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Effect of Colored Filters on PV Panels Temperature and Performance under Baghdad Meteorological Condition

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A B S T R A C T

In this work, the influence of colors of filters upon the photovoltaic panels rising temperature and electrical performance was studied under Baghdad Meteorological Condition. Basing on the energy analysis of a photovoltaic solar system and by using the photonic theory, the available energy on the PV plane system has been evaluated. Seven colored filters each with (85W) PV modules were used in this case study, to reveal the impact of colored filters upon the electrical productivity of PV panel with the variation in the temperature caused by these filters. There is the main issue of this work is to show how the performance of PV module by imposing colored filter and hence how and to how much improve it by reducing the cell temperature in hot climate. Outcomes showed that the PV technology is affected by the color filters. In other words, red filter gives light have least photons energy, and violet filter gives light have the most photons energy and green is between the two. So, red colors filter gives highest PV panel temperature comparative with others filters, while violet color filter was the lowest. PV module with the lowest temperature colored filter gives the best electrical performance than others.

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تأثير الفلاتر الملونة على حرارة واداء الالواح الكهروضوئية تحت الظروف الجوية لمدينة بغداد

الخلاصة

في هذا العمل، تمت دراسة تأثير ألوان الفلاتر على ارتفاع درجة حرارة والأداء الكهربائي للألواح الكهروضوئية تحت الظروف الجوية لمدينة بغداد . على أساس تحليل الطاقة لنظام الطاقة الشمسية الضوئية وباستخدام النظرية الفوتونية، تم تقييم الطاقة المتاحة على نظام اللوح الكهروضوئي .تم استخدام سبعة فلاتر ملونة مع كل نموذج كهروضوئي (85 واط) في هذه الحالة الدراسية، للكشف عن تأثير الفلاتر الملونة على إنتاجية الألواح الكهروضوئية الكهربائية مع التغير في درجة الحرارة التي تسببها هذه الفلاتر. القضية الرئيسية لهذا العمل هو إظهار كيفية أداء النموذج الكهروضوئي عن طريق فرض الفلترة الملونة وبالتالي كيف وإلى اي مدى يتم التحسين عن طريق خفض درجة حرارة الخلية في المناخ الحار .أظهرت النتائج أن التكنولوجيا الكهروضوئية تتأثر بالفلاتر الملونة . وبعبارة أخرى، الفلتر الأحمر يعطي ضوء له أقل طاقة فوتونية، ويمنح الفلتر البنفسجي ضوء له اعلى طاقة فوتونية والاخضر بين الاثنين. لذا ، الفلتر الأحمر اللون يعطي أعلى درجة حرارة للوح الكهروضوئي مقارنة مع بقية الفلاتر ، بينما كان الفلتر البنفسجي اللون هو الأقل. النموذج الكهروضوئي مع الفلتر الملون الاقل درجة حرارة يعطي أفضل أداء كهربائي من البقية.

1. INTRODUCTION

Photovoltaic panels are greatly affected by irradiance intensity and temperature rise. Irradiance intensity increasing led to increasing in power generated, but the increase in silicon cells temperature with the irradiance increasing gives negative influence on photovoltaic cells power generation. Solar radiation has a large amount of spectrum wave length having lengths between (400 nm) to (700 nm) that give visible one and less or more of this range will be invisible wave length. For the visible wave length; highest wave length (near to 700 nm) has less energy and the lowest wavelength near to (400 nm) have highest energy. The large amount of absorbed infrared radiation (invisible wavelength<700nm) by PV panels with increasing of solar radiation led to more increasing on silicon cell's temperature.

