Energy and Environment Research; Vol. 2, No. 1; 2012
ISSN 1927-0569 E-ISSN 1927-0577
Published by Canadian Center of Science and Education

The Efficacy of Light Emitting Diode (LED) Lamps Used in Rural Communities of Nigeria

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Received: March 1, 2012 Accepted: March 20, 2012 Online Published: May 16, 2012

doi:10.5539/eer.v2n1p121 URL: http://dx.doi.org/10.5539/eer.v2n1p121

Abstract

This work is focused on the efficacy of regulated LED lamps for effective lighting of rural community households in Nigeria. The result shows that most Nigerian household that were poorly lit by kerosene wick lamp are gradually adapting the light emitting diodes (LED) based lamps. However, since the power supply to this LED lamps are not regulated, the LED lamps suffer illumination looses at faster rate thereby discouraging users. Regulated LED lamps have been shown in this work to provide more stable and long lasting illumination levels for the user.

Keywords: illumination, regulated, LED, lamp, kerosene

1. Introduction

Inadequate electricity supply in Nigeria has made many households to resort to other alternative lighting sources. Only 40% of installed capacity of about 6000 MW electricity is available to the 167 million people living in Nigeria. About 60% of households in Nigeria that do not have access to electricity from the national grid live in rural areas and depend on other forms of lighting sources to meet their lighting needs or task (Sambo, 2009; Etiosa, 2009). The primary lighting sources for this population have been dominated by kerosene lamps (Hurricane or wick lamp). Kerosene lamps do not only provide low light output (0.3 lumen/Watt), but are a major contributor of green house gases and are dangerous to the users (Dunlop, 1998; Mills & Berkely, 2003; Schultz et al. 2008). Particulates from Kerosene lantern have been reported to coat walls and lungs with carcinogenic residue (Peon et al. 2005; Foster & Gomez, 2005). Foster & Gomez (2005) reported that there have been thousands of household fires per year caused by fuel based lighting claiming thousands of lives. A typical kerosene lamp delivers between 1 and 6 lumen per square meter (lux) while the measured energy used among kerosene lanterns varies from 0.005 to 0.042 liter per hour (Mills, 2003; Pode, 2010).

Globally, fuel-based lighting represents $38 billion per year in fuel cost and 260 MT of CO_2 emissions (Mills, 2003). The users of kerosene lamps pay more for lighting compared with electric lighting users and it is not likely that these group of people will get access to electricity grid soon or will experience improved services as population growth far exceed connection rates (Van Der Plas, 1997). For example, kerosene is purchased in rural areas at prices 150% in excess of their official pump prices (Sambo, 2009). Even the 40% of households that are connected to the national grid experience spasmodic power supply as a result of inadequate power generation by Power Holding Company of Nigeria (PHCN). This group also resorts to the use of kerosene lamps as alternative to lighting during those periods of power outages.

The advent of solid state lighting using light emitting diodes (LEDs) has considerably reduced the dependence on kerosene lamps. There has been a considerable shift towards the use of rechargeable and non-rechargeable LED lamps in many households in Nigeria for performing various tasks. Before the influx of China made LED lamps there were locally constructed LED lamps. The lamps were made from the 5 mm indicator LEDs with the compact disc serving as the reflector surface and a wooden stand. Each lamp had between six to twelve LEDs. Though these lamps provided low level illumination compared to kerosene lamps they nevertheless gained overwhelming acceptance because of the quality of light output, low cost and high energy savings. In fact they were referred to as “lamps that could be powered by dead batteries”.

Between 2004 and 2005 most Nigerian markets were “flooded” with China made LED lamps. Though these lamps provided better lighting qualities and were more efficient than the kerosene lamps and the locally constructed LED lamps, they also failed quite easily either from the electrical connecting wires or the LEDs themselves. The failure of the LEDs could be associated with increase in junction temperatures. The other challenge associated with the LED lamps is the unregulated power supply that drives the LED arrays which could reduce both the efficacy as well as the life span of the LED. A voltage regulator could be designed to provide predetermined DC voltage which is independent of the current drawn from the source and temperature. The advantage of using a regulator is that it can maintain a relatively constant supply voltage and current to a circuit over wide changes in load parameters including temperature. Thus, the use of a voltage regulator can improve the operation of the LED lamp since the drive current of the LED array would remain relatively constant despite variation in supply voltage. There are a number of reasons favouring the replacement of conventional lighting lamps like incandescent and kerosene lamps. Among these reasons are that LEDs are more efficient than kerosene and incandescent lamps at converting electricity into visible light (Gordon, 2008). They are also rugged, compact and can last for an estimated lifetime of 100,000 hours (OIDA, 2002). Longer lifetime means LEDs systems can pay for themselves within a short period with less maintenance cost. LEDs are also environmentally friendly.

