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Research article

Optimization of CPU Heatsink Design, A Simulation-Based Study on Temperature Distribution with Different Fin Number

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ABSTRACT

In this era of digitalization, a fast processor (CPU) is needed to meet computing needs, but a fast processor can produce high temperatures. With the water cooling technique, the heatsink can help in cooling the processor with the help of a blower/fan. A numerical study was conducted to review the temperature distribution in the heatsink with perforated fin, the effect of the number of holes, and the effect of inlet speed on the CPU temperature, in this study regular fin and perforated fin with 10, 20, and 30 were used. CPU performance relies heavily on an effective thermal management system, where the heatsink plays an important role in dissipating excess heat. This study aims to optimize the design of the CPU heatsink by analyzing the effect of the number of fins on temperature distribution. Simulations were performed using computational software to evaluate multiple heatsink models with varying numbers of fins under the same thermal load conditions. The observed parameters include maximum temperature, heat flux, and temperature distribution on the surface of the heatsink. The simulation results show that an optimal number of fins can significantly improve heat dissipation performance, while an excessive number of fins can actually inhibit airflow and decrease thermal efficiency. This study provides an overview of the thermal behavior of heatsinks and becomes a reference in designing more efficient cooling systems for electronic devices.

1. INTRODUTION

Cooling systems play an important role in maintaining the performance and reliability of electronic devices, both on an industrial and consumer scale[1]–[3]. Increased power density in semiconductor components leads to significant heat accumulation, so an effective heat dissipation method is required[4]–[6]. In a global context, research on heat management technology is growing, including both passive and active approaches with a focus on optimizing heatsink geometry, using high-conductivity materials, and integration with fluid based cooling systems[7], [8]. At the national level, the need for reliable cooling systems is becoming more and more urgent, especially in tropical countries such as Indonesia which have relatively high ambient temperatures[9], [10]. This condition worsens the risk of overheating, thus shortening the service life of electronic devices and industrial machinery[11], [12].

The main problem faced in heatsink design is the limited effectiveness of conventional geometry in increasing the rate of heat transfer[13]. Although the use of fins is able to expand the surface area of contact with air, an increase in the number of fins is not always linear to an increase in cooling performance due to additional thermal resistance and limited airflow space[14]. This raises scientific questions regarding the optimal number of fin configurations that can balance between surface area and heat transfer efficiency[15], [16].

Recent studies have evaluated the effect of variations in the number of fins and heatsink configurations on thermal performance.show that different fin geometry significantly affects temperature distribution and heat flux. The research of yi sun et al [17].also found that an increase in the number of fins can increase the heat transfer coefficient, but only to a certain extent before giving rise to the saturation effect[18]. emphasize the importance of multi parameter optimization including fin count, thickness, and interfin spacing to achieve efficient cooling under natural convection conditions[19]–[21]. Meanwhile, a review study by Jebeli et al.[22] concluded that heatsink research still needs to pay attention to the integration between numerical design and experimental validation[23]. However, most of the studies focused on general simulated conditions without taking into account tropical environmental factors relevant to the Southeast Asian context[24], [25].

Thus, there is a research gap in heatsink studies related to the systematic evaluation of thermal performance with variations in the number of fins in the context of tropical climates. This article aims to evaluate the thermal performance of heatsinks with variations in the number of fins (10, 20, and 30) using a numerical simulation approach based on the finite element method. The contribution of this research includes three aspects: (i) theoretical, by strengthening the understanding of conduction convection mechanisms in heatsinks, (ii) practical, by providing appropriate heatsink design recommendations for electronic devices in tropical environments, and (iii) methodological, through the presentation of replicable simulation procedures for the evaluation of cooling performance. With this analysis, the article is expected to expand the literature on thermal heatsink design as well as provide implications for the electronics and manufacturing industries.

