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Light Source Intensity Measurement using Averaging Spectroscopy Method for Optimum Usage

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ABSTRACT

There are many types of light source specifically bulbs in the market with different working principles. Each of them provides different intensity at different wavelength. In order to check energy efficiency, it is not appropriate to measure intensity at certain specific wavelength for the same power rating bulb. Therefore, this paper reported the averaging spectroscopy method for intensity measurement between 400-700 nm before comparison is carried out. It is observed that the light emitting diode (LED) bulb shows to be the most efficient light bulbs with the highest average light intensity compared to incandescent and fluorescent bulbs. Light stability test is also carried out and reported in this paper.

1. Introduction

Light transmission is an electromagnetic radiation. It can be created by making an electron oscillates which emits an oscillating electric and magnetic field thus producing light in the form of energy packet called photon. Light can be categorized into different types, some of them can be seen by human eyes and others cannot, but all of them are still under electromagnetic spectrum. The human eyes can perceive light in between approximately 400 to 700 nm that give off colors ranging from violet to red [1]. However, human eyes cannot quantify exactly the amount of light especially for a small intensity difference. Therefore, a measurement of light intensity using a spectroscopy method is reported in this paper.

Light intensity as reported in this paper is defined as the number of photons per unit area per time. In this research, the main purpose is to compare the intensity of light coming from bulbs with different working principle. Since different bulb produce different intensity at different wavelength, an intensity averaging method in the visible region is introduced. Besides that, the differences in average intensity of light between the same working principle light bulbs but of different power rating are also observed. The types of light bulb that were used in the experiment are incandescent,

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fluorescent, and light emitting diode (LED) light bulbs. The intensity of light emitted by these three light bulbs is expected to give different spectral power distribution graph. Fluorescent bulb is bulb filled with mercury vapor that emits UV light when electricity is applied by fluorescence effect. Then, incandescent bulb is bulb that used a filament that is heated to the point of glowing and the glowing filament produces the bulb's light. Lastly, LED bulb is bulb that used an electric current passed through semiconductor material to illuminate tiny diodes called LED by electroluminescence effect [2-4].

2. Theory

In this experiment three sets of light bulbs were used. Each set comprises of three light bulbs of different working principle which are incandescent bulb, fluorescent bulb, and LED bulb. The three sets of bulbs which are selected are 5watt, 15watt, and 20watt. For each set, the type of light bulbs is set as the manipulative variable while the power input is fixed. The power input values are obtained using the formula below:

$$P = V.I \tag{1}$$

where P is power, V is voltage, and I is current input.

Briefly, incandescent light bulb works by heating up a thin tungsten filament. The result upon heating creates an "incandescence" which is light produced by heat [5]. Meanwhile, a fluorescent bulb is built using a long glass tube where gas is discharged. Initially, the tube will be preheated by the electrode filaments to initiate a rapid conduction of electrons. These electrons will collide with the gaseous mercury atoms which increase the amount of energy. The ultraviolet light is emitted as electrons return to their original energy level which causes the phosphorous coating on the tube to give off visible light [6]. As for LED bulb, it uses two lead semiconductors that emit light when electrons pass through it. The transfer of the electrons from the conduction band to an empty space in the valence causes energy difference in the band gap. The energy is being released and emitted as photon [7].

The differences in how each light bulb works affect the pattern of the spectral intensity distribution. Each of them has a unique pattern and provide the highest intensity at different particular wavelength. Therefore, an average intensity for certain interval of wavelength is taken for intensity comparison and reported in this paper. This will help the consumers to identify which types of bulbs provides more light intensity with the same amount of power rating. In other words, an energy saving bulb can be determined.

