



# A Detailed Analysis of Daily, Seasonal and Yearly Performance Values of Photovoltaic Modules Using by a Simplified Method

Mehmet Azmi Aktacir<sup>1</sup> , Erdal Yıldırım<sup>2,\*</sup> , Yusuf İşiker<sup>3</sup> 

<sup>1,3</sup>Harran University, Mechanical Engineering Department, Şanlıurfa, Turkey

<sup>2</sup>Harran University, Technical Sciences Vocational School, Şanlıurfa, Turkey

## Abstract

The performance of panels for PV system design is determined according to the performance values in standard test conditions specified in the panel catalog, without knowing the performance under actual operating conditions. However, the operating performance of the PV panel depends on meteorological characteristics of place where the PV system is installed. Especially, if outside temperature values are above test conditions, the efficiency of the PV panel decreases and generation losses are observed. In this study, performance parameters of photovoltaic panel were calculated for four different PV panel technologies only by using their catalogue values like NOCT temperature (the cell temperature under conditions as solar radiation 800 W/m<sup>2</sup>, surface temperature 20°C, wind speed 1 m/s and air mass 1.5), power-temperature coefficient etc. For this purpose, real working conditions were simulated using 3-year climate data for the meteorological conditions of Şanlıurfa, Turkey. In the end, PV panel efficiency, electricity generation values and performance ratios were calculated in accordance with the temperature. According to the results obtained, the PV panels' performance ratios decreased up to 0.75 during the summer months. The highest unit energy generation was achieved with thin film PV technology.

**Keywords:** performance ratio; PV panel efficiency; energy generation

## 1. INTRODUCTION

The most important component of photovoltaic (PV) systems is PV panels that generate electricity directly from the sun. Electricity generation from PV panels depends on panel material, solar radiation and other atmospheric variables such as surface air temperature and surface wind velocity that affect panel efficiency [1, 2, 3]. PV panels are produced according to various technologies including silicon material. In practice, Mono-silicon, Multi-silicon crystal types and Thin-film technology are the most preferred panel types [4]. High efficiency (HIT) panels, which have recently been produced as multi-junctions, are also being used. The most important parameter that affects the choice of PV panels is PV panel efficiency. This shows the rate at which solar energy on the PV panel surface turns into electrical energy. PV panel efficiencies are measured at standard test conditions (STC). However, although STC, defined as solar radiation 1000 W/m<sup>2</sup>, surface temperature 25°C and air mass (A.M.) 1.5, are considered to be ideal conditions, they do not represent the actual field conditions in which the PV panel will operate [4]. The PV panels produced by different manufacturers can be easily compared in accordance with panel test efficien-

cies measured according to the STC. In addition, PV panel manufacturers give Nominal Operation Cell Temperature (NOCT) conditions for panel performance values that are closer to actual conditions. NOCT conditions are defined as solar radiation 800 W/m<sup>2</sup>, surface temperature 20°C, wind speed 1 m/s and air mass 1.5. In order to simulate actual operating conditions of PV panels, the performance values obtained for the NOCT conditions are taken into account. When a module is operating in NOCT, "standard operating conditions" (SOC) are used [3].

One of the most important factors affecting the PV panel efficiency is outdoor air temperature. Although some of the solar energy on PV surface is converted into electricity, larger part is converted to heat, increasing the surface temperature [5, 6]. Regarding this issue, there are various studies in the literature. There are many cooling methods investigations on PV, categorizing them according to heat transfer modes: convective cooling (hydro and aero-based cooling with or without extended surfaces), conductive cooling (phase change materials), and radiative cooling. Nanofluids have a significant enhancement of PVT systems performance as overall efficiency can reach 61.23% using MWCNT/water

\* Corresponding author  
Email: erdaly@harran.edu.tr



(0.075% concentration). Aero-based cooling of PVs can achieve an enhancement in electrical performance by ~29% [7]. Photovoltaic (PV) panels can increase their efficiency and durability by using water-cooled systems. The results showed that decreased temperature provided by a cooling system and the use of the hot water so generated increases the efficiency of the panels by 30% compared to the system without cooling arrangements [8]. Attaching PCMs at the back of PV panel introduces external cooling power of PV due to the latent heat storage capacity of PCMs and achieves better system performance. [9] Using both paraffin wax and beeswax as a phase change material in PV-PCM system was tested in outdoor environment. With PCM, one-day experimental results show PV efficiency is enhanced from 6.1%–6.5% to 7.0%–7.8% [10]. In an experimental study, it was observed that the increase of the PV module temperature decreased the efficiency [1]. In another study [5], the effects of environmental factors such as ambient temperature and solar radiation on the temperature of the PV panel and the output performance were investigated. It was shown that PV panel temperature had a very important role in output power generation. In a study of how photovoltaic (PV) module performance varies on continental scale [11], it has found that the strongest effect is seen in the dependence on irradiance and module temperature, which may range from –20% to +5% at different locations. A group of researchers have also shown that PV efficiency can be increased by passive and active cooling systems to reduce the PV surface temperature [6]. Similarly, there are studies examining the wind effect on PV power performance in literature as well. [12, 13]. For example, in a study, the wind effect was investigated to reduce the PV surface temperature. It was found that increased wind speed enhanced the efficiency by 10–12% [12]. There are identical studies that estimate the field performance of the PV system [4, 14]. A study [15] presented a reliable mathematical method for predicting energy production of grid-connected photovoltaic systems with different technologies commercially used in different regions of India. In another study [3], PV utility and PV power models that are existent in the literature were examined, depending on temperature. In addition, in a different study [16], the effect of increasing panel temperature on deposition of dust particles on PV surface was investigated. In general, it was stated that increasing the temperature of the PV modules reduces the energy conversion efficiency of these modules. However, in outdoor air conditions with a higher PV surface temperature difference, it was found that there was a higher output due to the deposition of less dust particles than at lower temperature differences.

