VOL. 9, NO. 9, SEPTEMBER 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
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# ANALYSIS OF TEMPERATURE DEPENDENCE ON SOLAR ENERGY RADIATION PATTERN AT DIFFERENT WAVELENGTHS

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## ABSTRACT
This paper presents a theoretical analysis of the effect of atmopharic temperature and the light emission wavelength from the Sun on the solar energy radiation pattern. In this study, we have investigated extensively the radiant emittance phenomena of the solar radiation by using Planck's law of radiation and the Stephan-Boltzmann's law. Wavelength dependence of radiant emittance has been analyzed at three different temperatures. We have considered the three different temperatures such as room temperature i.e. 300K, 275K as temperature below room temperature and 325K as the temperature above room temperature. The three different temperatures considered in this present analysis are chosen very close to each other to investigate exactly the effect of wavelength on the radiation pattern of the emitted energy from the Sun due to the small change in temperature. Further the effect of temperature on radiant emittance has also been investigated at three different wavelengths. The three wave lengths considered in our research work are 1.55µm, 1.3µm and 0.89µm respectively. The range of wavelength has been considered within the limit of 0.89µm - 1.55 µm because this range of wavelength corresponds to the energy bandgap of the semiconductor materials from 0.8 eVto 1.4 eV, which are widely used for solar cell fabrication. The investigation of the temperature dependence with maximum wavelength of the radiated energy was carried out up to the black body temperature. Numerical results obtained have been analyzed. It is revealed from the numerical analysis that not only the atmospheric temperature but also the wavelength of the emitted light from the Sun affects the radiation pattern significantly.

**Keywords:** solar energy, radiation pattern, temperature, radiant emittance, wavelength.

## INTRODUCTION
At the current rate of fossil fuel consumption, we are using up our energy resources faster thanthe natural production rate of the fossil fuels. Hence we are likely to start running out of adequate oil reserves in the very near future (Bentley 2002; Maugeri, 2012). Currently it has also been reported that the researchers are worried about the existence of other conventional non-renewable energy sources in the upcoming decades because of the ever increasing demand of the fossil fuel consumption, whichaffects significantly on the current reserve of thenon-renewable energy sourcesall over the world due tothe limitation of reliable alternative sources of energy (Dresselhaus, *et al*., 2001; Sidhu, 2007).

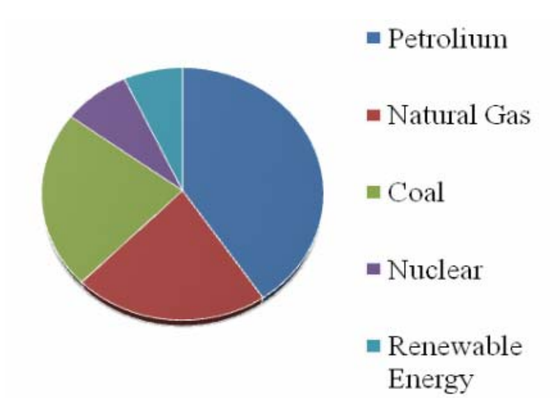


**Figure-1.** Portion of energy consumption from different sources of energy.

From Figure-1 it is clear that 85% of our overall consumed energy is met up by fossil fuels. However only 7% of the total energy comes from renewable energy sources, and only 1% of which is from solar energy, which is shown in Figure-2. This is also a common knowledge that we have to face enormous climatic disaster like global warming because of usingthe fossil fuels like oil and gas in homes and industriesin a in a large scale (Mor, *et al*., 2006). The amount of energy consumed from different sources of energy has been presented in Figure-1. The statistical data of energy consumption from different renewable energy sources has been represented in Figure-2.