3. Experimental Setup

There are many researches [8-10] has been carried out to study bulb performance and used various methods. In this project, an open path method is used and similar as reported before [11]. The experimental setup is shown in Figure 1. Light bulbs of different kind were used as the light source. The power supply used in this experiment is AC voltage of 236V. The light bulb was put in a full covered by a wooden black box with dimension 28cm x 30cm x 41cm. The box was made by using plywood sprayed with a matte black paint to reduce the chances of light from being reflected and to set the environment inside the box to be as dark as possible when the bulb is turned off. A collimating lens is attached inside a steel housing and was placed on one side of the box. It was directed to the point inside the box where the light from the bulb was captured.

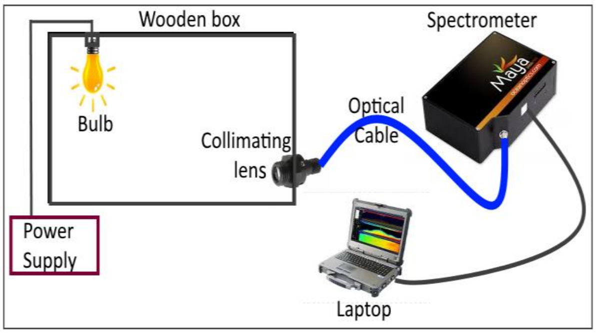

Fig. 1. Generic design of the experimental setup

An Ultra Violet Non Solarising optical fibre (Optran UVNS,) from CeramOptec with 600 µm core is connected to the box via collimating lens. The collimating lens was used to gather the light coming from the light source then channel it to the optical fiber. This captured light was then transmitted to the detector. In this research project, a spectrometer named Maya2000 from Ocean Optics was used as the detector. This type of UV-VIS spectrometer has wide range detection and has been used in many research projects [12-14]. The spectrometer can detect the light of wavelength between 190 and 1100 nm. It has resolution up to 0.65 nm (FWHM). The Maya2000 spectrometer is linked to the laptop installed with SpectraSuite software. SpectraSuite is a software specifically programmed and innovated by Ocean Optics to display information acquired from the spectrometer. This software also has some data processing function. It can calculate the average reading of intensity of the light source within the range of wavelength of interest and can be displayed on the screen.

4. Results and Analysis

Initially, the box was covered properly as not to allow any light to come in and affects the intensity reading. When the light bulb was switched on, the lights were gathered by the lens on the collimating lens. The light beam then travelled via fiber optic cable to the spectrometer. The fiber optic cables were used as they are a convenient way to channel light from one point to another. When the light as photons reached the spectrometer, they will be transmitted through a grating to be diffracted according to their respective wavelength [15]. The pixel of the detector collected the photon in the form of energy. In this experiment the integration time was set to100ms. After each integration time, the charge levels from all the pixels were read and converted into a specific number of "counts". The amount of photon is being translated into data, where the higher the number of counts indicates the higher the number of photons. The higher number of photons means higher intensity of light in this context.

The reading was taken for 20 minutes to make sure the light intensity coming from the light bulbs has been stabilized. At the end of 20 minutes, the data to compare the pattern of spectral power distribution was taken. The value of current input was also measured by using a handheld digital clamp multi-meter. The voltage value was fixed at 236V. The power input values were calculated using Eq. (1). The precision of the handheld digital bulb multi-meter is up to two decimal places for current reading and no decimal place for the voltage reading. The results from the experiment for current and power reading are shown in Table 1. It is found that the power measured for each bulb is different with the power claimed by the manufacturer.

Table 1
Measured current, voltage, and power input bulb

Type of Light Bulb	Current Input (A)	Voltage (V)	Power (W)
Philips LED 5W	0.02±0.01	236±1	4.72±2.38
FF Lighting LED 15W	0.06±0.01	236±1	14.16±2.42
Aletko LED 20W	0.09±0.01	236±1	21.24±2.45
Philips F 5W	0.02±0.01	236±1	4.72±2.38
Osram F 15W	0.07±0.01	236±1	16.52±2.43
Osram F 20W	0.09±0.01	236±1	21.24±2.45
Chiyoda ID 5W	0.03±0.01	236±1	7.08±2.39
Osram Halogen ID 15W	0.06±0.01	236±1	14.16±2.42
Chiyoda ID 20W	0.08±0.01	236±1	18.88±2.44

Chiyoda incandescent 5W bulb shows the biggest difference which is 41.6% error. The 5W label is over claimed by the manufacturer. It is believed for marketing purpose where low power bulb can save more energy. However, the bulb shows more energy consumption when power is being measured. The intensity of the light emitted by each light bulb of different working principle with the same power input of approximately 5W is shown in Figure 2.

