THERMAL ANALYSIS OF 15W LIGHT-EMITTING DIODE PANEL

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Abstract : Thermal management is most occurred problem in Light Emitting Diode (LED) which strongly affects the high performance of LED light. This paper presents, thermal analysis of 15W LED panel using experimental and simulation setup. Temperature is the main parameter for thermal analysis, which is measured by a thermocouple. Results are showing the variation of temperature with respect to operating time at 9 different position of heat sink. The temperature of fins and aluminium base are increases with time and stable after 6-7 hours at 41°C with the environment temperature of 27°C. Simulation also analysed using ANSYS FLUENT Engineering software. The results of simulation and experimental setup are compared at steady state temperature of 41°C. At environment temperature of 27°C, LED panel normally works, but LED panel shows poor reliability at environment temperature of 45°C.

IndexTerms - Light Emitting Diode (LED), ANSYS FLUENT, Thermal resistance and Junction temperature**.**

I. INTRODUCTION

Thermal dissipation has been a serious issue with the invention of high power LED lights. LED has many applications due to their variable colors and long life; it is widely used as indicator, street light lamp, large signs and displays, Liquid Crystal Display (LCD) and decorative lighting. LED Light is more reliable as compare to other lighting source. It has many advantages, such as long lifetime, variable colours, small size, low power consumption, high efficiency[1-3]. The actual thermal performance of an LED luminaire is subject to the thermal environment in a given application. Depending on the amount of ventilation available in a thermal environment, LEDs operate at different junction temperatures in the luminaire and thus have different performance results such as color shift and reduced lifetime. Therefore, successful luminaire designs for LEDs need to consider both the thermal path and thermal environment in order for the luminaire to ensure good thermal performance. LEDs are future lighting technology, because LEDs are consumes 15% energy of the total energy all over the world [3-5].

X. Luo et. al.[3] demonstrate the experimentally research on an 80W LED street lamp is described. The temperature of the street lamp was measured by thermocouples. A numerical model for the street lamp was built, and a comparison of the simulation results with the experimental results demonstrated that the numerical model was feasible for the present 80 W LED street lamp. From the simulation results and thermal resistance analysis it was found that the maximum surface temperature of the aluminium base of the lamp is about 80°C, and the junction temperature of the LED chips is nearly close to 120°C at an environment temperature of 45°C. The maximum junction temperature of the LED chips on the present 80 W LED street lamp would be equal to the critical temperature 120°C, which leads to poor reliability and lower life and optical efficiency of the LED street lamp.

For thermal management of high-brightness LEDs Xiaobing Luo and Sheng Lui [6] are proposed the closed microjet array cooling system. A small heat exchanger is used for the heat transfer between the system and the environment. Experimental investigation and numerical simulation on such a system are conducted. For achieving relatively exact temperature distribution in LEDs, thermocouples are packaged into LEDs and used for the temperature measurement and cooling effect evaluation. The experiments demonstrate that the present system has good cooling ability; however, the microjet device in the experiment needs to be further optimized. In optimization simulation, the effect of several factors such as microjet diameter, top cavity height, micro pump flow rate, and jet device material on the system performance are numerically studied. Based on the Preliminary experiment and numerical optimization, a new microjet device is fabricated and applied in a 220-W white light LED lamp.

Moon-Hwan Chang et. al. [7] presents a comprehensive review for industry and academic research on LED failure mechanisms and reliability to LED developers and focuses on the reliability of LEDs at the die and package levels. Also predict the method for lifetime of LEDs. The lifetime of LEDs are estimated in the accelerated life tests are multiplied by an acceleration factor. The process involves (1) measuring the light output of samples at each test readout time; (2) estimating LED life under the accelerated test conditions using functional curve fitting of time-dependent degradation under the test conditions or finding observed lifetime for L50 or L70, as shown in figure 1; (3) calculating an acceleration factor; and (4) predicting lifetime under the usage conditions by using the acceleration factor multiplied by the lifetime of the test condition.

