Performance Enhancement of Mini Agri-voltaic System for Roof Top Garden

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Performance enhancement of mini Agri-voltaic system for roof top garden

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Abstract

The Agri-voltaic (AV) is an emerging technology to harness the solar energy. The performance of the AV modules depends on the incident solar radiation, geographical location and the surface temperature of the modules. The performance of the AV system needs to be monitored by manually or embedded controllers. The commercially available technologies for monitoring the system is costlier and need to be optimised. The Arduino controller is used to monitor the performance of the photovoltaic (PV) system in Coimbatore (11.016^0 N, 76.9558^0 E), Tamilnadu, India. The PV surface temperature is monitored and controlled by flowing the water above the module by setting the mean ambient temperature as a reference temperature 34 °C when the system exceeds the reference temperature. PV surface temperature is reduced up to 16°C thus improved the electrical efficiency by 17% compare to the reference module. The Arduino controller control the

relay to switch on the motor to control the mass flow rate of the water at 0.0028kg/s. The various parameters are measured such as voltage, current and solar radiation of the location and analysed. The estimated cost of monitoring system and various sensor is 10$ which cost comparatively 50% lower than the other PV monitoring controllers. This method can be employed in the medium and large-scale irrigation system.

Keywords: **Arduino; PV; water cooling; Agri-voltaic*;***

1.Introduction

The building is the largest energy consumer in the world, which consumes 40% of the total generated power in the world. PV technology is the appropriate technology to harness the solar energy. Integration of the solar photovoltaic technology into the building which converts the building from energy consumers into energy producer (Chandrika et al., 2020; Reddy et al., 2020). The 5-25% of incident solar radiation on the PV module converts the light energy into electrical energy and the remaining energy into heat. The raise in the surface temperature of the module which influences the internal charge carrier recombination rate that affect the output voltage of the PV module (Ramanan et al., 2019). The PV surface temperature can be controlled by active and passive cooling method. The comprehensive review of the active cooling technologies presented by (Krishnavel et al., 2014; Sathyamurthy et al., 2020) and the passive cooling method can be seen in the works of (Ali, 2020; Pichandi et al., 2020).

(Cuadros et al., 2004) defined the procedure for the PV water pumping system for the drip irrigation of olive orchards in Spain. (Padmavathi & Daniel, 2011) investigated the various photovoltaic water pumping options and domestic water requirements for Bangalore City in India and concluded that photovoltaic paneling ranges from 60 Wp to 500 Wp is acceptable in respect of residential buildings in Bangalore. The efficiency of a PV pumping system in a village 30 km from

Keita (Niger) has been examined by (Saidou et al., 2013) to meet the water needs of 500 people and it was noted that the cost of one cubic meter of the PV system water pumped is better than other. Due to the presence of deep-water supplies and a high solar energy capacity of over 6 kWh / m^2 pumping was found to be ideal for dry and semi-arid areas. (Kolhe et al., 2004) investigated the performance of a photovoltaic DC pump. The results of the experiments are compared with the calculated values and a close fit between the PV array and the electromechanical device characteristics has been demonstrated.

The authors indicated that the performance obtained is 20% better than that of the tilted, fixed PV array, by manual monitoring by changing the orientation of the PV array three times a day to Sun. (Glasnovic & Margeta, 2007) implemented an advanced mathematical model of the hybrid simulation method using dynamic programming to optimize the PV irrigation system water pumping system. The simulation model describes constraints that consider elements related to the pumping method of photovoltaics: borehole, local environment, soil, crop and irrigation systems. The analysis model for PV cell temperature for variable solar insolation and ambient temperatures has been developed by (Mahjoubi et al., 2014). The authors reported that the individual PV cells could reach up to 45 °C at an average ambient temperature of 25 °C. (Kordzadeh, 2010) recorded a solution involving the use of a thin film of water to cover the PV array to reduce the operating cell temperature. Due to the use of water film, the water flow rate was increased by more than 60% at low nominal capacity, resulting in a decrease in the cell temperature of approximately 30 ° C. They also stated, however, that the water film does not work on high nominal strength. (Abdolzadeh & Ameri, 2009) instead of using fine water films to decrease photovoltaic cell temperatures, suggested occasional spraying of water. The findings showed that the output water flow rate for different pump heads was increased by between 15 and 30 %.

(A. Karthick, Kalidasa Murugavel, Ghosh, et al., 2020) conducted the experiments to reduce the surface temperature of the PV module by integrating the binary eutectic phase change material (PCM) between the PV cell and back glass of the PV module, which is the passive cooling method. It was concluded that the incorporation of the PCM behind the PV cell had reduced upto 12°C and improved the electrical efficiency by 8%. Even though PCM have higher latent heat to store the heat energy, the encapsulation of the PCM and the incorporation were difficult to enhance the heat transfer rate.

(Mohd Zainuri et al., 2014) regulated the surface temperature of the PV module by various water-cooling methods. It was concluded that film water method, backwater method and combined film-back water-cooling method controlled the surface temperature up to 16 °C, 18 °C and 25 °C respectively. Even though active methods reported higher efficiency, cost of the cooling system is higher compare to the passive method due to it requires pump and controller to monitor the system which also consumes more power. The sample embedded controllers used to monitor the performance of the PV system such as DSP TMS320F28335 (Padmavathi & Daniel, 2011), FPGA (Xilinx XC3S400) (Faraji et al., 2014), dSPACE-1103 (Boukenoui et al., 2017) and their reported cost of the controllers were 21.17$,38$ and 38$ respectively. The Arduino UNO (Fuentes et al., 2014) have numerous options to connect various application to the platform such as Wi-Fi, datalogger, Bluetooth, LAN and GPS. This feature is not available in all the platform and it is cost effective. The PV monitoring system and its application in irrigation system is listed in the table 1. According to the literature studies the various cooling methods and embedded controllers are tested for monitoring the performance of the PV system for irrigation. The main objective of the work is monitor and to regulate the surface temperature of the agri-voltaic system and also to develop the cost-effective embedded controller to monitor the performance of the PV system for smart irrigation applications. In this work the two 60 W PV system is monitored using the Arduino controller and also the surface temperature of the PV module is investigated. The effect of the water cooling and the performance enhancement is analysed.

Table 1: Earlier studies of PV powered irrigation system

Country	Research findings	Reference
Egypt	By manually performing the procedure three times a day, machine efficiency is increased to 20%	Kolhe et al., 2004
Thailand	The algorithm is designed for an insolation calculation of the water pumped.	(Amer & Younes, 2006)
India	Two important design aspects for PV water pumping system are identified; analyzing piping system to determine the type of pump to be used and power system planning.	(Setiawan et al., 2014)
Saudi Arabia	In order to balance full points of PV power with pump, electronic array configuration should be included.	(Benghanem et al., 2013)
India	Pay-back period recorded for six years including PV-module subsidies.	(Alagar Karthick et al., 2020)

2 Materials and Method

The experimentation is carried out at the KPR Institute of engineering and technology Coimbatore the geographical location is 11.016°N, 76.9558° E. The various parameters are measured such as output voltage, current, surface temperature and ambient temperature. The performance of the photovoltaic module varies depending upon the climatic conditions. In this work two 60W polycrystalline PV module and Arduino Uno embedded controller is used to monitor and control the operation of the water-cooling system. The one module is made provision with the water-cooling method and the other module is placed as the reference module. The specification of the PV module is listed in the Table 2. The rheostat is used as electrical loading arrangement to vary the and measure the maximum power point. The portable voltmeter and ammeter instruments are used to measure the voltage and current of the PV system. The program for the Arduino controller is coded in the “C” language. The internet of things (IoT) based control system is provided to control and monitor system. To monitoring and control the system various sensors are used, to measure the voltage of the system voltmeter sensor, current sensor is used to measure the current and the temperature is measures using the temperature sensor. The relay control is provided to control the DC water pump. The DC water pump is used to flow the water in the top surface of the PV module to reduce the surface temperature. The input and output of these sensors is connected to the Arduino board, in which the output of the voltage and current sensor of both the panels are compared. The relay on/off control is initiated by the Arduino controller. The output of the temperature sensor is compared with the reference temperature Which is set as 34 °C, whenever the temperature exceeds the reference temperature the control signal to the relay connected to the mini brushless submersible water pump. This relay will be closed so that the motor tends to get ON, so the water from the water tank will be supplied to the solar panel. The data logger, connected to Arduino board it is the handy Arduino shield. The data logger is to store the data from the sensors from the Arduino board to the SD card. This storage of data helps in the analysis of efficiency at a different condition. The experimental set up is shown in the figure 1. The flow of control of the Arduino is shown as the flow chart in the figure 2. The overall layout of the Arduino controller system with the various sensor such as voltage, current and temperature sensor are shown in the figure 3.

