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Application of LED Bulb with Perforated Plus Shape Fin Array in Mines

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Abstract

This paper works on design and developments of cooling system of LED. This work particularly studies on the passive cooling system of a 50W street-light lamp made by multiple LEDs. For analysis purposes, different parameters are considered such as: Density, kinematic viscosity, velocity, junction temperature, heat transfer rate, laminar flow and heat transfer modes. The findings suggest that using plus shape fins with a 1 mm diameter drill can enhance convection heat transfer, resulting in a 21.8% increase in surface area. Additionally, the "Plus" shape of the fins facilitates the formation of an air swirl, contributing to a 30.41% decrease in heat sink temperature. Furthermore, material porosity enhances cooling rates by generating swirls and promoting upward airflow. Ultimately, Plus shape fins emerge as an optimal solution for passive cooling systems, mimicking the efficiency of active cooling systems. The cooling model, proposed along with different shapes and weights of materials having specially designed fins porous materials, is unique so far in our knowledge.

Keywords: *Heat Transfer Coefficient, Laminar Flow, Life Span, Passive Cooling, Perforated*

1.0 Introduction

Improving the longevity of energy-efficient devices, such as high-power LEDs used for illumination, relies on effective thermal management. This involves reducing heat, which is directly proportional to brightness, to enhance performance and extend lifespan. By minimizing the temperature at the LED junction, thermal resistance decreases, improving overall efficiency. This can be achieved through optimized heat flow via conductive pathways and enhanced convection on the surface. Such advancements are commonly employed in electronics for cooling purposes and must consider additional factors like size, shape, and adherence to building codes in lighting applications. X Chen *et al*., Khosla R *et al.* and Akshath KR *et al.*[1-3] Different types of lamps are used in India, such as tube lights, CFLs, LED bulbs, and incandescent bulbs. A survey has been carried out in Pune city on bulbs uses of LED bulb is 51%, CFLs 25%, incandescent bulb 7%, tube light 6% and other 17%. The fins studied in this paper are square, triangular, and Y-shaped throughout the entire length at a Reynolds number of 11000. The heat exchanger used for testing the fins yielded results indicating that the square shape has a higher cooling rate than other types of fins. The heat transfer rate increases due to various parameters such as convective area, air density, kinematic viscosity, material porosity, ambient temperature, *etc.*

The parameter contemplates for enhancing the industrial facet of lighting areas follow Nitin Pawar *et. al.*[4]:

Cost: Efficiency in production and affordability for consumers are key considerations.

Environmental impact: Emphasis on energy efficiency and eco-friendly materials to minimize the carbon footprint.

**Author for correspondence*

Application skillfulness: Versatility in meeting diverse industrial needs, from warehouses to manufacturing plants.

Weight: Lightweight designs facilitate installation and reduce structural strain. Balancing these factors ensures lighting solutions that are cost-effective, environmentally responsible, versatile, and easy to implement, meeting the multifaceted demands of industrial settings[4].

2.0 Literature Review

2.1 Material Analysis

M. A. Dilawar *et al.*[5] and Trifale N *et al.*,[6] Porous is mostly used in the heat exchanger and used for gas cooling in the turbine. The laminar flow of heat studied in a porous square cylinder using the Darcy and Brinkman-Forcheimer model. A force equation is essential for laminar flow analysis. When the permeability exceeds 106, flow cannot pass through, and the aspect ratio of fins affects the heat transfer rate. S. Hoseinzadeh *et al*[7]. and Srikumar Panda *et.al*[8] investigated heat transfer through porous fins in laminar flow within an isotropic medium, employing the Darcy model. The study includes the porosity, heat transfer rate and heat dissipation was increase manner. A. Vahabzadeh *et. al.*[9], suggests that aluminum with a porosity of 0.85-0.95 was an optimal material for LED cooling. Yong Wang *et al.*,[10] a new multilevel modeling technique has been developed to estimate the Young's modulus of polymers reinforced with graphene nanoplatelets. This approach encompasses sequential modeling from the nanoscale up to the macroscale N. Kumar *et al*,[11]. Yangjian Xu *et al*.[12], investigated steady thermal state stress and the factors affecting it, finding that with increased thickness, the stress distribution was more optimal. An increase in convective heat transfer surface coefficient reduces thermal stress. The heat sink material Ti-9Al-4V was utilized, and it was found that the purity of the metal adversely affects the thermal stress of the workpiece, with no tensile stress observed. Additionally, increasing porosity reduces thermal stress in the metal. Foued Chabane analyzed the porosity of various materials using as heat sinks (referenced in Figure 1)[7]. Lipping Tan *et al.*,[13] found that fins cooled by a 3-D printed cooler were more effective than conventional cooling, achieving a reduction in temperature up to 90°C

