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Heat Transfer Analysis of a 7.5W LED Load with Passive and Active cooling for Constant Luminance Applications

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The aim of the present work is to study the thermal performance of a 7.5 W LED load with passive and active cooling and validation of the results using FEA analysis. In order to get a high cooling effect for 7.5W LED load, thermo electric cooling uses the peltier effect to create heat flux between the junctions of two different types of materials. A peltier cooler, which transfer heat from one side of the device to the other with the consumption of electrical energy, depends on the direction of the current. A peltier device (Active heat transfer device) is provided with the LED module for removal of heat generated in the module. The assembly (LED +heat sink +fan +peltier cooler) was tested for varying input power. With the use of the assembly, the junction temperatures were considerably reduced. The results indicate that, the assembly(case 4) performed better than any other cooling combinations. The validation of experimental data was done through FEA analysis.The differences between FEA results and the experimental values were 24%.

Keywords *LED, Active cooling, Passive cooling, Peltier cooler, Heat transfer*

1.0 INTRODUCTION

Globally, LEDs (Light Emitting Diode)are touted as the practical solution to a world going'green.' They are an efficient, reliable and cool-to-the-touch lighting solution. It is correct to say that high power LEDs are efficient, however they do still produce heat as a byproduct, and how to contain that heat is the challenge that faces design engineers today. A standard LED is roughly 10 microns square, runs on 30mA maximum and outputs anywhere from 1mcd to 1000 mcd depending on construction and packaging. These are very unassuming numbers because, as many designers will explain, heat dissipation is a priority. The junction temperature of a standard LED should not exceed 85 to 100°C, depending upon the design and construction. Incorporating these standard LEDs into a design is relatively simple because the small size and low power consumption generates little heat[1]. The challenge that has arisen stems from the new, high-power LEDs that have emerged into the marketplace. A high-power LED can draw 1W of power or greater and output more than 80 lumens. There is a 90% increase in power consumption (98% for a 5WLED). Therefore the amount of heat generated becomes significant. A typical 1WLED will have a maximum junction temperature (a point of failure or reduced life) of 125°C.Also LED can increase the temperature in its immediate environment by 55°C or more. Thermal management is now a critical consideration to the overall product functionality, performance and safety [3].

Today LED lights have taken place of most of the light bulbs. LED is a semiconductor diode which emits lights with the help of electric current. LED bulbs are used for many purposes such as indicator lights in various electronic device, flashlights and area lighting device. LED bulbs can be found in various shapes and colors. The color of emitting

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lights depends on the composition and condition of the semi-conducting materials used[6]. It can be green, red, yellow, infrared or ultraviolet. There are interesting applications also which uses LED bulbs such as UV-LEDs for the sterilization of water and disinfection of devices and to enhance the photosynthesis in plants as a grow light.

There are many types of LEDs and these are miniature, high power, flashing and multi-power LEDs. Every type of LED has different purpose to serve. Miniature LEDs come in different sizes and are used in building LED panels, dashboard backlight, etc. Flashing LEDs are used making attention required indicators. Flashing LEDs have inbuilt multivibrator circuit which makes them to flash. High power LEDs are used in home lighting system or for making LED lamp and the multi-color LEDs are used where two different colors light are needed in one single bulb.

LED is a semiconductor light source. LED's are used as indicator lamps in many devices and are increasingly used for other lighting, appearing as physical electronic components. Early LED's emitted low intensity red light, but modern versions are available across the visible, ultraviolet and infrared wave lengths, with very high brightness.

Though most of the lighting loads prefer passive cooling (cooling with no power consumption), but their performance depends on the property of the material of the heat sink and the ambient temperature. Active cooling (cooling with power) is a must in some of the industrial applications where loss of luminance leads to rejections. Hence,there is a need for LED lighting solutions which provide constant luminance over its period of service. This is possible with efficient cooling systems. With the use of active cooling, the effectiveness of heat transfer increases. This enhances the life of the lighting load and provides the desired constant luminance for a given period of operational time.

