30. First of all, tiles are removed from the roof and then roof hooks are mounted in order to install the profile carriers on the roof hooks. By the way, a carrier system is created in order to mount the panels on the roof.

Figure 3.31: Location/position of the Panels (Taken by author)

The distance between the panel and the roof is not enough for good ventilation. The distance is calculated as 7 cm. At the same time portrait panel organization can be seen from Figure 3.31.

3.2.6.1 Suggestions for the Current System

1. Distance between the panel and the roof should be minimum 10cm. But it is only 7cm. (Not well ventilated) How should be the distance between panels and the roof surface is shown at Figure 3.31.

2. Tilt angle is not enough. Angle of the roof is calculated as 13.39°. Slope of the roof is used as tilt angle. Extra 15° is needed to get the maximum efficiency.

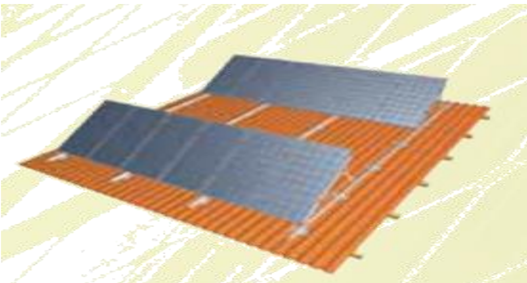


Figure 3.32: How should be the integration to the Current Facade (Antaris Solar, 2012)

3. Not enough space to install thin-film amorphous cell type panels. Polycrystalline cell type panels installed on 34,65m². However 48m² is needed for amorphous thin-film to provide 5, 04kWp.

4. Orientation is done correct. (South direction)

As an alternative suggestion, panels can be integrated on roof, at the facade and on the ground.

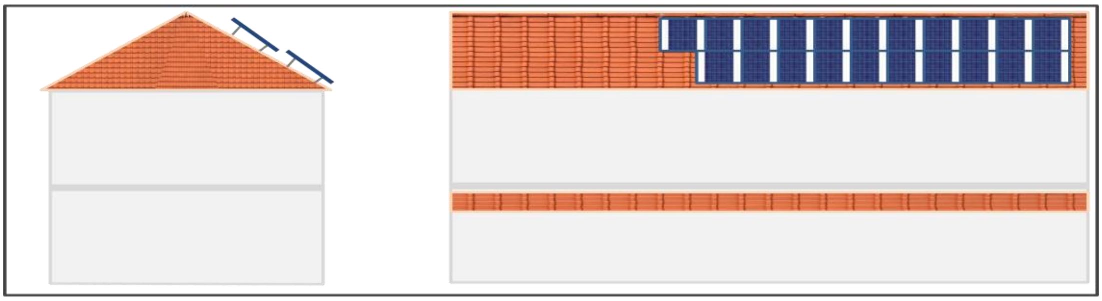


Figure 3.33: Side View and the Front View of the Roof Application by using the Current System Power and the Orientation. (Drawn by author)

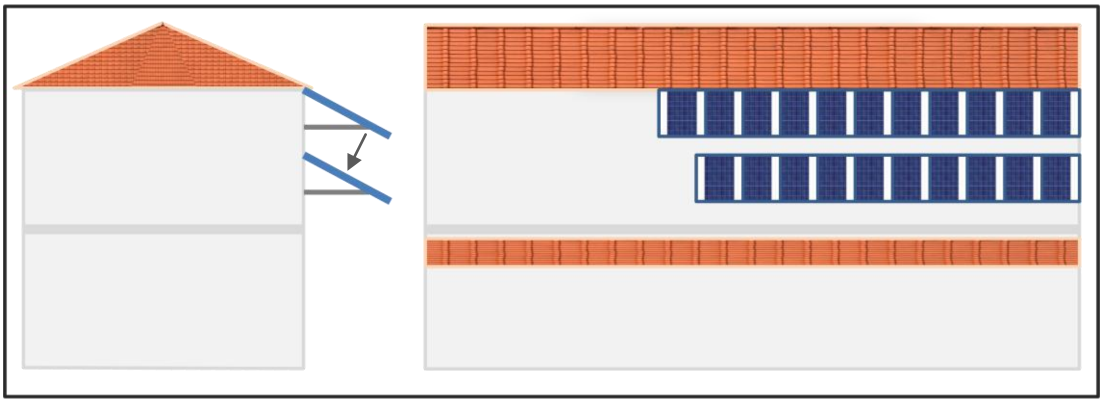


Figure 3.34: Side View and the Front View of the Facade Application by using the Current System Power and the Orientation. (Drawn by author)

Panels cannot be applied in two rows parallel to each other like in the Figure 3.34 because the row at the upper can shade the row at the below. By the way; panels can be applied to the facade like in the Figure 3.35. But there is not enough space at the facade so one row is not enough to install 5,04kWp system power. With this kind of facade application 4 panels remain missing.

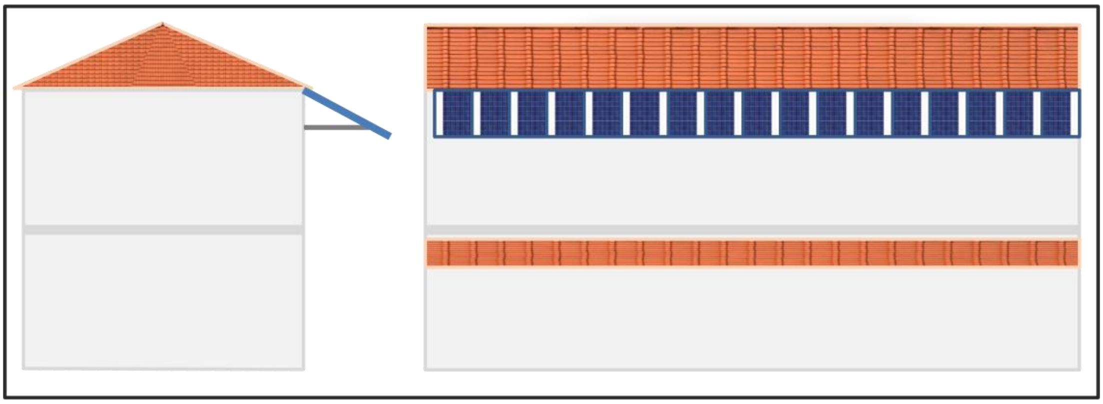


Figure 3.35: Suggestion for Facade (Drawn by author)

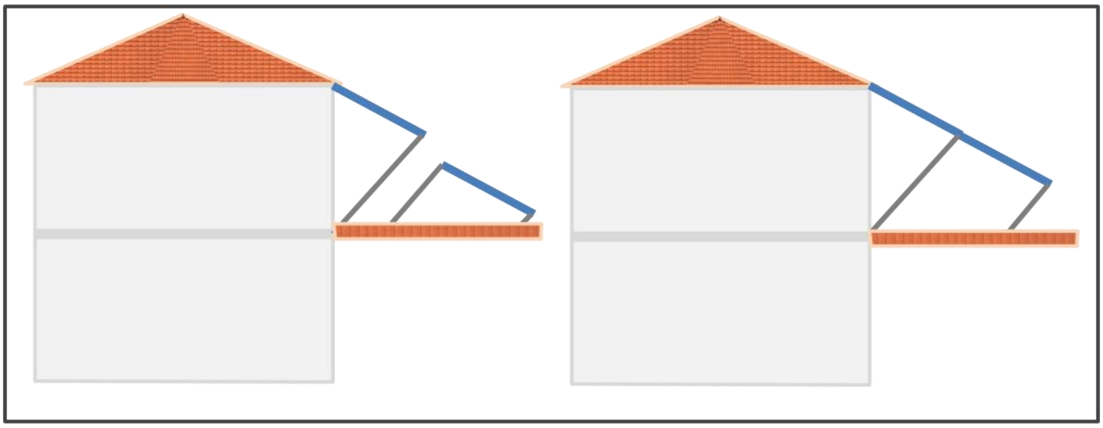


Figure 3.36: Alternative Suggestions for Facade Application (Drawn by author)

Panels can be applied to the facade seen in Figure 3.36. There is enough tilt angles, ventilation and no shading from neighbor buildings and trees.

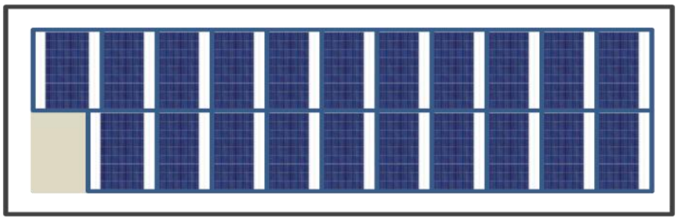


Figure 3.37: Ground Mounts Application Suggestion (Drawn by author)

3.2.7 Evaluation of Dereli Student Dormitory

Location of the system is in Yenikent/Gonyeli. Aim of the installation is to increase the interest of students and produce cheaper electricity. System power is 38,88kWp and 162 poly-crystalline cell type panels are installed. Panels are located on the flat roof using steel carriers. Installation space is calculated 260 m². On the other hand; tilt angle is calculated as 30°.

Table 14: Evaluation of Dereli Student Dormitory

Characteristics	
Name of the Project	Dereli Student Dormitory
Hemisphere (Location)	Northern Hemisphere
Climate Type	Hot climate
Panel Cell Type	Poly-crystalline silicon
Orientation	South direction
Tilt Angle	30°
Location/Position of Panels	Flat-roof
Supporting Elements	Profile carriers
Shading	No shade
Ventilation	Sufficient
Panel Organization	Landscape

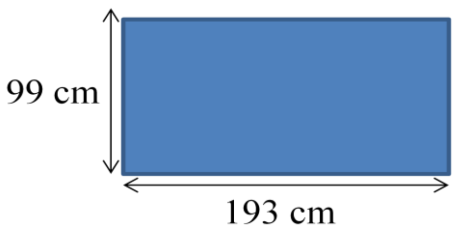


Figure 3.38: Dimension of One Portrait Panel (Drawn by author)

System type is on-grid system. Electricity that is produced by panels is used at the day time. Users have to use the grid system (KIB-TEK) at the night times. Building is used as a dormitory. This kind of cheap electricity increases the interest of students to stay in “Dereli Student Dormitory” because owner of the dormitory sells the electricity that is produced by the panels cheaper. Calculations are done considering the maximum electric usage. At the following days; 37 more panels will be added to the existing system. So, system power wills be increased to be 47,88kWp.

Figure 3.39: Photo shows the View from a Distance (Ekrem Güneş Solar, 2013)

Figure 3.40: Photos show the Distance Between the Two Arrays (Ekrem Güneş Solar, 2013)

As system is evaluated because of the orientation, tilt angle and the correct distance between the panels that no shade is observed that current installation is observed as a successful design. There is lack of space at the existing roof surface and at the garden of the dormitory for installing more efficient cell type panels like amorphous thin-film cell type panels.

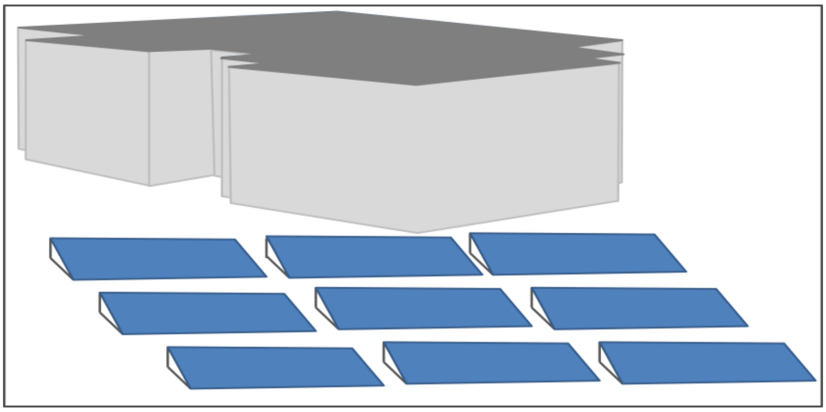


Figure 3.41: Ground mount /Freestanding Suggestion for Dormitory (Drawn by author)

Figure 3.41 is a suggestion that, if there is enough space at the garden of dormitory looking to the south direction, panels can be oriented to south direction by using nine single-axis sun-tracker systems. Each array will include 18 numbers of poly-crystalline panels for generating 38,88kWp. Sun-tracker system will be more efficient compared to the current fixed system. However, there has no more space to install ground mount system.

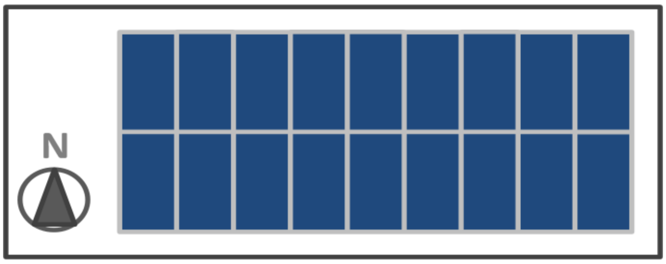


Figure 3.42: Top View of One Array for Sun-tracker System (Drawn by author)

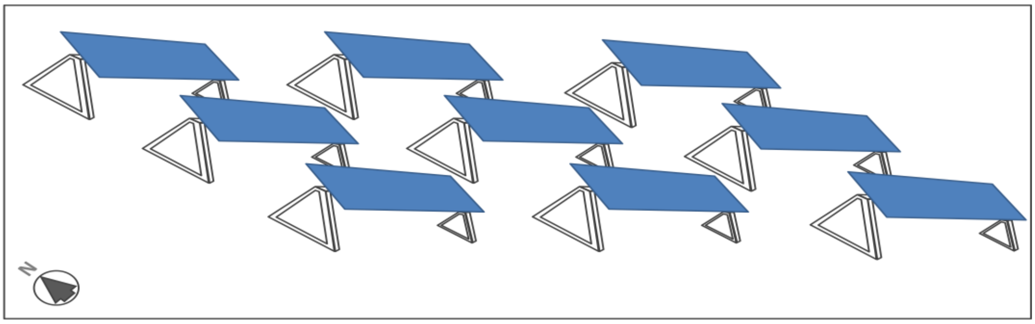


Figure 3.43: Nine One-axis Sun-tracker System Suggestions for Dormitory on the site. (Drawn by author)

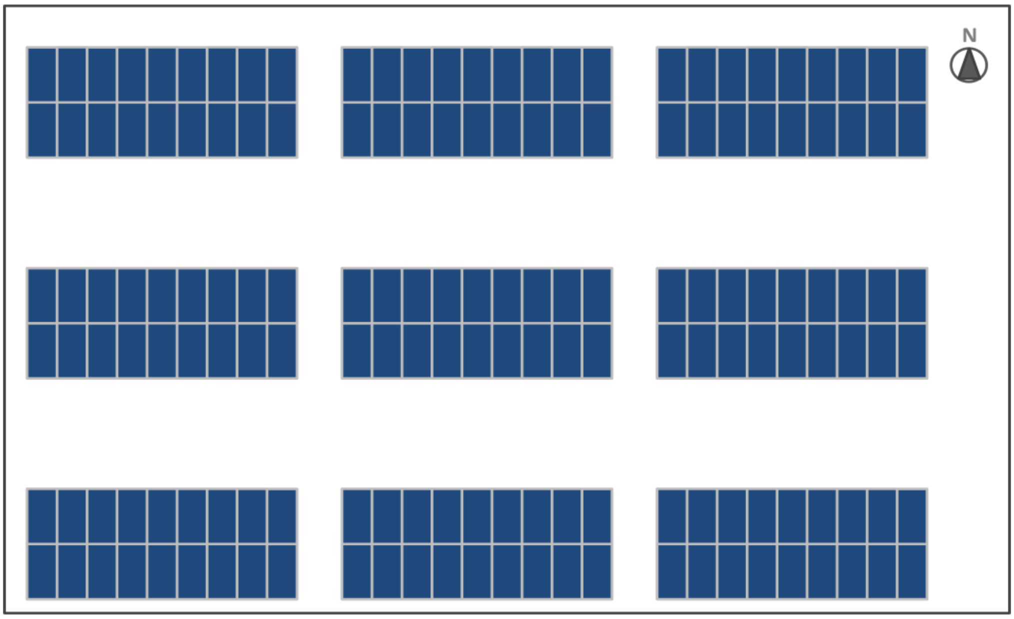


Figure 3.44: Nine One-axis Sun-tracker System's Top View (Drawn by author)

3.2.8 Evaluation of Development and Restructuring of the Energy Infrastructure Solar Power Plant

Location of the system is in Serhatkoy and installed in 2011. Aim of the installation is to produce electricity. System power is 1.3MWp (1300kWp). 6,192 Polycrystalline cell type panels used for the system and additionally installation was done on 40-50 acre space. Installations of the panels are located on ground (freestanding).

Additionally, arrays were oriented to the 210 ° South-West direction. Current tilt angle is calculated as 24.84°. Installation cost is 3,770.823 Euros.

Table 15: Evaluation of Solar Power Plant

Characteristics	
Name of the Project	Development and Restructuring of the Energy Infrastructure Solar Power Plant
Hemisphere (Location)	Northern Hemisphere
Climate Type	Hot climate
Panel Cell Type	Poly-crystalline silicon
Orientation	South-west direction
Tilt Angle	24.84°
Location/Position of Panels	Ground mount/Freestanding
Supporting Elements	Profile carriers
Shading	No shade
Ventilation	Sufficient
Panel Organization	Landscape

Figure 3.45: Photo shows the Outside View and Panel Cell Type (Taken by author)

Figure 3.46: Support Type of the System and the General Positioning of Arrays (Taken by author)

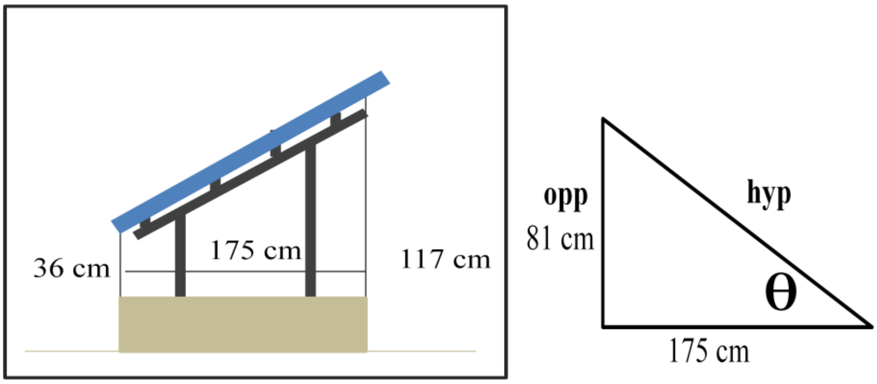


Figure 3.47: Calculations of the Tilt Angle (Drawn by author)

Angle = tan -1 (81/175)

Angle = tan -1 (0,463)

Angle = 24.84°

At the end of the calculations (Figure 3.47), 24.84° is found as a tilt angle. In the total there are 86 numbers of arrays in the site and each array includes 72 numbers of panels (Figure 3.48)

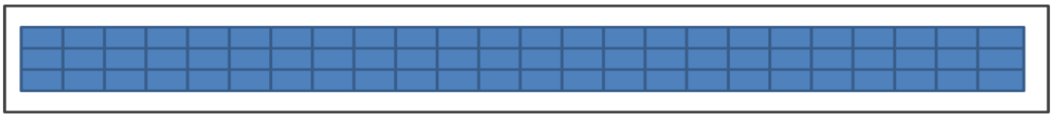


Figure 3.48: Top View of 1 Array Includes 72 Panels with Landscape Panel organization (Drawn by author)

Figure 3.49: Top View of the Total System (Drawn by author)

3.2.8.1 Suggestions for the Current System

1. As it can be suggested that, orientation of the panels can be done to the southward direction. Energy efficiency of the panels can be more compared to the current system. (Figure 3.50)

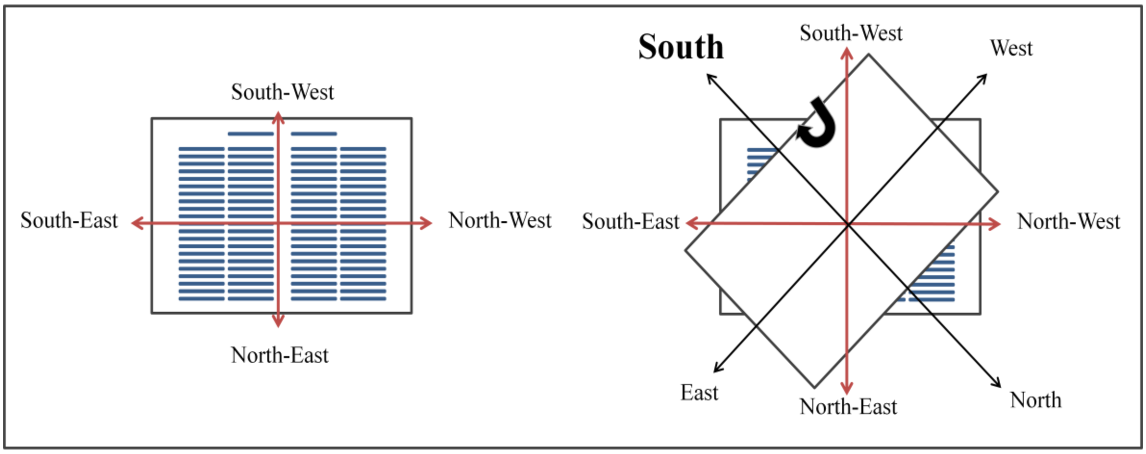


Figure 3.50: Arrays are rotated from South-West Direction to South (Drawn by author)

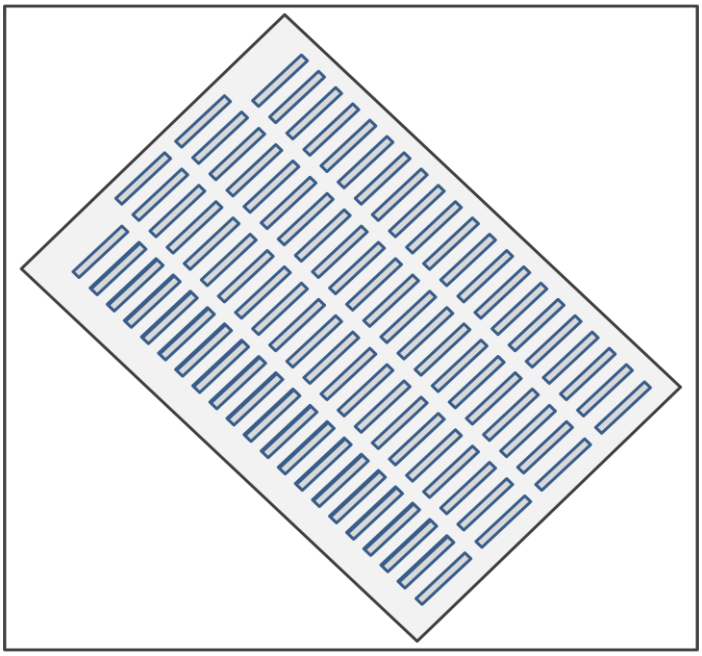


Figure 3.51: Correct Orientation of Arrays Looking to the South Direction (Drawn by author)

2. On the other hand, tilt angle can be inadequate for generating electricity. By the way, if tilt angle of the panels are designed as plus 4 and 5 degrees, energy efficiency will be more.