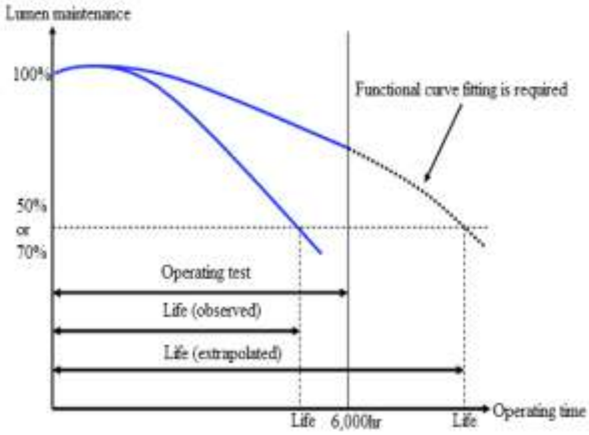

Figure 1: Lifetime estimation based on LED accelerated life testing.

Ross Wilcoxon, et. al. [8] describes thermal modeling and testing of a prototype cockpit display system light engine that uses four Light Emitting Diodes (LEDs) as the light source. Under worst case operating conditions, the local heat flux from these LEDs can be more than 1000 W/cm2. Appropriate thermal management of high heat flux at this level was a critical aspect of the design: it is well recognized that the performance and reliability of LEDs can be significantly affected by their operating temperature. Finite element modeling indicated that the junction temperature of the LEDs in this light engine would be close to their maximum values under worst case conditions. Experimental testing showed good agreement between modeling and the predicted values for the configuration tested, once assembly-related issues in the prototype devices had been identified and eliminated. The modeling indicated that, through the use of exotic materials such as diamond/aluminium composites, the LED temperatures could be significantly reduced below the values obtained in this testing. However, it also showed that relatively small changes in the design, such as the use of an alternate material for the carrier, could lead to substantial reductions in the peak temperatures.

In this paper presents experiment and simulation for single LED chip from a 15W LED panel. Temperature is the Main parameter in the experiment, which measured by a thermocouple. Results are showing the variation of temperature with respect to operating time at 9 different position of heat sink. The temperature of fins and aluminium base is increase with operating time, and stable after 6-7 hours about 41°C with the environment temperature of 27°C. Simulation analysis is also analysing using ANSYS FLUENT Engineering software. The results of simulation and experiment are compared at steady state temperature of 41°C. At environment temperature of 27°C, LED panel normally work, but LED panel shows poor reliability at environment temperature of 45°C.

II. 15W LED PANEL AND ITS THERMAL PATH

Figure 3 is the schematic diagram of the present 15W LED panel. The panel is mainly composed of two parts: 70 high-power LED modules and a mechanical frame for heat dissipation and supporting LED modules. The panel frame consists of an aluminium base and fins, which are made as one integrated design to save fabrication cost and as well as to decrease thermal resistance.70 high-power LED modules are bonded on the PCB and attached with the aluminium base to reduce thermal resistance.

When the electronic power is supplied, LEDs generate light and heat. The heat is dissipated into the environment through the aluminium base and fins. The length of the heat sink is about 16cmX16cm shown in Figure 3. The dimensions of heat sink are shows in figure 2.

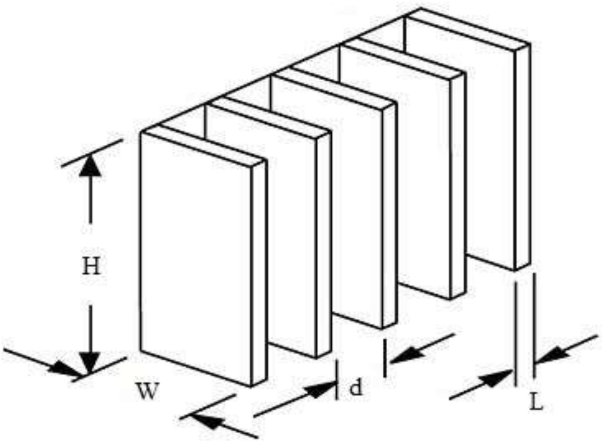

Figure 2: Detail of heat sink used in the experiment LED panel (all dimensions are in cm):- H=1cm, W=0.2cm, d=0.3cm and L=0.15cm.

