STUDIES OF CLIMATIC PARAMETERS UNDER AGRIVOLTAIC STRUCTURE

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ABSTRACT

In India, per capita electricity consumption has been continuously increasing over the years andsolar power can be the best solution of this increasing electricity consumption. Agrivoltaic system is co-developing the same area of land for both solar photovoltaic power as well as for conventional agriculture.In this paper, observations of diurnal variation in environmental parameters i.e. air temperature, relative humidity, light intensity and solar radiation under SPV structure and as for open field are presented. The total rating of SPV power plant was about 7.2 kW occupied over 153.88 m^2 area at the field of REE department, College of Agriculture Engineering and Technology, JAU, Junagadh (21.5˚N, 70.1˚E). It was observed that, both minimum and maximum monthly average air temperature remain higher in open field condition as compared to under the SPV structure. Minimum monthly RH for open field was observed lower than that for under SPV structure during winter months. both average and maximum monthly light intensity remains higher in open field condition as compared to under the SPV structure during the experimental period whereas monthly average highest solar radiation in open field condition was observed almost at par with open area and higher as compared to shadow area under SPV structure.

1. INTRODUCTION

In India, per capita electricity consumption has been continuously increasing over the years. From 734 kWh in 2008-09, the per capita consumption has reached 1075 kWh in 2015-16, an increase of 46 % in 8 years, *i.e.* approximately 6 % every year. Compared to some of the developed countries of the world, the per capita electricity consumption in India is very low.

In order to meet global energy demands with clean renewable energy such as with solar photovoltaic (PV) systems, large surface areas are needed because of the relatively diffuse nature of solar energy and low efficiency of solar cells. Some of this demand can be matched with aggressive building integrated PV and rooftop PV, but the remainder can be met with land-based PV farms. But use of more land for solar farms will decrease land resources for food production. These problems can be solved by using the new concept of agrivoltaic system; it is a solution to the intense competition for the land resources between food and energy production.

India has tremendous scope of generating solar energy. There as on being the geographical location and it receives solar radiation almost throughout the year, which amounts to 3000 h of sunshine. This is equal to more than 5000 trillion kWh. Almost all parts of India receive 4-7 kWh of solar radiation per square meters. According to MNRE, Gujarat is ranking sixth in solar power generation in India due to several factors: a very high solar power potential, availability of wasteland, good connectivity, transmission and distribution infrastructure, and efficient utilities.

Gujarat accounts for 8 % of India's total solar power with total installed capacity of 1344.69 MW as on 31st December 2017.

In agrivoltaic system, structure of the solar power plant is needed to be constructed with the appropriate design so that appropriate quantity of light can be transmitted through the gap of panels. Dark Shadow that are wider than 5 cm have negative impact on photosynthesis activity slowing down plant growth and can lead to tropism of plant as well as higher sensitivity to disease. Photosynthesis decreases dramatically when a dark shadow falls on plant if shadow is less than 3 cm wide the recovery time can be immediate. Thus study of climatic parameters under the agrivoltaic structure is the most important step for this novel system.

Bot *et al*. (2005) used Dutch greenhouse for agriculture without involving any fossil fuels. PV panels were set up to capture light energy during the summer months, store it and utilize the energy during the winter when incident light is less and days are shorter. Then the total realizable energy saving was more than 60 %.

Dupraz *et al*. (2011a) evaluated 'Agrivoltaic' system. They noted that a 57 % (resp. 29 %) reduction in light availability results in only a 19% (resp. 8%) reduction in wheat yield. Dupraz *et al.* (2011b) found that agrivoltaic schemes are profitable, environment friendly and have high levels of production.

Marrou *et al.* (2013) aimed to assess the effect on crop yield of two PVPs densities, resulting in two shade levels equal to 50% and 70% of the incoming radiation. They found that these leaves were both wider and longer in the shade than in the full sun.

Cossu *et al*. (2014) assessed the climate conditions inside a greenhouse with 50% roof area replaced with photovoltaic modules. The reduction in solar radiation was averagely 64 % inside the greenhouse and up to 82 % for the areas under the PV covers, and 46 % under the transparent covers.

Harinarayana and Venkata (2014) studied the use of fertile and cultivated land with about 5 m elevated structure with solar panels. It was observed20 % - 25 % reduction of sunlight for 11.4 m separated panels, 25 % - 30% reduction for 7.6 m and chess pattern shades, 60 % - 80 % reduction for 3.8 m separated panels.

Armstrong *et al*. (2016) reported that the PV arrays caused seasonal and diurnal variation in air and soil microclimate. Specifically, during the summer cooling up to 5.2 °C and during the winter gap areas were up to 1.7 ℃ cooler compared to under the PV arrays. PAR was 92 % lower; rainfall was on average three times higher and the wind speed was only 14% of that in control areas.