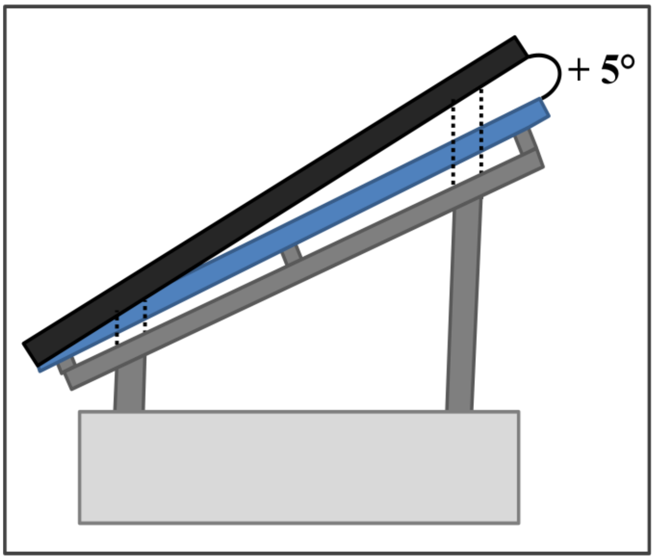


Figure 3.52: Suggested 28° Tilt Angle for Current System (Drawn by author)

As seen from Figure 3.52 that, installation type of the arrays were done as fixed. However, tilt angle of arrays were calculates as 24.84° as mentioned before. As it can be suggested that, tilt angle of the array should be +4 - 5° to get more perpendicular to the direction of the sun. By the way, tilt angle should be 28°-30°.

3. Distances between the arrays are correct. No shading is observed during the survey.

4. Order of the arrays found correct according to the available space.

Because of the freestanding of the arrays location; there has no more chance to make arrays to install to roof and facade. So, sun-tracker systems can be an alternative suggestion. There are 4 rows at the site 2 rows including 21 arrays and 2 rows include 22 rows.

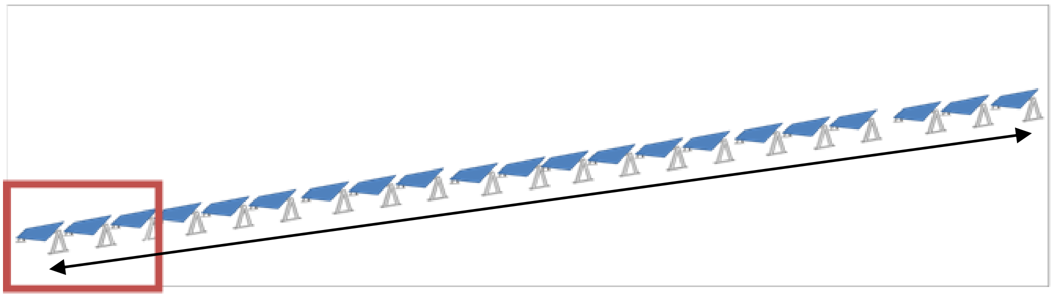


Figure 3.53: 21 Sun-tracker System Suggestions in One Row (Drawn by author)

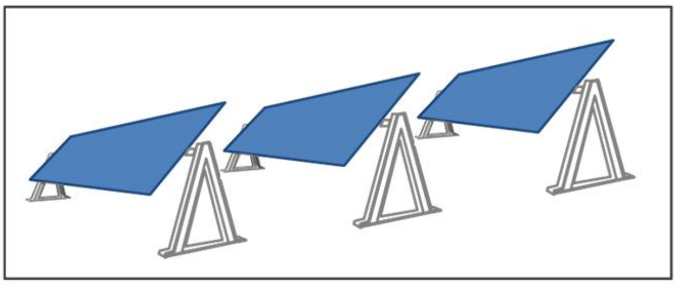


Figure 3.54: Detail of Sun-tracker System (Drawn by author)

3.2.9 Evaluation of 1001 Cesit Shopping Center

Location of the building is in Demirhan in TRNC. System power is 15.12kWp. Poly-crystalline cell type 63 panels were installed by using landscape organization method. Each panel power is 240 Watts. Installation is done on the roof. (Figure 3.55) Current tilt angle is calculated as 14° and panels were oriented to the south direction.

Table 16: Evaluation of 1001 Cesit Shopping Center

Characteristics	
Name of the Project	1001 Cesit Shopping Center
Hemisphere (Location)	Northern Hemisphere
Climate Type	Hot climate
Panel Cell Type	Poly-crystalline silicon
Orientation	South
Tilt Angle	14°
Location/Position of Panels	On-roof
Supporting Elements	Profile Carriers
Shading	No shade
Ventilation	Insufficient
Panel Organization	Landscape

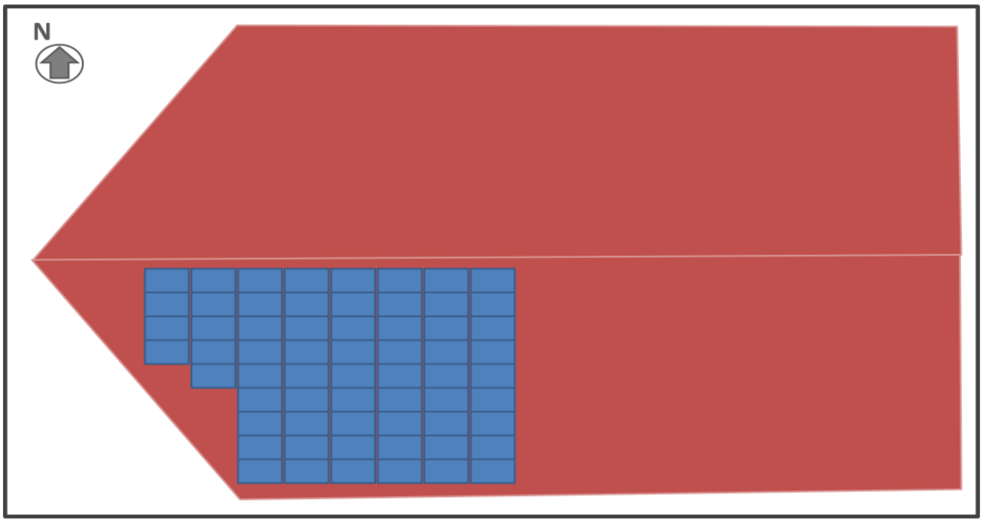


Figure 3.55: Top View of the Panels (Drawn by author)

Roof of the building is covered with sheet metal. By the way, sheet metal roofing can cause overheating of the panels. At the same time, there is not enough space for ventilation. The distance between the panels and the roof is calculated as 4cm.

Meter square of 1 panel: 0.9 x 1, 65= 1,485m²

Meter square of 63 panels: 63 x 1, 485 m² = 93, 555 m²

Panels are covering ≈94 m² of the roof surface.

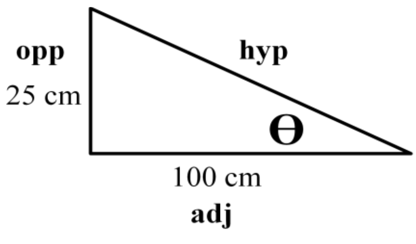


Figure 3.56: Calculation of the Roof Slope (Drawn by author)

Angle = tan -1 (25/100)

Angle = tan -1 (0, 25)

Angle = 14.036°

Figure 3.57: Poly-crystalline Cell Type Panels on the Metal Sheet Roof (Ekrem Gunes Solar, 2013)

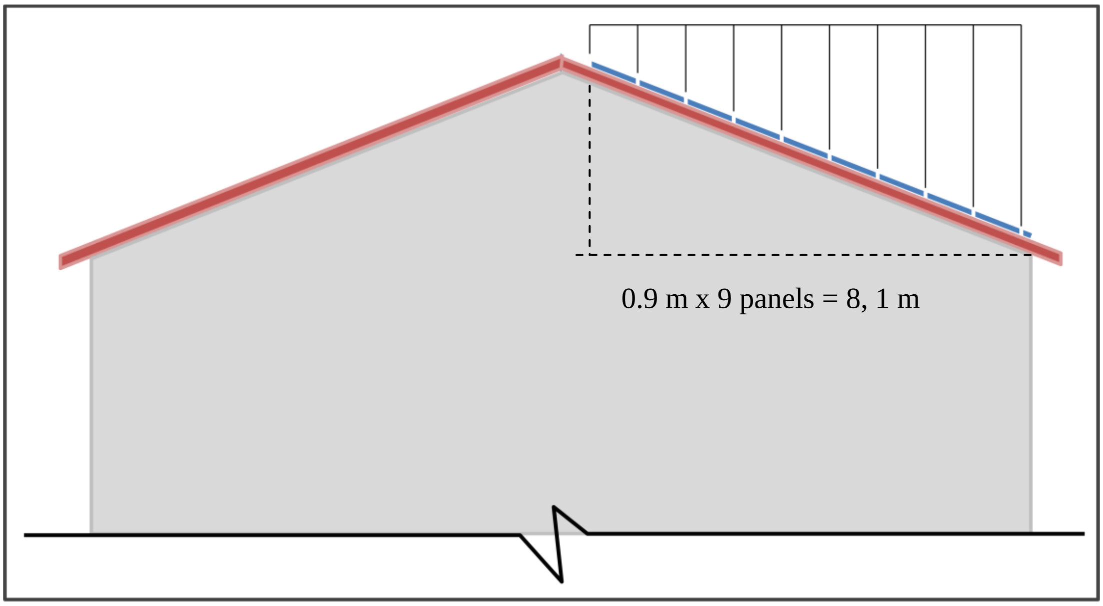


Figure 3.58: Side View of the Panels can be seen on the Roof (Drawn by author)

3.2.9.1 Suggestions for the Current System

1. As can be suggested that; panels oriented to the correct direction.
2. However sheet metal roofing is not a good type of roof material for on roof type of panel designs.

There is not chance to change the roof material by the way; by the help of the roof carriers panels should be raised to the upwards giving chance for panels to be ventilated. (Figure 3.60)

3. Additionally, tilt angle is not sufficient for better efficiency. Therefore optimum tilt angle of the panels can be installed like in the Figure 3.59.

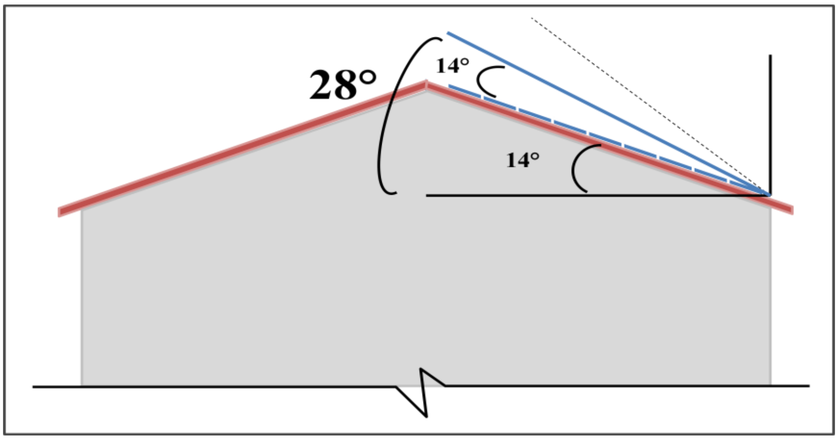


Figure 3.59: Optimum Tilt Angle Suggestion for the 1001 Cesit Shopping Center (Drawn by author)

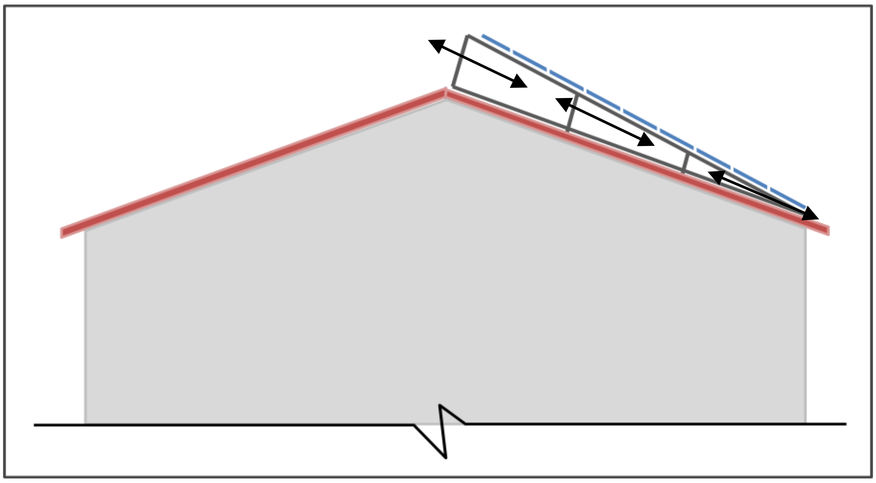


Figure 3.60: Supporting Type, Panel's Tilt Angle View and Ventilation Gap (Drawn by author)

As an alternative suggestion, if panels were designed during the installation of the building, different kind of roof system/structure should be selected. Metal sheet roof can cause overheating to the panels. There has not enough distance between the roof surface and the panels to be ventilated.

3.2.10 Evaluation of Levent Dagasan’s House

House is located in Gönendere. Aim of the installation is; there is not grid syste provided by KIB-TEK. 135,000 TL (Turkish lira) is wanted for 6 electric poles from the owner of the house for city electricity. Owner spoke with the minister of energy and economy to install photovoltaic panels and wind tribune to produce electricity by using the energy of sun. Off-grid system is designed. Additionally, system is supported with generator for winter times that usually less energy production is done. Year of the installation is in 2010 and 35,000 TL is spent for total installation. System power of the panels was calculated as 2, 88kWp and each panel’s power is 240Watts. Installation location is done on the site of the house (Freestanding). The orientation of the house is looking to the south-east direction. Additionally, tilt angle of the panels are calculated as 29.25°and portrait panel organization is observed.

Figure 3.61: Photo shows Wind Tribune and 12 Poly-crystalline Panels (Taken by author)

Table 17: Evaluation of 1001 Levent Dagasan's House

Characteristics	
Name of the Project	Levent Dagasan's House
Hemisphere (Location)	Northern Hemisphere
Climate Type	Hot climate
Panel Cell Type	Poly-crystalline silicon
Orientation	South-east
Tilt Angle	29.25°
Location/Position of Panels	Ground mount
Supporting Elements	Profile Carriers
Shading	No shade
Ventilation	Sufficient
Panel Organization	Portrait

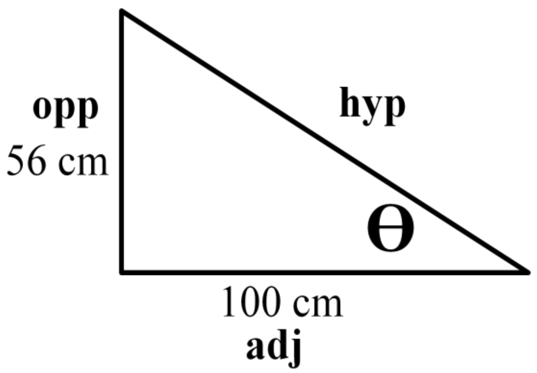


Figure 3.61.1: Calculation of the Current Tilt Angle (Drawn by author)

Angle = tan -1 (56/100)

Angle = tan -1 (0, 56)

Angle = 29.25°

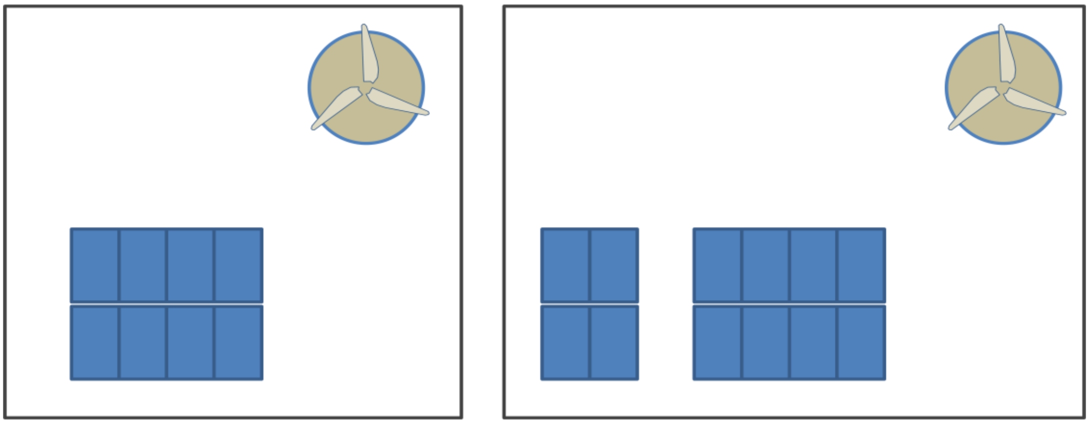


Figure 3.62: Top View of 8 Panels and Tribune (before) and 12 Panels and Tribunes (after) (Drawn by author)

According to owner of house Levent Dagasan, the most electricity efficiency is provided in spring and autumn months. Additionally, performance of batteries decreases approximately %20 at too hot seasons. Location of the house is on a little hill and owner of the house said that; great wind passes from the hill. By the way, wind tribune is selected. Panels were organized portrait. (Vertically) First of all 8 panels and 1 wind tribune is installed and at the following months because of the need, 4 panels were added to the left side of other panels as seen from Figure 3.62.

Figure 3.63: Photo shows Generator and 8 Watery (Juicy) Batteries (Taken by author)

As the current system is evaluated, orientation of the panels should look to the south direction by the way; panels should be rotated 45° to the left South direction. By this kind of design, panels will be more efficient.

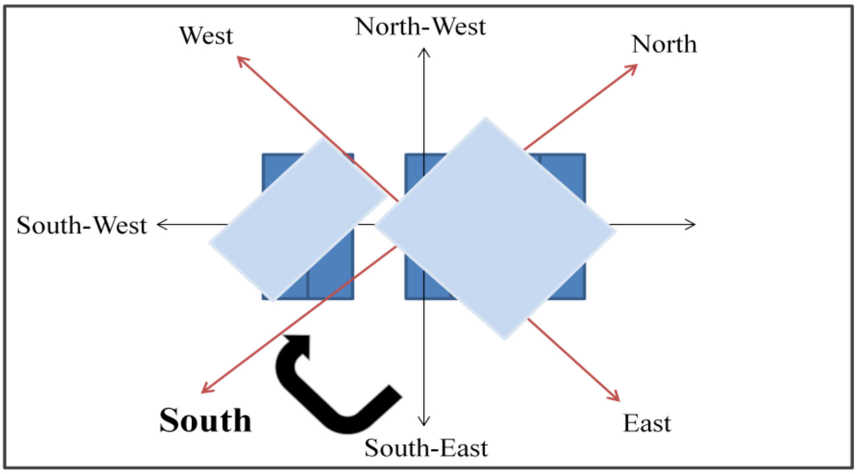


Figure 3.64: Current Orientation looking to South-east and Suggested Orientation looking to South (Drawn by author)

On the other hand, tilt angle of the panels are calculated and observed as sufficient for efficiency.

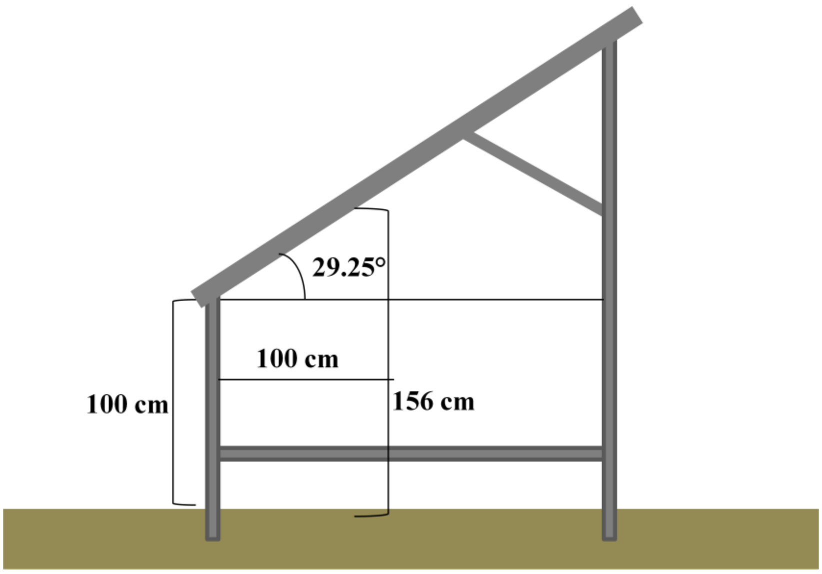


Figure 3.65: Support Type and Tilt Angle of the Array (Drawn by author)

It can be seen from the Figure 3.61 that, there is not enough space for install panels to the facade or on the roof. There is enough space at the garden of the house and owners of the house preferred to install panel on the ground. This kind of installation is known as freestanding positioning of the panels.

As an alternative suggestion to the current system; single-axis sun tracker system application can increase the energy efficiency. On the other hand, cost of the application will increase because of the sun-tracker system.

With the use of single-axis sun tracker system, 12 numbers of panels will be collected in one array. This can be an advantage for the owner of the house because more space can be used at the garden.

Advantages:

1. Increase energy efficiency
2. Increase space

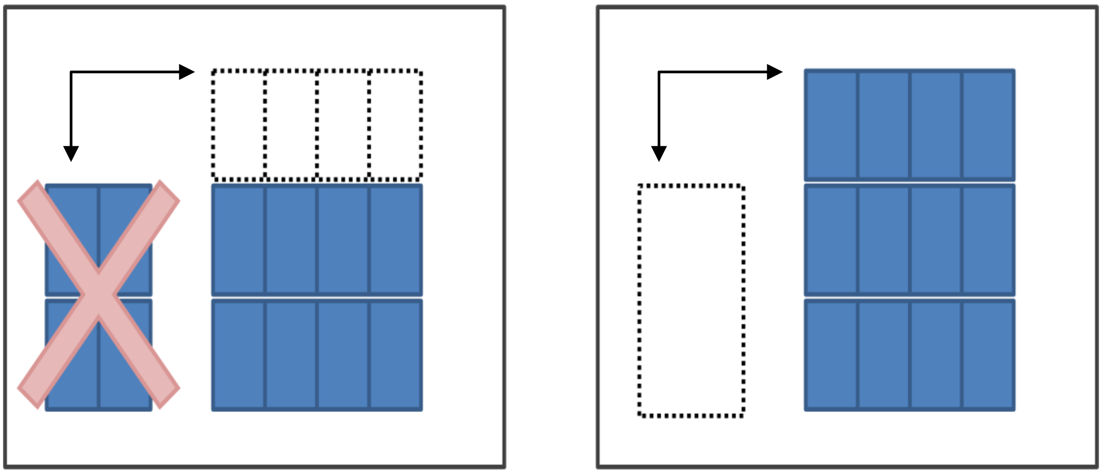


Figure 3.66: shows the suggestion for the array organization (drawn by author)

It can be seen from the Figure 3.66 that; the panels that were installed later away from the first array can be collected on 1 array. Panels organized vertically. Four panels side by side and 3 panels over each other.

