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Title :"Use of Building Integrated PV panels (BIPV)as shading device over roof of atrium in temperate and hot humid climates"

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Abstract

The task of this study is to investigate the effect of building integrated photovoltaic panels(BIPV)as roof or a shading device on atriums in temperate climate case of **Berlin, Germany** and hot humid climate case of **Famagusta, Turkish republic of Northern Cyprus**. The integration of different types of PV panel on top of buildings in the proper direction is nowadays a very welcomed solution in order to provide sustainable energy. This new technology is adequate for many benefits both in ecological but also economical aspects. The typologies of photovoltaics that companies are proposing to constructors give them the opportunity to use PV panels in several ways. From blind to semi-transparent PV panels we have many differences for example with appropriate optimization measures, the **semi-transparent** PV top light with 50% radiation transmission rate contributes to a maximum of 5.3% reduction in heating and cooling energy consumption compared with a standard solar roof (blind or non-transparent photovoltaics panels). The effect of daylighting in lighting energy saving is subtle as most of the buildings lighting demand occur during night time. For this study we are going to use the semitransparent thin film pv modules as atrium roof. From this research we will show how integrated PV panels(BIPV)has a large potential on energy saving and leading buildings to be NET zero energy building with acceptable thermal comfort level at the most of the working hours. Building performance can be analyzed by theoretical calculation, experiments, building simulation software and multiple uses of the above methods. In this study, BIPV is still on the developing stage specially in the Famagusta zone where the PV integration on buildings is a new deal. For this reason, experiments cannot be done on an existing building,

so to calculate the efficiency on bipv in this area photovoltaic building simulation software named "performance of grid connected PV" will be used. Contrary to Berlin where we have several existing building with BIPV system. The berlin central train station is taken as case study in order to give Performance indicator.

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Keywords
Building Integrated PV (BIPV), Atrium roof, Shading device, Temperate climate, Hot humid climate, Ecology, Economy.

INTRODUCTION

The idea of converting solar energy into usable energy from a solar cell with the help of semiconductors has changed our world. Photovoltaics gives us the opportunity to say goodbye to energy from dwindling supplies of fossil fuels. Energy and comfort are among the biggest concerns in the building industry when considering about building physics and services. The global warming and the destruction of our environment face us to think about reducing this huge dependence on fossil fuel energy. Energy cost reduction is one of the main drivers responsible for the growth of the global BIPV market. The most energy-intensive end-user segments are commercial buildings, healthcare facilities, and manufacturing plants — facilities which require round-the-clock maintenance and utilize high amounts of energy.

Growing requirement for energy certifications, hike in infrastructure spending, and increasing solar energy consumption and installation are other important drivers responsible for the growth of the market. Due to these factors, the global BIPV market is forecast to be valued at $1.14 billion by 2021.Since the global population is increasing exponentially the energy demand will also increase in parallel we will be about 13.000.000.000.00 people in 2070. The integration of new technologies and renewable energy use is welcome in that aspect, Solar energy is one of the best sources that the nature offers for free and forever to us. Photovoltaics panel are among those alternatives we have to produce energy as much as we need in condition of having the necessaire and proper materials and technics. In this research, PV panel is proposed as top light material for roof and atriums building for not only to generate energy but also as shading device to use and to control the daylighting into buildings since our research areas are in two different climates. Direct radiation is the

Figure 1'Das Sonnenschiff', the solar ship © Rolf Disch Solar Architecture, Freiburg, Germany source that causes glare. Shading devices, such as slat-blinds, reflect part of direct radiation and scatter the rest of incident direct radiation to be diffuse radiation that brings a soft visual effect. The design of a shading device should balance the daylight requirement versus the need to reduce solar heat gain.

Literature Review

Diffuse and Direct solar radiation

Direct radiation describes solar radiation traveling on a straight line from the sun down to the surface of the earth.

On the other hand, diffuse radiation is solar radiation scattered by molecules and particles in the atmosphere (e.g. clouds). Diffuse radiation does not have a definite direction but travels in all the directions. In a clear sunny day, the direct radiation is around 85% of total solar radiation, and the diffuse radiation is about 15%. In an extremely overcast day, 100% solar radiation can be diffuse radiation. Direct/diffuse ratio is changing by the climate, latitude and seasons. Diffuse radiation ratio is much higher in higher latitude, cloudier places than in lower latitude, sunnier places. Famagusta, which has a low diffuse radiation ratio, has an extreme case with low latitude and sunny weather.

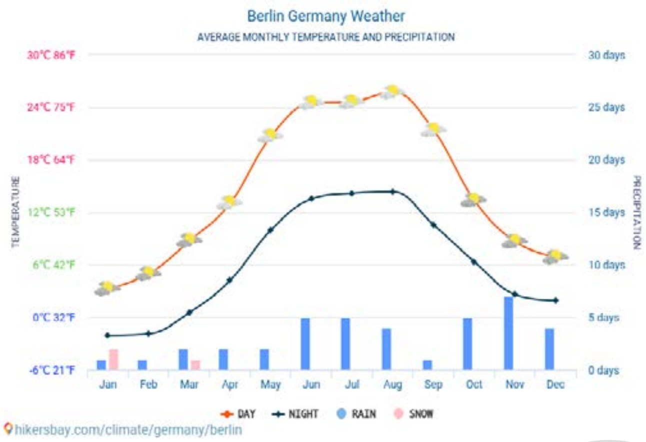

Figure 2 hikersbay.com/climate/germany/berlin

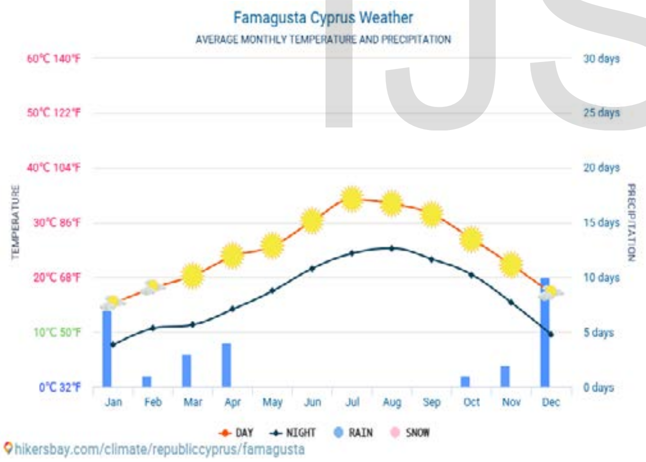

Figure 3hikersbay.com/climate/RepublicCyprus/Famagusta

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Solar Cell Type	Efficiency-Rate	Advantages	Disadvantages
Monocrystalline Solar Panels (Mono-SI)	~20%	High efficiency rate	Expensive
Polycrystalline Solar Panels (p-Si)	~15%	Lower price	Sensitive to high temperatures; lower lifespan & slightly less space efficiency
Thin-Film: Amorphous Silicon Solar Panels (A-SI)	~7-10%	Relatively low costs; easy to produce & flexible	shorter warranties & lifespan
Concentrated PV Cell (CVP)	~41%	Very high performance & efficiency rate	Solar tracker & cooling system needed (to reach high efficiency rate)

Table 1 Green match ,April 2018,types of solar panels.