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Nomenclature

A	Photovoltaic panel area, (m^2)
c	Light speed, (2.998×10^8 m/s)
En_{ph}	Energy of photon, (J)
Ep	Photonic energy available on the photovoltaic surface, (J)
FF	Fill factor
h	Planks constant, (6.626×10^{-34} J s)
I_{max}	Maximum current, (A)
Isc	Short circuit current, (A)
N_{ph}	Number of photons falling on earth, (1/s cm^2)
S_T	Hourly measured total solar irradiation, (W/m^2)
T_{amb}	Ambient air temperature, (°C)
T_{PV}	Photovoltaic panel temperature, (°C)
T_{sun}	Sun temperature, (5777 K)
V_{max}	Maximum voltage, (V)
V_{oc}	Open circuit voltage, (V)
λ	Wavelength of visible spectrum between (400 nm) to (700nm) of solar radiation
η	PV panel electrical efficiency, (%)

There are many trials to improve the efficiency photovoltaic cell by scientists, engineers, researchers and manufactures with various ways, by studying the effect of ambient conditions (ambient air temperature, solar irradiance) and the site geographical location of the used PV system place (longitude, latitude and altitude). To achieve better efficiency of PV cells; the heat might be removed from the PV panel. a PV/T air collector was compared and analyzed with another one having glass-to-tedlar and also glass-to-glass PV plane surface by Joshi et al. [1], it was found that, a better performance for the latter because of, the solar irradiance allowed to transmit through the system by transparent glass-to-glass PV surface and absorbed on a PV surface on the back, the heat energy is then removed out from the system by using a fan and can be used many applications such as air heating, drying of agriculture crop, etc.

Another way for reducing PV panels temperature was presented by Hussein et al. [2]. They designed and implemented a hybrid PV/T. The module tested indoor by using Al2O3 nanofluids and investigated the enhancement in the electrical and thermal efficiency with using nanofluid. To obtain the higher PV panel's efficiency, a constructed tandem organic solar concentrator with filter on top surface of PV panel was constructed by Currie et al. [3], The used concentrator not only concentrates sunlight but also has an ability to filter some of the infrared light. Joshi et al. [4] shows that the PV technology are influence with the red color of light by evaluating the available energy on the PV/T surface and an exegetic base calculation of the PV/T system by using solar radiation data for four months which are January, April, August and October for New Delhi, India, were conducted. A method was proposed by Orosz et al. [5] to evaluate the best division of the solar spectrum wave length in the hybrid PV/T system with software of a tracking system. It seen that the optimal wavelengths of the solar spectrum in the used PV/T system was compatible with (732 nm) and (1067 nm). A filter of nanofluid that contain gold nanoparticle with indium tin oxide nanocrystals was fabricated by Galleano et al. [6] to evaluate the optical properties, the results indicated that the efficiency of PV filter was up to (62%) of the solar spectrum. In the different sites located of northern hemisphere along (12 months) of experimental work, a solar spectra modeling was done by DeJarnette et al. [7], it seen that the spectral monthly deployments are effects of decreased with the latitude of the site. The impact of the solar spectrum at any location of the atmosphere was measured with a method that proposed by Alonso-Abella et al. [8], in the condition of providing their necessary information the used method proved that the semiconductor of PV module under non-standard conditions is advantageous.

The present work aimed to evaluate the effect of wavelength/color on PV panel's temperature that causes the highest outcome of PV panel and the best conversion in the electricity. Seven colored filters were used in this study, to show the effect of filters on the electrical performance of PV panel with the variation in the temperature caused by these filters.

$$E_P = En_{ph} \times A \times N_{ph} \times \left(1 - \frac{T_{PV}}{T_{sun}}\right) = \left(\frac{h \times c}{\lambda}\right) \times A \times N_{ph} \times \left(1 - \frac{T_{PV}}{T_{sun}}\right) \qquad (3)$$

2. METHODOLOGY

In this section, the mathematical formulation of the governing equation that used in this work can be classified into:

1. Photonic energy of the solar radiation.
2. PV panel electrical performance.

2.1. Photonic Energy of the Solar Radiation

The energy of solar radiation arriving the PV module surface may be computed considering the photons energy. Further; solar energy may also be specified as the photonic energy coming from the sun and it travels into the manner of small energy of particles, also it is so called 'photons'. The energy of a photon En_{ph} can be computed as follows [9]:

$$En_{ph} = \frac{h \times c}{\lambda} \qquad (1)$$

For a cloudless day, the number of photons (N_{ph}) striking the PV surface per second unit area can be determined for a given solar irradiance multiplying it by a factor 4.4×1021/1367 and may be presented as follows [9]:

$$N_{ph} = \left(\frac{4.4 \times 10^{21}}{1367}\right) S_T \qquad (2)$$

The received photonic energy to the photovoltaic panel can be determined as follows [10]:

2.2. PV Panel Electrical Performance

The electrical performance of PV panel can be found by using [11]:

$$FF = \frac{P_{\max}}{I_{sc} \times V_{oc}} \quad (4)$$

where:

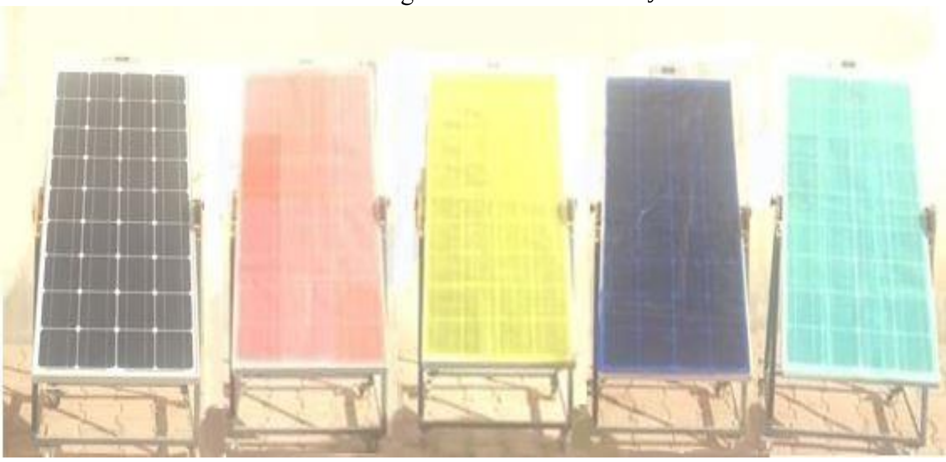
$$P_{\max} = I_{mpp} \times V_{mpp} \quad (5)$$

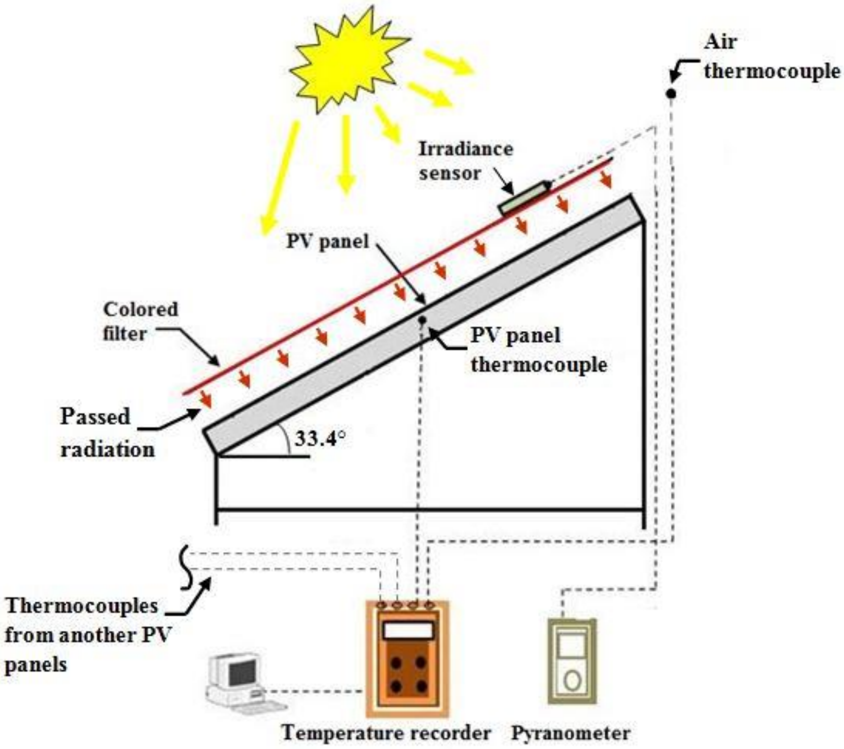
Then the electrical efficiency of PV panel (η_{el}) is:

$$\eta_{el} = \frac{P_{\max}}{G \times A_{PV}} \quad (6)$$

3. EXPERIMENTAL DETAILS

Solar radiation falling on the photovoltaic solar cells is directly converted to electricity. The solar radiation thermal energy led to a loss in the modules efficiency, owing the electronic circuits of solar cells get heated. It is essential to remove the heat from the panels in order to attain better electric performance of the system and to be maintained. Solar radiation consists of different light's wavelength. The effect of the light wavelength on the PV panel heating is considered in this work, seven color filters with same manufacturing prosperities (red, orange, yellow, green, blue, Neely and violet) are employed to absorb all wavelengths of light except that of their own color, thus tinting the light that color. So, when a panel is covered with a colored filter, it means it is exposed to a light of specified wavelength: shorter for blue, medium for green and longer for red. Five mono crystalline solar modules of 85W power capacity have been used in this work under meteorological condition of Baghdad city as presented in Fig. 1(a). This work was done to show the effect of colored filtration on the PV panel's temperature and performance without affecting the PV panels heated by the ground radiation. Thus, the test where done at clear days during 4th and 5th of November. The selection of mentioned days due to good irradiance and low heat irradiative by the ground. The first test day was done with PV modules with (red, yellow, blue, green) filters comparative with PV panel without filter. Second test day were done with others color filter.


(a) Experimental setup.



(b) System schematic diagram.

Fig. 1. Test rig.

The PV modules faced to south with 33.4º inclination angle from the horizontal which is close to the Baghdad city latitude. The calibrated k-type thermocouples with temperature recorder type (BTM-4208SD) were used to measuring the temperatures of ambient and solar cell. The accuracy of temperature data logger and thermocouples are (±0.01%, ±0.4%) respectively. Digital multi meter type (Protek/DM 301) with accuracy (±4%) was used to measure the current and voltage of PV panels. Digital pyranometer type (LI-COR PY 82186) with accuracy (±2%) was used to measure the global radiation in W/m^2. Figure (1 b) shows the system schematic diagram. The used PV modules specifications of employed PV modules are showed in Table 1.

Table 1
PV modules specifications.

Item	Description
Standard condition	1000 W/m^2, 25ºC
Maximum power (Pmax)	85 W
Maximum current (Imax)	4.78 A
Maximum voltage (Vmax)	17.8 V
Sort circuit current (Isc)	5.12 A
Open circuit voltage (Voc)	22.1 V

4. RESULTS AND DISCUSSION

For a crystalline solar cell, the electrical output voltage depends upon of the temperature, Intensity and color of the incident light. At test days of the used PV panel's colored filter where done at clear days during 4th and 5th of November. The first test day was done with PV modules with (red, yellow, blue, green) filters comparative with PV panel without filter. Second test day were done with others color filter.