2. METHODS

2.1 Research Desain

This study uses a numerical simulation approach based on Computational Fluid Dynamics (CFD) to evaluate the thermal performance of heatsinks with variations in the number of fins (10, 20, and 30). The research design was computationally experimental with a 3D geometry model built using

CAD software, then analyzed through the finite element method (FEM) to calculate the temperature distribution, heat flux, and heat transfer coefficient. The selection of the CFD approach is based on its accuracy and replicability in analyzing electronic refrigeration systems[26], [27].

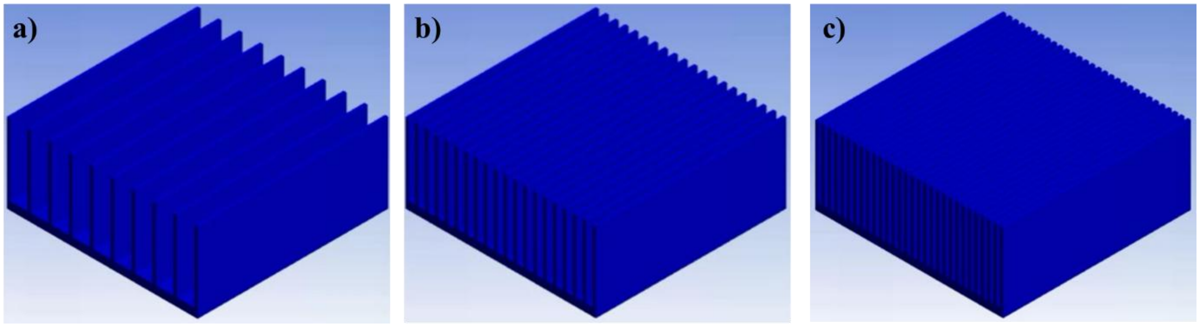

Figure 1. Desain of heatsink a) 10 fins, b) 20 fins, c) 30 fins

Figure 1. Desain of heatsink,3 are illustrations of the model of a heatsink with 10, 20, 30 fins used in this study The dimensions of the heatsink that have been modeled can be seen in the model on the regular and perforated fins have the same dimensions, but with a difference, namely in the number of fins in the heatshink.

Table 1. Heatsink size details

Parameter	**Value**
Fin Height	120mm
Fin Length	120mm
Fin Guesses	2mm
Number of Fins	10,20,30
Baseplate width	120mm
Baseplate Length	120mm
Thickness Baseplate	2mm

The model that has been created will be defined according to the conditions of its original dimensions. After that, the creation of a fluid domain is carried out using ANSYS. Next, the meshing process will be carried out, which is the breakdown of the model and fluid domain into small elements. The result of the heatsink mesh with fins 10, 20, and 30 uses ANSYS software. The mesh is made using the automatic method without adding a method or automatically, where the number of mesh elements for heatshink with 10 fins is 21240, the number of mesh elements for heatshink with 20 fins is 36120, the number of mesh elements for heatshink with 30 fins is 51000. The size of the meshing is made more and more tight, which aims to improve the accuracy of the simulation.

2.2 Sample Data

The research data was obtained from a heatsink model made of aluminum 6061, which is commonly used in the electronics industry due to its high thermal conductivity (167 W/m·K). The independent variables in this study were the number of fins (10, 20, and 30), while the bound variables included maximum temperature, temperature distribution, heat flux, and heat transfer coefficient. The simulation environment is set to natural convection conditions with an ambient air temperature of 27°C, as per the tropical climate.

2.3 Software dan Equipment

A geometric model of the heatsink was created using SolidWorks 2022[28]. The CFD simulation was conducted with ANSYS Fluent 2022 R2 (ANSYS Inc., Canonsburg, USA). The selection of this software is based on its validity in electronic refrigeration research [5].
The main parameters used:

1. Tetrahendral-based mesh with adaptive refinements in the fin area).
2. Limit conditions: free air flow (velocity ilnet = 0 m/s, outlet pressure = 1 atm).
3. Material: Aluminum (ρ=2700kg/m^3, Cp=896 J/KgK, k=167 W/m.K).
4. Model turbulensi : k-ε realizable.

