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PERFORMANCE ANALYSIS OF VARIOUS TYPES OF HIGH POWER LIGHT EMITTING DIODES

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ABSTRACT

Solid state, energy efficient light emitting diode (LED) technology is coming up to replace the conventional gas discharge, etc. light sources. Although declared life of LED is very high but in tropical countries their life time appears very short. This phenomenon is becoming the most drawbacks for usage of LED. To search out the reason for the failure lead to undertake thorough study on the performance of LED specifically on the various environmental conditions. Experimentation was carried out with various types of commercially available high power LED. Failure in tropical countries may be due to effect of temperature. Test results have been noted at various major parts of LEDs, e.g. die, and sink area. Detail analysis of test results at various parts of LEDs in different conditions tends to have some idea about the cause of failure of the LEDs in tropical countries with high ambient temperature and less scope of heat generation by the light source.

Keywords: chip on board (COB), heat sink, LED die, surface mounted devices (SMD), temperature

INTRODUCTION

Light emitting diode (LED) is a solid state lighting (SSL) device, which is mercury free, less hazardous, small wattage and provides high efficacy. LED can be used as any form of application from signage lighting to flood lighting. LED is a *p-n*-junction semiconductor device. When power is applied, the recombination occurs at *p-n*-junction and energy is released as photon in the form of light [1, 2]. In this recombination only some portion of electrical energy convert into light and the rest converts into the form of heat at the junction of the LED, which is determine the junction temperature [3]. The junction temperature of an LED is very important parameters because the light output, reliability and lifespan seriously depend on it. The electrical power is converted for the entire light source into the form of radiant and thermal energy [4, 5, 6]. For LEDs, a large portion of generated heat has to be dissipated by using conduction and convection process because this excessive heat may damage the LED devices. So, there must be needed an appropriate process to limit the temperature of the devices. Surface mounted devices (SMD) and COB type LEDs are required proper thermal management to minimize the generated heat from the devices to reduce the failures. The maximum junction temperature of the LED die or chip inside the package is based on the en-

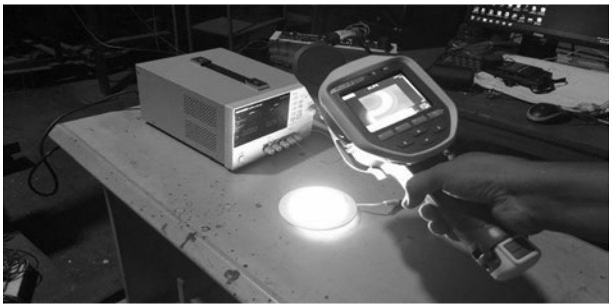

Fig. 1. Temperature measurement of the LED without driver by using Thermal Imager (Fluke Ti 400) methodology adopted

Table 1. Specification of LEDs

Sl. No.	Type of LED	Power rating, W	Dimensions* (mm)		LED mounting method	Material of heat sink	Electric Circuit of LED matrices
			DΦ	H			
1	SMD warm white LED	6	120	12	Recessed & Surface Mount	Aluminium alloy	Arrays are suitable arrange with series/parallel combination
2	SMD cool white LED	6	120	12	Recessed & Surface Mount	Aluminium alloy	Arrays are suitable arrange with series/parallel combination
3	COB warm white LED	5	88	40	Recessed ceiling down lighter	Aluminium alloy	Compact in-built chip
4	COB cool white LED	5	88	40	Recessed ceiling down lighter	Aluminium alloy	Compact in-built chip

*DΦ – Diameter, H- Height

durable thermal stress. But practically, it is impossible to maintain the proper rated value, which is provided the manufacturer due to this thermal imbalance in the LED devices.

TEST OBJECTS

The experiment has performed with four types of LED lamps of same make. Each and every LED are operated at 300 mA and they are listed in the Table 1.

EXPERIMENTAL SETUP

Experiments included two parts of a LED fixture, one is measurement of temperature near LED's chip and another is measurement the surface temperature of the LED heat sink. One Thermal Imager (Fluke make Model no: Ti 400) has been used to measure the temperature variations of a LED at different positions, Fig.1. Two COB type LEDs, where one is warm white type and other is cool white type, are affixed on the aluminium heat sink. The CCT of COB type warm and cool white LEDs are 3000K and 6500K respectively. Similarly, two SMD type LEDs where one is warm white type and another is cool white type and their CCT are 3000K and 6500 K respectively. The thermal measurement of LEDs are performed at ambient temperature T_a~ 28 °C. Duration of the thermal measurements is set to 60 minutes. LED was driven by the constant current LED driver with output current 300 mA.