The variations in irradiance intensity from (8:00 AM) to (4:00 PM) are presented in Fig. 2, and it was very close in irradiance values of the selected test days Fig. 3 shows the effect of using these filters on PV panel's temperature at the same test day. It noticed that the red color filter gives high PV panel temperature comparative with violet color filter. The effect of colored filter on the available photonic energy from PV panels are presented in Fig. 4. The capability of solar cell in capturing energy does not just determined by the strength of the energy, but by the ability to find light. It seen that the PV panel temperature have on the available photonic energy of PV panel, and the PV panel with violet filter gives highest available photonic energy depending on its temperature. Fig. 5 shows the variation in the maximum current of filtered PV panels along day test, to show the changes in these values with the effect of using colored filter exactly. From Fig. 6, it seen that the effect of colored filters on maximum voltage of PV panels, as seen from this figure the violet filter gives best values of maximum voltage. Fig. 7 gives the changes in both (maximum, short circuit) current and (maximum, open circuit) voltage values with the effect of using colored filter exactly at 12:00 PM of the day test, it seen that the rising in temperature led to rising in both maximum and short circuit current of PV panel as shown in red color filter. While; it seen that the rising in temperature led to dropping in both maximum and open circuit voltage of PV panel as shown in red color filter that has highest temperature comparative with other colored filters.

Depending on Eq. (4), Fig. 8 shows the enhancement in PV panels filling factor along the day test. It seen that from the last results figures there are two parameters affected on PV panels performance that it's, solar light

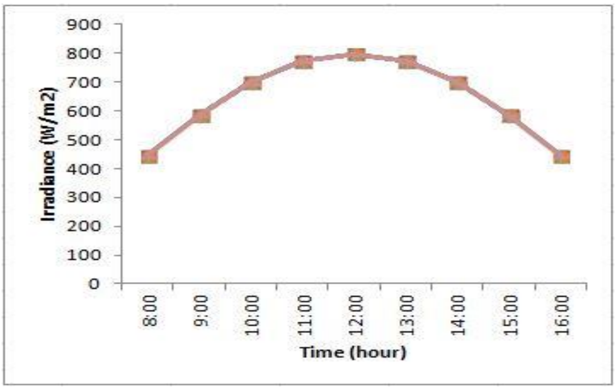


Fig. 2. Irradiance intensity at day test.

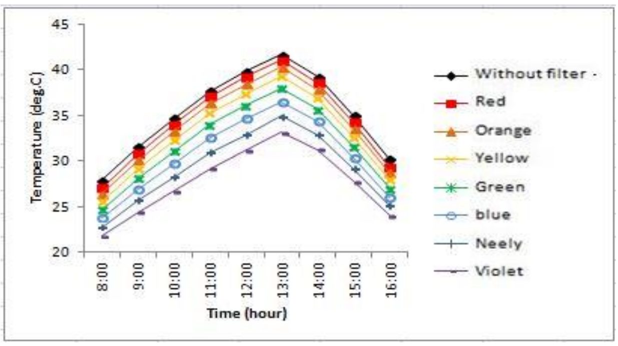


Fig. 3. PV panels temperature.

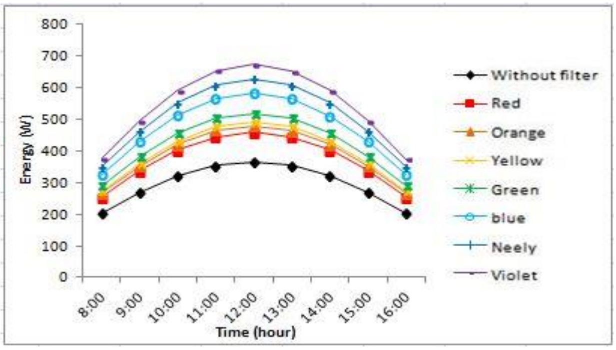


Fig. 4. PV panels available photonic energy.