Low thermal resistance is essential for achieving good thermal and optical performance. The thermal resistance of the 15 W LED panel includes five parts, which are illustrated in Figure 4.
The first part is the thermal resistance (R_{jc}) of the packaging of LEDs, which is related to the chip packaging technology. The second part is the thermal resistance (R_{cb}) of the PCB, at which LEDs are

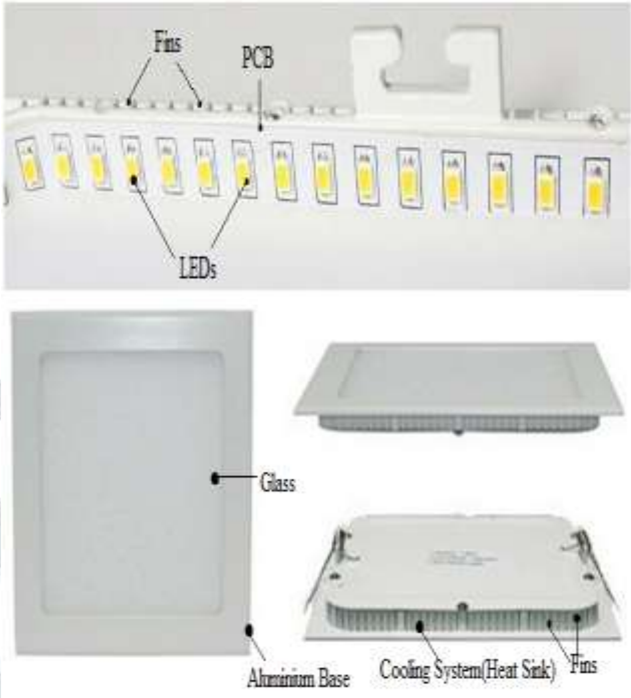

Figure 3: Schematic diagram of the15W LED panel

The third part is the thermal resistance (R_{TIM}) of the bonding between the LED substrate and the aluminium base with fins, determined by the bonding material and thickness. The fourth part is the bulk material resistance (R_H) of the aluminium base with fins, which is associated with the material and size of the panel frame. The last part is the thermal convection resistance (R_{conv}) between the fins and the environment, which is influenced by many factors such as fin structure, area and environment wind speed [3].

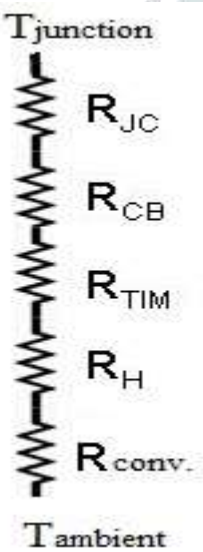

Figure 4: Thermal resistance model of the present 15 W LED panel

The thermal resistance between the LED junction and ambient is the sum of these resistances [6]:

$$R_{th\text{-}total} = R_{jc} + R_{cb} + R_{TIM} + R_{H} + R_{conv}$$

The power dissipated by the LED (P_d) is determined by multiplying the LED's forward voltage (V_f) by its forward current (I_f).

The junction temperature of any given LED can be calculated as following expression [9]:

$$T_j = T_a + (R_{th} \times P_d)$$

III. Experiment Setup

The thermal performance of the 15 W LED panel, the temperature distribution of the aluminium base and fins was measured by thermocouples. Figure 5 shows the experimental set-up of the 15W LED panel. This is a simple methodology to analyze the performance of heat dissipation from single chip LED packages. Since analyzing multi chip LED arrays would be complicate, we start from single chip packages and extend the result to the arrays.

