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Performance Characteristics of Building Integrated and Freestanding Photovoltaic System with Various PV Technologies and Angles: A Case Study in NEU Grand Library, North Nicosia

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Abstract: Solar energy can be an important source in the Northern part of Cyprus part not only to add a new capacity but also to increase energy security, addressing the environmental concerns. Solar radiation can be considered constant in a wide area. Therefore, the objective of this study is to analyze the monthly global solar radiation, sunshine duration, relative humidity and average temperature collected from the Meteorology Department for North Nicosia to show the potential of solar energy in North Nicosia. The data were collected from 2008-2018 and measured at 2 m height. The results showed that global solar radiation data are within the range of 5.4-341.9 kWhm^{-2} and the mean annual global solar radiation is found to be 2437.52 kWhm^{-2}. In addition, it is found that sunshine duration in North Nicosia is varied from 7.94-12.967 h/day with an average of 8.4 h/day. Moreover, this study is aimed to investigate the performance characteristics of grid-connected Building Integrated Photovoltaic (BIPV) in North Nicosia as exemplified by NEU grand library. In this study, a 30 kWp PV capacity is proposed based on the available roof and front of NEU grand library building and its performance in the BIPV system with various angles (slop and azimuth angles) and three PV technologies (crystalline, CIS and CdTe) is analyzed. Furthermore, the performance of freestanding mounting positions with various angles and PV technologies for roof building is studied and compared with BIPV systems. PVGIS simulation tool is used in this study. It concluded that among the proposed two systems, freestanding mounting position system performs better than BIPV and technology wise CdTe performs better than CIS and crystalline.

Key words: BIPV, freestanding system, NEU grand library, North Nicosia, solar energy, PV technologies

INTRODUCTION

Due to the growing populations, the number of the building has been increased that led to increase the energy consumption relies mainly on fossil fuel (Huovila, 2007; Chateau and Lapillonne, 1982; Sorrell, 2015). Consumption of fossil fuel leads to higher greenhouse gas emissions and air pollutions (Perera, 2018). In recent years, many of the studies are found that the use of renewable energy as a powerful energy source can reduce the total energy consumption and could potentially provide a promising solution for reducing the energy demand for urban building (Li and Loo, 2014; Owusu and Asumadu-Sarkodie, 2016; Chel and Kaushik, 2018; Vares *et al.*, 2019; Liu *et al.*, 2019b; Hossain, 2019; Harkouss *et al.*, 2019).

One of the most promising renewable energy is solar energy. Solar energy is considered an effective alternative energy source because of its environmental benefits. Solar Photovoltaic (PV) applications are utilized to convert the sun's power to electric energy which used for power supply to the building. Recently, the use of a solar PV system for urban building has become more popular (Liu *et al.*, 2019a; Lee *et al.*, 2014; Heinstein *et al.*, 2013). In this case, PV modules are integrated or attached to the building during the construction or after the construction phase. In addition, the integration of PV in the urban environment and building is proposed a huge potential such as environmental and economic benefits (Heinstein *et al.*, 2013). The integration of PV in urban building is called Building Integrated Photovoltaic (BIPV). The BIPV can be integrated into the new or old building mainly into roof or facade which referred to as BIPV facades and BIPV-roof (Debbarma *et al.*, 2016; Assi *et al.*, 2009). BIPV products including transparent or semitransparent glass PV modules will be replaced by the old-style material of the building that used for constructing the roof or wall. In fact, the local weather conditions and the building architecture are important factors that affect the functionality of the BIPV system (Kumar *et al.*, 2019a).

Numerous studies have been investigated the potential of BIPV in terms of environmental and economic benefits (Oliver and Jackson, 2001;

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Bonomo *et al*., 2017; Yang and Zou, 2016; Ng and Mithraratne, 2014; Li *et al*., 2013; Yang, 2015; Keoleian and Lewis, 2003). For example, Oliver and Jackson (2001) applied energy analysis and economic analysis to investigate the application of PV in the building. Bonomo *et al*. (2017) evaluated the cost-effectiveness of BIPV for building skin by using a multi-criteria approach. Yang and Zou (2016) identified the costs, benefits and risks of BIPV for greater BIPV applications.

Solar potential in Cyprus: Cyprus is an island that experiences a Mediterranean climate with huge potential for solar energy. Numerous studies have been investigated the potential of renewable energy in terms of solar energy and wind energy in Northern Cyprus. For instant, Ogbeba and Hoskara (2019) proposed PV as a shading device to reduce the heating problem in Northern Cyprus. They concluded that this system could be generated nearly 2800 W that can provide up to 50% of the electricity demand of the house. Ouria and Sevinc (2018) investigated the use of solar energy in Famagusta in Cyprus. The found that the rate of solar energy depends on the city's climatic, geographic features and other factors. Recently, Kassem *et al*. (2018) and (Fokaides and Kylili, 2014) studied the performance of 6.4 kW rooftop PV system for household buildings in three urban regions in Northern Cyprus. They found that the PV system has significant potential in reducing electricity consumption. Kassem and Gokcekus (2018) evaluated the techno-economic of the 1 MW grid-connected PV system in Lefke, Northern Cyprus. The researchers concluded that this system could be reduced the CO_2 emissions in the town. Kassem *et al*. (2018) evaluated and compared the techno-economic of 12 MW grid-connected PV plants and wind farms in two regions in Northern Cyprus. The results indicated that the PV system is the most economical option to generate electricity in Northern Cyprus. Moreover, according to the Deputy Prime Minister and Ministry Foreign Affairs Northern Cyprus (DPMMFA., 2019), International Cyprus University has completed the greatest PV project for generating electricity in the university. They found that the system was meeting 80% of the electricity of the university during the daytime. Yenen *et al*. (DPMMFA., 2019) evaluated, modeled and compared two solar thermal energy systems over Northern Cyprus. The results demonstrated that the highest solar irradiation absorption and lower GHG emissions and cost for the Northern part of Cyprus were obtained from Fresnel system. Maltini and Minder (2015) Mohammadi *et al*. (2018) designed and built 1.275 MW grid-connected PV plant at Serhatkoy site in Northern Cyprus. Ozerdem *et al*. (2015) evaluated the performance ratio, capacity factor of Serhatkoy PV plant in Northern Cyprus.

Figure 1 shows the long-term averages of solar resources generated by global solar atlas map in Cyprus including global horizontal irradiation, optimum angle of PV module, diffuse horizontal irradiation, direct normal irradiation, air temperature and PV electricity output. It is found that the annual average of global horizontal irradiation of Northern Cyprus is varied from 1900-2100 $kWhm^{-2}$. The highest global horizontal irradiation is in the northwestern part of Northern Cyprus which ranged from 2000-2100 $kWhm^{-2}$. These results indicate the Northern part of Cyprus has hug solar energy that can be used to generate electricity. The second most significant climate variable to determine the performance of the solar system is air temperature. It is noticed that the air temperature is within a range of 20-24 as shown in Fig. 1. Moreover, it is observed that the optimum angle of the PV module is within the range of 30-40° as shown in Fig. 1. The global solar atlas map is the most reliable source of data available that used to estimate the solar potential in the specific region.