Castellano *et al*. (2016) concluded that the amount of solar radiation, in the PAR range, falling inside a photovoltaic greenhouse is a very important parameter in order to define agronomic performances. Difference between average PFD values of calculated (338 μ mol $m^{-2}s^{-1}$) and measured (361 μ mol $m^{-2}s^{-1}$) over the entire period was almost the 6.3 %.

2. MATERIALS AND METHODS

The experimental SPV Power Plant structure was designed and installed earlier at the Dept. of Renewable Energy Engineering has been considered for this study and specification of it is given in Table 2.1. The tilt angle of SPV panels is kept as an equal to latitude of the Junagadh region to get maximum solar radiation. A dark shaded box in Fig. 2.1 and 2.2 indicates the SPV panels. Accordingly, 153.88 m^2 area of the field under the power plant was occupied. 12 numbers of panels in each row with 150 W output capacity of each panel were installed facing south direction. Total 48 numbers of panels were fixed in four rows keeping 1.36 m gap between two rows. The specifications of the solar panels are tabulated in Table 3.2.

Table 2.1: Specifications of SPV Power Plant

Latitude	21.51 ˚N
Longitude	70.47 ˚E
Elevation	107 m
Type of PV Module	Poly crystalline
Capacity	7.2 kW
Capacity of Each Module	150 W
No. of solar panels	48 nos.
Inverters Capacity	7.5 kVA
Battery	10 batteries (42 Ah)
Type of configuration	Chess Board type

2.1. Air Temperature, Rh And Light Intensity

The data logger recorded all three environmental parameters (Air Temperature, RH and light intensity) daily at every one-hour interval placed at the height of plant canopy and at the centre of the field.

2.2. Solar Radiation

Daily solar radiation intensity was measured manually for open and under SPV power plant by using digital solarimeter at 8:00, 10:00, 12:00, 14:00, 16:00 and 18:00 h.

