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Performance evaluation of solar PV module with filters in an outdoor environment

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ABSTRACT

Energy is the current need of the hour. Energy shortage in every part of the world has lead to the need for exploration of renewable sources of energy. Solar energy is the most prominently used renewable form of energy. Solar photovoltaic system efficiency depends on the wavelength of the solar radiation it is exposed to. In the present study, extensive research has been carried using different colour filter papers to evaluate the electrical performance of the solar photovoltaic module. Five different filters were used from magenta to red so that the relationship of frequency or wavelength and photonic energy can be determined. The efficiency and power of the solar photovoltaic module were measured with and without filters, and their performance was compared. From the study, it has been concluded that among all the colour filters used, magenta colour in the visible spectrum of solar radiation gave the maximum efficiency. The results also show that blue and magenta have maximum scope for producing more change in temperature when compared to other filters. The standard deviation is more in the case of these two filters, and all the filters have better standard deviation when compared without a filter.

1. Introduction

Nowadays, we require a large amount of energy which is available easily, conventional energy resources are available, yet we can't rely on them everlastingly as the assets are restricted [1]; But, once again, the world's energy demand is rapidly growing. The growing energy demands rely extensively on traditional energy forms. Hence, a need arises for looking for other forms of energy sources, which can give us energy in a realistic way [2]. In every second, a tremendous amount of energy is being produced from the Sun. The energy emitted from the Sun, as radiation, passes into space. Owing to the massive distance between the Earth and the Sun, a fragmental portion of sunlight is received by Earth [3]. Once solar radiation enters the atmosphere of Earth, entire radiation is not transmitted as some part gets absorbed [4]. The Earth's solar radiation is distributed through various wavelengths. The impact of the environment on terrestrial irradiance is based on the optical transmittance properties. The efficacy of primary silicon cells was about 6%, which is substantially lower than that of modern Solar cells (between 14–20%) [3]. Early endeavours to make photovoltaic cells a practical technique for applications were ineffective because of the high gadget costs. Owing to the shortage of energy and later because of the decrease in the costs of PV cells has led to the increasing development of Solar Photovoltaic technologies [5]. Photovoltaic System is a pioneering way of converting solar energy straightforwardly into power, using solar cells or comparable devices. Solar Photovoltaic systems have picked up noteworthy consideration in the recent decade. Photovoltaic systems have been implemented to power the billions of people who do not have access to electricity because the photovoltaic cells use a portion of solar energy powered by a semiconductor's bandgap. The cycle of thermalization is the predominant loss that restricts the execution of Solar cells [5].

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The entire band of Sun's energy is not entirely exploited in photovoltaic cells, as discussed earlier. The spectrum of visible region is determined by its frequency and is focused on the continuum of shading [6]. Various studies have been completed with increased yield. Several studies have been performed with the objective of development of solar cells with improved yield and energy performance. Photovoltaic panels have a major effect on the influence of irradiance and the increase in temperature. However, increasing the temperature of silicon cells with increasing irradiance has a negative effect on the life of photovoltaic cells.

Joshi et al. [7] verified how better efficiencies could be obtained by using the PV/T collector. They used a blower to use hot air for drying applications. Curie et al. [8] used a portion of the light to demonstrate the consequence of the red spectrum of light on the performance of PV/T. Joshi et al. [9] examined the energetic and exergetic performance of PV/T panels under the red filter. Sudhakar et al. [10] analyzed the relationship between the wavelength on the efficiency of the solar cell. Alonso-Abella et al. [11]designed a technique which predicts the type of PV module which results in maximum efficiency for the given environmental conditions. Karki [12] shower the dependency of current with light intensity and temperature. It was suggested that by decreasing the temperature of the solar panel, efficiency could be improved. Galleano et al. [13] have suggested that by incorporating a nanoparticle filter, the PV cell efficiency can be improved. Jarnette et al. [14] have suggested based on solar spectra modelling for four sites that with the decrease in latitude, the spectral monthly deployment also decreased. Orosz et al. [15] designed a tracking software that demonstrated the spectral compatibility of the different wavelengths on the efficiency of PV cells. Atse et al. [16] studied the effect of operating conditions on the performance of different types of PV modules. Evaldo et al. [17] established the relations between the spectral response under the influence of different filters with their relative efficiencies, respectively. Keith et al. [18] simulated a ray tracing application for predicting the colour of the incident illumination. Ahmad et al. [19] conducted an experimental analysis on Solar PV modules with nanofilm filters. Armstrong et al. [20] performed a detailed investigation on the Solar PV module under specific uncontrolled environment close to the river Nigeria. Several other research on the application of PV in building, campus, solar tree and cooling are reported [21–25].

