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The Effective Parameters on the Performance of Finned Heat Sinks Used for Light Emitting Diode Application: A Review

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ABSTRACT

The increasing demand for high-performance LED applications has led to the development of thermal management systems to reduce heat generation. This review paper examines finned heat sinks for LED applications, examining the impact of fin number, height, thickness, shape, type, direction, and materials used. The study concludes that creating holes in the fins improves heat sink performance, while shape, size, and number also affect heat transfer rate and temperature drop along the fins. This research highlights the importance of efficient thermal management systems in LED applications. This review paper examines the impact of various parameters on the performance of finned heat sinks used for LED applications. It explores the influence of fin number, height, thickness, shape, type, direction, and materials on heat transfer rate and temperature drop along the fins. The study emphasizes the importance of efficient thermal management systems in LED applications. From the beginning of March until the end of August 2022, tests will be conducted to determine the sensitivity of single-glass solar modules to environmental changes.

Introduction

Light Emitting Diodes (LEDs) have become popular due to their high-energy efficiency, extended lifespan, and compact size. However, the heat generated during their operation can affect their performance and durability. Initially, heat management was not a major concern for LED technology in low-power applications. However, as power levels increased, effective heat dissipation became crucial to maintain peak performance and prevent early failure.

Analyzing LED heat power dissipation involves understanding thermal resistance, junction temperature, and thermal routes such as conduction, convection, and radiation. Engineers utilize finite element analysis (FEA) and computational fluid dynamics (CFD) simulations to model; simulate thermal behavior for improved LED performance, and optimized heat dissipation techniques. Heat sinks are vital in dissipating heat from LED light sources through conduction, convection, or radiation. The choice of material for the heat sink depends on factors like thermal conductivity. While copper is the best material due to its high thermal conductivity, aluminum is more commonly used because of its lower cost.

Integrating phase change materials (PCMs) into heat sinks is A passive alternative to heat management due to their high heat storage capacity and isothermal phase transition. PCM-filled heaters can be used in a variety of applications where efficient thermal management is essential, such as LED lighting. The advancement of LED technology has resulted in more compact yet powerful devices that produce a significant amount of heat despite their higher efficiency. Proper management of this excess heat becomes crucial to prevent device failure and maintain superior light quality. Heat sinks utilizing conduction or natural convection have been extensively researched for controlling the dissipation of excess heat from LEDs.

In conclusion, effective thermal management systems are essential for optimizing the performance of finned heat sinks used in LED applications. The appropriate design and material selection can significantly impact the effectiveness of these systems. [2,16,28].

1. Background on LED applications and thermal management systems

(LEDs) have become all the rage in the lighting industry due to their superior efficiency and extended lifespan. However, the heat generated by LED chips can significantly affect their performance and overall efficiency. The use of heat sinks is crucial for dissipating heat and maintaining the efficiency and lifespan of LED devices. Various types of fins, such as rectangular, pin, annular, elliptical, and triangular fins, can be attached to the heat sinks used in LED lights, influencing the overall heat transfer rate. In LED applications, natural convection is preferred over forced convection as it eliminates the need for additional equipment. Parameters such as the number of fins, fin height, fin thickness, fin shape, fin type, fin direction, materials used in heat sink construction, and the impact of creating holes in the fins can all significantly affect the performance of finned heat sinks used for LED applications.

Efficient thermal management systems are essential for preserving the performance and longevity of LEDs. Numerous studies have delved into different aspects of thermal management for LED applications. For instance, a study by Baskaya et al. examined rectangular fin arrays and discovered that increasing fin height and decreasing fin length improved the overall heat transfer rate. Other studies have focused on optimization through changes in geometry or additional structures to induce a chimney effect for improved heat sink thermal performance. A numerical investigation looked into the cooling performance of a radial heat sink with trapezoidal fins under consideration of natural convection and radiation. The study revealed that both thermal resistance and the heat transfer coefficient decreased as the number of fins and fin height increased.