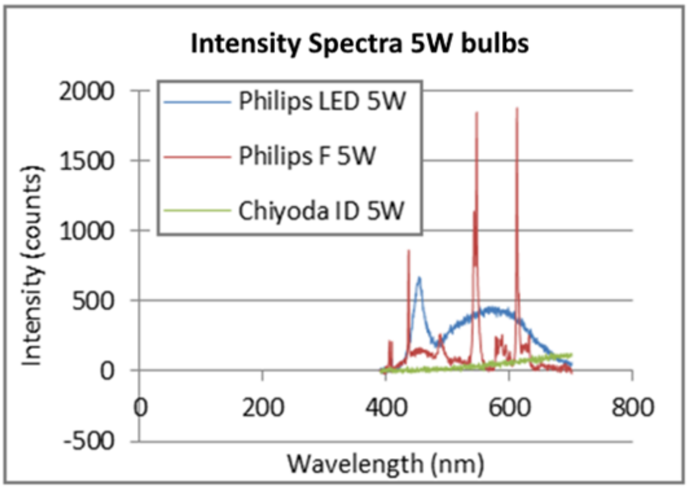

Fig. 2. The intensity spectra of different types 5W bulbs

As can be seen, different types of light bulb give different shape of intensity spectrum. Each of them has different wavelength peaks. For the LED light bulb reading, the peak is at wavelength 448.88 nm with 590 counts. The intensity then reduces until it reaches wavelength at 479.04 nm with 169 counts. Then, it increases until wavelength 567.91 nm with 428 counts before decreasing again. Based on the spectral shape, it is believed to be a phosphor-based LED with phosphors of different colors to form white light [16-17]. The distribution of the spectrum gives white bluish light due to the higher amount of blue light compared to other colors. Meanwhile, the fluorescent light bulb graph has several peaks. The four highest peaks are at wavelengths 436.51, 542.17, 546.7, and 611.96 nm with 818, 1142, 1842 and 1879 counts respectively. This kind of pattern creates white light as a result. The downside is that when the light is reflected on a surface, it will not show the true color of the surface because of the lack of variety color spectrum in the light. When illuminated by the light source, only the spikes of the color spectrum present will be emphasized in the rendering of color for objects [18]. Next, for incandescent light bulb, the amount of the photons increases as the wavelength increases. The highest count reading is at wavelength 690.86 nm with 106 counts. Within the visible light range, the intensity is higher at the yellow to red spectrum region compared to violet to blue color spectrum which makes the light appears orange. The experiment was repeated using light bulbs with different watts. The results using light bulbs of power input 15W and 20W are shown in Figure 3 and Figure 4.

