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# Thermal Issues of Warm and Cool White LED Bulbs

**K. Jeykishan Kumar*, G. Bharath Kumar and R. Sudhir Kumar**

Department of Energy Efficiency and Renewable Energy Division, CPRI,
Bengaluru – 560 080, India; jeykishan@cpri.in

## Abstract

For modern high-power LEDs, self-heating becomes a critical factor determining their functional characteristics and lifetime. For large-area LEDs with a complex structure, it is important to know not only the thermal resistance but also the detailed temperature distribution (temperature map) over the active area. In this paper, we present the thermal analysis of high-power Light-Emitting Diodes (LEDs) with under the real operating conditions. Thermal transient measurements were performed to study the thermal characteristics of high power LED bulbs. The purpose of this test is to analyze the heat dissipation from LED Lamps. The study concludes that the warm white LED bulbs show better thermal behavior than the cool white LED bulbs of low power.

**Keywords:** Cool White, Low Power, Temperature, Thermal, Warm White, LED

## 1. Introduction

This paper studies the thermal influence of a LED driver on a retrofit LED lamp, also reporting on a procedure for its thermal characterization and multiscale modeling. In this analysis, temperature is measured by infrared thermography and monitoring specific locations with thermocouples. Experimental results point out that temperature increases considerably in all lamp parts when the driver is installed in the lamp (up to 15% for LED board). The multiscale simulation approach is set with thermal parameters (thermal conductivity, emissivity, and LED board thermal resistance) measured from several parts of the lamp, reaching an agreement between experiment and simulation smaller than 10%. With this model, the driver temperature is investigated under operational conditions accounting for two alternative thermal designs. First, the driver is completely surrounded with a filling material (air completely removed, Case A), and, second, only the thermal contact between the board and the lamp is improved (air is kept, Case B). In both cases, the heat removal from the driver to the ambient by conduction is enhanced, observing that temperature decreases in its most heated components up to 10 °C in Case A, and up to 7 °C in Case B[2]. Even though light-emitting diodes may have a very long life, poorly designed LED lamp can experience a short life. A simulation of temperature distribution of four chips high-power LED down-light was made by finite element method. Based on the consistency of the LED lamp experimental and simulation results, the analyses of the effect of thermal conductivities of PCB, thermal grease, heat sink, convection coefficients and the height of the heat sink on the junction temperature were made, which provide an effective reference for the thermal design[4]. Thermal characteristics LED devices directly effects on the luminous efficiency and long term reliability of LEDs. Junction temperature and thermal resistance are the main parameter that reflection of the heat dissipation capability of the LED device. In this study, relationships between thermal resistance and luminous flux and electrical power are simplified based on the photo-electrothermal theory. A new method using the optical-electrical characteristic of the LED is proposed to measure thermal resistance and junction temperature.

This method is simple and credible, and requires no expensive thermal measuring instruments, making it valuable for engineering application[6]. In this paper, 6

*Author for correspondence

LED bulbs of two types manufactured by same brand were chosen for studying thermal characteristics and their analysis. The most common LED bulbs used in present days for residential, commercial and industrial applications are low power high & medium brightness LED's of less than 14 Watts. Tables 1 and 2 shows the nameplate ratings of 3Nos. of warm white and 3 Nos. of cool white LED bulbs respectively.

**Table 1.** Nameplate ratings of cool white LED bulbs

| SL. No. | Parameter | 7W | 9W | 14 W |
|---|---|---|---|---|
| 1 | Voltage (V)- AC | 220–240 | 220–240 | 220–240 |
| 2 | Luminous flux (Lumens) | 625 | 825 | 1400 |
| 3 | Efficacy (lm/W) | 90 | 91.7 | 91.7 |
| 4 | Power factor | 0.9 | 0.9 | 0.9 |
| 5 | current (A) | 0.075 | 0.05 | 0.055 |
| 6 | CCT (K) | 6500 | 6500 | 6500 |

**Table 2.** Nameplate ratings of warm white LED bulbs

| SL. No. | Parameter | 7W | 9W | 14 W |
|---|---|---|---|---|
| 1 | Voltage (V)-AC | 220–240 | 220–240 | 220–240 |
| 2 | Luminous flux (Lumens) | 630 | 825 | 1300 |
| 3 | Efficacy (lm/W) | 90 | 91.7 | 92.86 |
| 4 | Power factor | 0.9 | 0.9 | 0.9 |
| 5 | current (A) | 0.04 | 0.05 | 0.064 |
| 6 | CCT (K) | 3000 | 3000 | 3000 |

All the bulbs under consideration are of alternating current type with operating voltage around 220 V to 240 V and frequency of 50 Hz.