Effective thermal management is vital to ensuring optimal performance and longevity of LEDs. These findings highlight the importance of optimizing different parameters that affect the performance of finned heat sinks for LED applications. [3,7,11,14].

2. Parameters affecting the performance of finned heat sinks

2.1. Fin number

The use of heat sinks in LED applications is essential for effectively managing the heat generated by LED chips and maintaining their performance and longevity. Various studies have explored different aspects of heat sink design and optimization. For example, a study by Antonio Marcos de Oliveira Siqueira investigated the impact of the number of fins on thermal resistance and heat transfer coefficient, finding that increasing the number of fins led to a decrease in both parameters. However, there is an optimal value for the number of fins to achieve optimal cooling performance, beyond which further increases may not significantly improve efficiency.

Additionally, Se-Jin Yook's research on perforated fins in heat sinks revealed that a larger number of smaller perforations could improve heat-dissipation performance, but there are threshold values for both size and number of perforations to lower thermal resistance. This suggests that an optimal configuration of perforations is crucial for maximizing cooling efficiency. Furthermore, Abel Hernandez-Guerrero's analysis of a radial heat sink design for LED lamps highlighted the importance of considering not only the number but also the shape and arrangement of fins for promoting better heat dissipation rates due to natural convection.

Collectively, these findings underscore the importance of carefully optimizing the number and configuration of fins in heat sinks to achieve effective cooling performance for LED applications. [5], [11], [18].

2.2. Fin height

The utilization of heat sinks in LED applications is crucial for effectively managing the heat produced by LED chips and ensuring their performance and longevity. Numerous studies have delved into various aspects of heat sink design and optimization. For instance, Antonio Marcos de Oliveira Siqueira's study examined the impact of the number of fins on thermal resistance and heat transfer coefficient, revealing that increasing the number of fins resulted in a decrease in both parameters. However, there exists an optimal value for the number of fins to achieve optimal cooling performance, beyond which further increases may not significantly enhance efficiency.

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In addition, Abel Hernandez-Guerrero's analysis of a radial heat sink design for LED lamps emphasized the importance of considering not only the number but also the shape and arrangement of fins for promoting better heat dissipation rates due to natural convection.

In conclusion, these findings emphasize the importance of carefully optimizing the number and configuration of fins in heat sinks to achieve effective cooling performance for LED applications. [6,13,15,18,19].

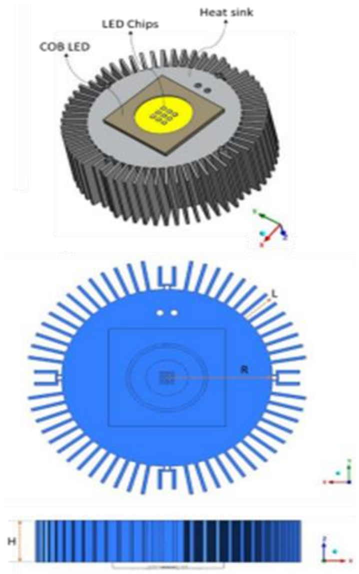

Figure 1: COB LED and heat sink model with optimization parameters. (source: reference [31]).

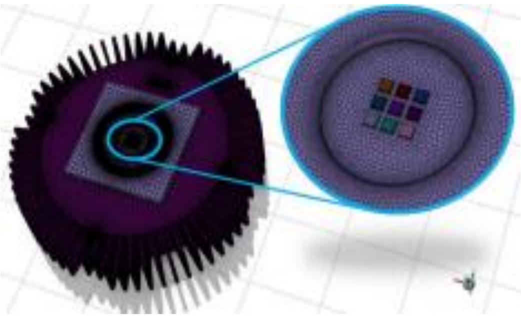

Figure 2: Mesh model of the COB LED and heat sink domains [31].