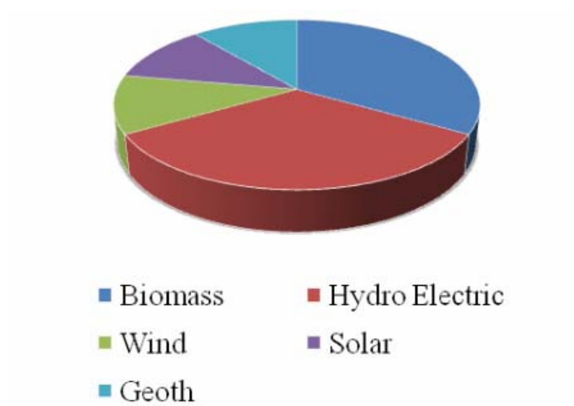


**Figure-2.** Portion of energy consumed from different sources of renewable energy.

 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
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Additionally the extreme production of harmful gases like carbon monoxide has destroyed the ozone layer exposing us not only to the harmless but also to the harmful sunrays. Definitely it is not a matter to worry about running out of the solar energy because it is the only unlimited source of energy available around the globe (Dincer, 2011; Sen, 2004). It has been reported that in one hour huge amount of sunlight reaches to the earth, which is more than enough to overcome the total energy demand all over the world for the entire year (Dwivedi, *et al*. 2014). Very recently scientists have estimated that the Sun will continue producing solar energy for another five billion years. Therefore among all the renewable energy sources available around the globe, solar energy alone holds the promise to become a sustainable energy source for survival of mankind (Fara, *et al*., 2012; Hepbasli, 2008).

Additionally power crisis has become a severe problem all over the world. Recently it has been reported that different sources of energy pollute our environment in different ways and in different degrees (Mahrane, *et al*, 2010). In last few decades several groups of researchers have acknowledged that the solar energy is the cleanest form of energy among the available source of energy in the world (Al-Badi, 2013; Sharaf, *et al*., 2005; Jwo, *et al*. 2013). Therefore the proper utilization of solar energy is the major challenge to the researchers in the era of modern science and technology, particularly to shield our world from global warming. Very recently researchers have acknowledged that carbon di oxide emission from the conventional energy conversion systems would be reduced remarkably through the enhancement of consumption of solar energy. Therefore the environment pollution and fossil fuel depletion will also be reduced significantly by introducing the utilization of solar energy in the different aspects of our everyday life (Rashid, *et al*., 2013; Ahmed, *et al*. 2014).

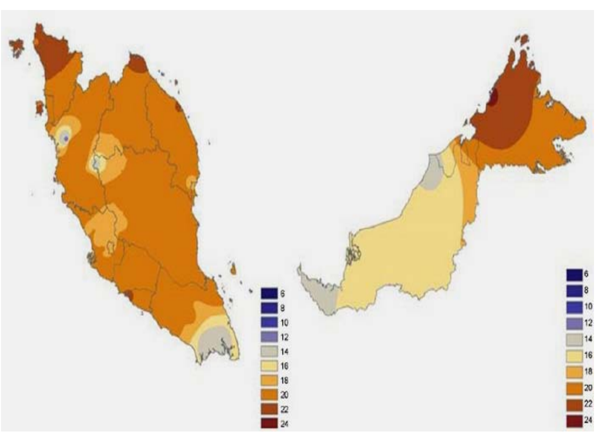


**Figure-3.** Annual average solar radiation in Malaysia ( ) (Mekhilef, *et al*., 2012).

From the above discussion it is clear that only the solar energy has the potential to meet up the ever increasing demand of energy for the mankind to survive in an environment friendly way. It is necessary to know about the factors affecting the solar energy radiation pattern and the different characteristics of the solar energy to utilize the unlimited source of energy. Therefore we have devoted our present research work towards the effect of two most important parameters on the solar energy irradiation pattern. These two parameters are atmospheric temperature and the wavelength of the emitted light from the Sun.

In this paper we have analyzed mainly the solar radiation characteristics in Malaysia because Malaysia receives a huge amount of solar energy almost at a constant rate throughout the year due to its geographical position in the tropical region. The annual average solar radiation in Malaysia has been shown in Figure-3 (Mekhilef, *et al*., 2012).

## MATHEMATICAL FORMULATION

This section presents the mathematical relationship among the solar radiance, wavelength of the light emitted from the Sun and the atmospheric temperature. First of all the Planck's equation has been used to analyze the effect of temperature and wavelength on the radiant emittance of solar energy. Then the effect of temperature on the radiant emittance has been analyzed by applying the Stephan-Boltzmann's law.

### Radiant Emittance

The radiant emittance of solar energy is a function of temperature and wavelength. The mathematical relationship among the radiant emittance, atmospheric temperature and the light emission wavelength is given by the well-known Planck's equation (White, 1999):

$$M = \frac{2\pi h c^2}{\lambda^5}\left[\frac{1}{e^{\frac{hc}{KT\lambda}}-1}\right] \tag{1}$$

where $h$ is the Planck's constant,

$c$ is the velocity of light,

$\lambda$ is the wavelength of light,

$K$ is the Boltzmann's constant and

$T$ is the temperature.

