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Experimental investigation of heat transfer characteristics in rectangular and inverted t-shaped fins

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ABSTRACT
Efficient heat management is critical in modern industries to maintain performance and prevent premature equipment failure. Excessive temperatures can slow operation, shorten component lifespan, or cause complete breakdowns. One effective approach for passive cooling is the use of extended surfaces, or fins, which enlarge the heat dissipation area exposed to ambient air. This study conducts an experimental comparison between two fin geometries rectangular and inverted T-shaped under natural convection. Both designs were fabricated from the same material and maintained identical base dimensions to ensure a fair evaluation. Temperature distribution and heat loss measurements were used to determine heat transfer rate and thermal resistance. Results indicate that while rectangular fins remain the most widely used due to their simplicity and reliability, the inverted T-shaped profile offers alternative airflow characteristics that can influence thermal performance.

***Keywords* -** Heat transfer, Natural convection, Extended surfaces, Rectangular fins, Inverted T-shaped fins.

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I. INTRODUCTION

In engineering systems, maintaining optimal thermal conditions is essential for both performance and durability. Industries such as electronics, automotive, and heavy machinery face persistent challenges caused by heat accumulation during operation. Operating machines and electronic devices naturally generate heat as a by-product. Without effective removal, this heat can reduce efficiency, shorten lifespan, or cause failure. Managing thermal loads is therefore critical in systems like computers, engines, and power plants. One of the simplest and most widely adopted cooling strategies is the use of fins small projections attached to a heated surface that increase the available area for heat transfer, thereby promoting greater dissipation into the surrounding environment. Among various passive cooling methods, the use of fins metallic projections attached to a heated surface is one of the most practical and cost-effective solutions. By increasing the surface area in contact with air, fins accelerate heat dissipation without requiring additional power. Rectangular fins are the most common design, favored for their straightforward geometry, ease of manufacture, and consistent results. Several recent studies have focused on enhancing the cooling performance of heat sinks under natural convection to meet the demands of compact and high-power electronic devices. Zheng Lan, Yu-hao Feng, and Ying-wen Liu [1] improved rectangular fin heat sinks by integrating experimental testing, computational simulations, and artificial neural networks for performance prediction. Yogesh K. Prajapati [2] examined how adding slits to rectangular fins could improve heat transfer without forced airflow, testing two- and three-slit configurations against a solid-fin baseline. Rajshekhar V. Unni and M. Sreedhar Babu [3] investigated the use of perforations, with 8 mm and 10 mm holes, in aluminium alloy fins to enhance thermal performance compared to solid fins. Rana A. Al-Luhaibi and Ibrahim Thamer Nazzal [4] compared circular, triangular, and rectangular aluminium fins to determine the most effective geometry for heat dissipation. Similarly, Qie Shen, Daming Sun, Ya Xu, Tao Jin, and Xu Zhao [5] contrasted rectangular and V-shaped fins, concluding that the V-shaped design provided superior cooling efficiency and higher heat transfer coefficients across different heat loads. A wide range of recent research has explored improving the thermal performance of heat sinks through both experimental and numerical methods. Hussein S. Sultan and colleagues [6, 7] conducted numerical analyses on natural convection in horizontal heat sinks fitted with arrays of rectangular fins, evaluating how geometric and thermal parameters influence heat dissipation. Zheng Lan, Yu-hao Feng, and Ying-wen Liu [8] applied experimental tests, computational modelling, and artificial neural networks to predict and enhance the performance of rectangular fin heat sinks. Martin Kirchhoff and co-researchers [9] investigated forced convection impingement on plate-fin heat sinks using three types of electronic cooling fans, combining experiments and simulations to compare airflow effectiveness. Mohammad Ismail Ahmad Manassas and team [10] examined the hydrothermal behavior of plate-fin heat sinks under various operating conditions, integrating both experimental data and numerical modelling. Panit Kamma and collaborators [11] optimized plate-fin configurations to balance thermal efficiency with ease of manufacturing. Jingzhi Zhang and colleagues [12] studied single-phase and flow-boiling heat transfer in staggered finned manifold microchannel heat sinks to address high-density cooling requirements. Peiqi Sun and team [13] utilized met model-based optimization techniques to design finned heat sinks with enhanced heat transfer characteristics. Finally, Zhi Xu [14] analyzed the thermal performance and carried out multi-objective optimization of thermosiphon heat sinks with rectangular radial fins, targeting efficient cooling solutions for high-power LED applications. Sun, Ismail, and Mustaffa (2025) [15] proposed a met model-based approach to optimize finned heat sinks, balancing thermal performance and spatial constraints. By using Latin Hypercube Sampling to generate 100 design variants (adjusting heat sink dimensions such as length, width, fin spacing, and height), they trained a Random Forest met model to predict heat transfer coefficients. An optimizer then identified an optimal design, which, upon experimental validation, achieved a 35 % increase in heat transfer efficiency compared to the baseline. Additionally, the optimized model reduced fin height by 43 % and overall volume by 26 %, with only a minor (~3 %) rise in operating temperature. Although many analytical and numerical studies have investigated fin design variations, there is still a need for experimental evaluations under realistic operating conditions. Nevertheless, alternative geometries, such as the inverted T-shaped profile, have been explored to improve thermal performance in specific applications. Since fin shape influences both heat conduction and airflow, even minor changes can significantly impact overall heat transfer. This work aims to experimentally evaluate and compare the performance of rectangular and inverted T-shaped fins under natural convection conditions, with a focus on determining which configuration delivers more efficient cooling.