From the above studies, a standardized approach to estimate the temperature, power and efficiency of the module with filters have not been reported elaborately in the literature although it can play a significant role in determining the real performance of the solar module. With this motivation, the current research is being focused on understanding the filter effect, which produces less temperature, more power and efficiency. In this paper, a detailed outdoor experimental study has been done to study the electrical characteristics of solar PV under the influence of solar wavelength parameters. The other objective of this study is to determine the best colour filter for the practical application.

2. Theoretical background

Earths atmosphere acts as a natural filter to solar radiation.The annual average solar energy received at the top of the Earth's atmosphere is nearly 1361 W/m^2. Inbound radiation is dispersed across the electromagnetic spectrum, from ultraviolet, visible light to infrared light. Approximately 50% of the energy is from the infrared light.The Sun 's rays are diminished as they transfer through the atmosphere, leaving maximum normal surface insolation at roughly 1000 W/m^2 at sea level on clear sky conditions. Neglecting clouds, the daily average irradiance on the Earth surface is approximately 6 kWh/m^2. Clouds consist mainly of droplets of water, frozen crystals and particulates suspended in the atmosphere. It has the significant potential to reduce much of the solar irradiation reaching the surface.

Light from the Sun incorporates all shades of the range, ranging from about 400 nm (nm) to about 780 nm (See Fig. 1). The photon energies are controlled by the frequency, E = hf. Where E is the photon's energy, f is its frequency in Hz, and h is the constant of Planck, h = 6.663 * 10 ^ 34 Js. As it is clear, the photonic energy depends on frequency. So if one wants to alter the energy, then one has to alter the frequency of the light that is falling.

From the literature survey, it is seen that red photons have the least energy, and the most energy is from blue photons. Green is halfway between the two. It is increasingly evident that the amount of light falling on the photovoltaic modules influences its performance. Currently, accessible solar photovoltaic cells respond prominently to a few frequencies. Various solar cells are intended to work productively at various frequencies, based on constituents used for their production. There has been an extensive study in the area of solar photovoltaic cells with an intensifying interest to create cells that would react productively at the wide scope of frequencies. Since frequency and wavelength are interrelated, so if one varies the wavelength of the spectrum of light, then one can vary the energy. The filter paper has the property to allow only frequencies corresponding to their own colour and therefore, when they are used over panel, they respond as if only that colour of light is falling.

3. Experimental methodology

The experiment is performed in the department of electrical engineering situated at SASTRA Deemed University, Srinivasa Ramanujam Centre, Kumbakonam Tamilnadu, India in the northern hemisphere (10.9602° N, 79.3845° E).

3.1. Experimental setup

The equipment needed for the state-of-the-art set up is described in this section. Two 50 W_p power capacity panel was used for performing this experiment. It was oriented at optimum tilt equal to the latitude of the place for maximum exposure to sunlight. A 3W lamp load was connected to the PV Module for measuring the VI characteristics. Low - cost cellophane colour filters are used to cover the photovoltaic cell in the real outdoor condition of the full solar spectrum. The filters of different colours (red, yellow, green, blue, and magenta) were used in the experiment. These filter papers are opaque to the frequency of light corresponding to their own colour. Furthermore, the Thermo-physical properties, optical properties, thicknesses of the filters were not known in the aforementioned work. All the colour filters were placed, and the measurements were taken and compared. The output of two modules with and without filters are measured individually. The block diagram and actual photograph of the experimental set up are shown in Figs. 2 and 3.

The specifications of the panel are listed in Table 1.

3.2. Instruments used

Artificial lamps are used as a load for IV measurements; a digital infrared thermometer was used to measure the module temperature. For measuring the solar radiation, a light sensor is used. The details of the instruments are given in Table 2.

3.3. Analysis

The experimental analysis is presented in Fig. 4. Energy is present in the sunlight in the form of tiny packets of energy called photons. The energy present in the photons can be calculated using the equation.