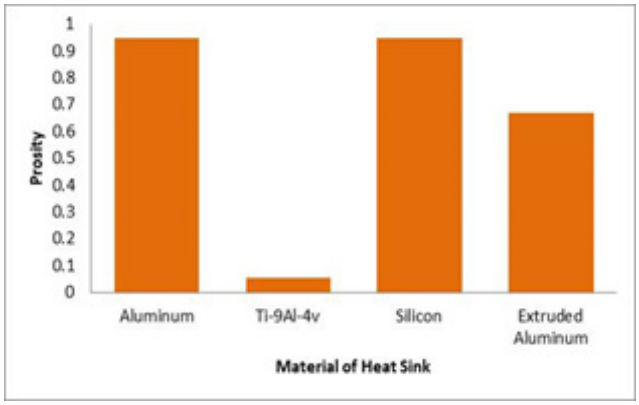


Figure 1. Material and porosity bar of sink material[3].

at an input of 50W. They used the Homotopy analysis method to study the temperature distribution of porous fins concerning internal heat generation, employing a 3-D integral fun boiling structure and scanning electron microscopy. Mariana Lucaci *et al.*[14], demonstrated that using porous material for cooling LED bulbs reduced the temperature by 370°C.

2.2 Heat Transfer Analysis

It was found that in L. V. Jing *et al.*[15], experimental observations on heat transfer performance in carbon dioxide as a working fluid, changing parameters like inlet pressure, mass flow rate, and cooling water flow rate significantly affected heat transfer performance. An increase in inlet pressure, mass flow rate, and cooling water flow rate can enhance the heat transfer coefficient and capacity. The heat transfer coefficient of carbon dioxide inside the tube surpasses that of water outside the tube. Even a small change in pressure significantly impacts the temperature of carbon dioxide, heat transfer coefficient, and capacity. The convective heat transfer coefficient is higher in CO_2 compared to water. Sanjoy Mondal *et al.*,[16] primarily focus on simulation criteria for projects or research parameters, indicating that computational fluid dynamics simulation highlights fluid flow as a critical factor in heat transfer. Liquid mass flowing in micro-fin architectures channels aids in removing heat generated on the chip. The cooling efficiency of 2D carbon nanotube fin arrays exceeds that of 1D carbon nanotube fin arrays. Venkitaraj K P.and luo X[17,18] notes that the convective heat transfer coefficient significantly influences thermal stress reduction. They discovered improvements in rectangular

fin array performance by incorporating grooves with various shapes like ellipses, squares, and triangles, with triangular grooves yielding better results. The paper guides thermocouple usage according to application, with temperature being a crucial parameter. Chabane F, *et al.*,[19] Various authors analyzed maximum temperatures up to 120°C. In the laminar region, Reynolds and Nusselt numbers exhibit linear behavior, while the transition region shows nonlinear behavior. J-type thermocouples with a response time of 0.1 sec were employed. A heat supply of 130 W was considered, with the Prandtl number for air being 0.7 and 0.74. Formulas utilizing Rayleigh and Nusselt numbers were applied. The equation no. 1 shows the mathematical formula for calculation of Nusselt number where Ra is a Rayligh Number.

$$Nu = 0.8516\ (Ra)^{0.198} \quad (1)$$

Where,

Ra = Rayligh Number

Nu = Nusselt Number

Hasan M. I. *et al.*[20] utilized the Schubert equation with k1, k2 set to 0, and k3 from a provided table. Using an empirical equation, the heat transfer coefficient is determined, with air temperature playing a crucial role in defining boundary conditions. Factors such as fin height, thickness, and pitch are considered, while conductive thermal resistance is disregarded. The empirical Equation (2) is applied to calculate the heat transfer coefficient[21-23].

$$h = K_1\ [1 + K_2\ (U_{air})^{K_3}] \quad (2)$$

Where,

h is a convective heat transfer coefficient

U is overall heat transfer coefficient

K_1, K_2 and K_3 are a constant.

