# EXPERIMENTAL INVESTIGATION ON THE EFFECTS OF PERFORATIONS AND EXTENSIONS ON THE HEAT DISSIPATION PERFORMANCE OF FINS

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*Natural convection cooling plays a critical role in improving the thermal performance and service life of passive heat-dissipating systems. This study experimentally investigates the influence of fin extensions of different geometries (rectangular, trapezoidal, and triangular) and circular perforations of varying diameters (17 mm, 20 mm, and 23 mm) on heat transfer enhancement in aluminium fin arrays. A controlled experimental setup was developed to measure surface temperatures, evaluate convective heat transfer coefficients, and compute Nusselt numbers under steady natural convection. Results show that fin geometry significantly affects heat dissipation. Rectangular extensions produced the highest improvement among the extension configurations, enhancing the heat transfer coefficient by 22.9%, while trapezoidal and triangular extensions yielded 11.25% and 8.1% improvements, respectively. Perforated fins demonstrated superior performance, with 23 mm perforations achieving a maximum enhancement of 31.99% over plain fins, followed by 20 mm (24.26%) and 17 mm (13.06%). The study highlights that larger perforations and sharper geometric transitions promote stronger buoyancy-driven airflow and reduce thermal resistance. These findings provide valuable insights for optimizing lightweight and energy-efficient passive cooling devices.*

**Keywords:** Fins arrays, heat transfer, energy-efficient cooling solutions, and natural convection.

## 1. Introduction

Fins are the focus of the heat transfer research community as they provide considerable heat transfer enhancement, and as a passive method, they improve the energy efficiency of the heat transfer system. In many applications where a higher amount of heat transfer is desired, fin arrays are employed, which is a group of fins that collectively deliver heat transfer enhancement. Fin arrays found their applications in many fields, including manufacturing, automobiles, and aviation

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applications. Dupuis et al. [1] used fin arrays for cooling in additive manufacturing applications. They studied the effectiveness of fin arrays experimentally as well as numerically. Results showed that the fins considerably affect the thermal and hydrodynamic performance at low Reynolds numbers. Colgan et al. [2] used fins in forced convection heat exchangers and found enhanced heat transfer. Jadhav and Balaji [3] used fin arrays for electronics cooling and investigated the cooling performance. They showed that the fin dimension considerably impacts the heat transfer performance.

The use of fins arrays is not as simple as one imagines it because it is not just an increasing number of fins; it requires a thorough optimization of the fin array because a poorly designed fin array might lead to reduced heat transfer. Hence, designers need to conduct optimization studies for fin arrays to use them effectively for particular applications. Kocak et al. [4] conducted an optimization study for finned surfaces using experimental and numerical approaches under forced convection (Re: 23,600 to 150,000). Their study consists of constructing a test setup and a numerical study of the 2D program based on the Open FOAM platform. The results of the numerical study closely agree with the experimental data. Results also concluded that fin geometry modification enhances heat transfer. Awasarmol et al. [5] investigated heat exchange between solid fins and circular perforated fin arrays. They used investigation parameters: inline and zigzag perforation configurations, angle of inclination (0°-90°), and perforation sizes (4-12 mm) under forced convection. This study showed that a 10 mm perforation diameter ($\beta$ = 21%) at a 45° inclination angle provides the best performance, with zigzag configurations outperforming inline ones. The highest Nusselt number ratio of perforated to solid fins is 1.73, achieving 57.27% heat transfer enhancement and 21% material savings.

Many researchers concentrated on studying the effect of fin arrangements on the heat transfer surfaces, which also impacts the overall heat transfer process. Gemici et al. [6] numerically studied the single-phase forced convection heat transfer in fin arrays. The fin configurations they used are shallow, rectangular, sandwich-like copper channels with staggered rectangular miniature-pin fins. Results showed that finned surfaces enhance heat transfer by up to 220% compared to plain surfaces. Yang et al. [7] used staggered fins in a heat transfer study and found that fins with shorter and fatter profiles are optimal to deliver better heat transfer. Hoi et al. [8] found that the plate-fin array provides a substantial heat transfer enhancement. Aldoori et al. [9] experimented on heat transfer in rectangular fins with varying heights (0.27, 0.47, and 0.67 m). They found that fins are more effective at greater Reynolds numbers. It also shows that the fin height and air velocity significantly increase heat transfer. Lampio et al. [10] conducted optimization study on fin array. They found that reducing the weight of fins can reduce maximum temperature and hence improve heat transfer. Reddy et al. [11] studied the optimization of micro pin-fin arrays for electronics cooling applications.