(a) (b)

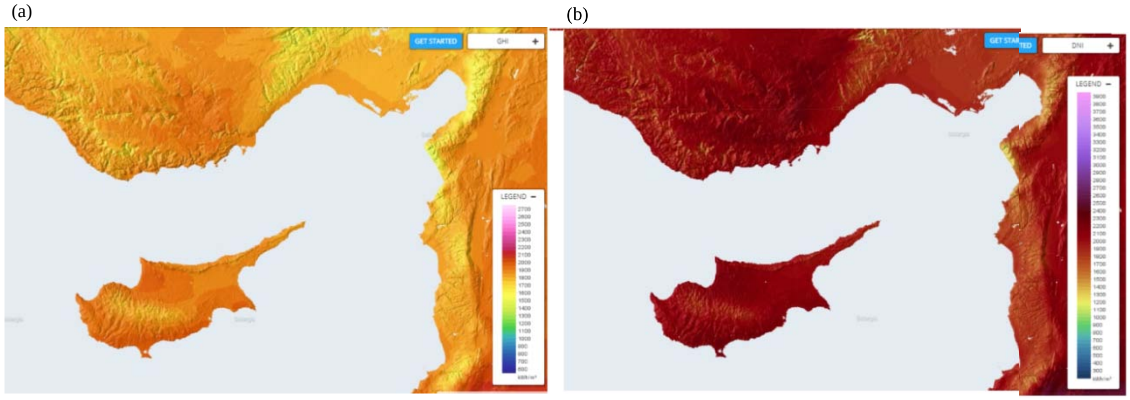

Fig. 1: Continue

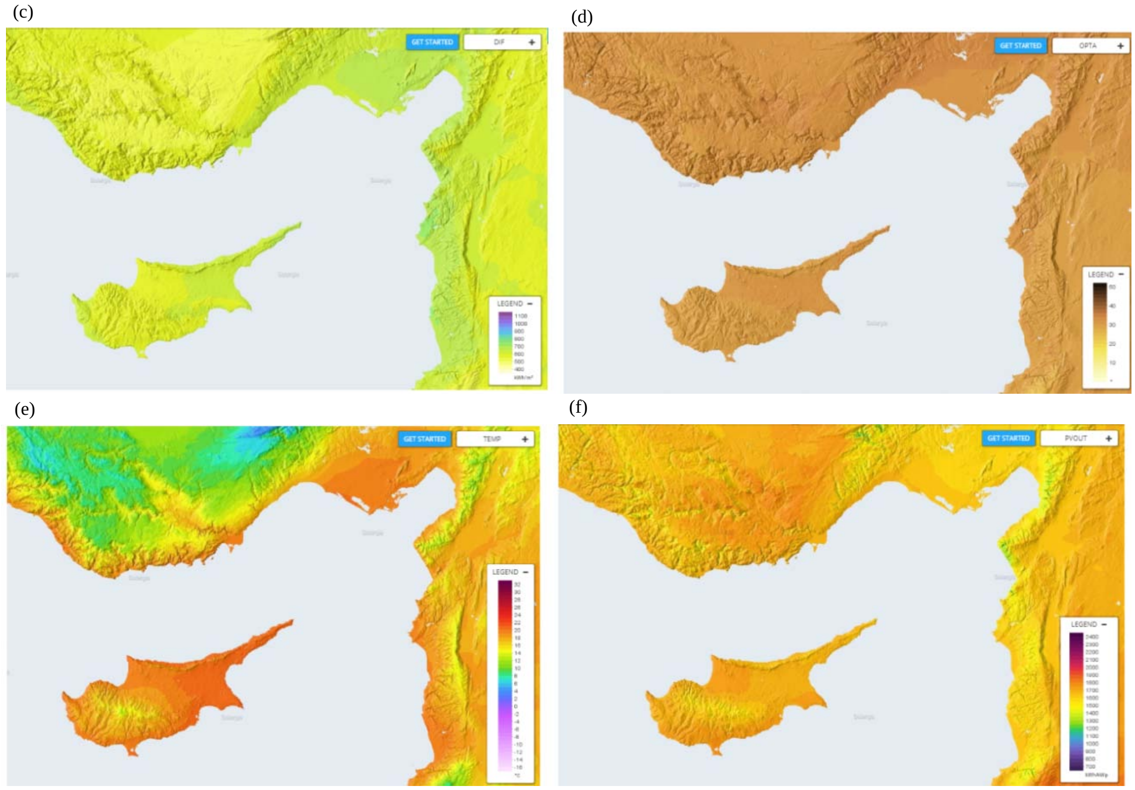

Fig. 1(a-f): Long-term averages of solar resource of Cyprus, (a) Global horizontal irradiation, (b) Direct normal irradiation, (c) Diffuse horizontal irradiation, (d) Optimum angle of PV module, (e) Air temperature and (f) PV electricity output

PV simulation software packages: In the field of solar PV system, a simulation method has been developed to study the solar energy potential at a specific region. Various studies have been investigated the solar potential using various simulation software packages such as PVGIS, PVWatts, RETScreen, Homer, PV*SOL and so on. For example, Kassem *et al*. (2018) and Ogbeba and Hoskara (2019) investigated the performance of a 6.4 kW rooftop PV system in three regions in Northern Cyprus using three simulation tools including PVGIS, PV*SOL and PVWatts. Sudhakar *et al*. (2016) investigated the feasibility of a 10 kW grid-connected PV system in India using Solargis PV Planner Software. Dondariya *et al*. (2018) analyzed the performance of 6.4 kW grid-connected rooftop of PV system using various software including PV*SOL, PVGIS, SolarGIS and SISIFO at in holy city Ujjain, India. Nassar and Alsadi (2019) evaluated the solar energy potential in Palestine using the System Advisor Model. Mohammadi *et al*. (2018) assessed the potential of 5 MW gird-connected PV systems in different cities in the Southern coast of Iran using RETScreen Software. Pavlovic *et al*. (2013) compared the mean monthly of daily solar radiation for three different locations in Serbia by taken the data from NASA, RETScreen, PVGIS and HMIRS. Enongene *et al*. (2019) evaluated the potential of solar PV system in residential buildings in Lagos metropolitan area, Nigeria using HOMER Pro. Shahzad *et al*. (2017) evaluated the electricity cost of the hybrid system (PV/Biomass) for an agricultural farm and a residential community in Pakistan using HOMER Software. Bocca *et al*. (2016) estimated and compared the PV electricity for installations in Italy using measurement data and the PVGIS simulation tool. Chang and Starcher (2019) evaluated the energy production of 45 kW PV system in different location in Texas using PVWatts calculator. Psomopoulos *et al*. (2015) compared the performance of three simulation tools (PVGIS, PVWatts and RETScreen) for evaluating three roof-integrated PV systems in Greece. Hassaine and Mraoui (2017) proposed a grid-connected PV system in Algeria based on a database collected from PVGIS. Belkilani *et al*. (2018) and Hassaine and Mraoui (2017) analyzed the ground measurement monthly global solar radiation for three different locations in Tunisia and compared the actual data of global solar radiation with a database collected from PVGIS. Chakraborty *et al*. (2014) evaluated the performance of a 1 MW solar PV system for