The temperatures of the subject item have been taken at all die and sink areas of the subject LEDs as referred above. Initially temperature at ambient has been measured with Thermo couple type thermometer. The temperatures at die and sink areas of the subject LEDs have been measured through thermal imager (Fluke make, Model no. Ti400). First the temperatures are measured when each lamp connected with LED-driver circuit, at its rated condition. Temperatures are also taken from the lamps by connecting DC power supply without LED-driver circuit. Data has recorded at the initial condition when switch is turn ON and then at every five minutes interval up to one hour.

RESULTS AND DISCUSSIONS

The values of the test results are listed along with the characteristics curve obtained from the result. Few samples of IR images are also furnished here, where the LED is operated with driver. In Figs. 2 and 3, where the maximum temperature at sink area for COB type warm white LED at lamp start-up time is 99.1 °F or 37.27 °C and after 60 minutes of burning the lamp it is 127.1 °F or 52.8 °C respectively. Similarly for COB type cool white LED the maximum temperature at sink area is 98 °F or 36.6 °C when the lamp is just turn on, which is

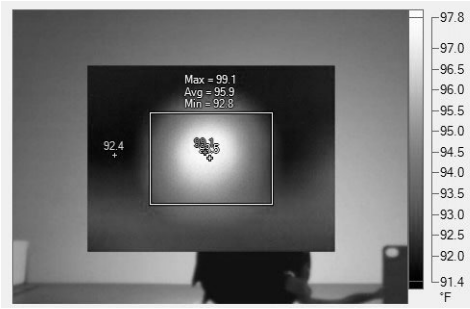

Fig. 2. Thermal image of COB type warm white LED at start-up time

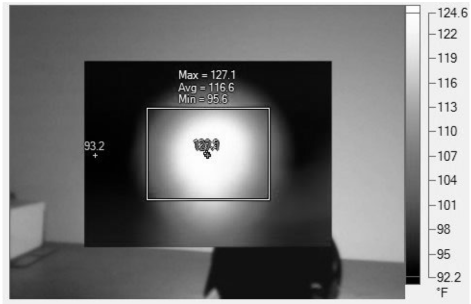

Fig. 3. Thermal image of COB type warm white LED after 60 min burning

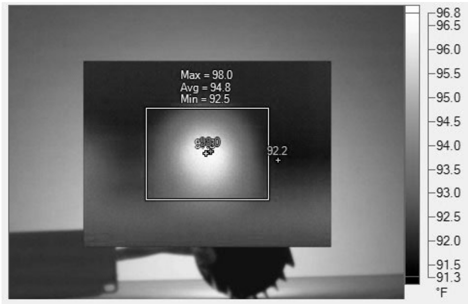

Fig. 4. Thermal image of COB type cool white LED at start-up time

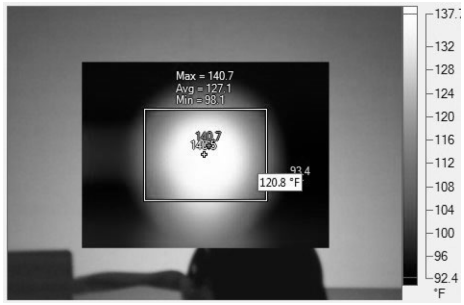

Fig. 5. Thermal image of COB type cool white LED after 60 min burning

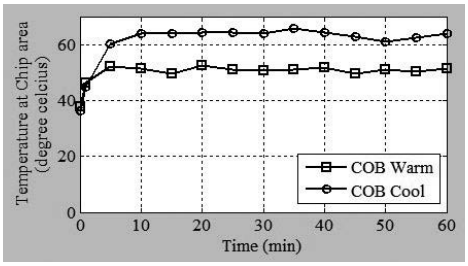

Fig. 6. Temperature at die area for COB type LED with time

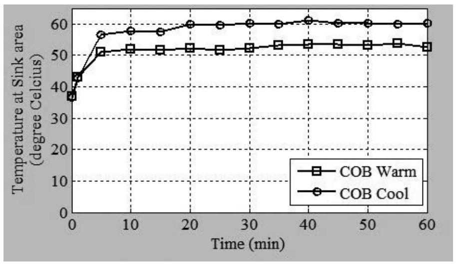

Fig. 7. Temperature at sink area for COB type LED with time

shown in Fig. 4. After 60 minutes of burning time, for same type of LED the temperature is 140.7°F or 60.3 °C which is shown in Fig. 5.