The findings of this study showed that pin-fins with symmetric convex lens shapes lead to effective heat transfer. Uç and Ekici [12] conducted a numerical optimization study for fin array for piezoelectric fan-driven forced convection application. In this study, they changed the number, fan arrangement, and width of fins. They found that horizontal fan arrangements have better cooling performance.

Adhikari et al. [13] investigated the forced convection heat transfer performance of straight rectangular fins on a horizontal surface at low Reynolds numbers. Results of this study showed that shorter fins are more effective than longer fins in heat transfer. Abbas et al. [14] investigated parallel rectangular fin array heat sinks for electronics cooling applications. They investigated heat transfer via conduction and turbulent convection. They found that fins at the center of the array have a higher temperature gradient compared to the ones situated away from the center. Mandal et al. [15] studied the impact of fin orientation on the heat transfer by using vertical fin arrays under accelerated convection. The findings showed that heat transfer is maximum at inline (40°) and staggered (120°) fin arrangements. El-Said et al. [16] explored the thermal behavior of the square and hexagonal pin fin arrays under forced convection at different twist angles and Reynolds numbers. They found that increasing the twist angle enhances the heat transfer with hexagonal fins. These studies showed that the space between fins, fin geometrical parameters, and shapes have considerable effect on the overall values of heat transfer. It shows the complexity of the design of the fin array and the need for optimization.

The present work systematically investigates the influence of three extension geometries (rectangular, trapezoidal, triangular) and three perforation diameters (17 mm, 20 mm, 23 mm) on the heat transfer behaviour of aluminum fin arrays. The objective is to provide a clear understanding of how geometric features affect convective heat transfer coefficients and Nusselt numbers, while also identifying the most effective configuration for natural convection environments.

## 2. Material and methods

An experimental study was conducted to examine how fin-geometry modifications—specifically, extensions and perforations—affect heat dissipation under natural convection. Fin arrays were machined from aluminium (thermal conductivity ≈ 205 W/m·K). The configurations studied include plain fins, fins with rectangular, trapezoidal, and triangular extensions, and perforated fins with hole diameters of 17 mm, 20 mm, and 23 mm.

### Design of Fins, perforations and extensions

Figure 1 shows the fin base, perforations and extensions used in this experimental investigation. Figure 2 shows the plain fin array without any extension or perforations. It shows three parallel fins of 0.215 m in length and 0.013 in width. The base dimensions are 0.215 m × 0.019 m × 0.15 m. The surface area of the fin array will be 0.1147 $m^2$ (excluding the base side, which will be on the side of the heater). This fin array is placed into the test section inside the enclosure and different thermocouples will be attached to the predetermined positions. After completion of reading this fin array will be replaced by the fin array.

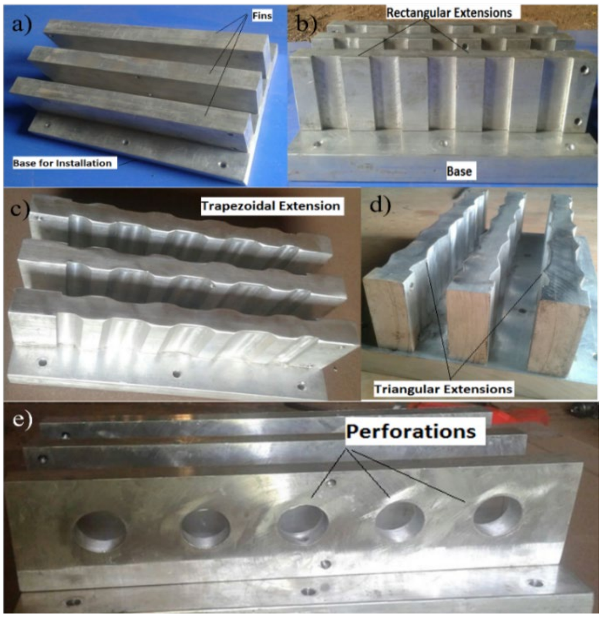

Fig. 1. Fin arrays a) Plain b) Rectangular extensions c) Trapezoidal extensions d) Triangular extensions e) Perforations