In this research work, cooling of 7.5 W LED load was done by employing active cooling where in, the heat at the junction is transferred through the peltier cooler provided with a Heat Sink and fan. The experimental results were validated using FEM analysis.

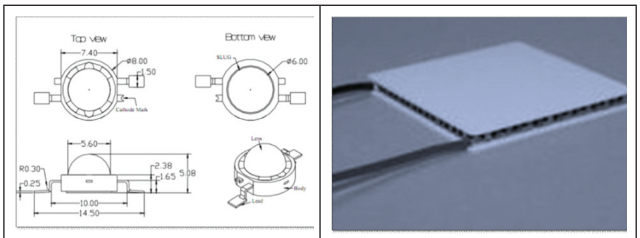
2.0 EXPERIMENTATION

In this study, different methods of heat transfer in an LED by active and passive cooling are explored. Peltier and fan is used for active cooling and Heat Sink is used as a passive cooling device. The experiment has been conducted for 4 different cases by employing peltier cooler (of the shelf), fan and heat sink.The thermocouples are placed on the concerned hardware device such as the junction or heat sink and the other end of the thermocouple wires are connected to the data logger. The required power supply is given to the peltier cooler assembly and is allowed to reach steady state condition. The data acquisition was done for a period of 20 minutes which includes transient and steady state. These temperature values were recorded in an excel sheet using data acquisition system(DAQ). The DAQ consists of a 8 channel data logger (Tracer Make),T-type thermocouples and software. To validate the experimental results Finite Element Method approach is employed where in the 3D module of the assembly was created using modeling package, exported to Finite Element Analysis package, boundary conditions were applied and temperature profile was generated.

TABLE 1 (A)

TYPICAL SPECIFICATIONS OF A LED LOAD

Parameter	Symbol	Value
Forward Current	I_f	800 mA
Power Dissipation	P_d	3.28 W
Junction Temperature	T_j	145 °C
Operating Temperature	T_{opr}	-40 - +80,°C



(A) (B)

FIG 1. 7.5 W LED
(A) SPECIFICATIONS OF AN 7.5 W LED
(B) IMAGE OF THE 7.5 W PELTIER COOLER

The specifications of the select LED, peltier cooler and heat sink are shown in Table 1 (a), 1(b) and 1(c) respectively.

TABLE 1(B)

SPECIFICATION AND PERFORMANCE PARAMETER OF A 7 W PELTIER COOLER

Length	40 mm
Breadth	40 mm
Thickness	3.8 mm
Ceramic material	Alumina, Al_2O_3
Qmax	57 W
Delta (T_{max}–T)	75 °C
I_{max} (Amps)	6.4 A
V_{max} (Volts)	16.4 V

TABLE 1(C)

SPECIFICATION AND PERFORMANCE PARAMETER OF A HEAT SINK

Parameters	**Value**
Density	2700 Kg/m^3
Specific Heat	0.91 KJ/kgK
Thermal Conductivity	205 W/mK
Number of fins	13

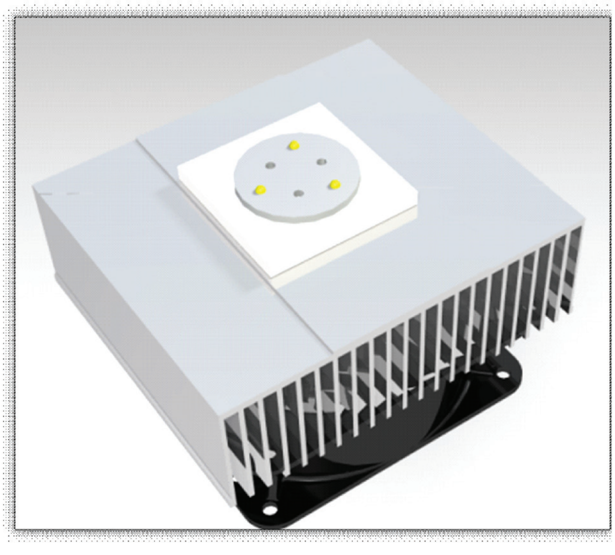


FIG. 2A CAD MODEL OF THE EXPERIMENTAL SET–UP (CASE 4)

