
EXPERIMENTAL ANALYSIS OF NATURAL CONVECTION HEAT TRANSFER AROUND RADIAL HEAT SINK

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Abstract

In this study, a systematic approach is adopted to study the natural convection heat transfer from rectangular fin array. The experiment set up consists of the different aluminum radial fin structures and nine thermocouples placed at different location on fin structure to measure fin surface temperature and base temperature. Experiments are performed and steady-state observations are recorded. Taguchi method is applied to manufacture different fin array structures which use only a portion of the total possible combinations to estimate the effects of main factors and the effects of some of the interactions thus minimize the number of tests required. For this Taguchi L9 orthogonal array was used, which has nine rows corresponding to the number of tests, with three columns at three levels. By using Taguchi optimization technique, nine different models were manufactured by varying length of fin, height of fin and number of fins. From this one optimum design will be found out using MINI TAB software. The experimental result are validated by using CFD software.

1. Introduction

The LED light bulb is a low power and highly efficient light source. It is superior to the conventional light bulb or florescent light in terms of energy efficiency, intensity of illumination, lifetime, and durability. Due to these advantages, the conventional light bulbs are gradually replaced by LED light bulbs. However, the LED light bulb is relatively expensive and may have

Received: 15.9.2025

Revised: 20.10.2025

Accepted: 31.10.2025

Published Online: 10.01.2026

Keywords: CFD, Fins, Taguchi, MiniTab,

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How to cite this article: Sandip S. Kale, Experimental analysis of natural convection heat transfer around radial heat sink, KT Journal of Mechanical Engineering, 2(2), 2025, 19-32. <https://doi.org/10.64188/3048956325022>

problems such as transition of color temperature, degradation of light efficiency, and short lifetime due to the increase of junction temperature. When the size of the LED component increases, the injection of the operating current increases and internal and external quantum efficiency degrades, which result in decreasing the amount of light and shortening its lifetime. In order to meet the expected long lifetime, LED lamps must operate below a certain temperature threshold, as given by the manufacturer. To resolve the heat radiation problem in LED light bulbs, the basic solution is the optimum design of the heat sink fin structure. The motivation for this project was the call to minimize the LED junction temperature for down-lighting applications by appropriately designing the convection flow pattern and heat sink geometry.

This project presents a numerical study concerning an improved heat sink for a light emitting diodes (LED) lamp operating under natural convection conditions. Basic geometry of the heat sink is radial, to be obtained by cutting aluminium extruded bar comprising a cylindrical central core and several uniformly distributed rectangular fins. Minimum diameter of the central core is fixed and the parameters to be explored are the number of fins, length and height. Different heat sink models will be manufactured by varying this parameter and applying the Taguchi method which uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. A radial heat sink would be ideal because LED lights are generally round. A radial heat sink can provide uniform cooling performance to improve the reliability of LED lights. The main objective of the heat sink is to cool the LED lamp so that the lamp maximum temperature at the contact region with the heat sink is maintained below the critical temperature given by the manufacturer. This is a crucial aspect in what concerns the expected lifetime of the LED lamp and should be achieved at the expenses of as low as possible aluminum mass. Parametric studies is performed to compare the effects of three geometric parameters (fin length, fin thickness, fin height, and number of fins) of operating parameter heat flux on the thermal resistance and the average heat transfer coefficient for the heat sink array and optimum design will be found from various fin structure array using MINI TAB software.

2. Literature Review

They performed experimental investigation of heat sink for cooling of electronic devices. The experimental study is based on measurement of temperature, flow and pressure, infrared radiometry, and high-speed digital video imaging. Veretel XF was chosen as the working fluid which is a dielectric fluid characterized by nonflammability, chemical and thermal stability and low toxicity. The heat sink has parallel triangular micro channels with a base of 250 μm . Experiments on flow boiling of Vertrel XF in the micro channel heat sink are performed to study the effect of mass velocity and vapor quality on the heat transfer, as well as to compare the two-phase results to a heat sink cooled by single-phase water flow. For cooling by Vertrel XF, the maximum temperature difference on the surface did not exceed 4–5 K, whereas for cooling by water this difference was about 20 K, at comparable flow rates [1]. They developed the heat sink for microelectronics application, which are compatible with sustainable development, involves the