2.4 Research Procedure

Geometry Model Making: Heatsinks with different number of fins (10, 20, 30) are designed with the same basic dimensions. Meshing: Independence mesh is tested with variations in the number of elements to ensure the stability of the results. Limit Condition Determination: A heat load of 50 W is applied to the heatsink base. CFD simulation: Steady-state analysis is performed up to convergence (residual $\leq 10^{-6}$).. Internal Validation: Results are compared with relevant numerical literature[27] to verify model reliability.

2.5 Evaluation Metrics

Performance evaluation is carried out using the following metrics: Maximum temperature (Tmax) on the Heatsink base. Heat Flux is calculated with Fourier equations.

$$q^n = -k\frac{dT}{dx}$$

And the heat transfer coefficient (h), calculated by:

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

with Q is the heat load (W), A is the surface area (m²), Ts is the surface temperature (K), and ΔT is the different temperature.

2.6 Statistical Analisys

The data from the simulation results were analyzed descriptively and inferentially. One-way ANOVA analysis was used to compare the effects of fin count on Tmax, ΔT, and heat flux. The significance level is set at $\alpha = 0.05$. The assumption of normality and homogeneity of variance was examined by the Shapiro Wilk and Levene tests.

3. RESULT AND DISCUTION

3.1. Influence of Fin Geometry

Simulation was carried out on the regular geometry and perforated fin heatsink with boundary Heat flux (Bottom Plate) is 6000 w/m^2, Convection (Fin Surface) is 10 W/m^2, Temperature

(Ambient) is 25°C.

3.2. Temperature Facing Fin Analysis

Cooling occurs in the CPU due to the heatsink being passed through by flowing air. The inlet speed is set constantly. Heatsinks with fin models that vary in number namely 10, 20, and 30. For the distribution of the front view temperature, it can be seen in Figure 2, and for the distribution of the side-view temperature, it can be seen in Figure 3.

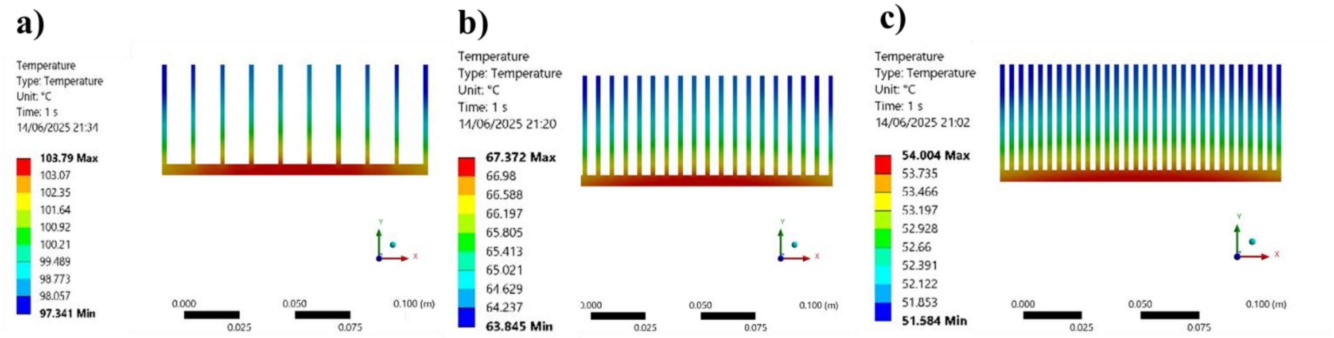

Figure 2. Distribution Temperature Font view a). 10 fins, b). 20 fins, c). 30 fins