2.3. Fin thickness

The thickness of the fin play a crucial role in determining the effectiveness of finned heat sinks utilized in LED applications. Studies have revealed that as the thickness of the fins increases, so does the thermal resistance of the heat sink. However, it has also been found that thicker fins are capable of handling more heat without compromising the performance of the LED application, ultimately leading to improved heat dissipation efficiency. In a research study exploring various The cylindrical designs, thicknesses and power ratings of the heat depositor fins have been shown that the cylindrical heat deposit fin with a thickness of 6 mm and a mass of 81.13g exhibits a slightly higher temperature even though the thinner fins This suggests that thicker fins have the capacity to manage more heat and deliver superior overall performance in dissipating heat from LED applications. Furthermore, it was noted that the power ratings of the LED chips did not affect the thermal resistance of the examined heat sink. This indicates that thicker fins were able to maintain high thermal efficiency regardless of the power ratings, highlighting their effectiveness in managing heat. These findings underscore the potential for enhancing LED performance in electronic circuits by carefully considering the thickness of cylindrical heat sink fins during assembly processes.

Future research in this area will involve further exploration of alternative heat sink configurations and diverse materials used in LED systems to develop more effective thermal management strategies .[2,4]

2.4. Fin shape

The design of the fins in a heat sink is critical in determining its overall thermal efficiency. The shape of the fins affects how quickly heat is dissipated and the temperature decrease along the fins. Various studies have delved into different fin shapes, such as longitudinal, radial, pin, straight, curved, and flared fins. Each type of fin shape has its own advantages and drawbacks in terms of heat transfer effectiveness. For example, it has been noted that straight profiles with consistent thickness are easy to produce and have been suggested for high-performance heat dissipation characteristics. Additionally, numerical optimization techniques have been used to determine the shape of pin-fins to enhance cooling efficiency. This indicates that optimizing fin shapes can significantly improve the effectiveness of heat sink modules and reduce design expenses. Furthermore, research has examined the impact of non-uniform heat transfer coefficients along the surface of the fin. It has been discovered that non-uniformities have a significant impact on the rate at which heat is dissipated by the fins. This emphasizes the importance of taking non-uniform heat transfer coefficients into account when designing fin shapes for efficient thermal management. Moreover, studies have demonstrated that different fin shapes can result in varying levels of temperature reduction from the base to the tip of the fin. For instance, triangular-shaped pin fins have been shown to lower element temperature compared to other shapes that were analyzed. In conclusion, these findings highlight the importance of carefully choosing and optimizing fin shapes to achieve optimal heat dissipation and thermal performance in LED applications. [6,9,13,19,20,22,27].

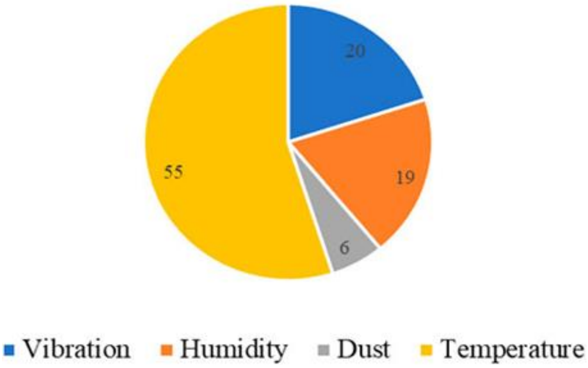

Figure 3: reasons why electrical equipment malfunctions [9].

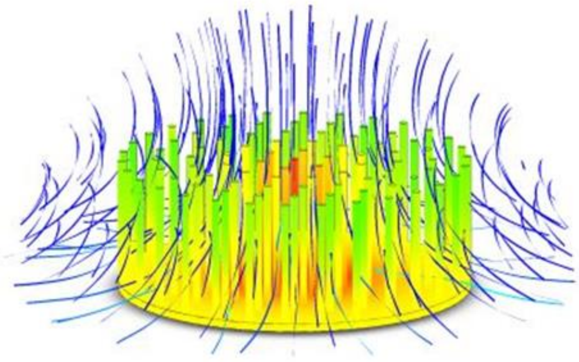

Figure 4: Free-convection flow around a pin-fin heat sink [27].