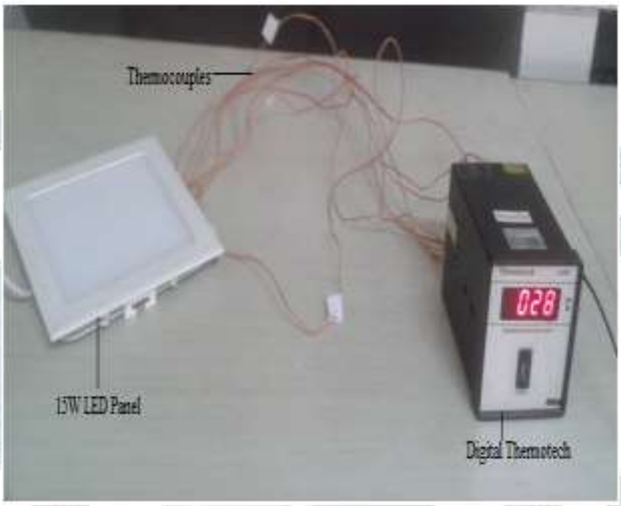

Figure 5: Schematic diagram of the experimental setup for the thermal analysis of 15W LED panel.

The tests were conducted in a natural environment and the 15 W LED panel subjected to natural working conditions. The ambient temperature was about 27°C. Nine thermocouples were placed at 9 different positions of the aluminium base and fins. The temperature data obtained by the thermocouples were transferred to the temperature measurement instrument (thermotech L2002) system and displayed on thermotech L2002. It has 8 channels to collect data. Figure 6 shows the thermocouple distribution on the aluminium base and fins.

In Figure 6, four thermocouples are located on the first fin, and they are numbered T1, T2, T3 and T4; and other four thermocouples are located on the second fin, and they are numbered T5, T6, T7, and T8; and one thermocouple is located on the fins base and it is numbered T9. The dimensions of the fins are shows in figure 2.

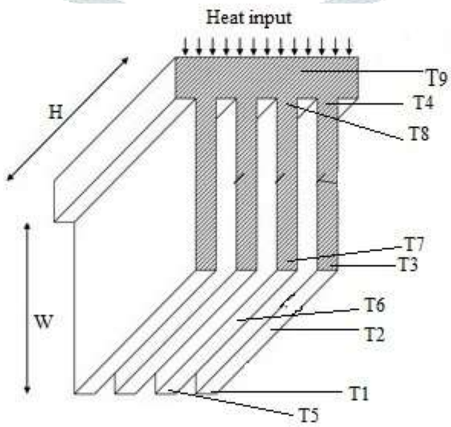

Figure 6: Schematic diagram of the heat sink for the position of thermocouples.

The average heat transfer coefficient of natural convection on the LED panel is calculate using the equation $Q = \alpha A \Delta T$

$$\alpha = \frac{Q}{A\Delta T}$$

Where α is the average convection heat transfer coefficient and Q the heat. A is the heat transfer area of the fins and base, which is about 1.11 cm2. ΔT is the temperature difference between the fin and the environment. Here, the steady average temperature of the fin and base is about 41°C. The environment temperature was about 27°C. Thus, ΔT is about 14 K. In the experiments, the total input power was 15W. Based on our measurements, study on the LEDs and from standard experience on LED chips, about 17% of the input electrical power is converted into optical energy. The other 83% of the electrical power generates heat. Therefore if the input power of the LED panel is 15 W, the heat produced by the LED panel is about 12.45 W, which is mainly dissipated by the fins in the environment [3].

a. Accuracy analysis

A number of factors affect the accuracy of a thermocouple. The errors associated with this experiment mainly included measurement error in the thermocouples and error in reading the digital thermotech. J-type thermocouples (Cu–CuNi) were used in the experiments. The temperature range of digital thermotech is from 0°C to 600°C. For accuracy measurement of thermocouples, use ice bath for 0°C and boiling water for 100°C. The total measurement error was about 1°C.