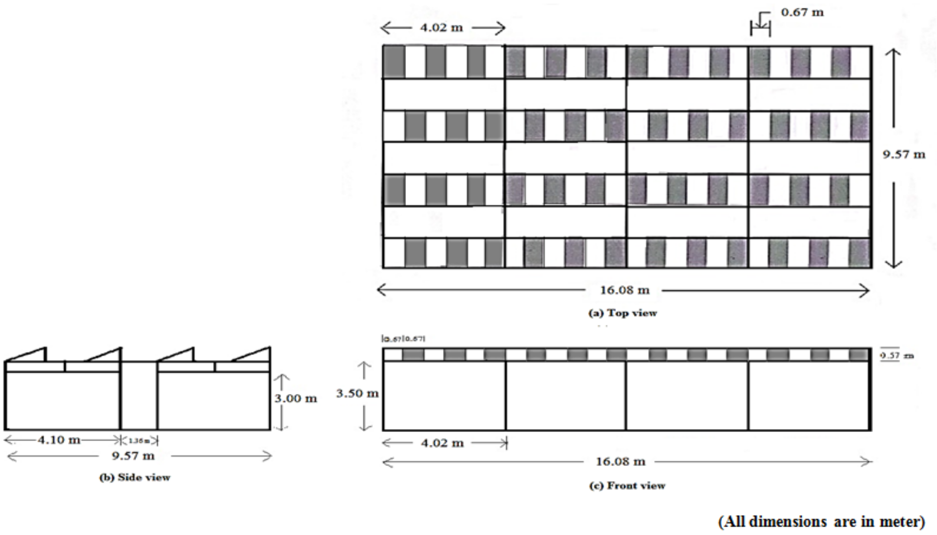


Fig. 2.1: Schematic view of SPV Power Plant

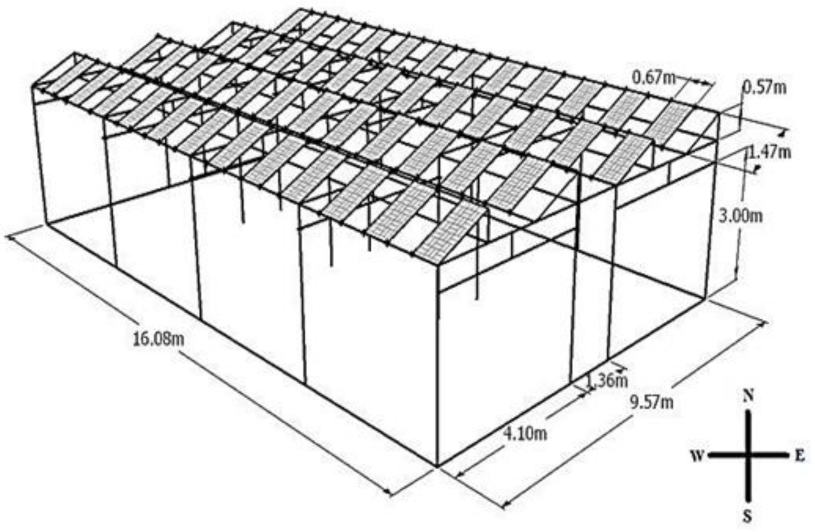


Fig. 2.2: Isometric view of SPV Power Plant

3. Results And Discussion

3.1 Measurement Of Environmental Data

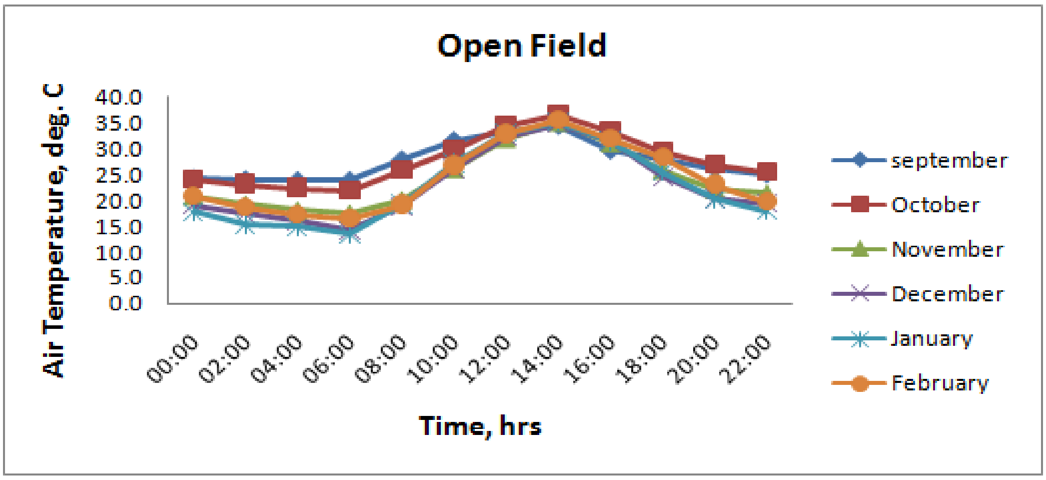
The observations of diurnal variation in environmental parameters i.e. air temperature, relative humidity, light intensity and solar radiation were taken at every two-hour interval and analysed at 0:00, 2:00, 4:00, 6:00, 8:00, 10:00, 12:00, 14:00, 16:00, 18:00, 20:00 and 22:00 h (for all 24 hours) during the study period (from 11th September 2017 to 28th February 2018) under SPV structure and as for open field also. The recorded data were analysed monthly average and reported here in tabular as well as graphical form.

a. Monthly Hourly Average Air Temperature

The diurnal variation in monthly average air temperature for open field and under SPV structure was computed from daily recorded data which are shown in Table 3.1 and depicted in Fig. 3.1.

Table 3.1: Monthly hourly average air temperature during Sept. '17 – Feb. '18

Sr. No.	Months	Air Temp.	
		Open Field	**Under SPV Power Plant**
1	September	23.78 ˚C to 34.28 ˚C	22.37 ˚C to 33.76 ˚C
2	October	21.91 ˚C to 36.59 ˚C	22.72 ˚C to 35.93 ˚C
3	November	17.31 ˚C to 35.11 ˚C	16.32 ˚C to 34.34 ˚C
4	December	14.12 ˚C to 34.80 ˚C	14.14 ˚C to 32.59 ˚C
5	January	13.41 ˚C to 35.14 ˚C	13.83 ˚C to 33.25 ˚C
6	February	16.49 ˚C to 35.36 ˚C	15.46 ˚C to 33.87 ˚C