On the other hand Stephan-Boltzmann's law also describes the temperature dependence of the radiant emittance of solar energy, which is given by the following equation (Khan *et al*. 1991):

$$M = \sigma T^4 \tag{2}$$

Where is the solar energy radiant emittance and is the Stephen's constant.

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**Maximum Wavelength of the Solar Energy**

As the wavelength of emitted solar energy is affected by the atmospheric temperature, the temperature dependence of the maximum wavelength of the solar energy is animportant factor in the field of solar engineering. To determine the relationship between the temperature and the maximum wavelength of emitted light we have considered the following equation (White, 1999):

$$\lambda_{max} = \frac{0.0029mK}{T} \quad (3)$$

where is the maximum wavelenght of the emitted energy from the Sun.

## RESULTS AND DISCUSSIONS

This section presents the numerical analysis of the radiant emittance phenomena of the solar radiation. First of allwe have analyzed extensively the effect of light emission wavelength on the solar energy radiation spectrum at different temperatures. Thenthetemperature dependence of radiant emittance at different wavelength has been analyzed. Finally the effect of atmospheric temperature on the maximum wavelength of the solar energy has also been analyzed numerically. We have analyzed the effect of wavelength of emitted energy from the Sun on the solar energy radiation spectrum at three different temperatures and the temperature dependence of the other characteristics were investigated at three different wavelengths for the temperature up to the black body temperature.

Firstly, the effect of wavelength on the solar energy radiation spectrum at three different temperatures has been investigated using the Planck's formula. We have analyzed this phenomenon at room temperature (300K), below room temperature (275K) and above room temperature (325K). We have performed this analysis using Eq. 1 and the result is shown in Figure-4. We have choosen the three different temperaturs very close to each other in order to analyze accurately the effect of little change in atmosphearic temperature.

Then we have analyzed the temperature dependence of radiant emittance at different wavelength for the temperature up to black body temperature. In this study we have considered the wavelengths within the range of 0.89μm - 1.55 μm because the light of these wavelengths are absorbed by the semiconductor materials widely used for solar cell fabrication like Si, Ge and GaAs. Figure-5 shows these characteristics up to the black body temperature of 6000 K. We have divided the temperature range from 0K-3000K and 3000K-6000K for clear explanation. These are shown in Figure-6 and Figure-7 respectively.

Finally the temperature dependence of maximum wavelength has been analyzed by using Eq. (3), which is shown in Figure-8. The parameters used for calculation are given in Table-1.

**Table-1.** List of Parameters and their values in SI unit used for Numerical calculations.

| Symbols | Definition | Value |
|---|---|---|
| $h$ | Planck's constant | $6.63 \times 10^{-34}$ Js |
| $c$ | Velocity of light | $3 \times 10^{8}$ $ms^{-1}$ |
| $K$ | Boltzmann's constant | $1.38\times10^{-23}$ $JK^{-1}$ |
| $\sigma$ | Stephen's constant | $5.6710^{-8}$ $Wm^{-2}K^{-4}$ |

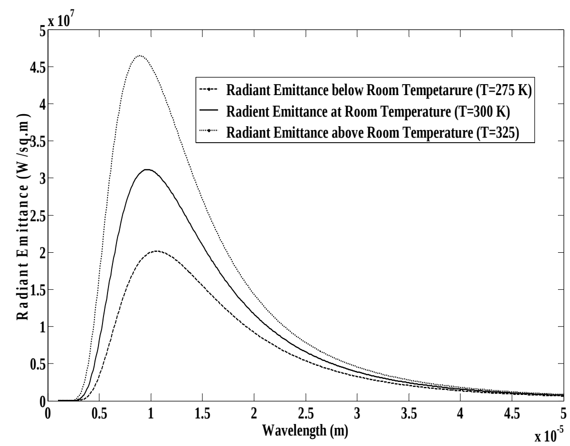


**Figure-4.** Wavelength dependence of radiant emittance at different temperatures. The solid line represents the solar energy radiant emittance at room temperature. The dashed line and the dotted line represent the radiant emittance of solar energy below room temperature (T=275K) and above room temperature (T=375K) respectively.