Photonic Energy $(E) = \frac{hc}{\lambda}$

The electrical efficiency, power output is computed with the help of standard approaches available in the literature. The efficiency of solar panels is based on standard testing conditions (STC), under which all solar panel manufacturers must test their modules. STC specifies a temperature of 25 °C (77 F), solar irradiance of 1000 W/m^2, and an air mass 1.5 (AM1.5) spectrums.

PV panel electrical performance is calculated by

$$FF = \frac{V_{mp} I_{mp}}{I_{sc} V_{oc}}$$

$$\eta = \frac{P_{max}}{GA_{PV}}$$

∴ Theoretical Efficiency = [Power @STC ÷ (Area of the Module X 1000 W/m^2)] x 100%

∴ Actual Efficiency = [Power ÷ (Area of the Module X G W/m^2)] x 100%

3.3.1. Uncertainty analysis

Uncertainties of the used instruments depend on calibration, observation of readings, atmospheric condition and the selection of instruments. It is used to determine the accuracy of instruments used during the study. The uncertainty depends on several parameters such as temperature, solar irradiance, and power measurements.Based on the accuracy and precision of the instrument used, the overall uncertainty in the analysis is within ±2%. The above indicates that reduced uncertainty has been obtained in the observations.

$$= \sqrt{\{(Tm)^2 + (G)^2 + (Voc)^2 + (Isc)^2\}}$$

$$= \sqrt{\{(1)^2 + (0.5)^2 + (1)^2 + (1)^2\}}$$

$$= \pm\ 1.80\%$$

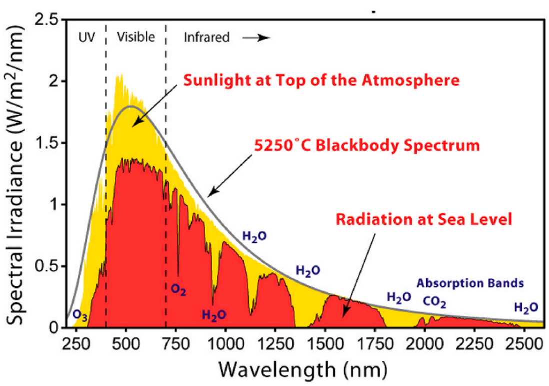

Fig. 1. Solar Radiation Spectrum [11].

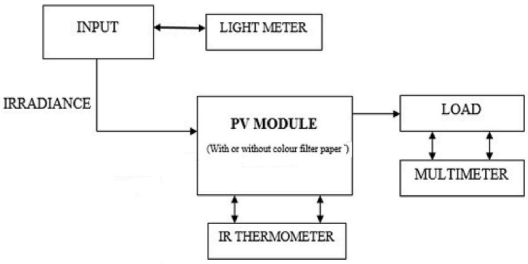

Fig. 2. Block diagram of the experimental setup.

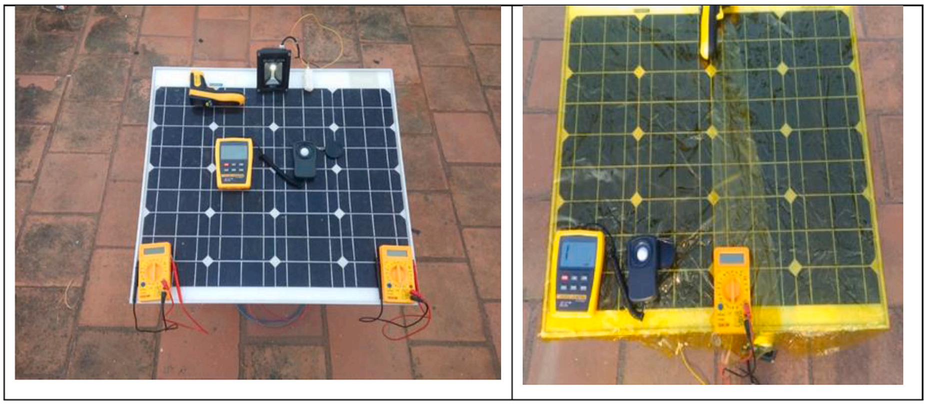

Fig. 3. Experimental arrangements of the photovoltaic module without and with a colour filter. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1

Model No.	SSPV 50
Maximum power (PM)	50Wp
Open circuit voltage (Voc)	22.3
Short circuit current (Isc)	3.15 A
Voltage at Maximum power (VMP)	17.8 V
Current at Maximum power (IMP)	2.81 A
Maximum System Voltage	1000 V
Series Fuse Rating	15 A
Maximum Design load 2400 Pa	2800 Pa
Application Class	Class A
Safety Class	Class II
Power measured in Standard Conditions (STC)	Irradiation 1000 W/m^2, AM 1.5, cell temperature 25 °C

Table 2
Details of the instrument.