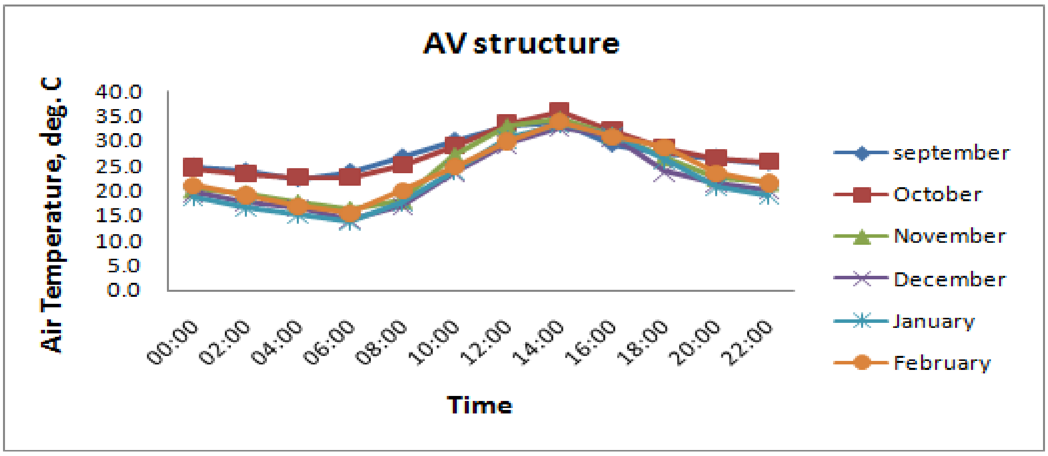


Fig. 3.1: Monthly hourly average air temperature during Sept. '17 – Feb. '18

The Fig. 3.2 shows that both minimum and maximum monthly average air temperature remain higher in open field condition as compared to under the AV structure.

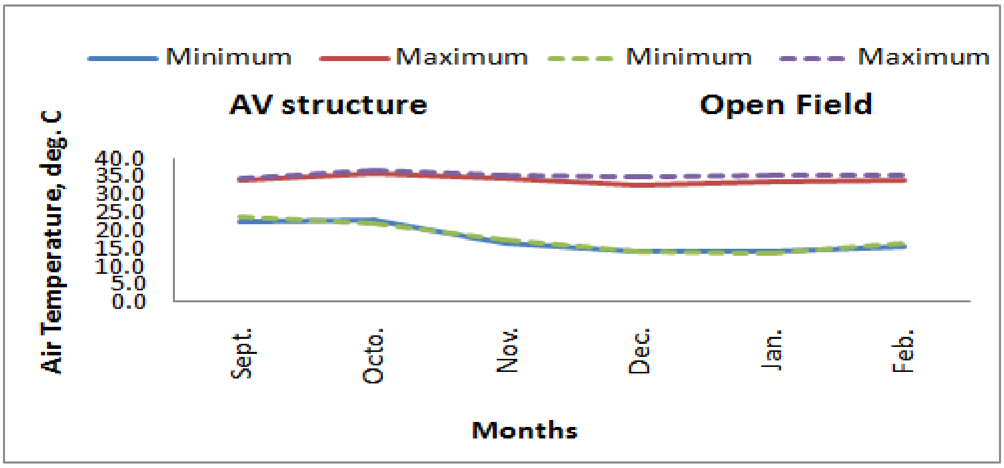


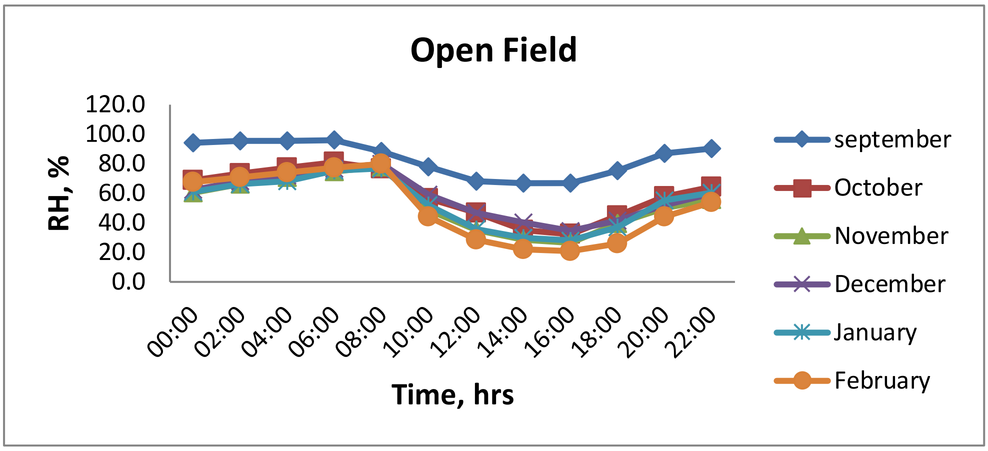
Fig. 3.2: Monthly average maximum and minimum air temperature during Sept. '17 – Feb. '18

b. Monthly Hourly Average Relative Humidity

The diurnal variations in monthly average RH for open field and under SPV structure was computed from daily recorded data which are shown in Table 3.2 and depicted in Fig. 3.3.