In this work, we design a simple switching regulator for the commercially available China made LED lamps and compare the efficacy of the regulated lamp with the unregulated LED and kerosene lamps.

1.1 LED Lighting

Light emitting diode is mainly a P-N injected semiconductor device, adopting direct band-gap semiconductor materials to generate light through electron hole-pair recombination. The energy of the emitted photons is approximately equal to to the energy difference of the energy band gap (Sze, 1985; Bhattacharya, 2002; Schubert, 2010). Virtually all LED structures employ double heterostructures. They consist of two confinement layers and an active region (Schubert, 2010). In a double heterostructure, the active region has a smaller bang gap and as a result the confinement regions are transparent to the light emitted by the active region (Schubert, 2010). The advantage of the heterostructure LED over the conventional homojunction LED is that it enhances recombination of electrons and holes and thereby increasing the overall quantum efficiency (brightness) of the LED. The generation of light in LED is classified as electroluminescence or injection luminescence. Because LED emits light by spontaneous emission that requires forward bias, it operates at lower current densities than incandescence and fluorescence. This low energy consumption is a great potential for the overall energy savings (OIDA, 2002).

Under forward biased, large populations of electrons are injected into the empty conduction band of an LED. When the electrons relaxes to the valence band and recombine with holes, light is emitted in the narrow band characterized by the type of semiconductor material. The light emitted is therefore coloured and must be converted to white light if it must be adapted for use for general illumination (Schubert, 2010). One striking advantage of this lighting technology is that, unlike fluorescence technology, the wavelength of the narrowband emission in an LED can be tailored with relative ease to either increase the quantum efficiency, or to minimize the Stokes –shift associated with its conversion to semi-broadband emission, thus making this new technology potentially even more efficient than fluorescence (OIDA, 2001).

There are broadly two methods of obtaining white light from LEDs; the colour mixing approach where a blue, green and red LEDs are combined either side by side or in a vertically stacked geometry to obtain white light with high colour rendition index and the phosphor down-conversion method, where a blue or ultraviolet (UV) InGaN LED is used to excite phosphors to produce white light (IESN TM-16-05, 2005; Schubert & Kim, 2005; Brittenham & Vittitow, 2006; Wang, et al. 2007; Zhu & Narendran, 2007; Azevedo, 2009).

The commonly available white LEDs are fabricated using a cerium doped yttrium aluminium garnet (YAG: Ce) phosphor combined with indium gallium nitride (InGaN) based blue LED. Some wavelength of the blue LED is down-converted by the phosphor and the combined light is perceived as white by the human visual system (Narendra, et al., 2004). The other significant advantage of LEDs is that they rarely fail catastrophically; instead, their light output degrades slowly over time.

The efficacy of white LEDs has increased steadily since the development of blue InGaN LED by Nakamura in 1992. The efficacy has increased from 5 lm/W in 1996 to 160 lm/W in 2010 (Narukawa, 2010; Swoboda, 2010) and a laboratory value of 231 lm/W in 2011 (Amogpai, 2011).

2. Methodology

A Lanclanche battery operated LED lamp was purchased from road side vendors. The lamp consist of thirty arrays of 5 mm LEDs and uses four 1.5V batteries (unregulated). In the second experiment the constructed regulator was connected to the lamp and measurements were carried out (see Figure 1).