DISCUSSION

Conceptual models

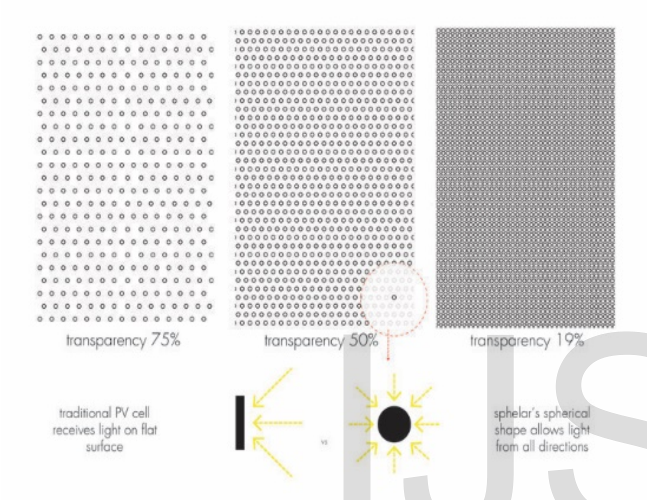
There are three parts of physics of BIPV determining the building performance: optical, thermal and electrical parts. The theoretical study of these three parts helps to have a thorough understanding of its physics. However, optical performance is not in the scope of this study. The focuses are on thermal and electrical models.

Types of Photovoltaic panel

Building Integrated Photovoltaic Systems

Acronym of BIPV (Building Integrated Photovoltaics) refers to photovoltaic systems integrated within an object. It means that such systems are built/constructed along with an object. Yet, they could be built later on. Due to specific task cooperation of many different experts, such as architects, civil engineers and PV system designers, is necessary. According to how and where such systems are built, whether integrated into the facade or in the roof, the following BIPV systems are recognized: Facade or roof systems added after the building was built, Facade integrated photovoltaic systems built along with an object, Roof-integrated photovoltaic systems built along with an object, Shadow-Voltaic PV systems also used as shading systems.

Photovoltaic systems can be used for shading, where photovoltaic modules serve as Venetian blinds. In some of such cases photovoltaic modules tilt angle can be adjusted manually or automatically allowing photovoltaic module and/or building shading efficiency optimization. Such systems are also known as shadow-voltaic systems. The best results and efficiency can be reached with systems, which are tightly integrated into the building's envelope; however, the use of active solar systems is an additional possibility. High level of expertise is required for successful BIPV systems planning, not only in regard to architecture,



but also to civil and photovoltaic engineering. The projects realized in the past show that successful BIPV systems designing is based heavily on technical experience and knowledge. Poorly designed systems usually have to be redesigned or repaired later, consequently swelling maintenance costs and lowering system efficiency rate.

SEMI-TRANSPARENT PV PANLES

Transparent solar modules offer very attractive BIPV solutions. Modules with different transparency rates and/or different technologies are available on the market. Most common they consist of transparent crystalline cells, very often are also modules with transparent back side and with standard crystalline cells. Another interesting solution are thin film transparent amorphous modules. Transparent modules can be used as window glazing in usual windows, sunspaces, they can be integrated into roofs etc. Quite often they are also a part of shading devices whether movable or not. Such systems are also known as shadow-voltaic systems. Transparent modules can be also part of energy efficient glazing, where they are used instead of usual glass. With colored back side interesting architectural visual effects can be obtained. Such solutions are often used in old architectural protected heritage buildings. Example of

Figure 4 TRANSPARENCY LEVELS OF THIN FILM PV BY ARCHIPLEASURE

heritage building renovation with photovoltaic roof tiles you may also find in roof tiles section. Very attractive are also thin film modules because they offer some tailor made solutions - different shapes or patterns within modules are possible.

Transparent Modules as Shading Devices

Transparent modules are often part of shading devices. Shading devices, like overhangs for example, can be fixed or movable. Manual tracking-combined with shadowing system, or automatic tracking systems can be realized. Very often they are realized as venetian blinds or classic awnings. Vertical and horizontal shading devices are used in practice. If transparent modules are integrated into transparent roof or sunspace glazing they also offer some shading so additional shading devices are usually not necessary. Some shading devices you may find in pictures below. For details about shading calculation, shading analysis tools etc. please see shading section.

Optical model

Optical model is used to predict the visual performance. The visual performance determines the use of artificial lighting and shading. How much percent artificial lighting is used influences casual heat gain from lighting. The optical model is based on the optical properties of the used material of fenestration elements, such as transmittance and reflectance. The optical properties can be tested by experiments and then calculated. However, there is no products/sample produced yet. The only known part of the optical model is that ISTPV consists of transparent slats with very tiny metal dots (CPV cells).

Thermal model and Electrical model

Thermal model is used to indicate the thermal behavior of the object. The thermal behavior determines heating and cooling load of a building. The impact of fenestration elements on the building's energy is based on the location of the window, its size, construction (including cavity, frame, roof type, spacers etc.) and optical properties of the glazing. Temperature driven heat transfer and solar heat gain are two heat transfer processes contributing to the thermal energy flow. Heat gain or loss through fenestration elements is caused by convection, conduction and radiation of the

Figure 5 laminated solar windows, vidrio laminado fotovoltaico, semi translucent color modules.

difference between indoor and outdoor temperature. Solar heat gain is caused by solar radiation processes. ISTPV has much influence on solar heat gain of the fenestration

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element because of the treatments of solar radiation processes. However, the outside and inside temperatures are dominated by environment and indoor HVAC system. Thus, solar heat gains and its processes are vital to be analyzed comprehensively.

CASE STUDY

Berlin Hauptbahnhof Berlin Central Station

Figure 6 Berlin Hauptbahnhof TRAIN STATION

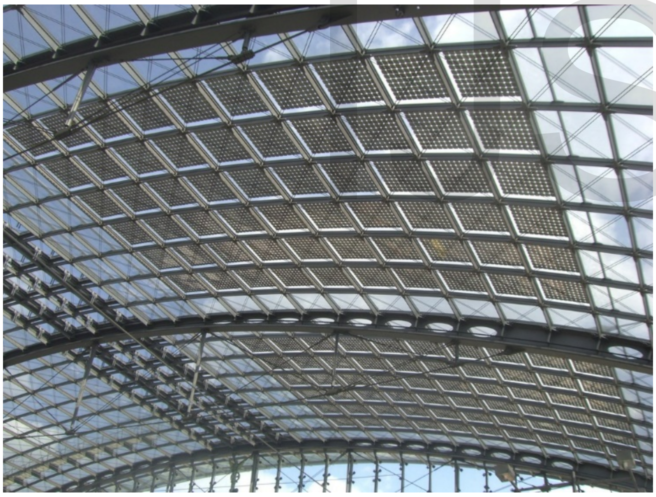

Figure 7 SEMI TRANSPARENT PV THIN FILM

- **ARCHITECTS: JÜRGEN HILLMER, MEINHARD VON GERKAN, MARG & PARTNERS HAMBURGO GERKAN**
- YEAR: **1996 - 2006**
- LOCATION: **BERLIN, GERMANY**

The frameless PV modules replace part of the laminated glazing of the transparent concourse of Berlin main railway station. They are mounted in lines on a steel grid. Because the structure had to follow the curve of the tracks, each module is unique in terms of angularity and dimensions – ranging between 1.5m² and 2.5m². The different angles of inclination of these practically ideally customized modules result in a connection concept based on string inverters. This not only maximizes yield, but also simplifies monitoring of the system. The upper platform hall, which runs east-west, is 321 meters long and consists of the arch-shaped arched column-free glass roof structure, which is supported by the two outer railway overpass structures. In the glass surface, **a 2700 square meter photovoltaic system with a capacity of 330 kilowatts** was integrated.