Table. 2 Specification of Solar Photovoltaic panel

Particular	**Module 1**	**Module 2**
Maximum Power ($\mathbf{P_{max}}$)	60W	60W
Open Circuit Voltage ($\mathbf{V_{oc}}$)	22.2V	22.2V

Short Circuit Current (I_{sc})	3.56A	3.56A
Maximum Power Voltage (V_{max})	18.2V	18.2V
Maximum Power Current (I_{max})	3.3A	3.3A
Module Efficiency (η)	14.22%	14.22%
Terminal Box	IP65	IP65
Cooling system	--------	Water cooling
Monitoring Controller	Arduino	Arduino

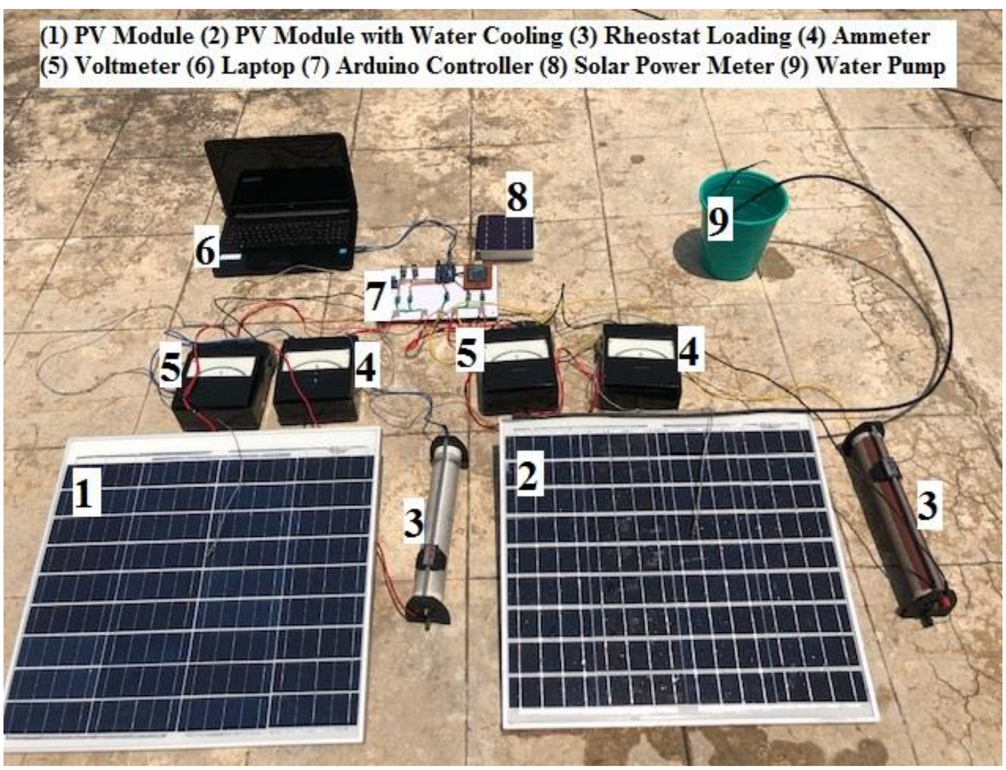

Figure 1. Experimental setup of Photovoltaic module with measuring devices

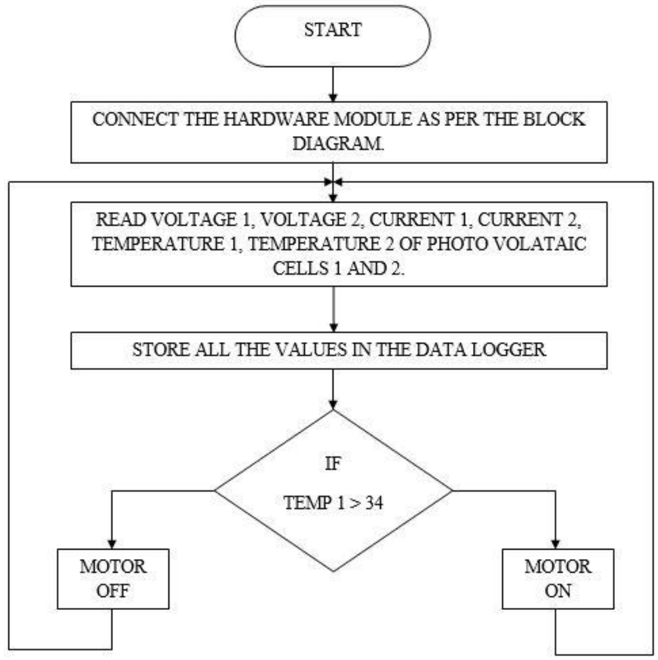

Figure 2 Overall flow chart of the Solar powered irrigation system

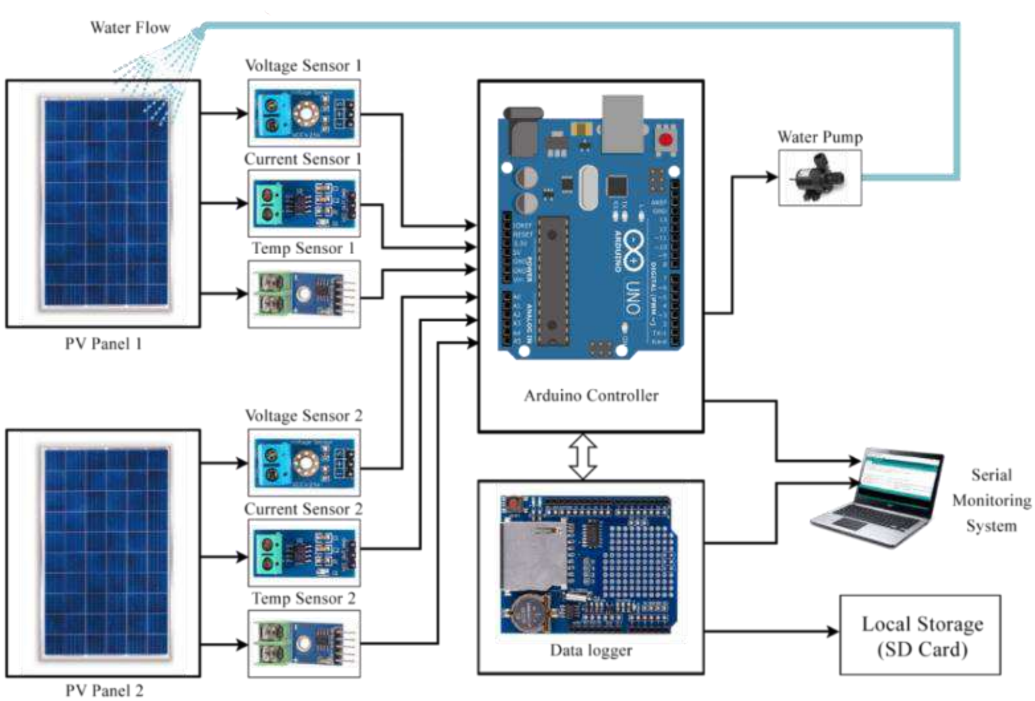

Figure 3 Various sensors connected to the Arduino controller unit

Electrical Energy gain of the SPV system is given as (A. Karthick, Kalidasa Murugavel, Sudalaiyandi, et al., 2020)

$$P_{DC} = P_{m,stc} * \frac{I}{I_{ref}}\left[1 + \beta_m\left(T_{pv} - T_{ref}\right)\right] \qquad (1)$$

$$\eta_{elec} = \eta_o\left[1 - \beta_o\left(T_{pv} - T_{ref}\right)\right] \qquad (2)$$

The Annual electrical power (W) is [23]

$$E_{el.hourly} = \eta_{elec}\ X\ A_m\ X\ I\Delta t_{hourly} \qquad (3)$$

Table 3 Instrument specification and its uncertainty.

Instrument	Range	Accuracy	Standard uncertainty
Voltmeter	75V	±1V	0.57 %
Ammeter	0-5A	±0.1A	0.057%
Rheostat	90 ohm, 4 A	±0.1%	0.057%
Thermocouple wires	K-type 220^{0}c	±1^{0}C	0.57%
Temperature indicator	0-500 ^{0}c	±1^{0}C	0.57%
Solar Radiation meter	0 – 2000 W/m^2	±1W/m^2	0.57%

The expression for daily electrical energy in kWh is

$$E_{el.daily} = \sum_{i=1}^{S} \frac{E_{el.hourly,i}}{1000} \qquad (4)$$

Where S is number of sunshine hours per day. The expression for monthly electrical energy in kWh is given as

$$E_{el.monthly} = E_{el.daily} X\ m_o \qquad (5)$$

Where m_o is number of clear days in a month. The expression for annual electrical energy in kWh is

$$E_{el,annual} = \sum_{m=1}^{12} E_{el.monthly,m} \qquad (6)$$

These researches are used for testing the CO_2 reduced during the operation period of the PV module in the atmosphere. The CO_2 emission reductions from the energy savings potential of the PV modules are estimated (A. Karthick et al., 2018). The instrument used in the study is listed in the table 3.

$$CO_2\ emissions = Overall\ elctrical\ \ energy/Annum \times 2.04\left(\frac{kg}{kWh}\right) \qquad (7)$$

3.Experimental Uncertainty analysis

During the experimentation process there is a possibility of the error happen due to measurement and measurand. To estimate the uncertainty of the study instrument is suggested by the (Sudalayandi et al., 2021). The various parameters of the quantity are measured and it is discussed, the accuracy of the temperature measured is estimated by the thermocouples, concrete collector efficiency vary with respect to mass flow rate, surface area of the concrete absorber and incident solar.

$$u_n = \frac{a_n}{\sqrt{3}} \qquad (8)$$

Where 'u_n' is the standard uncertainty and 'a_n' is the accuracy of the instrument specified by the instrument manufacturers. The uncertainties related with the experimental equipment are shown in Table 2. When z depends on a number of inputs w_i, then the uncertainty of z is calculated by (Manoj Kumar et al., 2020)

$$u(z) = \left[\left(\frac{\delta z}{\delta w_1}\right)^2 u^2(w_1) + \left(\frac{\delta z}{\delta w_2}\right)^2 u^2(w_2) + \cdots\right]^{\frac{1}{2}} \qquad (9)$$

Uncertainties in the calculation of different amounts have been measured and detected within the control limits which is listed in the Table 3. The maximum uncertainty for daily efficiency is calculated as 0.057%.