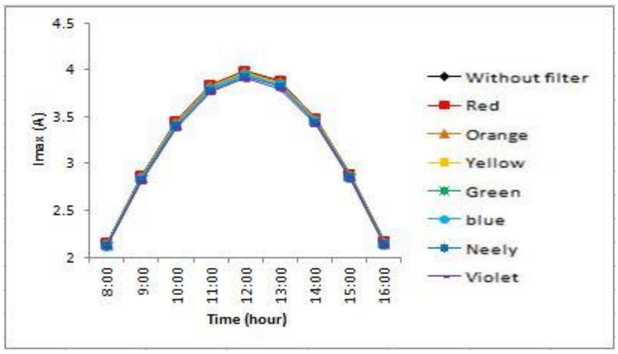


Fig. 5. PV panels maximum current at the day test.

wave length and PV panels temperature. The used colored filters lead to drooping in PV panel's temperature and absorb all wavelengths of light rather than that of their own color, thus tinting the light that color. They affected on electrical efficiency of PV panels at the same operation condition along the day test, as shown in Fig. 9.

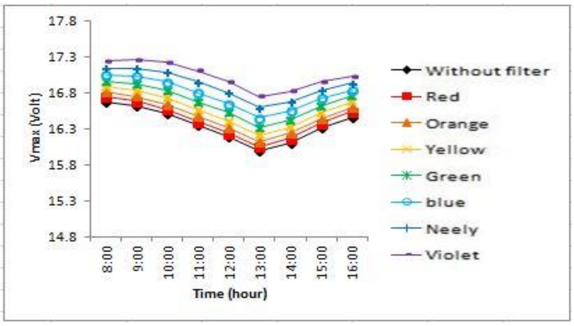


Fig. 6. PV panels maximum voltage at the day test.

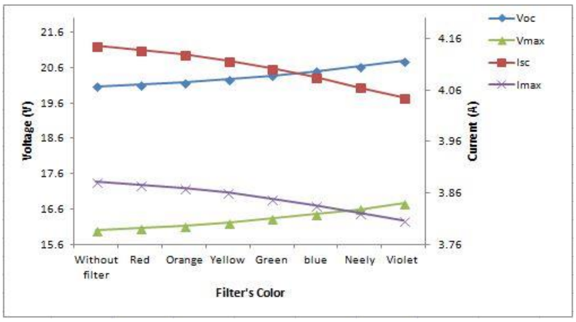


Fig. 7. The variation on PV panel's (V_{max}, I_{max}) and (Voc, Isc) at 12:00 PM of the day test.

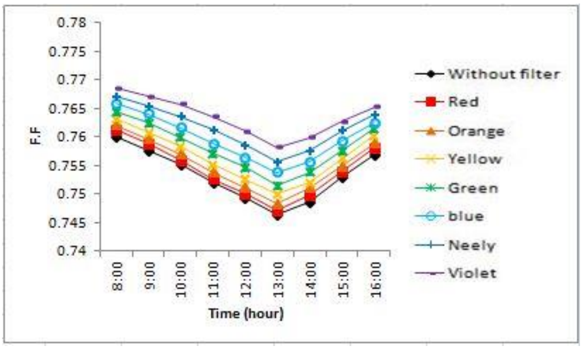


Fig. 8. PV panels fill factor at the day test.

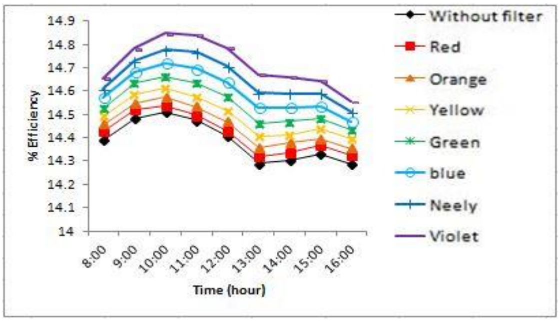


Fig. 9. PV panels efficiency at the day test.

5. CONCLUSIONS

From this work, after analyzing the results it can conclude that PV panel temperature are more effect on its performance beside irradiance intensity. The light wavelengths is doing effect on the of solar panel temperature, red filter gives light have least photons energy, and violet filter gives light have the most photons energy and green is between the two. So, red colors filter gives highest PV panel temperature comparative with others filters, while violet color filter was the lowest. PV module with the lowest temperature colored filter gives the best electrical performance than others

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