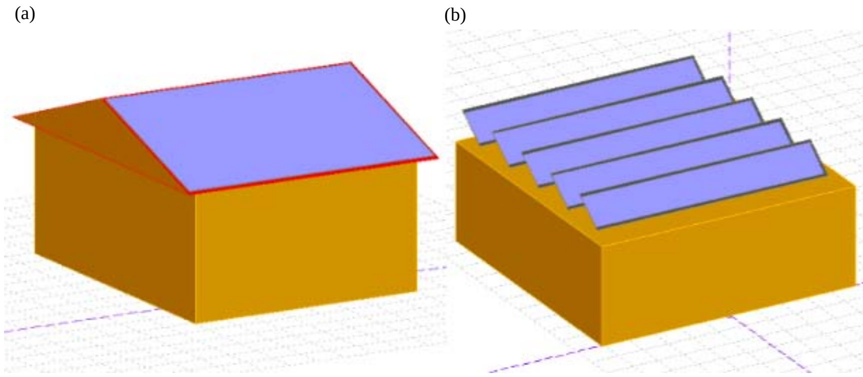

Fig. 2(a, b): (a) BIPV and (b) BAPV system

an energy efficient building in Bangladesh by utilizing NASA SSE solar radiation data, PVsyst simulation Software and RETScreen simulation Software. Ohijeagbon and Ajayi (2014) used HOMER and RETScreen Software to investigate the feasibility and economic viability of standalone hybrid systems for an off-grid rural community of Sokoto in North-West Nigeria. Assamidanov *et al.* (2018) utilized RETScreen Software to analyze the techno-economic feasibility of implementing a residential PV system in South Kazakhstan. Kumar *et al.* (2019b) studied the feasibility of 1 MW PV system at Universiti Malaysia Pahang by utilizing two-simulation software PVWatts and PVGIS.

Building attached and building integrated photovoltaic systems: There are two basic types of PV systems used on building: Building Attached PV (BAPV) and Building-Integrated PV (BIPV) (Halbe *et al*., 2014). For the BAPV system, the PV models are installed on the surface of the building roofs with a certain inclined angle and they are supported by some superstructure while for BIPV system, the PV arrays are placed on the top of the building or to replace conventional building materials (Singh, 2013; Zomer *et al*., 2013; Henemann, 2008) as shown in Fig. 2. There are many studies have been concerned with BIPV and BAPV applications (Kumar *et al*., 2019a; Zomer *et al*., 2013; Bakos *et al*., 2003; Wu *et al*., 2015; Wang *et al*., 2016; Osseweijer *et al*., 2018; Salem and Kinab, 2015; Fina *et al*., 2019; Fouad *et al*., 2019; Zhou *et al*., 2017; Imenes, 2016). For instant, Kumar *et al.* (2019a) evaluated the performance of 32.7 kWp PV for building application in two different configurations (BAPV and BiPV) with three various PV technologies using PVGIS simulation tool. Zomer *et al.* (2013) compared BIPV and BAPV applications on the envelopes of two different Brazilian airports. Bakos *et al.* (2003) evaluated the techno-economic of grid-connected BIPV system installed in Northern Greece. Wu *et al.* (2015) studied the performance monitoring of the first home-based grid-connected BAPV located in Shanghai, China. Wang *et al.* (2016) estimated the environmental impacts of 3 kWp BAPV and 10 kW BIPV system in Shanghai, China. Salem and Kinab (2015) and Osseweijer *et al.* (2018) identified techniques and strategies that can be used today on buildings located in the Mediterranean region.

Objective of the study: The objectives of the study are as follows: to evaluate the validity of the simulated data in comparison with the meteorological data in North collected from meteorological department in North Nicosia. To investigate the applicability of PV system for NEU grand library building applications in two different configurations with various angles (slope and azimuth angles) (BIPV and freestanding systems) and to compare the performance of these systems. To recognize the best PV technology (crystalline, CIS, CdTe technology) for NEU grand library building in North Nicosia.

MATERIALS AND METHODS

Study location: Study location where BIPV system is proposed in Near East University (NEU) in practically NEU Grand Library. It is located in North Nicosia of Cyprus at a latitude of 35.255°N, longitude of 33.327°E. Moreover, Fig. 3 shows a panoramic view and architectural overview of NEU Grand Library as designed as two floors above ground and one underground building. Furthermore, the NEU Grand Library covers an area of 15000 m^2 of interior space, this huge complex includes excellent library format and content on the island, Cyprus, not only in size but also with its extensive services. With regard to its physical dimensions and potential, the library has more than a million items printed on its open shelves. It is a center of culture and access to information built according to international standards including more than 150 million electronic articles, 700 computer tablets, 17 cinema booths, 12 personal and group study rooms, 4 seating stands of 1000, theater of 350 people, cafeteria of 600 people and 600 study

Fig. 3(a-d): Panoramic view of NEU Grand Library

Table 1: Comparison of PV technologies

PV cell material	Cell color	Efficiency (%)	Advantages
Crystalline	Dark blue, black	13-18	Easily available and more efficient photovoltaic cells
CIS	Black	10-12	Less impact on the performance due to variations in temperatures as well as shadow conditions
CdTe	Dark green, black	9-11	-

tables and 24 h free internet open 24 h a day. The photovoltaic modules are planned to incorporate into the building in BIPV.The capacity of the proposed system is estimated to as 30 kWp and it is based on the available roof and front of the building.

Modeling of BIPV systems: In the present study, PVGIS is used to analyze the performance of the proposed 32.7 kWp BIPV system. Generally, PVGIS used to analyze the performance of stand-alone, grid-connected and tracking PV systems for different locations in various installation configurations over the world. It also provides the irradiation in the form of TMY files in three different databases ranging from 2005-2014, 2006-2015 and 2007-2016. Hence, this tool with a large database of solar irradiance for major locations allows the users to calculate electricity potentials from the PV power plants with an option of selecting PV technologies installed at various tilt and azimuth angles. Moreover, three types of PV technologies are used. The comparison between these technologies is given in Table 1. Following the building special form, the BIPV plant was distributed to cover all the available space in the roof and four orientations of the building. In this study, horizontal and inclined PV systems are applicable on the roof and four orientations of the building.

Performance parameters: The performance of energy of BIPV system is evaluated by considering the following parameters:

- Location of the site
- Type of PV technology used
- Loss due to the angle of incidence, temperature and irradiance

In the current study, four major technical criteria are used for evaluating the performance of the BIPV system (Ayompe *et al*., 2011; Kumar *et al*., 2017; Sharma and Chandel, 2013; Okello *et al*., 2015; Sundaram and Babu, 2015; Sharma and Goel, 2017).