b. Experiment result and analysis

Figure 7(a) shows the variation of the fin temperature with the operating time for the case shown in Figure 6. In the experiments, the room temperature was about 27°C and there were 9 thermocouples used to measure the temperatures at 9 different positions. The temperatures obtained by the four thermocouples numbered T1, T2, T3 and T4 were used for this description. In Figure 7(a), it can be seen that the fin temperature increased as time extended; initially, the fin temperature was nearly the same as the room temperature. After the LED panel was activated, its temperature increased. Several hours later, it steadied and the temperature remained stable at nearly 41°C. It can also be noted from Figure 7(a) that the temperatures achieved by all thermocouples showed the same trend. The temperature achieved by thermocouple T4 was early increased than the fin tip temperature measured by other thermocouples, which conflicted with the usual understanding about heat sink temperature distribution. In the tests shown in Figure 7(a), the temperature differences among the four thermocouples were very small, less than 1°C. Therefore the temperature difference between thermocouple T4 and other thermocouples display in the figure 7(a). Since the temperature differences among the thermocouples were very small, it can be concluded that the bulk material thermal resistance of the aluminium heat sink was very small and can therefore be neglected.

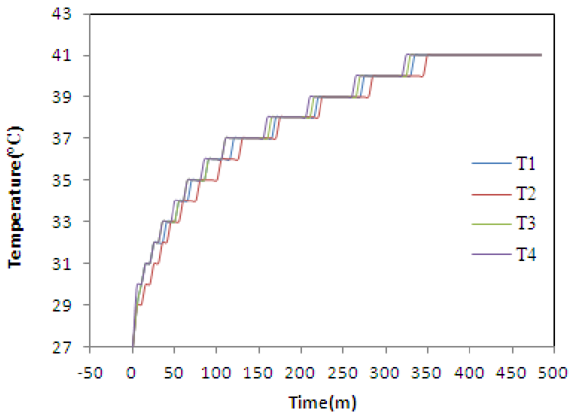

Figure 7: (a) Variation of the fin temperature with operating time.

Figure 7(b) shows the variation of the fin temperature with the operating time for the case shown in Figure 6. The temperatures obtained by another four thermocouples numbered T5, T6, T7 and T8 were used for this description. In Figure 7(b), after 6-7 hours, the temperature remained stable at nearly 41°C. It can also see in above case for first fin noted from Figure 6. The temperature achieved by thermocouple T8 was early increased than the fin tip temperature measured by other thermocouples, which conflicted with the usual understanding about heat sink temperature distribution. In the tests shown in Figure 7(b), the temperature differences among the four thermocouples were very small, less than 1°C. Therefore the temperature difference between thermocouple T8 and other thermocouples display in the figure 7(b).

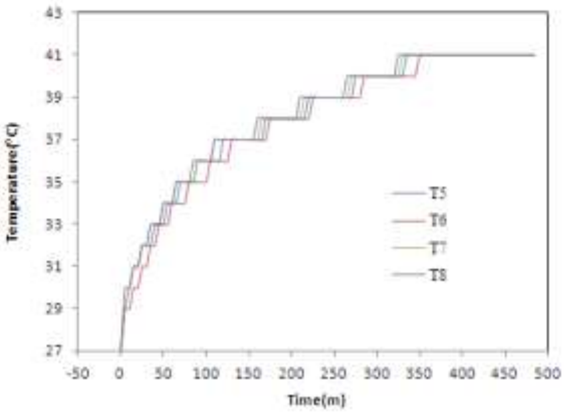

Figure 7: (b)Variation of the fin tenperature with the operating time as shown in figure 6

IV. SIMULATION ANALYSIS

a. Simulation model

The dimensions of simulation model are same as used in experiment. The ambient temperature is 27°C. For the simulation analysis, the basic model of the single LED chip is developed using the ANSYS FLUIENT 14.0.0 software. The basic model is shown in Figure 8. Face area statistics of the model are minimum face area (m2): 1.186119e-08 and maximum face area (m2): 3.113821e-07. The model included 6151 nodes and 27129 elements (thermal solid elements) [8].

b. Boundary conditions

Thermal boundary conditions are applied at the surfaces of the given model such as LED, Fins and Aluminium base. The heat flux value 50W/cm^2 is applied to the LED in the model to define the heat source. For the residual control of the energy equation is $1x10^{-9}$ and continuity equations are $1x10^{-5}$. Table 1 and table 2 showed the model setting and material properties, which are used in simulation analysis.