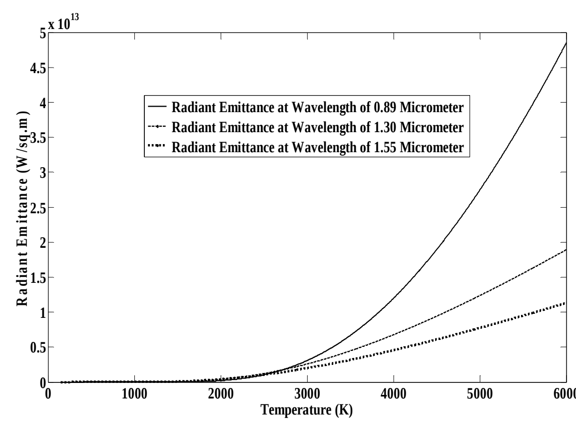


**Figure-5.** Temperature dependence of radiant emittance at different wavelengths for the temperature up to black body temperature. The solid line, dashed line and the dotted line represents the solar energy radiant emittance at the wavelength of 1.55μm, 1.3 μm and 0.89μm respectively.

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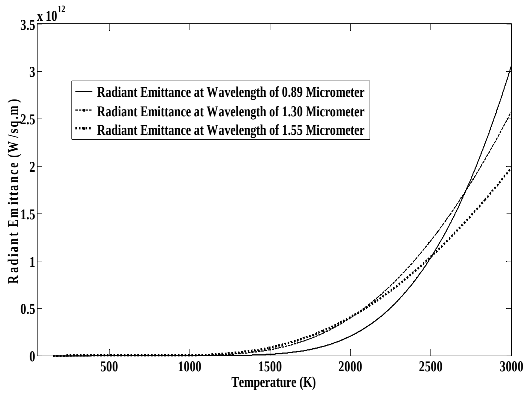


**Figure-6.** Temperature dependence of radiant emittance at different wavelength up to 3000K. The solid line, dashed line and the dotted line represents the solar energy radiant emittance at the wavelength of 1.55μm, 1.3 μm and 0.89μm respectively.

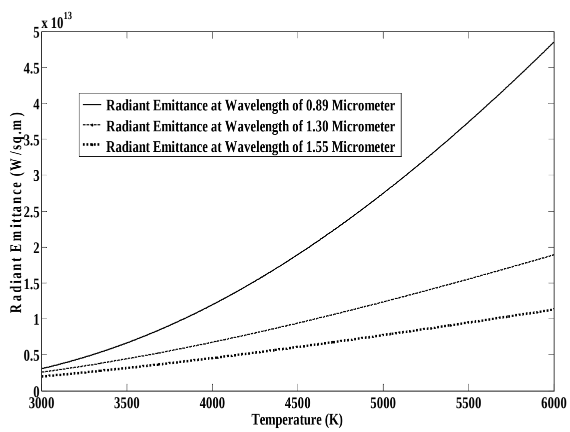


**Figure-7.** Temperature dependence of radiant emittance at different wavelength within the temperature range of 3000-6000 K. The solid line, dashed line and the dotted line represents the solar energy radiant emittance at the wavelength of 1.55μm, 1.3 μm and 0.89μm respectively.

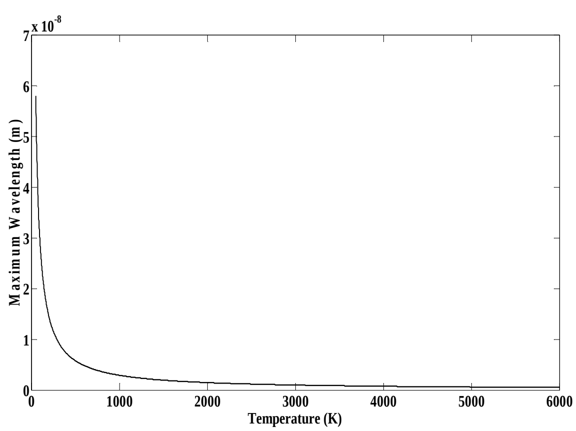


**Figure-8.** Temperature dependence of maximum wavelength for the temperature up to black body temperature.

Figure-4 presents the radiant emittance as a function of wavelength at different temperatures. Three different temperatures have been considered for analyzing this phenomenon. We have investigated this characteristics at room temperature (T=300K), below room temperature (T=275 K) and above room temperature (T=325K). We have chosen the three different temperatures within the interval of 25K from each other for the numerical analysis to investigate the effect of small change in temperature on the radiation pattern of the emitted energy from the Sun. It is revealed from the Figure-4 that the radiant emittance varies nonlenierly with the increase of wavelength at any temperature. From the Figure it is also ascertained that the radiant emittance increases with the increase of temperature and reaches to the maxima around the wavelength of 0.12 μm at the temperature of 275K.