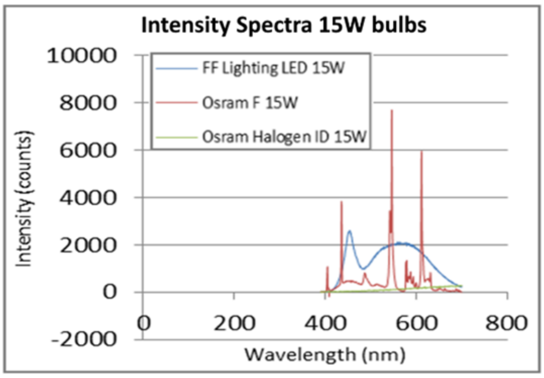

Fig. 3. The intensity spectra of different types 15W bulbs

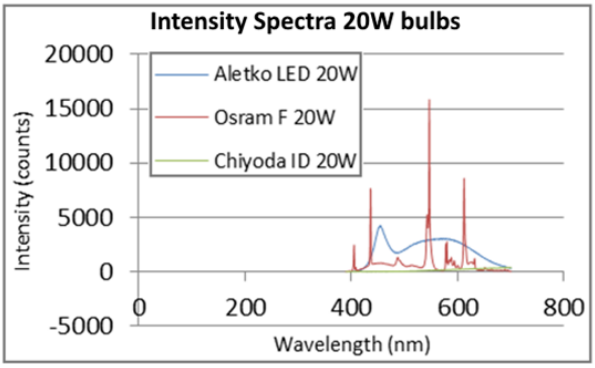

Fig. 4. The intensity spectra of different types 20W bulbs

Based on Figure 3 and Figure 4, it can be observed that the general patterns of the spectrum for 15W and 20W LED light bulbs are similar with the 5W LED light bulb. The same goes to 15W and 20W fluorescent bulb. The pattern is similar to 5W fluorescent bulb. The difference is only on the intensity counts of lights. The 20W bulb has higher counts as compared to 15W and 5W bulbs. It is quite difficult to compare different light bulb intensity as they emit lights at best on different wavelength. Therefore, an average intensity reading from 400 to 700nm is taken and the result is shown in Figure 5. As expected, 20W bulbs show the higher intensity reading as compared to 15W and 5W bulbs. The highest average intensity reading for 20W bulb is LED, followed by fluorescent bulb and lastly incandescent bulbs.

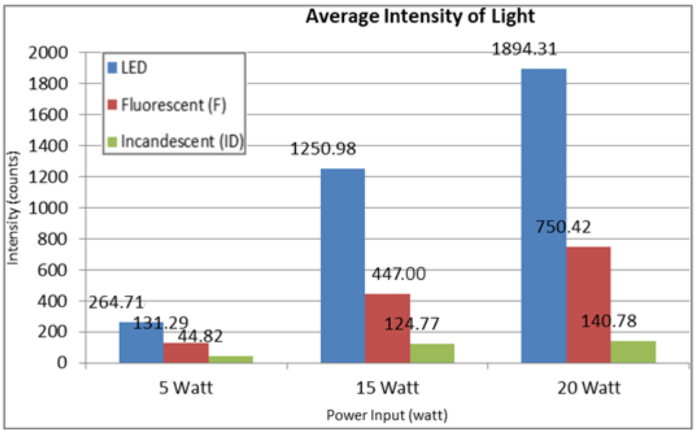

Fig. 5. The average intensity of different types light bulbs

The 15W and 5W light bulbs also show the same pattern where the average intensity of light of LED bulb is the highest. In another experiment, the light intensity stability for different types of bulb is carried out. The average intensity of 5W bulbs light within the visible light range (400-700 nm) is captured for 20 minutes and the result is displayed in Figure 6.

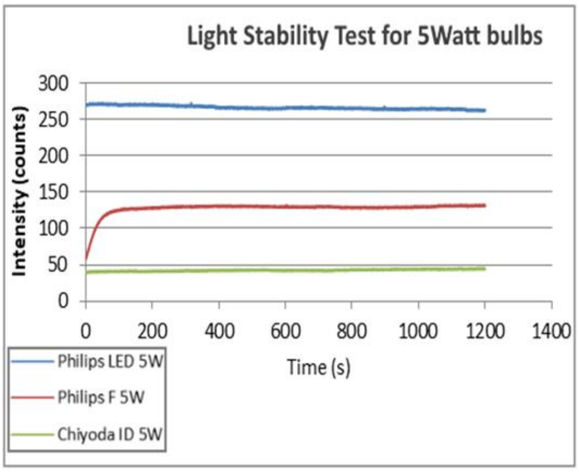

Fig. 6. Light stability test of 5W bulbs over 20 minutes

The data shows that for LED light bulb, the intensity of the light decreases linearly before it reaches a stable intensity. However, the intensity for fluorescent and incandescent light bulbs increases over time until they reach their maximum intensity. Fluorescent light shows a rapid rise within the first 2 minutes compared to incandescent light that has linear increment. The experiment is repeated using 15W and 20W bulbs and the results are shown in Figure 7 and Figure 8 respectively.