Reference Yield (RY):

$$RY = \frac{\text{In plane radiation on PV array in kWhm}^{-2}}{\text{Global radiation at STC array in kWhm}^{-2}} \quad (1)$$

Yield Factor (YF):

$$YF = \frac{\text{Total amount of energy produced during the period of operation in kWh}}{\text{Installed capacity in kWp}} \quad (2)$$

Array Yield (AY):

$$AY = \frac{\text{Array output energy in kWhd}^{-1}}{\text{Installed capacity in kWp}} \quad (3)$$

Capacity utilization factor (CF):

$$CF = \frac{YF}{365 \times 24} \quad (4)$$

Performance Ratio (PR):

$$PR = \frac{YF}{RY} \quad (5)$$

RESULTS AND DISCUSSION

Solar potential in North Nicosia

Characteristics of meteorological parameters in North Nicosia: Solar radiation can be considered constant in a wide area (Bhatia, 2014). However, wind is a very local resource and it must be studied in the specific location and not in the region in which the wind turbine will be placed by considering that some locations in the region have more wind than the other area (EWEA., 2015). Therefore, solar potential and other meteorological parameters including temperature, humidity and sunshine duration for North Nicosia are studied. The data were collected from the meteorological department located in North Nicosia and measured at the height of 2 m. In general, the accuracy of the satellite data is not enough to decide for designing a solar PV system (Argungu and Dabai, 2017; Huld, 2017). Therefore, to ensure the accuracy of the performance of PV solar system results based on satellite data, the solar radiation values collected from PVGIS were compared with the actual measurement of North Nicosia. Table 1 describes the location including geographical coordinates, altitude, measuring height and period of record.

Different statistical measures including the mean, Standard Deviation (SD), Coefficient of Variation (CV), minimum, median and maximum are calculated for each meteorological parameter. Table 2 shows the statistical

Table 2: Description of meteorological parameter in North Nicosia

Parameter/Year	Mean	SD	CV	Minimum	Median	Maximum
Average temperature [°C]						
2008	19.64	7.39	37.61	8.120	19.57	29.80
2009	19.46	7.27	37.38	10.56	19.14	29.75
2010	20.02	6.80	33.98	11.15	19.75	30.66
2011	18.87	7.44	39.43	10.69	18.12	29.35
2012	19.20	8	41.68	8.380	18.88	30.44
2013	19.35	7.21	37.28	9.620	18.85	29.51
2014	19.48	6.60	33.85	11.60	19.10	29.20
2015	19.13	7.50	39.22	9.180	19.09	29.68
2016	19.97	7.47	37.40	9.260	20.87	30.17
2017	19.37	7.64	39.42	8.410	19.26	30.67
2018	20.18	7.05	34.91	11.00	20.55	29.60
Maximum temperature [°C]						
2008	27.11	8.04	29.67	14.32	27.26	38.30
2009	26.54	8.11	30.57	16.40	27.00	37.34
2010	27.73	7.76	27.98	16.64	27.90	39.72
2011	26.04	8.29	31.82	16.43	24.95	38.06
2012	26.50	8.83	33.33	14.55	26.89	38.33
2013	26.88	7.93	29.49	15.83	26.80	38.07
2014	26.77	7.06	26.37	17.90	26.85	37.70
2015	26.55	8.32	31.34	15.04	26.69	37.80
2016	27.39	8.29	30.26	14.89	29.18	38.21
2017	26.87	8.43	31.36	14.58	26.52	39.17
2018	26.58	8.24	31.02	14.10	26.80	37.30
Minimum temperature [°C]						
2008	12.69	6.97	54.91	1.69	12.48	22.72
2009	12.71	6.65	52.32	4.85	11.56	22.70
2010	12.93	6.22	48.12	5.88	11.76	23.30
2011	12.03	6.74	56.05	4.47	11.22	21.61
2012	12.45	7.46	59.92	2.46	12.68	23.27
2013	12.15	6.69	55.06	3.84	11.43	21.57
2014	12.84	6.36	49.56	4.70	11.95	22.00
2015	12.21	7.07	57.91	3.50	11.60	22.58
2016	12.95	7.02	54.22	3.18	13.12	22.72
2017	12.30	7.02	57.10	2.43	12.09	22.94
2018	13.83	6.63	47.99	3.20	14.45	22.40
Sunshine duration [h/day]						
2008	8.718	2.182	25.03	5.731	8.288	12.967
2009	8.189	2.551	31.15	4.397	8.319	11.873
2010	8.332	2.299	27.59	4.384	8.605	11.603
2011	8.288	2.038	24.59	5.268	7.940	11.552

Table 2: Continue

Parameters/Years	Mean	SD	CV	Minimum	Median	Maximum
2012	8.517	2.387	28.03	4.626	8.65	11.944
2013	8.534	2.324	27.23	4.926	9.152	11.567
2014	8.270	2.067	24.99	4.916	8.368	11.594
2015	8.209	2.254	27.46	4.648	8.301	11.323
2016	8.519	2.292	26.9	4.568	8.918	11.573
2017	8.389	2.204	26.27	5.406	8.449	11.890
2018	8.358	2.017	24.14	5.400	8.800	11.200
Global solar radiation [kWhm^{-2}]						
2008	225.3	80.6	35.78	112.6	223.1	334.2
2009	220.1	89.9	40.83	94.4	219.5	338.0
2010	218.6	85.0	38.88	102.6	227.2	335.2
2011	218.1	78.0	35.76	115.7	222.2	328.9
2012	224.6	85.1	37.87	107.9	244.3	334.3
2013	224.6	86.0	38.32	103.7	227.9	341.9
2014	219.7	80.4	36.59	101	225.1	334.7
2015	218.3	82.9	37.99	107.5	222.1	331.6
2016	226.5	84.0	37.1	100.7	235.4	334.5
2017	222.6	81.9	36.81	109.9	224.8	341.5
2018	219.1	80.2	36.6	114.3	231.9	327.5