Table 3.2: Monthly hourly relative humidity during Sept. '17 – Feb. '18

Sr. No.	Months	RH	
		Open Field	Under SPV Power Plant
1	September	66.83 % to 95.94 %	55.27 % to 95.60 %
2	October	32.24 % to 80.94 %	29.58 % to 82.95 %
3	November	26.44 % to 78.15 %	27.99 % to 79.01 %
4	December	34.60 % to 80.06 %	41.39 % to 75.78 %
5	January	28.12 % to 76.84 %	29.51 % to 81.70 %
6	February	20.86 % to 79.88 %	27.68 % to 77.33 %



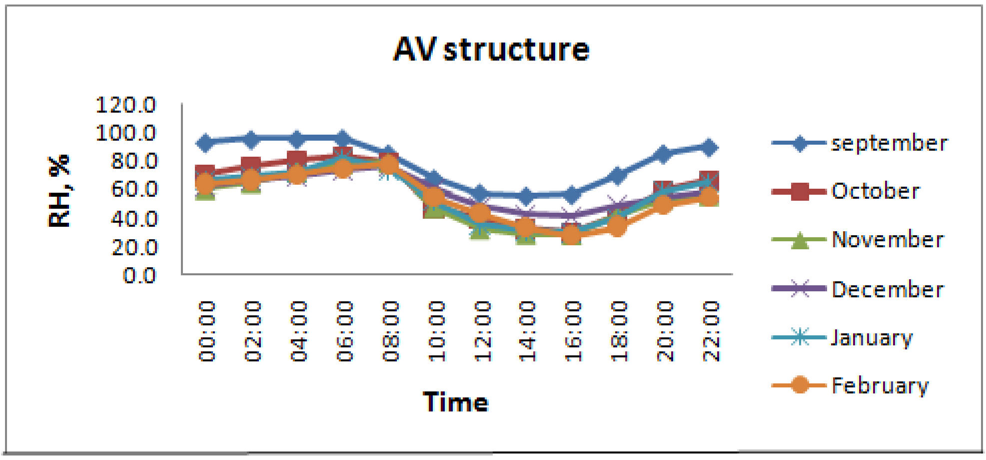


Fig. 3.3: Monthly hourly average RH during Sept. '17 – Feb. '18

Monthly average maximum RH and minimum RH during experimental period is shown in Fig. 3.4. It can be seen that Maximum monthly RH for open field was nearly at par with it was for under AV structure whereas in minimum monthly RH for open field was observed lower than that for under AV structure during winter months.