## 2. Thermal Standard for LED Lamps

Thermal issues of LEDs are of paramount importance due to two reasons. On one hand, long-term reliability strongly depends on the operating junction temperature of the LEDs as most of the failure mechanisms leading to light output degradation are thermally assisted. Statistically seen this means that the so called "lumen maintenance" (precisely: long term maintenance of the emitted total luminous flux) of LED components is determined by the junction temperature: at higher junction temperature light output degradation happens more quickly. On the other hand, the light output characteristics of LEDs strongly depend on the operating conditions. The forward current applied to an LED is the key variable; the higher the supplied current, the more light that is generated by the device. But the LED's light output drops when its junction temperature increases, even when the device is driven by a constant current source. As the measurement of light emission of LEDs and LED-based products is affected by the junction temperature, CIE (International Commission on Illumination) have also revised their recommendations on LED measurements and established several technical committees (such as CIE TC2-64, TC2-64 or TC2-76) which aim to define LED testing procedures with consideration of LED operating junction temperature. For LEDs the JESD 51-5x series of documents were published and April and May of 2012 and are summarized as follows:

- **JESD 51-50:** An overview standard that outlines the basic principles and possible future aspects of LED thermal characterization. The standard contains an overview chart which refers to the already published LED thermal characterization standards and includes foreseen topics of future standardization activities.
- **JESD 51-51:** This standard is the extension of the classical JESD51-1 standard to the measurement of the real thermal resistance or real thermal impedance of power LEDs. When this standard is used in combination with the JESD 51-14 standard, one can obtain the real junction-to-case thermal resistance of an LED package.
- **JESD 51-52:** This document provides guidelines on how to apply the recommendations of the CIE 127-2007 standard regarding the measurement of the total flux of LEDs when such measurements are performed in combination with thermal testing of LEDs for the determination of the total radiant flux (emitted optical power). This JEDEC document also provides additional guidelines which were missing from the above CIE document.
- **JESD 51-53:** This document is the glossary of terms and symbols used in the JESD 51-50 and 51-52 documents.

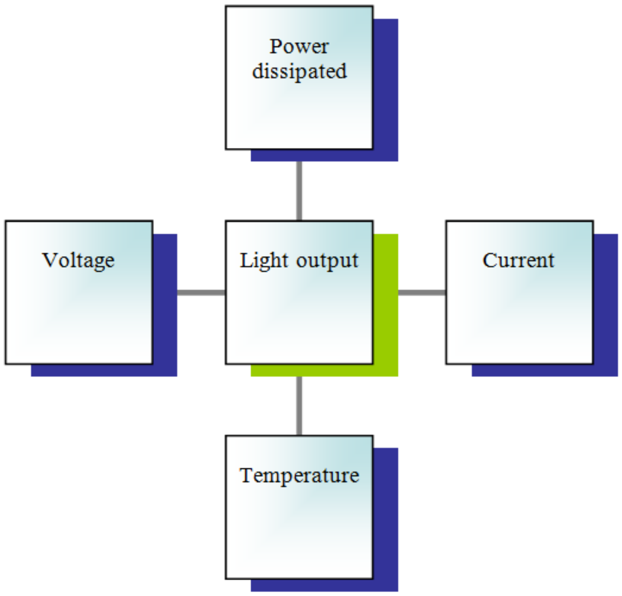



**Figure 1.** Inter-dependency of light output in a LED.

Figure 1 shows, the light output from an individual LED dependents on various other parameters viz. voltage, current, power dissipation and temperature. With forward voltage applied to LED, the current drawing increases leading to power dissipation through heat. Because of this power dissipation, the surface/body temperature of LED increases and the performance in terms of radiant flux decreases (lumen output decreases).

## 2.1 Experimental Results

**Table 3.** Measured electrical parameters of the LEDs

| Sl. No | Watts | Input Power (W) | Voltage (V) | Current (A) | Power Factor |
|---|---|---|---|---|---|
| Warm white LED bulbs | | | | | |
| 1 | 7 W | 6.3 | 230.24 | 0.029 | 0.95 |
| 2 | 9 W | 8.2 | 230.40 | 0.037 | 0.95 |
| 3 | 14 W | 11.6 | 230.90 | 0.052 | 0.97 |
| Cool white LED bulbs | | | | | |
| 4 | 7 W | 6.7 | 230.98 | 0.046 | 0.62 |
| 5 | 9 W | 9.2 | 230.06 | 0.041 | 0.97 |
| 6 | 14 W | 11.7 | 230.05 | 0.052 | 0.98 |

Table 3 shows the measured electrical parameters for the six LEDs under consideration 3 Nos. each in warm and cool white type. It is important to observe that, the power factor improves with increase with power consumption along with values of current drawing for both the warm and cool white LED bulbs.