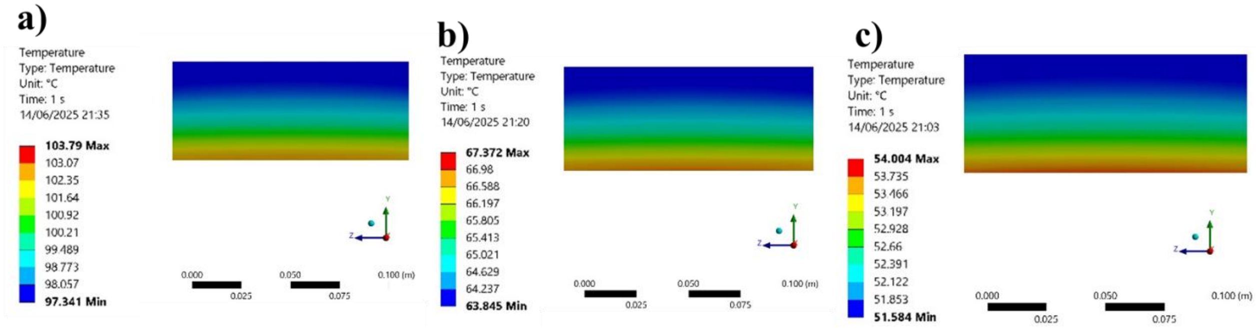

Figure 3. Distribution temperature heatsink side view a). 10 fins, b). 20 fins, c). 30 fins

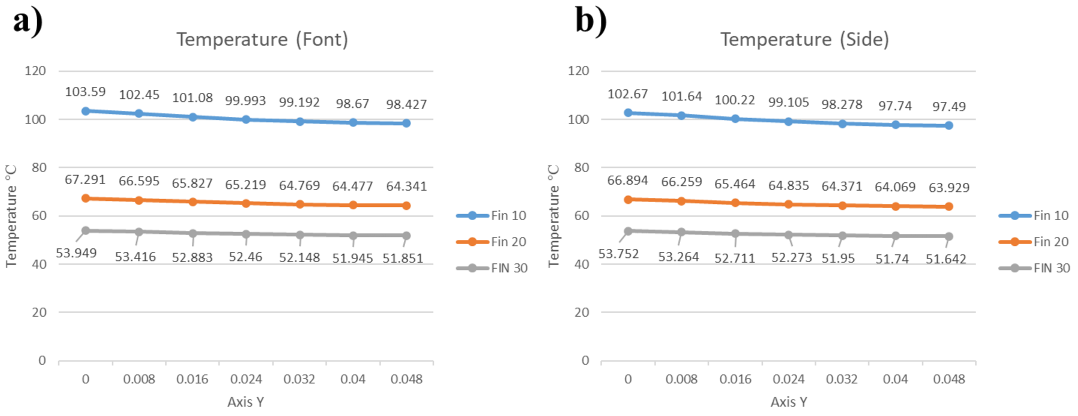

Figure 4. Temperature distribution graph a). Front view b). Side view

Figure 4 illustrates the temperature distribution along the Y-axis for heatsinks with 10, 20, and

30 fins, observed from both the front (Figure 1a) and side (Figure 1b). A consistent downward trend in surface temperature is observed with increasing fin numbers, confirming the effect of enhanced surface area on thermal dissipation.

For the front view (Figure 1a), the heatsink with 10 fins exhibits the highest surface temperature, ranging from 103.59 °C to 98.43 °C along the Y-axis. In contrast, the 20 fins configuration shows a reduced temperature range of 67.29 °C to 64.34 °C, while the 30-fin heatsink demonstrates the lowest values, decreasing from 53.39 °C to 51.65 °C. A similar pattern is observed in the side view (Figure 1b), where the 10-fin model ranges from 102.67 °C to 97.49 °C, the 20-fin model ranges from 66.89 °C to 63.93 °C, and the 30 fins model ranges from 59.75 °C to 54.65 °C.