The performance of solar panels is reduced on hot days when the outdoor air temperature is higher than STC test temperature (25°C). The temperature-power coefficient is used to determine the effect of operating temperature on PV performance [4]. The PV panels with low temperature-power coefficient are less affected by temperature.

Performance ratio (PR) is variable to calculate efficiency of a PV panel. PR is the ratio of actual output and theoretical output energy. The performance ratio is one of the most important parameters for evaluating the efficiency of a PV panel [15, 4, 17, and 18]. PR is largely independent from the orientation of a PV system and incident solar irradiation on the PV plant. For this reason, the performance ratio can be used to compare PV system at different locations all over the world [17]. Generally, PR is used as a fruitful way of quantifying the overall effect of losses due to PV module temperature, spectrum, module mismatch and other losses such as optical reflection, soiling and downtime failures [4]. Another measurement parameter describing the performance of PV-systems is the Specific Yield (SY). It measures the production per installed power and is a very good way of measuring the performance of PV systems since the production is proportional to the potential earnings of the system while the installed power reflects the cost of the system [18].

PV panel performance depends on parameters such as meteorological value, panel technology as explained above. In PV system design, when panels are selected according to standard test conditions, PV system design may be faulty/inadequate. In this study, it is aimed to easily determine the performance parameters of photovoltaic panels in real working conditions. For this purpose, a simple method has been proposed to calculate the daily, monthly and yearly performance parameters of PV panel. In this study, 4 different PV panel technologies were employed, and 3-year outdoor temperature and solar radiation values in meteorological conditions of Şanlıurfa, Turkey were used. Besides, Nominal Operation Cell Temperature (NOCT) conditions and power-temperature coefficient easily found in the panel catalogues were used in calculation of panel performance parameters. Thus, the PV system was simulated for one year and performance values were determined accordingly.

In this study, while designing PV systems, measured real values were used instead of standard test conditions. By selecting the prominent PV technologies, their performances were calculated using real operating conditions. Thus, an efficiency calculation method consists of Specific Yield and Performance Ratio was proposed to determine the daily, monthly, and annual performances of selected PV technologies with locational data.

## 2. MATERIALS AND METHODS

### 2.1. Şanlıurfa's Climate

In this study, the performance of PV panels will be examined in the meteorological conditions of Şanlıurfa which has a hot climate. Şanlıurfa is located in the southeast Anatolia region of Turkey and has a continental climate with a high solar energy potential. The global solar radiation potential map of Turkey is given in Fig. 1 [19, 20]. As can be seen from the figure, the value of global solar radiation in the north of Turkey is about 1400 kWh/m<sup>2</sup> per year while these values are in the range of 2000 kWh/m<sup>2</sup> per year in the south. This

shows that Turkey’s southern region has a significant potential for solar energy applications.

### 2.2. Meteorological Data

In this study, data from the meteorological station of Harran University called GAPYENEV center in Şanlıurfa was used. These data include the global radiation on horizontal surface, sunshine durations, and outside air temperatures measured over a period of 10 minutes between the years 2014 and 2016. Monthly mean values of all meteorological data and average daily variation for each month were also calculated.

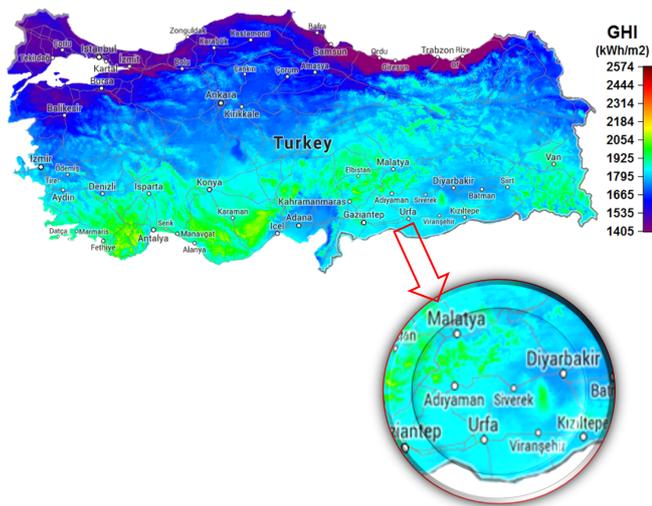


Figure 1. Annual global solar radiation potential map of Turkey [21]

### 2.3. Photovoltaic Panel Technologies

Four different PV technologies were used in this study. These are HIT, Mono-silicon, Multi-silicon and Thin-film (CdTe), respectively. The characteristic values of these panels are presented in Table 1 [22,23,24,25]

### 2.4. Solar radiation analyses

PV panels were investigated in two different positions, horizontal and inclined at 30° to the south. The isotropic diffuse model, given in the study by Schwingshacklet al. [13], is used to calculate the total solar radiation values on the inclined surface. With this method, the total solar radiation on the inclined surface is calculated as below,

$$I_T = I_b R_b + I_d \left( \frac{1 + \cos \beta}{2} \right) + I \rho_g \left( \frac{1 - \cos \beta}{2} \right) \quad (1)$$