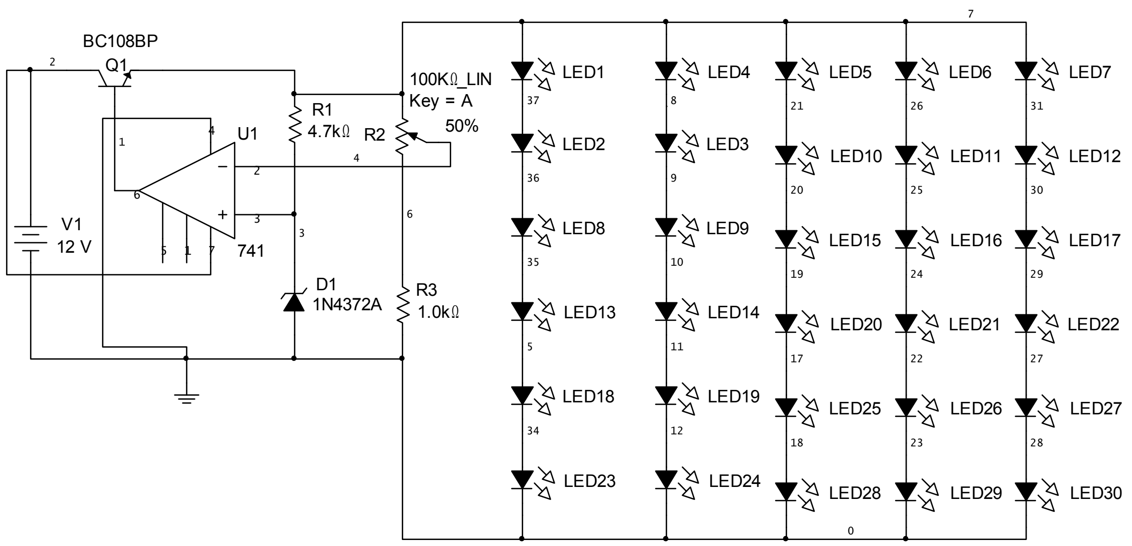

Figure 1. Regulator circuit

First the illumination level of the regulated LED lamp was measured using a Lux meter in a dark room. The lamp was powered by a 6.0V source made of four 1.5V Tiger Leclanche batteries connected in series. The regulated LED lamp was placed on a reading table, with the lux meter placed at a horizontal position some distance away from the lamp. Measurements were taken at 5.0 cm increment away from the lamp. Similar measurements were carried out using unregulated LED lamp, candle and a kerosene wick lamp.

Secondly, the energy used by both regulated LED lamp and kerosene lamp were evaluated. Energy consumed in Watts by LED lamp was determined from voltmeter and ammeter readings using the formula

$$\text{Power (Watts)} = \text{voltage x current} \tag{1}$$

LED lamps are not usually used for longer times; they are often kept at places that are accessible to the user even in the dark. The energy consumed by the kerosene wick lamp was evaluated assuming 6 hours/day of use. In Nigerian villages, it is most common for households to use the lantern for about 3.5 hours at full brightness in order to perform tasks but thereafter dim it when going to bed until the following morning. There are two reasons for this, the likelihood of using the lamp during the night for emergency/children calls and also in some cases the lamps are used in the morning to startup fire for cooking. In order to determine the amount of energy used up by kerosene lamp, the lantern was weighed when empty with dried wick using a weighing balance. The lantern was then filled with kerosene and its weight with the content was measured. Furthermore, the lantern was then lit and the weight of the lantern and content was measured at two hours interval.

2.1 The LED Regulator and Principle of Operation

To maintain constant light intensity in LEDs, precise control is achieved with current regulation (Irvine-Halliday et al. 2005). The simple LED regulator was designed according to Ramya (2011). The simple voltage regulator circuit shown in Figure 1 employs an operational amplifier (op amp) which accepts an unregulated voltage, and provides a regulated output voltage that remains at or very close to its intended output level. The unregulated input voltage must be higher than the desire output level by a sufficient margin in order to achieve effective regulation. The Zener diode D_1 acts as a voltage reference signal for the circuit and is fed into the non-inverting input of the op amp. The voltage divider formed by R_1 and potentiometer R_3 sets the voltage level of the inverting input of the op amp which is basically a feedback from the circuit to the op amp. The transistor is used to boost the output of limiting current of the circuit.

Fixed resistor R_2 is for the purpose of limiting current or reducing voltage. The voltage at the non-inverting input of OP Amp is pegged at the Zener voltage, while the voltage at the inverting input is always a fraction of the output voltage defined by the potentiometer R_3 and R_1. When the output exceeds the set level, the inverting input voltage exceeds that of the non-inverting input causing the output of the OP Amp to go low. This turns off the transistor causing the output voltage to dip. When the output goes below the set level, the reverse happen, that is the OP Amp output goes high causing the transistor to turn on and push the voltage up.

Thus this circuit works by turning off the transistor when the output voltage is too high and turning it on when the output is too low. This balancing action happens continuously with the circuit reacting instantaneously to deviation in the output voltage. Resistor R_3 which is a variable resistor is adjusted to set the desire output voltage of the circuit.