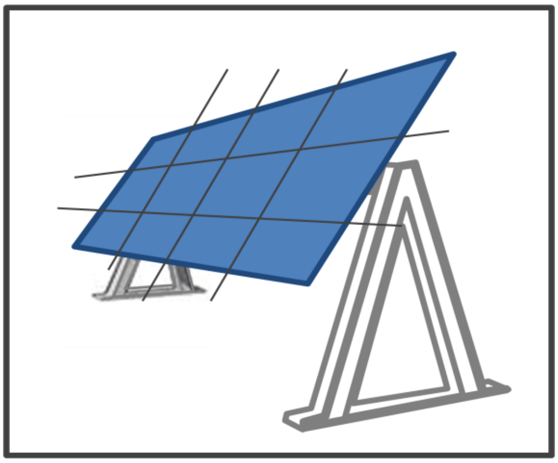


Figure 3.67: Twelve Panels Collected on One Single-axis Sun-tracker System (Drawn by author)

3.2.11 Evaluation of Alagadi Restaurant

Alagadi Restaurant is located in the Kyrenia district. There is not city electricity given to the restaurant. By the way, PV panel installation is done to generate electricity. 18 poly-crystalline numbers of panels were used. Locations of the panels were on the pitched roof surface. Each panel has 60 cells (6 x 10) and has 235Wp power class. Total square meter of the panels that covers roof surface is calculated as 29, 7 m².

Each panel dimension: 1,65m x 1m = 1, 65 m²

Total meter square of the panels: 1, 65 m² x 18 numbers = 29, 7 m²

Panels were installed on the current slope of the pitched roof. Therefore, tilt angle of the panels were noted as 20°. At the same time, orientation of the panel installation is done towards to the south direction. System type is off-grid system. Installation was done in September 2008 and total installation payment is approximately 70,000 TL.

Table 18: Evaluation of Alagadi Restaurant

Characteristics	
Name of the Project	Alagadi Restaurant
Hemisphere (Location)	Northern Hemisphere
Climate Type	Hot climate
Panel Cell Type	Poly-crystalline silicon
Orientation	South
Tilt Angle	20°
Location/Position of Panels	On-roof
Supporting Elements	Profile Carriers
Shading	No shade
Ventilation	Insufficient
Panel Organization	Portrait

Figure 3.68: General View of the Panels Added on the Pitched Roof (Taken by author)

It can be seen from Figure 3.68 that, panels were added on the roof surface and there is not enough distance between the panels and the roof system for good ventilation. Distance is approximately 7cm.

Figure 3.69: Distance between the Panels and the Roof Surface (Taken by author)

Figure 3.70: Photos show Batteries (Taken by author)

Watery battery type was used. Each battery is 1,000 TL (Turkish lira). Owner of the restaurant found each battery too expensive.

Figure 3.71: Photo show Generator, Mate Control and Charge controller (Taken by author)

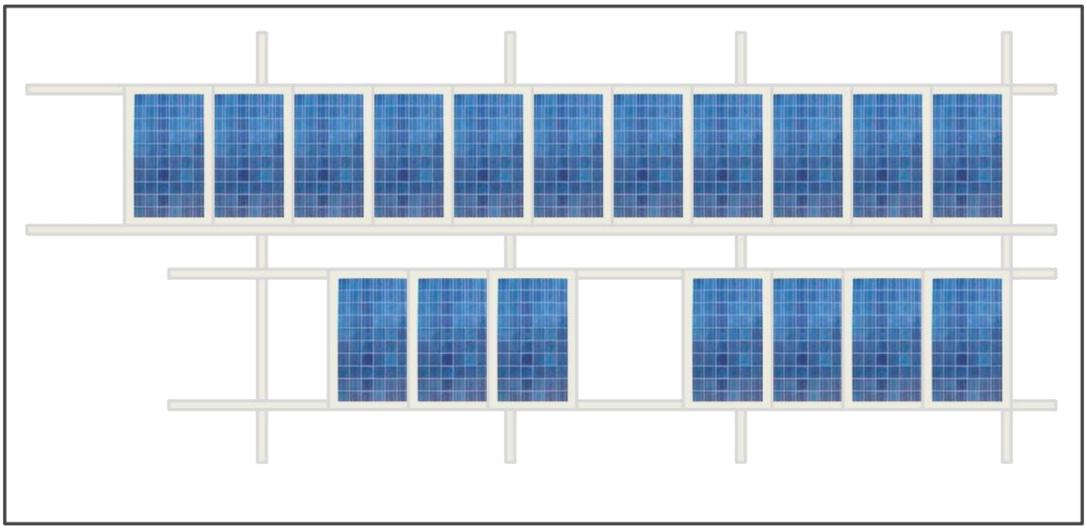


Figure 3.72: Top View of the Panels on the Roof Surface (Drawn by author)

Panels were oriented in two rows portrait as seen from Figure 3.72. First group of array is created by 11 panels and second group of array is created with 7 panels. According to Gokmen Gunes who is the owner of the restaurant, panels are not enough for generating the whole electricity of restaurant. For this reason, owner is spending 1,500 TL (Turkish lira) in 1 month for fuel in order to operate the generator.

As it can be evaluated that orientation of the panels were applied according to the most efficient way. However, the gap that is 7 cm between the roof surface and the panel is not sufficient for good ventilation. Additionally, trees around the restaurant can cause shading at certain times, so trees should be trimmed periodically in order to prevent shading. Lastly, tilt angle of the panels should be adjusted with the profile carriers. Current angle is not sufficient therefore, +8°- 10° degrees are needed for the fixed angles.

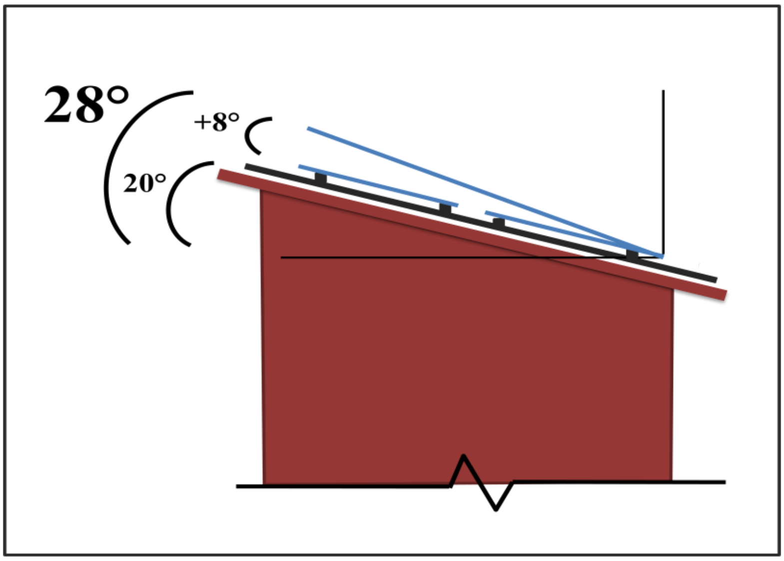


Figure 2.73: Appropriate Tilt Angle of Alagadi Restaurant (Drawn by author)

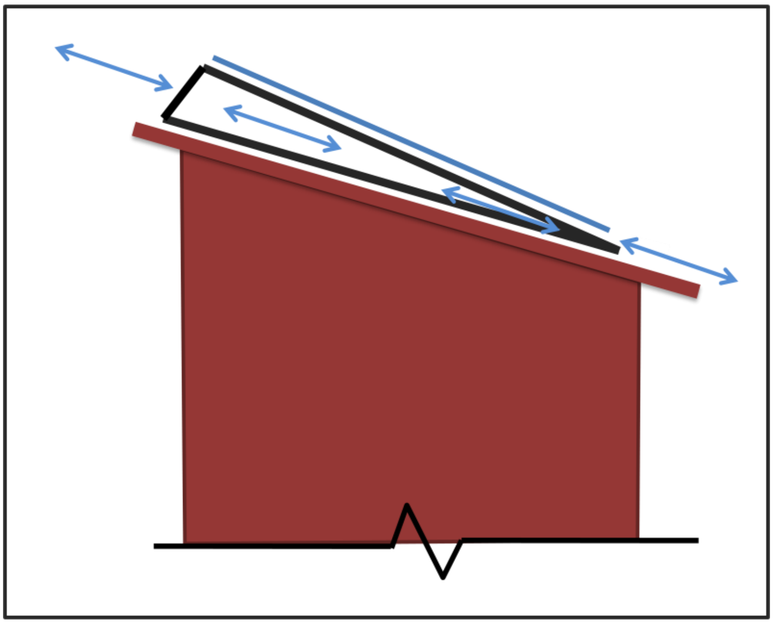


Figure 3.74: Enough Ventilation for Installation (Drawn by author)

As a result of conversation with the owner of the place, total system is not enough for generating electricity. By the way, total system should be extended. However, there is not enough space on the roof surface, facade and the site of restaurant to expand.

3.2.12. Example of a House from Gonyeli

Location of the building is on old Gonyeli-Girne road. Aim of the installation is to reduce high electricity bills. Owner of the house said that, they were spending approximately 700-800 TL electricity bills at every month. Installation was done on 27 May 2013. System type is on-grid system and total system power is 4, 9kWp. Each panel has 245 W power rates. 20 poly-crystalline cell type panels were added on the roof of the house. Total meter square of the panels were calculated as 33m² and panels were tilted with 28°.

Meter square of each panel: 1m x 1,65m = 1,65m²

Meter square of 20 panels: 1,65m² x 20 panels = 33m²

Table 19: Evaluation of House at Gonyeli

Characteristics	
Name of the Project	House at Gonyeli
Hemisphere (Location)	Northern Hemisphere
Climate Type	Hot climate
Panel Cell Type	Poly-crystalline silicon
Orientation	South
Tilt Angle	28°
Location/Position of Panels	Shading Device
Supporting Elements	Profile Carriers
Shading	No shade
Ventilation	Sufficient
Panel Organization	Portrait

Figure 3.75: General View of the House with Panels Located in the Site (Taken by author)

Figure 3.76: 20 Panels Organized Portrait added on the Roof (Taken by author)

Figure 3.77: Photo shows how Panels Supported (Taken by author)

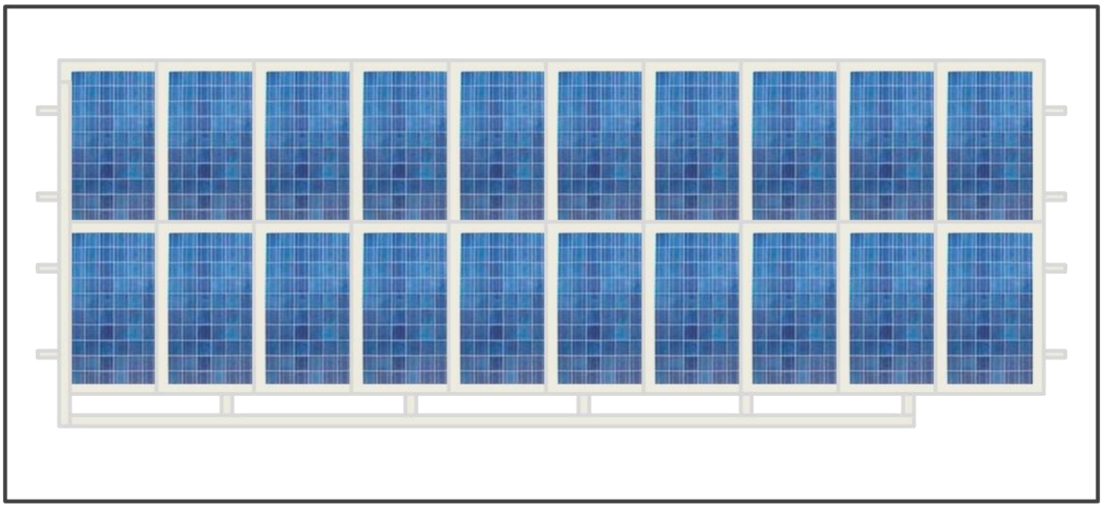


Figure 3.78: Top View of 20 Poly-crystalline Panels (Drawn by author)

As seen from Figure 3.78 that, poly-crystalline panels were organized portrait on the roof surface with an adjusted angle.

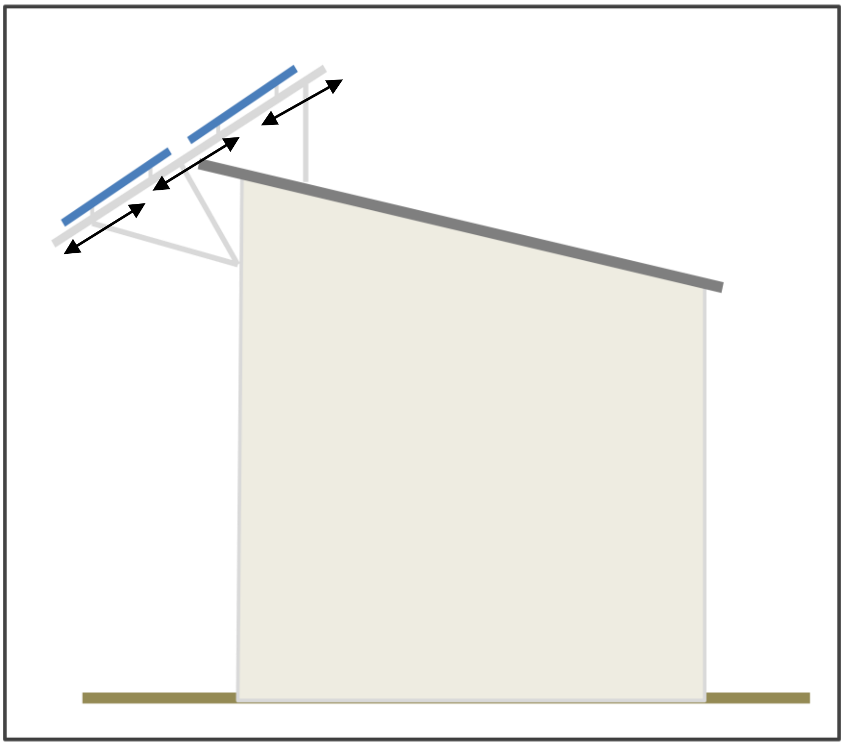


Figure 3.79: Side View of the Panels (Drawn by author)

As seen from Figure 3.79 that; there has not roof slope looking to the south direction. Therefore, appropriate optimum tilt angle was given by the profile carriers looking to the south direction. It can be a successful design solution. Because, panels can be well ventilated, can be a shading device for the owners of the house, not covering space on the ground. Additionally, panels are not shaded by neighboring houses and trees.

If the system is evaluated, there is not enough space at the garden and the facade of the house to make installation. Tilt angle of the system is suitable and no shading coming from the neighbor buildings and no trees were observed around the building. At the same time, orientations of the panels were done correctly and panels are ventilated.

3.2.13 Evaluation of Lakeside Dairy

System is located in Hanford, California USA. Latitude and longitude of Hanford is found as 36.33 N, 119.65 W .System powers is 891 kilowatt. It is providing %75 electricity needs of dairy. System power saves $160,000 money annually. Construction was finished in 9 February 2011.For electricity production of the dairy, 3,240 polycrystalline cell type panels used. 104 single-axis sun tracker systems are used to follow sun from east to west. Installation of the arrays was done on 4 acre ground. By the way, installation type can be named as freestanding. Arrays generate more than 1.7 megawatt (1,700,000watts) hours annually. System costs $3.5 million. Grant program of government paid %30 of the project. So, this means that 1 million dollars paid by the Government. (Goble, 2012)

Table 20: Evaluation of Lakeside Dairy

Characteristics	
Name of the Project	Lakeside Dairy
Hemisphere (Location)	Northern Hemisphere
Climate Type	Hot climate
Panel Cell Type	Poly-crystalline silicon
Orientation	Single-axis sun-tracker
Tilt Angle	28°
Location/Position of Panels	Ground mount
Supporting Elements	Profile Carriers
Shading	No shade
Ventilation	Sufficient
Panel Organization	Landscape


Figure 3.80: Photos show the Panel Cell Type, Location and Orientation of the Arrays

Sources: First picture (Nidever, 2011) and second picture (Goble, 2012)

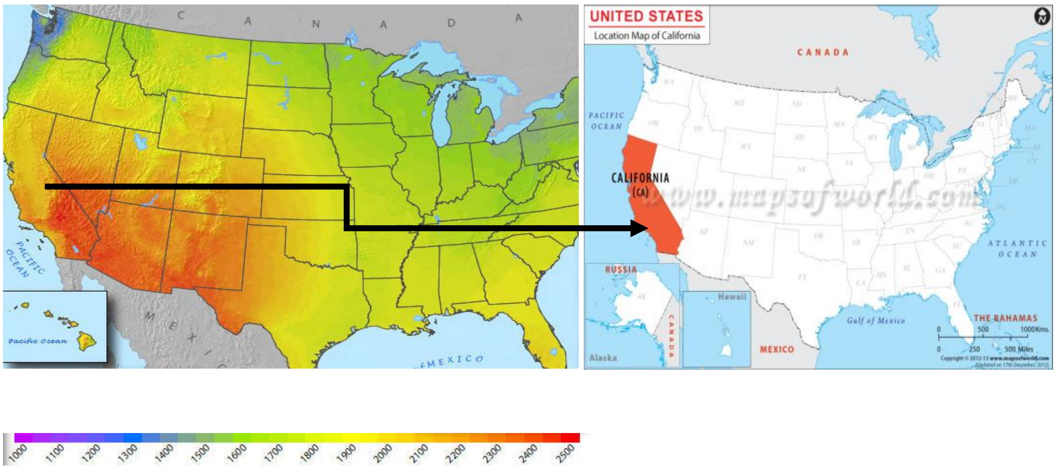


Figure 3.81: Photovoltaic Solar Resource of United States and Location of California in United States (kWh/m² Year)

California is located at the West of the United States and solar irradiation of California is noted as 2200-2500kWh/m².

Figure 3.82: Photo shows the Top View of the Panels (Google Earth, 2013)

Figure 3.83: Photos taken from Different Directions (Youtube, 2013)

It is one of the North America’s largest solar-powered dairy.

Figure 3.84: Distance between the Two Arrays (Youtube, 2013)

It can be seen from the Figure 3.84 that; array that is in front of the other arrays are not shading arrays that are at the back. There is enough space between two arrays.

Figure 3.85: Photo shows the Electric Meter (Youtube, 2013)

When the electric meter is pointing to the left direction, this means that the solar system is producing more energy than what their needs are. Solar electricity gets used by the dairy and the excess goes to the grid for utility company to sell.

Source: http://www.youtube.com/watch?v=oKFd2g7XFa4

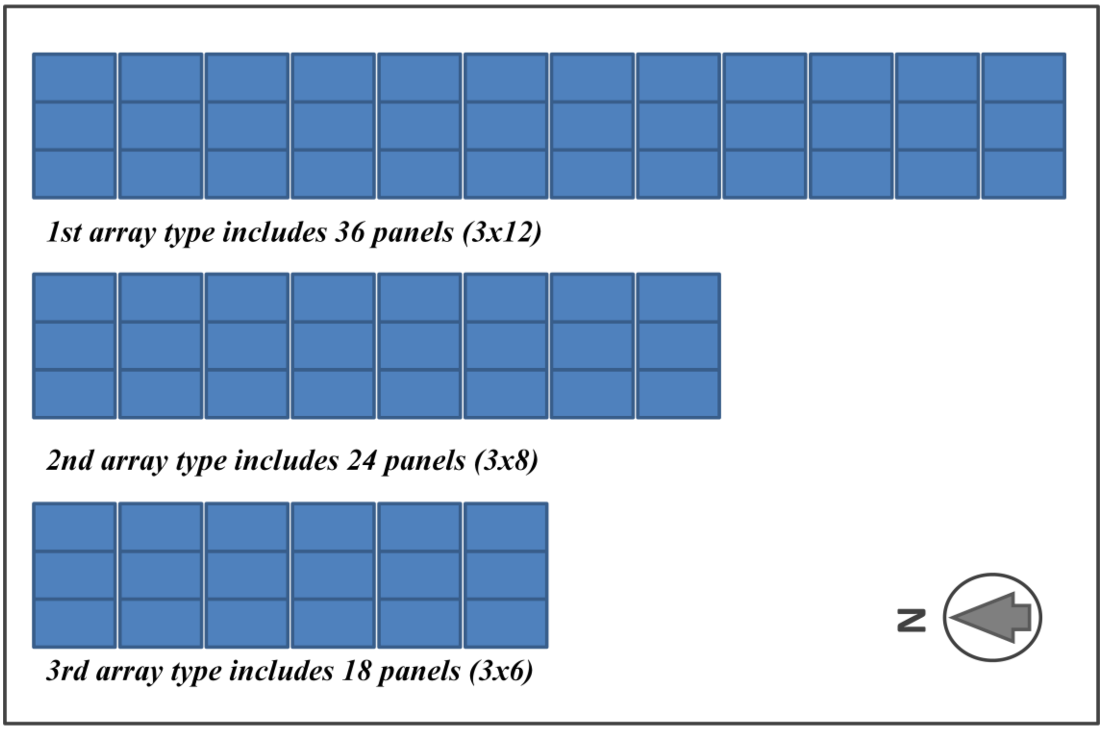


Figure 3.86: Top View of the Array Types on the Site (Drawn by author)

There are three types of arrays in the Lakeside Dairy (Figure 3.86). 1st type of array group is including 36 panels and there are 75 numbers of arrays on the site. On the other hand, second type of array group is including 24 panels and there are 3 numbers of arrays on the side. Lastly, third group is created by 18 panels and there are 26 numbers of panels on the site. Total watt is calculated as 891,000 Watts and total panel numbers are 3,240 panels.

In order to find each panel's watt provide;

891,000 / 3,240 = 275 Watts

According to the calculation, each panel capacity is 275 Watts.

3.3 General Evaluation of Hot Climate Case Studies

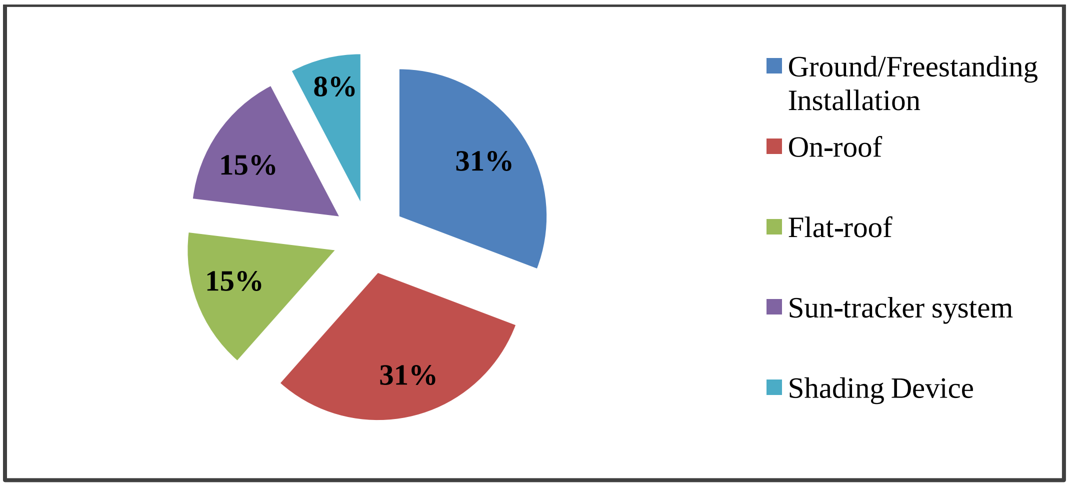


Figure 3.87: Percentage of Position/Location used at 13 Hot Climate Cases (Drawn by author)

As seen in Figure 3.87 that pitched roof space and ground space is selected mostly for the installation of PV panels. The least selected space is the facade for installing as shading device. On the other hand, the most selected cell type is poly-crystalline silicon compared to the other types. Poly-crystalline is used in 61% of the projects and thin-film amorphous silicon is used only in 8% of the projects.