4.Result and discussion:

The mini solar photovoltaic system is designed for the smart Agri voltaic system. The irrigation system is classified as the drip irrigation, sprinkler irrigation, Centre pivot irrigation, localized irrigation and sub irrigation system which is shown in the figure 4. In this work the sprinkler irrigation system is adopted in this study which can be used for the agriculture purpose and also in the roof top garden of the building.

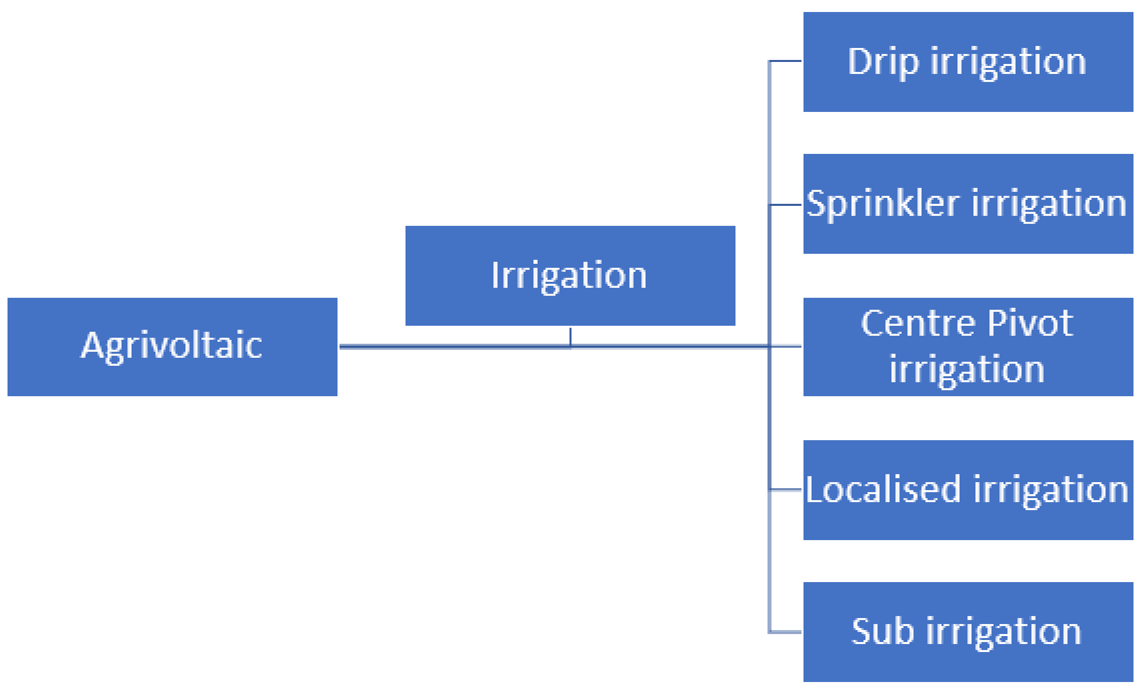

Figure 4 Agri voltaic irrigation system

The year-round performance analysis of the PV system is analyzed with and without cooling method for the Coimbatore region where the climatic condition is semi-arid. In the PV cooling system is provisioned with the front cooling which allows the water to flow above the module surface. The impact of the flow of water-cooling system, incident solar radiation, effect of temperature on the photovoltaic module is analyzed for the year 2019.The performance of the solar energy system varies with respect to the geographical coordinates and environmental parameters. The PV module system performance indices are analyzed. To investigate the system performance various parameters are analyzed such as, PV module, voltage, current, ambient temperature, solar radiation, surface temperature. solar radiations are measured over the horizontal surface using pyranometer. The PV module generated voltage is feed into the Arduino controller. The module temperature and ambient temperature is measured using K type thermocouple. Anemometer is used to measure the wind velocity. Finally, the performance of the PV module with and without cooling is compared and results are discussed in the subsequent section.

4.1 Solar radiation

The annual solar radiation of the Coimbatore location is plotted in the figure 5(a). It is inferred from the graph that during the month of the march obtained the maximum energy of 209 kWh/m^2/month and minimum of 112 kWh/m^2/month is obtained during June in the test site. The maximum and minimum temperature is plotted in the figure 5(b) in which the march has maximum temperature while the minimum temperature during the month of the December. However, the average temperature is higher during the month of the May. Hence the sample experimentation days is shown on the summer day and it is plotted in the figure 6(a-b).

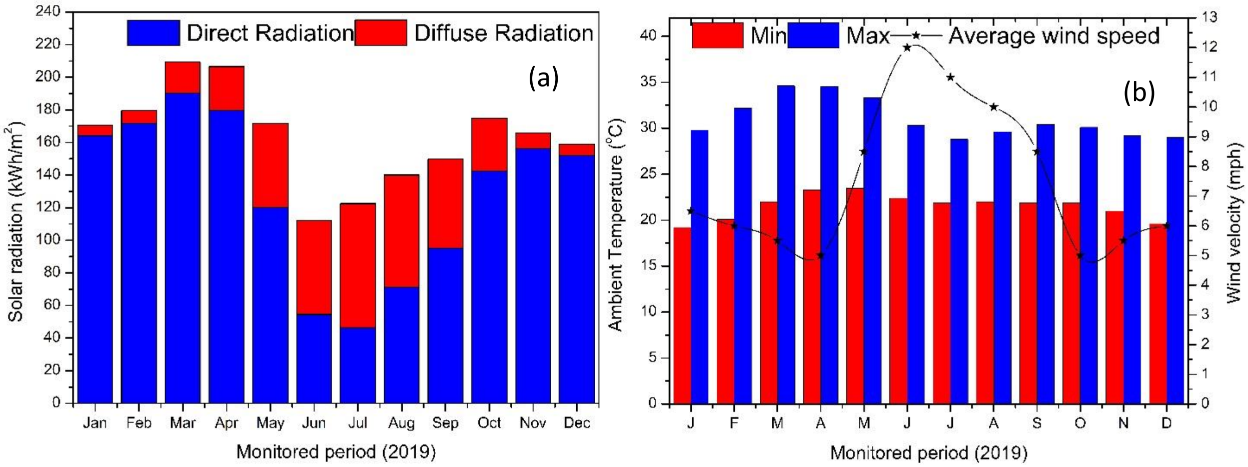

Figure 5 Monthly incident solar radiation (b) Ambient parameters of the Coimbatore area

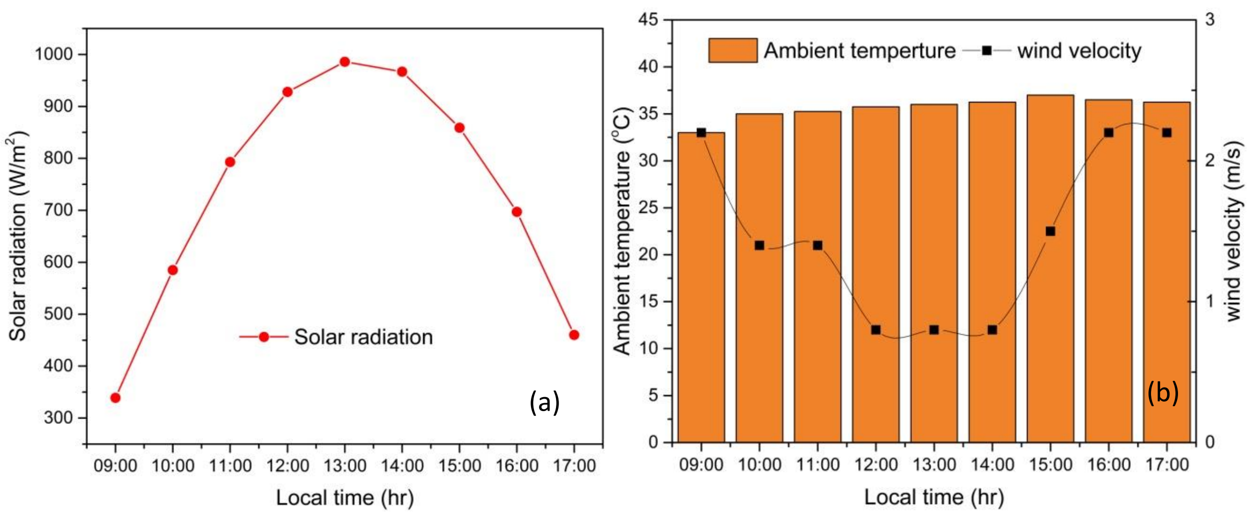

Figure 6. Average hourly variation of ambient parameters during typical day in summer May 2019 (a) solar radiation (b) Ambient temperature and wind velocity.