II. DEVELOPMENT OF HEAT SINK AND EXPERIMENTAL SETUP

2.1: Heat sink base model

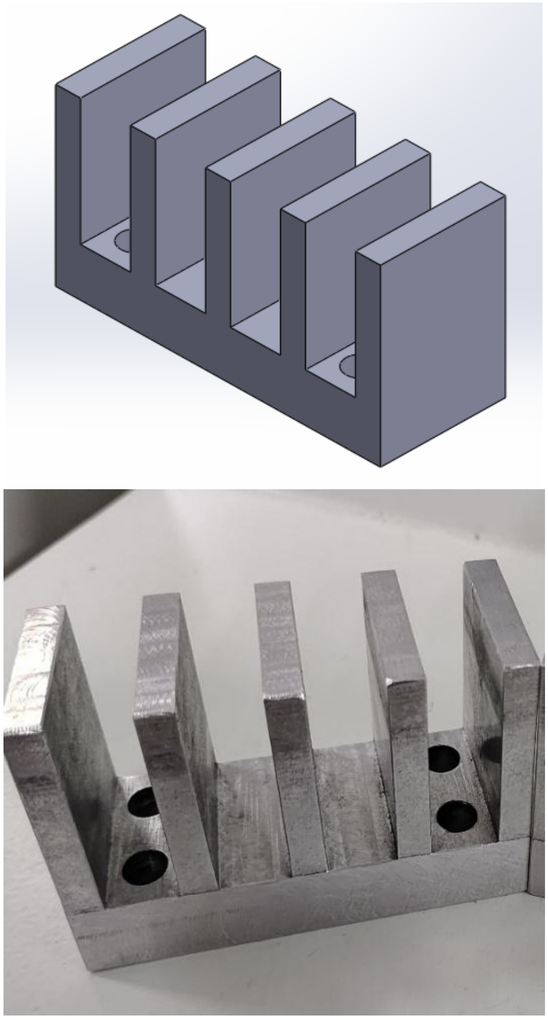


Fig: 1: Photograph of plane heat sink model

An aluminium heat sink machined using a CNC machine was used in the experiment, with the following dimensions: length 104 mm, width 40 mm, height 58 mm, fin thickness 8 mm, 5 fins in total, each fin having a height of 42 mm and width of 40 mm as shown in fig.1 and Table.1 shows heat sink specifications.