Performance indicator

For the implementation of ISTPV into dynamic simulation model, the performance indicator should consider two aspects. One indicates the component performance of ISTPV in-between double skin facade to assess the success of the implementation. The other should indicate the building performance of a building/room with this component. The performance indicators expressed in values is used to assess how well the subject behaves. For the component, the focus is on how much direct radiation can be concentrated, how much diffuse radiation can be transmitted to the indoor and how much solar radiation can be absorbed in the component and then transform to be solar heat gain and to be electricity respectively. For the building, the initial focus is on how the building behaves on energy that consists of space heating and cooling loads and electricity generation. In a simplified case, the building performance can be explained by the component performance. Thus, in this chapter, solar radiation distribution through the component and space heating and cooling load and electricity generation are used as performance indicators can be explained by the component performance. Thus, in this chapter, solar radiation distribution through the component and space heating and cooling load and electricity generation are used as performance indicators.

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Selection of simulation software

On account of the importance of development of the proper model, the simulation tool becomes to be the first step after a well understanding of the system. Currently, none of the existing simulation tools can treat diffuse and direct radiation separately for a fenestration construction. For this reason, a modification of an existing simulation tool is needed. Here in this project an online simulation database named “Photovoltaic Geographical Information System” developed by CMSAF EUMETSAT under the European commission is going to be used in order to show us the performance and the economical aspect of the crystalline silicon category of PV panels. This results are changing from according to the area where the building is located (Berlin or Famagusta), the installment inclination angle (slope) and months over the year.

FINDINGS

Geographical Assessment of Solar Resource and Performance of Photovoltaic Technology

In these simulations we will consider a commercial building with a 1kwp **semitransparent** thin film PV in 0° and 45° angle in Berlin and Famagusta. The energy cost is 0.295€ in berlin and 0.144€ in Famagusta.

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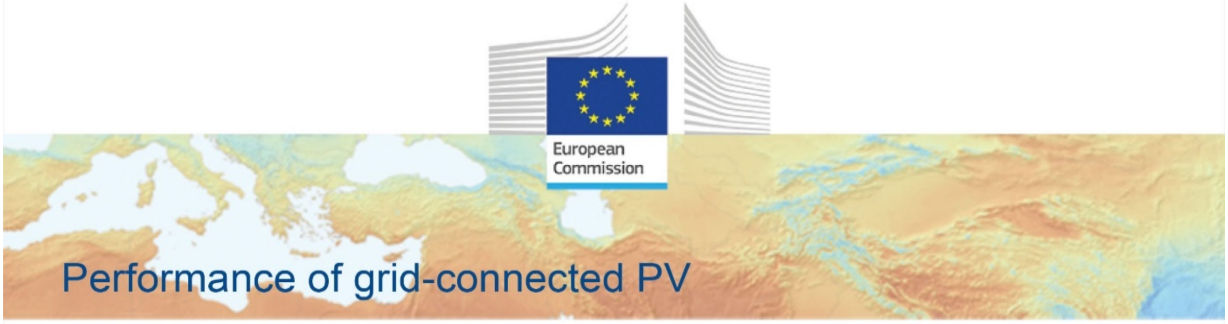
1ST case: BERLIN GERMANY with 0° angle.



PVGIS-5 estimates of solar electricity generation:

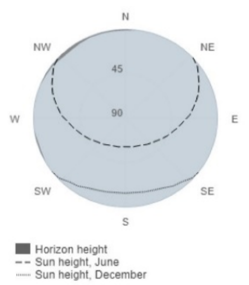
Provided inputs:

Latitude/Longitude:	52.508, 13.402
Horizon:	Calculated
Database used:	PVGIS-CMSAF
PV technology:	Crystalline silicon
PV installed:	1 kWp
System loss:	14 %

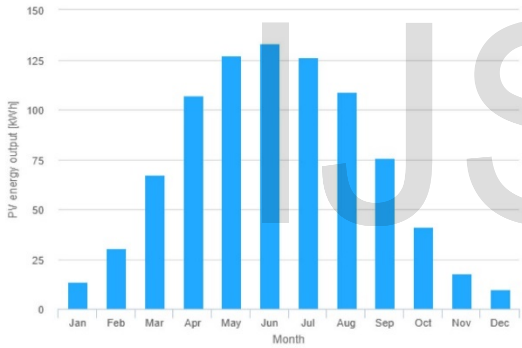
Simulation outputs

Slope angle:	0 °
Azimuth angle:	60 °
Yearly PV energy production:	857 kWh
Yearly in-plane irradiation:	1110 kWh/m²
Year to year variability:	30.60 %
Changes in output due to:	
Angle of incidence:	-4.4 %
Spectral effects:	1.6 %
Temperature and low irradiance:	-7.6 %
Total loss:	-22.8 %
PV electricity cost:	0.637 per kWh

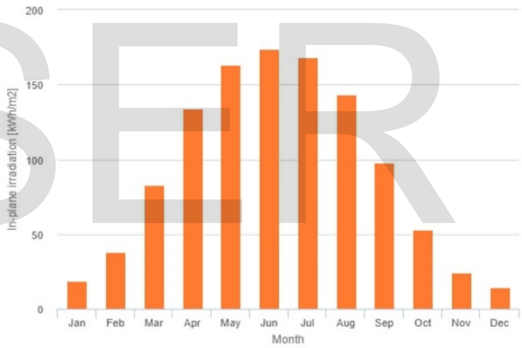
Outline of horizon at chosen location:



Monthly energy output from fix-angle PV system:



Monthly in-plane irradiation for fixed-angle:



Monthly PV energy and solar irradiation

Month	Em	Hm	SDm
January	13.6	18.9	1.43
February	30.6	38.3	5.75
March	67.2	82.8	6.58
April	107	134	12.1
May	127	163	16.7
June	133	174	10.2
July	126	168	11.7
August	109	143	10.7
September	75.9	97.6	9.42
October	41.1	53.2	5.45
November	17.7	24.3	3.55
December	9.92	14.5	1.24

Em: Average monthly electricity production from the given system [kWh].