Sun Lungfang *et al.*,[24] discusses the resistance factors in fluid during vertical heat convection through passive mode. The paper examines various resistances, including flow-following resistance, thermal fouling resistance, and cleaning effectiveness. Ting Cheng *et al.*,[25] employed silicon with thermal resistance. Equation (3) is presented as follows:

$$\text{Thermal resistance} = b/k \quad (3)$$

Where,

b is a width of fins

k is a coefficient of thermal conductivity

Different power found at different materials and temperature of sink as shows in Table 1.

2.3 Light Emitting Diode Mathematical Analysis

Zhang Lina *et al.*[26], defined good characteristics of L.E.D. bulbs should be energy-saving, environmentally

Table 1. Sink material with power and temperature

Sl. No	Sink Materials	Watt	Temperature
1	Extruded aluminum	50W	35 ℃
2	Extruded aluminum	110W	96 ℃
3	Carbon nanotube	100W	135 ℃
4	Aluminum Sheet	125W	120 ℃
5	aluminum	121W	92 ℃
6	GaN	120 W	108 ℃
7	aluminum	100 W	^{0}C

friendly, small volume, quick response, high reliability, and convenient control. Sagnik Bhattacharya *et al.*[27] authors define the active energy parameter in the term of photovoltaic cell uses. Tan *et al.* Harichandan A B *et al.* and Roy K *et al.*,[28-30] explained the empirical equation of junction temperature and a lifetime of LED bulb k = Stefan Boltzmann constant (8.617×10^{-5} eV/K) Ea = active energy (0.5). When temperature increases by 40^{0}C to 50^{0}C and life decreases by 42000 to 180000 hours, respectively. Entropy generation is studied with the porosity of circular fin that porosity, as well as Reynold number, related directly with entropy generation in Equation (4)

$$time = e^{\frac{Ea}{kTj}} \quad (4)$$

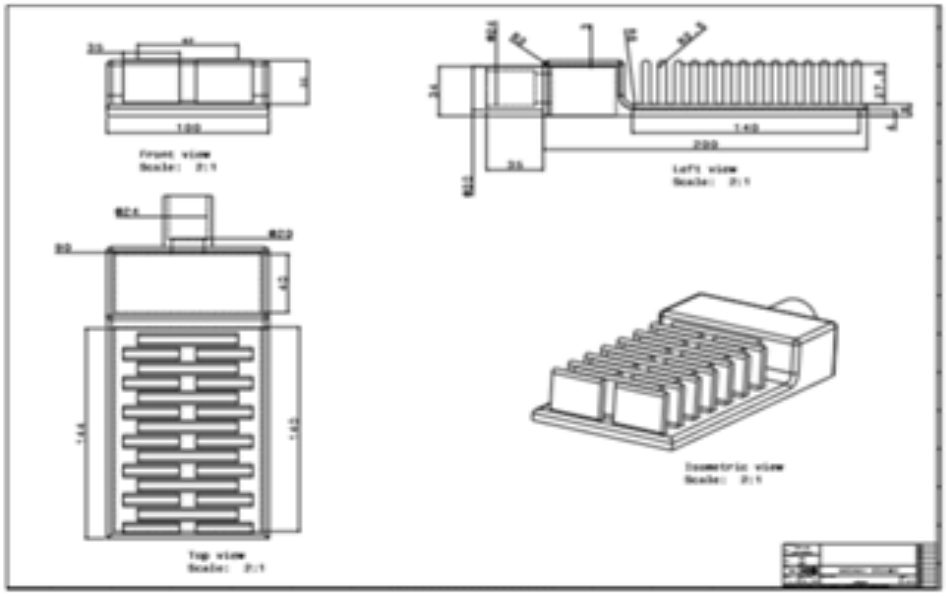


Figure 2. Design layout of rectangular fins array pattern[4,31].