Table: 1: Base heat sink specifications

Heat sink length	104 mm
Heat sink width	40 mm
Heat sink height	58 mm
Fin thickness	8 mm
Fins quantity	5 No's
Fins height	42 mm
Fins width	40 mm

2.2: Heat sink 14 mm depth cut-out model

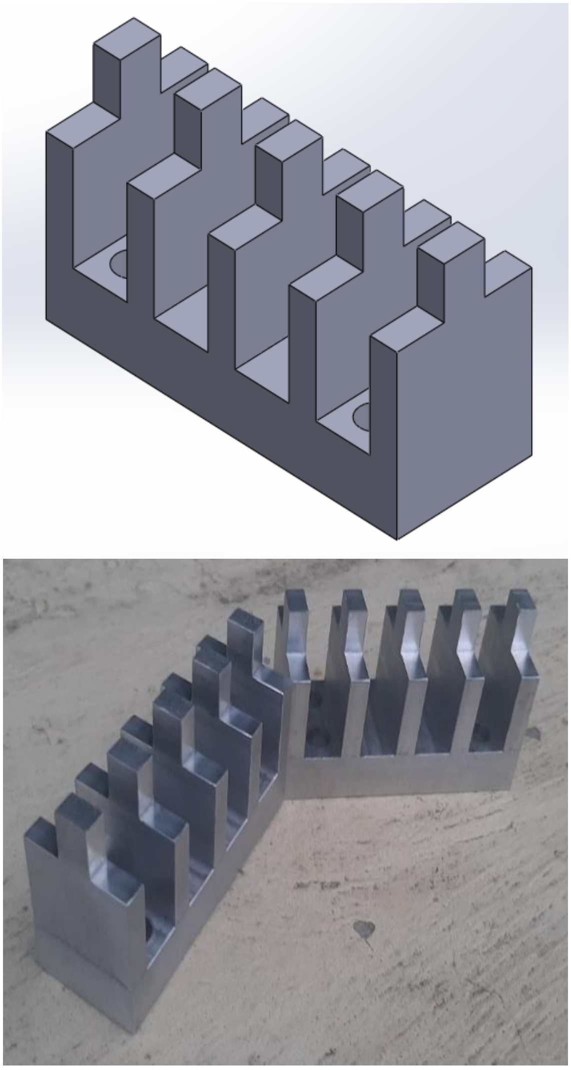


Fig: 2: Photograph of the 14 mm depth-cut heat sink model

An aluminium heat sink precisely machined using a CNC machine was used in the experiment, featuring dimensions of 104 mm in length, 40 mm in width, and 58 mm in height, with 5 fins each 8 mm thick, 42 mm high, 40 mm wide, and including a 14×14 mm cut-out depth. as shown in fig.2 and Table.2 shows heat sink specifications.

Table: 2: Specifications of Heat sink 14 mm depth-cut

Heat sink length	104 mm
Heat sink width	40 mm
Heat sink height	58 mm
Fin thickness	8 mm
Fins quantity	5 No's
Fins height	42 mm
Fins width	40 mm
Depth cut out	14*14 mm