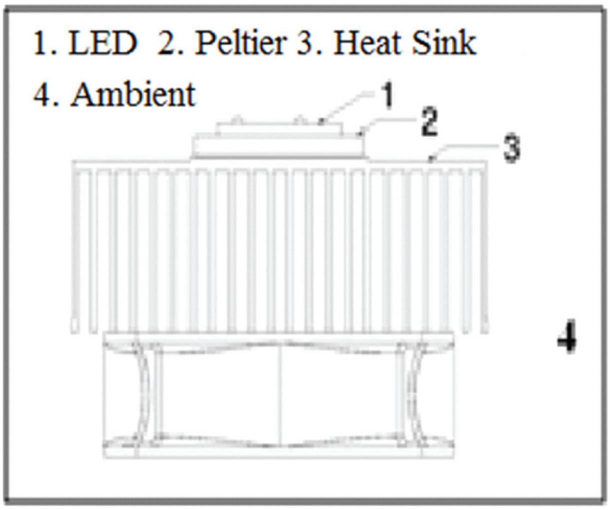


FIG. 2 B VIEW OF THE ASSEMBLY

The CAD model of the assembly is shown in Figure 2a.The thermocouples are placed at the LED junction, peltier hot side, Heat Sinkandambient as shown in Figure 2b. Figure3 shows schematic of the circuitry of the data acquisition system.

Figure 2a and Figure 2b show the CAD drawings of a 7.5 W LED load. The tests were done on four Combinations (case studies):

- Case 1: LED load with heat sink
- Case2: LED load with peltier cooler andheat sink
- Case 3: LED load with heat sink and fan
- Case 4: LED load with peltier cooler, heat sink and fan (Full assembly)

3.0 RESULTS AND DISCUSSIONS

From the experimentation temperatureswere measured at various points in the LED load, heat sink and peltier for all the four cases at different power input i.e. from 4W to 9W. The same experiment is repeated five times for all 4 cases for accurate and good results.The experiments were carried out by considering aluminum heat Sink as a common elementin all the four cases.