On the right side of the equation are direct, diffuse and reflected elements of total solar radiation, respectively.  $I_b$  and  $I_d$  represent the direct and diffuse radiation on the horizontal

surface.  $R_b$  is the surface slope. is the ratio of direct radiation on tilted surface to radiation on horizontal surface at any time and is calculated as,

$$R_b = \frac{\cos \theta}{\cos \theta_z} \quad (2)$$

The incident angle  $\theta$  of solar radiation is the angle between direct radiation and the surface normal. The relation between  $\theta$  and the other angles is as below,

$$\begin{aligned} \cos(\theta) &= \sin(\delta) \cdot \sin(\varphi) \cdot \cos(\beta) - \sin(\delta) \cdot \cos(\varphi) \cdot \sin(\beta) \cdot \cos(\gamma) \\ &+ \cos(\delta) \cdot \cos(\varphi) \cdot \cos(\beta) \cdot \cos(\omega) + \cos(\delta) \cdot \sin(\varphi) \cdot \sin(\beta) \cdot \cos(\gamma) \cdot \cos(\omega) \\ &+ \cos(\delta) \cdot \sin(\beta) \cdot \sin(\gamma) \cdot \sin(\omega) \end{aligned} \quad (3)$$

For horizontal surfaces, the angles of incidence are equal to the zenith angle  $\theta_z$ . In this case, the slope  $\beta = 0$  and the equation 3 becomes as follows,

$$\cos(\theta_z) = \cos(\varphi) \cdot \cos(\delta) \cdot \cos(\omega) + \sin \varphi \cdot \sin(\delta) \quad (4)$$

$\varphi$  and  $\omega$  are the latitude and hour angle respectively.  $\gamma$  is the azimuth angle and the value for south facing surfaces is zero.  $\delta$ , declination angle is calculated using the formula given as below,

$$\delta = 23,45 \sin \left( 360 \frac{284 + n}{365} \right) \quad (5)$$

### 2.5. Determination of Panel performance parameters

The surface temperature ( $T_{panel}$ ) of the photovoltaic panel is critical parameter, governing the efficiency performance of photovoltaic panel [26]. The method used in this study for the estimation of PV performance can be expressed as a function of solar radiation and panel temperature. In literature, there a lot of photovoltaic module temperature models [27]. For the present study it has used the model described in [28]. In another study [15], for validation of this model actual field output of PV plants were compared with the predicted value. It has been determined that the model performs satisfactorily.

The surface temperature ( $T_{panel}$ ) of the photovoltaic panel is calculated by Equation 6 [15, 18, 28] according to the outside air temperature ( $T_{air}$ ). NOCT represents nominal operating conditions of the panel. Standard NOCT values for all panels are given in Table 1 (20°C and 800 W/m²). In Equation 6,  $T_{NOCT}$  and  $I$  represent panel temperature at nominal operating conditions, and solar radiation value, respectively.

Table 1. Typical panels of the different technologies available

Technology	HIT	Thin-film	Mono-silicon	Multi-silicon
Manufacturer	Panasonic	First solar	Solar world	Yingli solar
PV Efficiency	% 19.7	%14.6	% 17.89	% 16
NOCT	44°C	45°C	46 °C	46 +/-2 °C
Temperature-Power Coefficient	-0.29 %/°C	-0.34 %/°C	-0.39 %/°C	-0.42 %/°C
Panel Surface Area for 1kWp	4.70 m²	6.86 m²	4.87 m²	5.62 m²
NOCT Conditions	20°C, 800 W/m², 1.5 A.M., 1 m/s wind speed			
STC Conditions	25°C, 1000 W/m², 1.5 A.M.			

$$T_{panel} = T_{air} + \frac{T_{NOCT} - 20}{800} \quad (6)$$

The efficiency of PV panel at different surface temperatures ( $\eta_{temp\_panel}$ ) is calculated by Equation 7. Here,  $\eta_{panel}$  represents the panel efficiency for the standard test conditions given in the PV panel catalog. While  $T_{STC}$  is the operating temperature for standard test conditions,  $K_{pc}$  is the temperature power coefficient given in catalogs.

$$\eta_{temp\_panel} = \eta_{panel}(1 - (T_{panel} - T_{STC})K_{pc}) \quad (7)$$

For the unit area, the theoretical electric energy ( $P_{elect\_teoric}$ ) generated from the PV panels is calculated by Equation 8. The electricity generation depending on the temperature ( $P_{elect\_temp}$ ) is calculated by Equation 9. Equations 8 and 9 are shown as the standard test efficiency ( $\eta_{panel}$ ) given in PV panel's catalogue and the temperature dependent PV panel efficiency ( $\eta_{temp\_panel}$ ), respectively. There is a generation loss due to dust, electricity and inverter loss in PV systems. In this study, the total loss ( $P_{loss}$ ), including dust, electricity and inverter losses, was accepted as 10% [18].

$$P_{elect\_teoric} = I\eta_{panel} \quad (8)$$

$$P_{elect\_temp} = I\eta_{panel\,temp}(1 - P_{loss}) \quad (9)$$

The temperature dependent generation loss/gain from PV panels is determined by proportioning the electricity energy ( $P_{elect\_temp}$ ) generated from PV panels, depending outside air temperature to the electricity ( $P_{elect\_teoric}$ ) generated under standard test conditions (Equation 10). This is the performance ratio (PR) of the PV system [15, 4, 17, 18]. PR is stated as percent and describes the relationship between actual and theoretical energy outputs of a PV system.

$$PR = \frac{P_{elect\_temp}}{P_{elect\_teoric}} \quad (10)$$

Another performance indicator of PV system is the total output per 1 kWp installed power, called as Specific Yield (SY). In this study, SY value is calculated by Equation 11. The unit of SY is kWh/kWp. A is the surface area of the PV panel required for 1 kWp installed power.