2.3: Heat sink 28 mm depth cut-out model

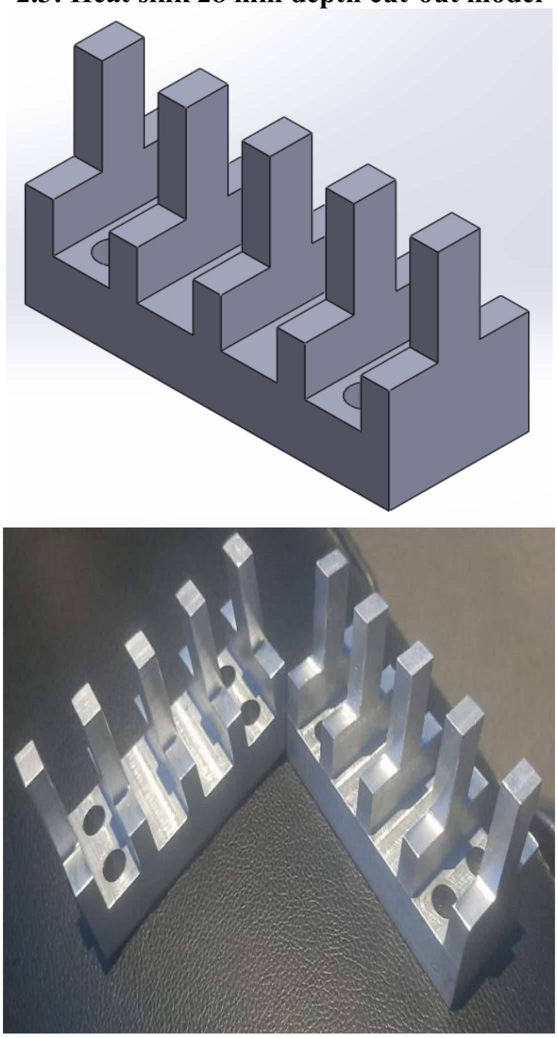


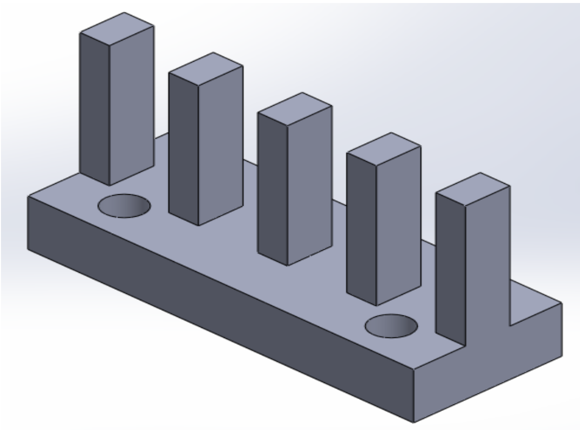
Fig: 3: Photograph of the 28mm depth-cut heat sink model

An aluminium heat sink precisely machined using a CNC machine was used in the experiment, featuring dimensions of 104 mm in length, 40 mm in width, and 58 mm in height, with 5 fins each 8 mm thick, 42 mm high, 40 mm wide, and including a 28×14 mm cut-out depth as shown in fig.3 and Table.3 shows heat sink specifications.

Table: 3: Specifications of Heat sink 28 mm depth-cut

Heat sink length	104 mm
Heat sink width	40 mm
Heat sink height	58 mm
Fin thickness	8 mm
Fins quantity	5 No's
Fins height	42 mm
Fins width	40 mm
Depth cut out	28*14 mm

2.4: Heat sink 14 mm depth cut-out model



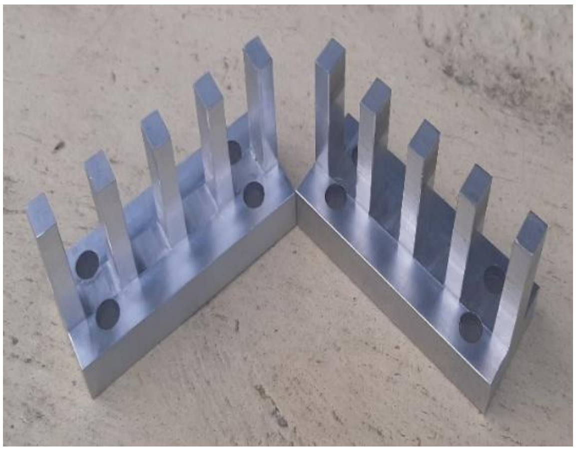


Fig: 4: Photograph of the 42 mm depth-cut heat sink model

An aluminium heat sink precisely machined using a CNC machine was used in the experiment, featuring dimensions of 104 mm in length, 40 mm in width, and 58 mm in height, with 5 fins each 8 mm thick, 42 mm high, 40 mm wide, and including a 42×14 mm cut-out depth as shown in fig.4and Table.4 shows heat sink specifications.