Hm: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].

SDm: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

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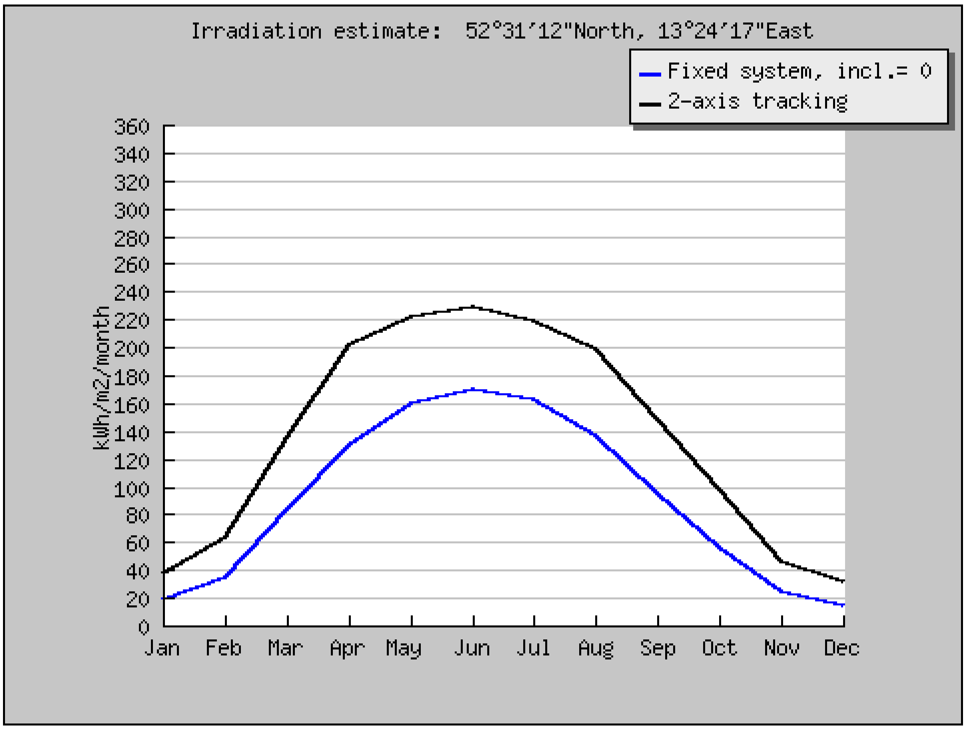
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Fixed system, incl.= 0
2-axis tracking
kWh/m2/month
360
340
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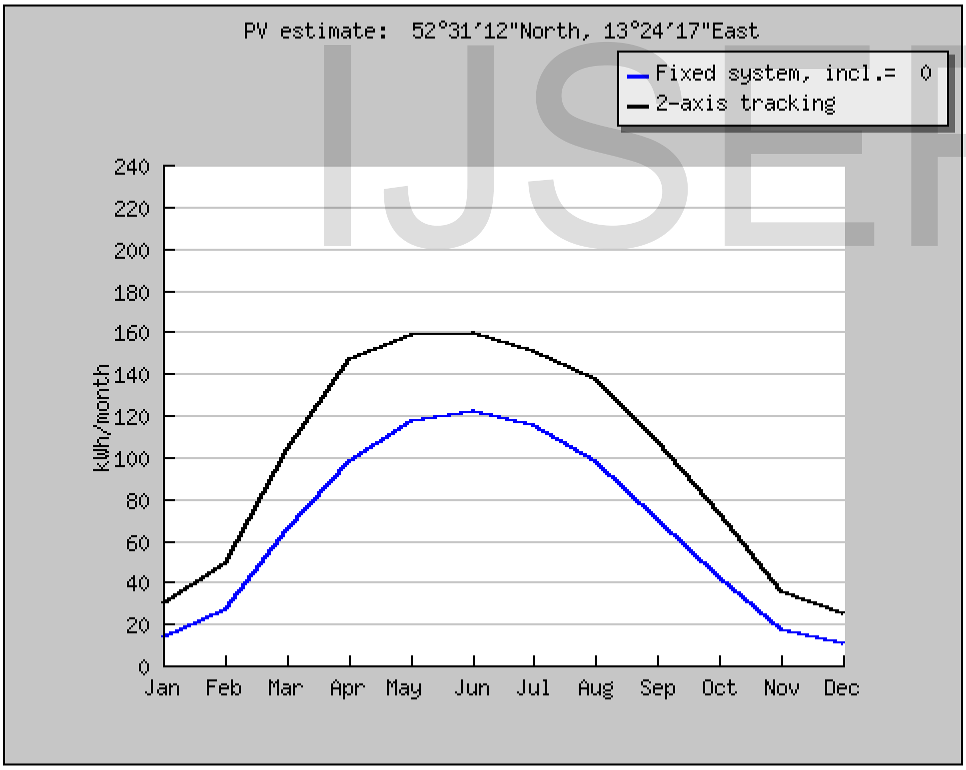
PV estimate: 52°31′12"North, 13°24′17"East
Fixed system, incl.= 0
2-axis tracking
kWh/month
240
220
200
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Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

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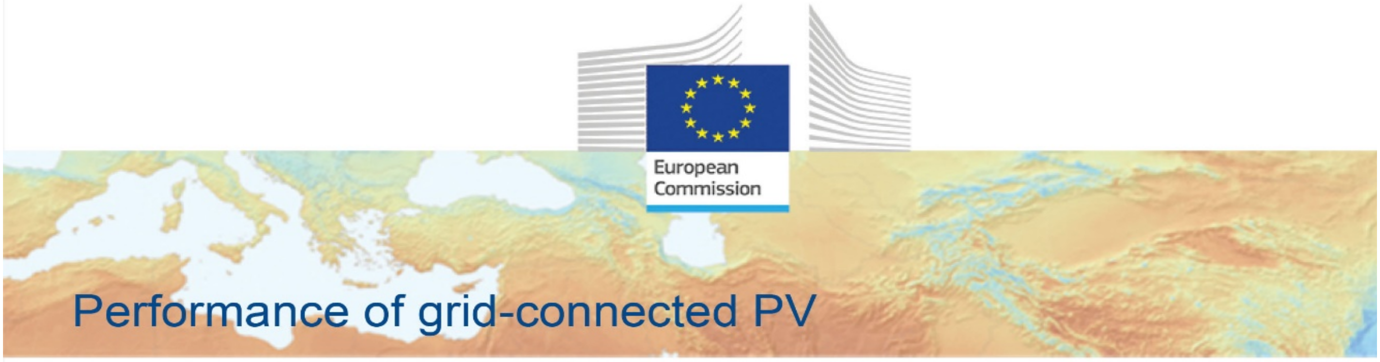
2nd case: BERLIN GERMANY with 45° angle.