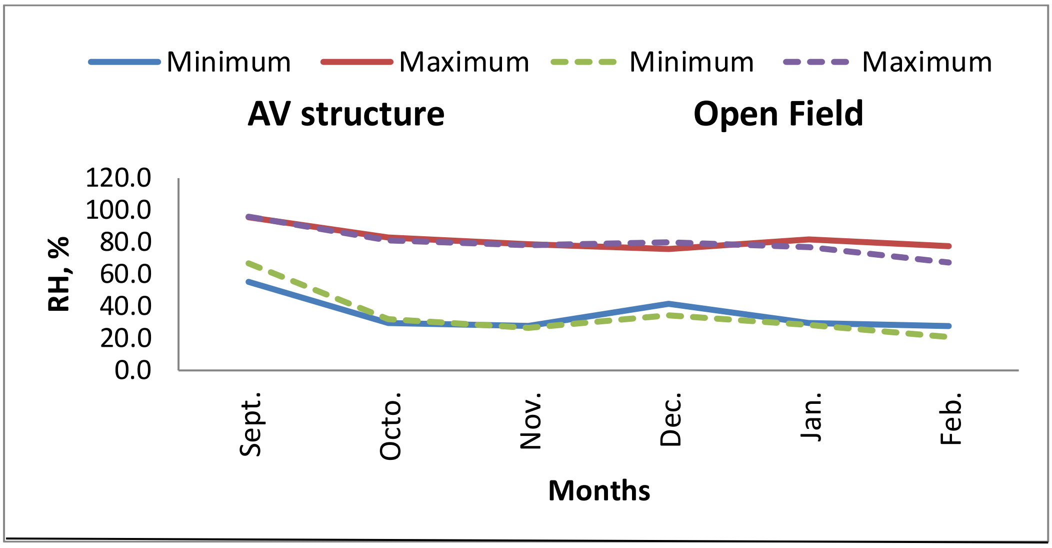


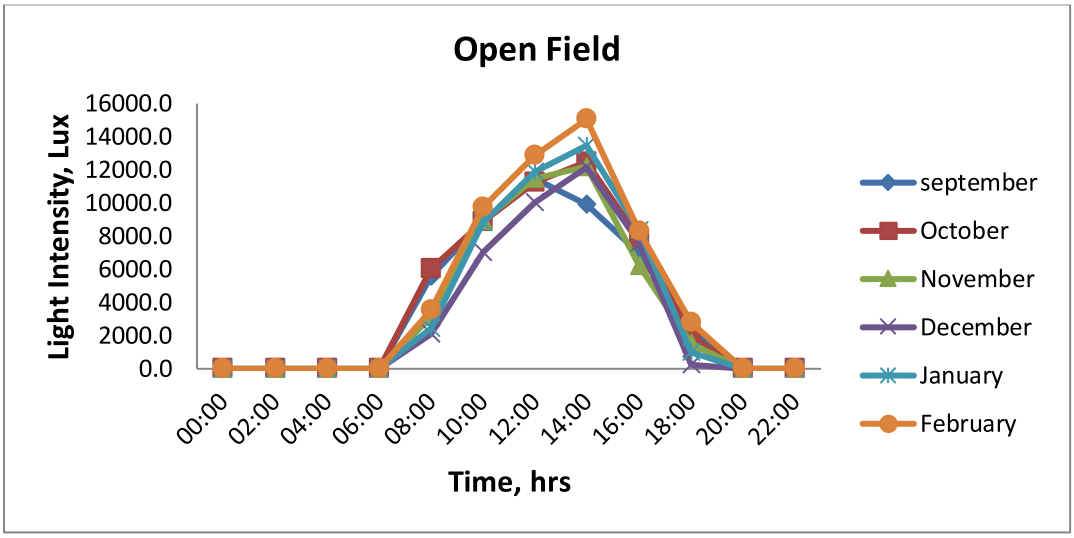
Fig. 3.4: Monthly average maximum and minimum RH during Sept. '17 – Feb. '18

c. Monthly Hourly Average Light Intensity

The diurnal variations in monthly average light intensity for open field and under SPV structure was computed from daily recorded data which are shown in Table 3.3 and depicted in Fig. 3.5.

Table 3.3: Monthly hourly light intensity during Sept. '17 – Feb. '18

Sr. No.	Months	Light Intensity(lux)	
		Open Field	Under SPV Power Plant
1	September	11472.57	7843.78
2	October	12485.28	8087.29
3	November	12196.56	6464.15
4	December	12148.75	6023.33
5	January	13470.07	7121.48
6	February	15049.86	9390.42



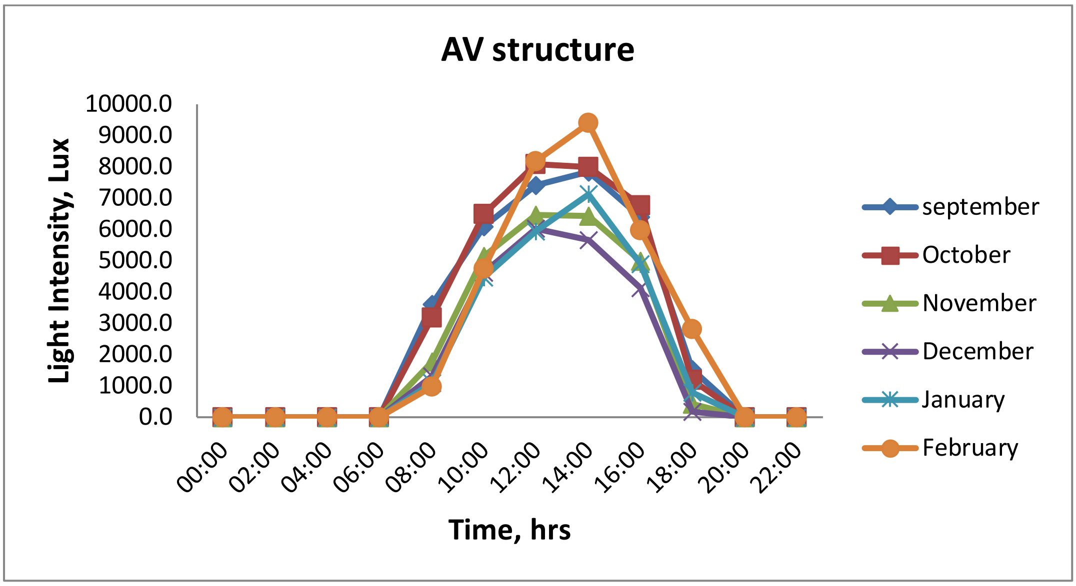


Fig. 3.5: Monthly hourly average light intensity during Sept. '17 – Feb. '18

The Fig. 3.6 shows that both average and maximum monthly light intensity remains higher in open field condition as compared to under the AV structure during the experimental period.