The performance of the PV modules depends on the incident solar radiation. The incident solar radiation stimulates the flow electron in the semiconductor material to generate the direct current (DC).

4.2 Power indices

The power production of the PV module is monitored and measured using the Arduino controller the monthly power generation of the PV system is plotted in the figure 7 (a-c). The maximum power generated in the system is obtained during the month of the march 9300 W and the minimum of during the month of June of 6800 W. The yearly energy gain of the system is 96 kW. The PV system with water cooling method is controlled by the Arduino controller to switch on and off system performance is found to be maximum in March and minimum in June such as 10620 W and 7550 W respectively.

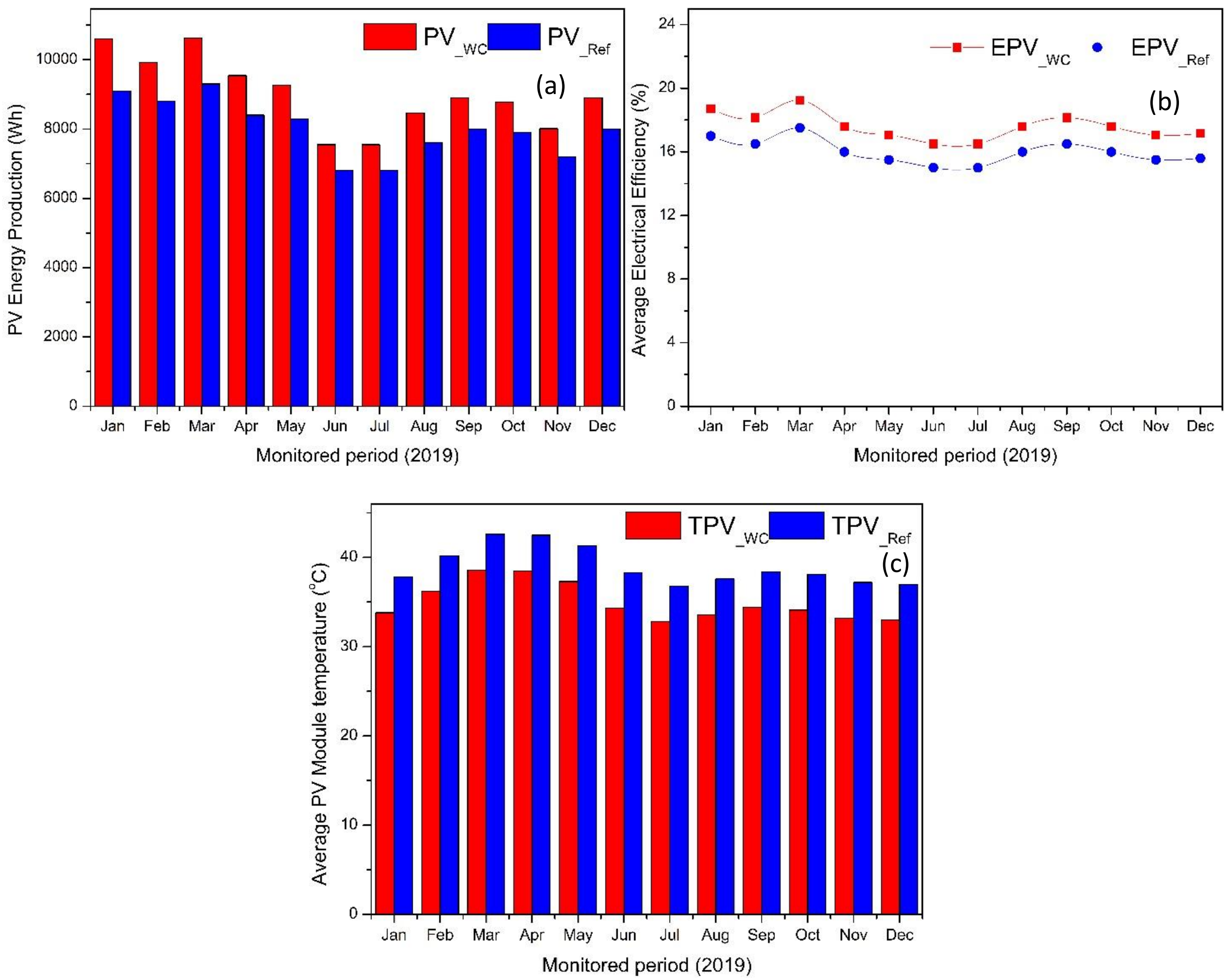

Figure 7. Hourly variation of (a) DC power, (b) Surface temperature and (c) Electrical energy conversion efficiency of Photovoltaic modules.

The water cooling with proper controller system have yielded the energy savings of 1320 W in a month for the prototype module of the 60 W system. The large-scale system can yield the more of the energy generation while the installation of the plant in the MW size and the irrigation powering system also viable solution. The average power generated from the module with (PV_wc) and without (PV_ref) cooling method is analyzed and plotted in the figure 8 (a-c) for the month of the May 2019 in summer. The module obtained the maximum voltage, current of 18.2V and 3A respectively during the noon hour. During afternoon the incident solar radiation is higher than the morning and the output power is slightly lower due to the increase in the surface temperature of the module. It is inferred from the figure 8(a) which is plotted between DC power (W) and local time (hr). Comparing the PV_wc and PV_ref, the DC power in PV_wc is high due to the module is exposed to water cooling mechanism. PV_wc obtained the maximum DC power of 53W during 13:00 hour at the same time the DC power in PV_ref is about 48W.The impact on the water cooling is reflected in the surface temperature of the module. The variation in surface temperature of the PV module with cooling (PV_twc), reference PV module surface temperature is noted as (PV_tref) and ambient temperature is shown in fig. 4(b). On comparing l the three, the ambient temperature lies in the range of 33 °C – 35°C, the PV_twc ranges between 33 °C – 36 °C and the PV_tref ranges between 33 °C to 50 °C. The temperature of PV_twc is made to decrease by cooling the PV_twc cell. The variation of the output power while increases in the surface temperature is due to the temperature negative coefficient which affect the output voltage of module for every 1 °C rise in temperature.