PVGIS-5 estimates of solar electricity generation:

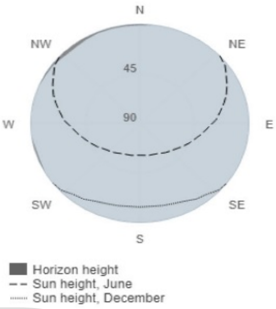
Provided inputs:

Latitude/Longitude:	52.508, 13.402
Horizon:	Calculated
Database used:	PVGIS-CMSAF
PV technology:	Crystalline silicon
PV installed:	1 kWp
System loss:	14 %

Simulation outputs

Slope angle:	45 °
Azimuth angle:	60 °
Yearly PV energy production:	868 kWh
Yearly in-plane irradiation:	1120 kWh/m²
Year to year variability:	42.60 %
Changes in output due to:	
Angle of incidence:	-3.3 %
Spectral effects:	1.7 %
Temperature and low irradiance:	-8.5 %
Total loss:	-22.7 %
PV electricity cost:	0.629 per kWh

Outline of horizon at chosen location:



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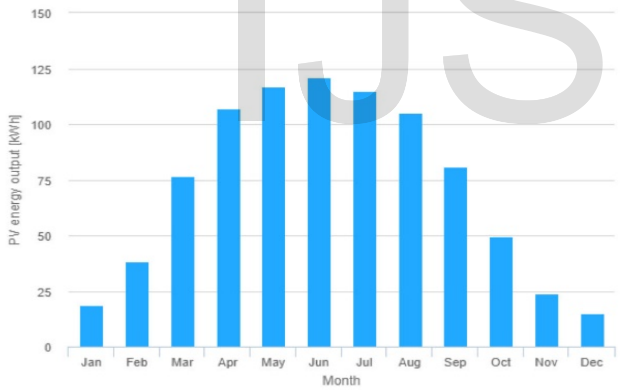
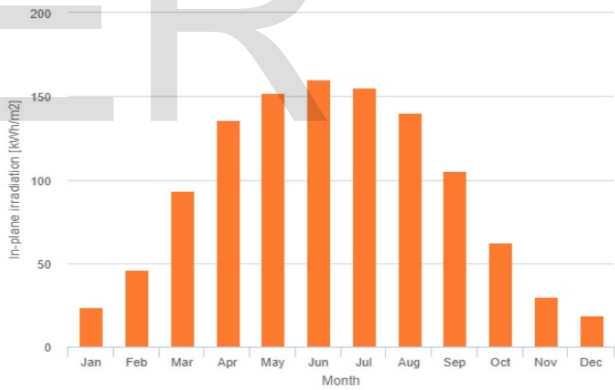
Monthly energy output from fix-angle PV system:



Monthly in-plane irradiation for fixed-angle:



Monthly PV energy and solar irradiation

Month	Em	Hm	SDm
January	18.9	23.8	3.01
February	38.4	46.1	10.1
March	76.6	93.7	10.1
April	107	136	15.1
May	117	152	15.3
June	121	160	10.1
July	115	155	11.7
August	105	140	12.4
September	81	105	11.9
October	49.3	62	8.59
November	23.9	30.2	7.05
December	14.8	19	3.03

Em: Average monthly electricity production from the given system [kWh].

Hm: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].

SDm: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

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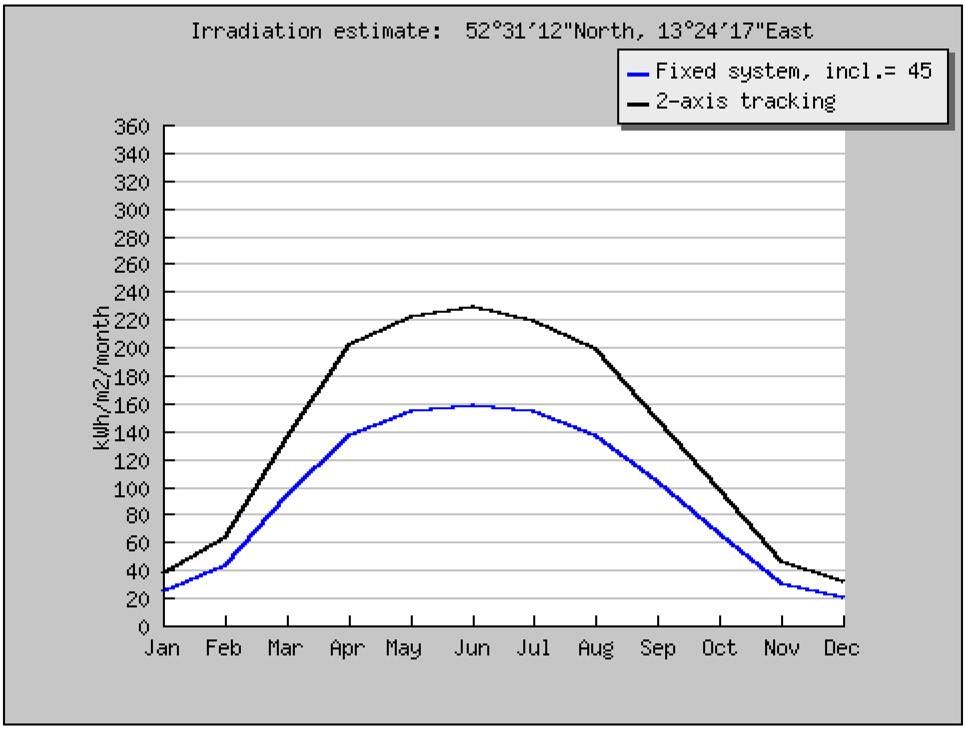
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Fixed system, incl.= 45
2-axis tracking
kWh/m2/month
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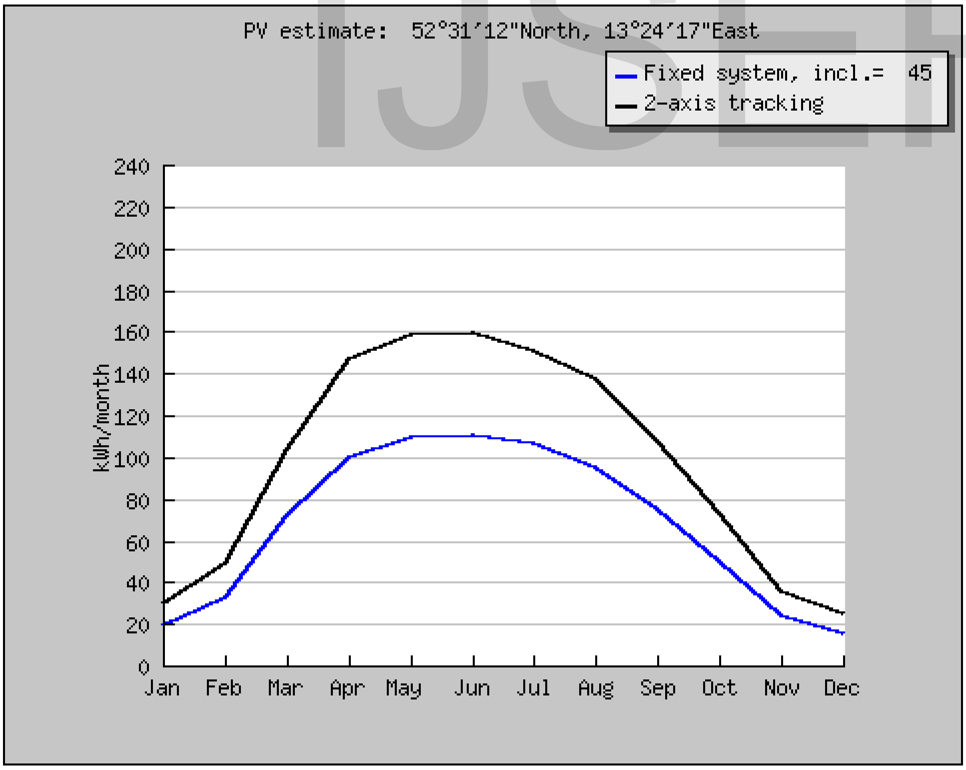
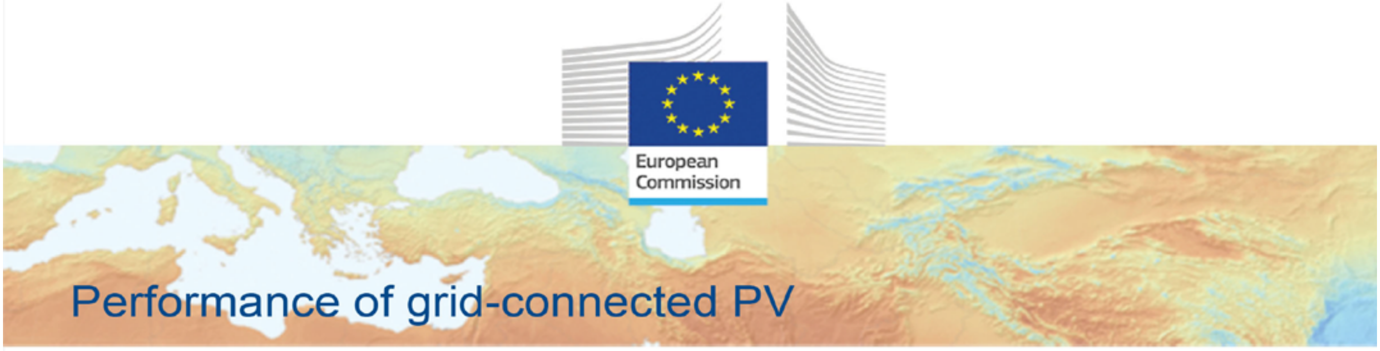
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