achievement of a subtle balance between superior thermal design, minimum material consumption and minimum pumping power. He studied heat transfer from fin array for both natural and forced convection. He conclude that to achieve the maximum thermal performance in an air-cooled heat sink it is necessary to develop high fin count heat sink designs with high aspect ratio fins, which will operate at high pressure drop and moderate air flow rates. This presentation explores the potential for the less energy optimization of natural and forced convection cooled rectangular plate heat sinks. The results evaluated in terms of a heat sink coefficient of performance, relating the cooling capability to the energy invested [2]. They presented a numerical study for an improved heat sink for a light emitting diodes (LED) lamp operating under natural convection conditions. Basic geometry of the heat sink is of cylindrical nature, obtained by cutting a aluminium extruded bar comprising a cylindrical central core and several uniformly distributed radial fins. Minimum diameter of the central core is fixed and effect of number of fins, their thickness, length (radial dimension) and height was investigated. The main objective was to find the improved geometrical configuration for a heat sink operating under natural convection conditions, to be used for the cooling of a recent FORTIMO 4th generation LED lamp and to achieve a maximum core temperature of 65 °C keeping the heat sink total mass and occupied volume contained. Basic configuration led to a core temperature 22.65 °C above the required limit, the objective core temperature of 65 °C was reached by increasing the number of fins and their height and reducing the fin thickness. These geometrical modifications lead heat sink mass increase by 0.047 kg, but with considerable temperature decrease which was the main requirement [3]. They presented the work which was focused on the numerical study of steady, laminar, conjugate natural convection in a square enclosure with an inclined thin fin of arbitrary length. The inclined fin is attached to the left vertical thin side of the enclosure while the other three sides are considered to have finite and equal thicknesses of arbitrary thermal conductivities. The left wall of the enclosure to which the fin is attached is assumed heated while the external sides of the other three surfaces of the enclosure are cooled. The inclined thin fin is perfectly conductive and is positioned in the middle-heated surface of the enclosure. Three different fin lengths equal to 20, 35 and 50 percent of the heated surface are considered. The problem is formulated in terms of the vortices-stream function procedure. A numerical solution based on the finite volume method is obtained. Representative results illustrating the effects of the thin fin inclination angle and length and the thermal conductivity of the thick surfaces on the streamlines and temperature contours within the enclosure are reported. In addition, results for the local and average Nusselt's numbers are presented and discussed for various parametric conditions [4]. Experimentally investigated for different fin spacing and fin lengths the natural convection heat transfer and fluid flow characteristics in horizontal and vertical narrow enclosures with heated rectangular finned base plate at a wide range of Rayleigh number (Ra). Comparisons of finned surface effectiveness (ϵ) and heat transfer rate between horizontal and vertical enclosures have been reported. In comparison with enclosure of a bare base plate, insertion of heat conducting fins always enhances heat transfer rate. Optimization of fin-array geometry has been addressed. The results gave an optimum fin spacing at which Nusselt number (Nu) and finned surface effectiveness (ϵ) are maximum. It has been found that:

(1) increasing fin length increases Nu and e ; (2) increasing Ra increases Nu for any fin-array geometries and (3) for any fin-array geometry and at $Ra > 10,000$, increasing Ra decreases e while for fin-array geometries of large fin spacing and at $Ra < 10,000$, increasing Ra increases e . Useful design guidelines have been suggested. Correlations of Nu have been developed for horizontal and vertical enclosures [5].