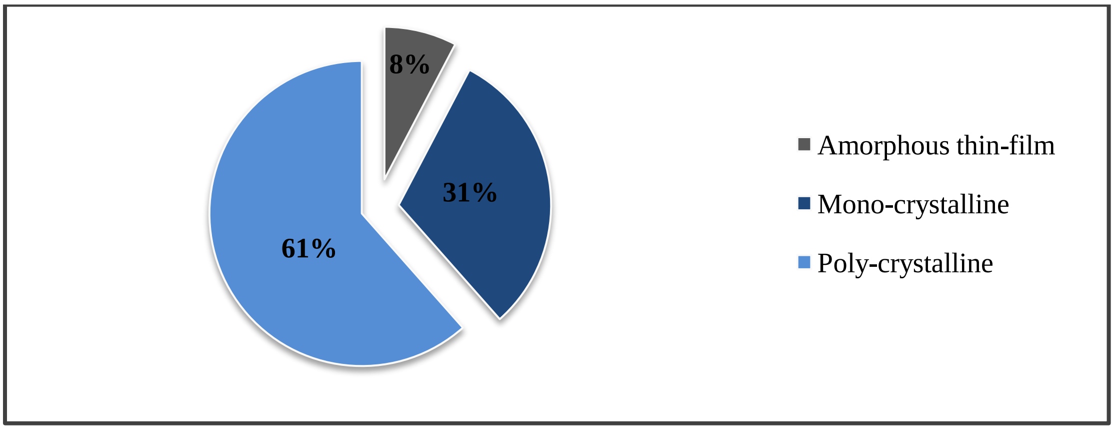


Figure 3.88: Percentage of Cell Type used at 13 Hot Climate Cases (Drawn by author)

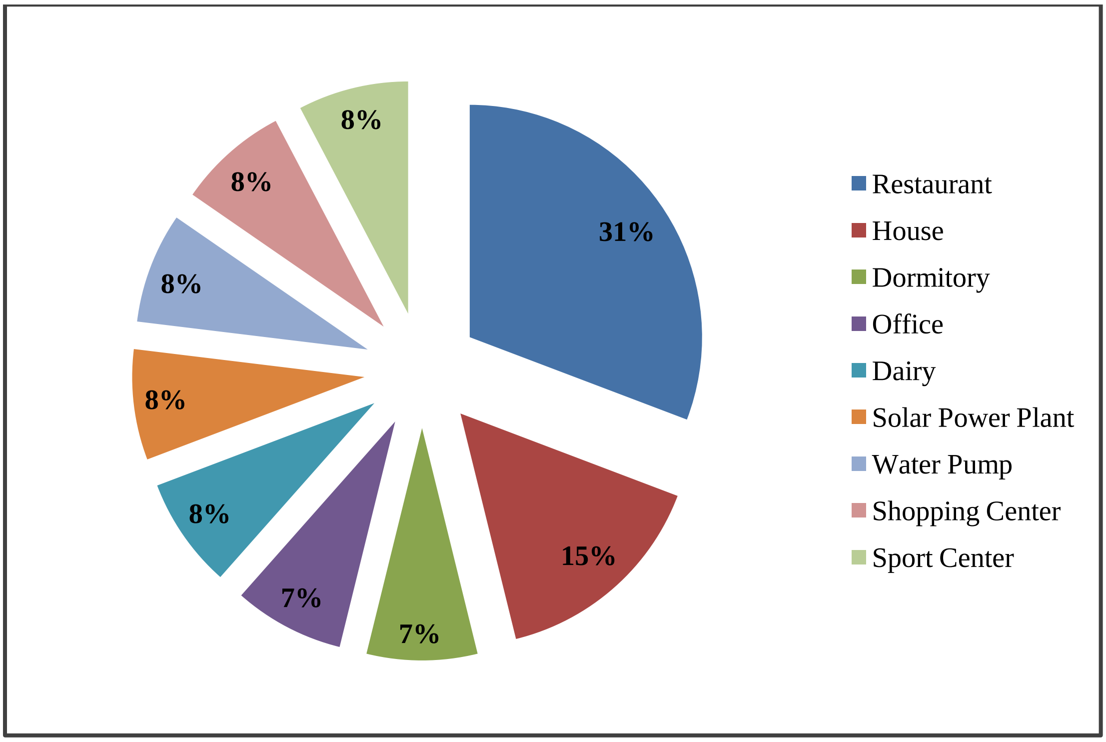


Figure 3.89: Percentage of Installations According to the Usage at 13 Hot Climate Cases (Drawn by author)

Lastly, the most usage of PV panel is at the restaurant average 31%. Secondly, 15% of the PV panel installation is used at houses. On the other hand, PV panel installation is least preferred at other usage areas like dormitory, office, dairy, solar power plant, water pump, shopping center and sport center.

3.4 Case Studies for Cold Climates

Cold climate case studies are selected from the countries that are located northern of Turkish Republic of Northern Cyprus. One case study is from Canada, 1 is from Germany, 1 is from Serbia and 10 of the case studies are selected from UK. These case studies are, Sarnia Photovoltaic Power Plant, Templin Solar Park, Example from Nis in Serbia, Cornish School in Cornwall, Dr. Rhoden's House, Blackfriars Station, House in Staffordshire, House in Shirley, House in Burton on Trent, House in Repton, House in Repton, Example from Ashbourne and Example from Derbyshire.

3.4.1 Evaluation of Sarnia Photovoltaic Power Plant

Location of the Power plant is in Sarnia, Ontario Canada. Latitude and longitude (coordinates) of Sarnia is found as 42° 56′ 16″ N, 82° 20′ 30″ W. System power of the power plant is 97MWp. Thin-film module panel types is used for the power plant and 1,300,000 modules used for creating the power plant. Cadmium-telluride (CdTe) solar photovoltaic cells (Figure 3.93) are selected and cell efficiency is 17.3%. (Andrew, 2011) Installation space is on the ground (freestanding style). At the same time, installation area is 1,100 acres (450 hectares). (Whitmore, 2010) *"In September 2010 was the world's largest photovoltaic plant"* Solar irradiation of Sarnia is found as 1100-1200 kWh/kW. Modules are mounted with 25° degree tilt angle. (SolarServer, 2010) Organizations of the panels were done landscape.

Table 21: Evaluation of Sarnia Photovoltaic Power Plant

Characteristics	
Name of the Project	Sarnia Photovoltaic Power Plant
Hemisphere (Location)	Northern Hemisphere
Climate Type	Cold climate
Panel Cell Type	Thin-film Cadmium-telluride
Orientation	Sun-tracker system
Tilt Angle	25°
Location/Position of Panels	Ground mount
Supporting Elements	Profile Carriers
Shading	No shade
Ventilation	Sufficient
Panel Organization	Landscape

Figure 3.90: Location of Sarnia in the Canada Map (Wikimedia, 2009)

Figure 3.91: Different Views are taken from Photovoltaic Power Plant (Enbridge, 2010)

Figure 3.92: Top View of Power Plant (Enbridge, 2010)

Figure 3.93: Thin-film Modules were mounted to the Profile Carriers (SolarServer, 2010)

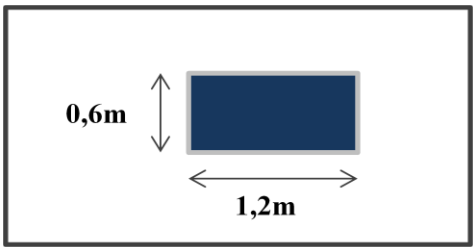


Figure 3.94: Dimensions of 1 CdTe Thin-film Module (Drawn by author)

3.4.1.1 Suggestions for the Current System

Because of the cold climate of Canada; mono-crystalline cell type can be selected for the installation.

$$\textbf{1 modules Watt: } \frac{\textbf{Total Watt of the system}}{\textbf{Number of Modules}}$$

$$\textbf{78 Watt} = \frac{\textbf{97,000,000Watts}}{\textbf{1,300,000 Modules}}$$

Figure 3.95: Formula for Finding Each Module’s Watt (Drawn by author)

Meter square of each module: 0,6m x 1,2m = 0, 72 m² (CdTe Thin-film)

Meter square of total system: 0, 72 m² x 1,300,000 = 936,000 m²

As a suggestion, mono-crystalline cell type dimensions 0, 8 x 1, 58 are generating 190 Watts. If 1 mono-crystalline module (190 Watt) is divided with total system power (97,000,000 Watts), number of modules that are going to be used at the system will be found.

Number of modules: 97,000,000 / 190 Watts = 510,526 mono-crystalline silicon modules needed to install.

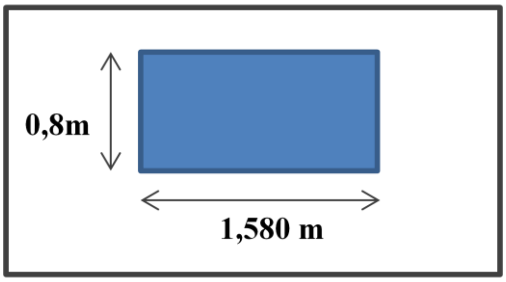


Figure 3.96: Dimensions of 1 Mono-crystalline Module (Drawn by author)

Meter square of each module: 0,8m x 1,580m = 1,264 m² (Mono-crystalline)

Meter square of total system: 1,264 m² x 510,526 = 645, 304, 86 m² (suggestion)

By using mono-crystalline cell type modules 290, 695 m² will be recovered.

Calculation of the recovered space: 936,000 m² - 645, 305 m²

(Thin-film) - (mono-crystalline)

3.4.2 Evaluation of Templin Solar Park

Templin Solar Park is the Europe's largest thin-film PV power. Location of the Solar Park is in Templin, Brandenburg/Germany. Latitude and longitude of Templin is 53° 1′ 54″ N, 13° 32′ 19″ E. Total system size is 128,48 MWp(128,480,000Watts). 1, 5 million thin-film cell type modules were used for the installation. Installation area was done on 214 hectares space. Dynamic relative power control and 114 central inverters were used. 205,000,000 EURO was spent for whole installation. Owner of the project is Commerz Real and project was completed in 2012. (SMA, 2013)

Table 22: Evaluation of Templin Solar Park

Characteristics	
Name of the Project	Templin Solar Park
Hemisphere (Location)	Northern Hemisphere
Climate Type	Cold climate
Panel Cell Type	Thin-film Cadmium-telluride
Orientation	Sun-tracker system
Tilt Angle	25°
Location/Position of Panels	Ground mount
Supporting Elements	Profile Carriers
Shading	No shade
Ventilation	Sufficient
Panel Organization	Landscape

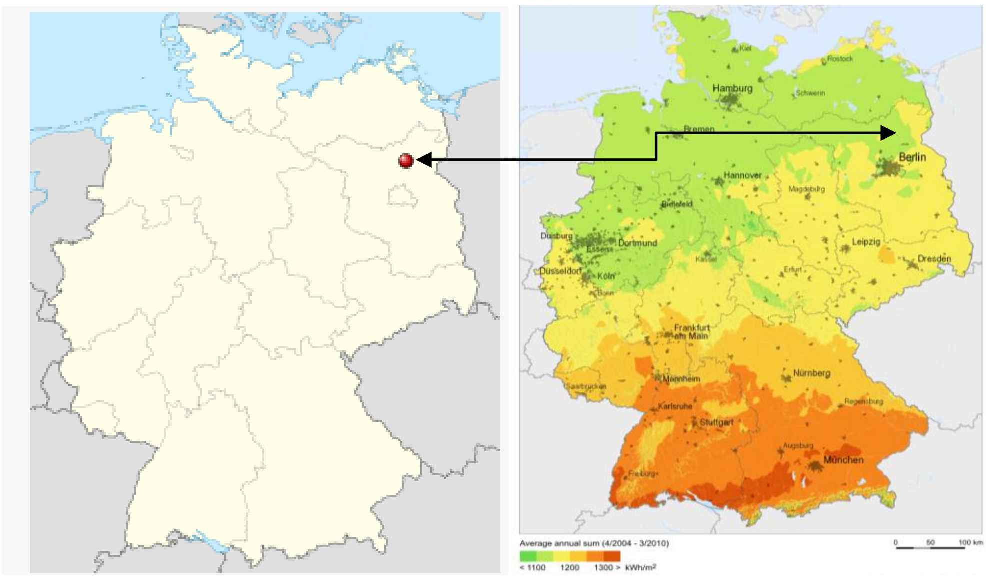


Figure 3.97: Location of Templin Solar Park (Wikipedia, 2008) and Solar Irradiation Map of Germany (Solargis, 2011)

Templin Solar Park is located at the north-east of the Germany shown as red color at the Figure 3.97. Solar irradiation of Templin is 1100kWh/m² shown in the Figure. Templin due to the north-east of the country, solar irradiation is lower compared to the other locations of the country. Southern parts of the country are more temperate and solar irradiation is higher than the northern parts. Panels were organized landscape as seen from Figure 3.99.

Figure 3.98: Photo shows the General View of the Templin Solar Park (SMA, 2013)

Figure 3.99: Thin-film PV Modules at Templin Solar Park (Schwers, 2012)

3.4.2.1 Suggestions for the Current System

1 modules Watt: $\frac{\text{Total Watt of the system}}{\text{Number of Modules}}$

78 Watt = $\frac{\text{128,480,000Watts}}{\text{1,500,000 Modules}}$

Figure 3.100: Formula for Finding Each Module's Watt (Drawn by author)

Meter square of each module: 0,6m x 1,2m = 0, 72 m² (CdTe thin-film)

Meter square of total system: 0, 72 m² x 1,500,000 = 1,080,000 m²

As a suggestion, mono-crystalline cell type dimensions 0, 8 x 1, 58 are generating 190 Watts. If 1 mono-crystalline module (190 Watt) is divided with total system power (128,480,000 Watts), number of modules that are going to be used at the system will be found.

Number of modules: 128,480,000 / 190 Watts = 676, 211 mono-crystalline modules needed to install.

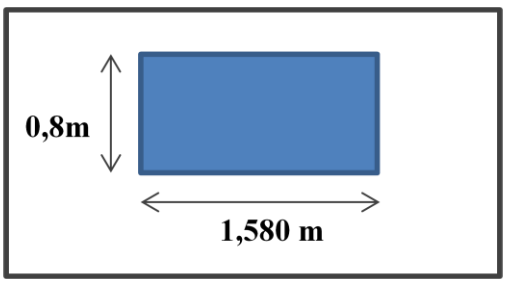


Figure 3.101: Dimensions of 1 Mono-crystalline Module (Drawn by author)

Meter square of each module: 0,8m x 1,580m = 1,264 m²

Meter square of total system: 1,264 m² x 676, 211 = 854,730 m² (suggestion)

By using mono-crystalline cell type modules 225,270 m² will be recovered.

Calculation of the recovered space: 1,080,000 m² - 854,730 m²

(Thin-film) - (mono-crystalline)

3.4.3 Evaluation of Example from Nis in Serbia

Location of the system is in Serbia, Nis. Serbia is in the northern hemisphere and climate type of city is noted as moderate continental climate. In this project, Mono-crystalline silicon solar cell (Siemens solar module SM 55) (Figure 3.105) type is used for testing the best tilt angle for the location. Maximum power of the panel is 55 Watts. Dimensions of the panel are calculated as 31cm x 125cm. Latitude and longitude of Serbia is 43°19" North and 21°54"East. (Pavlovic et al, 2010) Serbia is located to the North-west away from the Cyprus.

Table 23: Evaluation of Example from Nis in Serbia

Characteristics	
Name of the Project	Example from Nis in Serbia
Hemisphere (Location)	Northern Hemisphere
Climate Type	Cold climate
Panel Cell Type	Mono-crystalline
Orientation	Two-way axis sun-tracker system
Tilt Angle	Changeable
Location/Position of Panels	Flat-roof
Supporting Elements	Profile Carriers
Shading	No shade
Ventilation	Sufficient
Panel Organization	Portrait

Figure 3.102: Location of Serbia in the World Map (Maps of World, 2013)

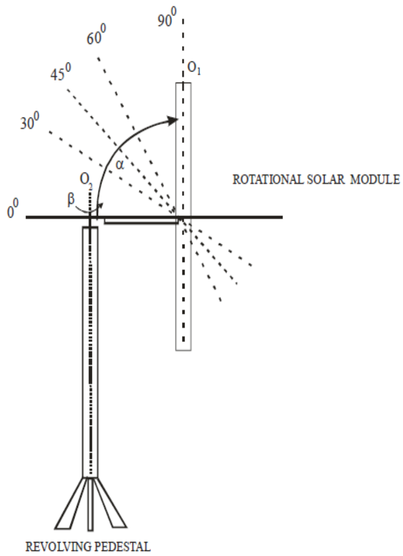


Figure 3.103: Two Way Axis Sun-tracker System (Pavlovic et al, 2010)

Time	Direction and angle of maximal power (*optimal position*)	Power (W)
8	East 60^0	28,20
9	East 45^0	29,67
10	East 45^0	30,00
1	East 30^0	28,31
12	South 30^0	29.18
13	South 30^0	30.80
14	West 30^0	27,60
15	West 30^0	28,69
16	West 45^0	27,44
17	West 60^0	32,33
Total		292,22

Figure 3.104: Values of Power Obtained by Solar Module in Optimal Position (Pavlovic et al, 2010)

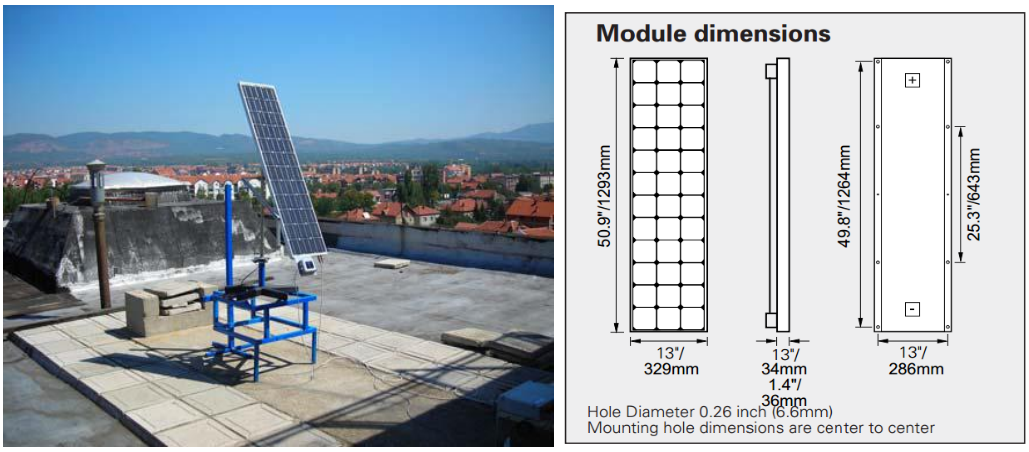


Figure 3.105: Photos are showing the Panel Type on the Roof

Source: First picture (Pavlovic et al, 2010) and Second picture (Siemens, 1998)

It is noted that, between the months from April to October, it is best to use solar energy. Serbia has 272 sunny days during a year. South 30° is the optimal tilt angle in the summer period in Nis. Two way axis sun-trackers used to follow sun from east to west (0° to 180°) and change the tilt angle of the panel. Angels are fixed 0°, 30°, 45°, 60° and 90°.

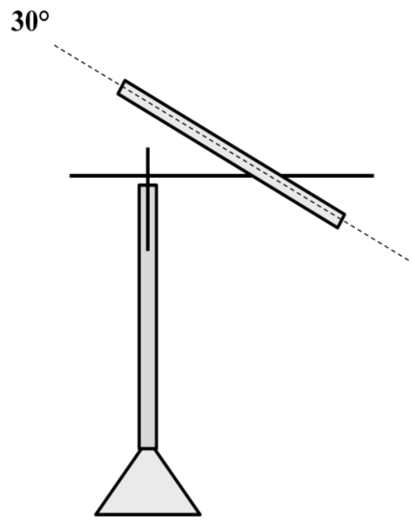


Figure 3.106: Fixed Optimum Tilt Angle for Summer Period in Nis (Drawn by author)

Solar module oriented towards the South gives the greatest value for electrical energy for the angle of 30° of 219.81Wh, which is the maximum registered value for electrical energy. Therefore, optimum tilt angle for summer is calculated as 30° (Figure 3.106) and this means that, optimum tilt angle for summer will be minus 13 degrees of the local latitude. So, optimum tilt angle for winter will be 56°.

3.4.4 Evaluation of Cornish School

Cornish School is located in Cornwall, United Kingdom. Latitude and longitude of Cornwall is noted as 50°26'N, 04°40'W. 333 panels were installed on the roof. One panel has 255 Watts system power. Mono-crystalline cell type panel is selected to generate the electricity. Tilt angle of the panels are observed as 0º. Size of the system power is 84.5kWp and the total surface area of the installation area is 750m². Additionally, aim of the project is for heating gym and swimming pool. 1637 x 997 x 46 mm is the dimensions of the mono-crystalline panels. 10 x 6 number of cells used and landscape panel organization is used. (Sambata, 2012)

Table 24: Evaluation of Cornish School

Characteristics	
Name of the Project	Cornish School
Hemisphere (Location)	Northern Hemisphere
Climate Type	Cold climate
Panel Cell Type	Mono-crystalline
Orientation	No angular direction
Tilt Angle	0°
Location/Position of Panels	Flat-roof
Supporting Elements	Profile Carriers
Shading	Nearby shade by trees
Ventilation	Sufficient
Panel Organization	Landscape

Figure 3.107: Photo shows the General View of the Panels (Sambata, 2012)

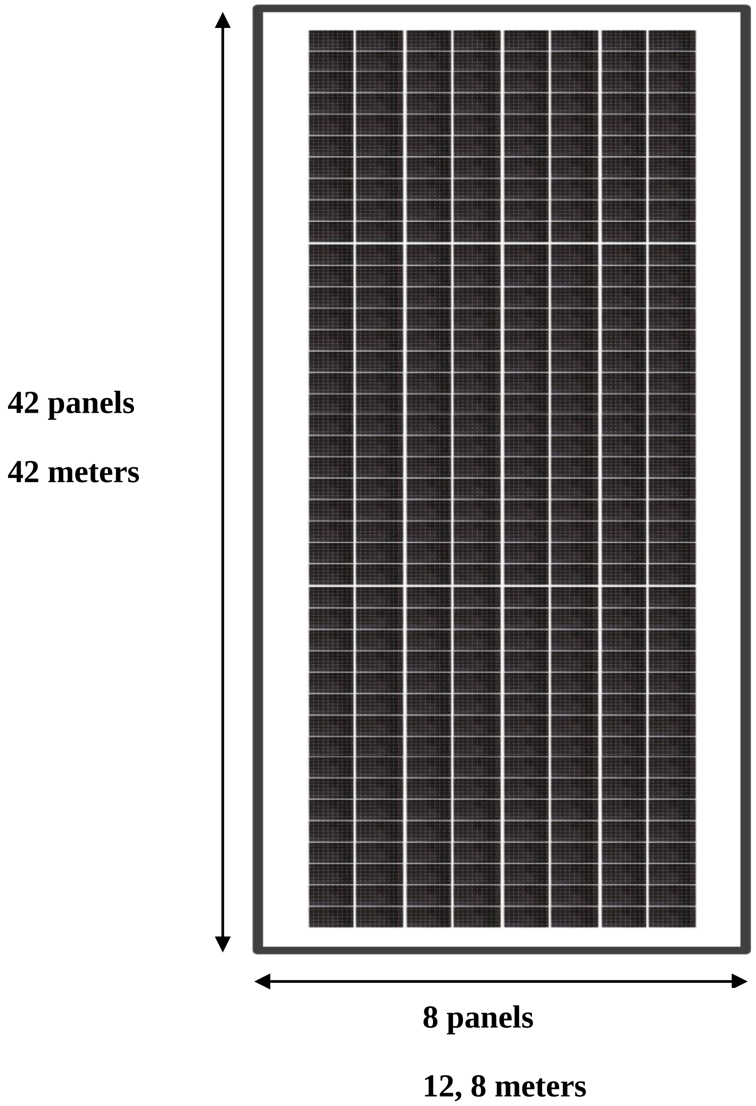


Figure 3.108: Top View Orientation and Organization of the Panels (Drawn by author)

Total meter square of the panels that covers the roof: 42m x12, 8m = 537, 6 m²

Total space that stay empty on the roof: 750m² - 540m² = 210m²

As it can be evaluated that, orientation of the panel is not known because of the tilt angle is 0°. Panels are attached to the roof surface parallel. As it can be suggested that, if panels were tilted with appropriate angle taking in consider the location, efficiency of the panels will increase. Secondly, panels increase the roof insulation because of the cold climate of the region. The aim of the installing of panels without an angle can be the reason to insulate the swimming pool. But this is a disadvantage for the energy efficiency. On the other hand, mono-crystalline cell type selection is the most efficient type for cold climates. Lastly, nearby shading from the trees can be observed from the surface of the panels.