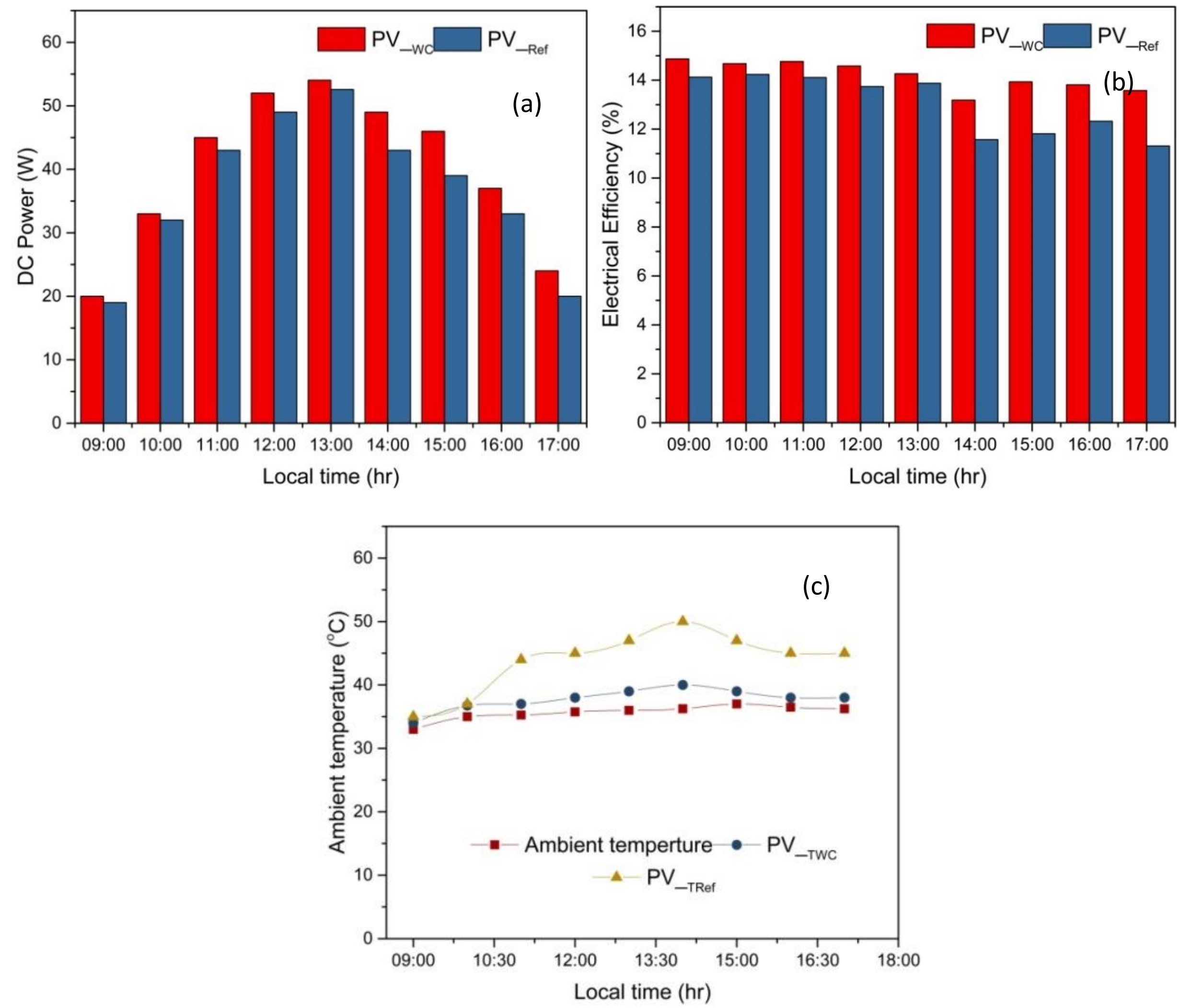

Figure 8. Hourly variation of (a) DC power, (b) Surface temperature and (c) Electrical energy conversion efficiency of Photovoltaic modules.

The electrical energy conversion efficiency of the PV with cooling (PV_wc) and reference PV module (PV_ref). is shown in fig. 8(a-c). At peak time 13:00 the efficiency of PV_wc is about 14% and the efficiency of PV_ref is about 13%. The maximum electrical efficiency of 14.1 % is obtained at 9:00. At the time interval of 15:00 – 17:00 the efficiency of PV_wc remains at 13.8%, whereas the efficiency of PV_ref falls down to 12%. The difference between the electrical efficiency improvement due to the regulating of surface temperature is PV_wc 17% compare to the reference module (PV_ref). The energy consumed by the motor and the controller device is 10 Wh.

The total energy generated by the module PV_ref is 344 Whr/day and PV_wc is 388 Whr/day. The energy improvement due to the active cooling method is 44whr in a day. Figure 9 (a). shows the Annual electrical energy gains of the PV module with cooling and without cooling. The CO_2 emission reduction due to the power generation of the PV modules is plotted in the figure 9 (b).

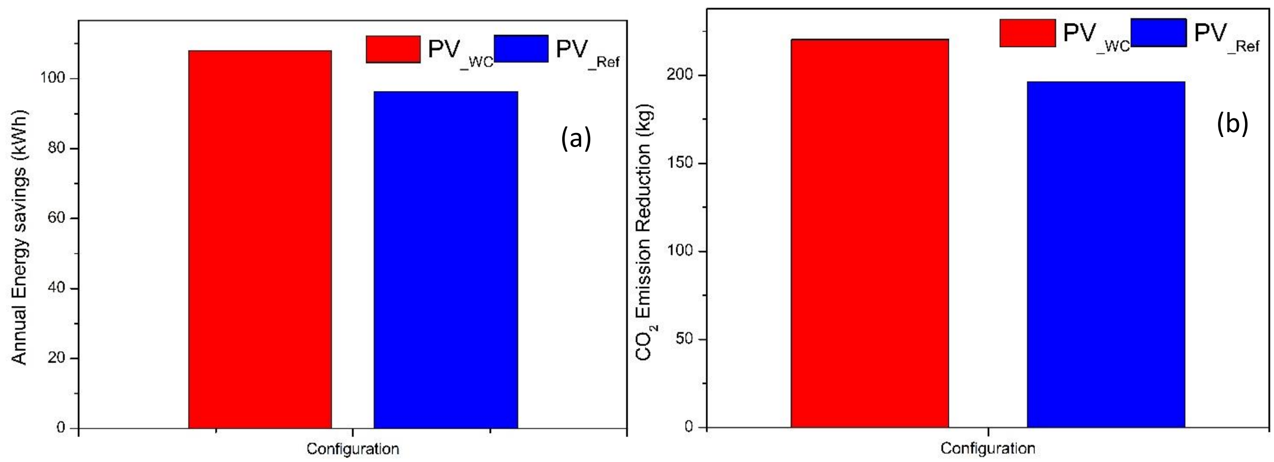

Figure 9 Solar Photovoltaic system (a) Annual Energy savings (b) CO_2 Emission reduction due to power production

4.Conclusion

The PV module is provided with the water-cooling method to control the surface temperature of the module. The novel PV system monitoring and enhancement system is developed. The Arduino embedded controller is used to monitor the performance of the module and regulate the surface temperature by control the relay to switch on and switch of the motor. Due to the water cooling the PV module efficiency is improved by 17% compared to the reference module and the surface temperature of the module is reduced up to 16 °C. The cost of the Arduino controller and sensor used is 10$ which is cost effective compare to the other controllers. The Arduino controller is capable to monitor the performance of the PV system for the smart irrigation and record the environmental parameters. The water cooling through the above surface is the cost effective and it can be used in the irrigation system to power the pump.

Author Contributions:

Arani Rajendra Prasad, Robbi Rahim Conceptualization, Alagar Karthick Supervision, Ramalingam Shankar, Methodology, Alagar Karthick, Ramalingam Shankar, Investigations, Chandrashekhar K. Patil, Robbi Rahim Writing - Chandrashekhar K. Patil, Robbi Rahim original draft Amit Kumar: Writing - original draft, Amit Kumar, Alagar Karthick Validation.