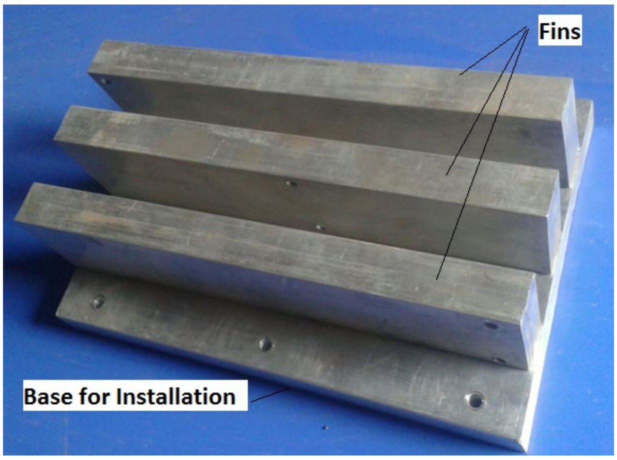

Fig. 2. Plain Fin Array

All the three fins are equipped with four extensions on each side which in total gives 24 extensions on the fin array. Each extension is 0.02 m wide and has thickness of 0.003 m. The area of fin array with rectangular extension is 0.1231 $m^2$. All other dimension and material of this fin array is similar to the plain fin array

Figure 1 c) shows the fin array with the trapezoidal extensions. Figure 1 d) shows the fin array with the triangular extensions and Figure 1 e) shows the fin array with perforations.

**Fin array with Triangular Extensions:**

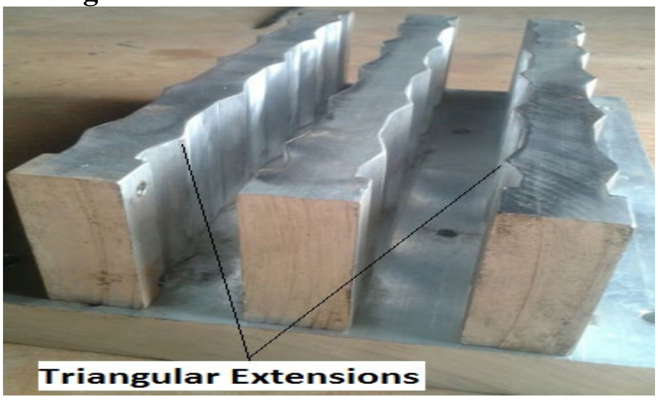


Fig. 3. Fin array with triangular extensions

Table 1.

**Geometrical details of different fin configurations**

| Fin Type | No. of Perforations / Extensions | Total Surface Area ($m^2$) |
|---|---|---|
| Plain Fin | – | 0.01147 |
| Rectangular Extension Fin | 24 extensions | 0.01231 |
| Trapezoidal Extension Fin | 24 extensions | 0.01196 |
| Triangular Extension Fin | 30 extensions | 0.01202 |
| Perforated Fin (Ø17 mm) | 15 perforations | 0.01183 |
| Perforated Fin (Ø20 mm) | 15 perforations | 0.01178 |
| Perforated Fin (Ø23 mm) | 15 perforations | 0.01145 |

Three different sets of perforations are shown in Table 1. These three variants are connected to the heater and tested for heat transfer enhancement study. In this, each fin is drilled to generate perforations. Each fins contains five perforations and array totally contains 15 perforations generated by drilling with the required diameter of drill. The total area of fin array varies with diameter of perforations.

Figure 4 shows the block diagram of setup used for experimental Investigation of fin arrays with perforations and fin arrays with extensions under natural convection conditions.