2.5. Fin type

The selection of fin types for heat sink design in LED applications is a critical factor in the overall thermal management system. Various fin designs have been researched to enhance heat transfer performance, with different studies proposing innovative designs to improve cooling efficiency. For instance, Zhang et al. [28] introduced a W-type finned heat sink, which demonstrated a significant reduction in temperature due to increased airflow perpendicular to the substrate and thinning of the thermal boundary layer. Similarly, Naserian et al., [29] investigated various shapes of a 90-degree V-type fin and identified an optimal design for enhanced heat transfer. Altun et al. discovered that sinusoidal wavy fins improved heat transfer compared to rectangular fins, but with an increase in wave amplitude, the enhanced heat transfer effect diminished. Additionally, Nilpueng et al. examined sinusoidal wavy plate fins with varying phase shifts and observed a notable impact on thermal performance based on the phase shift. Furthermore, research has indicated that incorporating hollow cylinders in conjunction with radial heat sinks can boost thermal performance by increasing the airflow to the heat sink fins. This underscores the significance of additional components in addition to fin shape in influencing heat dissipation efficiency. Moreover, various studies have explored different geometries and orientations of fins to optimize their performance for LED applications.

The effectiveness of these diverse fin types is crucial for achieving efficient thermal management in LED systems. In conclusion, the comprehension and selection of the appropriate fin type for heat sinks are vital for enhancing heat transfer performance in LED applications. [3,9,12,15,20].

2.6. Fin direction

The positioning of the fins in a heat sink is pivotal in determining its thermal efficiency, particularly when utilized in LED applications. Research has indicated that optimizing the placement of fins can significantly enhance the heat dissipation capacity of the heat sink. For example, Akin et al. conducted an experimental analysis on the impact of fin placement on the cooling performance of finned heat sinks integrated with phase change material (PCM). They noted an 83.4% improvement in operation time as the inclination angle varied from 0 to 60 degrees. Furthermore, they determined that optimal thermal efficiency was achieved with three fins positioned at an angular orientation of 60 degrees.

This highlights that the configuration and orientation of the fins can have a substantial impact on the overall cooling effectiveness of the heat sink. Additionally, Choi and Kim examined the efficacy of an angled cross-cut cylindrical heat sink for LED bulbs and concluded that by adjusting the placement angles, the thermal efficiency could be enhanced. Their findings suggest that altering the orientation angle can directly influence the heat dissipation performance of the heat sink. These studies clearly demonstrate that fin direction is a critical factor that affects the ability of the thermal management system to efficiently dissipate heat in LED applications. By optimizing and thoughtfully selecting the orientation and layout of fins, it is feasible to enhance the overall cooling performance and ensure effective thermal management for LED modules. [9,10, 21].

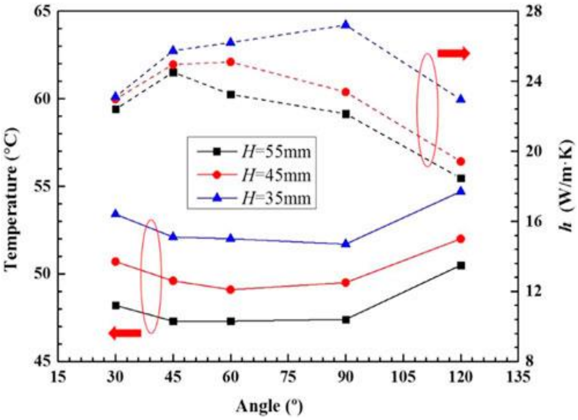

Figure 5: Connection between the fin inclination angle and the W-type heat sink's heat transfer efficiency [9].