Compliance with ethical standards

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Figures

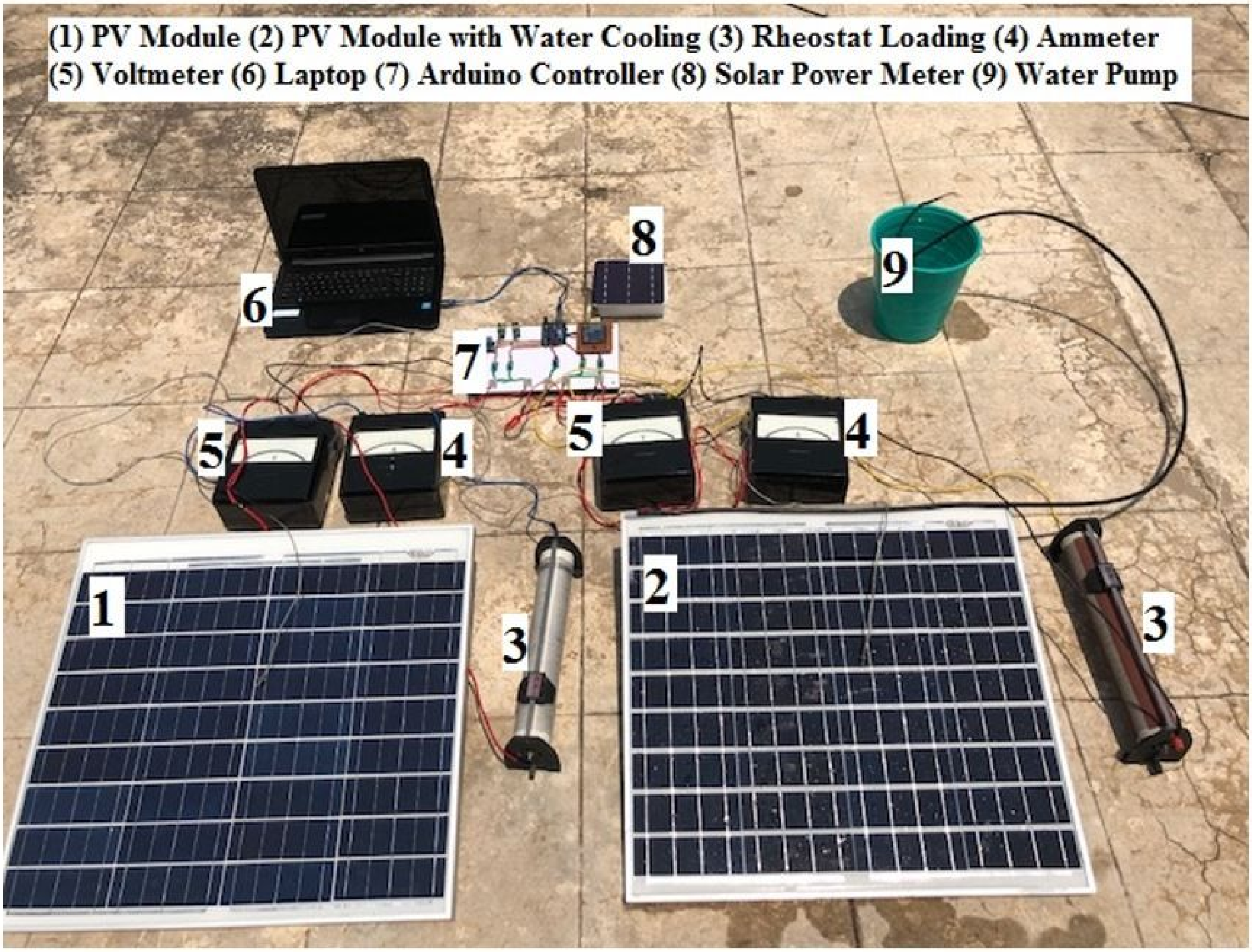

Figure 1

Experimental setup of Photovoltaic module with measuring devices

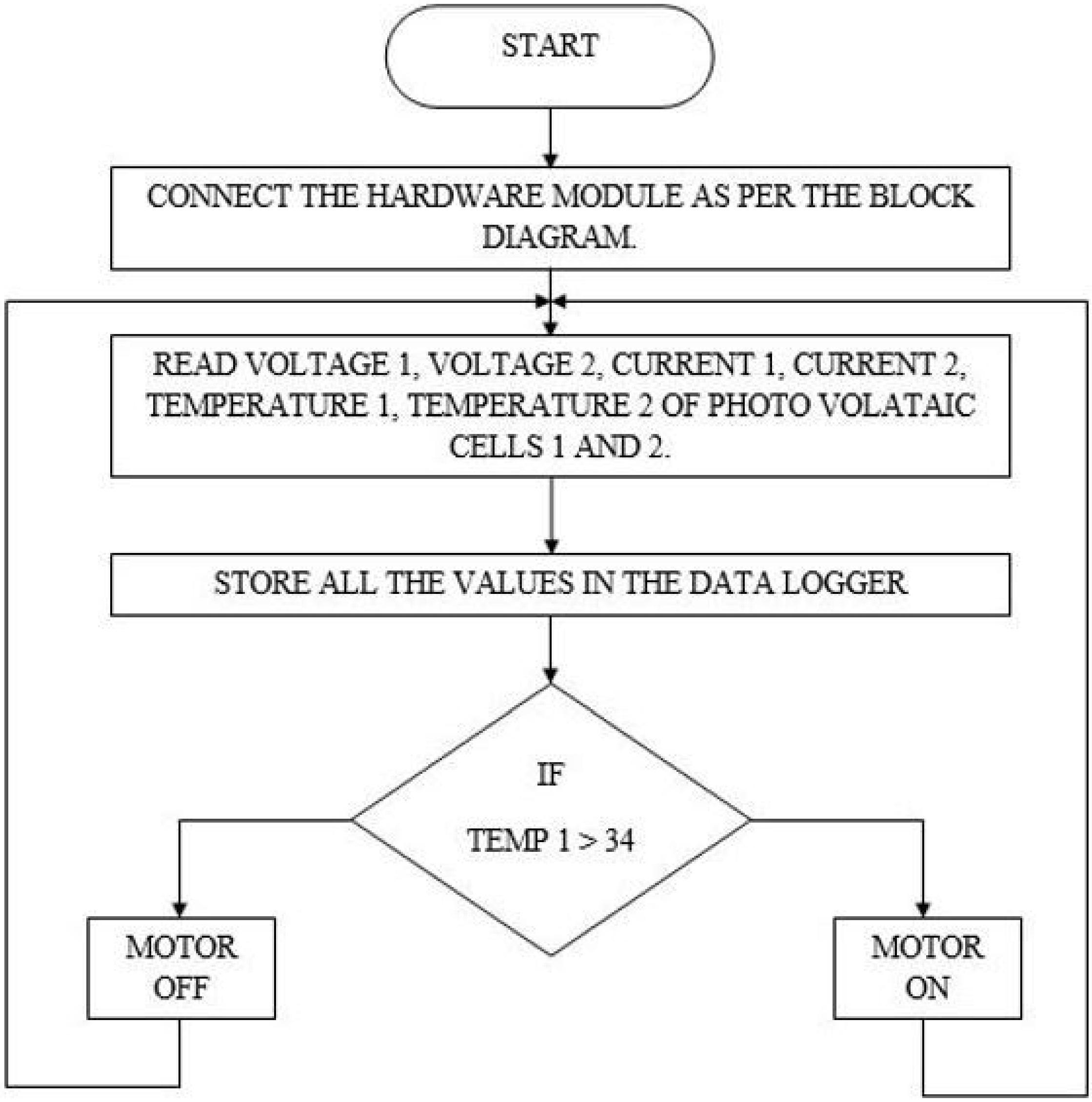

Figure 2

Overall flow chart of the Solar powered irrigation system

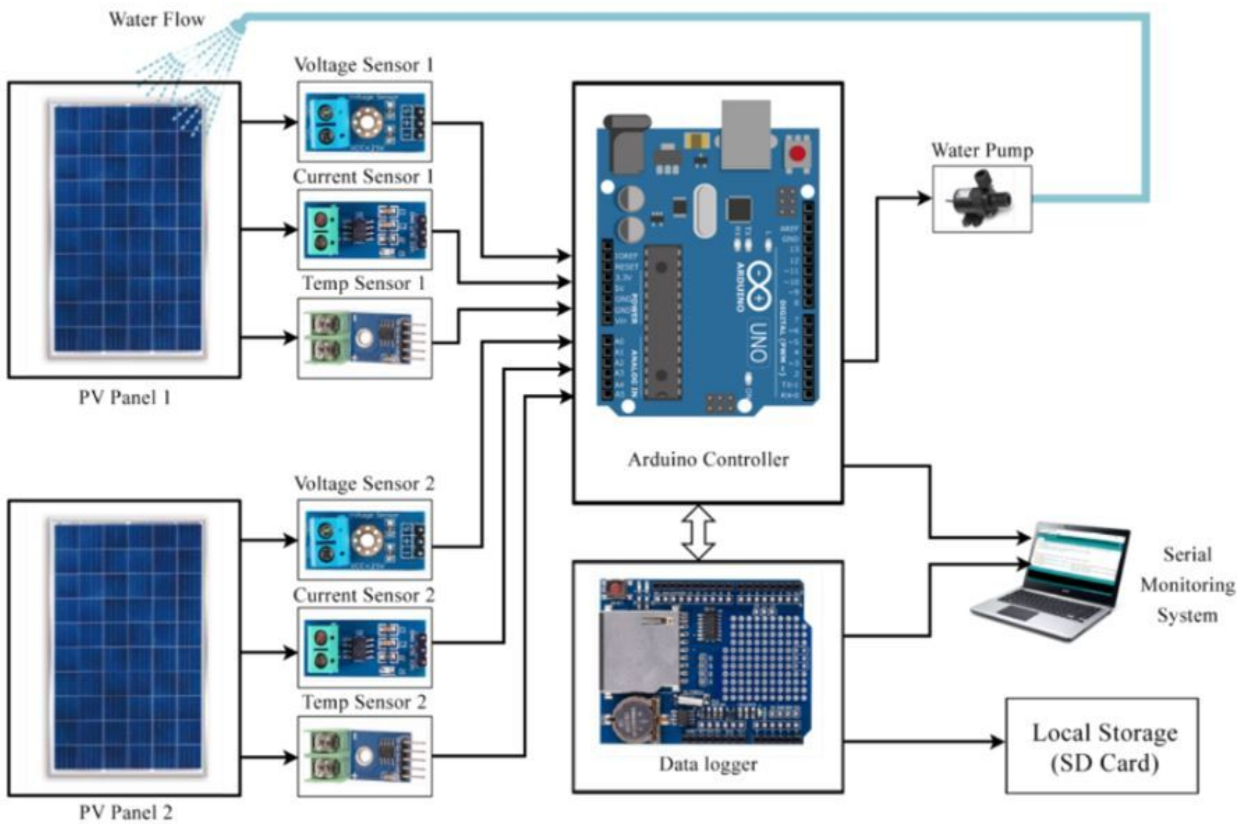

Figure 3

Various sensors connected to the Arduino controller unit