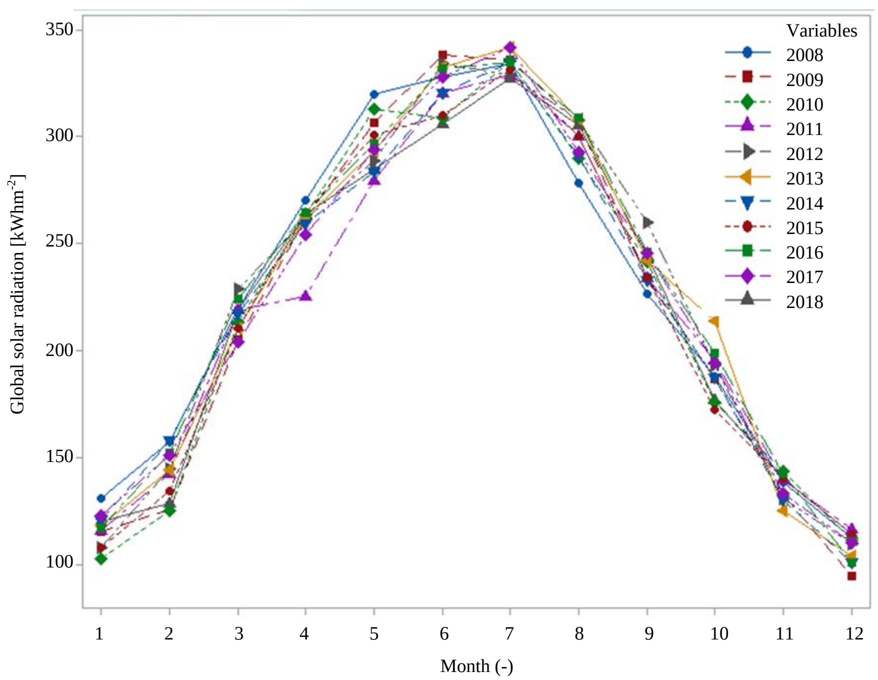

Fig. 4: Monthly mean global solar radiation in North Nicosia

summary of the monthly meteorological parameter from the years 2008-2018. It is found that the maximum and minimum mean temperature values are recorded in 2018 and 2011 with a value of 20.18 and 18.87, respectively. In addition, it is observed that the highest maximum temperature is found to be 39.72 in 2010 while the lowest minimum temperature is achieved in 2008 with a value of 1.69. Furthermore, it is noticed sunshine duration in North Nicosia is varied from 7.94-12.967 h/day with an average of 8.4 h/day. Additionally, it is found that global solar radiation data are within the range of 5.4-341.9 kWhm^{-2} and the mean annual global solar radiation is found to be 2437.52 kWhm^{-2}. The variation of monthly mean global solar radiation is illustrated in Fig. 4. It is found that the maximum monthly global solar radiation of 341.85 kWhm^{-2} is recorded on July 2013 and the minimum value of 94.37 kWhm^{-2} is achieved in December, 2009.

Generally, the relative humidity and air temperature are most important of meteorological parameters for the operating safety conditions of the PV module are satisfied or not. The monthly mean values of relative humidity obtained for North Nicosia is depicted in Fig. 5. It is

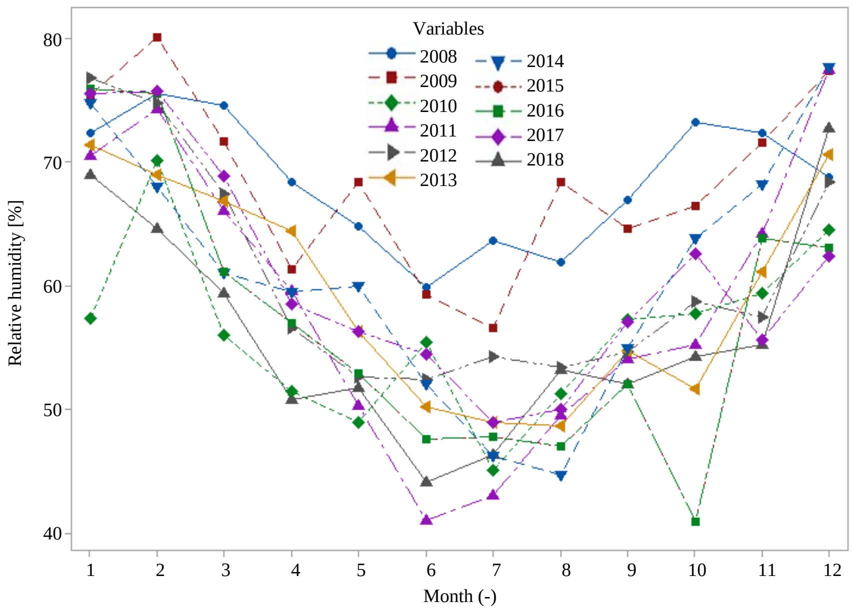

Fig. 5: Monthly mean relative humidity in North Nicosia

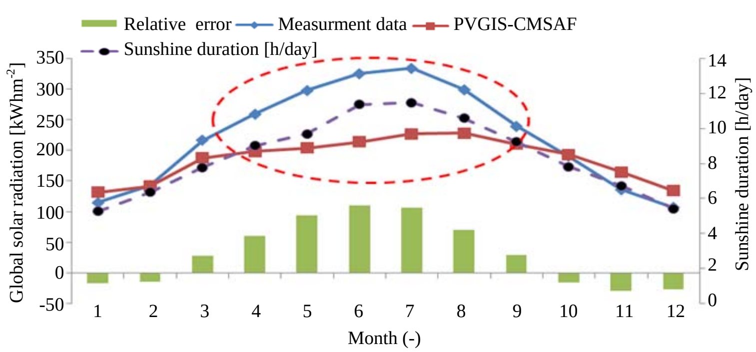

Fig. 6: Global solar radiation for North Nicosia in the year 2015 using meteorology data measured and PVGIS

observed that the minimum and maximum relative humidity values are obtained in October, 2016 and February, 2009, respectively.

Based on the measurement data, the annual mean air temperature in North Nicosia is 19.5, the mean relative humidity is 60.4% and the total sunshine duration and annual global solar radiation are 100 and 2437.52 kWhm^{-2}, respectively.

Global solar radiation for North Nicosia using meteorology data measured and PVGIS: In the current study, the measurement data were collected from 2008-2018 in North Nicosia. North Nicosia is the capital city of Northern Cyprus and located at the latitude of 35.180°N and a longitude of 33.374°E. Figure 6 shows the mean monthly value of global solar radiation for North Nicosia during the period of 2008-2016. It is observed that relative error during Spring and Summer season is within the range of 61.09-110.93 kWhm^{-2}, this is due to the highest number of bright sunshine attainment in these seasons as shown in Fig. 6. Moreover, Fig. 7 shows the variation of averaged temperature during the period of 2008-2016. It is noticed that a good agreement between the measured temperature (actual data) and simulated data obtained from PVGIS Software. It is also found that the relative error is varied from -4.21-2.12.

Solar potential in NEU Grand Library

Variations in solar radiation and energy generation for BIPV system: This section is aimed to show how much solar energy will be absorbed by the surfaces of the building which can be helpful, especially when PV systems are used in the building in the shapes of solar panels to convert sunlight into electricity. Therefore, the

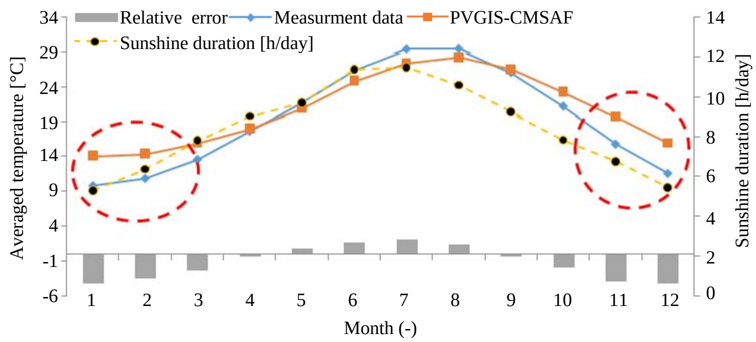

Fig. 7: Averaged temperature for North Nicosia in the year 2015 using meteorology data measured and PVGIS