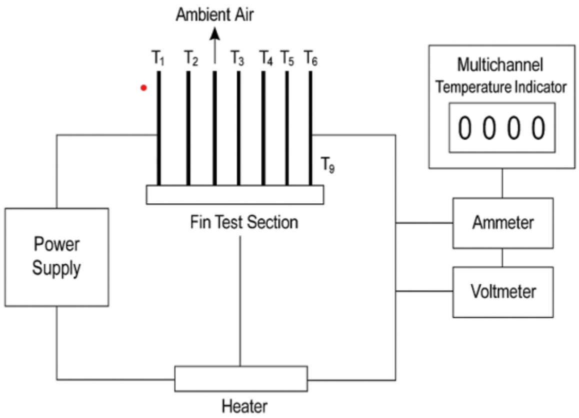


Fig. 4. Experimental set up of fin arrays

## 2.1 Experimental Overview

An experimental apparatus has been prepared to evaluate the heat transfer performance of plain, extended, and perforated aluminium fin arrays under natural convection. All fins were machined from aluminium. All above mentioned configurations in Figure 1 were tested. The perforations used are of dimensions 17 mm, 20 mm and 23 mm. Each fin array consisted of three fins mounted on a base plate, affixed directly to the heater. Thermocouples were placed at fin tips, mid-height positions, and base regions for accurate surface temperature measurement.

## 2.2 Experimental Procedure

The fin array was mounted on the heater and placed inside an insulated enclosure. Voltage and current were gradually increased, and steady-state conditions were confirmed when the temperature variation fell below ±0.2 °C. All thermocouple readings were recorded simultaneously through the 12-channel digital indicator. Each fin configuration was tested under identical conditions.

The heat transfer performance of the fins arrays is then calculated using collected data.

Heater Input $Q = VI$ (1)

Where V is the voltage supplied to heater, and I is the current supplied to the heater. In the fin array a small amount of heat is also lost to radiation and is calculated as:

$$\dot{Q}_{rad} = \sigma\varepsilon A(T_s^4 - T_{amb}^4) \quad (2)$$

Where, σ is Stefan Boltzmann constant ($5.67 \times 10^{-8}$), ε is emissivity (0.1), A is area available for radiation, $T_s$ is the average surface temperature in K is $\frac{T_1+T_2+T_3+T_4+T_5+T_6+T_7+T_8}{8}$ and $T_{amb}$ is ambient temperature in K ($T_9$). The amount of heat lost to radiation is then used to calculate the heat transfer through convection, and then the convective heat transfer coefficient is calculated.

$$\dot{Q}_{conv} = \dot{Q} - \dot{Q}_{rad} \tag{3}$$

$$h = \frac{\dot{Q}_{conv}}{A(T_s - T_{amb})} \tag{4}$$

Where A is the area available for convection and $\Delta T = T_S - T_{amb}$, this heat transfer coefficient is then used to calculate the Nusselt number.

$$Nu = \frac{hL}{k} \tag{5}$$

Where L is Characteristic length and k is the Thermal conductivity of air at the average mean film temperature

**Instrumentation and Uncertainty Analysis**

The experimental setup utilized a digital temperature indicator (12-channel, range 0–400 °C, accuracy ±0.5 °C) connected to K-type thermocouples (±1.5 °C). Voltage and current were measured using calibrated digital voltmeter (accuracy ±0.1 V) and ammeter (accuracy ±0.01 A). Dimensional measurements were obtained using a digital Vernier caliper (accuracy ±0.02 mm). The overall uncertainty in heat transfer coefficient and Nusselt number calculations was estimated following the Kline–McClintock