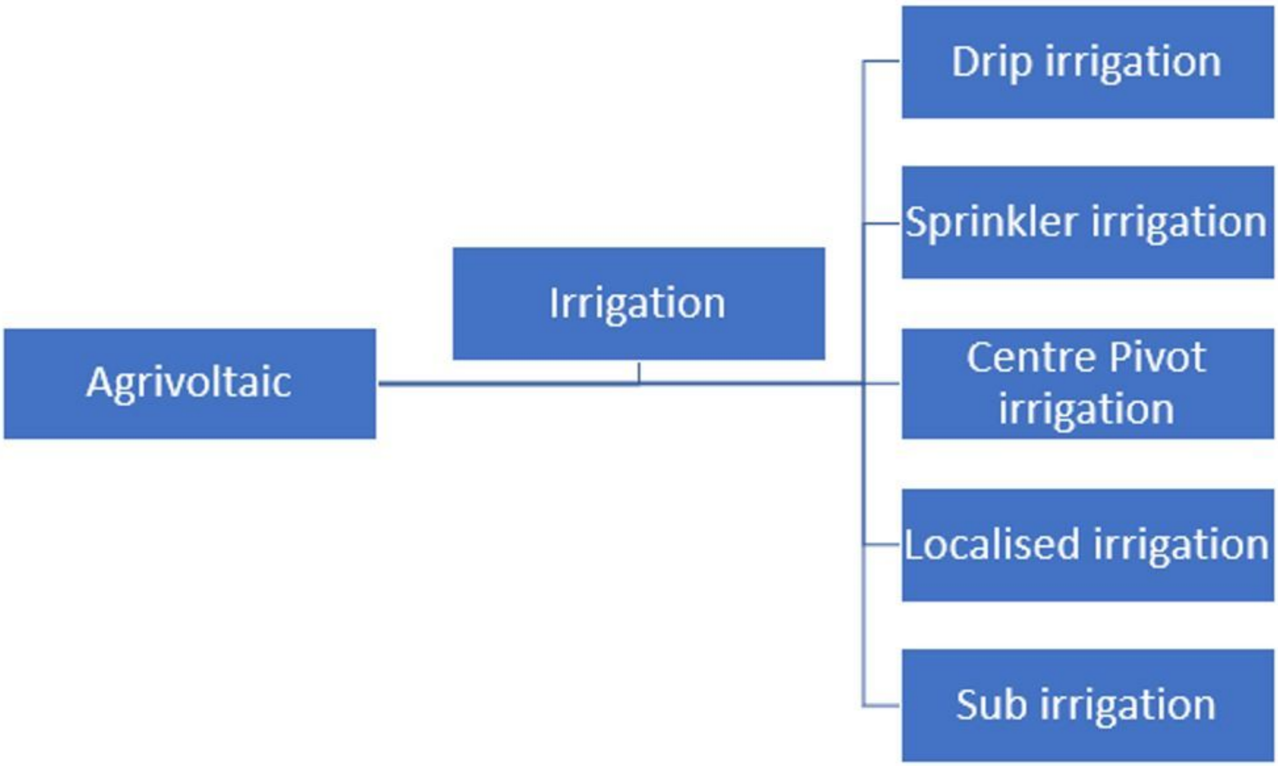

Figure 4

Agri voltaic irrigation system

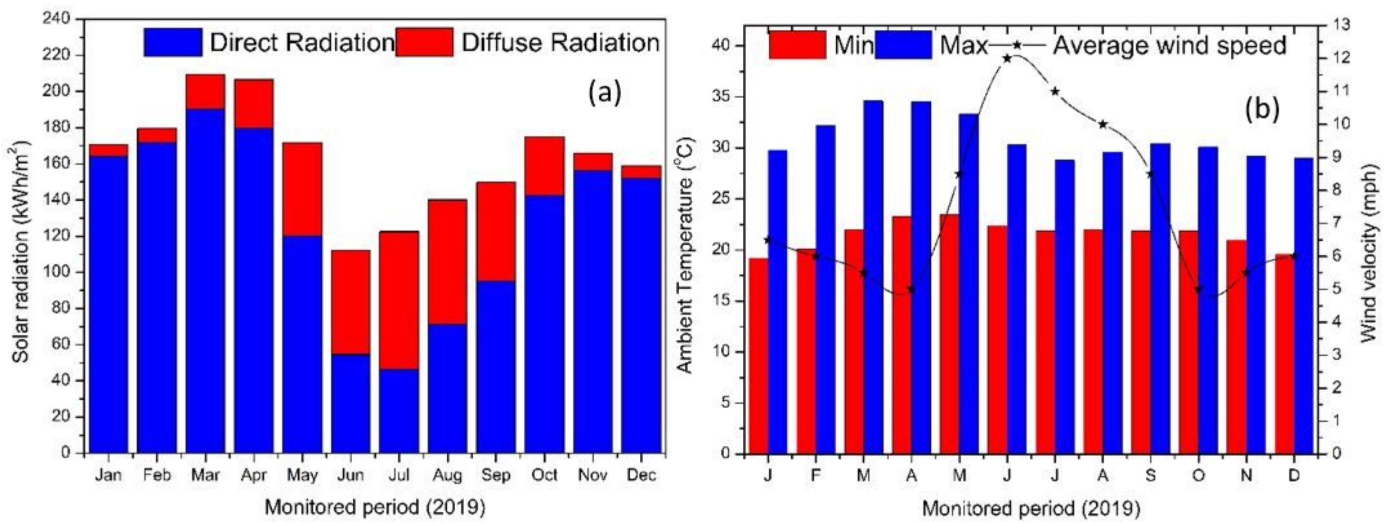

Figure 5

Monthly incident solar radiation (b) Ambient parameters of the Coimbatore area

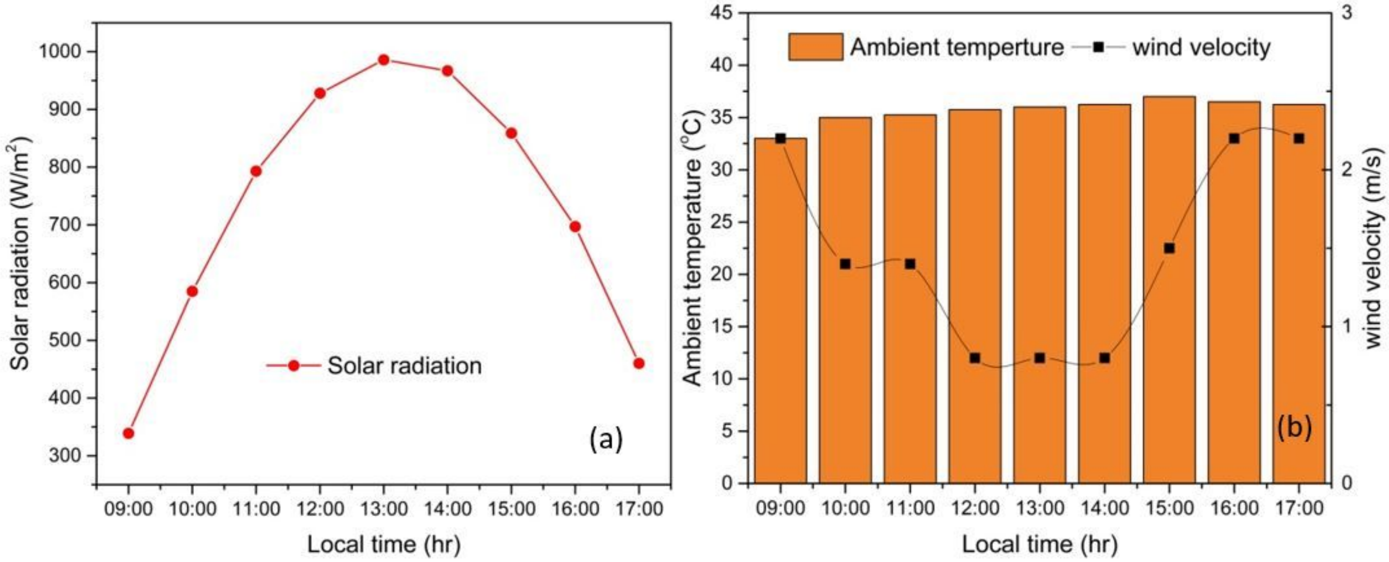

Figure 6

Average hourly variation of ambient parameters during typical day in summer May 2019 (a) solar radiation (b) Ambient temperature and wind velocity.