Instrument	Purpose	Specification
Multimeter	To measure the open-circuit voltage and short circuit current of the solar panel	Brand: Hao Yue S.No: D830D AC Voltage Measuring Accuracy + -(0.8% + 5); DC Voltage Measuring Accuracy + -(0.5% + 3)
Light meter	To measure solar irradiance	Range: 0–2000, 0–20000 & 0–50000 Lux (3 Ranges) Accuracy: 1% Resolution: 0–2000(1 Lux), 0–20000(10 Lux) & 0–50000(100 Lux), (3 Ranges)
Infra-red thermometer	To measure the temperature of the object without direct contact.	Range: 30 °C–500 °C Resolution: 0.1 °C (0.2 °F)

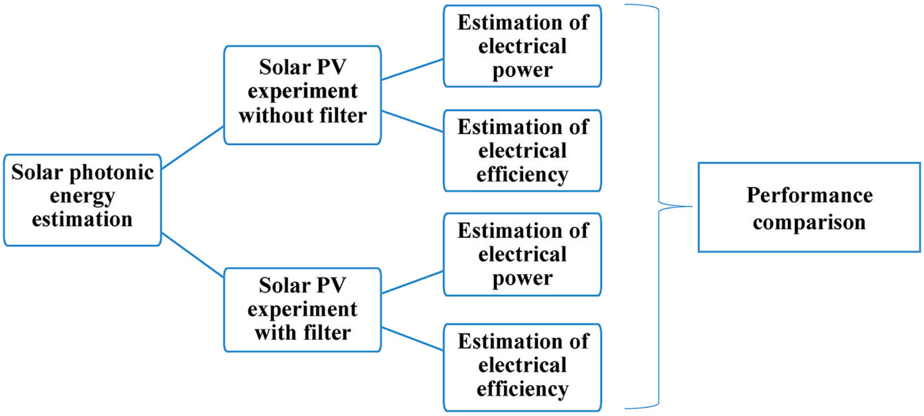

Fig. 4. Flow chart of experimental methods.

4. Results & discussion

The investigation involves determining the efficiency of PV module covered with the following colour filters, 1)Blue filter, 2)Green filter,3)Red filter,4)Yellow filter, 5) Magenta filter. The experiment was carried out from 08:00 a.m. to 04:00 p.m. in the month of May in Thanjavur, Tamil Nadu, India. By covering the panel with various colour filters, the electrical characteristics of the panel are studied.

4.1. Estimation of photonic energy

The average energy present in the photons for various colours are determined using the equation Photonic Energy $(E) = \frac{hc}{\lambda}$ and listed in Table 3 [11].

The above table shows the various wavelengths, frequencies and corresponding photon energies for multiple colours. Since photonic energy is inversely proportional to the wavelength, it can be seen the colours having lower wavelengths have higher energy. This can be also be explained in terms of frequency as colours having higher frequencies have higher energies. Violet has the highest energy, and red is having the least. This is due to the fact it does not allow maximum radiation to pass through.

4.2. Variation of module temperature

From Table 4, it is clear that the peak temperature is least for without colour filter. It is found that even the average temperature decreases when one uses a colour filter, it is not the same with respect to peak temperature, the peak temperatures are high in the case when filters are used. The measured temperature of the photovoltaic cell with filters is about 4 °C lower than that of the conventional panel without a filter. So even though by using filters the overall temperature there is a decrease, it does not affect the peak temperature. The peak temperatures were obtained during 11:00 a.m.–1:00 p.m (See Fig. 5). So the further standard deviation of the given data was carried out. The temperature difference would definitely vary from hour to hour depending on the orientation of the Sun as well as the intensity of the incident radiation.

From Table 5, one can see that blue filter has more standard deviation, that means it provides more cooling, there is much difference when compared to lower and higher values, all the filters have more standard deviation when compared to without filter case. It is to be observed here that blue and magenta, which are having higher energy densities, have maximum standard deviation when compare to others.