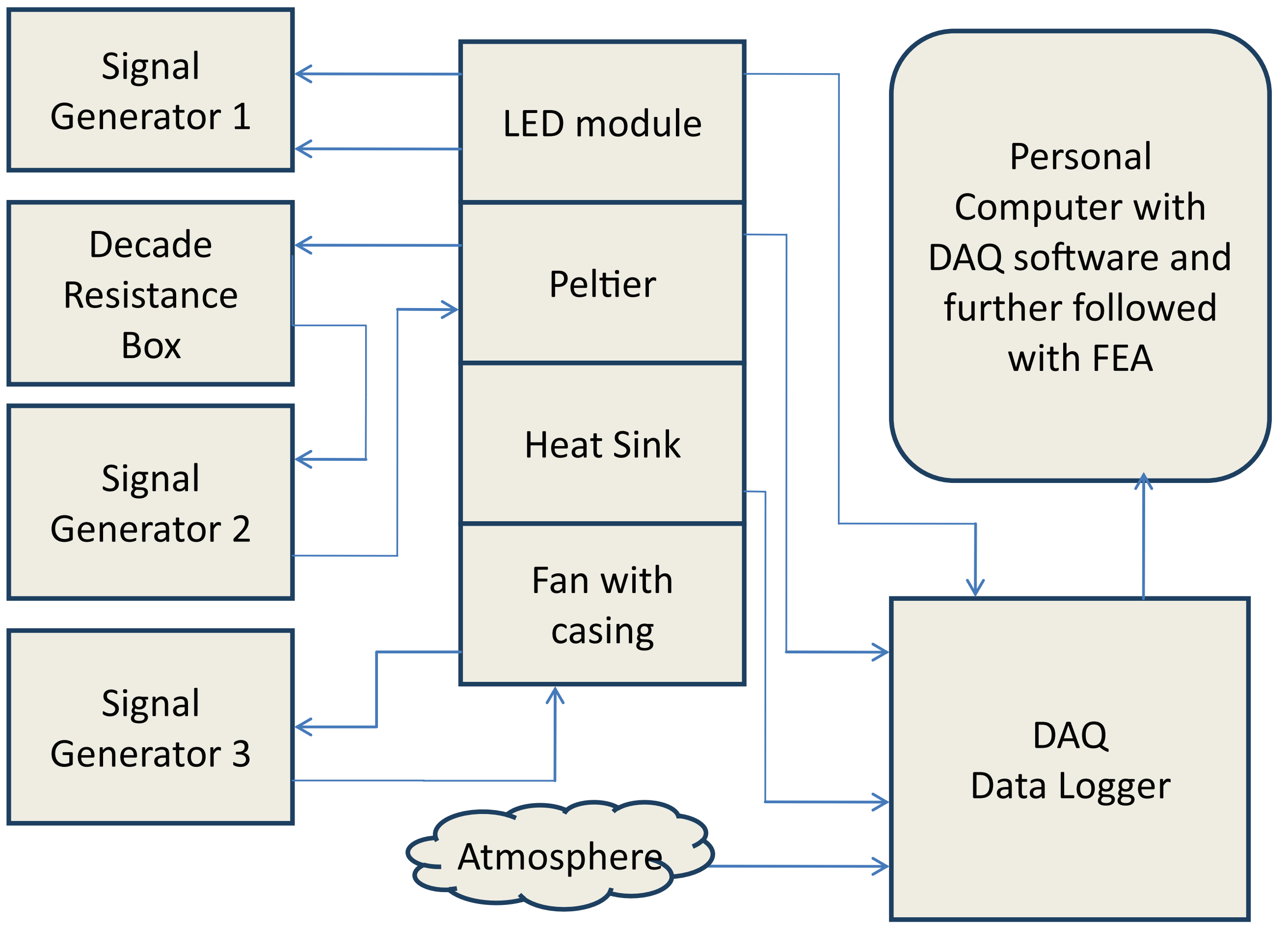
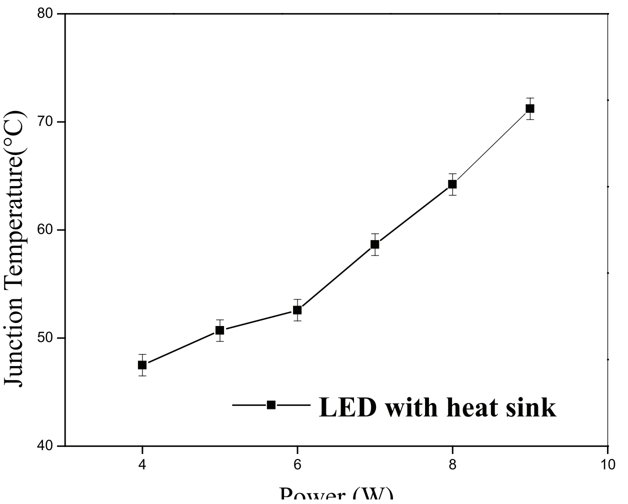


FIG. 3 SCHEMATIC OF THE CIRCUITRY OF FULL ASSEMBLY WITH DATA ACQUISITION

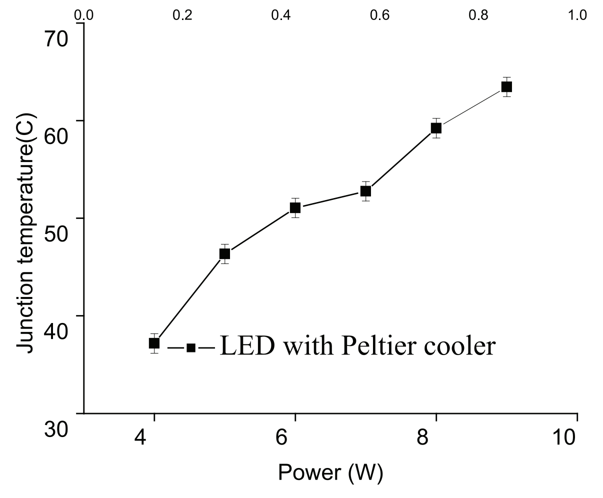
The following section highlights the results on the junction temperature–power coordinate system of all the four cases and a comparison is also presented. The average and standard deviation of data set are computed and one standard deviation is marked on either sides of the average.