$$SY = P_{elect\_temp}A \quad (11)$$

### 3. DISCUSSION AND RESULTS

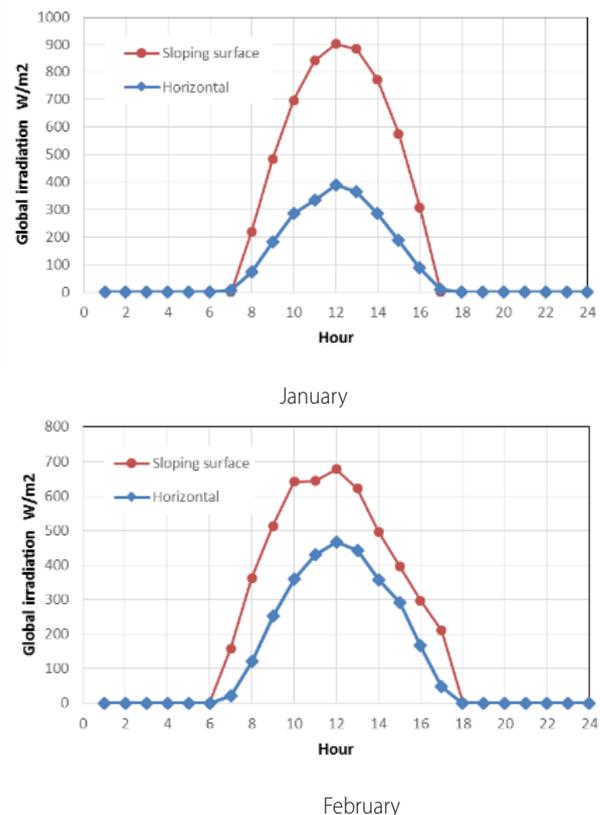
The monthly mean solar radiation, sunshine duration and outdoor air temperature values of Şanlıurfa, obtained from GOPYENEV meteorological station, are given in Table 2. CH-1 model pyr heliometer mounted on Kipp & Zonen 2AP solar tracking system with  $9.76 \times 10^{-6} \text{ Wm}^{-2}$  sensitivity was used in direct solar radiation measurement. CMP11 model pyranometer with  $8.89 \times 10^{-6} \text{ V/Wm}^{-2}$  sensitivity was used in diffuse radiation measurement. As can be seen from the table, Şanlıurfa's annual global radiation value is 1828 kWh/m<sup>2</sup> per year, sunshine duration is 3434 hours and annual average temperature is 18.8°C. According to monthly average

values, maximum values were reached in July. In July, the average outside temperature is 32.2°C, global solar radiation is 244 kWh/m<sup>2</sup> per year and sunshine duration is 421 hours. Outside temperature values fell below 10°C in December, January and February.

**Table 2.** Monthly average solar radiation, sun duration and outdoor air temperature of Şanlıurfa

	Average Outdoor Air Temperature (°C)	Average Global Solar Radiation (kWh/m <sup>2</sup> year)	Average Sun Duration (h)
January	5.2	68	188
February	9.4	83	237
March	11.8	136	214
April	16.9	185	278
May	22.3	215	325
June	28.0	234	411
July	32.2	244	421
August	31.2	217	392
September	26.5	172	339
October	20.5	117	280
November	12.8	90	243
December	8.9	66	126
Yearly	18.8	1828	3454

The mean hourly solar radiation of Şanlıurfa on horizontal and south facing areas with a tilt of 30° is given in Figure 2. As can be seen from the figure, the solar radiation on horizontal surface varies according to month and reach maximum values in summer (946 W/m<sup>2</sup> at 12.00 in July). The solar radiation reaches maximum values in the months when solar rays strike directly to the surface of PV facing south with 30°. In September, 1000 W/m<sup>2</sup> values are seen between 9.00 and 14.00 hours (Figure 2).