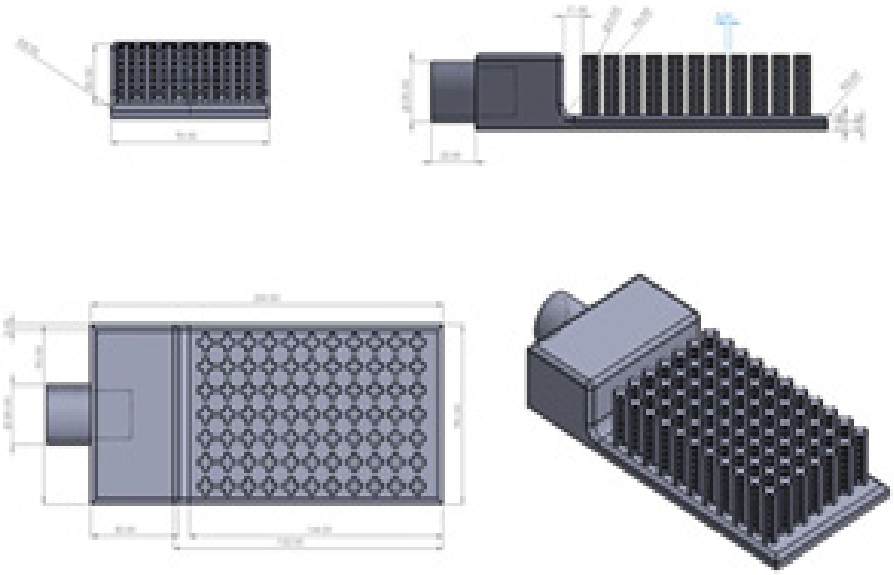


Figure 3. Design layout of plus shape fins array pattern[4,31].

Where,
k= Stefan Boltzmann constant (8.617×10^{-5} eV/K)
Ea=active energy (0.5)
T_j=Junction temperature.

3.0 Design of LED Pattern

Using an AUTOCAD tool, design of LED bulb is employing thumb rule principles with the same heat sink surface area of 12600 mm^2 for both rectangular and plus-shaped fin arrays. The cross-sectional area of the fins is 45 mm^2, and the height of the fins is 30 mm. The power of the bulb is 50W. Figure 4 illustrates the rectangular pattern of the LED bulb with a capacity of 50W[4,31].

Figure 5 depicts the please-sign fin array pattern of an LED bulb with a 50W capacity. On the vertical faces of the fins, horizontal drilling of 1 mm diameter is conducted with a center-to-center distance of 3 mm, accompanied by a 0.5 mm fillet at each corner.

4.0 Experimental Setup

Aluminum material is extruded for manufacturing both the Plus-shaped and Rectangular fin array patterns, where milling, drilling, and other operations are conducted. Photographic images of the Rectangular array pattern and Plus-shaped array pattern are depicted in Figure 4 and Figure 5, respectively[1,31].

50 W power bulbs are manufactured with 10 bulbs of 5 W each capacity are shown in Figure 6 for the rectangular, and plus sign fin array pattern.

The material of a Plus sign fin array LED bulb and a Rectangular fin array LED bulb, are studied. The weight of

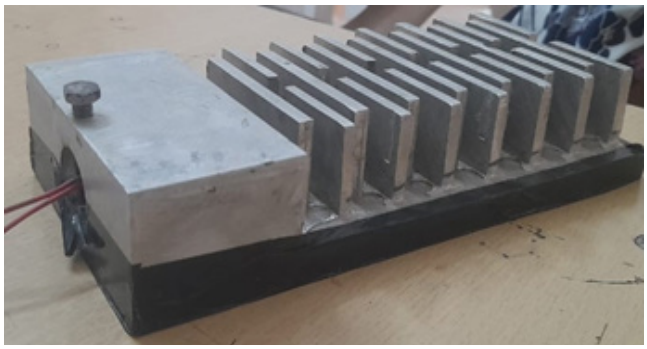


Figure 4. Prototype of a rectangular fins array pattern of 50 W LED bulbs.



Figure 6. Manufacture model front side of 50 W LED bulbs.

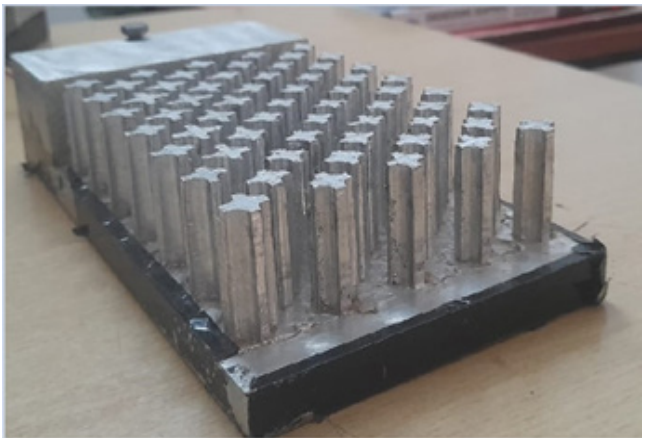


Figure 5. Prototype of a plus shape fins array pattern of 50 W LED bulbs.