Table: 4: Specifications of Heat sink 42 mm depth -cut

Heat sink length	104 mm
Heat sink width	40 mm
Heat sink height	58 mm
Fin thickness	8 mm
Fins quantity	5 No's
Fins height	42 mm
Fins width	40 mm
Depth cut out	42*14 mm

2.5 Assembly of Model

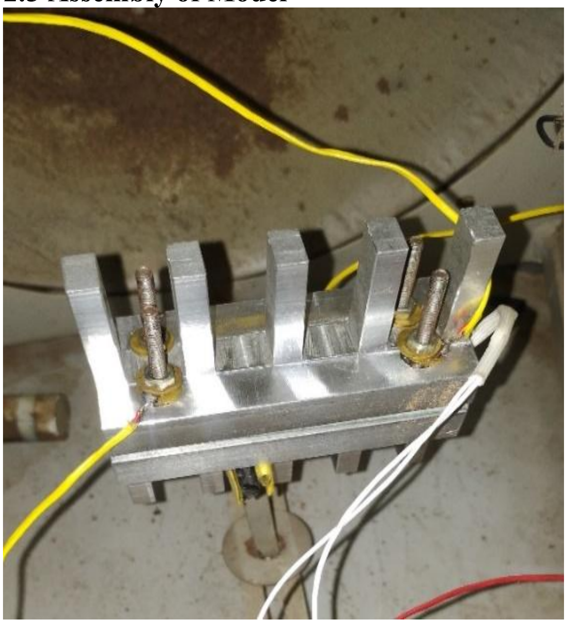


Fig: 5: Photograph of Assembly of heat sink

Each heat sink was mounted securely in the experimental test rig to prevent any movement during trials. Thermocouples were positioned at selected points on both the base and fins to monitor temperature distribution. Leads from the thermocouples were connected to a digital data logger for real-time recording as shown fig,5.

2.6: Schematic diagram of experimental setup

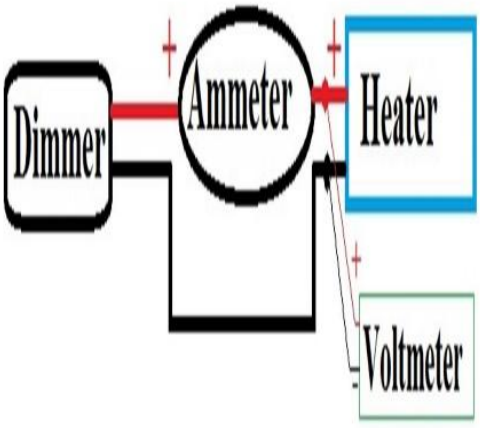


Fig: 6: Schematic diagram of the circuit

The test setup consisted of:

- **Heat source**: An electrical resistance heater attached directly to the heat sink base for efficient thermal contact.
- **Measurement system**: Thermocouples and a data logger for continuous temperature tracking.
- **Power supply**: A regulated source connected through a dimmer stat for precise voltage control.
- **Instrumentation**: Ammeter and voltmeter for monitoring electrical input.
- **Thermal insulation**: High-temperature insulation surrounding the assembly to minimize heat loss to the environment.

2.7 Experimental setup

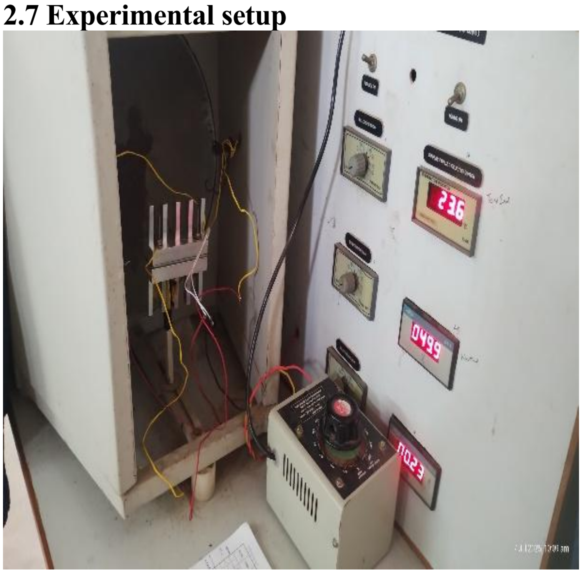


Fig: 7: Photograph of Assembly of experimental setup

The heat sink was mounted in a vertical orientation to promote natural convection and improve passive cooling performance. During testing, the voltage supplied to the heating coil was gradually increased in controlled increments, and the corresponding current was measured at each step to determine the electrical input. Temperatures at multiple points on both the fins and the base were recorded using precision sensors, with measurements taken only after steady-state thermal conditions had been reached to ensure accuracy. To maintain consistency and reliability, all configurations were tested under identical ambient conditions, minimizing the influence of external environmental factors on the results as shown in fig 7.