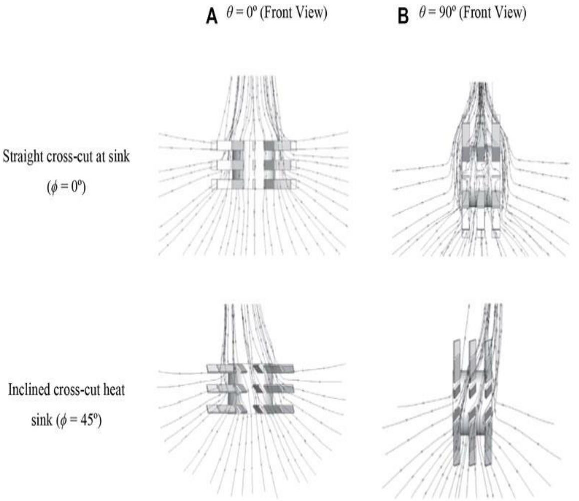

Figure 6: A cylindrical heat sink with fluid flow channels around it for different installation angles [6].

2.7. Materials used

In the realm of heat sinks for LED applications, the material utilized is a pivotal element in determining overall performance. Although copper is acknowledged as the top heat sink material due to its high thermal conductivity, it often comes with a higher price tag compared to aluminum. Consequently, aluminum is more frequently employed for LED heat sinks due to its cost-effectiveness and widespread availability. The utilization of thermoplastics is also gaining momentum, especially for smaller LEDs with less demanding heat dissipation needs, as they are lightweight and can be shaped into various forms.

In addition to the selection of materials, the design and structure of heat sinks play a critical role in their performance. For instance, optimizing fin structures and employing hollow designs have been proven to decrease the amount of material required for production while boosting heat dissipation efficiency. The thickness of the heat sink base and the spacing between fins are also influential factors that contribute to the overall performance of the heat sink.

Moreover, research has demonstrated that introducing perforations through the fin base can notably improve air circulation and enhance heat transfer performance, resulting in a decrease in thermal resistance. These findings suggest that innovative designs and alterations to traditional heat sink structures can lead to enhanced thermal management for LED applications.

In conclusion, the choice of materials used in heat sinks, coupled with their design and structure, has a direct impact on their effectiveness in dissipating heat from LED light sources. By carefully considering these factors and conducting optimization analyses, it is feasible to develop efficient thermal management systems that contribute to energy savings and reduced environmental impact.[3,7,8,9,12,16,23,31]

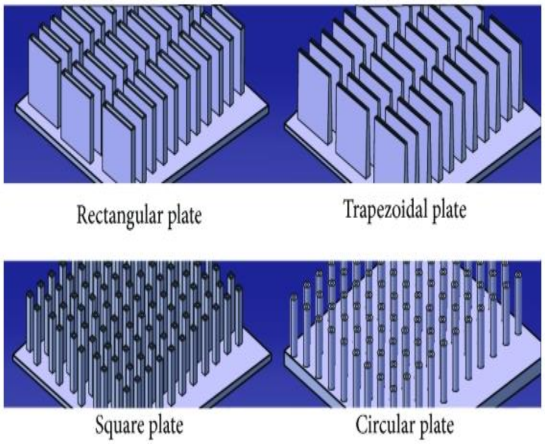

Figure 7: Types of hollow fin heat sinks [23].

2.8. Impact of creating holes in the fins

Extensive research and experimentation have focused on the effects of introducing perforations in heat sink fins. One particular study aimed to enhance the efficiency of a unique fin heat sink while reducing the amount of aluminum utilized. By implementing a hollow structure and adjusting the base thickness, a notable decrease in temperature was achieved, leading to reduced CO2 emissions during production. This indicates that the introduction of perforations in the fins can improve heat dissipation and minimize material usage.

Another study delved into the use of perforated fins to boost the cooling performance of a heat sink. It was discovered that increasing the number of smaller perforations resulted in improved cooling performance. Additionally, researchers investigated how varying the size and quantity of perforations affected heat dissipation, highlighting their potential to enhance thermal management for LED applications. The addition of shroud plates to a horizontal-base straight-fin heat sink was shown to significantly improve natural convection heat transfer performance. By effectively manipulating airflow around the heat sink, substantial enhancement in heat transfer was achieved, leading to improved mass flow rate and air admission into the fin channel. This suggests that incorporating partial shroud plates can enhance heat transfer performance, particularly when faced with size constraints.