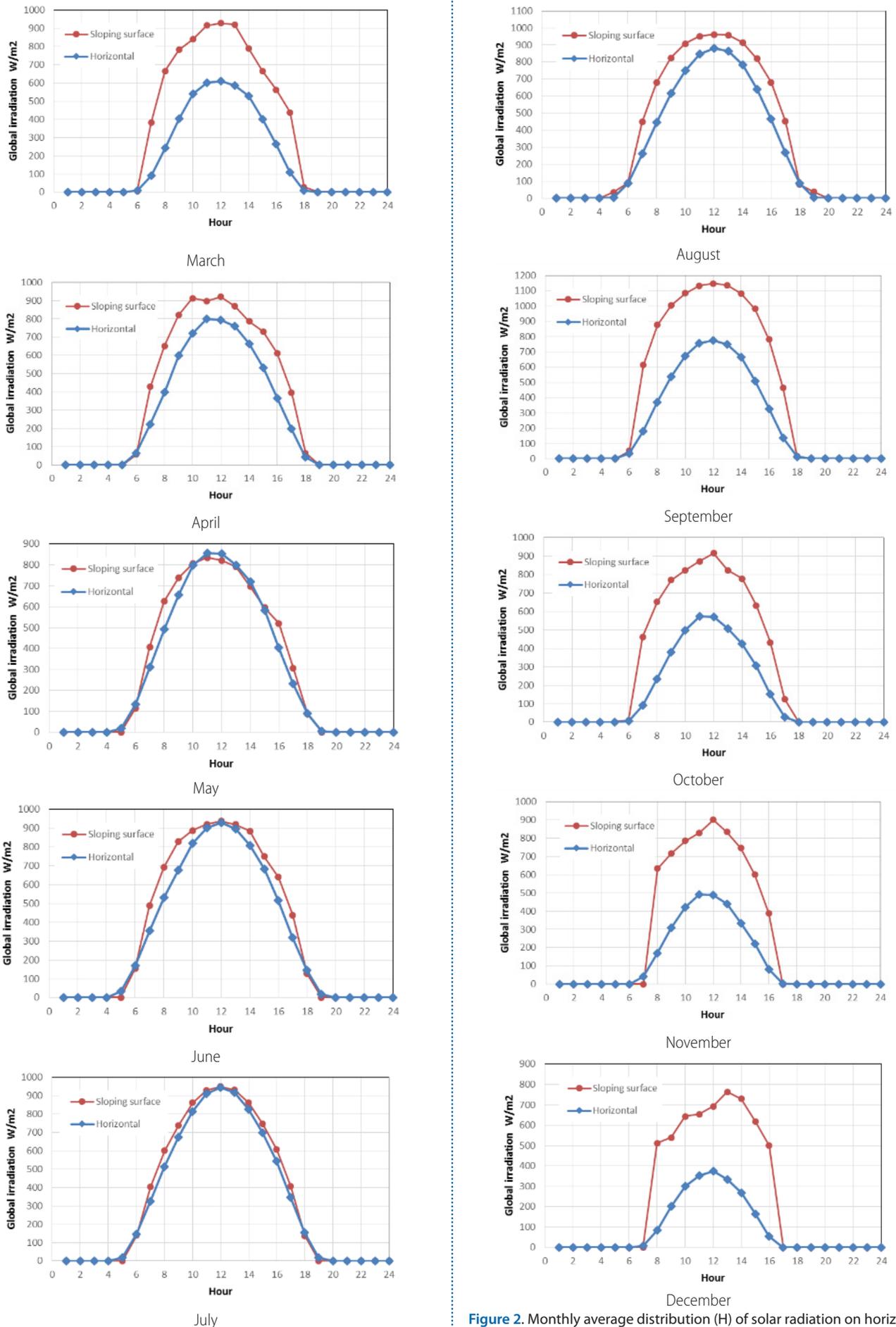
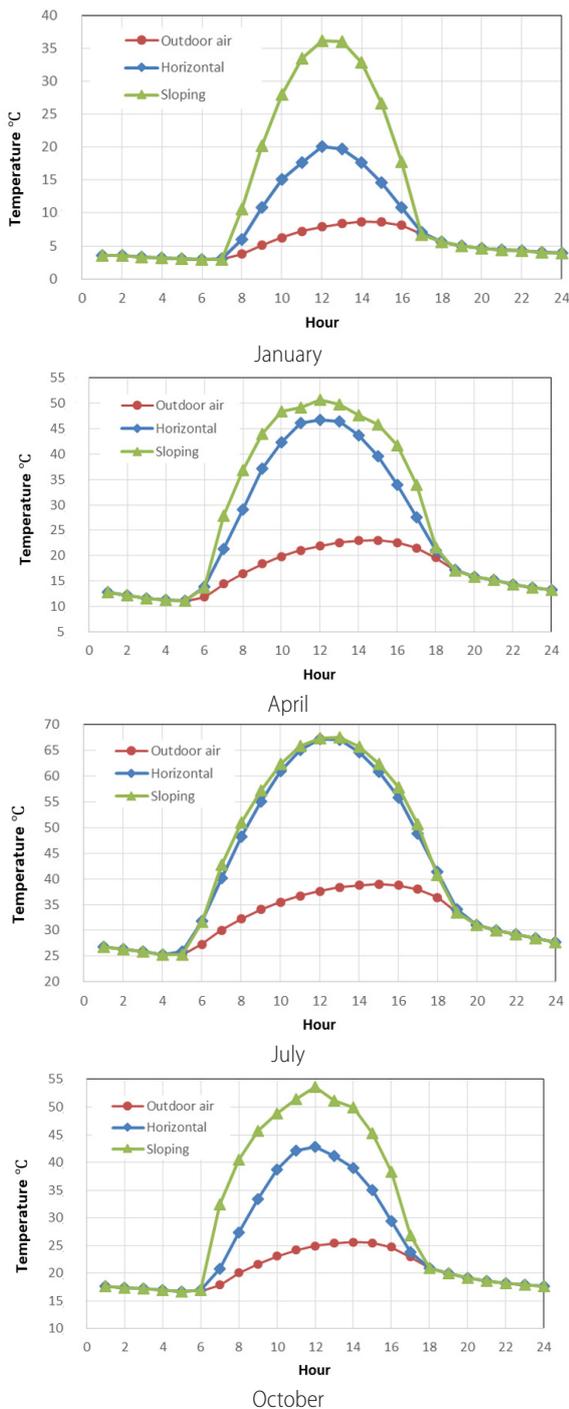
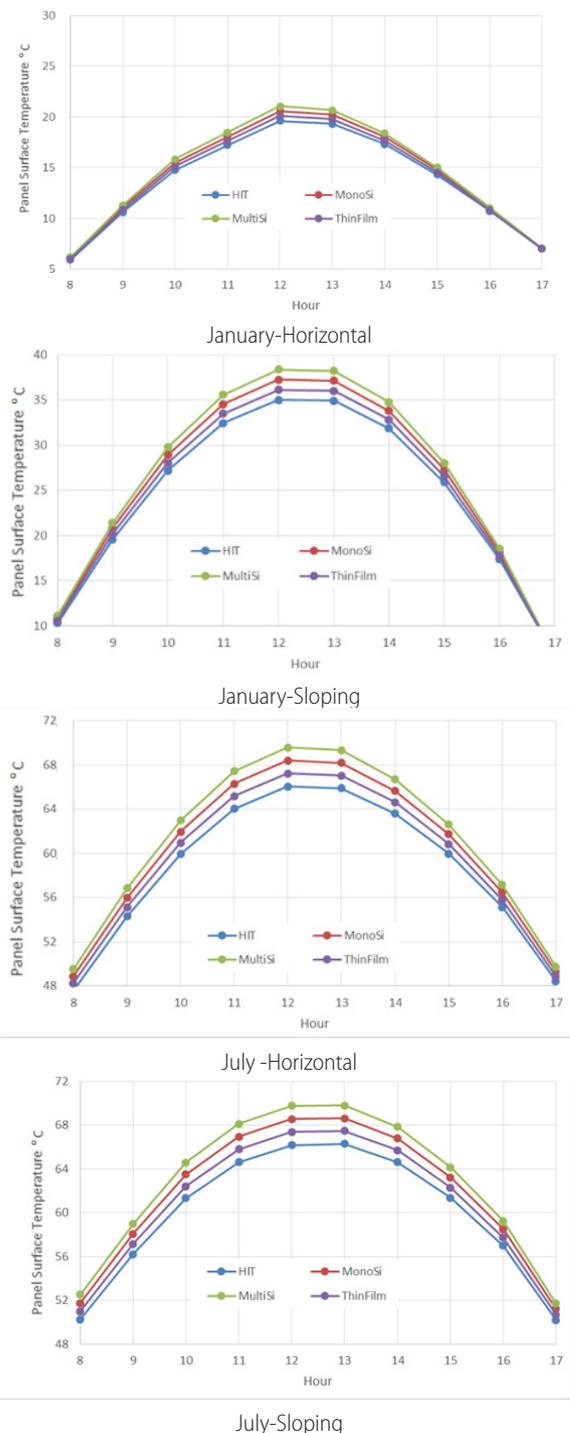


