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Thermal Analysis of Al and Cu Metals Heat Sinks with Different Geometries at Raspberry Pi Control Cards Used for Image Analysis-Based Drone Control in Smart Agriculture Drones

Akıllı Tarım Drone'larında Görüntü Analizi Tabanlı Drone Kontrolünde Kullanılan Raspberry Pi Kontrol Kartları İçin Farklı Geometrilere Sahip Al ve Cu Metal Isı Alıcılarının Termal Analizi

Abstract

A heat sink is a tool for dissipating the heat generated by electronic parts. The equipment's specific operating conditions necessitate the equipment's extra heat dissipation. This research compared and optimized the temperature and heat flux parameters based on the results of the design of a heat sink for CPU, RAM, and PCLe to a USB 3.0 bridge. It is aimed at an examination of the advantages and disadvantages of using square, rectangular, and circular shapes in the design of a heat sink. Copper and aluminum (Al) are the most common heat sink materials (Cu). Autodesk Inventor Pro software with Nastran module is used for design and thermal analysis.

According to Inventor Nastran's thermal analysis results it is found that there is no significant difference between Al and Cu materials based on cooling capacity at designed models. Also, it is found that the geometry of the heat sinks directly affects the cooling capacity of a heat sink.

The application results show that the cooling achievement is directly related to the correct heatsink design and enough surface area.

Keywords: Heat sink, Heat transfer, Thermal design, Al and Cu metals, Raspberry Pi.

Akıllı Tarım Drone'larında Görüntü Analizi Tabanlı Drone Kontrolünde Kullanılan Raspberry Pi Kontrol Kartları İçin

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Farklı Geometrilere Sahip Al ve Cu Metal Isı Alıcılarının Termal Analizi

Özet

Bir ısı alıcı, elektronik parçalar tarafından üretilen ısıyı dağıtmak için bir araçtır. Ekipmanların belirtilen çalışma koşulları sahip oldukları fazla ısının dağılımını gerektirir. Bu çalışmada, CPU, RAM ve PCLe den USB 3.0 köprüsü için ısı alıcı tasarımındaki sıcaklık ve ısı akışı parametrelerinin sonuçları karşılaştırılıp optimize edilmiştir. Bir ısı alıcı tasarımında kare, dikdörtgen ve dairesel tasarım şekilleri kullanmanın avantaj ve dezavantajlarının incelemesi yapılmıştır. Bakır (Cu) ve alüminyum (Al) en yaygın ısı emici malzemelerdir.

Tasarım ve termal analiz aşamaları için Nastran modülüne sahip Autodesk Inventor Pro yazılımından yararlanılmıştır. Autodesk Inventor Pro Nastran termal analiz sonuçlarına göre, tasarlanan modellerde soğutma kapasitesi bazında Al ve Cu malzemeleri arasında önemli bir fark olmadığı bulunmuştur. Ayrıca sonuç olarak ısı alıcıların geometrisinin bir ısı alıcının soğutma kapasitesini doğrudan etkilediği belirlenmiştir.

Araştırma sonuçları, soğutma başarısının doğru ısı alıcı tasarımı ve yeterli yüzey alanı ile doğrudan ilişkili olduğunu göstermiştir.

Anahtar Kelimeler: Isı alıcı, ısı transferi, termal tasarım, Al ve Cu metaller, Raspberry Pi.

Introduction

Agriculture drones with their adaptability and the ability to be outfitted with a wide variety of sensors and novel computing power, drones have a wide range of potential uses in agriculture, including crop management, mapping, irrigation, diagnosis, disaster relief, early warning systems, wildlife preservation, and forestry preservation, also drones have the potential to be used in a variety of ways in agriculture, such as crop and growth monitoring, yield estimation, water stress assessment, and the detection of weeds, pests, and diseases (Huang et al., 2021; Negash et al., 2019; Inoue, 2020; Panday et al., 2020). However, drones have their own set of restrictions. Some of these include pilot involvement; average image quality; average implementation costs; stability; maneuverability; reliability; standardization; engine power; limited power sources; limited flight duration; collision and cyberattacks; limited payload weight; large datasets and limited data processing capabilities; absence of regulation; lack of expertise; and high entry barriers to access to agricultural applications (Zhang & Kovacs, 2012). Given drones' potential applications across the agricultural sector, attracted the attention of numerous academic fields.

Agriculture drones and other electronic and electrical systems face an increasing challenge in keeping their electronic components cool during operation and design. The vast quantity of electronic components in a typical electronic circuit causes it to overheat and function less efficiently. If an electronic component is to function reliably, it requires rapid cooling. In addition, as production methods advance, minicomputers are becoming much more compact. As a result, the rate at which the CPU, RAM, and PCLe to USB 3.0 bridge are being heated and alarming. The market has also driven a reduction in the physical size of electronic cards. This means that there is nowhere near enough room for a conventional cooling system, and traditional convectional cooling methods are insufficient to meet the ever-increasing demands.