They heat transfer characteristics of square pin fin heat sinks subject to the influence of orientation are examined under natural convection. A flat plate and seven square pin fin heat sinks with various arrangements are tested under a controlled environment. He concluded that the downward facing orientation yields the lowest heat transfer coefficient. However, the heat transfer coefficients for upward and sideward facing orientations are of comparable magnitude. It is found that the performance of sideward arrangement exhibits a greater dependence on fin structure [6]. They designed four different types of fin shape and structure and optimum heat sink for a 30 W chip on board (COB) LED down-light was found. Each design has a total surface area of 181 m². The dimension of the four heat sinks is 20 mm × 120 mm × 62 mm. The thickness of the base and fin is 7 mm and 2.8 mm, respectively. The heat sink is made from aluminum. The thermal analysis for the four different types of heat sink is performed with SolidWorks Flow Simulation, a thermal analysis simulator. Four different types of heat sink are simulated and an optimum structure of the heat sink is found. The simulated temperature of the heat sink when operating the LED down-light is 54.9°C, which is only a difference of 2°C from the measured temperature. To reduce the temperature further, a copper spreader is introduced to the heat sink. The temperature of the heat sink with the copper spreader is 3°C lower than without the copper spreader [7]. They investigated the comprehensive description of the thermal conditions within a heat sink with rectangular fins under conditions of cooling by laminar forced convection. The analysis, in which increasing complexity is progressively introduced, uses both classical heat transfer theory and a computational approach to model the increase in air temperature through the channels formed by adjacent fins and the results agree well with published experimental data. The calculations show how key heat transfer parameters vary with axial distance, in particular the rapid changes in heat transfer coefficient and fin efficiency near the leading edges of the cooling fins [8]. They investigated the effects of orientation and geometry on natural convection cooling with the help of finned surfaces. In lengthwise short array where single chimney flow pattern is present, a stagnant zone is created at the central bottom portion of fin array channel and hence it does not contribute much in heat dissipation. An experimental setup is developed for studying the investigation on normal and inverted notched fin arrays (INFAs). Fin spacing, heater input, and percentage of area removed in the form of inverted notch are the parameters. For few spacing, it is verified by computational fluid dynamics analysis and the results are well matching. It is found that the average heat transfer coefficient for INFAs is nearly 30–40% higher as compared with normal array [9]. They discussed a three-dimensional model of heat transfer and fluid flow in noncircular micro channel heat sinks which is developed and analysed numerically. It is found that Nusselt number has a much higher value at the inlet region, but quickly approaches the constant fully developed value. The temperature in both solid and fluid increases along with the flow direction.

In addition, the comparison of thermal efficiencies is conducted among triangular, rectangular, and trapezoidal micro channels. The result indicates that the triangular micro channel has the highest thermal efficiency [10]. They investigated experimentally mixed convection heat transfer from longitudinal fins inside a horizontal channel has been investigated for a wide range of modified Rayleigh numbers and different fin heights and spacings. An experimental parametric study was made to investigate effects of fin spacing, fin height and magnitude of heat flux on mixed convection heat transfer from rectangular fin arrays heated from below in a horizontal channel. The optimum fin spacing to obtain maximum heat transfer has also been investigated. During the experiments constant heat flux boundary condition was realized and air was used as the working fluid. The velocity of fluid entering channel was kept nearly constant using a flow rate control valve so that Reynolds number was always about $Re = 1500$. Experiments were conducted for modified Rayleigh numbers $3 \times 10^7 < Ra < 8 \times 10^8$ and Richardson number $0.4 < Ri < 5$. Dimensionless fin spacing was varied from $S/H = 0.04$ to $S/H = 0.018$ and fin height was varied from $H_f/H = 0.25$ to $H_f/H = 0.80$. For mixed convection heat transfer, the results obtained from experimental study show that the optimum fin spacing which yields the maximum heat transfer is $S = 8-9$ mm and optimum fin spacing depends on the value of Ra [11]. They experimentally and numerically investigated the natural convection in a radial heat sink, composed of a horizontal circular base and rectangular fins. The general flow pattern is that of a chimney; i.e., cooler air entering from outside is heated as it passes between the fins, and then rises from the inner region of the heat sink. Parametric studies are performed to compare the effects of three geometric parameters and a single operating parameter (heat flux) on the thermal resistance and the average heat transfer coefficient for the heat sink array. In addition, a correlation is proposed to predict the average Nusselt number for a radial heat sink [12].

He established an analytical model for thermal performance and optimization of a constructed fin subject to variable thermal conductivity of fin material and convective heat transfer coefficient over the fin surface. For the adaptation of these considerations, the governing energy equation for the stem as well as the flange becomes nonlinear. A new analytical scheme based on the A domain decomposition method has been established for the solution process. As the present study is an analytic, it can be extended to the analysis for determining the optimum dimensions of fins satisfying either the maximization of rate of heat transfer for a given fin volume or the minimization of fin volume for a desired heat transfer rate. From the results, it can be highlighted that the present model predicts the fin performance always an under value in comparison with that the published results whereas the optimum heat transfer rate determined by using the present analysis gives an over value. The effect of different geometric and thermos-physical parameters on both the fin performance and optimization has been studied. For a comparative study, the present and published results are executed for a wide range of thermal geometric parameters [13]. He studied numerically the laminar free convection about a single pin fin attached to a horizontal base plate has been reported in this article. Fluid at the far field moves horizontally towards the fin and then rises almost vertically along the fin and finally leaves through the top. For short fins, convection rather than the conduction is the controlling mode and this renders the fin thermal