These results clearly indicate that increasing the number of fins significantly reduces the operating temperature of the heatsink, with the 30-fin design achieving an average temperature reduction of 45% compared to the 10 fins design. Moreover, the parallel behavior observed in both front and side measurements confirms the uniformity of heat dissipation across the heatsink geometry. These results are consistent with research by [27] which showed that an increase in the number of fins can lower peak temperatures.

3.3. Analysis of the number of fins against the distribution of Heat Flux

For the Heatflux of the front view, it can be seen in Figure *5*, and for the Heatflux of the side-view, it can be seen seen in Figure *6*.

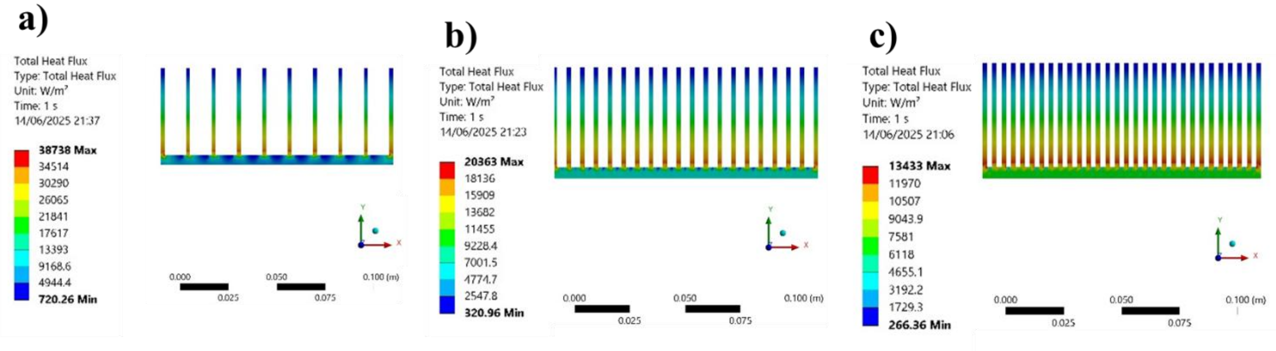

Figure 5. Heatflux Heatsink Font view a). 10 fins, b). 20 fins, c). 30 fins

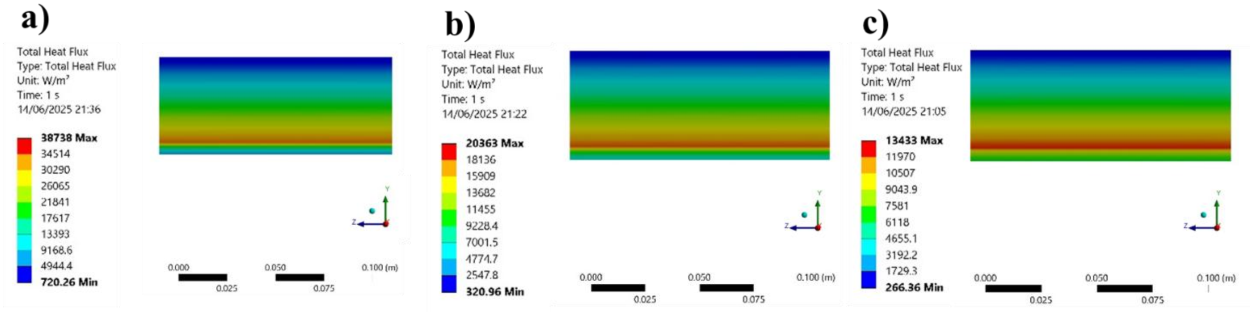

Figure 6. Heatflux Heatsink side view a). 10 fins, b). 20 fins, c). 30 fins

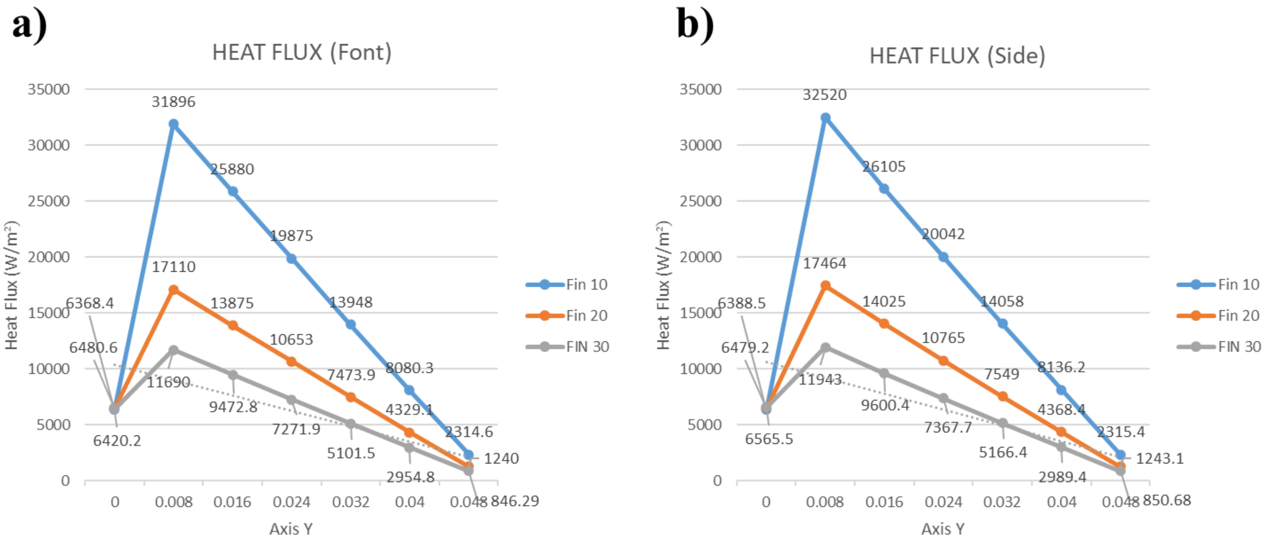

Figure 7. Heatflux graph a). Front view b). Side view

Figure 7 illustrates the variation of heat flux at the front and side surfaces of the heatsink with different fin numbers (10, 20, and 30 fins). The results reveal a strong dependence of heat flux on the fin configuration. At the front surface, the 10 fins heatsink recorded the highest peak heat flux of approximately 31,896 W/m², followed by the 20 fins configuration at around 17,130 W/m², and the 30-fin configuration with about 9,472 W/m². A similar trend was observed at the side surface, where the maximum heat flux reached 32,630 W/m² for the 10-fin design, compared to 14,025 W/m² for the 20-fin and 9,600 W/m² for the 30 fins heatsink. The curves indicate that as the number of fins increases, the overall heat flux decreases, suggesting that higher fin density promotes a more uniform thermal distribution but reduces the intensity of local heat transfer. Conversely, fewer fins lead to higher localized flux values due to larger temperature gradients across wider fin spacing. These results emphasize a clear trade-off: the 10-fin design enhances localized heat transfer but risks thermal hotspots, while the 30-fin design ensures more even distribution with lower flux intensity. The 20-fin configuration provides an intermediate condition, balancing surface area and heat transfer uniformity.

3.4. Analysis of the number of fins Heat Transfer Coeficient

The results of the analysis of the number of fins on the heat transfer coefficient can be seen in the Figure 8 Heat Transfer Coeficient a). Font view, b). Side view