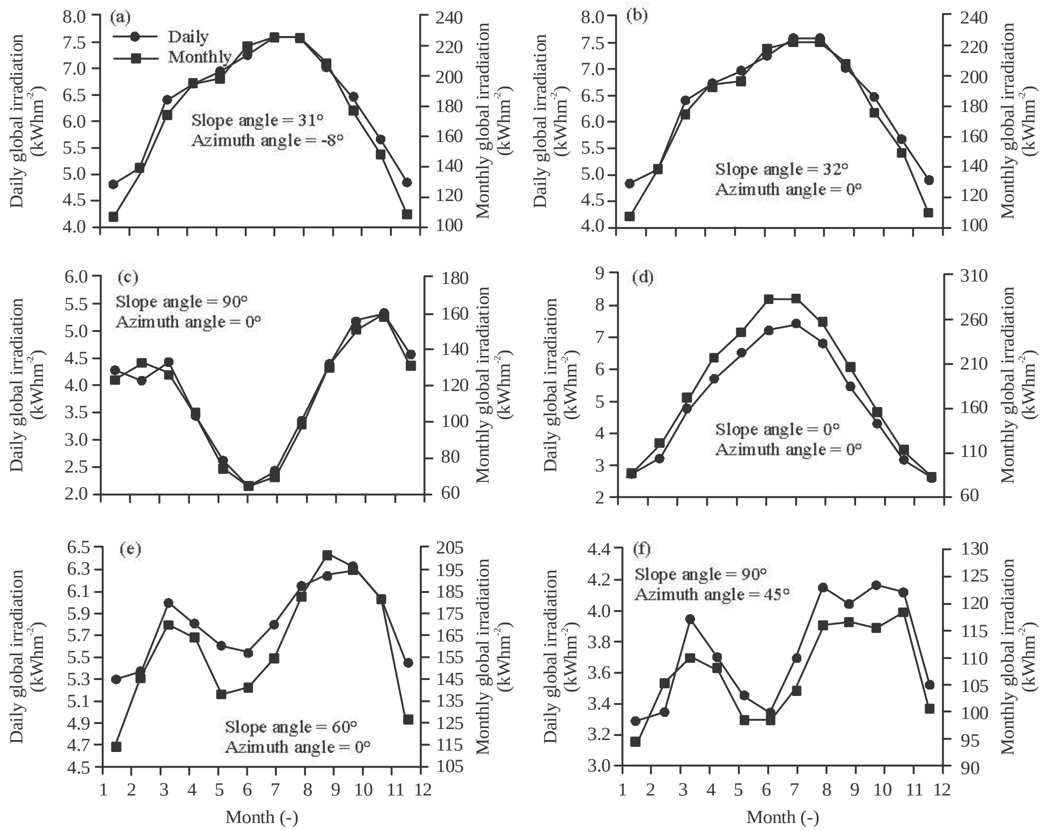

Fig. 8(a-f): Global irradiation per square meter received by the modules of the given system

slope and azimuth angles are varied based on the orientation of the walls and roof. The mean daily and monthly global irradiation with various slope and azimuth angles and PV technologies simulation tool are shown in Fig. 8. In addition, the average daily and monthly energy productions from the proposed system using crystalline, CIS, CdTe technology are shown in Fig. 9 and 10, respectively.

Considering the PVGIS simulation tool, it is found that the optimum slope and azimuth angles are 31 and -8°, respectively. According to these angles, it is observed that the monthly maximum and minimum solar radiation are achieved in July and January with a value of 235 and 130 kWhm^{-2}, respectively. Furthermore, the maximum possible energy recorded in July, i.e., 4940 kWh/year with crystalline technology, 5240 kWh/year with CIS and 5580 kWh/year with CdTe technology under same climatic condition. The analysis indicates that the BIPV system with CdTe technology is observed to perform better than

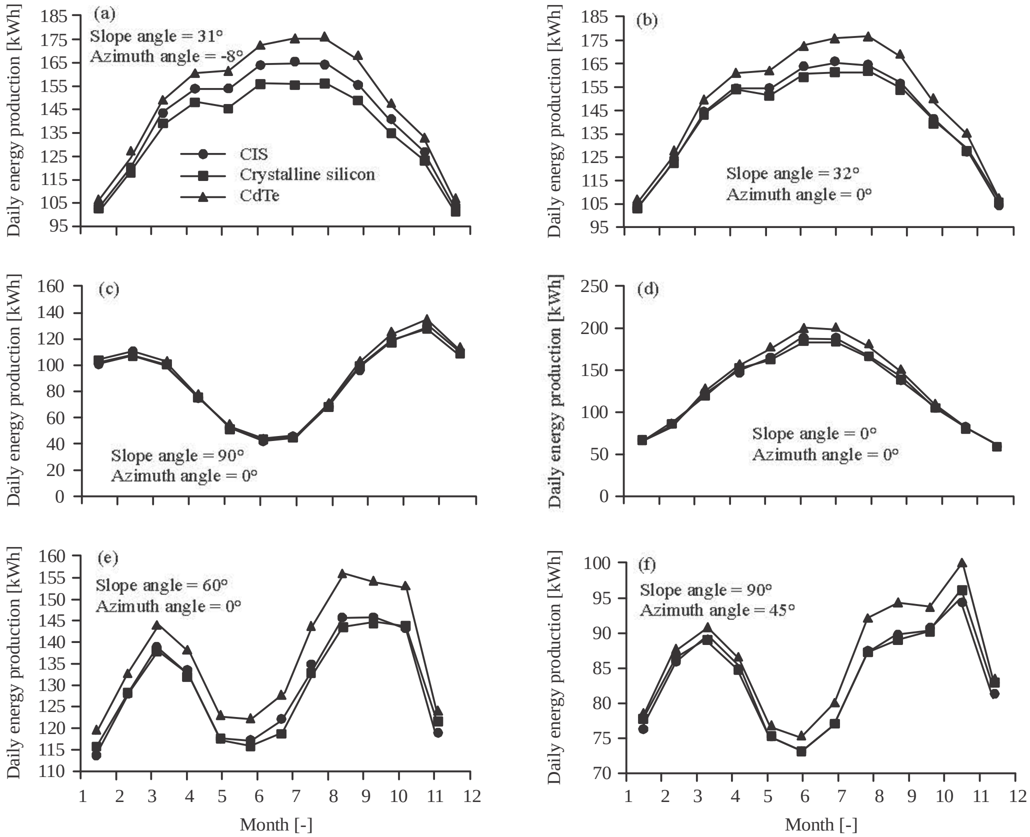

Fig. 9(a-f): Average daily energy production from the given system

Table 3: Solar radiation and energy generation with various angles and technologies

PV technology/Slope angle [°]	Azimuth angle [°]	Ed [kWh/d]	Em [kWh]	Hd [kWh/m^{2}d]	Hm [kWh/m^2]
Crystalline silicon					
31	-8	138	4200	6.21	189
32	0	143	4340	6.19	188
90	0	87	2650	3.79	115
0	0	126	3840	5.49	167
60	0	130	3940	5.59	170
90	45	84.1	2560	3.65	111
CIS					
31	-8	144	4380	6.21	189
32	0	144	4370	6.19	188
90	0	86.2	2620	3.79	115
0	0	127	3863	5.48	167
60	0	130	3960	5.59	170
90	45	83.9	2550	3.65	111
CdTe					
31	-8	151	4610	6.21	189
32	0	151	4600	6.19	188
90	0	89	2710	3.79	115
0	0	133	4050	5.49	167
60	0	136	4150	5.59	170
90	45	86.6	2630	3.65	111

Ed: Average daily energy production from the given system, Em: Average monthly energy production from the given system, Hd: Average daily sum of global irradiation per square meter received by the modules of the given system, Hm: Average monthly sum of global irradiation per square meter received by the modules of the given system

crystalline and CIS technologies with the maximum possible energy of 5580 kWh in July and the minimum energy of 3300 kWh in January. Moreover, Table 3 is summarized the average value of solar radiation and energy generation with various angles and technologies. It is noticed that the PV system with CIS technology has minimum energy production compared to crystalline technology for slope angle of 90° and azimuth angle of 45°.