conductivity a parameter of little importance for such fins. Heat flux at the base of the fin decreases with increase in fin diameter confirming the benefits of large number of thinner fins. The upper bound of rate of heat transfer from any horizontal heat sink with circular pin elements may be determined with the use of the correlation developed in the investigation. Comparison of heat transfer so calculated for a heat sink with the recently published results indicates that the percentage difference between the two results decreases with increasing plate temperature [14]. They investigated the cooling performance of electronic devices. In the present study the effect of pin-finned heat sink has been investigated for steady state laminar flows. The optimization of the fin profile to transfer the highest power with the smallest volume is a problem that is not yet completely solved. Therefore, the optimized fins have been the desire of the designer. In this work, the square pin fin heat sink with twisted fin profiles for different angles of twist for laminar flows have been numerically simulated for thermal performance using the CFD module FLOTRAN of ANSYS UNIGRAPHICS system to optimize the structural design of the square pin fins. From the studies carried out it was found that the enhancement in thermal performance is achieved by twisting the square pin fins of the heat sink. The methods followed for numerical simulation is validated against the analytical results [15-19].

3 Methodology

3.1 Types of extended surfaces (fins)

1) Straight fins, 2) Tapered fins and 3) circular Fins

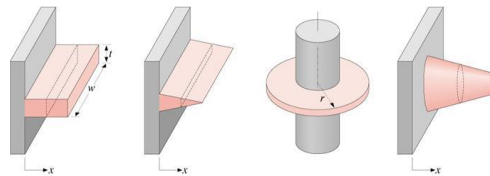


Fig. 1. Types of Extended Surfaces

4.1 Experimental Setup

The experimental set up consist the different aluminum fin structures and nine thermocouples are placed at different location on fin structure to measure fin surface temperature. Basic geometry of the heat sink is radial, is obtained by cutting an aluminum extruded bar comprising a cylindrical central core and several uniformly distributed rectangular fins. Minimum diameter of the central core is fixed and the parameters to be explored are the number of fins, length, and height. Different heat sink models will be manufactured by varying this parameter and applying the Taguchi method which uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. Circular heater is placed on insulating material called Sindanyo to prevent the heat loss, and radial sink is placed on top of the heater so that all the heat is transferred to sink. A groove of 4 mm is done on the insulating material so that heater and heat assembly doesn't move. The array is placed in a sufficiently large enclosure to provide natural convection condition. Calibrated thermocouples with temperature indicator are used to measure temperatures at various

locations of fin array. Total nine thermocouples are used out of which four are attached to base of fin and other four are mounted on fins. Dimmer stat is provided to change the current to the heater.

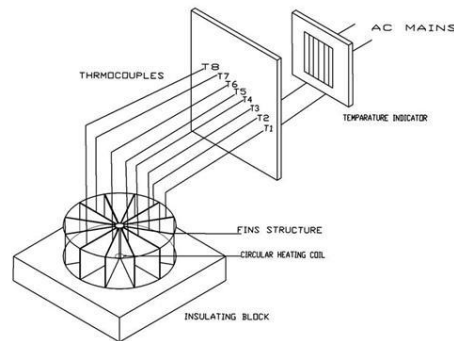


Fig. 2. Block diagram for experimental analysis of natural convection

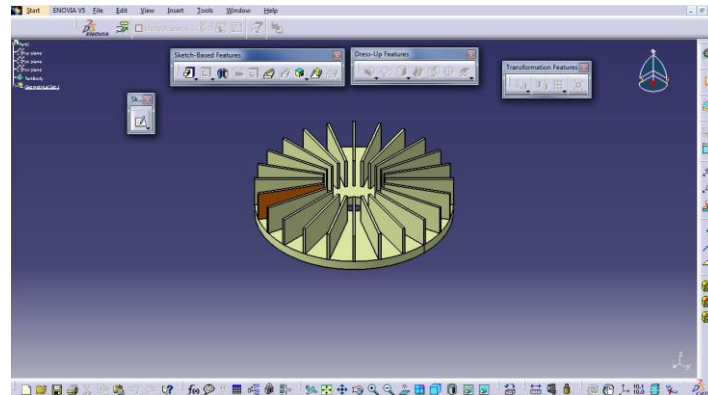


Fig. 3. Model 1 on CATIA software

Similar model manufactured based on specification according to Taguchi optimization by using CATIA software. Same model is sent to VMC machine by using different manufacturing process.