**Table 4.** Temperature measurement results

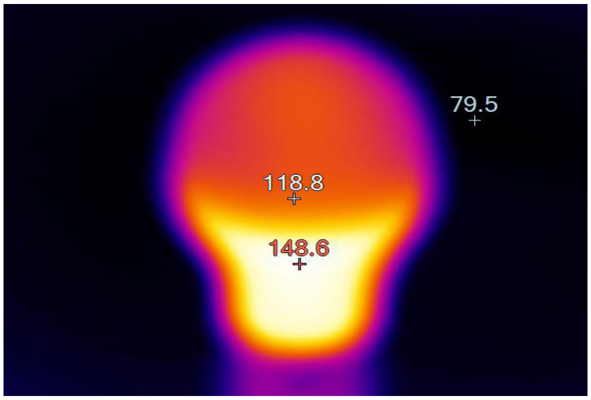
| Sl. No | Power (W) | Surface Temperature °C |
|---|---|---|
| Warm white LED bulbs | | |
| 1 | 7 W | 64.8 |
| 2 | 9 W | 72.2 |
| 3 | 14 W | 84.1 |
| Cool white LED bulbs | | |
| 4 | 7 W | 59.4 |
| 5 | 9 W | 70.8 |
| 6 | 14 W | 78.6 |

From Table 4, it can be observed that the temperature of the surface of both warm and cool white LED bulbs increase with increase in electric power consumption. The above surface temperatures mentioned in units of Degree Celsius were converted from Fahrenheit values of infrared thermal images obtained from Thermography instrument (Make: Fluke/Name: Thermal Imager).

# 3. Thermal Analysis

## 3.1 Thermal Analysis for Warm White LED Bulbs

For the temperature values mentioned in the Table 4, the corresponding Fahrenheit equivalent based infrared thermography images are shown in Figure 2 for warm white LED bulbs of different wattages. The highest temperature was observed near the point of placement of LED driver. The temperature at center point of LED is lower than the maximum temperature point. As per the nameplate details provided in the Table 2, the color correlated temperature is around 3000K which is warm region for human eye. Also the efficacy and luminous flux increases with increase in electric power consumption. These parameters can also be linked to thermal characteristics of warm white LED bulbs. Therefore, the surface temperature on LED will increase with luminous flux, efficacy and power consumption.

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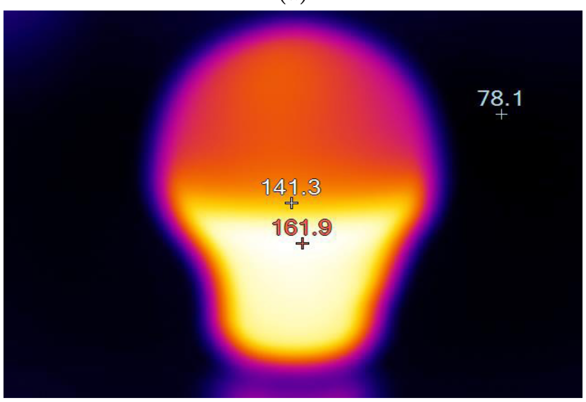


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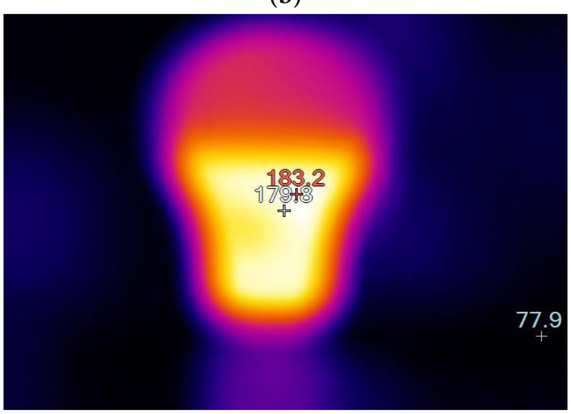
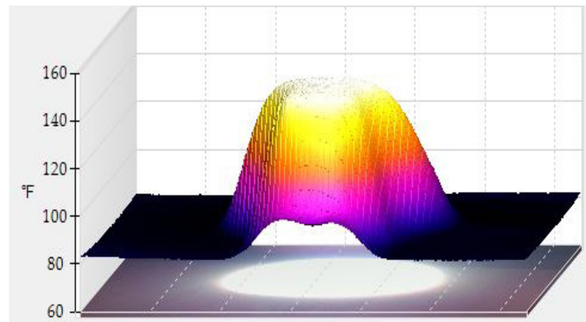



**(c)**

**Figure 2.** Infrared thermal images of warm white LEDs. **(a)** Maximum body temperature in Infrared mode of 7 W warm white LED. **(b)** Maximum body temperature in Infrared mode of 9 W warm white LED. **(c)** Maximum body temperature in Infrared mode of 14 W warm white LED.