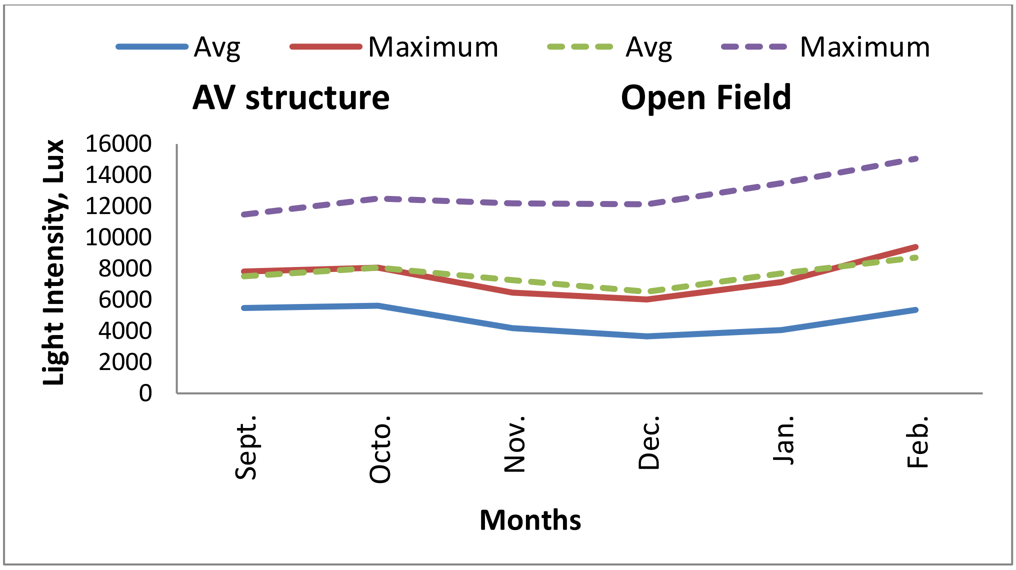


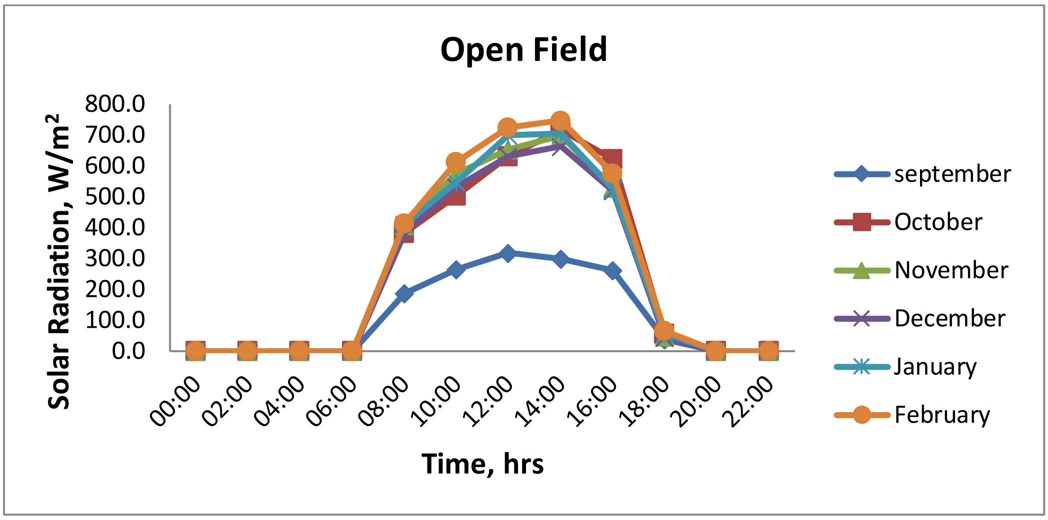
Fig. 3.6: Monthly avg and minimum light intensity during Sept. '17 – Feb. '18

d. Monthly Hourly Average Solar Radiation

The diurnal variations in monthly average solar radiation for open field and under SPV structure. Under the AV structure it was measured for open area as well as shadow area. Since for open area under AV structure was found at par with that of open field condition. It is not plotted here and only monthly average solar radiation for open field and shadow area under AV structure was computed from daily recorded data which are presented in Table 3.4 and depicted in Fig. 3.7.

Table 3.4: Monthly hourly solar radiation during Sept. ’17 – Feb. ’18

Sr. No.	Months	Solar Radiation (W/m^2)	
		Open Field	Under SPV Power Plant (shadow area)
1	September	318.90	143.15
2	October	716.65	163.45
3	November	698.53	159.90
4	December	663.96	161.61
5	January	705.16	165.61
6	February	747.79	169.18