For COB warm white LED the temperature near chip area of the LED is not constant. The temperature increased to about 52 °C at five minutes burning time from its initial start up position. Then the temperature decrease slightly after five minutes to fifteen minutes of the LED's burning time. After that the temperature of the COB warm white LED is near about 50 °C. The temperature near the chip area for both of COB type warm and cool white LEDs are shown in Fig. 6. The temperature is raised up to 63.8 °C for first 10 minutes of its burning time for the COB type cool white LED. After 10 minutes for its burning time to one hour the average temperature of the LED is 64 °C. For both the LEDs the ambient temperature was 29 °C when the measurements have been taken.

The sink area temperature for both of COB warm and cool white LEDs are shown in Fig. 7. Similarly the temperatures at sink area are increased till five minutes of burning time for both the LEDs and after that the temperatures are nearly in constant manner. The temperature rise of COB type warm white LED is lower than COB type cool white LED.

The temperatures near the chip of SMD type warm and cool white LEDs are shown in Fig. 8. The temperatures of both type LEDs are increased for first fifteen minutes of their burning time. After that the temperature of the chip area observed as decrease for five minutes and then the temperature again increased. In this way, the temperatures are varied with respect to their burning time till steady state remains and equilibrium is reached through the

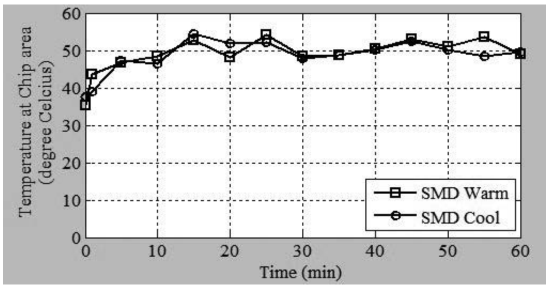

Fig. 8. Temperature at die area for SMD type LED with time

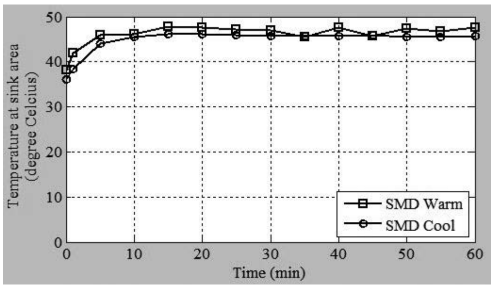

Fig. 9. Temperature at sink area for SMD type LED with time

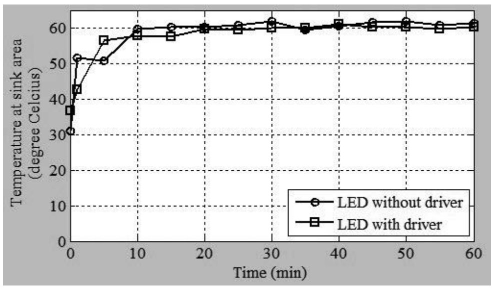

Fig. 10. Temperature at sink area for COB type Cool white LED without and with driver condition

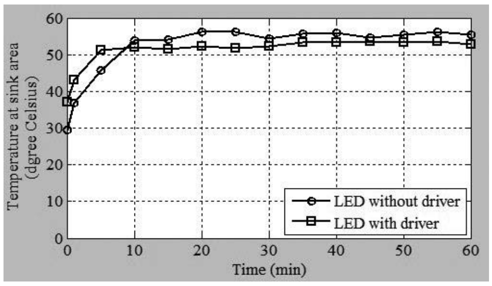

Fig. 11. Temperature at sink area for COB type warm white LED without and with driver condition

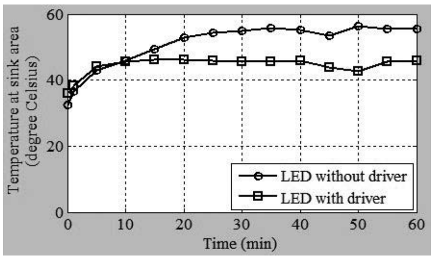

Fig. 12. Temperatures at sink area for SMD type cool white LED without and with driver condition