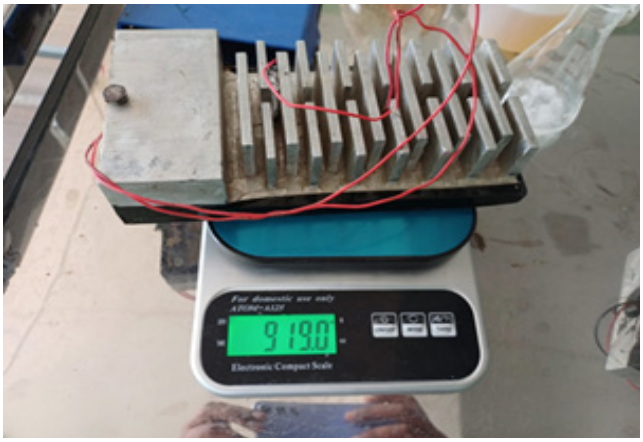


Figure 7. The weight of rectangular fin array LED bulb.

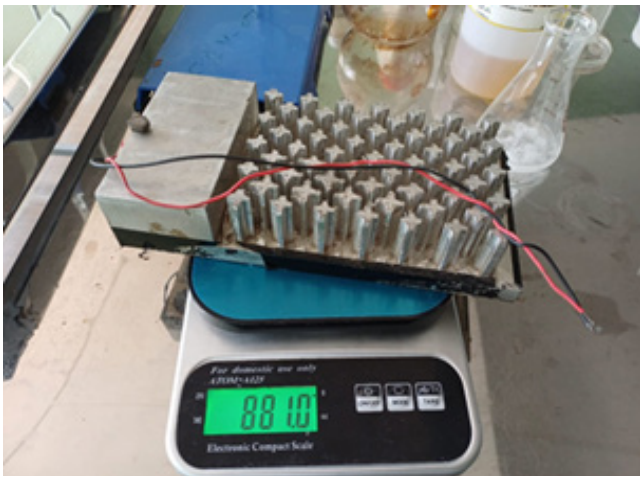


Figure 8. Shows the weight of plus shape fin array LED bulb.

the respective bulb is measured in weight span. Figure 7 and Figure 8 show the weight of the Rectangular fin array and plus sign fin array photograph.

5.0 Result and Discussion

MATLAB tool is used to calculate the thermal performance of an LED bulb in the parameters of Density (Kg/m3), Dynamic Viscosity (Nm/s2), Thermal Conductivity of Air(W/mk), Grashoff Number, Prandtl number, rayleigh number, Nusselt Number, Convective heat transfer coefficient (W/m2k) are calculated. Program has been run based on the square error method. After a successful run of program, the values are found as shown in Table 2.

Table 2. The value of different parameter in MATLAB for rectangular fin array LED bulb

Sr. No.	Temperature (k)	Prandtl Number (pr)	Rayleigh Number (ry)	Grashoff Number (gr)	Convective heat transfer coefficient (W/m^{2}k)
1	339.41	0.69325	65191.50	94225.53	9.252
2	337.03	0.69214	62990.91	91018.36	9.122
3	336.90	0.69208	62865.10	90834.93	9.115
4	336.89	0.69208	62857.89	90824.42	9.114
5	336.89	0.69208	62857.47	90823.82	9.114
6	336.89	0.69208	62857.34	90823.63	9.114
7	336.89	0.69208	62855.62	90821.11	9.114
8	336.89	0.69208	62825.51	90777.21	9.113
9	336.86	0.69207	62300.44	90011.63	9.082
10	336.31	0.69187	53333.93	76933.02	8.560

MATLAB is used to calculate the thermal performance of an LED bulb, focusing on parameters such as density (kg/m³), dynamic viscosity (N·s/m²), thermal conductivity of air (W/m·K), Grashoff number, Prandtl number, Rayleigh number, Nusselt number, and convective heat transfer coefficient (W/m²·K). The program employs the square error method, and upon successful execution, the results are presented in Table 3.