As suggested that there is not extra space on the roof for installing panels with a given tilt angle. If desired angle will be given to panels, each array will be shaded the array that is located at the back. By the way, half of the total panels should not be used if proposed tilt angle will be given to the panels.

3.4.5 Evaluation of Dr. Rhoden's House

Location of the house is in London, England. Panel module type is Mono-crystalline 240Wp Sanyo modules. Installations of the panels were done on the roof. So, Orientations of the panels are 230° South direction. Total system size is 3.6kWp. 15 panels were used to create the system. Panels are covering 19, 2 m² space.

Table 25: Evaluation of Dr. Rhoden's House

Characteristics	
Name of the Project	Dr. Rhoden's House
Hemisphere (Location)	Northern Hemisphere
Climate Type	Cold climate
Panel Cell Type	Mono-crystalline
Orientation	South
Tilt Angle	20°
Location/Position of Panels	On-roof
Supporting Elements	Profile Carriers
Shading	No shade
Ventilation	Sufficient
Panel Organization	Landscape

Figure 3.109: General View of the Total System (Solar century, 2013)

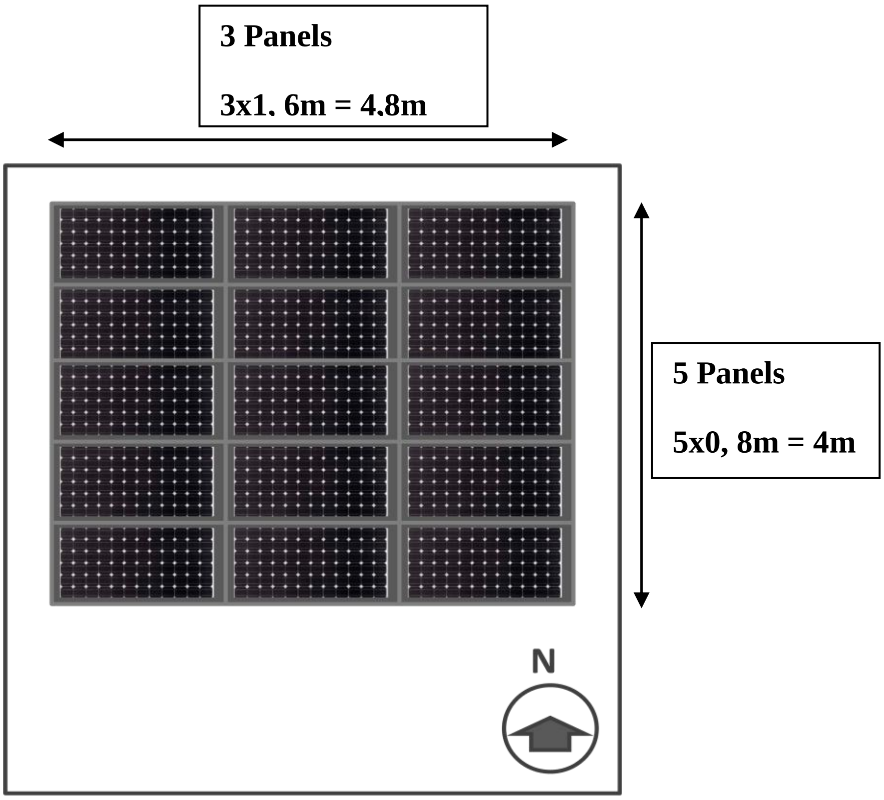


Figure 3.110: Top View of the Panel Orientation (Drawn by author)

Space that panels cover: 4,8m x 4m = 19, 2 m²

Panels were oriented in the most efficient way. Secondly, gap between the roof surface and the panels were designed correctly, panels provides extra insulation for house. On the other hand, mono-crystalline silicon selection is the most efficient for the climate type of London. However, tilt angle is not sufficient for panels to be more efficient. So, if the tilt angles of the panels are 50°, the efficiency of the panels will increases.

3.4.6 Evaluation of Blackfriars Station

Blackfriars Station is located in London, England. Latitude and longitude of the location is noted as 51°30′N, 0°08′W. Station is the biggest solar array in London by mid 2012. Total solar power capacity is 759MW. 4,410 solar panels were used for the solar bridge. The installation space's meter square is calculated as 6,000m². 900,000kWh of electricity generated every year. System is providing 50% of the station's electricity energy. Arrays are looking to the south direction.

Table 26: Evaluation of Blackfriars Station

Characteristics	
Name of the Project	Blackfriars Station
Hemisphere (Location)	Northern Hemisphere
Climate Type	Cold climate
Panel Cell Type	Hybrid (HIT)
Orientation	South
Tilt Angle	25°
Location/Position of Panels	Shading Device
Supporting Elements	Profile Carriers
Shading	No shad
Ventilation	Sufficient
Panel Organization	Landscape

Figure 3.111: General View of the Station with the Photovoltaic Arrays (Solar century, 2013)

Figure 3.112: Orientation of the Arrays (Renewable Technology, 2013)

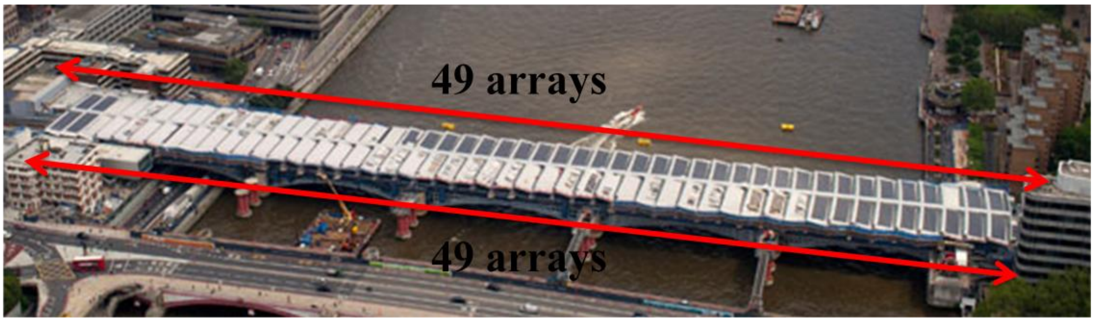


Figure 3.113: Total View of the Arrays on the Station (Guardian, 2012)

It can be seen from the Figure 3.113 that arrays are oriented on 2 rows. 49 arrays were oriented to the left and 49 arrays oriented to the right row. There are 98 numbers of arrays which one array created with 45 panels at the total system power.

By the way, as 49 arrays can be multiplied with 45 panels, 4,410 panels can be found in the total.

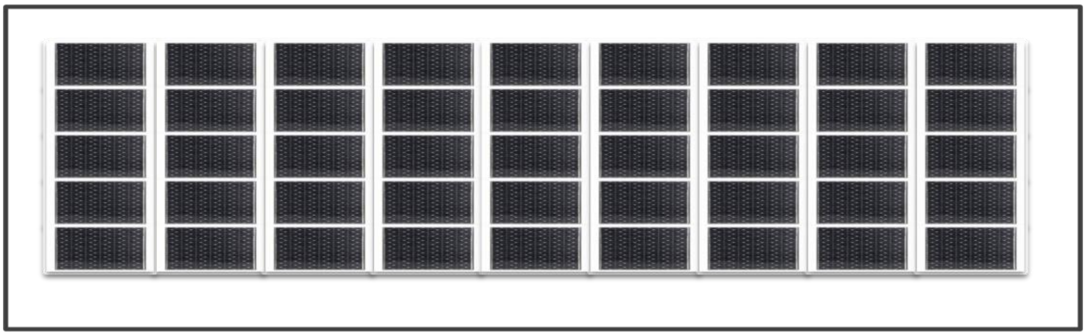


Figure 3.114: Top View of 1 Array (Drawn by author)

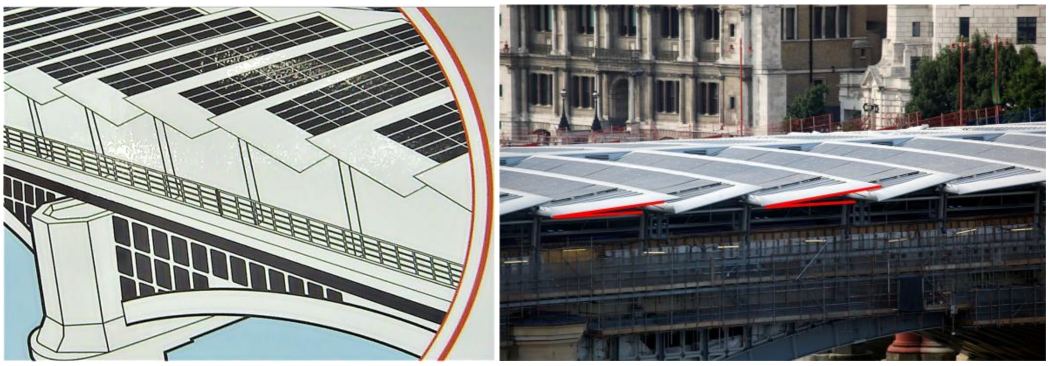


Figure 3.115: Photos show the Current Tilt Angle of the Panels (Bloomberg, 2012)

Source: http://greentrailsandteapottales.files.wordpress.com/2012/08/snv80953.jpg

Sanyo Hybrid HIT (Hetero junction with Intrinsic Thin Layer) Solar Cell type panels were used. This kind of solar cell is composed of a mono-thin crystalline silicon wafer surrounded by ultra-thin amorphous silicon layers. (Hellotrade, 2012)

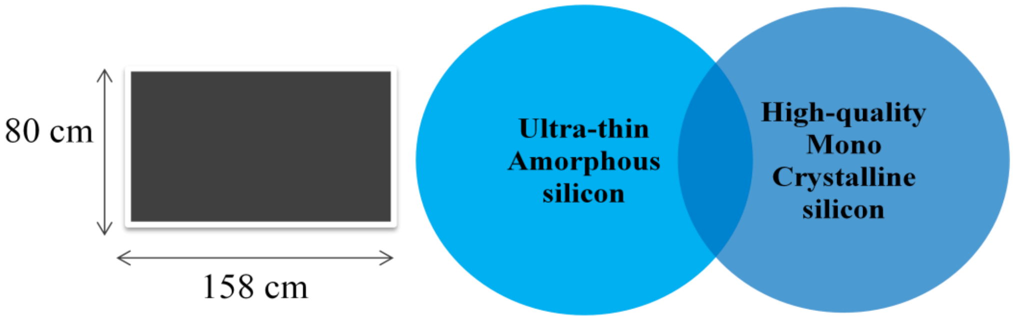


Figure 3.116: Hybrid (HIT) is the Mixture on Thin-film Amorphous Silicon and Mono-crystalline Silicon

As can be evaluate that orientation of the panels were used to south direction, by the way, orientation was done in most efficient way. Secondly, there is no shade from the front panels, distance that is left between the two arrays is calculated and applied sufficiently. Like at the previous cases, panels are providing insulation, so there is no need to leave gap between the supporting element and the panel. Lastly, tilt angle of the panels are 25°. However, tilt angle is not sufficient for the most efficient energy production. Therefore, tilt angle of the panels can be plus 15 or 25 degrees more.

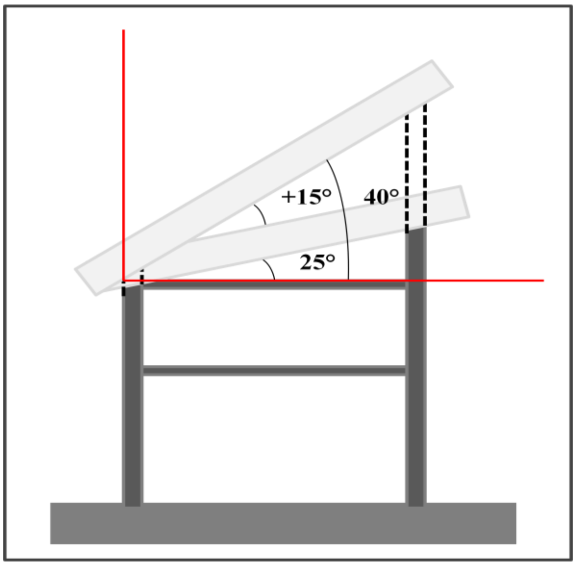


Figure 3.117: Suggested Optimum Tilt Angle for Blackfriars Station (Drawn by author)

3.4.7 Evaluation of House in Staffordshire

House is located in Staffordshire, UK. System power (system size) is 2.88kWp. 12 numbers of poly-crystalline cell type panels were installed for generating electricity. Installation/location of the panels were done on the roof space. Installation type is on-roof design. Installation was done on 19, 6 m². At the same time, panels were oriented to south direction and tilt angle is noted as 31°. Each panel has 1, 65 x 0, 99 dimensions and organized as landscape. By the way, each panel has 1,63m². Latitude of Staffordshire is noted as 52.76°N.

Table 27: Evaluation of House in Staffordshire

Characteristics	
Name of the Project	House in Staffordshire
Hemisphere (Location)	Northern Hemisphere
Climate Type	Cold climate
Panel Cell Type	Poly-crystalline
Orientation	South
Tilt Angle	31°
Location/Position of Panels	On-roof
Supporting Elements	Profile Carriers
Shading	No shade
Ventilation	Sufficient
Panel Organization	Landscape

Figure 3.118: Landscape Oriented Panels on the Roof Surface

Source: http://www.c-changes.com/carefully-designed-pv-systems

Figure 3.119: Mounting the Profile Carriers of the Panels on the Roof Surface

Source: http://www.c-changes.com/carefully-designed-pv-systems

As seen from the Figure 3.119 that, panels' support type is roof hooks and profile carriers. Tilt angle of the panels were given by using the current slope of the pitched roof.

Figure 3.120: Location of Staffordshire in UK map (Wikipedia, 2010)

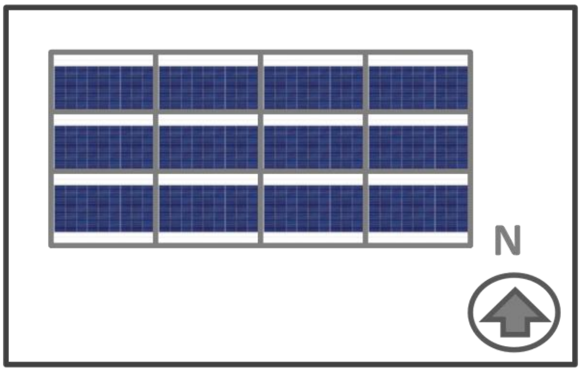


Figure 3.121: Top View of the Panels (Drawn by author)

Firstly, as an evaluation orientation of the panels were done sufficient according to the rules. At the same time, poly-crystalline cell type panels are suitable also for colder countries. Distance between the roof space and the panels are enough for ventilation. (Panels can be closer to the roof surface for increasing the heat insulation) However as a disadvantage, average tilt angle can be higher for increasing the efficiency of the production. Optimum tilt angle can be plus 15 in winter times and minus 15 in summer times. By the way, tilt angle for winter can be 65° and 35°

for summer times. Calculation of the tilt angle is done according to the average latitude of UK is taken as 50°.

Winter Tilt Angle: 50° + 15° = 65°

Summer Tilt Angle: 50°- 15° = 35°

For this reason, average tilt angle should be equal to the latitude. Average tilt angle of England should be 50° seen in Figure 3.123.

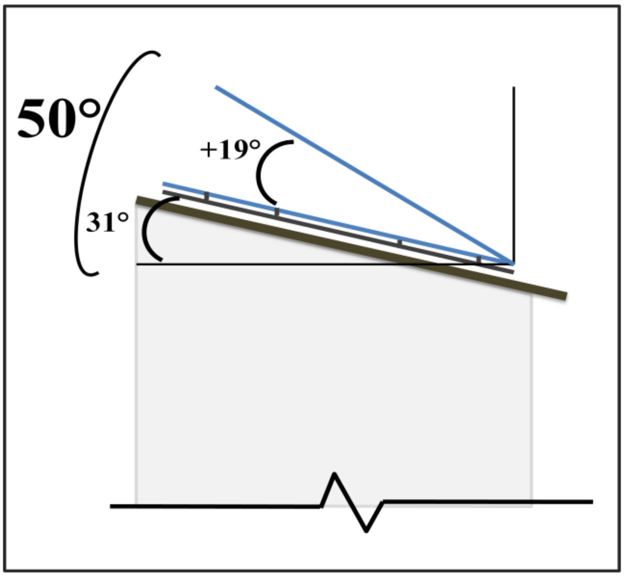


Figure 3.122: Suggestion for the House in Staffordshire (Drawn by author)

3.4.8 Evaluation of Houses in Shirley

House is located in Shirley, UK. Total system power is 20.7kWp. Poly-crystalline cell type is selected. Locations of the panels were done on the roof surface. Installation was completed in June 2010. Aim of the project is to generate own electricity. Panels were oriented east, west and south-east and tilt angle of the panels were noted as 30°. Solar irradiation of Shirley is 1100 kWh/m². Additionally location of the Shirley is at the south of the UK seen from Figure. By the way, more warmer compared to the other parts of the UK.

Table 28: Evaluation of House in Shirley

Characteristics	
Name of the Project	Houses in Shirley
Hemisphere (Location)	Northern Hemisphere
Climate Type	Cold climate
Panel Cell Type	Poly-crystalline
Orientation	East, West and South-East
Tilt Angle	30°
Location/Position of Panels	On-roof
Supporting Elements	Profile Carriers
Shading	No shade
Ventilation	Sufficient
Panel Organization	Landscape and Portrait together

Figure 3.123: Location of Shirley in UK Map

Source: http://www.postcode-info.co.uk/shirley-info-73478.html

Figure 3.124: Photo shows the 1st House and the Top View (Portrait Organization)

1st Source: http://www.c-changes.com/greenest-street-in-derbyshire

2nd Source: Drawn by author

Figure 3.125: Photo shows the 2nd House Panel and the Top View (Portrait and Landscape Organization)

1st Source: http://www.c-changes.com/greenest-street-in-derbyshire

2nd Source: Drawn by author

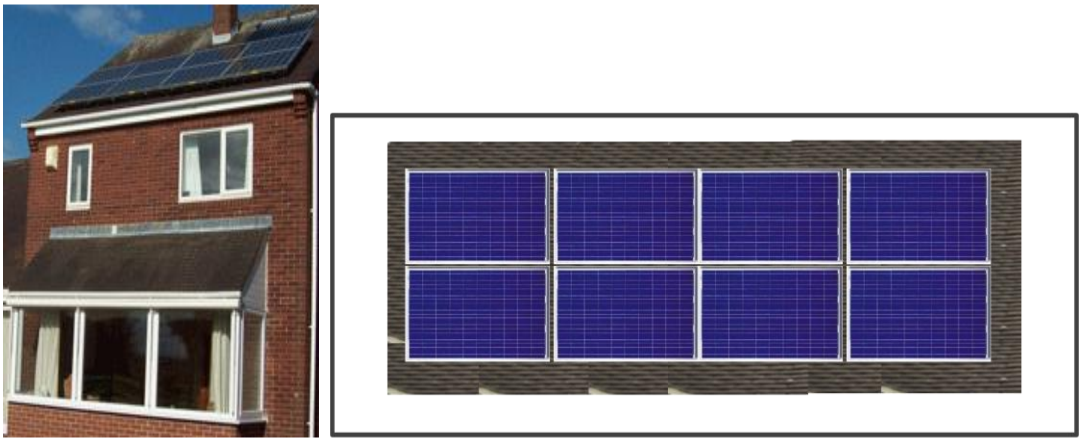


Figure 3.126: Photo shows the 3rd House Panel and the Top View (Landscape Organization)

1st Source: http://www.c-changes.com/greenest-street-in-derbyshire

2nd Source: Drawn by author

Figure 3.127: Photo shows the 4th House Panel and the Top View (Portrait Organization)

1st Source: http://www.c-changes.com/greenest-street-in-derbyshire

2nd Source: Drawn by author

Figure 3.128: Photo shows the 5th House Panel and the Top View (Portrait Organization)

1st Source: http://www.c-changes.com/greenest-street-in-derbyshire

2nd Source: Drawn by author

Figures show the east, west and south-east orientation of the panels. Total installation was done on 155,25m² space. 5 houses in Shirley used solar panel system on their different kind of roofs. The entire roofs slope is calculated as 30°.

First of all, there was not enough roof space looking to the south direction. By the way, panels were oriented to the east, south and south east direction. As suggested if there has enough space 62 panels can be oriented side by side and compose 1 array looking to the south direction. By this kind of installation, panels will get more solar irradiation and can be more efficient.

Secondly, tilt angle of the panels were 30°. However, 30° is not sufficient for the average tilt angle of the location. Average tilt angle of the panels should be plus 20° on the current slope of the roofs. Angle can be given by the roof hooks and the profile carriers. On the other hand, poly-crystalline silicon selection can be suitable according to the climatic conditions of the location.