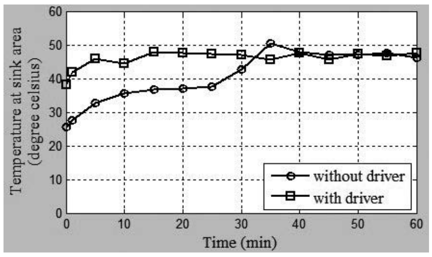

Fig. 13. Temperatures at sink area for SMD type warm white LED without and with driver condition

total generated heat distribution by conduction. For SMD type LEDs the temperature at the chip area of warm white LED is higher than cool white LED.

The temperature at sink area for SMD type warm and cool white LEDs are increased very rapidly within five minutes of their initial power on, which is shown in Fig. 9. After that the heat dissipation from chip area to sink area are occurred and the temperature at sink area of both type LEDs are decreased for few minutes. Because the generated heat from chip is dissipated to the sink area and then the heat at sink area is dissipated to the ambient. Again the temperature of the sink area is increased due to the heat generation of the chip area. The temperature rise at sink area for the SMD type cool white LED is lower than for the SMD type warm white LED.

To compare the temperature at sink area of the LEDs here the studies are occurred without driver. At start up time, the temperature at sink area of the COB type LEDs are less than the previous condition (with driver), which is shown in Table 2. But after ten minutes switch on the COB type Cool white LED for both the condition, the temperature is increased and higher than the LED luminaires with drivers, which is shown in Fig. 10. Similarly in Fig. 11 for COB type warm white LED, the temperature at initial time is lower when the LED devices without connection to driver but supply the DC rated voltage and after ten minute switch on the LED, the temperature is increased.

The sink area temperatures of SMD type warm and cool white LEDs for both conditions (without driver and with driver) are shown in Table 3. The temperature analysis of SMD type cool white LED is the next: the temperature is increased after ten minute of its switch on for when the lamp is without driver condition what is depicted in Fig. 12.

Table 2.Measured temperature distribution in sink area of COB type LED

Sink area temperature,°C				
	COB warm white LED		COB cool white LED	
Time (min)	Without driver	With driver	Without driver	With driver
Initial	29.6	37.0	31.1	36.6
1	36.9	43.0	51.7	42.7
5	45.6	51.2	50.7	56.6
10	53.8	52.0	59.8	57.9
15	54.1	51.6	60.3	57.6
20	56.1	52.2	60.2	59.8
25	56.2	51.7	60.9	59.5
30	54.4	52.2	62.0	60.1
35	55.7	53.3	59.4	59.9
40	55.9	53.4	60.4	61.2
45	54.7	53.5	61.5	60.3
50	55.5	53.2	61.9	60.2
55	56.1	53.7	60.8	59.8
60	55.5	52.7	61.3	60.3

But for a SMD type warm white LED the temperature at sink area is lower up to twenty five minute when LED is without driver condition and after that the temperature is approximately near the temperature when the LED connected with driver, Fig. 13.

The light output of both COB warm and cool white LEDs are decreased when the lamp is switch on and after 10–15 minutes, the light output of cool white LED is increased and near about 4300 lx, but for COB warm white LED the light output is approximately 3800 lx, Fig. 14. Similarly for SMD type LEDs, variation of light output with burning time is shown in Fig. 15. Where for SMD cool white LED the light output is averagely 1500 lx. But, light output characteristics are slightly different for SMD type warm white LED and the average illuminance value is equal to 1460 lx. The light output or illuminance was measured at 1 feet distance from the lamps.

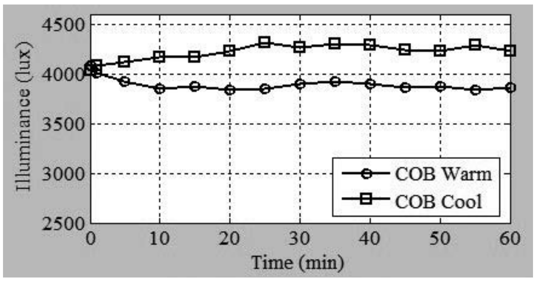

Fig. 14. Light output for different temperature at sink area when time in progress for COB type cool & warm white LEDs