4.3. Variation of voltage

It is observed that the peak voltage obtained was about 19V. Among all the filters, the red filter maintained constant voltage for more time.

From the voltage, values obtained it was seen that with and without filters the peak temperature was around 18V(±) 1.5V(See Fig. 6). So there was not much difference in the peak voltage, But this can be attributed to the fact that since the experiment was carried

Table 3
Wavelengths, frequency and photon energy of the different colours.

Color	Violet	Blue	Green	Yellow	Orange	Red
Wavelength(nm)	415	510	533	580	605	685
Frequency(THz)	729	637	566	517	532	242
Photon energy(eV)	3.005	2.625	2.335	2.135	2.05	1.825

Table 4
Peak temperature and average temperature of all filters.

S.No.	Condition	Peak Temperature(^{0}C)	Average Temperature(^{0}C)
1.	Without color filter	73.6	61
2.	blue color filter	78.9	59.4
3.	yellow color filter	72.3	58.2
4.	green color filter	74.9	61.5
5.	red color filter	74.5	57.4
6.	magenta color filter	75.9	57.3

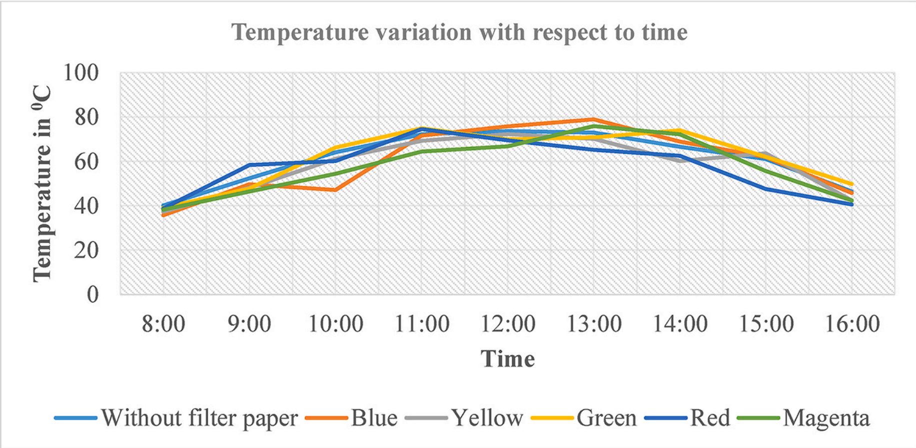

Fig. 5. Temperature variations with time.

Table 5
Standard deviation from the mean temperature in all the filters.

S.No.	Condition	Standard Deviation(^{0}C)
1.	Without colour filter	12.2
2.	blue color filter	15.3
3.	yellow color filter	12.7
4.	green color filter	12.9
5.	red color filter	12.5
6.	magenta color filter	13.3

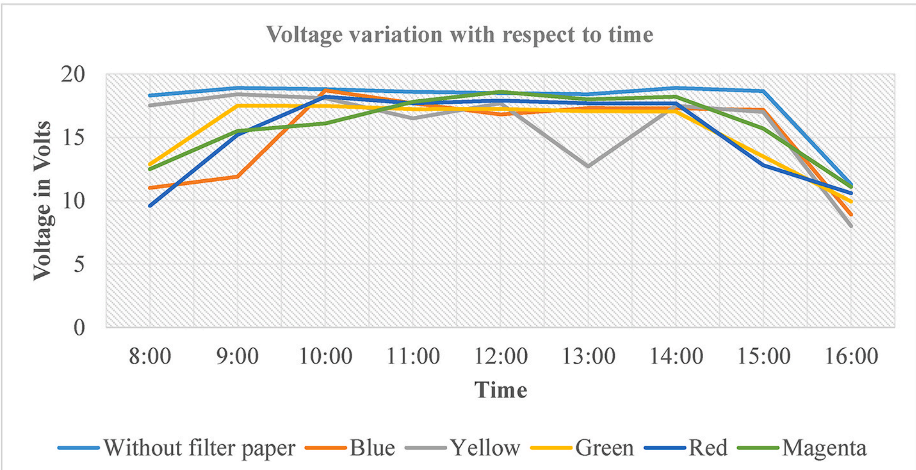

Fig. 6. Voltage variations with time.

out on a single panel. If the experiment was repeated with an array of panels connected in series, then even this voltage will be significant. The maximum voltage was without a filter which is natural since white light contains all the radiation. The closest to it was with blue and magenta filter as they have higher energy densities. It also means that this is the reason why most of the panels are in blue colour because it has this property. Apart from it, each filter has a spectral energy distribution curve. If these curves cover the primary wavelength, it will result in a decrease in voltage and hence, therefore, the power and efficiencies.