Several fields of study, include cooling and the temporal evolution of temperature distributions. Increasing the flow rate of the external fluid, altering the geometry of the conducting material to increase the convection surface area, and altering the conducting material to increase the surface temperature and achieve a higher convection coefficient are the three major techniques for improving the efficiency of heat dissipation from computer components using air cooling systems (Kumar & Rao, 2018).

Heat transfer in electronic systems has been the focus of numerous studies. Webb (2005) modeled an entire desktop PC setup with an 80 W central processing unit. Total system heat dissipation is 313 W once other components are included. They modeled the CPU heat sink as a volume resistance with the same impedance as the detailed geometry to keep the model simple. The PCI side vents and baffle are designed to enhance the cooling of PCI cards.

When an electric current flows through an electronic device, some of the power is lost as heat, as pointed out by Färcaş et al. (2012). Overheating an electronic device has a detrimental effect on its functionality and longevity. As a corollary, the electronic device's lifespan may be shortened. Normal operation generates a great deal of heat for all power electronic devices. To prevent electronic equipment failure, this heat must be dissipated. It's been found that the surface area for heat transfer in electronic devices directly correlates to the total amount of heat dissipated by those devices.

The thermal analysis of heat sinks of varying geometries and constructions was the subject of research by Reddy et al. (2018). The findings indicate that copper provides better temperature distribution than aluminum, and that rectangular slots provide better temperature distribution than other geometries.

However, as Pal (2014) points out, dealing with the resulting heat is often a major challenge for LED light fixtures. LED efficiency, life, performance, and reliability all suffer at lower junction temperatures. This study examines the relationship between the junction temperature of LEDs cooled by natural convection and the thermal performance of a selection of popular design approaches on heat sink fins. Basic rectangular fins, pin fins, and trapezoidal scaled tapered fins have all been subjected to thermal simulation using Solidworks Thermal Simulation, and the results are compared and contrasted.

For a 30 W chip on board (COB) LED down-light, Seo et al. (2012) designed and characterized an optimal heat sink. Using a heatsink designer, they determined that 181 m^2 is the optimal total surface area of a heat sink for the 30 W COB LED downlight. In this work, they compared four distinct heat sink designs and determined the type that provides the best overall performance. Due to the COB LED package structure, the heat sink's center gets very hot, so a copper spreader is used to distribute that heat to the heat sink's periphery.

According to Özdilli & Şevik (2020), advancements in technology have allowed manufacturers to create electronic parts that are both more versatile and more powerful. However, as performance improves, the amount of heat produced by the components also rises. When electronic components are subjected to extreme heat, they often malfunction or perform inadequately; to prevent this, active or passive heat sinks are used to efficiently and quickly remove the excess heat generated by the electronic components. Five distinct heat sink designs are developed in their investigation, including the primary design (Cylindrical heat sink) and four geometries derived from the primary design (Cylindrical concave, cylindrical-convex, cylindrical-wave, and cylindrical-wave). Aluminum 6063 was opted to be used as the material for the heat sinks. Each heat sink had 10W of thermal power applied to it from a heat source, and their respective designs' heat dissipation performances were analyzed in the computational fluid dynamics program Solidworks Flow Simulation. Temperature profiles, fin heights, material weights, and surface areas are just some of the metrics used to evaluate the designed heat sinks.

The thermal issues of electronic components are typically solved by using heat sinks, which are widely regarded as the most cost-effective, hassle-free option. In this simulation analysis, we present different pin designs for a pin fin of a heat sink, in which the pins are changed to create more different shapes between them. Then, a numerical thermal analysis is performed for natural convection for circular shape in an inline arrangement under steady-state conditions on both the traditional pin fin heat sink and the modified pin fin heat sink. Improved efficiency is one of the many benefits of the modified pin fin heat sink compared to the standard design. The finite element method is utilized in conjunction with Solidworks to perform this numerical thermal analysis (Arefin, 2016).

Aluminum and copper, in their various forms, both have high heat conduction coefficients and are thus used in the fabrication of heat sinks. Particularly popular are aluminum alloys due to their high strength and low weight. Sixty-five percent of the market is dominated by the 6XXX series of aluminum alloys due to their superior specific strength, toughness, corrosion resistance, and weldability as well as the presence of silicon and magnesium (Mengjun et al., 2005; Panigrahi et al., 2009; Panigrahi et al., 2009).

The most significant issue is the overheating that is produced by electronic equipment, which leads to an increase in temperature and, ultimately, permanent damage to the electronic components. Because of this, having an effective electronic cooling system is crucial. Temperature and other thermal quantities can be measured and analyzed over time through a process called transient thermal analysis. The current investigation is aimed at developing a heat sink for an electronic printed circuit board CPU, RAM, and PCLe to USB 3.0 bridge. Autodesk Inventor Pro with Nastran module was used to conduct the analyses of the different fin configurations and aluminum and copper material combinations used in this work.