3. Results and Discussions

Figure 2 shows the variation of illumination with horizontal distance for the regulated LED lamp, kerosene lamp and candle stick. The result shows an exponential decay in illumination for all the lamps. However, the illumination level of the regulated lamp at 70 cm is slightly higher than the illumination at 5 cm for both kerosene lamp and candle. This implies that the regulated LED lamp can light up (107 lux) a task area located on a horizontal level at 70 cm from it as much as a kerosene lamp would light up (105 lux) an area when a task is being performed at 5 cm from it.

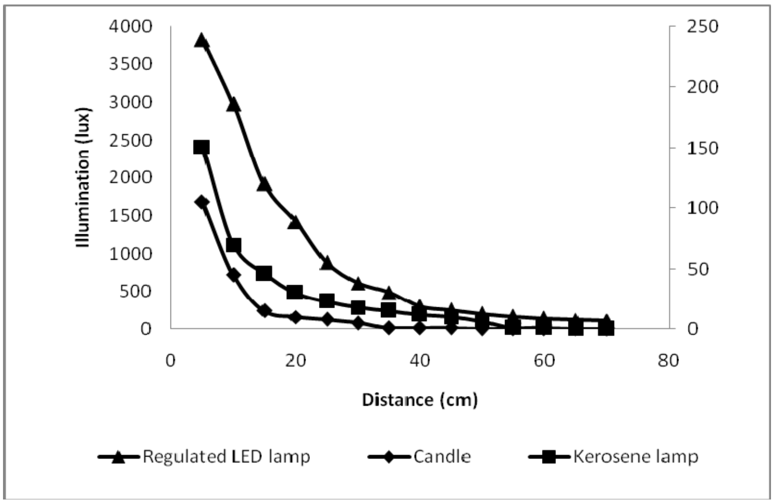

Figure 2. Variation of illumination level with distance

Figure 3 shows the energy consumed (in litres/hour) by the kerosene wick lamp when lighted for six hours. The result shows that kerosene wick lamp consumes 0.031 litres per hour and 0.1914 litres for the six hours considered in this study. This result is consistent with the result of Dutt & Mills (1994) and Mills (2003). If each household uses a lamp for 6.0 hrs, this will give a total of 70.08 litres of kerosene consumed by each lamp in a year. If the cost of kerosene per liter is one US dollar (₦150) in villages, then a household in the village using a single kerosene wick lamp would pay 70.08 dollars (₦10, 512. 00) per year, this amount agrees with the report by Peon et al. (2005). This cost is quite high for the 70% Nigerian poor people living on less than one United State dollar (US$1or ₦150.00) per day (United Nations, 2009).

The energy consumed in watts as a function of time for the unregulated and regulated LED lamps is shown in Figure 4. The results indicate that the rate of energy consumed by the unregulated lamp (89.9%) is much higher than the energy consumed by the regulated lamp (58.6%). Though, compared to the kerosene wick lamp, the energy consumed by both the unregulated and the regulated LED lamps are much less than the kerosene lamp.

The illumination of the unregulated LED lamp was found to be higher (>4000 lux) than the regulated lamp at the onset of illumination. However, the illumination decreased at a rate that is almost twice the rate of the regulated lamp (Figure 5). This shows that regulating the power supplied to the LED lamp increase the number of usage hours of lamp the with illumination after six hours (2590 lux) being almost twice the illumination offered by the unregulated LED lamp (1320 lux) after six hour of use. The illumination of the regulated LED lamp after six hours of operation is slightly more than the illumination of the unregulated LED lamp when used for just three hours. Thus, the regulated LED lamp has better efficiency and can be used at twice the number of hours the unregulated LED lamp can be used. It was reported by Adkins et al. (2010) that the people of Malawi reportedly spent less ($0.09 as compared to $0.61 per week) on kerosene after switching from kerosene lantern to LED lamps. The report also claimed that there was 63.0% increase in extended hours of lamp use. Therefore, it is expected that there would be a significant lower recurrent expenditure for households using regulated LED lamps compared to those using the unregulated LED lamps since they would have more hours to perform their activities.