Case 1: LED with heat sink

The LED junction attained temperatures of around 58.5°C at 7W power input. The temperature keeps on increasing with time which has to be controlled. This setup enables to find out how well a heat sink performs in dissipating heat under no external power supply (passive cooling only). The variation of junction temperature as a function of input power for LED with heat sink is shown in Figure 4(a). With increase in input power, the junction temperature was also found to increase.



4 A. VARIATION OF JUNCTION TEMPERATURE AS A FUNCTION OF INPUT POWER OF CASE 1



4B. VARIATION OF JUNCTION TEMPERATURE AS A FUNCTION OF INPUT POWER OF CASE 2

Case 2: LED load with peltier cooler

For case 1, it was observed that the junction temperature around 58°C was recordedat 7 W input power and was found to increase beyond the operating temperature range of the LED load due to lack of proper cooling which is not desirable.Hence,the peltiercoolerwas placed between the LED junction and heat sink in order to dissipate the heat from the LED junction. The LED junction temperature reachedaround 53°C and the same temperature was maintained which was withinspecified limits. An improved performance in terms of heat transfer was observed in comparison to case 1 and the difference was found to be around 8%. The variation of junction temperature as a function of input power for LED with peltier cooler and heat sink is shown in Figure 4(b).

Case 3: LED load with heat sink and fan

For positive air circulation around the heat sink, a fan was used as an active cooling device with an input power of 1 W. The variation of junction temperature as a function of input power for LED with heat sink and a fixed supply of 1W power are given to the fan as shown in Figure 4c. The fan with the heat sink maintains the LED junction at a constant temperature at around 52°C at an input power of 7 W. The performance was found to be better than case 1and the difference between case 1 and 3 was found to be around10%.

Case 4: LED load with peltier cooler, heat sink and fan

The peltier, heat sink and fan were all brought together for study. The temperature distribution across the LED load and heat sink was measured. The peltier was effective in transferring heat from the LED junction to the heat sink. The fan provided positive air circulation across the fins of the heat sink leading to improved performance in terms of heat transfer. This resulted in the reduction of junction temperature to around 39°C. This assembly yielded highest efficiency at 7W input power and the difference is 32 %. The variation of junction temperature as a function of input power for LED with peltier cooler, heat sink and a fixed supply of 1W power are given to the fan as shown in Figure 4 d.

4.0 COMPARISON OF LED JUNCTION TEMPERATURE FOR DIFFERENT CASE STUDIES

Comparing the LED junction temperatures for the above four setups, it is observed that the full assembly (case 4) yields a very low junction temperature followed by case 3 and then the case 2. The variation of junction temperature as a function of input power of all four cases is shown in Figure 4e. Poor performance was observed in case 1 for 7 W input.