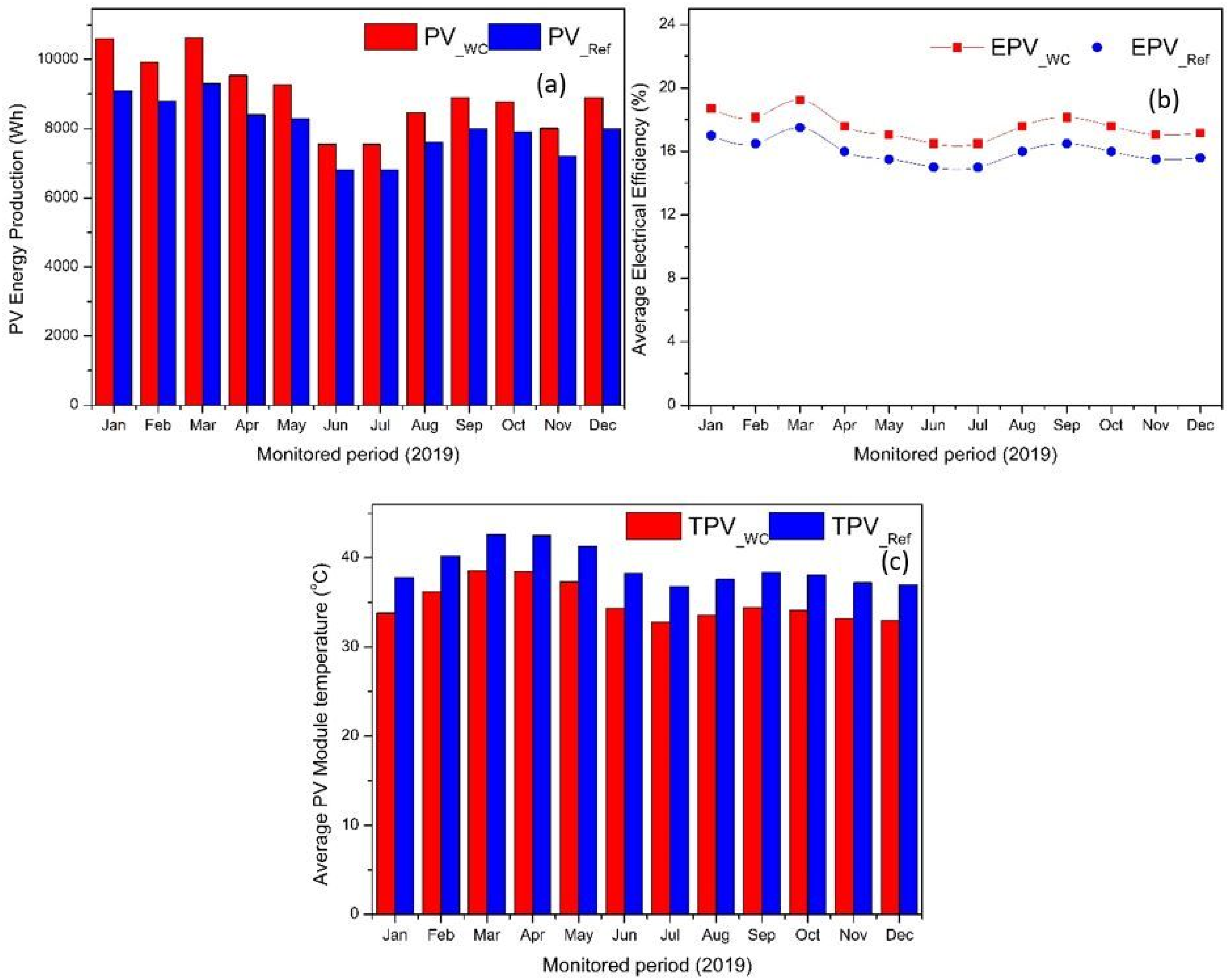

Figure 7

Hourly variation of (a) DC power, (b) Surface temperature and (c) Electrical energy conversion efficiency of Photovoltaic modules.

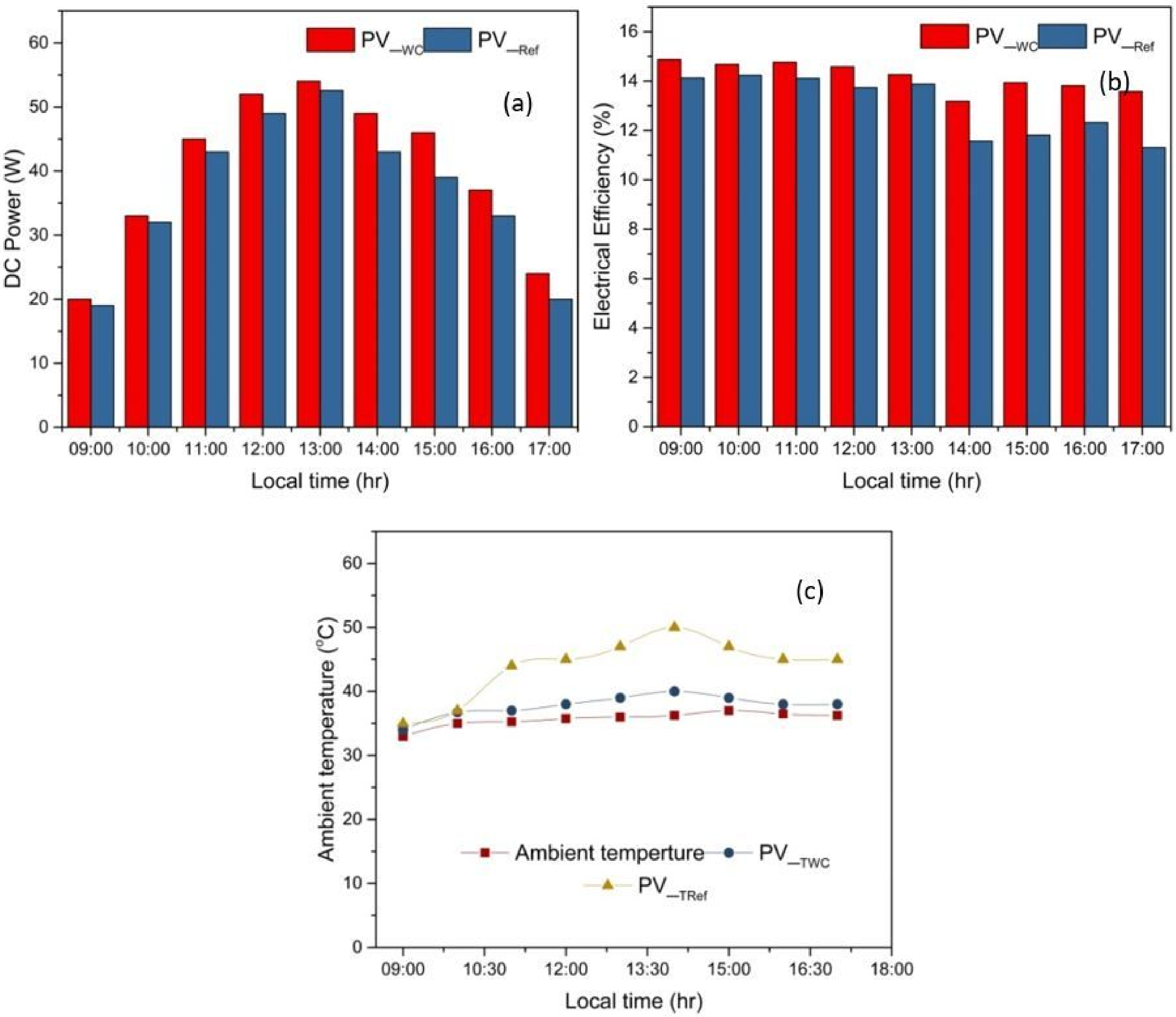

Figure 8

Hourly variation of (a) DC power, (b) Surface temperature and (c) Electrical energy conversion efficiency of Photovoltaic modules.

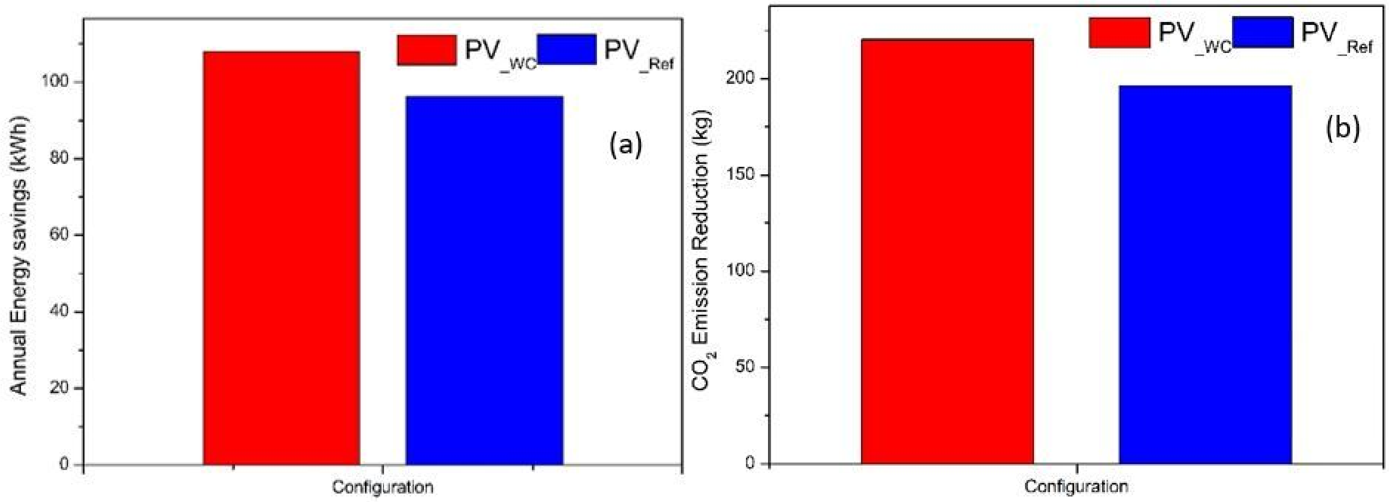

Figure 9

Solar Photovoltaic system (a) Annual Energy savings (b) CO2 Emission reduction due to power production