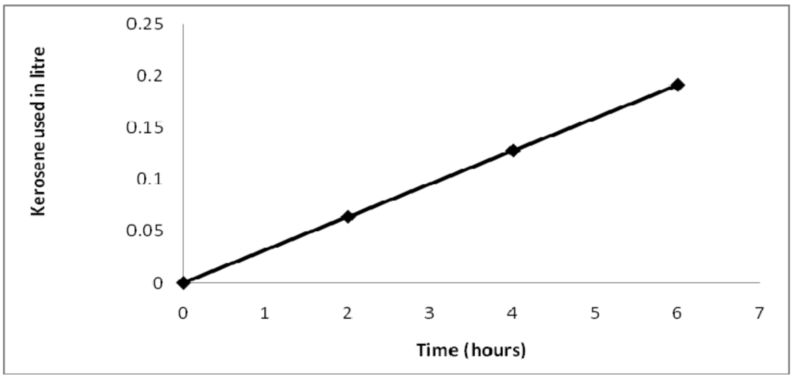

Figure 3. Rate of kerosene fuel consumption by a wick lamp

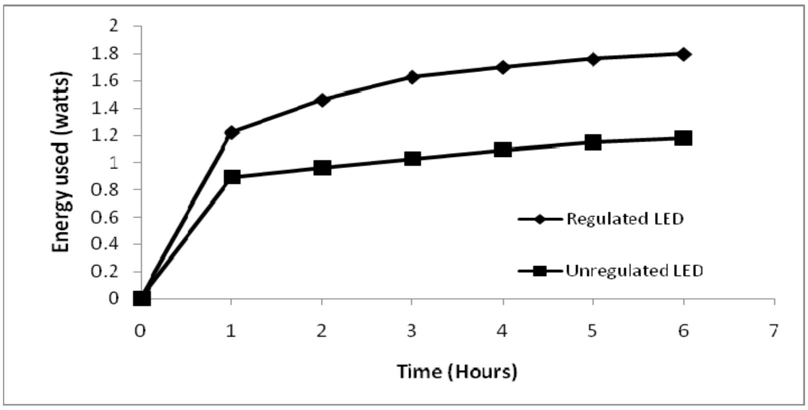

Figure 4. Rate of energy consumption for regulated and unregulated LED lamp

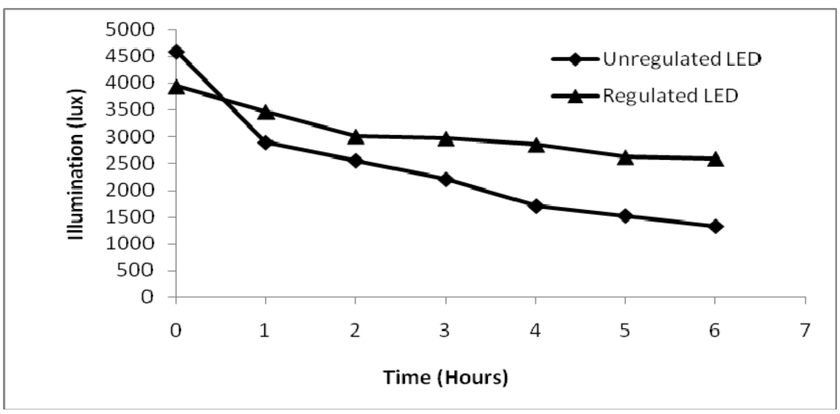

Figure 5. Illumination level for regulated and unregulated LED lamps as a function of time

4. Conclusion

The energy use and lighting output of kerosene wick lamp is highly inefficient and consumes considerable energy. Thus, kerosene wick lamp is poor for reading and many other tasks that require reasonable distance from the lamp, particularly on a horizontal level. Our estimates of useful luminance at various distances show that the kerosene wick lamp delivers between 1 to 151 lux. This level of illumination is considerably lower than the typically western standard of 300 lux for reading (Dunlop, 1998; CEATI, 2007).

A comparative analysis of kerosene wick lamp versus LED lamps shows that that there is considerable improvement in the level of illumination, economic and environmental benefit in replacing a kerosene lamp with a LED lamp.

Furthermore, analysis of the regulated LED and unregulated LED lamps show a remarkable improvement in energy utilization potential with a steady maintenance of illumination level of the regulated LED lamp over the unregulated LED lamp. Thus, the efficacy of LED lamps available in rural communities of Nigeria can be enhanced and the number of useful hours increased with adequate illumination of a task area if the energy supplied to the commercially battery driven LED lamps are properly regulated.

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