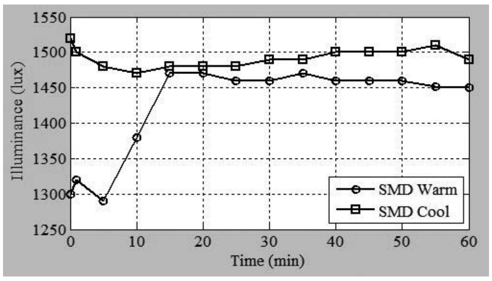

Fig. 15. Light output for different temperature at sink area when time in progress for SMD type cool & warm white LEDs

TEMPERATURE CALCULATION

Here only two types of COB LED module are used for the calculations of the temperature at sink area:

– Maximum case temperature of both the COB module is T_c = 85°;

– Ambient temperature of both COB module is T_a = 45 °C (as declared by manufacturer in their catalogue);

– Diode current, I_D =300mA and diode forward voltage V_f = 18 V dc;

Table 3. Measured temperature distribution in sink area of SMD type LED

Sink Area Temperature,°C				
	SMD warm white LED		**SMD cool white LED**	
Time (min)	**Without driver**	**With driver**	**Without driver**	**With driver**
Initial	25.5	38.2	32.5	36.1
1	27.6	41.9	36.6	38.4
5	32.8	45.9	43.0	44.1
10	35.5	46.1	45.9	45.6
15	36.7	47.8	49.4	46.1
20	37.0	47.5	52.8	46.1
25	37.5	47.2	54.4	45.9
30	42.8	47.0	54.8	45.7
35	50.4	45.6	55.9	45.7
40	48.0	47.5	55.1	45.8
45	47.0	45.7	53.4	43.9
50	47.0	47.3	56.3	42.6
55	47.7	46.8	55.4	45.6
60	46.2	47.6	55.4	45.8

Table 4. Temperature at heat sink area – calculated and measured values

Parameters	**Temperature at heat sink area,°C**	
	COB Cool type LED	**COB Warm type LED**
Calculated Value	63.096	58.096
Measured Value	60.772	55.272

Table 5. Statistical errors between calculated and measured data

Temperature at Heat sink Area	**RMSD,%**	**MBD,%**	**MPD,%**
COB Cool white LED	+ 0.048	+ 4.79	+ 3.824
COB Warm white LED	+0.071	+ 7.17	+6.67

– System power = 5.4 W.

a) For COB Cool white LED:

Maximum junction temperature T_j =105 °C;

Thermal resistance of the COB module $R_{j\text{-}c}$ is 3.6 °C/W, so, the maximum temperature added in the total design is $T_j – T_a$ = 60 °C. Here assume 80 % of total power to be dissipated (P_d) = 0.8 (80 %) × 5.4= 4.32 W;

Thermal resistance of the grease between COB module and heat sink is R_b =0.4 °C/W;

Now calculated case temperature $T'_c = T_j – (R_{j–c}×P_d)$ = 105 °C – (3.6×4.32) = 89.448 °C; Then calculated $T_b = T'_c – (R_b×P_d)$ = 89.448 °C – (0.4× 4.32) = 87.72 °C; Heat dissipated to the ambient (T'_a) is calculated and the value is $T'_a = T_b – (R_{th}×4.32)$ = 87.72 °C – (5.7×4.32) = 63.096 °C, where the thermal resistance of the heat sink R_{th} is 5.7 °C/W;

Now the measured average temperature at heat sink area is 60.772 °C.

b) For COB warm white LED:

Maximum Junction Temperature T_j =100 °C;

Thermal resistance of the COB module $R_{j\text{-}c}$ is 3.6 °C/W;

So, the maximum temperature added in the total design is $T_j – T_a$ = 55 °C;

Here assume 80 % of total power to be dissipated P_d = 0.8, (80 %) × 5.4= 4.32 W;

Thermal resistance of the grease between COB module and heat sink is R_b =0.4 °C/W;

Now calculated case temperature $T'_c = T_j – (R_{j\text{-}c} \times P_d)$ = 100 °C – (3.6 × 4.32) = 84.448 °C;

Then calculated $T_b = T'_c – (R_b \times P_d)$ = 84.448 °C – (0.4 × 4.32) = 82.72 °C;

Heat dissipated to the ambient (T'$_a$) is calculated and the value is

$T'_a = T_b$- (R_{th} × 4.32) = 82.72 °C – (5.7 × 4.32) = 58.096 °C, where the thermal resistance of the heat sink R_{th} is 5.7 °C/W

Now the measured average temperature at heat sink area is 55.272 °C.