Figure 2. Monthly average distribution (H) of solar radiation on horizontal and south facing surface with a 30° tilt in Şanlıurfa



**Figure 3.** Monthly average distribution (H) of outdoor air temperature and surface temperature of PV panel mounted horizontal and 30° tilt south facing surfaces in Şanlıurfa

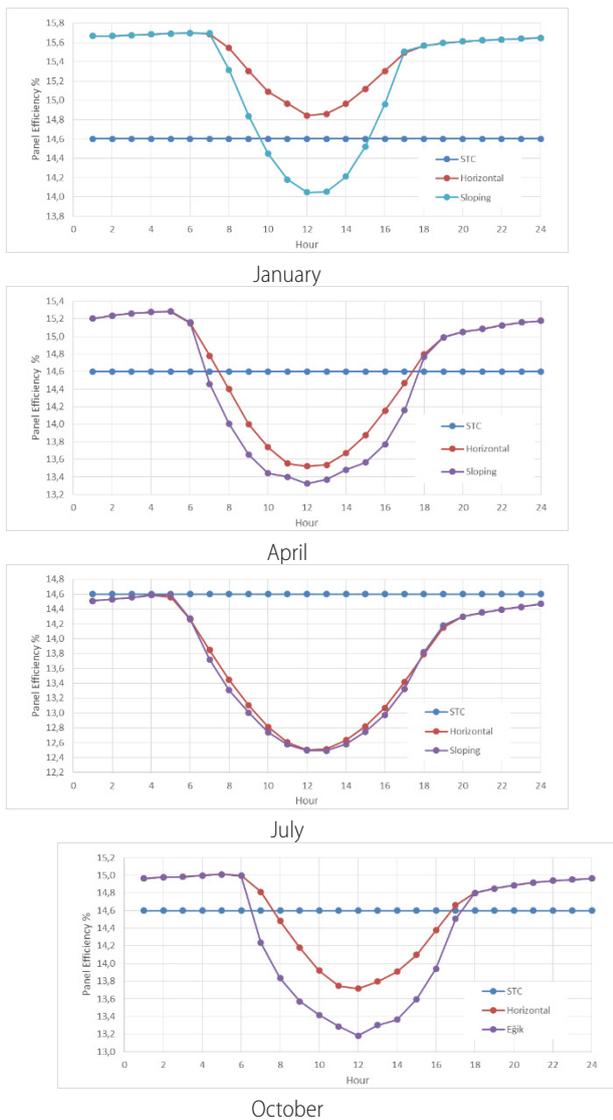
Similarly, Figure 3 shows the PV panel surface temperature distribution for Şanlıurfa in January, April, July and October calculated according to the hourly average outdoor temperature. These graphs are calculated for thin-film technology panels. As can be seen from the figure, the outside temperature is maximum 9°C in temperature distribution graph obtained for January, while the surface temperature of horizontal PV panel is 20°C and it is 36°C for the south facing panel with 30° slope. A similar profile was obtained in October. The outside air temperature is maximum 25 °C while the surface temperature of horizontal PV panel is 43°C and the surface temperature of south facing PV panel (with 30° slope) reaches 54°C. The temperature distribution profiles



**Figure 4.** For different PV technologies, surface temperature distribution of PV Panels mounted as Horizontal and Sloping surfaces

in July and April are similar. In July, the surface temperatures of horizontal and south facing (with 30° slope) were very close to each other and the maximum was 68°C. According to the annual data, the maximum PV panel surface temperature for Thin-film technology reaches to 68°C.