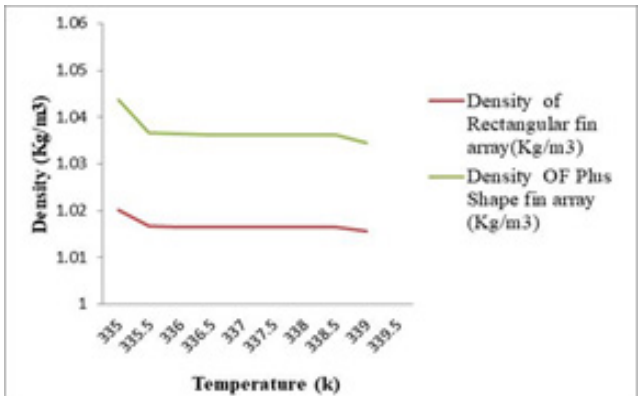


Figure 9. The weight of plus shape fin array LED bulb.

The behaviors of various parameters concerning temperature were studied. The conclusive observation is as follows: The density of air varies directly with temperature. The graph illustrates the change in density for temperature, as depicted in Figure 9.

LED bulbs were operated continuously for 8 hours. Temperature readings were taken, showing 311 K for the Rectangular fin array bulb and 305 K for the Plus sign fin array bulb. The ambient temperature was recorded as 298 K. The relationship between the Nusselt number and temperature (^{0}C) for both types of fin arrays is presented in Figure 10. It was observed that the Nusselt number for the Plus sign fins was 3.19%

Table 3. In the below mentioned table defines the performance values of plus shape a fin array using a MATLAB tool

Sr. No.	Temperature (k)	Prandtl Number (pr)	Rayleigh Number (ry)	Grashoff Number (gr)	Convective Heat Transfer Coefficient (W/m2k)
1	336.47	104275.6	0.6925	72104.58	9.67
2	335.90	90237.2	0.6922	62455.10	9.09
3	335.87	89429.8	0.6922	61901.45	9.06
4	335.87	89383.4	0.6922	61869.59	9.06
5	335.87	89380.7	0.6922	61867.76	9.06
6	335.87	89380.5	0.6922	61867.62	9.06
7	335.87	89379.9	0.6922	61867.18	9.06
8	335.86	89368.7	0.6922	61859.53	9.06
9	335.73	89175.2	0.6921	61726.82	9.05
10	333.46	85829.3	0.6915	59432.81	8.91

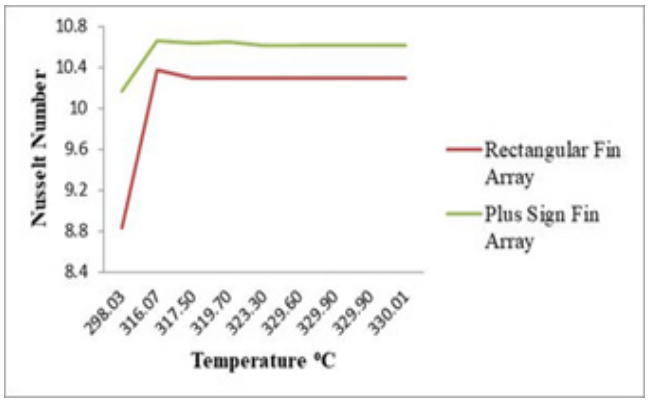


Figure 10. Graph shows the nusselt number behavior with respect to temperature.

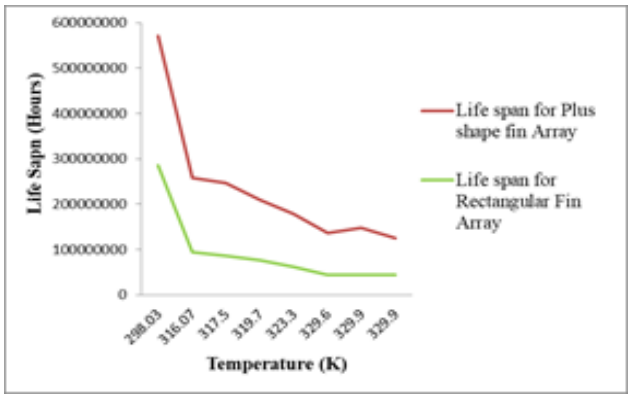


Figure 12. The lifespan for plus shape array LED bulb and rectangular shape array LED bulb.