The difference in temperature values of maximum temperature point and the center point decreases with increase in power consumption of warm white LED bulbs. For 7 W, 9 W and 14 W, the respective temperature differences are 30 °F, 20 °F and 5 °F.

In the three dimensional (3D) thermal distribution graphs shown in Figure 3 for warm white LED bulbs, the temperature map for different wattage is plotted between the Fahrenheit and surface area/location on the LED. It can be observed that the distribution is narrower as we increase with power consumption of LED bulb. This is attributed to the focusing nature of high wattage warm white LED bulbs. Also the distribution of temperature over the surface is uniform from low temperature at the outset of LED surface and high temperature at the middle or location of LED driver.

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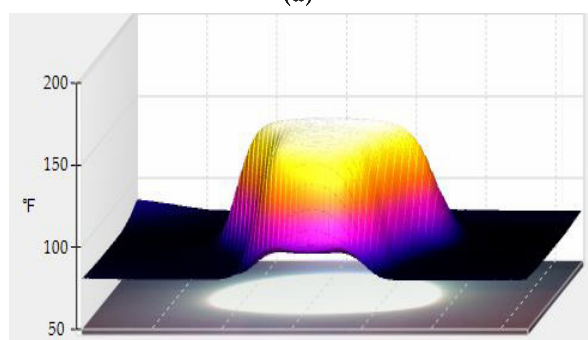


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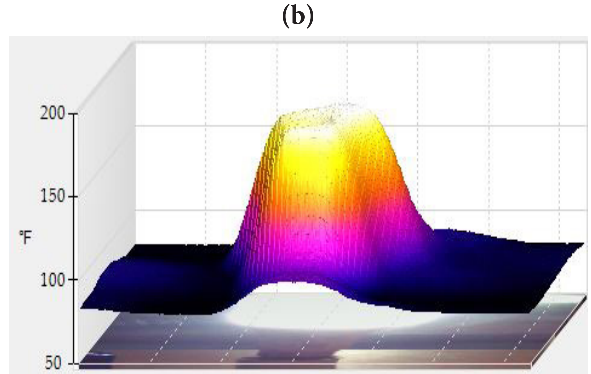
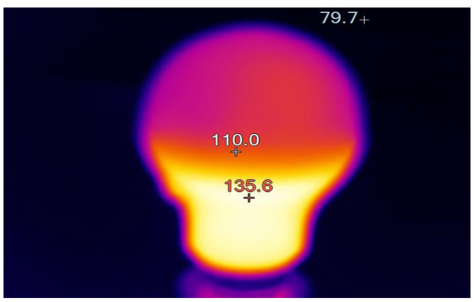



**(c)**

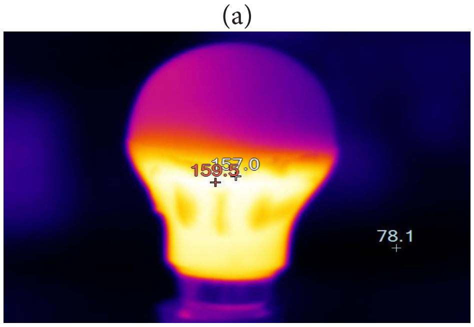
**Figure 3.** Infrared thermal images of warm white LEDs **(a)** 3D thermal distribution of 7 W warm white LED **(b)** 3D thermal distribution of 9 W warm white LED **(c)** 3D thermal distribution of 14 W warm white LED.

## 3.2 Thermal Analysis for Cool White LED Bulbs

Figure 4 shows the body temperatures of cool white LED bulbs in infrared thermograph mode indicating the maximum point and center point temperature values. Definitely the cool white LED bulbs shows higher amount of heat dissipation in comparison to warm white LED bulbs. With increase in power consumption, the surface of the cool white LED bulbs increases. From Table 1, the color correlated temperature value is around 6500 K which is 50% higher than the warm white LED bulbs which are of 3000K. Also the luminous flux and efficacy can be related to this temperature values. With increase in the surface temperatures of cool white LED bulbs, the luminous flux and efficacy will decrease.