## 3. Results and Discussions

### 3.1. Effect of Size of the Perforation on Heat Transfer Coefficient

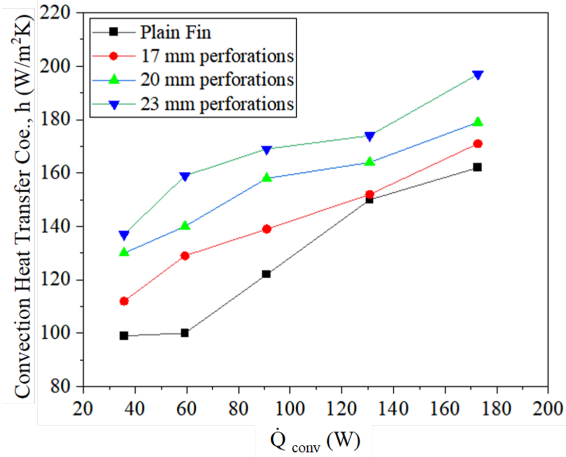


Fig. 5. Variation of Perforation sizes on Heat Transfer Coefficient

Figure 5 indicates effect of size of perforation on the heat transfer coefficient of the system. It is found that perforation size has a considerable impact on the coefficient of heat transmission. As the perforation size increases heat transfer coefficient also increases. The heat transfer coefficient is higher in perforations having higher diameters. It can be seen from the Figure that the plain fin has the lowest values of heat transfer coefficient with increasing heat input. The heat transfer coefficient in plain fin increases from 12.76 $W/m^2$ K to 21.96 $W/m^2$ K. For 17 mm perforations heat transfer coefficient increases from 14.32 $W/m^2$ K to 23.44 $W/m^2$ K, which is 13.06% higher than plain fin. For fin array with 20 mm perforations heat transfer coefficient is varies from 16.74 $W/m^2$ K to 24.45 $W/m^2$ K which is 24.26% higher than plain fin. Fin array with 23 mm shows highest values of heat transfer coefficient which are 31.9% higher than values of heat transfer coefficient in plain fin. Larger perforations facilitated stronger airflow recirculation through the openings, reducing thermal resistance.

The theoretical heat transfer coefficient was estimated using standard natural convection correlations (Churchill and Chu, 1975). The maximum deviation between experimental and theoretical results was within ±7.6%, validating the experimental accuracy.

3.2 Effect of Perforation variation on Nusselt Number

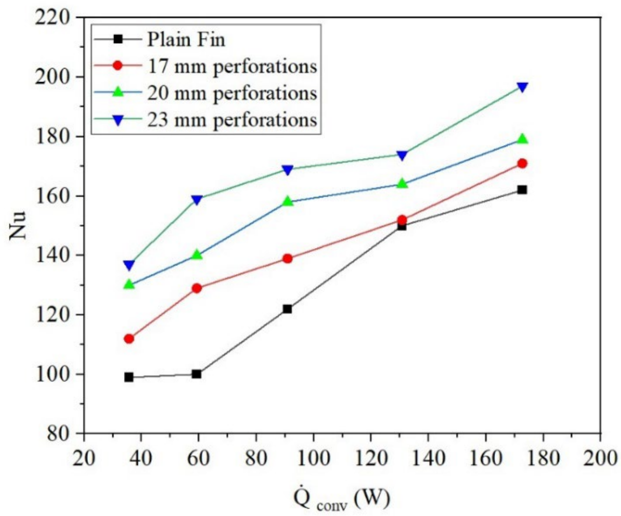


Fig. 6. Effect of Perforation Variation on Nusselt Number

The effect of the size of the perforation on the Nusselt number can be observed in Figure 6. The fin arrays with 17 mm perforations, 20 mm perforations, and 23 mm perforations are tested in this study, and their results are presented. It can be observed here that the higher the perforation sizes in fin arrays, the higher the Nusselt number. It is shown that for plain fin, the Nusselt number varies from 99 to 162; for fin arrays with 17 mm perforations, these values of the Nusselt number increase from 112 to 171. The values of Nusselt number further increase for 20 mm perforations 130 to 179 and for 23 mm perforations 134 to 192.

3.3 Effect of Shape of the Extension on Heat Transfer Coefficient

Figure 7 indicate effect of shape of fin extension over the coefficient of heat transfer of the system. The impact of the fin extensions shape on heat transfer is due to the abrupt change in the surface contacting the air, more abrupt the surface more will be the heat transfer. The triangular and trapezoidal extensions are more like smooth extensions and rectangular extension is abrupt in nature. It can be noted clearly from the Figure 8 that plain fin shows lowest values of the heat transfer coefficient for all the situations of increasing heat input, the heat transfer coefficient of plain fin varies from 12.76 $W/m^2$ K to 21.96 $W/m^2K$ . The fin array with triangular extensions shows slightly greater values of heat transfer coefficient of 13.65 $W/m^2$ K to 22.25 $W/m^2$ K. The average increase in fin array with triangular extension observed is 8.1 %.