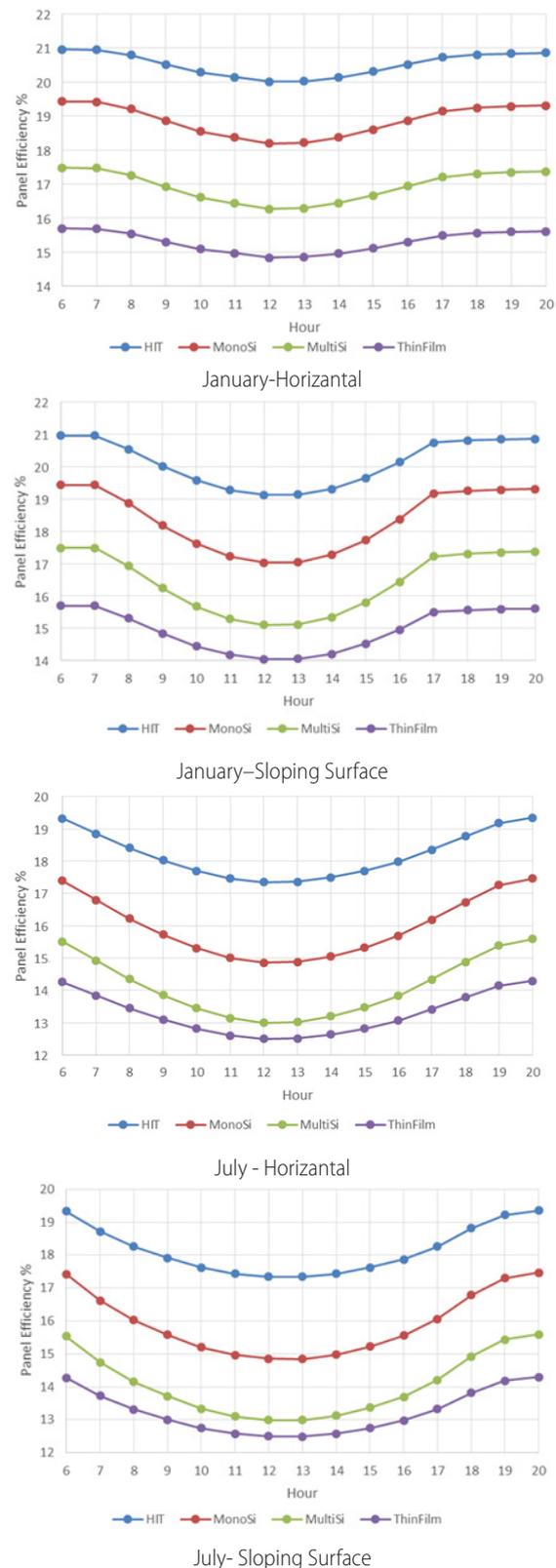
On the other hand, Figure 4 shows the surface temperature distributions of horizontal and south facing PV panels for January and July for 4 different PV technologies examined in this study. The highest temperature value in all graphs was observed in Multi-silicon technology. This was followed by Mono-silicon, Thin-film and HIT PV technologies, respectively. In January, the surface temperature of the horizontal



**Figure 5.** PV panel efficiency distribution (H) of Thin-film PV panels mounted horizontal and sloping surface in January, April, July and October in Şanlıurfa

PV panels is 20°C. However, in the case of tilted PV panels, it increased to 35-40°C depending on the technology employed. In July, the temperature profiles are very close and similar. In this month, the highest temperature value was observed at 70°C for Multi-silicon technology. This is followed by Mono-silicon (68°C), Thin-film (67°C) and HIT PV (66°C), respectively.

Figure 5 shows the hourly distribution of panel efficiency for horizontal and sloping conditions of Thin-film PV type, calculated according to hourly average outdoor temperature values in Şanlıurfa in January, April, July and October. In Figure 5a, it is seen that the efficiency of the PV panel is 14.6% at standard test conditions. The PV panel efficiencies vary depending on the panel surface temperature for horizontal or southward surfaces. In case of the PV panel laid horizontally in Figure 5a, the panel efficiency is higher than the PV panel efficiency (14.6%) in the standard test conditions since the outside air temperature and therefore the panel surface temperatures are low in January. If the panels placed at a slope of 30° to the south, the PV panel efficiency becomes similarly high except for 10.00-15.00 hours. As seen in Figure



**Figure 6.** PV panel efficiency distributions according to Different PV Technologies

re 5b and d, if the PV panel is placed horizontally and oriented with a 30° slope to the south, the profiles of the panel efficiencies obtained for April and October become similar and lower than the PV panel efficiency (14.6%) in standard test conditions except for sunrise and sunset times. On the other hand, in Fig. 5c, the panel efficiencies obtained for July are lower than the PV panel efficiencies for all hours under standard test conditions and it is 12.5% at 12.00. Panel effi-

ciencies vary between 12.5 and 14.6 during the day.

Figure 6 shows the daily distribution of PV panels efficiencies placed horizontally and sloping 30° to the south in January and July for 4 different PV technologies examined in this study. As can be seen in the figure, the highest panel efficiency in January and July was observed for HIT PV technology. This is followed by Mono-silicon, Multi-silicon and Thin-film technologies, respectively. Horizontal panels' efficiencies were less affected in January than in July with respect to those of sloped panels.

Table 3 shows the performance ratio obtained by proportioning the electric energy generated from the PV panels depending on the outside air temperature to the electric energy generated under standard test conditions. The values of PR below 1.0 are regarded to be losses according to the temperature dependent theoretical production at standard test conditions. On the other hand, the values above this level indicate the production gain. For example, if PR=1.03, it indicates that production is 3% higher than the theoretical production, whereas it is 11% lower if PR=0.89. As can be seen from Table 3, in January, the PR value of HIT PV panels is 1.03 and the electricity production based on the outside air temperature is 3% higher than the theoretical electri-

city generated under standard test conditions. However, in September, the PR value of Multi-silicon PV panels is 0.75, which means 25% less energy than standard test conditions. Annual production losses of PV panels due to temperature effect were observed in all PV technologies examined. The lowest annual performance values were found to be in the Multi-silicon PV technology, calculated to be 0.94 and 0.82, respectively, according to the horizontal and inclined installation of the PV panel. On the other hand, the highest annual performance values were found to be 0.96 and 0.85, respectively, for horizontal and inclined installations of the HIT PV panel technology.