(a)

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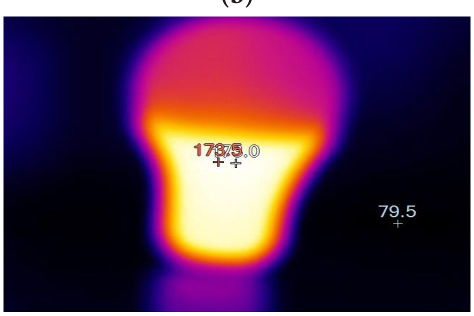
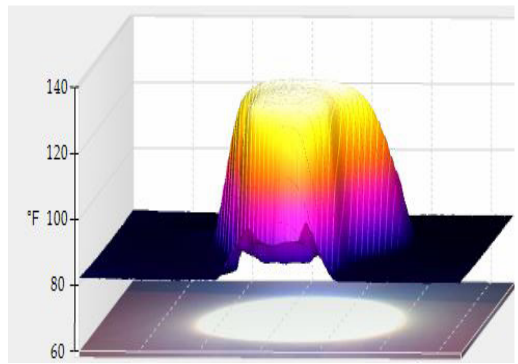


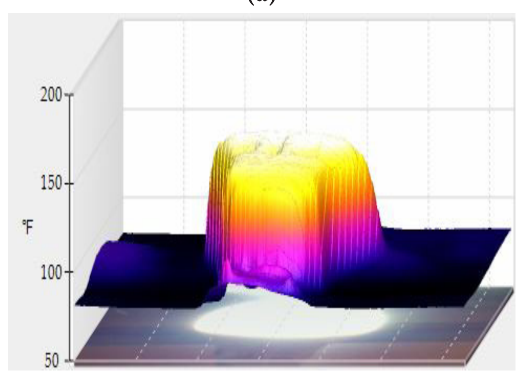

**(c)**

**Figure 4.** Infrared thermal images of cool white LEDs **(a)** Maximum body temperature in Infrared mode of 7 W cool white LED **(b)** Maximum body temperature in Infrared mode of 9 W cool white LED **(c)** Maximum body temperature in Infrared mode of 14 W cool white LED.

In the three dimensional thermal distribution graphs shown in Figure 5 for cool white LED bulbs, it can have observed that the temperature map is plotted between the Fahrenheit and location on LED surface. The temperature distribution is not uniform as it is in the case of warm white LED bulbs. From the 3D plot, it can also be observed that there are presences of wrinkles in distribution for cool white LEDs. This can be attributed to the presence of blue light peak wavelength which is not in the case of warm white LED bulbs where the peak wavelength is from orange color.




**(a)**

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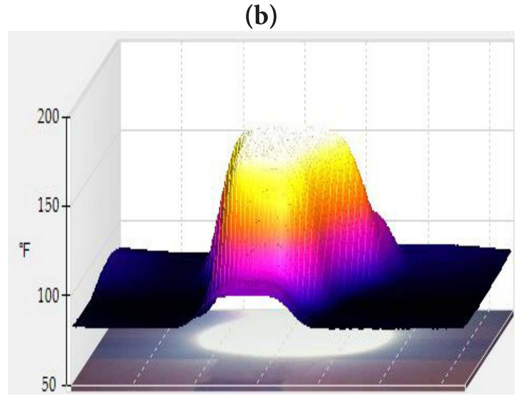


(c)

**Figure 5.** Infrared thermal images of cool white LEDs **(a)** 3D thermal distribution of 7W cool white LED **(b)** 3D thermal distribution of 9W cool white LED **(c)** 3D thermal distribution of 14W cool white.

## 4. Conclusion

The drive to increased electrical currents input to achieve high lumen for Light Emitting Diode (LED) has led to a series of thermal problems. The study has shown the heat generation levels from warm and cool white LED. It is seen that, all LED bulbs produce heat between 59.4 °C and 84.1°C and the highest heat is concentrated at the point of driver location in the LED. From analysis, the warm white LED bulbs show lower heat dissipation than cool white LED bulbs. Also the temperature distribution pattern over the surface of warm white LED bulbs are uniform and smoother in comparison to cool white LED bulbs. Cooperation between thermal, electrical, and optical standards bodies like BIS, IEC, IEEE, BSI, etc. and professional societies is required to arrive at globally accepted thermal standards to measure junction and surface temperatures to ensure performance and reliability. Since the end user needs total reliability of the final products, reliability research of LED bulbs has to be expanded to the reliability study of the complete LED-based system, including the luminaires and electronics.

## 5. Acknowledgement

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