PV estimate: 52°31′12"North, 13°24′17"East
Fixed system, incl.= 45
2-axis tracking
kWh/month
0 20 40 60 80 100 120 140 160 180 200 220 240
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

3RD case: Famagusta ,Turkish Republic of Northern Cyprus with 0° angle.



PVGIS-5 estimates of solar electricity generation:

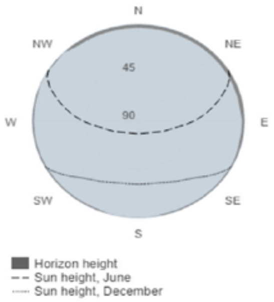
Provided inputs:

Latitude/Longitude:	35.105, 33.900
Horizon:	Calculated
Database used:	PVGIS-CMSAF
PV technology:	Crystalline silicon
PV installed:	1 kWp
System loss:	14 %

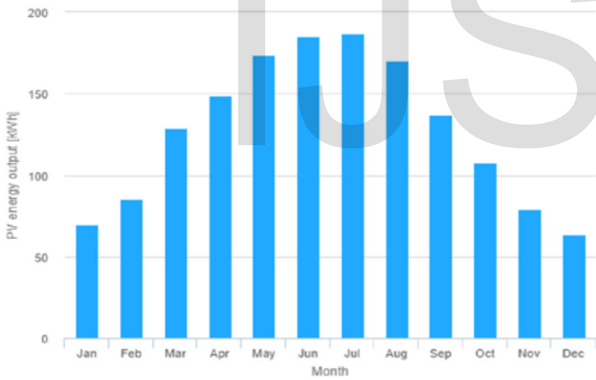
Simulation outputs

Slope angle:	0 °
Azimuth angle:	75 °
Yearly PV energy production:	1540 kWh
Yearly in-plane irradiation:	2070 kWh/m²
Year to year variability:	17.90 %
Changes in output due to:	
Angle of incidence:	-3.3 %
Spectral effects:	0.2 %
Temperature and low irradiance:	-10.6 %
Total loss:	-25.6 %
PV electricity cost:	0.354 per kWh

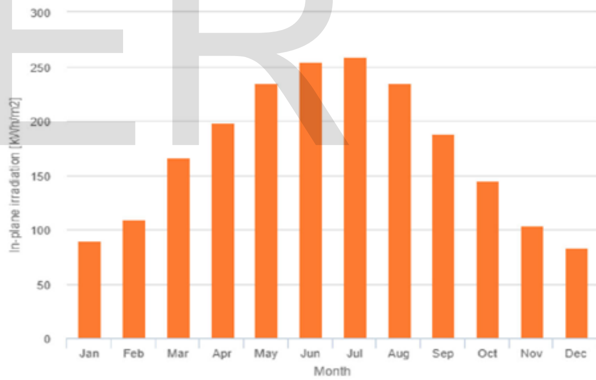
Outline of horizon at chosen location:



Monthly energy output from fix-angle PV system:



Monthly in-plane irradiation for fixed-angle:



Monthly PV energy and solar irradiation

Month	Em	Hm	SDm
January	69.9	89.3	3.67
February	85.5	109	7.54
March	129	166	3.76
April	149	198	7.15
May	174	235	6.38
June	185	254	1.93
July	187	259	1.56
August	170	235	1.93
September	137	188	4.12
October	108	145	5.33
November	79.4	104	2.43
December	63.7	82.9	4.65

Em: Average monthly electricity production from the given system [kWh].
Hm: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].
SDm: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