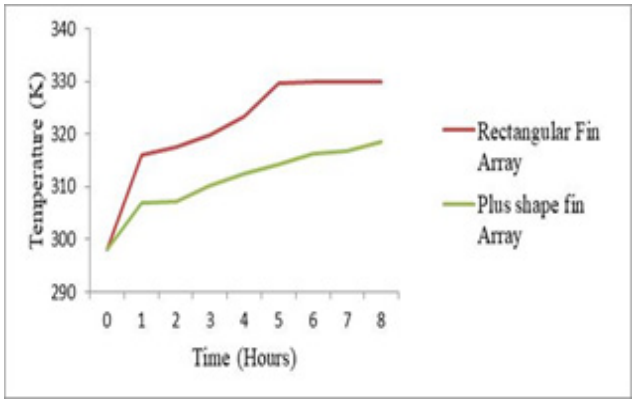


Figure 11. The temperature behavior of plus shape array and rectangular shape array.

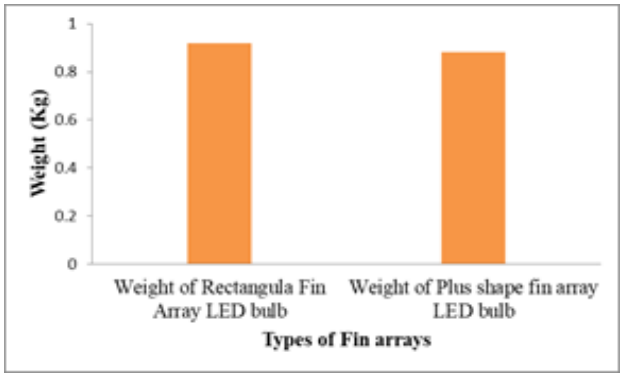


Figure 13. The difference in weight of the rectangular fin array led bulb array and plus shape fin array led bulb.

higher than that for the Rectangular fins. The figure illustrates the behavior of the Nusselt number concerning temperature.

Figure 10 displays the temperature readings after an 8-hour continuous operation of a bulb in a room. The temperature is measured using a digital thermal indicator with an accuracy of 0.01 ^{0}C. The graph below indicates that the Plus-shaped fin array LED bulb exhibits a lower temperature compared to the rectangular fin array LED bulb. The temperature decrease is noted to be 4.98% in the Plus-shaped fin array LED bulb compared to the rectangular LED bulb.

As discussed in the literature, lower temperatures contribute to an increase in the life of LED bulbs. Figure 11 illustrates that the Plus-shaped fin array LED bulb has a longer lifespan compared to the Rectangular fin array LED bulb. The lifespan increases by 13.72% with the Plus-shaped fin array.

As discussed in the literature, lower temperatures contribute to an increase in the life of LED bulbs. Figure 11 illustrates that the Plus-shaped fin array LED bulb has a longer lifespan compared to the Rectangular fin array LED bulb. The lifespan increases by 13.72% with the Plus-shaped fin array. Weight comparison between the Rectangular fin array LED bulb and the Plus-shaped fin array LED bulb were conducted by weighing both bulbs. It was found that the weight of the Rectangular LED bulb and the Plus-shaped fin array LED bulb are 0.919 kg and 0.881 kg, respectively. The weight of the Plus-shaped fin array bulb decreases by 4.91% compared to the Rectangular fin array bulb.

6.0 Conclusions

This study highlights the efficacy of square-shaped extruded fins in passive cooling systems for LED bulbs. The following conclusions are extracted:

1. Through mathematical modeling and simulation methods, it demonstrated that square-shaped fins, particularly when equipped with a 1 mm diameter drill, significantly enhance convection heat transfer, leading to a notable 21.8% increase in surface area.
2. Additionally, the "Plus" shape of fins promotes air swirl formation, resulting in a substantial 30.41% reduction in heat sink temperature.
3. The utilization of porous fin materials may be utilized to boosts cooling rates by facilitating airflow.
4. These findings underscore the square-shaped fins suitability as an optimal solution for passive cooling, rivaling the efficiency of active cooling systems.

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