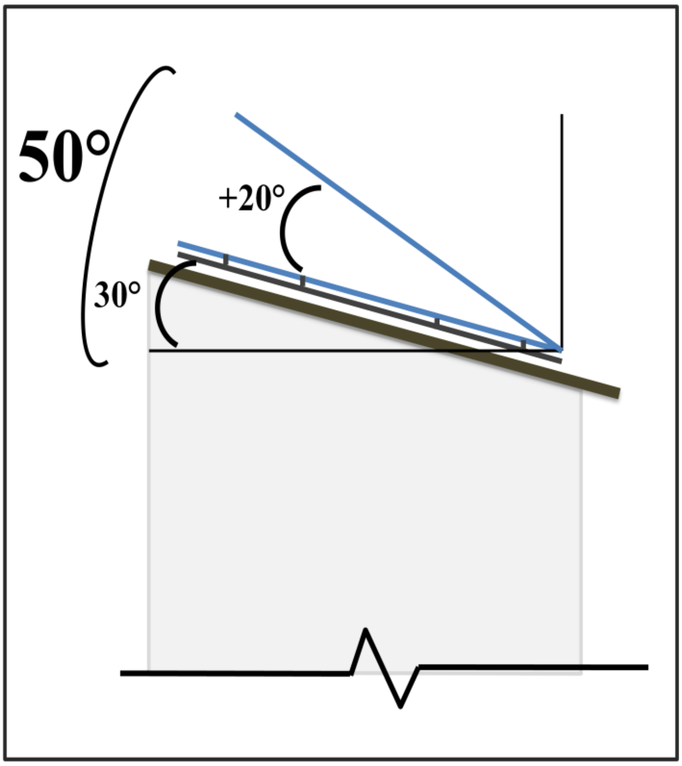


Figure 3.129: Optimum tilt angle for house in Shirley (Drawn by author)

3.4.9 Evaluation of House in Burton on Trent

House is located in Burton (also known as Burton on Trent) that is at the east of the Staffordshire, UK. Total system power is 3.885kWp. Polycrystalline cell type panels were selected for the installation. Installation was done on the 40 ° pitched roof. Panels installed parallel to the roof surface so tilt angle is 40°. 21 numbers of panels were installed and oriented to the south, east and west direction. Poly-crystalline 21 panels cover an area of 29.1m² tile roofs.

Calculation of total meter square of panels: (3.88x30) / 4 = 116.4/4 = 29.1 m²

Table 29: Evaluation of House in Burton on Trent

Characteristics	
Name of the Project	Houses in Burton on Trent
Hemisphere (Location)	Northern Hemisphere
Climate Type	Cold climate
Panel Cell Type	Poly-crystalline
Orientation	South, east and west
Tilt Angle	40°
Location/Position of Panels	On-roof
Supporting Elements	Profile Carriers
Shading	No shade
Ventilation	Sufficient
Panel Organization	Landscape and Portrait together

Figure 3.130: Photo shows the General View of the Panels

Source: http://www.c-changes.com/overcoming-shading

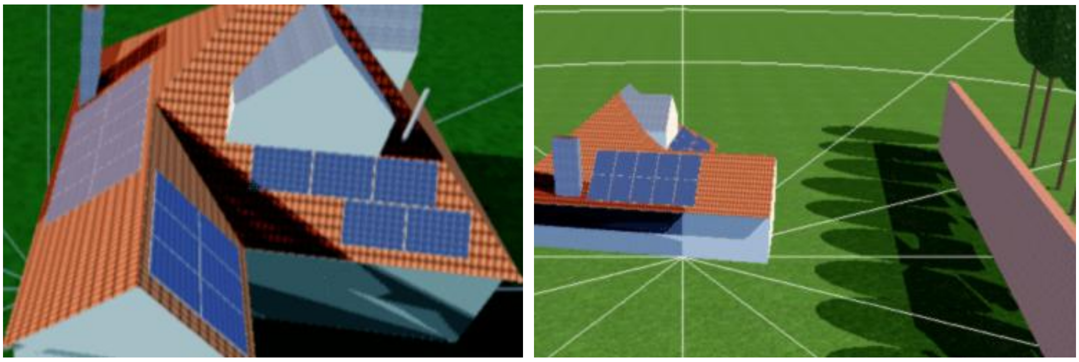


Figure 2.131: 3Dimensional Drawings of the House together with the Panels

Source: http://www.c-changes.com/overcoming-shading

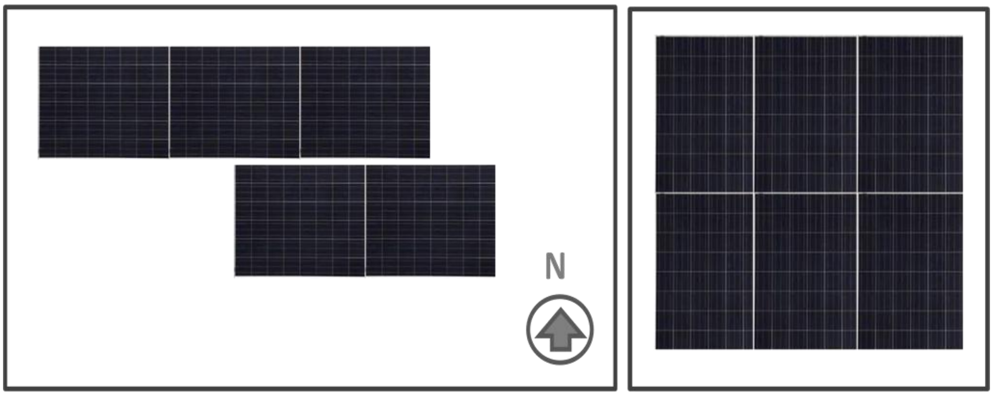


Figure 3.132: Top View of Panels looking to the South Direction and East Direction (Drawn by author)

Panels that are looking to the south direction are organized as landscape and secondly, panels that are looking to east and west direction are organized as portrait.

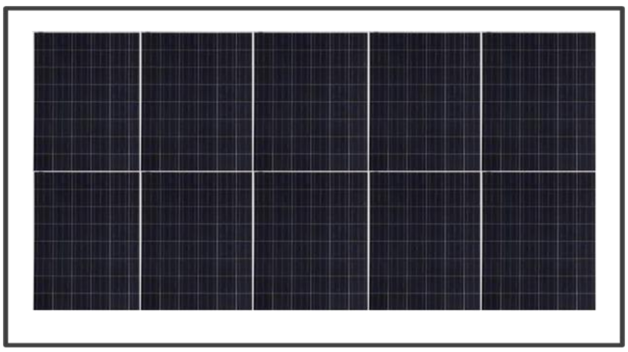


Figure 3.133: Top View of Panels looking to the West Direction (Drawn by author)

There is not enough space on the roof surface to install all of the panels looking to the south direction. Therefore, one part of the panels oriented to west and east direction. Only small back roof is facing to south direction. This causes a decrease at the efficiency of the panels. Secondly, there is no shade cause from the neighbor houses or from the trees as seen from the 3D Figure. Tilt angle can be +10 more over the existing system. (Or tilt angle is correct, if panels stay parallel to the roof surface)

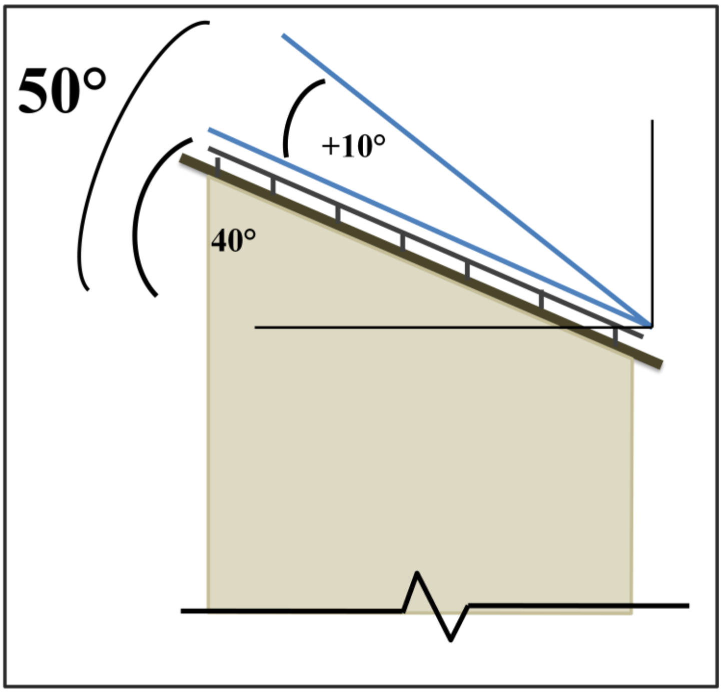


Figure 3.134: Optimum Tilt Angle for the House in Burton (Drawn by author)

As an alternative suggestion, if there is enough space at the garden of the house, panels can be installed by using freestanding positioning type both using landscape organization and portrait organization together with sun-tracker systems.

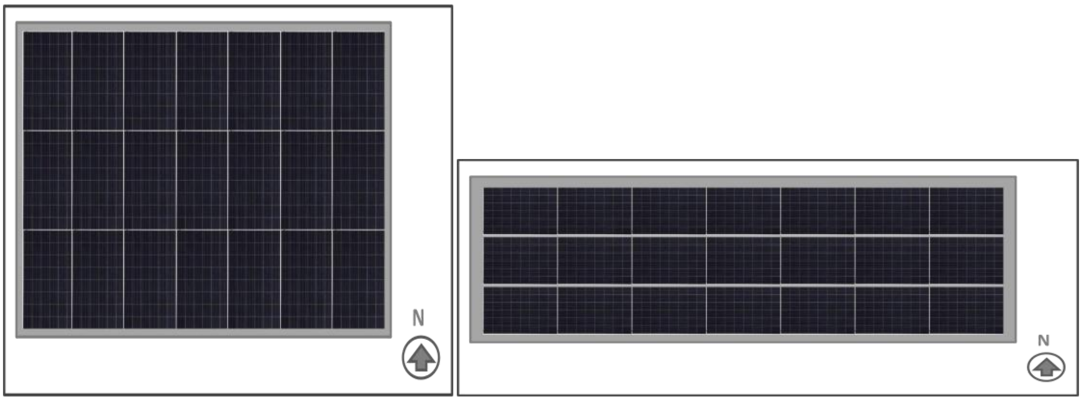


Figure 3.135: Alternative Portrait and Landscape Organized 21 panels with Sun-tracker System on Freestanding Location (Drawn by author)

3.4.10 Evaluation of House in Repton

House is located in Repton, Derbyshire in UK. Total system power is 3.995kWp and 17 numbers of poly-crystalline cell type panels were used. Each panel generates 235 Watts. Location/ Position of the installation was done on the roof surface of the building and oriented to the west direction. The pitch of this roof is very steep at around 48°. So, tilt angle of the panels can be noted as 48 degrees. Panels cover 29.97 ≈ 30 meter square of the roof surface.

Calculation of total meter square of panels :(3.995 x 30)/4 = 119.85/4 = 29.97 m²

Table 30: Evaluation of House in Repton

Characteristics	
Name of the Project	House in Repton
Hemisphere (Location)	Northern Hemisphere
Climate Type	Cold climate
Panel Cell Type	Poly-crystalline
Orientation	West
Tilt Angle	48°
Location/Position of Panels	On-roof
Supporting Elements	Profile Carriers
Shading	No shade
Ventilation	Sufficient
Panel Organization	Portrait

Figure 3.136: General View of Poly-crystalline Panels Located on the Roof Surface (Portrait Organization)

Source: http://www.c-changes.com/west-facing-roof-in-repton

17 Poly-crystalline panels, organized portrait in 3 rows as seen from Figure 2.138.

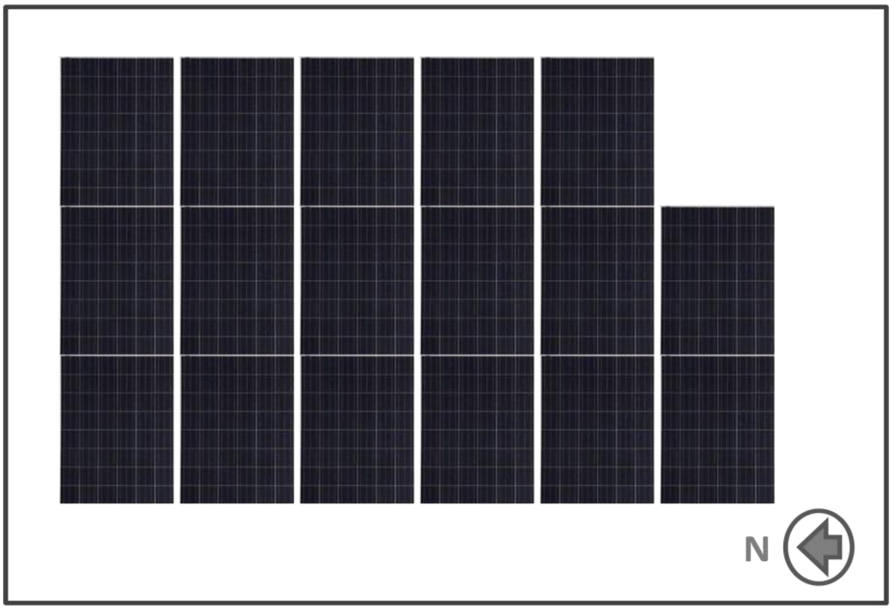


Figure 3.137: Top View of Portrait Organized Panels looking to the West Direction (Drawn by author)

If the installation is evaluate, orientation of the panels was designed to west direction because of lack of space on the roof. If there is enough space at the garden; panels can be organized to the south direction. However, tilt angle of the installation is sufficient.

3.4.11 Evaluation of House in Quarndon, Derby

House is located in Quarndon, Derby UK. Total system power of the PV installation is 4kWp. 17 poly-crystalline cell type panels were installed on the roof surface and oriented to the south direction of the pitched roof. Angle of the pitched roof is calculated as 38°. Each panel’s generation capacity is 235 Watts.

Table 31: Evaluation of House in Quarndon,Derby

Characteristics	
Name of the Project	House in Quarndon, Derby
Hemisphere (Location)	Northern Hemisphere
Climate Type	Cold climate
Panel Cell Type	Poly-crystalline
Orientation	South
Tilt Angle	38°
Location/Position of Panels	On-roof
Supporting Elements	Profile Carriers
Shading	No shade
Ventilation	Sufficient
Panel Organization	Portrait

Figure 3.138: Poly-crystalline Panels were Installed on the Roof and Organized Portrait

Source: http://www.c-changes.com/black-framed-panels-in-derby

Panels were organized portrait in 2 rows. First row includes 8 panels and second row includes 9 panels.

Figure 3.139: 3Dimensional View of the Building (C-changes, 2013)

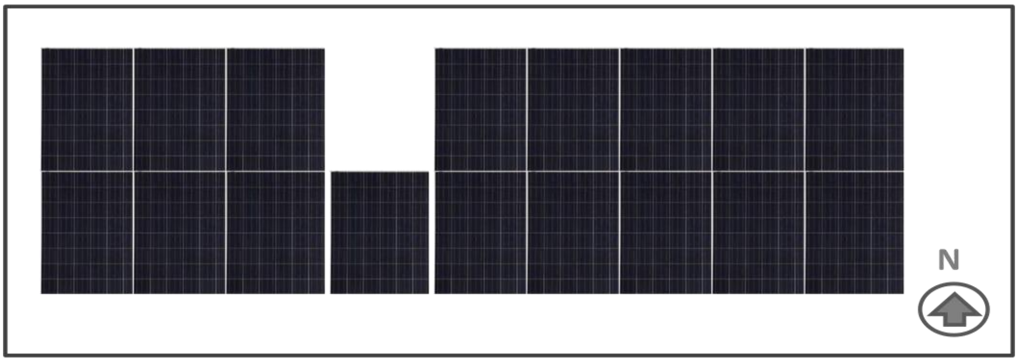


Figure 3.140: Top View of the Array (Drawn by author)

As an evaluation of the building that, orientation, average tilt angle, shade and ventilation was designed as sufficiently. By the way, no need to give extra suggestion for the installation.

3.4.12 Evaluation of Example from Ashbourne

Location of the building is in Ashbourne, UK. Total system power of the installation is 6.5kWp. 27 poly-crystalline cell type panels were used for the installation. Each panel generates 240 Watts. Angle off the roof pitch is calculated as 35°. Panels oriented on the two pitched roof looking to the south direction. Panels were installed on 48, 75 meter square space.

Calculation of total meter square of panels: (6.5 x 30) / 4 = 195 / 4 = 48, 75 m²

Table 32: Evaluation of Example from Ashbourne

Characteristics	
Name of the Project	Example from Ashbourne
Hemisphere (Location)	Northern Hemisphere
Climate Type	Cold climate
Panel Cell Type	Poly-crystalline
Orientation	South
Tilt Angle	35°
Location/Position of Panels	On-roof
Supporting Elements	Profile Carriers
Shading	No shade
Ventilation	Sufficient
Panel Organization	Portrait

Figure 3.141: General View of the Panels Installed on the Two Pitched Roofs

Source: http://www.c-changes.com/farms-and-rural-locations

Figure 3.142: View of the Front Building with the Panels

Source: http://www.c-changes.com/farms-and-rural-locations

At the front building; 18 panels were installed in two rows and portrait organization method is selected. On the other hand, 9 panels were installed at the back part of the building. Panels were designed portrait like in the front building in order to look similar to each other. However, panels were designed only in 1 row.

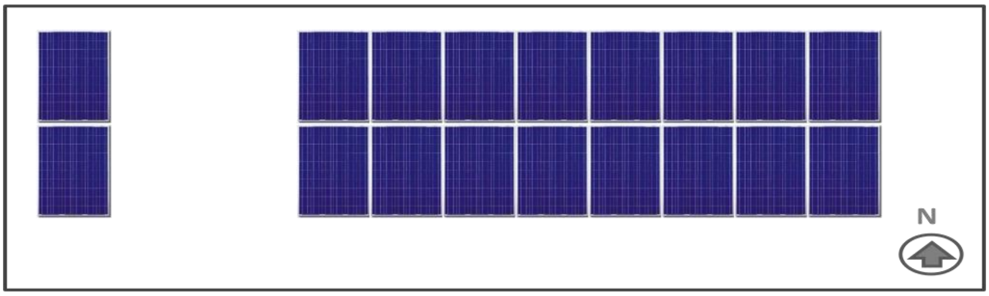


Figure 3.143: Top View of Panels on Front Building (Drawn by author)

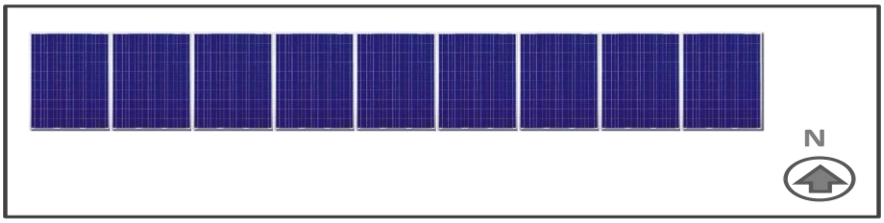


Figure 3.144: Top View of Panels on Back Building (Drawn by author)

Panels on the back roof were mounted as high up as possible and out of the valley area, so that they were not badly affected by shade from the front barn seen from Figure 3.141. (C-changes, 2013) Front building is supported with additional strengthening work to the purlins. Because the roof structure age is too old. (C-changes, 2013)

In order to get more sun light on the panels, current tilt angle of the panels should be +15° more. On the other hand direction of the panels and the selection of PV cell type appropriate for high energy efficiency.

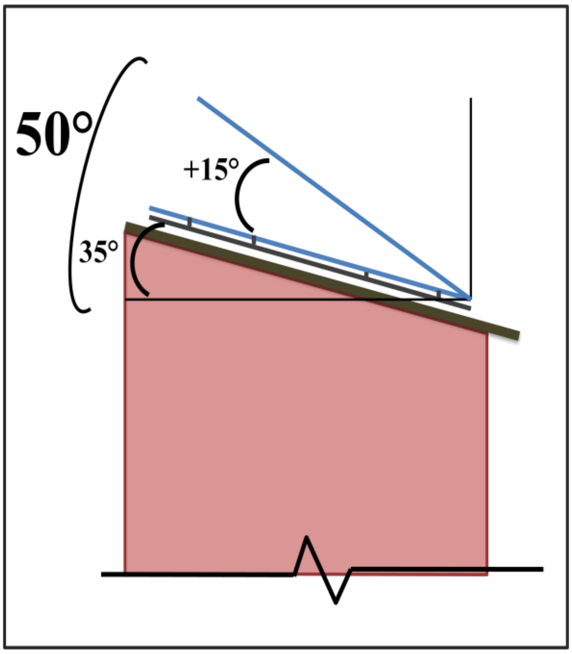


Figure 3.145: Optimum Tilt Angle for the Buildings (Drawn by author)

3.4.13 Evaluation of Example from Derbyshire

Installation of the panels was done in front of the church attached to the building skin. 16 numbers of Poly-crystalline cell type panels were used for the installation. Each panel has capacity to generate 245 Watts. Total system size is 3.92kWp and oriented to the southward direction. Because of the existing roof slope, panels were preferred to install on the current slope of the roof. (On-roof installation type) Slope of roof pitch is 9°.

The panels look fantastic on the roof and were positioned so that they are away from the surrounding parapet to prevent shading issues but also so that they cannot be seen from ground level anywhere in the surrounding area. (C-Changes, 2013)

Table 33: Evaluation of Example from Derbyshire

Characteristics	
Name of the Project	Example from Derbyshire-church
Hemisphere (Location)	Northern Hemisphere
Climate Type	Cold climate
Panel Cell Type	Poly-crystalline
Orientation	South
Tilt Angle	9°
Location/Position of Panels	Façade
Supporting Elements	Profile Carriers
Shading	No shade
Ventilation	Sufficient
Panel Organization	Portrait and landscape

Figure 3.146: General View of the Panels Installed to the Facade of Building

Source: http://www.c-changes.com/church-lead-roof-installation

As seen from Figure 3.146 that, two rows of arrays designed to the facade of the church. First group of array that is attached to the building skin is designed as portrait (vertical) and the second group of array is designed as portrait.