4.4. Variation of current

It is observed that the peak current was obtained was about 2.45 A(See Fig. 7). Among all the filters, the yellow and magenta yielded peak current. The green filter had a minimum current when compared to others. This can be attributed to the fact that the green lies in the mid-range of the solar energy spectrum. The results from the literature [20] also support the same. This shows that the yellow spectrum of light has a unique property which can produce more current when compared to other spectra of light. It also means that energy possessed by the photons in the range of wavelength corresponding to yellow colour has more energy content to produce more current.

4.5. Comparison of electrical characteristics with and without filter

The electrical output for a solar cell depends on factors such as irradiance level, the temperature of the cell, and wavelength of the incident light. The colour of the filter influences the amount of energy it passes through to the solar PV panel. From the comparison Table 6, it is clear which filter gives more voltage, more current and more power, so according to the requirement of the application, one can use filters to get the desired voltage and desire current values so one can meet the power requirements. From the results obtained, it was clear that there is a significant reduction in voltage, current, power, and efficiency of the Solar cell with filter when compared to without filters. This can be attributed to the fact that the solar cells receive maximum energy from solar radiation in the absence of any of the filters. PV cell with magenta colour produced maximum power and electricity as expected since it is having the least wavelength and the highest energy. PV cell with green filter produced the least power and efficiency because of their wavelength and photonic energy.

Ideally, a coloured PV panel should be able to reflect only a narrow band of the visible spectrum and transmit all the rest. The performance losses of PV module with filter are mainly due to the lower amount of photons that are transmitted to the solar cells, which in turn leads to lower current and reduced power production. Losses also strongly depend on the specific colour, because each colour is characterized by a specific reflection spectrum. Red colour performs better in terms of electrical conversion efficiency (Average 5.5%) followed by magenta (5.1%) (See Fig. 8). Green and blue generate less electricity than other colours resulting in lower conversion efficiency (Average 4.1% and 4 .7%). Hence, it is best when the filter is applied on the solar cell. It lowers the impact of excessive heating on the cell, which may lead to better conversion efficiency. The above results are in synchronization with the different results obtained from the other researchers.

5. Conclusion

The objective of this experimental investigation was to correlate the effect of various colour filters on the performance of Solar panels. From the results, it can be concluded.

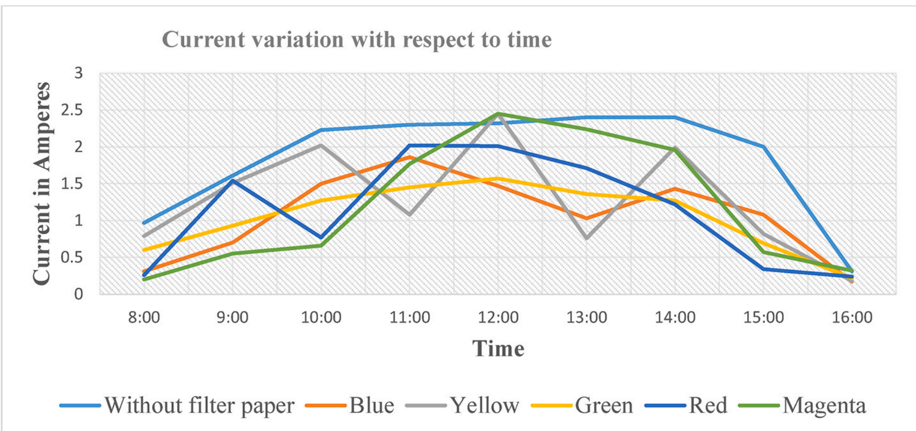

Fig. 7. Current variations with time.

Table 6
Comparison of peak voltage, current, and power for various conditions.