Furthermore, studies have explored how altering the geometry or structure of a heat sink can generate an updraft or chimney effect, increasing heat transfer rates by creating more efficient airflow around the heat sink. This indicates that modifying the structure or introducing additional elements to a finned heat sink can positively impact its thermal performance. Overall, these findings underscore the importance and potential benefits of creating perforations or modifying fin structures in heat sinks for LED applications. The implications for reducing temperature, enhancing cooling performance, and improving natural convection heat transfer emphasize the significance of this parameter in optimizing thermal management systems for LED applications. [6, 7, 23, 31, 34].

3. Experimental methods and results

The investigation into the thermal performance of finned heat sinks for LED applications used experimental methods and simulations. One study found that the thermal resistance of cylindrical heat sinks (CHS) remained unaffected by power ratings but increased with thicker fin thickness. The efficiencies of the heat sink improved with an increase in cylindrical fin thickness, with the best performance observed for a 6 mm thick CHS fin.

Another study used design of experiment (DOE) and thermal simulations to analyze the impact of design parameters on heat sink structure for LED systems. It emphasized the need for customized solutions to meet different design requirements for each LED application.

An experimental investigation showed that using a finned heat sink reduced both case temperature and junction temperature in LEDs compared to a bare heat sink. Phase change material-based heat sinks were evaluated for various configurations and orientations of fins, with vertical square fins showing superior performance, especially during power surges. Experiments on new design considerations for aluminum alloy heat sinks showed that higher fin density resulted in lower orientation dependency under natural convection conditions. [10, 14,17,24,25].

4. Discussion and analysis of findings

Multiple studies have highlighted the critical parameters affecting the performance of finned heat sinks for LED applications, including the number of fins, fin height, thickness, shape, type, and direction. The material used and creating holes in the fins also significantly influence heat dissipation.

Rajendaran Vairavan et al.'s research focused on optimizing the design of a heat sink with round pins to improve cooling capacity. Their results showed that optimized heat sink structures could reduce junction temperature by up to 6%, emphasizing the importance of proper design for optimal performance. Chakravarthy Balaji's study investigated various configurations and orientations of fins in phase change material (PCM) based heat sinks, highlighting the significant effect on heater temperature, especially under high power surge conditions.

Another plate-finned heat sink design with different fin width ratios was introduced in order to provide heat transfer to the PCM for transient electronic cooling, resulting in a decrease in maximum temperature, heat out of the sink -and an increase in discharge rate. research emphasized the importance of proper thermal management for LED devices and systems due to their susceptibility to damage from high temperatures, showcasing the influence of various design parameters on LED system junction temperature.

In conclusion, these studies underscore the significance of considering multiple parameters when designing finned heat sinks for LED applications. By carefully optimizing these parameters based on empirical findings and experimental data, it is possible to significantly improve the performance of finned heat sinks for effective LED thermal management. [17,23,24, 25,26,30].

5. The importance of efficient thermal management systems in LED applications

When evaluating the influence of various factors on heat transfer rate and temperature decrease along the fins in LED applications, it is important to consider several key parameters. The performance of finned heat sinks is affected by numerous parameters, which can have a significant impact on the overall thermal management system for LEDs. One crucial factor to take into account is the number of fins, as it has been proven to affect thermal resistance and, consequently, heat transfer efficiency. This is particularly important when aiming to optimize the design of LED heat sinks for effective cooling.

Additionally, parameters such as fin height, thickness, shape, type, and orientation also play a critical role in determining the heat transfer rate and temperature decrease along the fins. For instance, increasing fin height can result in a larger surface area for heat dissipation, while variations in fin thickness and shape can affect the overall thermal performance of the heat sink. Moreover, the choice of materials used in constructing finned heat sinks significantly impacts their performance. Studies have shown that different materials can influence thermal conductivity and subsequently affect heat transfer rates and temperature decreases along the fins. Furthermore, creating perforations in the fins has been found to impact both pressure drops and heat transfer efficiency.