Performance analysis: The annual solar radiation and energy production were estimated based on the PVGIS simulation tool. The quantities that used to assess the performance of BIPV system in terms of specific annual yield, annual array yield, annual reference yield and capacity factor were calculated for different PV technologies and angles as shown in Table 4. It is found that the minimum capacity factor for PV system with all PV technologies is recorded for slope angle of 90° and azimuth angles of 0° and 45° (Table 5). Therefore, the

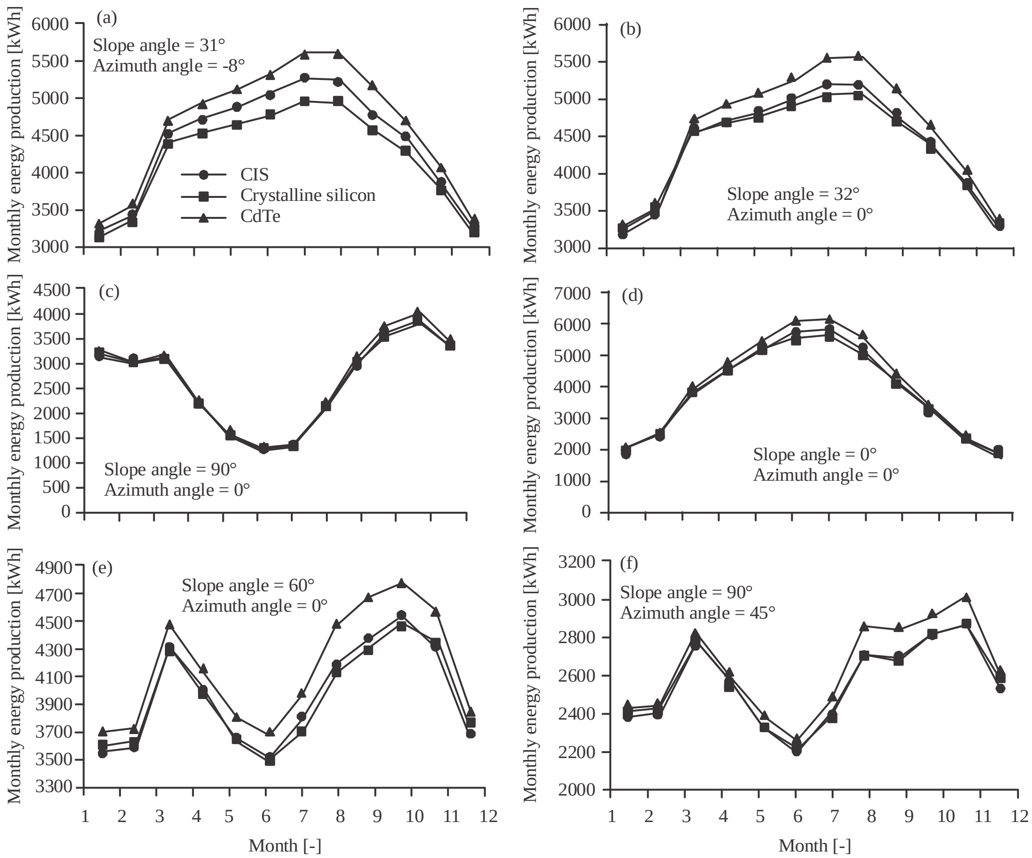

Fig. 10(a-f): Average monthly energy production from the given system

Table 4: Summary of performance parameters of BIPV system

PV technology/Parameters	Slope and azimuth angles 31 and -8°	32 and 0°	90 and 0°	0 and 0°	60 and 0°	90 and 45°
Crystalline silicon						
PV system [kWp]	30	30	30	30	30	30
Annual PV energy [kWh]	52100	52100	31800	46000	47300	30700
Array output energy [kWh/d]	2260	2260	1380	2000	2040	1330
Yearly in-plane irradiation [KWh/m^2]	2454	2449	1501	2170	2210	1442
Annual mean daily irradiation in array plane [kWhm^{-2}d]	6.21	6.19	3.79	5.49	5.59	3.65
Specific annual yield [kWh/kWp]	1737	1737	1060	1533	1577	1023
Annual array yield [kWh/kWp.d]	75	75	46	67	68	44
Annual reference yield [kWh/kWpd]	6.21	6.19	3.79	5.49	5.59	3.65
Capacity factor [%]	19.82	19.82	12.10	17.50	18.00	11.68
CIS						
PV system [kWp]	30	30	30	30	30	30
Annual PV energy [kWh]	52800	52400	31500	46400	47500	30600
Array output energy [kWh/d]	2260	2260	1380	2000	2040	1330

Table 4: Continue

PV technology/Parameters	Slope and azimuth angles 31 and -8°	32 and 0°	90 and 0°	0 and 0°	60 and 0°	90 and 45°
Yearly in-plane irradiation [$KWhm^{-2}$]	2454	2449	1501	2169.91667	2210	1442
Annual mean daily irradiation in array plane [$kWhm^{-2}d$]	6.21	6.19	3.79	5.49	5.59	3.65
Specific annual yield [kWh/kWp]	1760	1747	1050	1547	1583	1020
Annual array yield [KWh/kWpd]	75	75	46	67	68	44
Annual reference yield [kWh/kWpd]	6.21	6.19	3.79	5.49	5.59	3.65
Capacity factor [%]	20.09	19.94	11.99	17.66	18.07	11.64
CdTe						
PV system [kWp]	30	30	30	30	30	30
Annual PV energy [kWh]	55300	55200	32500	48600	49800	31600
Array output energy [kWh/d]	2260	2260	1380	2000	2040	1330
Yearly in plane irradiation [$KWhm^{-2}$]	2455	2449	1501	2170	2210	1442
Annual mean daily irradiation in array plane [$kWhm^{-2}d$]	6.21	6.19	3.79	5.49	5.59	3.65
Specific annual yield [kWh/kWp]	1843	1840	1083	1620	1660	1053
Annual array yield [KWh/kWp.d]	75	75	46	67	68	44
Annual reference yield [kWh/kWpd]	6.21	6.19	3.79	5.49	5.59	3.65
Capacity factor [%]	21.04	21.00	12.37	18.49	18.95	12.02