S.No.	Condition	Peak Voltage (V)	Peak Current (I)	Peak Power(W)
1.	Without color filter	19.04	2.4	45.32
2.	blue color filter	18.7	1.86	32.64
3.	yellow color filter	18.4	2.45	43.35
4.	green color filter	17.49	1.57	27.07
5.	red color filter	18.2	2.01	35.94
6.	magenta color filter	18.6	2.45	45.31

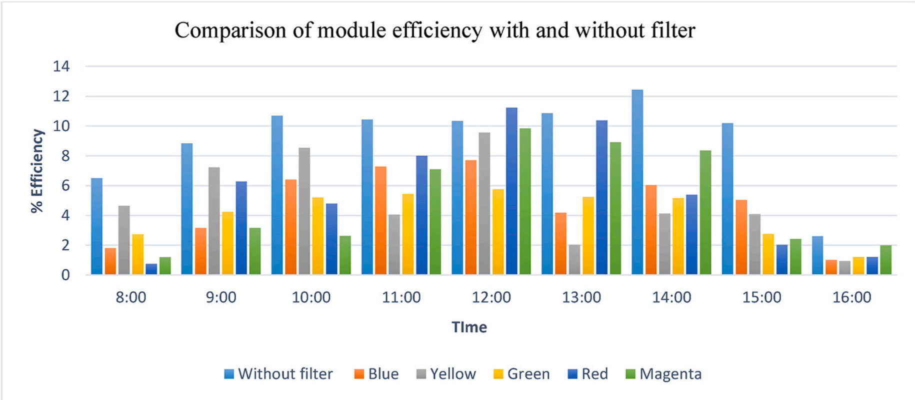

Fig. 8. Comparison of solar module efficiency with time.

- The wavelengths of light affect the performance of the solar cell. White light, which consists of all the colours, has the highest energy present in it. Hence it generates higher efficiency and higher peak voltage. Contrary to popular belief, both longer and shorter wavelengths of visible light, performed better than the one in the mid-range of the visible spectrum.
- Magenta colour light generates more electricity than other colours and produces efficiency nearer to the energy of white light, which absorbs all the visible light. By exposing to wavelengths corresponding to a magenta colour, the efficiency can be improved.
- The optical filter plays the primary role of filtering out the unwanted wavelengths while allowing the visible light region to transmit through, thus further reducing the temperature of the solar panel and also indirectly prolongs the lifespan of the cell.
- In large scale solar power plants, if the magenta filter is implemented in extreme hot climatic conditions, the electrical power and efficiency of the panel can be improved. Also, the total cost for increasing efficiency becomes economical as the cost of the colour filter is minimal.
- The surface temperature of the panel can be reduced by keeping sand or silica or coolant, which eventually increases the efficiency of the panel. The results are useful in the development of BIPV coloured modules for facade applications.
- Further improvement can be made to this hardware set up by using various affordable coolants. The future runs towards automation, hence by using IoT and sensors, the working and calibration can be done automatically where we have done it manually.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

B. Ramkiran: Conceptualization, Writing - original draft, Resources. **C.K. Sundarabalan:** Supervision, Formal analysis, Visualization. **K. Sudhakar:** Supervision, Visualization, Writing - review & editing.

References

[1] K. Sudhakar, M. Winderla, S.S. Priya, Net-zero building designs in hot and humid climates: a state-of-art, Case Stud. Therm. Eng. 13 (2019), https://doi.org/10.1016/j.csite.2019.100400.
[2] Cuce E, Bali T. Variation of cell parameters of a p-Si PV cell with different solar irradiances and cell temperatures in humid climates. Fourth International Exergy, Energy and Environment Symposium. 19-23 April 2009, Sharjah, United Arab Emirate.
[3] Cuce E, Bali T. Improving performance parameters of silicon solar cells using air cooling. Fifth International Ege Energy Symposium and Exhibition. 27-30 June 2010, Denizli, Turkey.