Likewise, Table 4 shows monthly and annual production quantities (SY) (kWh/kWp) per 1 kWp installed power according to the PV panel technologies. In the case of the PV system which is installed horizontally, the lowest SY value for all PV technologies was observed in December and January while the highest SY value was observed in July. Unit production values are found to be the highest for Thin-film PV technology and the lowest for Mono-silicon PV technology. The highest unit production values were calculated to be 1703 kWh/kWp per year for Thin-film PV technology whereas the lowest was for Mono-silicon with 1468 kWh/kWp.

**Table 3.** Monthly and yearly PV performance ratios (PR) for PV panel technologies

Months	HIT		Mono-Silicon		Multi-Silicon		Thin-film	
	Horizontal	Sloping Surface	Horizontal	Sloping Surface	Horizontal	Sloping Surface	Horizontal	Sloping Surface
January	0.96	0.85	0.94	0.83	0.94	0.82	0.95	0.84
February	1.03	0.89	1.03	0.88	1.03	0.87	0.93	0.88
March	1.01	0.89	1.01	0.89	1.00	0.88	1.01	0.89
April	0.99	0.87	0.98	0.85	0.97	0.84	0.98	0.86
May	0.96	0.85	0.94	0.83	0.93	0.82	0.95	0.84
June	0.94	0.84	0.91	0.82	0.90	0.81	0.92	0.83
July	0.92	0.82	0.88	0.79	0.87	0.77	0.90	0.80
August	0.90	0.81	0.86	0.77	0.85	0.76	0.88	0.79
September	0.91	0.81	0.87	0.77	0.86	0.76	0.89	0.79
October	0.93	0.81	0.90	0.77	0.89	0.75	0.92	0.79
November	0.96	0.85	0.95	0.82	0.94	0.81	0.96	0.83
December	0.99	0.86	0.99	0.85	0.98	0.84	0.99	0.86
Yearly	1.01	0.88	1.02	0.87	1.02	0.87	1.01	0.88

**Table 4.** Monthly and yearly Specific Yield (SY) for PV panel technologies (kWh/kWp)

Months	HIT		Mono-Silicon		Multi-Silicon		Thin-film	
	Horizontal	Sloping Surface	Horizontal	Sloping Surface	Horizontal	Sloping Surface	Horizontal	Sloping Surface
January	65	145	62	135	64	138	63	156
February	77	116	73	109	75	112	84	125
March	125	197	116	182	119	186	134	212
April	164	193	151	176	154	180	176	206
May	187	178	171	162	174	166	199	190
June	199	198	180	178	183	181	211	209
July	204	194	183	174	186	176	216	205
August	183	206	165	185	168	187	194	217
September	148	233	135	209	138	211	158	246
October	104	177	97	162	99	165	112	189
November	83	155	77	142	80	146	89	165
December	62	144	59	133	61	137	67	154
Yearly	1601	2135	1468	1947	1500	1985	1703	2275

On the other hand, in case of inclined PV panels, the lowest SY value for all PV technologies was observed in February while the highest SY value was observed in September. Monthly and yearly unit production values were highest in Thin-film PV technology and lowest in Mono-silicon PV technology. The highest unit production value was obtained in Thin-film PV technology with 2275 kWh/kWp per year whereas the lowest was in Mono-silicon PV technology with 1947 kWh/kWp.

#### 4. CONCLUSION

In this study, PV panel performance values in detail were examined in meteorological conditions of Şanlıurfa. In the simulation, 4 different PV panel technologies, which are Multi-silicon, Mono-silicon, Thin-film and HIT PV technologies, and 3year outdoor temperature and solar radiation values of Şanlıurfa province were used. In the present study, the field performances of PV systems could be easily found by calculating the PV panel efficiency in accordance with the temperature.

According to the results obtained, it was observed that panel surface temperature increased due to an increase in outdoor air temperature. But, the increase in surface temperature of the panel decreased the efficiency owing to the temperature power coefficient of the panel. Efficiency losses were least observed in the months when the outdoor air temperature was low. However, the efficiency losses were particularly noticeable in summer months. In these months, PV panels' performance ratios decreased up to 0.75.

Moreover, in the case of inclined PV panels, the lowest unit production value in all PV technologies was observed in February while the highest was in September. On the other hand, for horizontally installed PV panels, the lowest production was reached in December and January, and the highest production was observed in July. Among the PV technologies examined, the best unit production quantity was obtained in Thin-film technology whereas the lowest unit production values were obtained in Mono-silicon PV technology.

#### Nomenclature

$I_T$  -Total Radiation on a tilted surface [ $W m^{-2}$ ]

$I_b$  -Direct solar radiation on a horizontal surface [ $W m^{-2}$ ]

$I_d$  -Diffuse solar radiation on a horizontal surface [ $W m^{-2}$ ]

$R_b$  -Geometric factor

$I$  -Hourly solar radiation on a horizontal surface [ $W m^{-2}$ ]

$\eta$  -Day of the year

#### Greek symbols

$\beta$  -Slope [ $^{\circ}$ ]

$\gamma$  -Surface azimuth angle [ $^{\circ}$ ]

$\delta$  -Declination, [ $^{\circ}$ ]

$\eta$  -Efficiency [%]

$\theta$  -Angle of incidence [ $^{\circ}$ ]

$\theta_z$  -Zenith angle [ $^{\circ}$ ]

$\rho_g$  -Ground reflectance

$\phi$  -Latitude [ $^{\circ}$ ]

$\omega$  -Hour angle [ $^{\circ}$ ]

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