Table 5: Annual performance comparison and losses of BAPV and BIPV system

Type PV technology/Parameters	Slope and azimuth angles 31 and -8°	32 and 0°	90 and 0°	0 and 0°	60 and 0°	90 and 45°
BAPV (Crystalline silicon)						
PV energy production [kWh/year]	54500	54400	32700	47900	49300	31700
In-plane irradiation [$kWh/m^2/year$]	2260	2260	1380	2000	2040	1330
Angle of incidence losses [%]	-2.7	-2.6	-6.3	-3.4	-3.2	-4.5
Spectral effects losses [%]	0.4	0.4	0.7	0.2	0.5	0.5
Temperature and low irradiance losses [%]	-8.8	-8.7	-7.2	-8.5	-8.1	-8.1
Total loss [%]	-19.8	-19.7	-21.1	-20.3	-19.5	-20.6
Capacity factor [%]	20.74	20.70	12.44	18.23	18.76	12.06
Performance ratio [%]	80.38	80.24	78.99	79.83	80.56	79.45
BIPV (Crystalline silicon)						
PV energy production [kWh/year]	52100	52100	31800	46000	47300	30700
In-plane irradiation [$kWh/m^2/year$]	2260	2260	1380	2000	2040	1330
Angle of incidence losses [%]	-2.7	-2.6	-6.3	-3.4	-3.2	-4.5
Spectral effects losses [%]	0.4	0.4	0.7	0.3	0.5	0.5
Temperature and low irradiance losses [%]	-12.8	-12.7	-10	-12.1	-11.8	-11
Total loss [%]	-23.3	-23.2	-23.5	-23.4	-22.8	-23.1
Capacity factor [%]	19.82	19.82	12.10	17.50	18.00	11.68
Performance ratio [%]	76.84	76.84	76.81	76.67	77.29	76.94
BAPV (CIS)						
PV energy production [kWh/year]	53800	53700	32000	47400	48500	31200
In-plane irradiation [$kWhm^{-2}/year$]	2260	2260	1380	2000	2040	1330
Angle of incidence losses [%]	-2.7	-2.6	-6.3	-3.4	-3.2	-4.5
Spectral effects losses [%]	-	-	-	-	-	-
Temperature and low irradiance losses [%]	-9.6	-9.6	-8.7	-9.3	-9	-9.2
Total loss [%]	-20.8	-20.8	-22.9	-21.2	-20.7	-21.9
Capacity factor [%]	20.47	20.43	12.18	18.04	18.46	11.87
Performance ratio [%]	79.35	79.20	77.29	79.00	79.25	78.20
BIPV (CIS)						
PV energy production [kWh/year]	52800	52400	31500	46400	47500	30600
In-plane irradiation [$kWhm^{-2}/year$]	2260	2260	1380	2000	2040	1330
Angle of incidence losses [%]	-2.7	-2.6	-6.3	-3.4	-3.2	-4.5
Spectral effects losses [%]	-	-	-	-	-	-
Temperature and low irradiance losses [%]	-11.8	-11.7	-10.2	-11.3	-11	-10.8
Total loss [%]	-22.7	-22.6	-24.2	-22.8	-22.5	-23.3
Capacity factor [%]	20.09	19.94	11.99	17.66	18.07	11.64
Performance ratio [%]	77.88	77.29	76.09	77.33	77.61	76.69
BAPV (CdTe)						
PV energy production [kWh/year]	56300	56200	32900	49300	50600	32000
In-plane irradiation [$kWhm^{-2}/year$]	2260	2260	1380	2000	2040	1330
Angle of incidence losses [%]	-2.7	-2.6	-6.3	-3.4	-3.2	-4.5
Spectral effects losses [%]	0.8	0.8	0.9	0.7	0.8	0.8
Temperature and low irradiance losses [%]	-6.2	-6.2	-7	-6.3	-6	-7.5

Table 5: Continue

Type PV technology/Parameters	Slope and azimuth angles 31 and -8°	32 and 0°	90 and 0°	0 and 0°	60 and 0°	90 and 45°
Total loss [%]	-17.2	-17.1	-20.8	-17.9	-17.4	-19.8
Capacity factor [%]	21.42	21.39	12.52	18.76	19.25	12.18
Performance ratio [%]	83.04	82.89	79.47	82.17	82.68	80.20
BIPV (CdTe)						
PV energy production [kWh/year]	55300	55200	32500	48600	49800	31600
In-plane irradiation [kWhm^{-2}/year]	2260	2260	1380	2000	2040	1330
Angle of incidence losses [%]	-2.7	-2.6	-6.3	-3.4	-3.2	-4.5
Spectral effects losses [%]	0.8	0.8	0.9	0.7	0.8	0.8
Temperature and low irradiance losses [%]	-7.8	-7.8	-8	-7.7	-7.4	-8.7
Total loss [%]	-18.6	-18.6	-21.8	-19.2	-18.7	-20.8
Capacity factor [%]	21.04	21.00	12.37	18.49	18.95	12.02
Performance ratio [%]	81.56	81.42	78.50	81.00	81.37	79.20

vertically mounted BIPV system will be neglected, since, it will be produced minimum energy production. Moreover, the results show that the best slope angle is 32° with an annual energy production of 56400 kWh/year for PV system with crystalline silicon. In addition, the best slope angle to obtain the maximum annual energy production is found to be 56890 kWh/year and 59900 kWh/year for PV system with CIS and CdTe technologies, respectively is 31°.

Comparing the performance energy of BAPV and BIPV: Type of the PV technology used, system losses and loss due to the angle of incidence, loss due to temperature and irradiance are the most important parameters that should be considered during the estimation of the energy performance of PV system. Therefore, system losses and the loss due to the angle of incidence, loss due to temperature for different angles (slope and azimuth angles) have been calculated using PVGIS simulation tool and listed in Table 5. In addition, the capacity factor and performance ratio of each proposed configuration are calculated using Eq. 4 and 5 and presented in Table 5. It concluded that among the proposed two systems, BAPV system performs better than BIPV and technology wise CdTe performs better than CIS and crystalline.

CONCLUSION

The objective of this paper was to analyze the performance of 30 kWp grid-connected BIPV and BAPV with various angles (slop and azimuth angles) and three PV technologies using PVGIS simulation tool. From this analysis, the following conclusion were drawn:

Based on the measurement data, the annual mean air temperature in North Nicosia is 19.5, the mean relative humidity is 60.4% and the total sunshine duration and annual global solar radiation are 100.7 h/day and 2437.52 kWhm^{-2}, respectively.

It is observed that relative error between the actual data and simulated data during spring and summer season is within the range of 61.09-110.93 kWhm^{-2}, this is due to the highest number of bright sunshine attainment in these seasons.

It is noticed that PV system with CIS technology has minimum energy production compared to crystalline technology for slope angle of 90° and azimuth angle of 45°. The total losses in a CdTe technology were observed to be lower than CIS and c-Si technology. Based on these outcomes, it concluded that CdTe is the best PV technology compared to most widely used PV technologies (c-Si) and the existing buildings can be turned into power stations with this approach of BIPV and BAPV.

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