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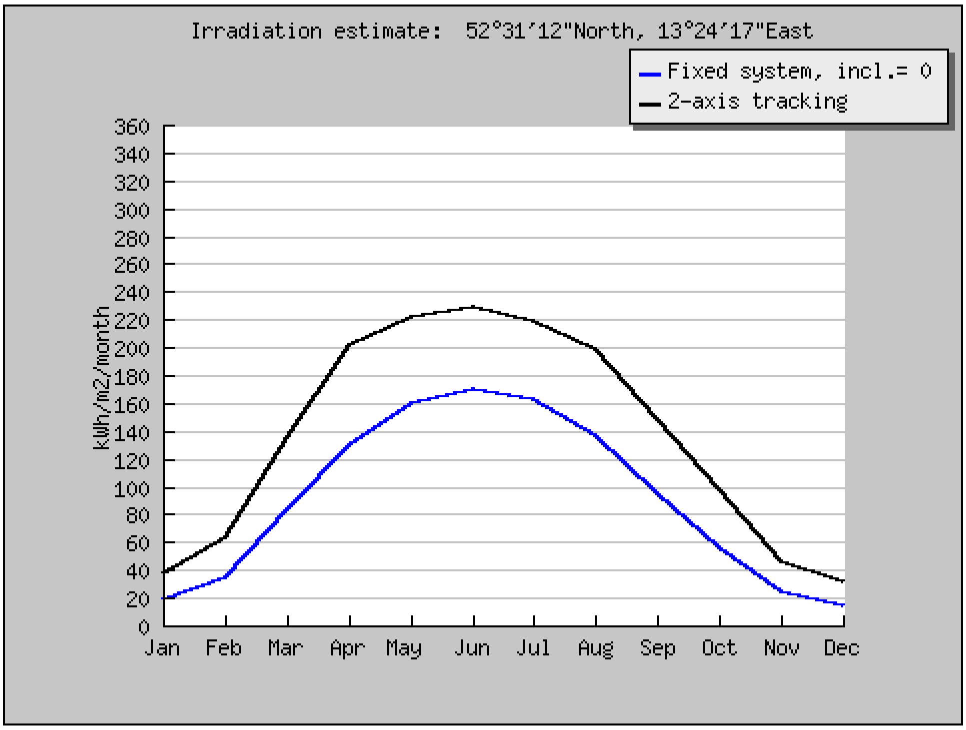
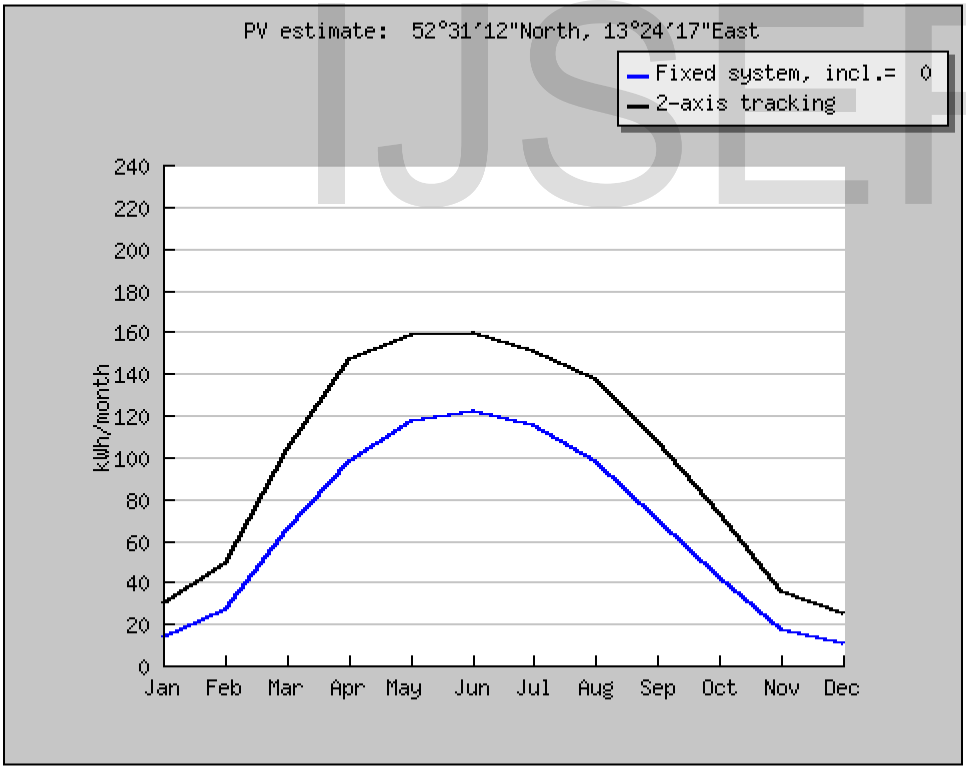

Irradiation estimate: 52°31′12"North, 13°24′17"East
Fixed system, incl.= 0
2-axis tracking
kWh/m2/month
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


PV estimate: 52°31′12"North, 13°24′17"East
Fixed system, incl.= 0
2-axis tracking
kWh/month
240
220
200
180
160
140
120
100
80
60
40
20
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

4th case: Famagusta, Turkish Republic of Northern Cyprus with 45° angle.

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Performance of grid-connected PV

PVGIS-5 estimates of solar electricity generation:

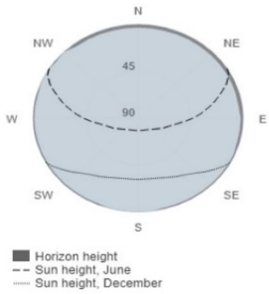
Provided inputs:

Latitude/Longitude:	35.105, 33.900
Horizon:	Calculated
Database used:	PVGIS-CMSAF
PV technology:	Crystalline silicon
PV installed:	1 kWp
System loss:	14 %

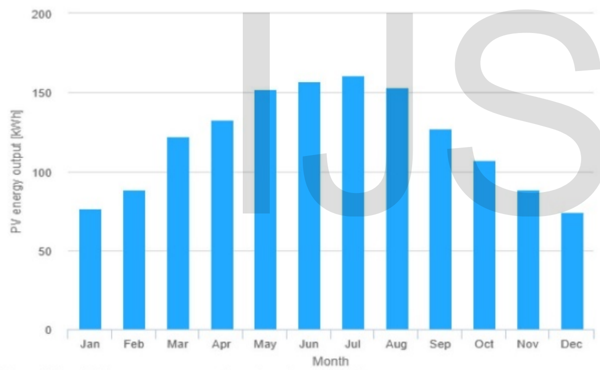
Simulation outputs

Slope angle:	45 °
Azimuth angle:	75 °
Yearly PV energy production:	1440 kWh
Yearly in-plane irradiation:	1940 kWh/m²
Year to year variability:	18.40 %
Changes in output due to:	
Angle of incidence:	-2.9 %
Spectral effects:	0.3 %
Temperature and low irradiance:	-11.1 %
Total loss:	-25.6 %
PV electricity cost:	0.379 per kWh

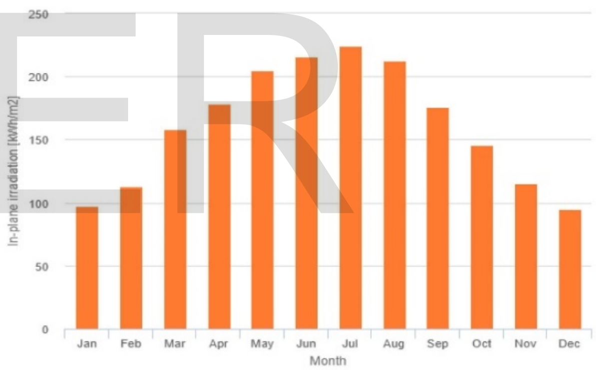
Outline of horizon at chosen location:



Monthly energy output from fix-angle PV system:



Monthly in-plane irradiation for fixed-angle:



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Monthly PV energy and solar irradiation

Month	Em	Hm	SDm
January	76.6	97.2	5.05
February	88.3	113	8.28
March	122	158	5.36
April	133	178	7.83
May	152	205	6.3
June	157	216	2.7
July	161	224	1.51
August	153	213	2.42
September	127	176	5.62
October	107	146	6.5
November	88.3	115	3.69
December	74.3	94.7	5.85

Em: Average monthly electricity production from the given system [kWh].