2.8: Data reduction

- Heat Transfer:
  Q: h a ΔT **1**

  Where:
  h = Heat transfer Co-efficient (W/m2 K)
  ΔT = Temperature difference
  a = Area

- Heat Flux:
  q=Q/A **2**

  Where:
  Q = Heat Transfer
  A = Area

- Cutout model area:
  A_C= Total Area - [cut-out area*10]

III. RESULTS & DISCUSSIONS

3.1: Effect of variation on temperature with respect to voltage

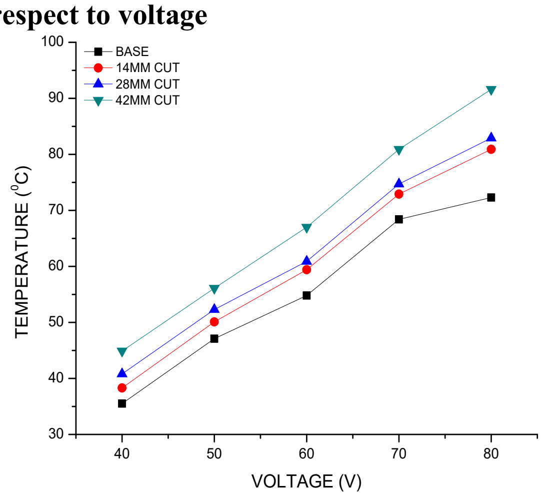


Fig: 8: Temperature v/s Voltage

Increasing voltage resulted in higher average wall temperatures for all fin types due to greater heat input. The base model consistently recorded the lowest temperatures, indicating better heat conduction through its unmodified structure. Conversely, the 42 mm cut-out model exhibited the highest temperatures, likely due to disrupted conduction paths as shown in fig 8.

4.2: Effect of variation on thermal resistance with respect to voltage

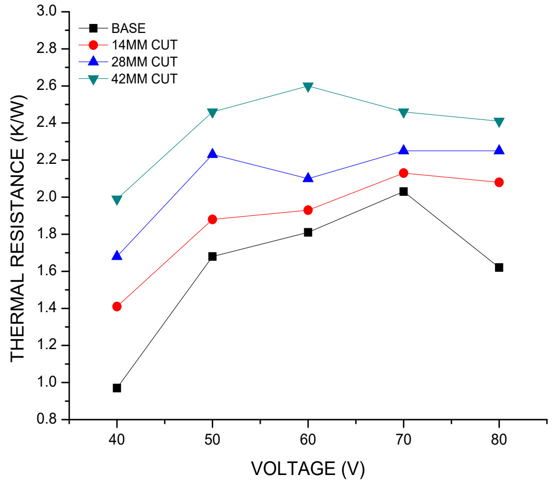


Fig: 9: Thermal Resistance v/s Voltage

Thermal resistance rose with increasing voltage for all configurations. The base model displayed the lowest values, while the 42 mm cut-out model showed the highest, suggesting that deeper cut-outs hindered heat conduction and altered airflow patterns unfavorably as shown in fig 9.

3.3: Effect of variation on heat flux with respect to voltage

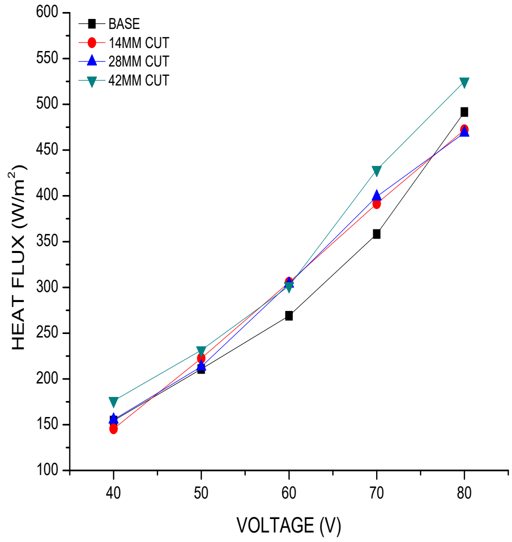


Fig: 10: Heat Flux v/s Voltage

Heat flux increased with voltage in every case. Cut-out designs, particularly the 42 mm depth, demonstrated higher heat flux compared to the base, likely due to increased surface area and induced airflow turbulence. However, this did not necessarily translate into improved overall cooling efficiency because conduction losses offset some gains as shown in fig 10