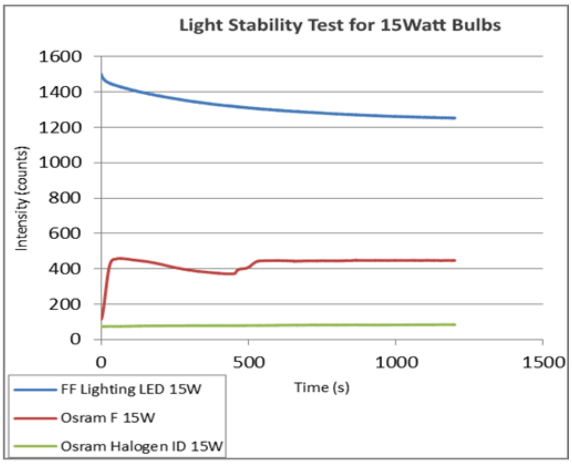

Fig. 7. Light stability test of 15W bulbs over 20 minutes

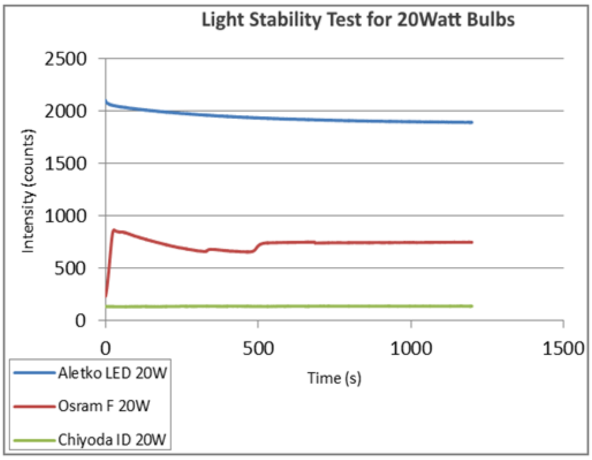

Fig. 8. Light stability test of 20W bulbs over 20 minutes

Based on these figures, it can be observed that the patterns for intensity over time for 15W and 20W LED are the same with 5W LED. The same goes to incandescent and fluorescent bulb. It shows that the same working principle bulb has the same stability pattern even though they have different power rating. For fluorescent 15W and 20W bulb, there is some drop after the average intensity reaches maximum value. This could be because of the flickering of the light bulb. Nevertheless, the value increase again and then stabilizes after 8 minutes. All three sets show that the average light intensity of LED light is the highest while the average intensity of incandescent light is the lowest.

4. Conclusions and Future Work

The comparison between the intensity of light bulbs of different working principle but the same power rating has been described in this paper. It can be concluded that light bulbs that work with different operating principle will emit light intensity with different pattern of spectral distribution. Each of them has the highest intensity at different particular wavelength. Therefore, the average intensity from 400-700 nm is introduced in this paper. It is found that the average intensity of light of LED bulb shows to be the highest followed by fluorescent and lastly incandescent bulb even though the amount of power rating is the same. Therefore, it can be concluded that LED bulb has the optimum energy usage. Nevertheless, there are differences between the value of power rating stated by the manufacturer and the power that are being measured. This will affect the energy usage of each bulb. Thus, for optimum energy usage, consumers need to identify the bulb power rating and true power measured. Future work will focus on energy usage of LED bulb with different color dispersion. This will contribute in the improvement of electricity energy saving based on color selection.

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