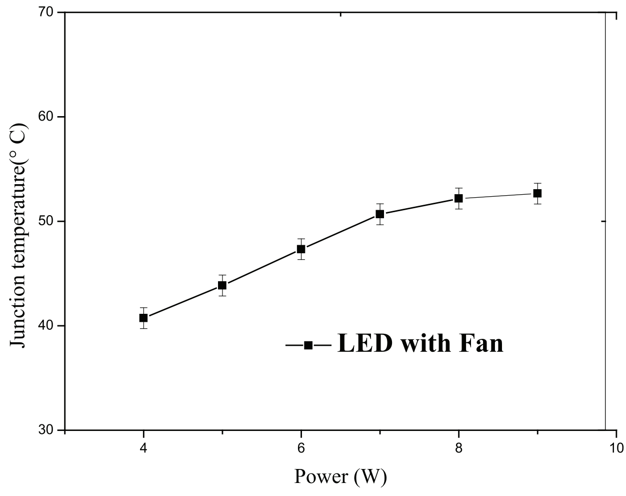


FIG. 4C VARIATION OF JUNCTION TEMPERATURE AS A FUNCTION OF INPUT POWER FOR CASE 3

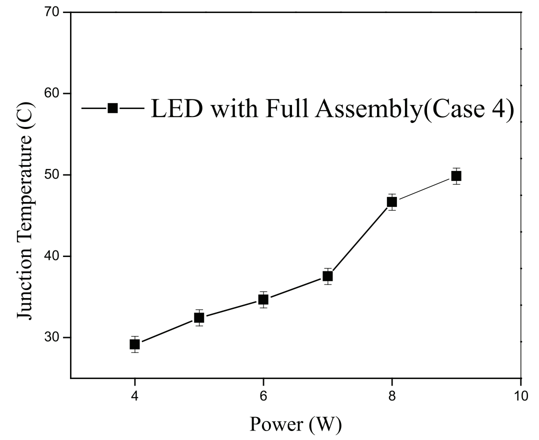


FIG. 4D VARIATION OF JUNCTION TEMPERATURE AS A FUNCTION OF INPUT POWER FOR CASE 4

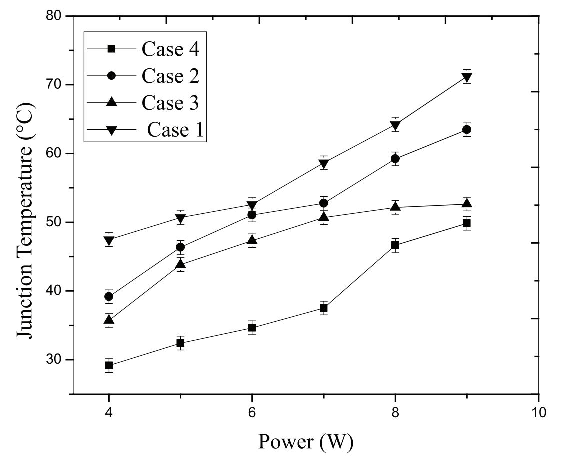


FIG. 4 E COMPARISON OF JUNCTION TEMPERATURE AS A FUNCTION OF INPUT POWER OF ALL CASES

The Table 2 gives the comparison of junction temperature for different power input. The data pertaining to 7 W load is highlighted in the Table 2.

TABLE 2

SHOWS THEJUNCTION TEMPERATURE FOR DIFFERENT CASE STUDIES

Power Supply (W)	**Junction Temperature (°C)**			
	Heat Sink	**Peltier Cooler**	**Fan with Heat Sink**	**Full Assembly**
4	47.48	37.17	40.72	29.15
5	50.68	46.34	43.84	32.42
6	52.57	51.05	47.32	34.64
7	58.64	52.76	50.67	39.82
8	64.2	59.22	52.16	43.64
9	71.2	63.45	52.64	49.64

When the heat sink alone is used for heat dissipation from the LED load, temperatures beyond acceptable values were reached due to which the LED life decreases and also reduces electroluminescence & service life.

The peltier when singularly used along with the heat sink it attains steady state after some duration and maintains the junction temperature within specified operating conditions for the LED. This is only true in case of power supplies ranging from 4W to 8W.The peltier device works satisfactorily when operated at a power input in the range of 4W to 8W for which the peltier cooler is designed. But when the input to the peltier exceeds to 8W the peltier cooler itself generates internal heat and thus cooling is not satisfactory.

When the fan coupled to the heat sink and operated without the peltier the junction temperature was around 50°C which depends on the input power to the fan. The input power to the fan is fixed at 1 W. For an input power 1W to the fan and 4W to the LED, the junction temperature reduced to 38 °C. It is observed that when the peltier cooler along with the fan coupled to the heatsink was used, the heat transfer from the LED module was at its best maintaining temperatures at around 39 °C and ambient temperature (29 °C) at an input power of 4 W.