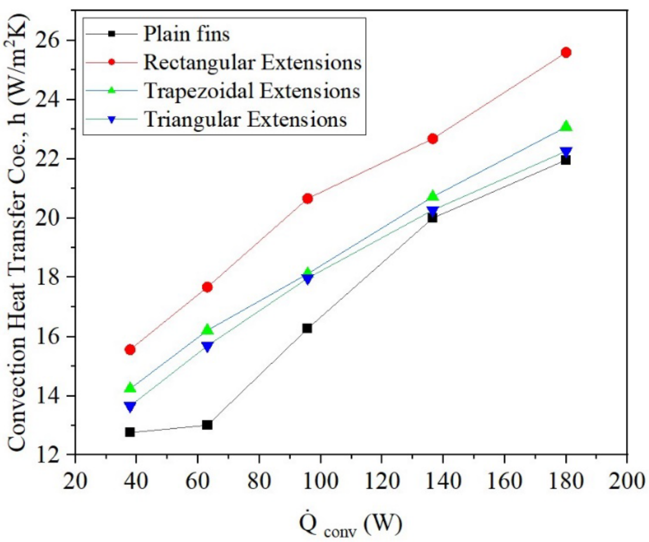


Fig. 7. Effect of Shape of the Extension on Heat Transfer Coefficient

In this work, the fin array with trapezoidal extension was also examined. It was found that the heat transfer coefficient of the trapezoidal fin array was higher than that of the plain fin array and the fin array with triangular extensions. The heat transfer coefficient of the fin array with trapezoidal extensions varies from 14.21 $W/m^2$ K to 23.08 $W/m^2$ K. The average increase in the values of heat transfer coefficient of fin array with trapezoidal extensions when compared to plain fin is

11.25%. The fin array with rectangular extensions shows best results in heat transfer enhancement from the system. The heat transfer coefficient of the fin array with rectangular extensions varies from 15.56 W/m$^2$ K to 25.59 W/m$^2$ K. The total increase in the h value of the system is observed to be 22.93%.

3.4 Comparison between Effect Extensions and Perforations on Heat Transfer Coefficient

Figure 8 gives the comparison between effect of extensions and perforations on the value of h. It is seen that the fin array has the lowest heat transfer coefficient values. The increasing order of heat transfer coefficient observed as plain fin array, fin array with triangular fin extensions, fin array with trapezoidal extension, fin array with 17 mm perforations, fin array with rectangular extensions, fin array with 20 mm perforations and fin array with 23 mm perforations respectively. In this study, it is also observed that the fin array with rectangular extensions performed better at high heat input than 20 mm perforations, but at low heat input, the fin array with 20 mm perforations performed better. This might be due to the fact that at high heat input, air present inside the perforation will become hot, which will reduce heat transfer from surface to air as temperature difference decreases.

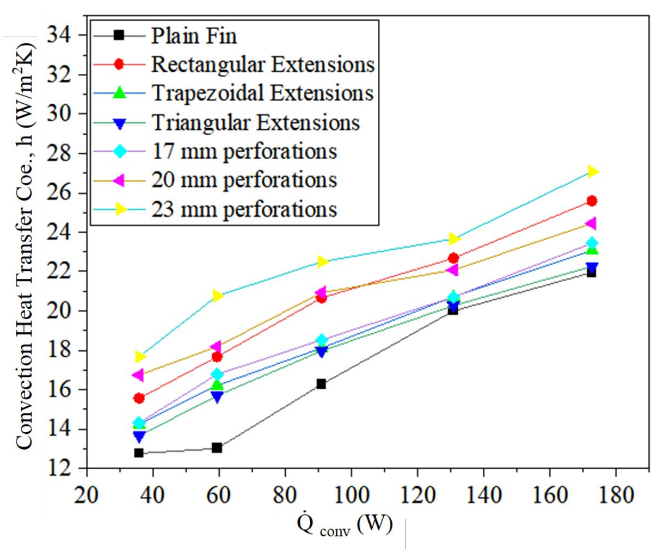


Fig. 8. Comparison between Effect 0f Extensions and Perforations on h

## 4. Conclusion

This study systematically examined the performance of fins with geometric extensions and perforations under natural convection. The findings indicate that both design strategies significantly enhance heat transfer. Rectangular extensions provided the highest performance among extension types with a 22.9% increase in heat transfer coefficient. Perforated fins offered even greater enhancement, with the 23 mm perforated fin demonstrating a 31.99% improvement over plain fins. Perforated fins reduce material weight by 8–12%**,** lowering manufacturing cost. Extensions increase effective heat transfer area without enlarging base size. Simple geometries make fabrication inexpensive and scalable. Larger perforations increase convective mixing and buoyancy effects. Rectangular extensions offer high enhancement with minimal structural complexity. Overall, geometric modification plays a crucial role by altering airflow patterns, reducing thermal resistance, and promoting buoyancy-driven plume development. These results offer valuable guidelines for the design of compact, low-cost heat sinks.

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