Figure 3.147: Photos are showing inverter and the structure of the profile carriers

Source: http://www.c-changes.com/church-lead-roof-installation

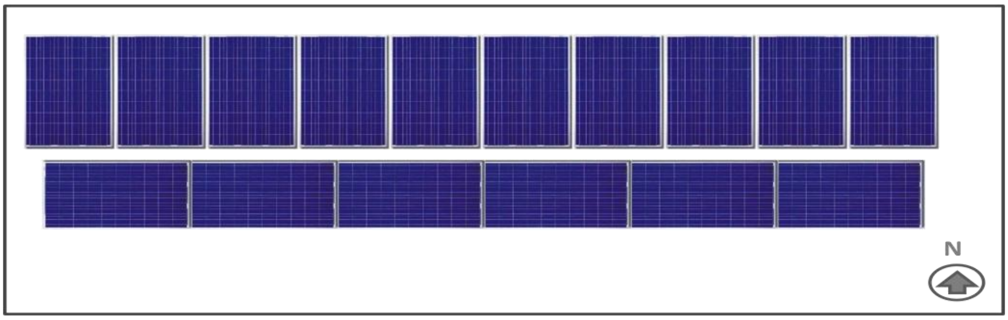


Figure 3.148: Top view of the 16 poly-crystalline panels (drawn by author)

If the installation is evaluated, the orientations of the panels were done sufficient to the southwards direction. However, current tilt angle is very inadequate. There is too much energy efficiency lost. In order to be an optimum tilt angle +41° (plus 41 degrees) is needed for better energy efficiency. If the optimum tilt angle is raised to 41° degrees, the front array will be shaded by the array at the back. There is not enough space at the installation area because if the front array were installed some more distance away from the back array, parapet wall will be shade the panels on the front array. (Figure 3.149) On the other hand, there is not ventilation and shading problem coming from trees or neighbors at the current installation

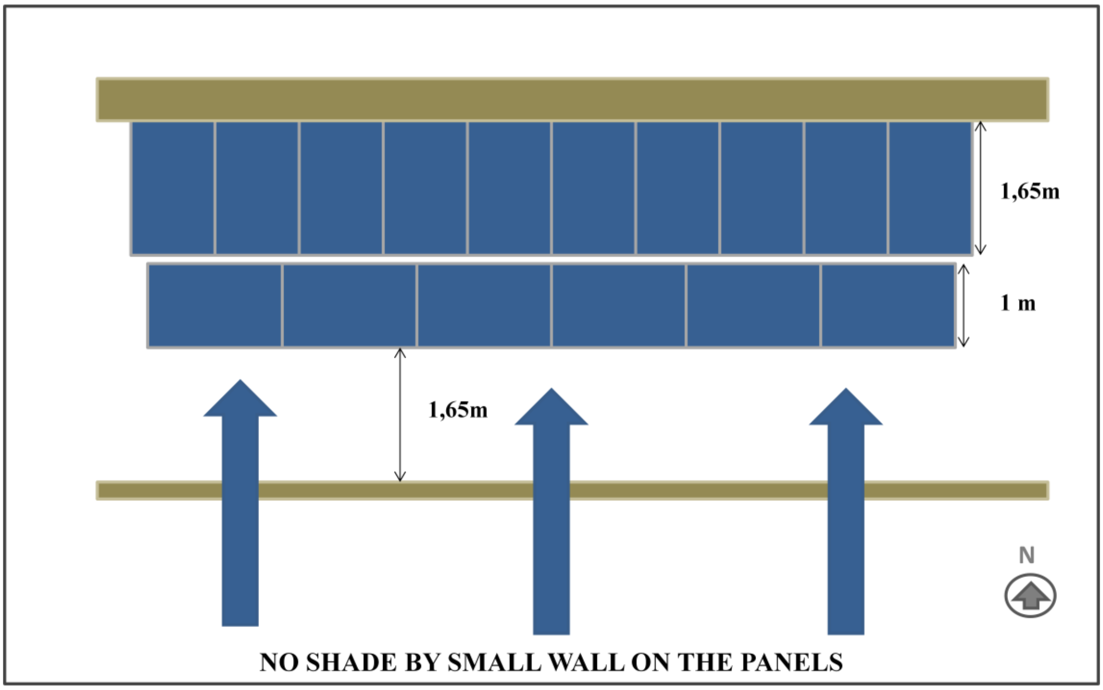


Figure 3.149: Evaluation of Current System (Drawn by author)

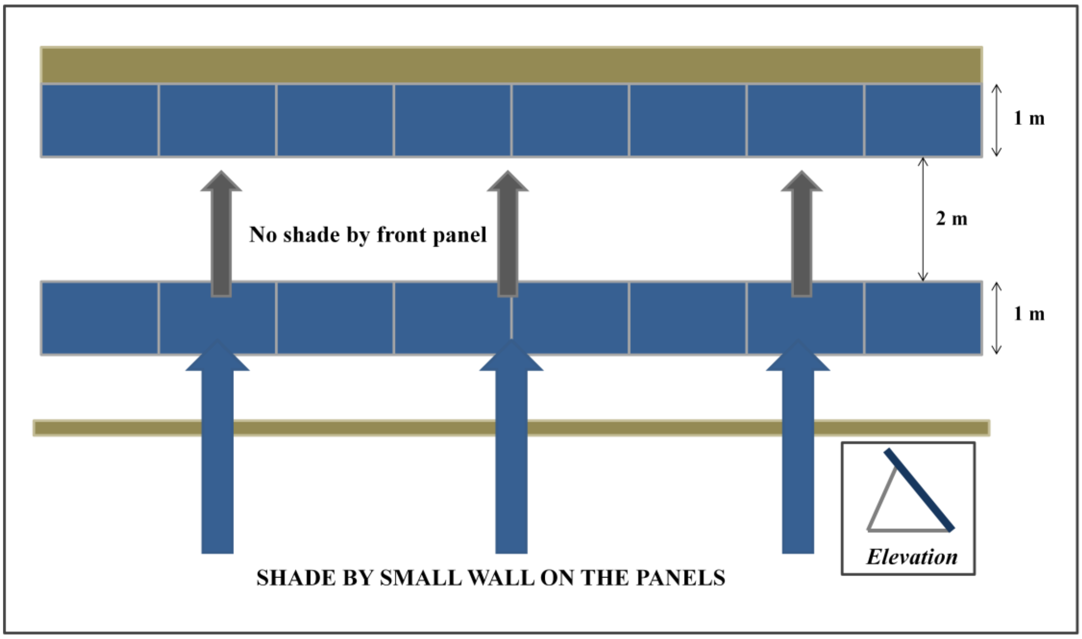


Figure 3.150: Suggested System (Drawn by author)

No matter, what is done in this space, there will be mistakes about shading and at the tilt angle of the installation by the way another kind of application should be done. As an alternative suggestion, if there is enough area at the site of the building, ground mounts system application can be done. There is not enough space at the facade and roof space for the installation.

3.5 General Evaluation of Cold Climate Case Studies

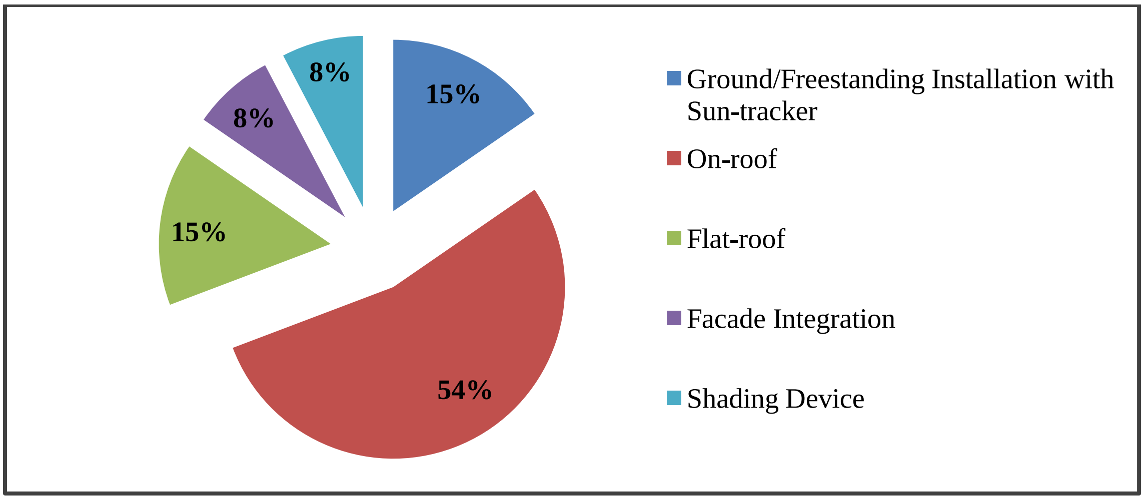


Figure 3.151: Percentage of Position/Location used at 13 Cold Climate Cases

As seen in Figure 3.151 that pitched roof space is selected mostly for the installation of PV panels approximately 54%. Secondly, the most selected location is ground mount installation with sun-tracker system and flat roof approximately 15% each. The least selected space is the facade and shading devices. On the other hand, the most selected cell type is poly-crystalline silicon compared to the other types. Poly-crystalline is used in 54% of the projects and hybrid (HIT) is used only in 8% of the projects.

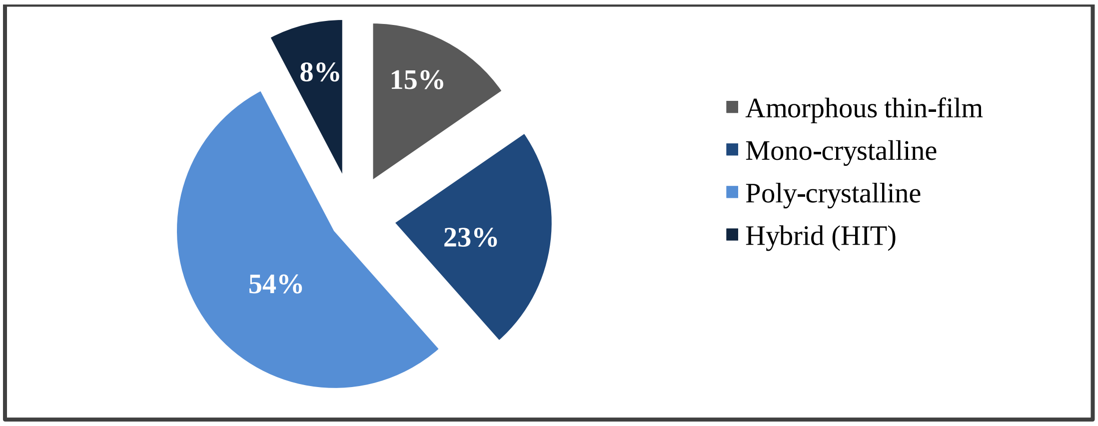


Figure 3.152: Percentage of Cell Type used at 13 Cold Climate Cases

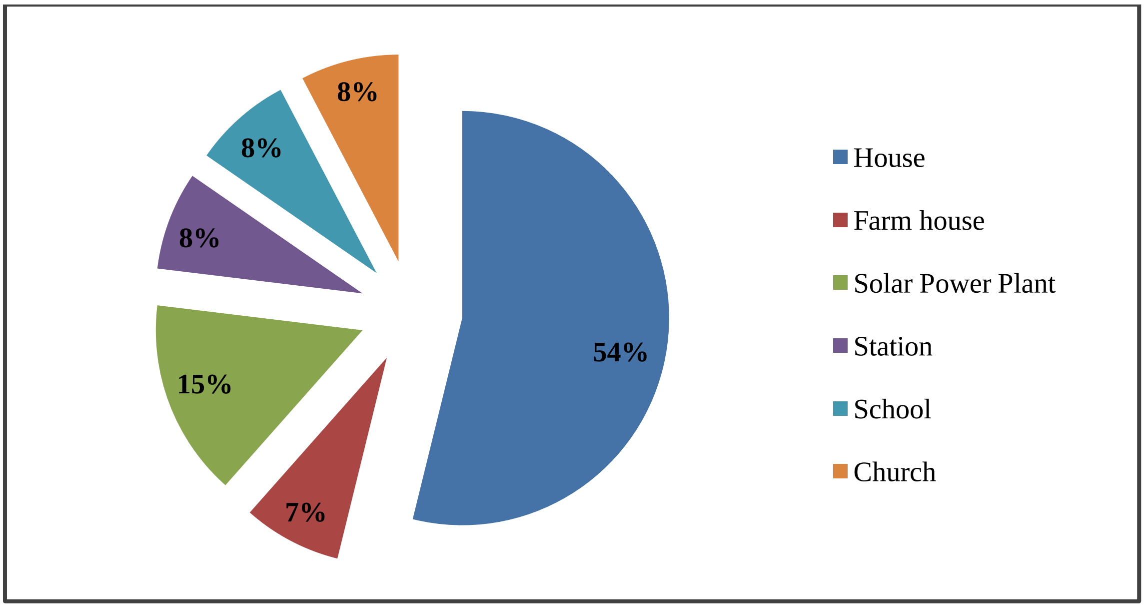


Figure 3.153: Percentage of Installation According to the Usage at 13 Cold Climate Cases

According to the Figure 3.153 that PV panel usage is mostly used at houses approximately 54%. Secondly, usages of PV panels were done at solar power plants. Lastly, the least usage of PV panels is at buildings like farm houses, stations, schools and churches.

3.6 Discussion for Usage of PV in Hot and Cold Climates

At the end of the Chapter 3, it can be said that poly-crystalline cell type panels were selected mostly at hot and cold climate case studies. This is because poly-crystalline cell type has high efficiency at hot and cold climates.

Cell types: There is a reason in hot climates that, poly-crystalline cell type has higher power output efficiency compare to mono-crystalline and amorphous thin film cell types in high level of average solar irradiation however poly-crystalline cell type has lower power output in low level compared with mono-crystalline and amorphous thin film cell type. At the same time, it is understood that Amorphous thin- film PV modules and polycrystalline PV modules are the most suitable type of PV to be used under hot climates like Cyprus. Amorphous thin-film cell is the best efficient panel for hot climates however at thin-film more installation space is needed compared to mono-crystalline and polycrystalline cell type. So, polycrystalline cell type is selected mostly.

Secondly, Mono-crystalline is better to use in high average solar radiation however efficiency decreases at too much solar irradiation. Therefore, mono-crystalline cell type panels were not appropriate for Cyprus climatic conditions. Because power output of cells will drop as the module temperature reaches high values.

Tilt Angle: Optimum tilt angle of the panels can change the efficiency of the panels. As it can be discussed, at hot climate case studies, most of the tilt angles were done correctly. On the other hand, in contrast at cold climate case studies most of the tilt angles were not appropriate for receiving the maximum solar irradiation.

Ventilation and Supporting: Correct designs of the supporting elements of the panels are playing an important role during the installations. The reason is that, ventilation of the panels can increase the efficiency of the panels in hot climates. At some of the cases in hot climate studies, there is not enough space between the roof surface and the panels were observed. These kinds of applications can cause a decrease at the efficiency. By the way, there should be an adequate gap between the panel and roof/facade/ground surface. Therefore, ventilation problem should be solved for too hot climates in order to get the best efficiency.

On the other hand, it is not important to do this kind of application at the cold climates. In-roof installation type can increase the roof insulation. At cold climate case studies, in general gap between panels and the roof were done as it should be.

Shading: Another important point is shading. At some of the cases both in hot and cold climates, panels were shaded by high trees. Surrounding of the building or site should be observed well before doing the installation.

Orientation: At most of the cases at hot and cold climates, orientation of the panels was done wrong. Some were done without making calculation and observation, randomly. However, some were done since there is not another choice.

Organization: It is same at both hot and cold climates. If there is enough space, there is no importance to install portrait or landscape. However at some cases, if there is not too much area, organizations of the panels play an important role.

Location/Position: There is no difference at the location of PV in hot and cold climates. If there is enough space at the building and at surrounding, panels can be installed where the user wants. In some cases, although there is appropriate place at ground, panels were installed on inappropriate roof or facade space.

Table 34: Comparison of Mono-crystalline Cell and Amorphous Cell Type (Drawn by author)

COMPARISON	
PV MODULES	**EXPLANATION**
Mono-crystalline Cell type (M-si)	Mono-crystalline PV is better in high average solar radiation. As the module temperature reaches to high values, power output of cells drop. Market share of cell is 30%
Amorphous Thin film (A-si)	Amorphous PV module produces more power in low intensity of solar irradiation. Amorphous has cooler module temperature than poly-crystalline and mono-crystalline. Market share of cell is %10
Poly-crystalline Cell type (P-si)	Poly-crystalline cell type is most appropriate cell type for both hot and cold climates. Market share of cell is %60

Table 35: General Evaluation of Different Installation Types in Hot and Cold Climates (Drawn by author)

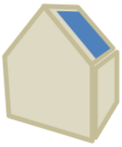
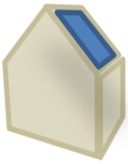
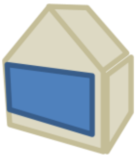
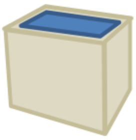
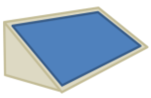
Installation Location	Cell Type	Supports	Orientation	Tilt Angle	Ventilation	Shading
In-roof 	Thin-film (Suitable for hot and cold climates) Mono-crystalline (Suitable for cold climates) Poly-crystalline (Suitable both hot and cold climates)	Profile carriers	Modules Panels Arrays must be oriented to the South direction in Northern Hemisphere and must be oriented to North direction in Southern Hemisphere	At in roof PV panel design, appropriate angle should be given during the constructions of the roofs.	No ventilation Suitable for colder countries. Provides insulation	If models connected to each other; no shading from the panels If Enough space is left between two panels; no shading. (Space can be equal to the height of the total array) Surrounding buildings and trees can cause shade to the facade installation, roof installation and freestanding installation
On-roof 				If roof angle is not suitable for the countries' tilt angle; appropriate angle can be given with profile carriers	At least 15 cm space between the roof and the panel. (Suitable for hot countries)	
Façade 				When panels installed parallel with the facade and on the roof without any tilt angle; efficiency decreases because panels tilt angle will be 90°. Angle should be determined according to the position of the country.	If panels will be parallel to the facade and parallel to the flat roof, there should be 15cm space. If tilt angle is given, there will be enough space for ventilation	
Flat roof 		1)Plastic Tubs 2)Plastic Carriers				
Adjustable tilt angle 				Appropriate angle can be given with profile carriers.	Remains enough space for the ventilation	
Freestanding 						

Table 36: Comparison of Republic of Northern Cyprus and United Kingdom (Drawn by author)

COMPARISON	
TRNC	**UK**
Same supporting elements can be used	
28° (Fixed optimum tilt angle)	50° (Fixed optimum tilt angle)
Same Shading Problems	
15cm gap for ventilation	No need to give gap (Provide insulation)
Poly-crystalline Amorphous thin film	Mono-crystalline Amorphous thin film Poly-crystalline
Same orientation (south direction)	
High solar irradiation	Lower solar irradiation

Chapter 4

CONCLUSION

It is mentioned at the previous chapters that, the most important is to know the region of the place in order to decide for correct installation of the PV panels. Optimum tilt angle can be changeable according to the latitude of the place. When viewed from the world map, latitude of the places decreases from North Pole to the equator. At the same time, conversely solar irradiation increases. The increase in solar irradiation is showing a warming of the climates gradually in the regions from north to south. Optimum tilt angle of any region is calculated by knowing the latitude of the region. At the summer times, due to the angle of the sun is higher; the angle of the panel should be lower minus 15 degrees of latitude to be parallel to the sun. On the other hand, sun is lower compared to the summer times. For this reason, the angle of the panels should plus 15 degrees of the latitude to be parallel. For example latitude of Cyprus is 35°N that is mentioned at the previous chapters. It is calculated that summer tilt angle should be 20° and winter tilt angle should be 50° for receiving the maximum sunshine. On the other hand latitude of England is 50°N. By the way, summer tilt angle should be 35° and winter tilt angle should be 65° for the England. In order to decide the number of panels, electric usage of the building should be known. At the end of finding the optimum tilt angle of the regions and the electric usage amount; location/position of the panels should be decided for the installation. If the number of panels are too much to install on the roof surface, and there is enough space at ground and facade; installation can be done as ground mount installation and facade installation.

The importance of architecture occurs in such a situation. If panel application is designed during the design of the buildings, sufficient need of angle and space area is provided by the architect. This kind of design can influence design positively in two ways. Both building perceived as aesthetical and sufficient space is provided for panels. As seen from the case studies selected from hot and cold climates, installation of the panels were done later on the current design. This kind of design is known as additive design method. During this kind of method, some kind of mistakes/faults can be emerged.

Eventually, as PV panels can be concluded that some principles/rules are similar at hot and cold climates. Supporting types that are used during the mounting are usually same in cold and hot climates. Also, directions of the panels are same at cold and hot climates. The important is to know the region in which hemisphere. The distance between the two panels (front and back) should be the same in two kinds of climates. The reason is that shading problem can be seen at two kinds of climates. Secondly, some principles are observed different from each other. These are; ventilation, latitude and selection of cell type.

At hot climates, panels should be well ventilated in order to reduce the temperature of the cells. For instance in Cyprus, temperature of cell's increase to 65°C at the summer times. By the way, there should be appropriate gap between the panel and the roof surface. Otherwise, at cold climates, there is no need to leave gap between the panel and the roof surface. In contrast to hot climates, panels can provide extra insulation for the building if attached to the roof.

Because of the high latitude of colder countries, optimum tilt angle of panels are higher compared to the hot climates.

Lastly, the type of cell selection plays an important role during the installation. Amorphous thin-film is both efficient in hot and cold climates but at thin-film panels more installation area is needed. Therefore, cost of the panels will increase. Otherwise, mono-crystalline cell type's efficiency is decreases at too hot climates. By the way, mono-crystalline cell type is more appropriate for colder climates. On the other hand, poly-crystalline cell type is suitable both for cold and hot climates.