5.0 FEA ANALYSIS

The CAD model was generated using modeling software and exported to ANSYS for analysis. The computational domain was discretised with about three lakhs hexahedral finite volumes with good mesh quality. The boundary conditions include:

- Atmospheric pressure of zero Pascals gauge pressure was imposed on both the inlets.
- The mass flow rate of air 0.00945 Kg/s is imposed at the fan suction surface.
- Heat flux of 463965 W/m2 is imposed on the shell elements representing the LED base.
- Properties of Aluminium, Peltier and air are imposed on the three dimensional hexahedral elements, at appropriate regions.
- Power input to the LED load is 7 W.

The FEA results of case1 to 4 are shown in Figure 4f to Figure 4i.

Case 1

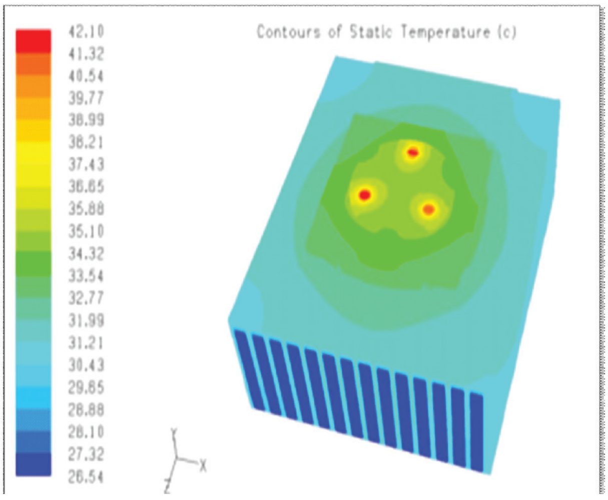


FIG. 4F FEM MODEL OF CASE 1

Case 2

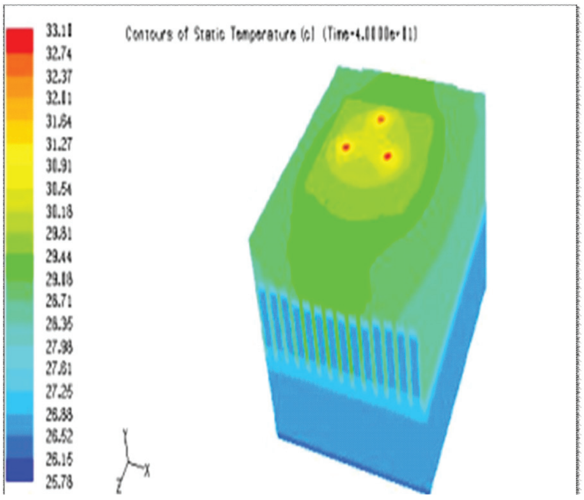


FIG. 4G FEM MODEL OF CASE 2

Case 3

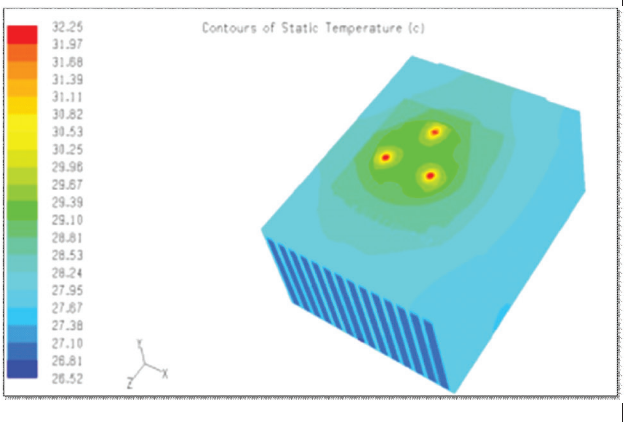


FIG. 4H FEM MODEL OF CASE 3

Case 4

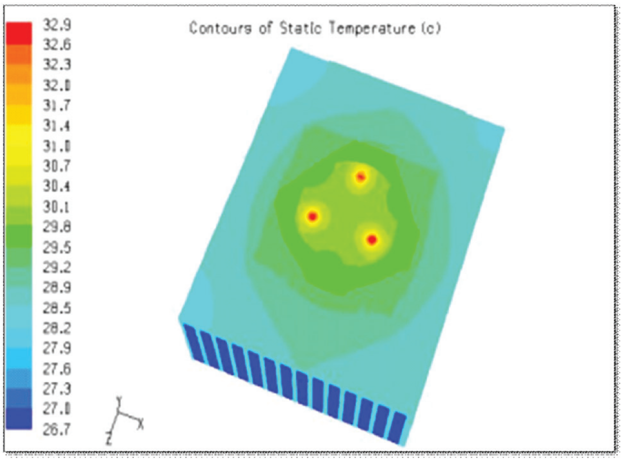


FIG. 4I FEM MODEL OF CASE 4

6.0 COMPARISON BETWEEN EXPERIMENTAL AND FINITE ELEMENT ANALYSIS RESULTS

Comparison of experimental and FEA values of measured junction temperature for various assemblies is presented in Table 3.

The junction temperatures estimated by Finite Element Analysis are less than the experimental results which may be attributed to the following:

For the FEA the internal heat generated in the peltier cooler is not considered where as in the experimental setup the power supply given to the peltier cooler (equal to the power supply of LED) is converted to internal heat, which may contribute for the raise in junction temperature.

Even in the FEA analysis,LED Module with full assembly provides the lowest junction temperature.

In case 1, the LED junction temperatures will be around 42°C for the fixed input power of 7 W and increases with time and reduces the life of the LED as shown in Figure 4(f).

In case 2, the junction temperature attained is 33°C as shown in Figure 4g. The difference between

FEA and experimental results is around 70%. This may be attributed to the fact that the FEA modeling does not account for the heat generated in the peltier cooler due to power supplied to it.

In case 3,with the fan considered the LED junction at a constant temperature at around 32°Cas shown in Figure 4(h).