Experimental research has demonstrated that optimizing fin arrangements through nanofluid-filled microchannels can lead to enhanced thermal performance. Innovations such as plate-fin-based heat sinks with phase change materials (PCM) have been proposed by researchers to improve conduction and natural convection melting heat transfer mechanisms.

Furthermore, an examination of hybrid fin designs that combine plate fins with pin fins and oblique fins revealed lower junction temperatures and enhanced thermal performance compared to traditional designs.

In conclusion, comparing the impact of different parameters on heat transfer rate and temperature decrease along the fins is essential for optimizing finned heat sinks in LED applications. Understanding how each parameter affects thermal performance is crucial for developing efficient thermal management systems that ensure reliable LED operation. [9,15,22, 26,29,36].

Improving the performance of finned heat sinks in LED applications requires careful consideration of various parameters that can enhance heat dissipation and maintain optimal operating temperatures. One key factor is the design of the fins, including the number, height, thickness, shape, and type. Incorporating phase change materials (PCMs) within the heat sink can also greatly enhance thermal performance. PCMs have a high thermal storage capacity and isothermal phase transition, making them an effective passive technique for thermal management in LED applications. It is crucial to include extended surfaces such as fins inside PCM enclosures to augment heat transfer performance. Furthermore, the combination of plate fins with pin fins and oblique fins can offer improved cooling for high-power LED lamps. These new types of fin heat sinks demonstrate lower junction temperatures and improved thermal performance compared to conventional models. Additionally, incorporating high conductivity metal structures in the form of fins within PCM enclosures can enhance heat transfer performance.

The use of a three-dimensional chimney-flow pattern for fin-height profiles has been proposed as an optimized design for reliable cooling performance in high-power LED lighting applications. This approach considers natural convection and radiation heat transfer to minimize thermal resistance while maintaining a similar mass to traditional plate-fin heat sinks. In addition, innovative techniques such as variable or dual-height fin arrays can provide wide-spread applicability in rapid heat transfer processes involved in engineering equipment. These designs have the potential to enhance overall thermal performance by reducing heat sink mass while maintaining simplicity in manufacturing processes.

In summary, optimizing the design of finned heat sinks by considering factors such as fin number, height, thickness, shape, type, and incorporation of PCMs can significantly improve their performance in LED applications. Furthermore, innovative approaches such as three-dimensional chimney-flow patterns and variable or dual-height fin arrays show promise for enhancing heat dissipation and maintaining optimal operating temperatures. [6], [21,28,29,35].

Conclusion

The impact of creating perforations in the fins and the overall design of the heat sink are also essential considerations. Effective thermal management is vital for ensuring the proper operation and longevity of LED devices. As LED technology evolves to become more compact and powerful, effective heat dissipation becomes increasingly critical to prevent damage and ensure reliability. The junction temperature of the LED system is directly affected by these factors, which in turn impacts light output, quality, reliability, and lifespan. In recent years, there has been a significant focus on improving heat transfer through various types of heat sinks such as MCPCB (Metal Core Printed Circuit Board), IMS (Insulated Metal Substrate), ceramic materials, extruded-fin heat sinks, pin-plate fin heat sinks (PPF), oblique-plate fin heat sinks (OPF), and cylindrical heat sink fins. Thermal simulation studies have indicated that certain configurations, such as a cylindrical heat sink fin with a 6 mm thickness, have shown enhanced thermal efficiency despite having slightly higher thermal resistance. Additionally, it has been observed that optimal substrate designs play a critical role in thermal management for high-power LEDs. The findings from experimental simulations and numerical analyses suggest that proper sizing of the heat sink along with suitable thermal conductive pastes can significantly improve LED heat dissipation. In conclusion, it is clear that efficient cooling systems are essential for maintaining optimal temperature levels for LEDs. Continued research into different geometrical configurations and materials will further enhance our understanding of effective thermal management in LED applications.

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