Fig. 4. Machining of heat sink model on VMC

4.2 Experimental Investigation

In the present work it is proposed to study the heat transfer coefficient and thermal resistance by around radial heat sink and its performance analysis.

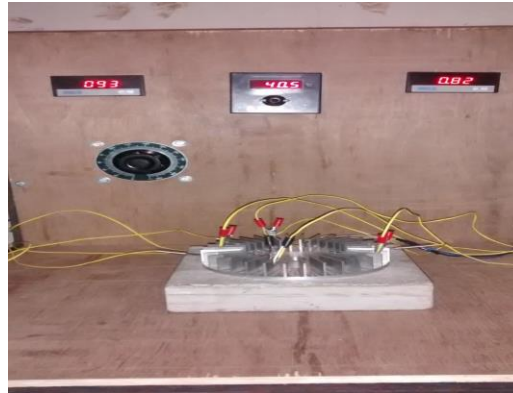


Fig. 5. Experimental set up diagram

5.3 Design of experimentation by Taguchi methodology

The Taguchi method is efficient for a design problem with several parameters and is frequently used in industry because it can readily improve a reference model based on the objective function without repeating experiments. For example, the computational effort required for the Taguchi method increases little when the number of design parameters increases unlike the response surface method. Also, the Taguchi method is superior in applying an optimum design to real products because it proposes an optimum model based on a combination of feasible design parameters. Thus, the Taguchi method is especially effective for improving the design of products that have already been manufactured. There are many ways to design a test, but the most frequently used approach is a full factorial experiment. However, for full factorial experiments, there are two possible combinations that must be tested therefore it is very time-consuming when there are many factors. In order to minimize the number of tests required, fractional factorial experiments (FFEs) were developed. FFEs use only a portion of the total possible combinations to estimate the effects of main factors and the effects of some of the interactions. Taguchi developed a family of FFE matrices which could be utilized in various situations. These matrices reduce the experimental number but still obtain reasonably rich information. The conclusions can also be associated with statistical level of confidence. In Taguchi's methodology, all factors affecting the process quality can be divided into two types: control factors and noise factors. Control factors are those set by the manufacturer and are easily adjustable. These factors are most important in determining the quality of product characteristics. Parametric optimization in laser micro-engraving is to find out the main control factors and select their appropriate levels. For the hardware used in this project, typical control factors include average laser power, engraving speed, pulse repetition rate, beam

expansion ratio and lens focal length. Noise factors, on the other hand, are those undesired variables that are difficult, impossible, or expensive to control, such as the ambient temperature, humidity and ageing of parts. The major steps of implementing the Taguchi method are: (1) To identify the factors/interactions, (2) To identify the levels of each factor, (3) to select an appropriate orthogonal array (OA), (4) To assign the factors/interactions to columns of the OA, (5) To conduct the experiments, (6) To analyze the data and determine the optimal levels, and (7) To conduct the confirmation experiment.

4. Results and Discussion

The experimental investigation and the calculations were discussed in the last chapter. Now the present chapter deals with interpretation of the obtained results. Parametric studies were carried out by numerically investigating the effects of the number of fins, fin length, fin height, and heat flux on the thermal resistance and the heat transfer coefficient. Find out one optimum design from various fin structure (heat sink) Compare the temperature difference between the experimental and numerical results. Experimental investigations of local heat transfer characteristics and study the mechanism of convective mode of heat transfer. The effects of various parameters and compared the different result that are observed and calculate various output parameters like as temperature difference, mass of heat sink, thermal resistance, heat transfer coefficient, and effectiveness of fin. The following are resulting graphs with calculated value of above parameters like as ΔT , M , R_{th} , h for respective model.