IV. CONCLUSION

Across all fin designs, increasing voltage led to higher average wall temperatures, with the base model consistently recording the lowest values and the 42 mm cut-out the highest. Thermal resistance showed a similar trend, suggesting that deeper cut-outs reduced heat conduction and disrupted airflow. Although heat flux increased with voltage in all configurations, the higher values observed in cut-out models particularly the 42 mm were offset by greater conduction losses. The 14 mm cut-out delivered moderate performance, while the 42 mm cut-out was the least effective. Overall, the uncut base model demonstrated the best cooling performance, achieving the highest heat transfer coefficient and the lowest thermal resistance.

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REFERENCES

Journal Papers:

[1]. Study of rectangular fin heat sink performance and prediction based on artificial neural network Zheng Lan, Yu-hao Feng 1, Ying-wen Liu Key Laboratory of Thermo-Fluid Science and Engineering of MOE, School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi, 710049.

[2]. Influence of fin height on heat transfer and fluid flow characteristics of rectangular microchannel heat sink Yogesh K. Prajapati Department of Mechanical Engineering, National Institute of Technology Uttara hand, Srinagar (Garhwal), Uttara hand 246174, India.

[3]. Experimental Investigation of Heat Sinks with and Without Perforation Addressing Toward

Higher Cooling Rates and Optimum Material Rajshekhar V. Unni and M. Sreedhar Babu.

[4]. Investigation of Heat Sinks with Different Perforation Patterns Rana A. Al-Luhaibi1, Assis. Prof. Ibrahim Thamer Nazzal.

[5]. Orientation effects on natural convection heat dissipation of rectangular fin heat sinks mounted on LEDs Qie Shen, Daming Sun, Ya Xu, Tao Jin, Xu Zhao.

[6]. Numerical investigation of natural convection from a horizontal heat sink with an array of rectangular fins Hussein S. Sultan a, Khalid B. Saleema, Badr M. Alshammari b, Mohamed Turki c, Abdelkarim Aydi d, Lioua Kelsi.

[7]. Numerical investigation of natural convection from a horizontal heat sink with an array of rectangular fins Hussein S. Sultan a, Khalid B. Salem.

[8]. Study of rectangular fin heat sink performance and prediction based on artificial neural network Zheng Lan, Yu-hao Feng 1, Ying-wen Liu

[9]. Experimental and numerical investigations of forced convection impingement heat transfer on plate-fin heat sinks using three different electronic cooling fans Martin Kirchhoff a, Michael Krieger b, Dominik Hofer

[10]. Hydrothermal performance of a heat sink using Plate-fins: Experimental and numerical investigations Mohammad Ismail Ahmad Manassas, Abdullah Masood Ali, Moussa Abedalaziz

[11]. Optimization of plate-fin heat sink configurations for enhanced thermal performance and manufacturability Panit Kamma, Kittipos Loksupapaiboon, Juthanee Phromjan, Machimontorn Promtong, Chakrit Suvanjumrat

[12]. Single-phase and flow boiling heat transfer characteristics in staggered finned manifold microchannel heat sink Jingzhi Zhang, Jinjin Xu, Hao Han, Li Lei, Gongming Xin.

[13]. Met model-based design optimization for heat transfer enhancement of finned heat sinks Peiqi Sun, Mohd Azmi Ismail, Ahmad Fikri Mustaffa.

[14]. Thermal performance and multi-objective optimization of thermosiphon heat sinks with rectangular radial fins for high power LED lamps cooling Zhi Xu.

[15]. Sun, P., Ismail, M.A., Mustaffa, A.F., 2025. Met model-based design optimization for heat transfer enhancement of finned heat sinks. International Journal of Thermal Sciences, 207, 109896.