[4] E. Cuce, Toward multi-functional PV glazing technologies in low/zero carbon buildings: heat insulation solar glass - latest developments and future prospects, Renew. Sustain. Energy Rev. 60 (2016) 1286–1301.
[5] E. Cuce, P.M. Cuce, C.H. Young, Energy saving potential of heat insulation solar glass: key results from laboratory and in-situ testing, Energy 97 (2016) 369–380.
[6] Erdem Cuce, Tulin Bali, Suphi Anil Sekucoglu, International Journal of Low-Carbon Technologies 6 (4) (December 2011) 299–308, https://doi.org/10.1093/ijlct/ctr018.
[7] A.S. Joshi, A. Tiwari, G.N. Tiwari, I. Dincer, B.V. Reddy, Performance evaluation of a hybrid photovoltaic thermal (PV/T) (glass-to-glass) system, Int. J. Therm. Sci. 48 (1) (2009) 154–164.
[8] K. Sudhakar, Noopur Jain, Shivani Bagga, Effect of color filter on the performance of solar photovoltaic module, in: International Conference on Power, Energy and Control, 2013.
[9] Atse Louwen, C. de Waal Arjen, Ruud E.I. Schropp, Andre P.C. Faaij, Wilfried G.J.H.M. van Sark, Comprehensive characterization and analysis of PV module performance under real operating conditions, Prog. Photovoltaics Res. Appl. 25 (2017) 218–232.
[10] M.J. Currie, J.K. Mapel, T.D. Heidel, S. Goffri, M.A. Baldo, High-efficiency organic solar concentrators for photovoltaics, Science 321 (226) (2009) 1158342–1158348.
[11] M. Alonso-Abella, F. Chenlo, G. Nofuentes, Torres-Ramirez, Analysis of spectral effects of the energy yield of different PV technologies: the case of four specific sites, Energy 67 (2014).
[12] Indra Bahadur Karki, Effect of temperature on the I-V characteristics of polycrystalline solar cell, J. Nepal Paediatr. Soc. 3 (1) (2015) 35–40.
[13] R. Galleano, W. Zaaiman, D. Alvarez, A. Minuto, N. Ferreti, Preliminary Results of the 5th International Spectroradiometer Comparison for Improved Solar Spectral Radiance, Instituto Nacional de Tecnica Aerospacial Madrid, 2015.
[14] D. DeJarnette, E. Tunkara, N. Brekke, T. Otanicar, Nano particle enhance spectral filtration of insolation from trough concentrators, Sol. Energy Mater. Sol. Cells 149 (2016).
[15] Armstrong O. Njok, Joel I. Iloke, Manoj K. Panjwani, Fareed H. Mangi, The impact of Coloured filters on the performance of polycrystalline photovoltaic panel in an uncontrolled environment, Int. J. Electr. Comput. Eng. 10 (2020) 4436–4446.
[16] A.S. Joshi, I.Y. Dincer, B.V. Reddy, Effect of colors of light on the PV/T system performance, Int. J. Energy Res. 36 (2012) 572–578.
[17] Evaldo C. Gouvea, Pedro M. Sobrinho, Teofilo M. Souza, Spectral response of polycrystalline silicon photovoltaic cells under real-use conditions, Energies 1–13 (2017).
[18] Keith R. McIntosh, Mohamed Amara, Fabien Mandorlo, Malcolm D. Abbott, Benjamin A. Sudbury, Advanced simulation of a PV module's color, AIP Conf. Proc. (1999) 2018.
[19] Ahmad Manasrah, Ali Al Zyoud, Eman Abdelhafez, Effect of Color and Nano Film Filters on the Performance of Solar Photovoltaic Module," Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2019.
[20] M. Orosz, N. Zweibaum, T. Lance, M. Ruiz, R. Morad, Spectrum –splitting hybrid CSP-CPV solar energy system with standalone and parabolic trough plant retrofit applications, in: AIP Conference Proceedings, 2016.
[21] A.K. Shukla, K. Sudhakar, P. Baredar, R. Mamat, BIPV in Southeast Asian countries – opportunities and challenges, Renew. Energy Focus 21 (2017), https://doi.org/10.1016/j.ref.2017.07.001.
[22] A.S. Baitule, K. Sudhakar, Solar powered green campus: a simulation study, Int. J. Low Carbon Technol. 12 (4) (2017), https://doi.org/10.1093/ijlct/ctx011.
[23] P. Kumar, A.K. Shukla, K. Sudhakar, R. Mamat, Experimental exergy analysis of water-cooled PV module, Int. J. Exergy 23 (3) (2017), https://doi.org/10.1504/IJEX.2017.085768.
[24] F. Hyder, P. Baredar, K. Sudhakar, R. Mamat, Performance and land footprint analysis of a solar photovoltaic tree, J. Clean. Prod. 187 (2018), https://doi.org/10.1016/j.jclepro.2018.03.249.
[25] A. Sahu, N. Yadav, K. Sudhakar, Floating photovoltaic power plant: a review, Renew. Sustain. Energy Rev. 66 (2016), https://doi.org/10.1016/j.rser.2016.08.051.