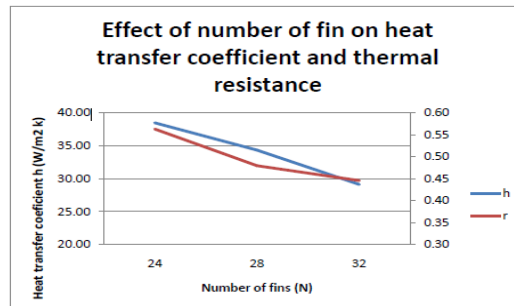


Fig. 6. Effect of number of fins on heat transfer coefficient (h) and thermal resistance (R_{th})

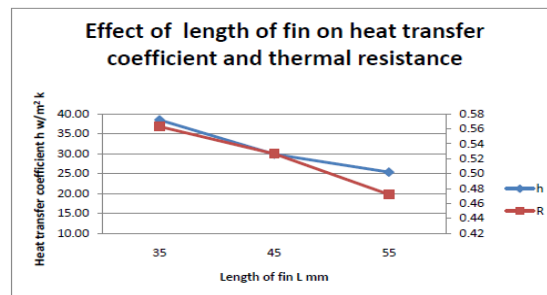


Fig. 7. Effect of length of fin on heat transfer coefficient and thermal resistance

As the fin length increased, the thermal resistance and average heat transfer coefficient decreased. The thermal resistance levelled off and reached a steady value when the fin was longer than 55 mm. This was because the air temperature in the inner region was almost the same as the heat sink temperature, and hence any additional fin length beyond 55 mm did not contribute to the heat transfer rate.

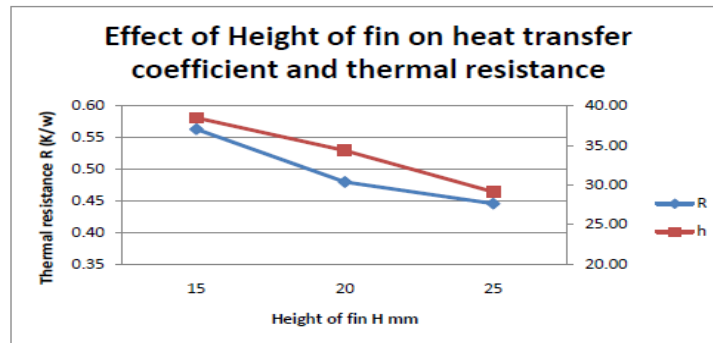


Fig. 8. Effect of height of fin on heat transfer coefficient and thermal resistance

A lower thermal resistance resulted from the increased heat transfer surface area created by the incremented fin height. However, the change in the heat transfer coefficient was relatively small, since the velocity of the air entering from outside increased very little with increasing fin height. By putting the above value of input and output parameter we get the following result on Minitab software by Taguchi optimization below result is for lower thermal resistance.

5. Conclusions

Natural convection from a radial heat sink was experimentally and numerically investigated. Parametric studies were performed to compare the effects of the number of fins, fin length, fin height, and heat flux on the thermal resistance and the heat transfer coefficient. Following important conclusions are drawn from the work carried out on heat sink for different heat input.

1. As the number of fins, fin length, and fin height increased, the thermal resistance and heat transfer coefficient decreased. However, there existed optimal values of the number of fins and fin length to obtain an effective low heat sink temperature. From the experimental investigation model, no 3 having length 35 mm, height 25mm and number of fins 32 gave the optimum result. Experimental thermal resistance for model 3 is 0.45 K/W.
2. The optimum design of aluminum heat sink increases the heat transfer rate from the LED source, avoid the overheating of the LED source and reduce the weight of fin structure.
3. Natural convection from a radial heat sink was experimentally and numerically investigated. The CFD analysis show that general flow pattern was like that of a chimney; i.e. the cooling air entering from outside was heated as it passed between the fins, and then rose from the inner region of heat sink.

4. The heat transfer coefficient increases and thermal resistance decreases with increase in heat input to base surface of heat sink.
5. The heat transfer coefficient and thermal resistance both decrease with increase in number of fins on base surface of heat sink.
6. Fins maintain the required temperature of heat sink in less time thus reducing the temperature around LED thus enhancing its life.
7. Cost of energy required to run LED application is also reduced hence, it can be concluded that heat sink with radial fins is effective and reliable

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