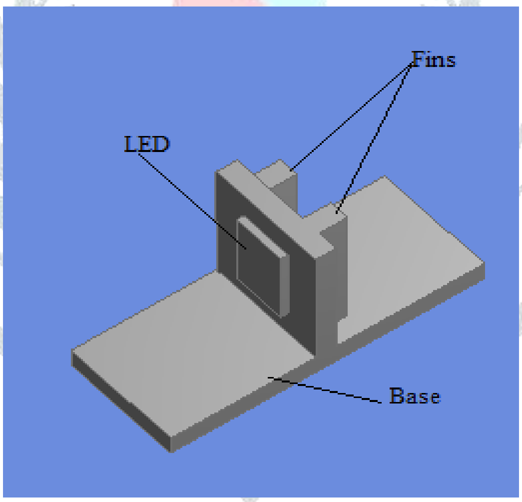

Figure 8: simulation geometry for the single LED chip.

Table 1: Model setting

Model	Settings
Space	3D
Time	Steady
Viscous	Laminar
Heat Transfer	Enabled
Solidification and Melting	Disabled
Radiation	Surface to Surface
Species	Disabled

Table 2: Material property

	Material			
	Air (Fluid)		Aluminium (solid)	
Property	Method	Value	Method	Value
Density (kg/m3)	boussinesq	1.22	constant	2719
Cp(specific heat)(j/kg-k)	constant	2.005	constant	871
Thermal conductivity (w/m-k)	constant	0.0242	constant	202.4
Viscosity (kg/m-s)	constant	15.11	None	#f
Molecular weight (kg/kgmol)	constant	28.966	None	#f
Thermal Expansion Coefficient(1/k)	constant	3.34	None	#f
Speed of Sound (m/s)	none	#f	None	#f

c. Simulation results

Figures 9(a) and figure 9(b) are shows the temperature contours of the simulated temperature distribution of the single LED chip with operating time. For the simulation process environment temperature is 27°C. The temperature at the chip module contact spot is the highest. The temperature in most of the area, around the chip is nearly the same, about 41°C. In the aforementioned experiments, all 9 thermocouples are placed around the LED chip modules, the measured temperature values are nearly the same, and the simulation results shown in Figure 9(a) clearly explain and demonstrate the phenomena. It can also be seen that the temperature of the fin and aluminium base at the corner of the lamp is the lowest, 37°C. This low temperature area is very small.

V. From Figure 9(a), the thermal spreading resistance can also be estimated because the total temperature distribution is obtained, which is different from the former experimental measurement. Actually, for all the LED products including the present 15 W LED panel, the junction temperature of the single LED chip is the main concern, which directly determines the life and luminescence efficiency of the LED panel.

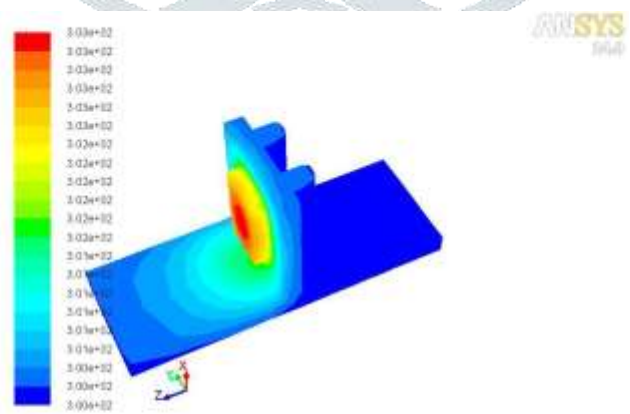

Figure 9 (a) Side view of temperature distribution for single LED chip at 27°C.