CFD analysis results have shown that the temperature measured on the LED junction is about 33°C in the presence of peltier, fan and Heat Sink (Case 4) as shown in Figure 4(i).

TABLE 3

COMPARISON OF LED JUNCTION TEMPERATURE

Particulars	**Junction Temp °C**	
	FEA Results	**Experimental Results**
LED Module with Heat Sink	42°C	58°C
LED Module with Thermo Electric Cooler (Peltier effect) and Heat Sink	33°C	52°C
LED Module with Heat Sink and Fan	32°C	51°C
LED Module with Full Assembly	33°C	39°C

7.0 CONCLUSION

i. The peltier device works satisfactorily when operated at a power input of 4 W to 8 W.

ii. If the input to the peltier exceeds 8W of input to LED module, the peltier cooler generates internal heat and thus cooling is not satisfactory.

iii. It is observed that when the peltier cooler with the Heat sink and fan coupled to the heat sink, the heat transfer from the LED module is at its best, maintaining temperatures at around ambient conditions for an input power of 4 W.

iv. When the Heat sink alone is used in heat dissipation from the LED module, temperatures beyond acceptable values are reached which not only reduces the performance of the LED but also reduces electroluminescence and service life.

v. In comparison, the junction temperature in all the 4 cases measured by CFD Analysis is less than the experimental values. The difference between the experimental and CFD is 24% for case 4.

vi. The drawback of the system is that the peltier cooler and the fan also consume power. This adds to the total power consumption of the LED load power. The power requirement of fan is too small (~1 W). The power supplied to the peltier is equal to that of the heat sink. However with the use of the peltier and fan along with heat sink,least junction temperature is maintained which enhances the life of the module and provides constant luminance over a period of time, i.e.,the gain is in terms of reduction in loss of luminance of the LED over a time period of operation which is mandatory in some of the industrial/ medical applications. One such example could be the operation theatre where constant luminance over a prolonged service period.In industrial environment, most of the manual operations need constant luminance for minimizing the rejection rate of defective parts which can be ascertained with this setup.

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