Hm: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].

SDm: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

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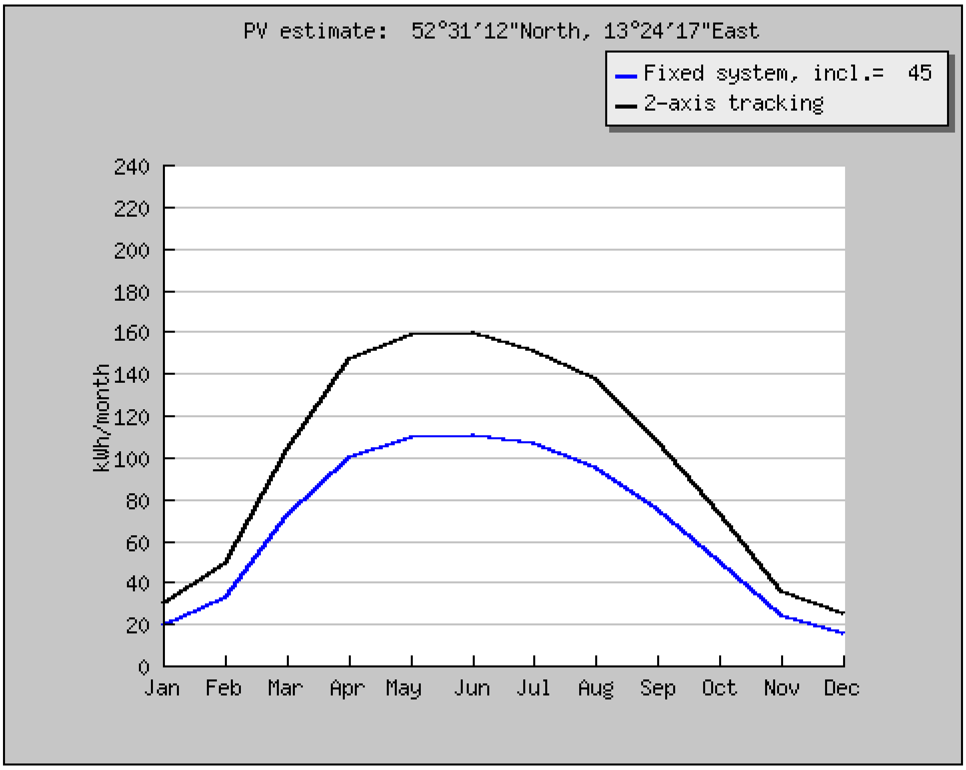

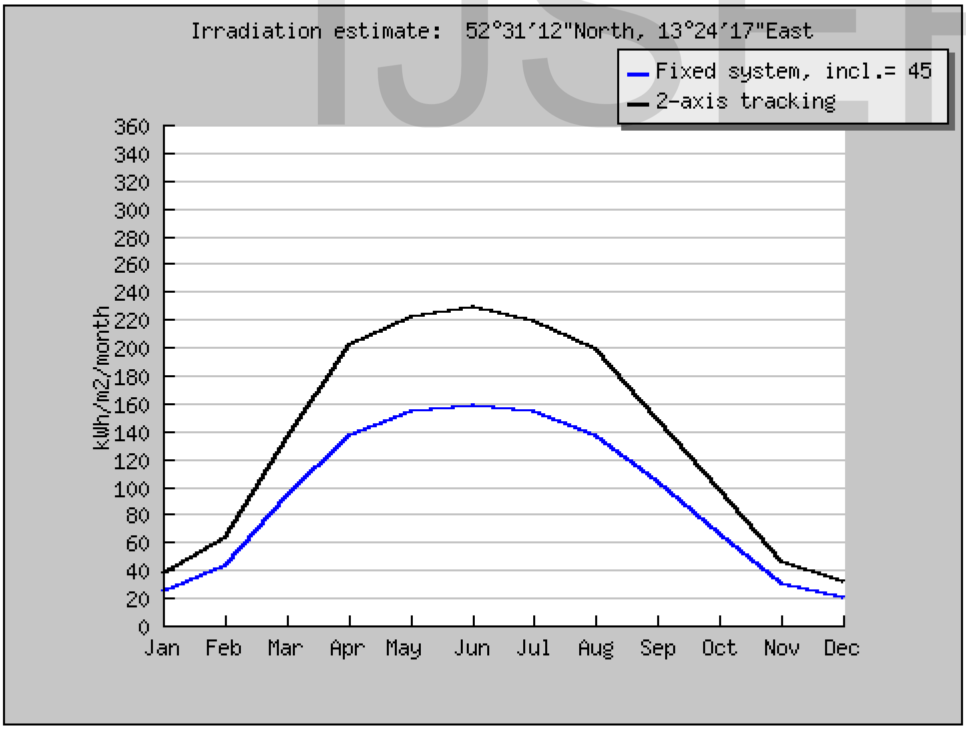

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Results:

From these graphs we can clearly note that the tilt angle, the weather and the location where the photovoltaics panels are fixed have an influences on their performances. So in berlin with a 0degree angle a 1kwp semitransparent PV panel can produce monthly 857 kwh counter to

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1540kwh in Famagusta. With a 45-degree angle a semitransparent PV panel in berlin can produce 868 kwh energy compare to1440 kwh in Famagusta. So aside the daylight that the modules diffuse into the building the 1kwp pv can also produce a certain amount of energy which can reduce the electricity bills cost. Economically if the kwh energy cost is 0.295 € in berlin an average of 252.81 € per month will be saved and 221 € per month in Famagusta with a kwh cost of 0.144 €.

CASE	BERLIN	FAMAGUSTA
0°	857kwh	1540kwh
45°	868kwh	1440kwh

Conclusion

Semitransparent cells are very challenging devices to fabricate and have the potential to be used for a large number of applications. we can conclude that aside the daylight that the semitransparent pv panels provide to us when they are used as shading devices on top of atriums they can generate electrical energy which can reduce the electricity bills cost but also allow smart heat management in indoor environments, thereby utilizing solar energy more efficiently and effectively. This technology is a marvelous ecofriendly method the Use of solar energy release no CO_2, SO_2, or NO_2 gases and don't contribute to global warming. Photovoltaic is now a proven technology which is inherently safe as opposed to some dangerous electricity generating technologies. Over its estimated life a photovoltaic module will produce much more electricity then used in its production and a 100 W module will prevent the emission of over two tons of CO_2. Photovoltaic systems make no noise and cause no pollution in operation. Solar energy is clean, silent, and freely available.

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