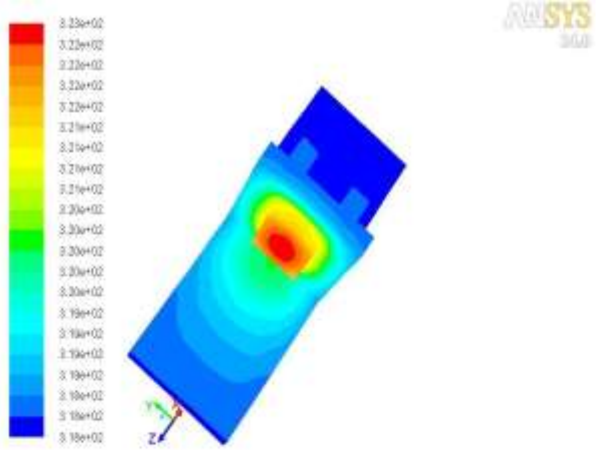

Figure 9: (b) Front view of temperature distribution for single LED chip at 45°C.

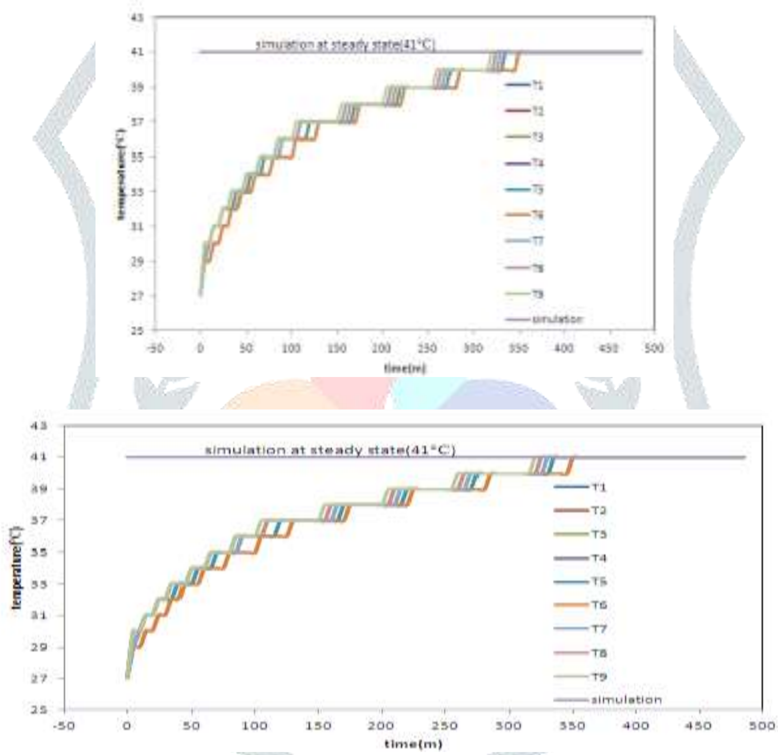

Figure 10: Temperature comparison between experiment and simulation

To verify the simulation model, figure 10 shown the variation of temperature with operating time, comparison between experiment and simulation. From figure 10 see that the steady simulation temperature at the location where thermocouple T4 was placed about 41°C and the steady state of experiment measured by the thermocouple T4 is same. The steady state temperature of simulation results are also compared with the temperature reading of other thermocouples at the same positions in the experiment.

VI. CONCLUSIONS

This paper demonstrates that the thermal analysis of 15W LED panel. Nine thermocouples were used to measure the temperature points on the aluminium base and fins. The experimental and simulation results shows that the heat flow in heat sink is depend on the various factors such as structure, thermal resistance of heat sink and speed of wind around the heat sink of LED panel. The results of simulation and experiment setup are compared at steady state temperature of 41°C. At environment temperature of 27°C, LED panel is normally working but LED panel have poor reliability at environment temperature of 45°C.

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