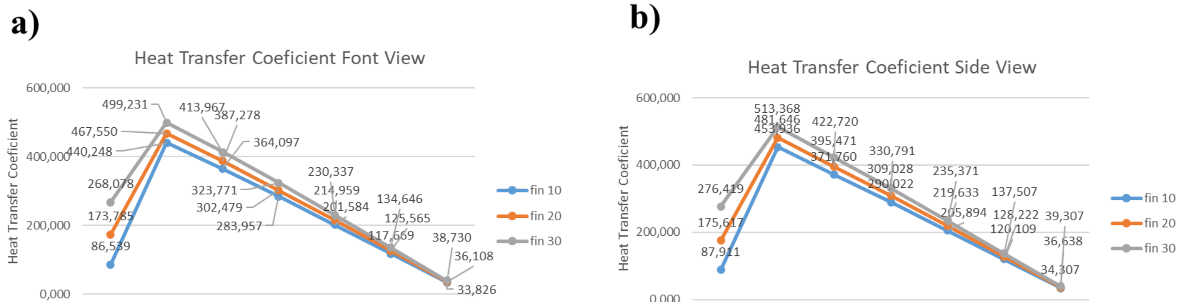

Figure 8 Heat Transfer Coeficient a). Font view, b). Side view

Figure 8 shows the variation of the heat transfer coefficient on the front and side surfaces of the heatsink with different numbers of fins (10, 20, and 30 fins). The results indicate a strong dependence between the heat transfer coefficient and the fin configuration.

4. DISCUSSION

The simulation results show that the increase in the number of fins has a significant effect on the decrease in temperature and the increase in the rate of heat transfer. This phenomenon can be explained through the basic theory of conduction convection: the wider the surface, the greater the capacity of the fins to release heat into the environment[29]. However, increasing the number of fins also has limitations. According to Zhou et al. [30], under certain conditions, the addition of too many fins can inhibit the airflow between the fins, so that performance does not increase proportionally. In the context of this study, comparisons between 10–30 fins showed a significant increase, but saturation trends need to be reviewed at larger numbers of fins.

Another study by Lymaye et al. [14] found that heatsink optimization depends not only on the number of fins, but also on the geometry of the fins (height, thickness, distance between fins) as well as flow conditions (natural or forced). Therefore, the results of this study can be used as a basis for further studies with geometric variations. The results show that an increase in the number of fins directly enlarges the surface area of heat transfer, so that thermal resistance is reduced and temperature decreases. This is in accordance with the basic theory of forced convection on heatsinks[27].

The improvement in thermal performance is indicated by an increase in the heat flux value and the heat transfer coefficient. A similar study by Goksu[12]. Confirms that the optimization of the number of fins is able to increase the rate of heat release by 25–40% When compared to the latest research by Guggari et al[13]. However, these results also confirm a practical limitation: the more fins, the greater the pressure drop, so the increase in thermal performance is not always linear. Research by Sun et al[17]. shows that there is an optimum point of the number of fins that depends on the airflow speed and the basic geometry of the heatsink. Overall, the study supports previous findings that heatsinks with more fins provide better thermal performance, but practical implementation must consider the balance between heat transfer efficiency, physical size, and cooling fan energy consumption.

5. CONCLUTION

This study investigated the thermal performance of CPU heatsinks with different fin configurations (10, 20, and 30 fins) through simulation based analysis of temperature distribution and heat flux behavior. The results consistently demonstrated that fin number significantly influences both surface temperature reduction and heat transfer characteristics. Temperature distribution analysis revealed that increasing the number of fins leads to a notable decrease in surface temperature. Specifically, the 30 fins configuration achieved the lowest average temperature on both the front and side surfaces, indicating superior thermal spreading and enhanced convective heat dissipation. By contrast, the 10 fins design exhibited the highest temperatures, reflecting limited cooling effectiveness due to reduced surface area.

Meanwhile, the heat flux results showed an inverse trend. The 10 fins heatsink produced the highest localized heat flux peaks (32,520 W/m²), while the 30 fins design yielded the lowest values (846.29 W/m²). This suggests that a lower fin density amplifies local temperature gradients, resulting in higher but less uniform flux distribution.

Overall, the findings highlight a trade off between thermal uniformity and peak flux intensity. Among the three tested designs, the 20 fins heatsink provided the most balanced performance, offering effective temperature reduction while avoiding excessive localized hotspots. These insights are relevant for optimizing heatsink designs in high-performance CPU cooling applications.

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