Similarly the radiant emittace reaches at the maximum point at 0.1 μm at the temperature of 325 K and it remains in between 0.1 μm to 0.12 μm at room temperature. Therefore it is ascertained from the above discussion that the maxima of the radiant eittence shifts to the left with the increase of temperature. However after reaching to the maxima the radiant emittance starts to dropdown drastically.

Figures 5-7 presents the radiant emittance as a function of temperature for the range of 0-6000K at different wavelengths. We have considered three different wavelengths for analyzing this phenomena. We have investigated this characteristics at three different wavelengths such as 0.89 μm, 1.3 μm and 1.55 μm. It is ascertained from Figure. 5that the radiant emittance increases exponentially with the increase of temperature at any wavelengths. From the Figure it is obseved that there is some irregular pattern within the temperature range of 0-3000K. However, these characteristics vary nonlenierly but the irregular patern is observed. Therefore we have divided the temperature range from 0K-3000K and 3000K-6000K for clear explanation of the irregularity in the solar energy irradiation pattern. These are shown in Figure-6 and Figure-7 respectively.

Figure-6 represents the temperature dependence of radiant emittance within the range of 0-3000K at at three different wavelengths like 0.89 μm, 1.3 μm and 1.55 μm. It is ascertained from Figure-6 that the radiant emittance increases exponentially with the increase of temperature at any wavelengths. However some interesting irregular patterns have been discovered within this temperature range through numerical analysis.

Figure-7 highlights the effect of temperature on radiant emittance within the range of 3000-6000K at the three different wavelengths mentioned in the previous paragraphs. It is clear from Figure-7 that althow the radiation pattertn have some irregular characteristics within the temperature range of 0-3000K the radiant emittance increases exponentially with the increase of temperature at any wavelengths within the range of 3000K-6000K.

Figure-8 presents the maximum wavelength as a function of temperature for the temperature range of 0-

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6000K. From Figure-8 it is clear that the maximum wavelength decreases with the increase of temperature. The maximum wavelength of the solar energy decreases radically within the temperature range of 0-500K and the maximum wavelength decreases slowly with the increase of temperature afterwards. From Figure-8 it is revealed that the peak value of the wavelength changes spontaneously with the change of temperature in the range of 0-500K. However the variation in the maximum wavelength reduces at relatively higher temperature. Therefore it can be concluded that the maximum wavelength can be considered as almost constant at and above black body temperature.

## CONCLUSIONS

This paper highlights the effect of atmospheric temperature and light emission wavelength on the irradiance characteristics of solar energy. The effect of atmosphearic temperature on the solar energy irradiance pattern has been analyzed at different wavelengths and the wavelengtht dependence of the irradiance has been analyzed at different temperatures. Then the effect of temperature on the maximum wavelength of emmitedenergy from the sun has also been analyzed numerically.

From the numerical analysis we have found that the peak of irradiation shifts to the left of the plot, which indicates that the temperature affects the radiation pattern significantly. More importantly we have also found some irregular patterns for the solar irradiation within the temperature range of 1500K-2600K.Finally it has been found that the maximum wavelength decreases with the increase of temperature and it becomes nearly constant above the black body temperature. Hence from the results presented in this paper it can be concluded that the solar energy radiation pattern is affected by the atmospheric temperature as well as the wavelength of the emitted energy from the Sun. The outcome of this numerical analysis would be very much helpful for the researchers to analyze the performance of the photovoltaic devices taking into account the influence of atmospheric temperature and the light emission wavelength from the sun on the pattern of the solar energy radiation.

## ACKNOWLEDGEMENTS

Authors would like to acknowledge the financial and technical supports from the Fundamental Research Grant Scheme (Grant no. 9003-00324) of University Malaysia Perlis (UniMAP), Malaysia for the successful completion of the research work.

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