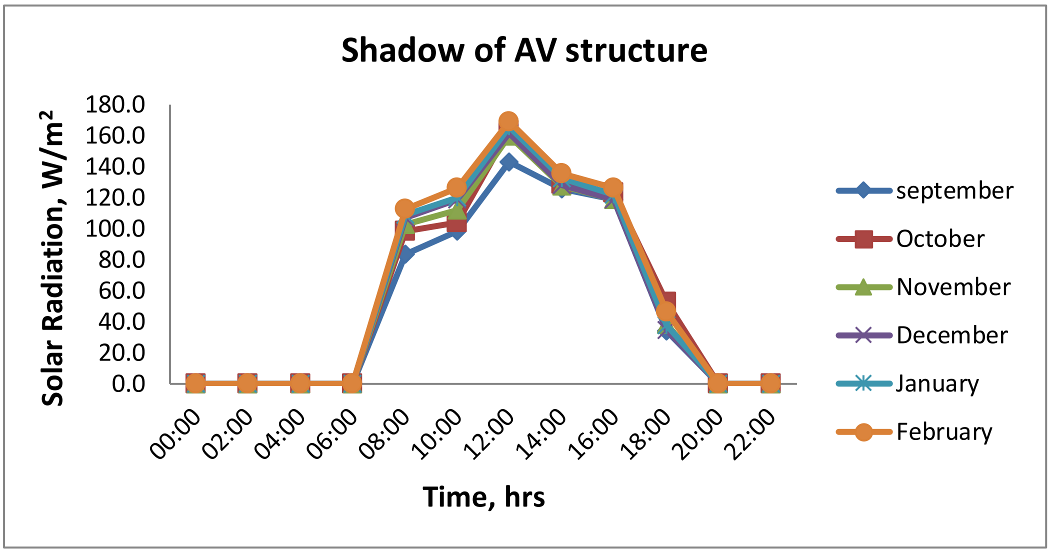


Fig. 3.7: Monthly hourly average solar radiation during Sept. ’17 – Feb. ’18

Monthly average solar radiation and maximum solar radiation during experimental period is shown in graphically in Fig. 3.8.

The reduction in monthly average solar radiation under AV structure of shadow area for the month of September was observed about 55.92 % whereas for the month of October, November, December, January and February it was 77.00 %, 77.337 %, 75.87 %, 77.69 % and 77.19 % respectively.

The reduction in monthly average highest solar radiation under AV structure of shadow area for the month of September was observed about 55.12 % whereas for the month of October, November, December, January and February it was 77.20 %, 77.11 %, 75.66 %, 76.52 % and 77.38 % respectively.

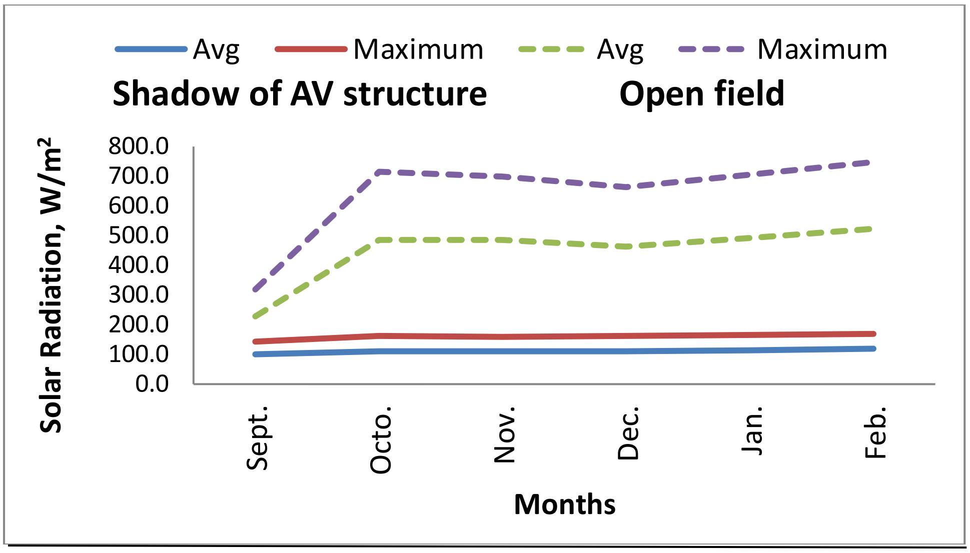


Fig. 3.8: Monthly avg and maximum solar radiation during Sept. '17 – Feb. '18

4. CONCLUSION

Minimum and maximum monthly average air temperature remains higher in open field condition as compared to under the AV structure. Maximum monthly RH for open field was nearly at par with it was for under AV structure whereas in minimum monthly RH for open field was observed lower than that for under AV structure during winter months. Average and maximum monthly light intensity remains higher in open field condition as compared to under the AV structure during the experimental period.

The minimum reduction in monthly average solar radiation and monthly average highest solar radiation under AV structure of shadow area was about 55.92 % and 55.12 % observed for the month of September respectively.

At light saturation point, increasing the light no longer causes an increase in photosynthesis. Hence, excess sunlight can be tapped for generating power with the help of agrivoltaic structures. It can be seen from the above observations that agrivoltaic structure provided favourable environment for cultivation of crop.Agrivoltaic structure have several variables used to maximize solar energy absorbed in both the panels and the crops.

In future following studies can be done by the researcher: Study of crop parameters under the agrivoltaic structure, comparison between energy generation from agrivoltaic structure and SPV power plant as well as cost economics with and without subsidy consideration of agrivoltaic system.

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