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APPENDICES

Appendix A

1. **Dimensions of Different Cell Type Modules**

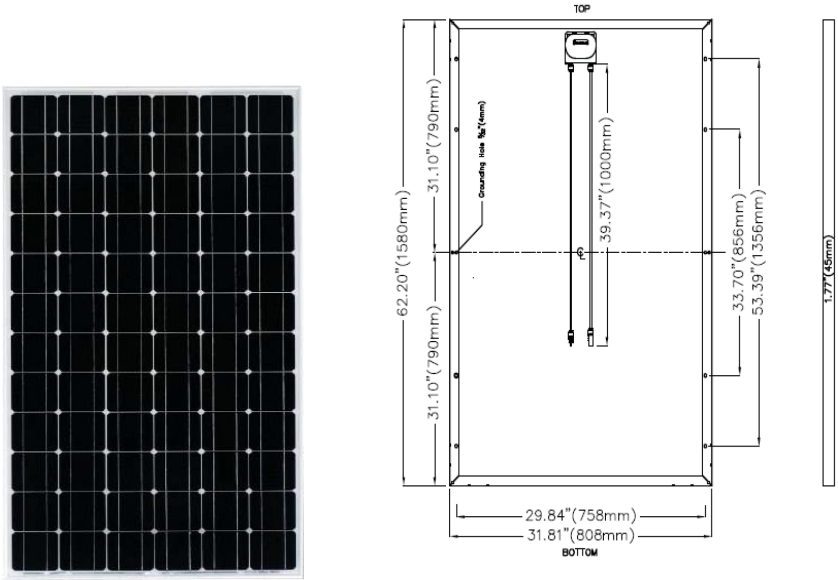

Figure 4.1: Mono-crystalline Cell Type Module Appearance and Dimensions (190Wp)

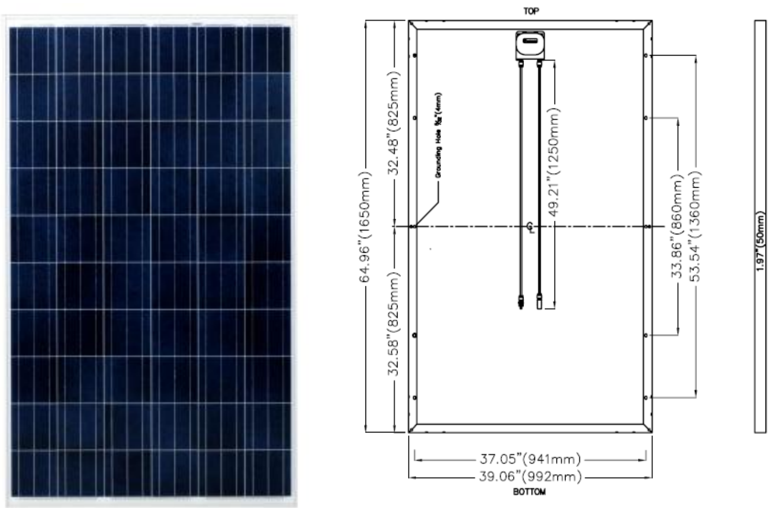

Figure 4.2: Poly-crystalline Cell Type Module Appearance and Dimensions (235Wp)

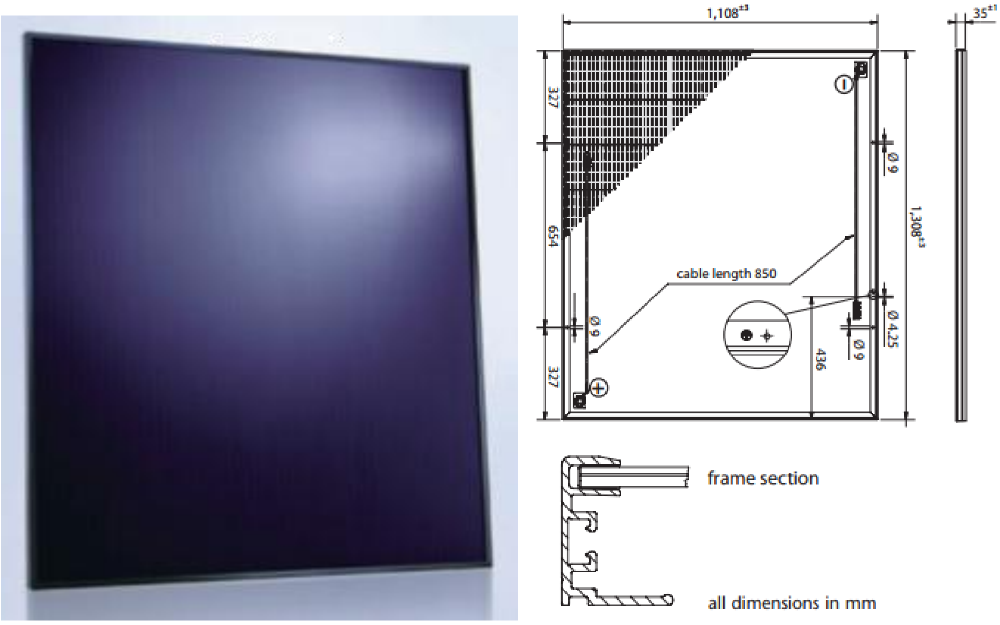

Figure 4.3: Amorphous Silicon (A-si) Thin-film Cell type Module Appearance and Dimensions (100Wp)

Appendix B

1. **Right Triangle Trigonometric Calculation used to Calculate Pitched Roofs Tilt Angle**

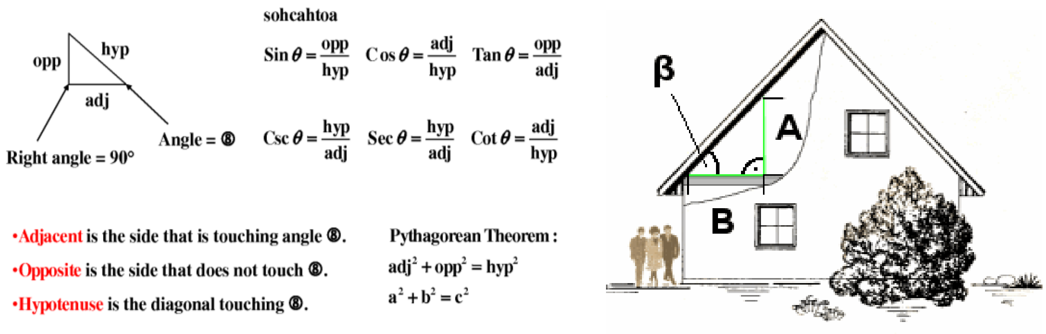

Figure 4.5: Right Triangle Trigonometry Calculation

Appendix C

1. **Solar Irradiation Maps of Case Studies**

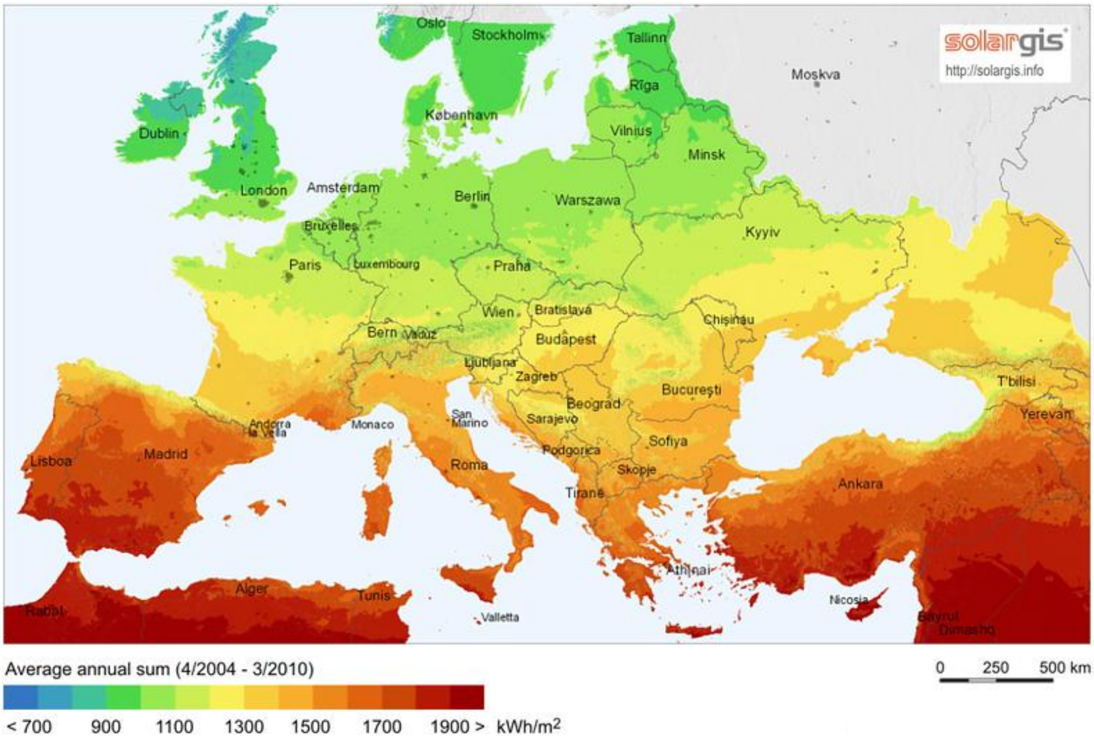

Figure 4.6: Global Horizontal Irradiation Map of Europe (Solargis, 2011)

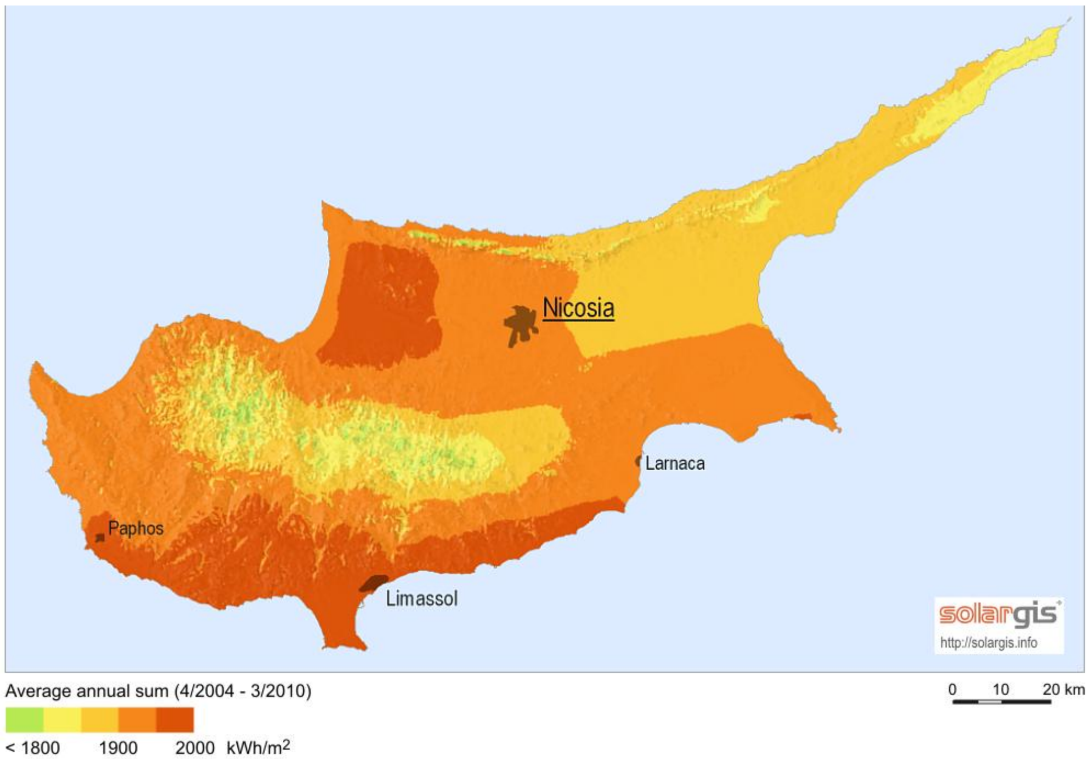

Figure 4.7: Global Horizontal Irradiation Map of Cyprus (Solargis, 2011)

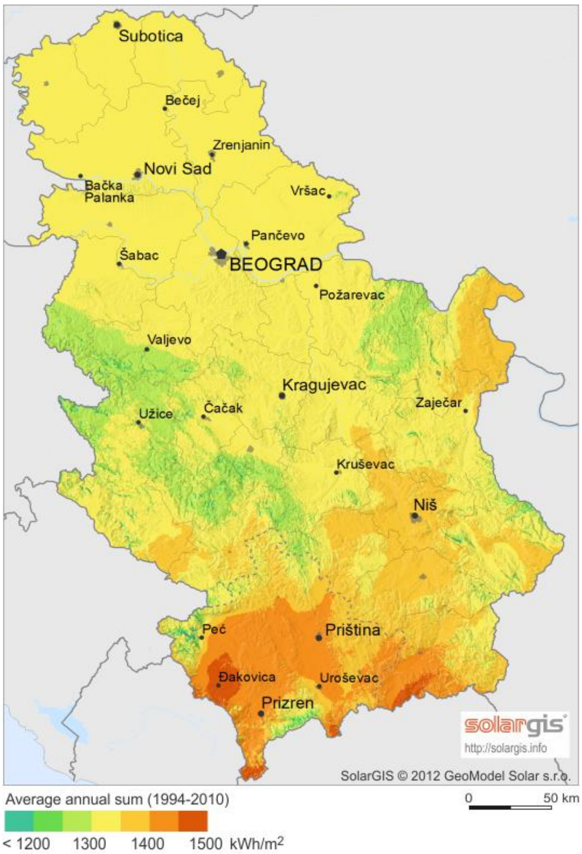

Figure 4.8: Global Horizontal Irradiation Map of Serbia (Solargis, 2012)

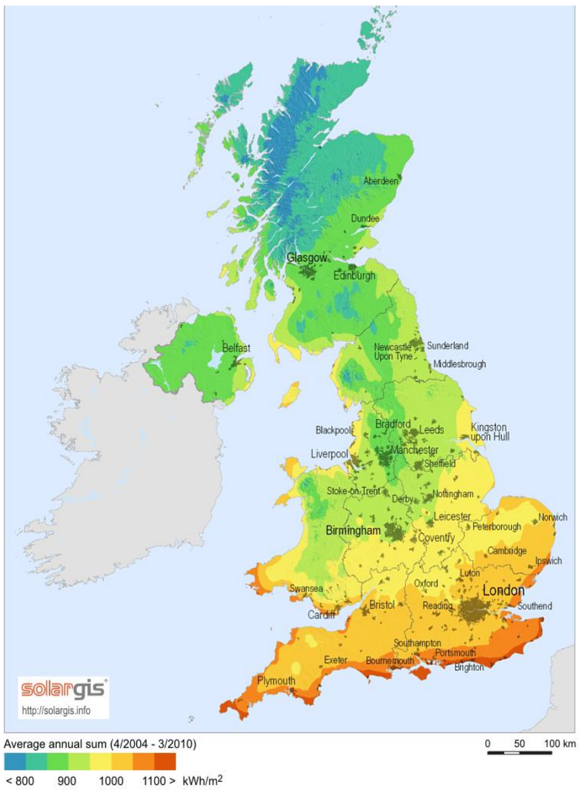

Figure 4.9: Global Horizontal Irradiation Map of United Kingdom (Solargis, 2011)

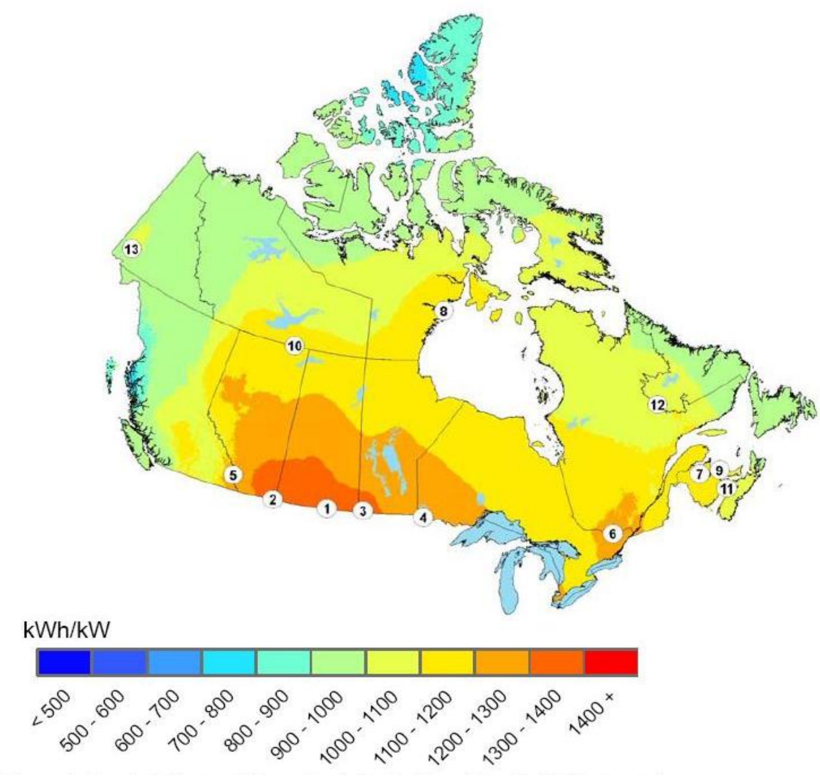

Figure 4.10: Solar Irradiation map of Canada (Pelland et al, 2013)

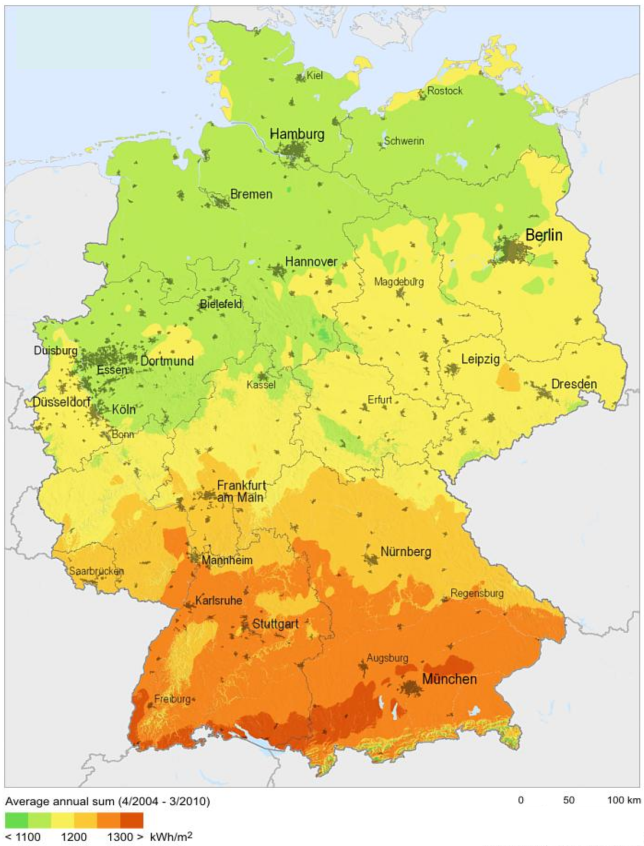

Figure 4.11: Solar Irradiation Map of Germany (Solargis, 2011)

Appendix D

1. **Installation Details of Photovoltaic Panels**

Figure 4.13: On-Roof System

Source: http://ww3.mounting-systems.info/en/news-reader/the-on-roof-systems-with-the-plus.html

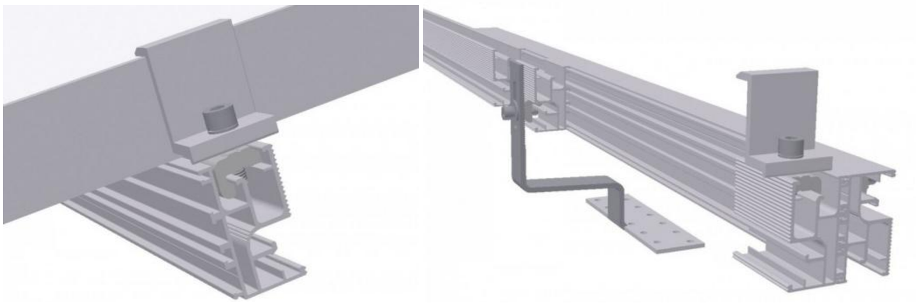

Figure 4.14: Connection Details of On-roof System (Profile Carriers and Roof Hook)

Source: http://ww3.mounting-systems.info/en/on-roof-mounting-system-alpha.html

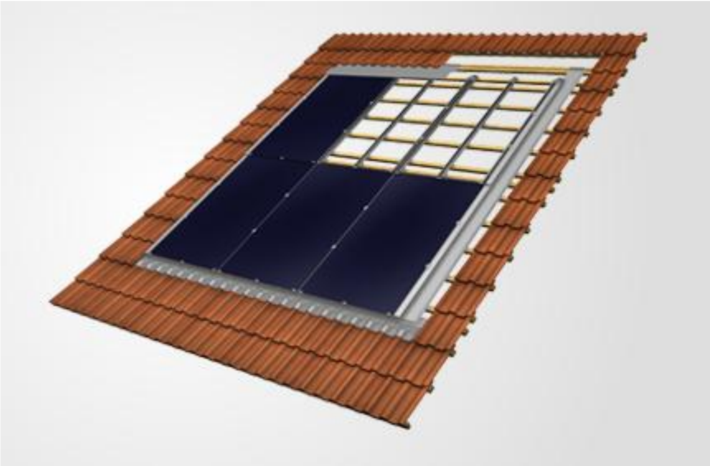

Figure 4.15: In-roof system

Source: http://ww3.mounting-systems.info/en/in-roof-mounting-system-kappa.html

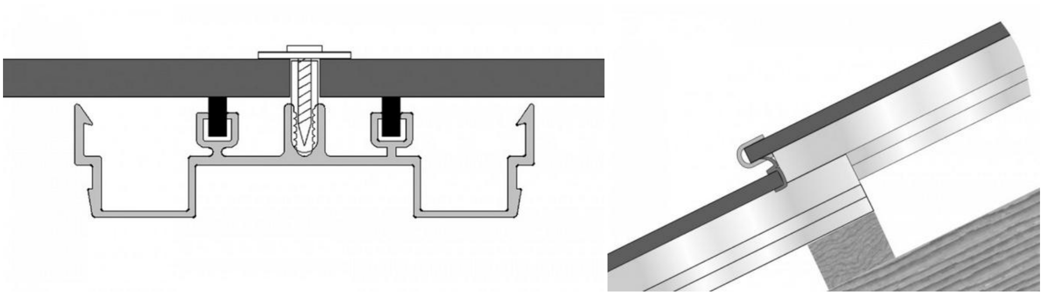

Figure 4.16: Front and Side View Detail of In-roof System Installation

Source: http://ww3.mounting-systems.info/en/in-roof-mounting-system-kappa.html

Figure 4.17: Flat Roof Mounting System

Source: http://ww3.mounting-systems.info/en/flat-roof-mounting-system-lambda.html

Figure 4.18: Side View and Perspective Drawing of Profile Carriers for Flat Roofs

Source: http://ww3.mounting-systems.info/en/flat-roof-mounting-system-lambda.html

Figure 4.19: Ground Mounting System

Source: http://ww3.mounting-systems.info/en/open-terrain-mounting-system-sigma1.html

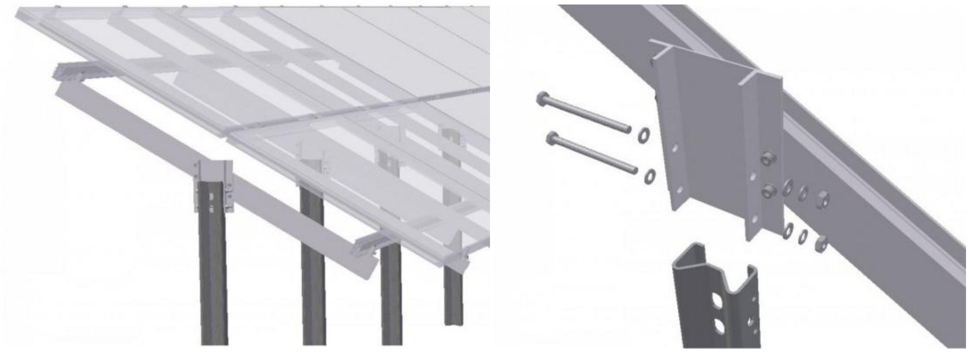

Figure 4.20: Side View and Profile Carrier Connection Detail

Source: http://ww3.mounting-systems.info/en/open-terrain-mounting-system-sigma1.html

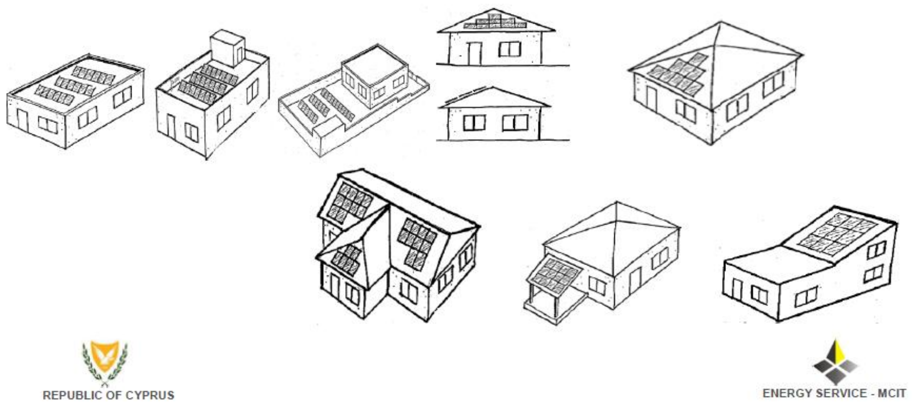

Figure 4.22: New Legislation for Supporting Standard PV Installation in Republic of Cyprus (Partasides, 2010)