The final comparison between calculated and measured values can be seen in Table 4.

COMPARISON OF TEMPERATURE – CALCULATED AND MEASURED VALUES

The temperature measured on heat sink has been validated by calculated values obtained from simulation.

To assess the predictive accuracy of the theoretical simulation model, statistical indicators are used. The dimensionless statistical indicators, Mean Bias Deviation (MBD) and Root Mean Square Deviation (RMSD) are expressed as fractions of mean values during the respective time interval. The mathematical expressions for MBD and RMSD are given in equation (1) and (2) respectively as,

$$MBD = \left[\frac{\sum_{i=1}^{N} \left(T_{cal,i} - T_{meas,i} \right)}{N \times T_{mean}} \right] \times 100 \quad (1)$$

$$RMSD = \left(\frac{1}{T_{mean}} \right) \times \sqrt{\frac{\sum_{i=1}^{N} \left(T_{cal,i} - T_{meas,i} \right)^2}{N}} \quad (2)$$

The Mean Percentage Deviation (MPD) between calculated and measured temperature are given by the equations (3) as,

$$MPD = \frac{\sum_{i=1}^{N} \left[\frac{T_{cal,i} - T_{meas,i}}{T_{meas,i}} \right]}{N} \times 100 \quad (3)$$

The estimated errors between calculated and measured values of temperature at sink area are shown in Table 5.

CONCLUSION

Several experiments have performed for analyzing the nature of temperature distribution with same make of COB and SMD type LEDs, which have a number of applications in lighting field. So, it needs to be taken in consideration for observing the thermal behaviours for these types of LEDs in ambient conditions. The temperature generation at die as well as sink area of a warm white COB LED is lower than cool white COB LED. But for SMD warm white LED, the temperature of die and sink area is higher than the cool white SMD type LED. Another aim of this work is to find the temperature value when the LED lamps are drive with direct DC supply, i.e. directly without driver circuit; for this condition the temperature is almost higher than the LEDs, which are connected with driver circuit. From this temperature analysis designers can modify the construction of the LED for proper heat management.

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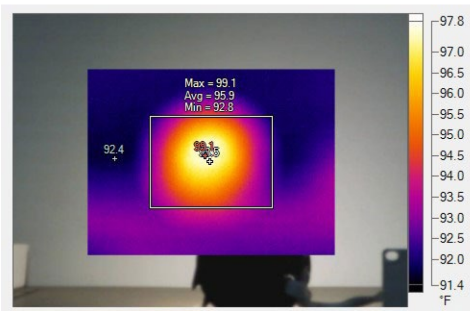
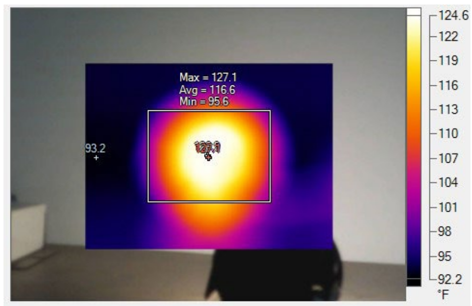


Fig. 2. Thermal image of COB type warm white LED at start-up time



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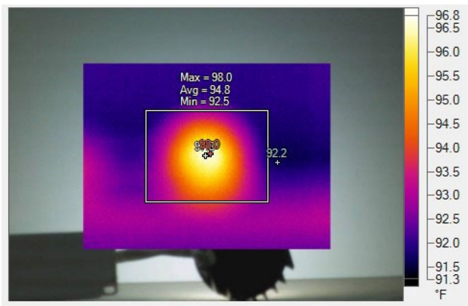
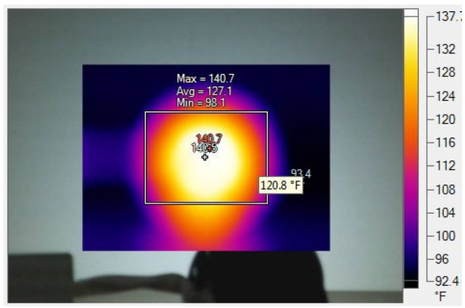


Fig. 4. Thermal image of COB type cool white LED at start-up time



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