Material and Method

Material

Raspberry Pi is a well-known development card. It is used for different image processing and analysis, deep learning, control, and prototyping applications of smart farming drones. A Raspberry Pi card operating temperature changes between 0°C and 85°C (Anonymous, 2023). The main usage points for heat sinks at a Raspberry Pi development card are CPU, RAM, and PCLe to USB 3.0 bridge (Figure 1).

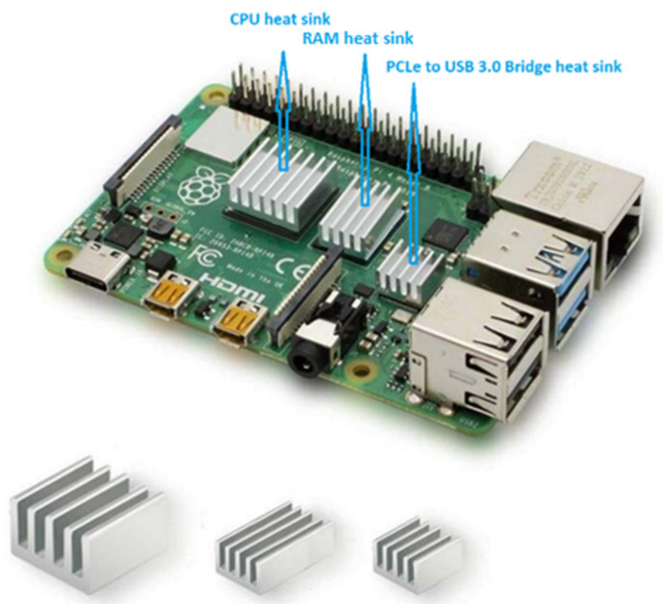


Figure 1. Raspberry Pi with heat sink usage points

The design of heat sinks has been created and analyzed in Autodesk Inventor Pro with Nastran In-CAD (under education license) and has the dimensions 14 x 14 x 6 mm, 14 x 9 x 5mm, and 9 x 9 x 5 mm for CPU, RAM, and PCLe to USB 3.0 bridge, respectively (Fig. 2). The slot in a rectangular heat fin is typically a maximum of 140 mm by 50 mm, while a circular heat fin's slotted hole is typically 1 mm in diameter.

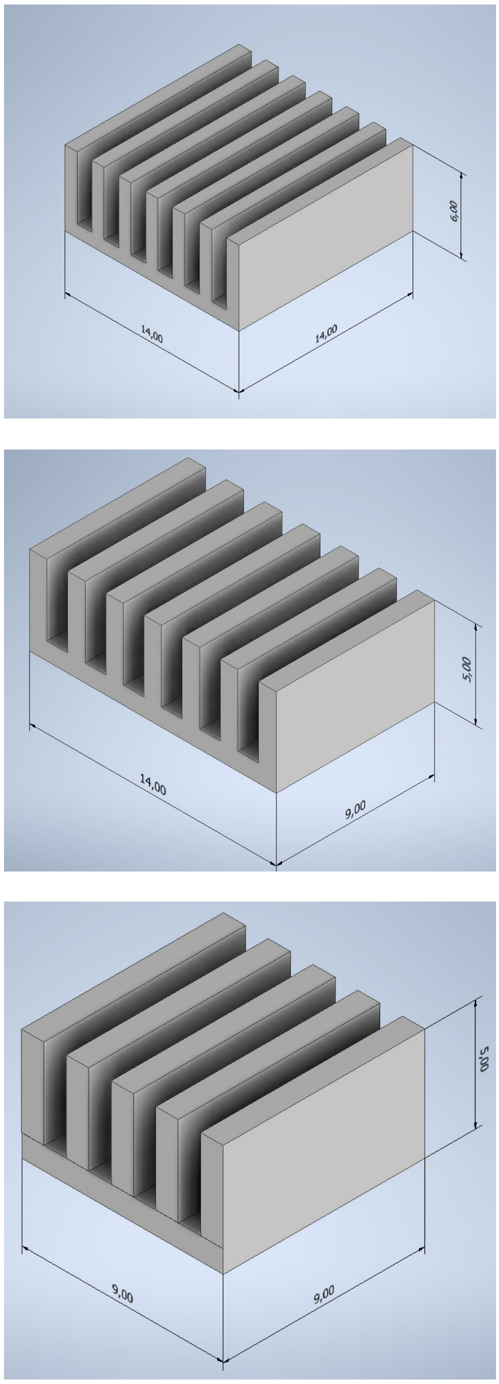


Figure 2. Dimensions of the designed heat sink models

Autodesk Inventor Pro's Nastran analysis module is utilized for post-design evaluation for Al and Cu materials (Table 1).

Table 1. Material properties of designed models for thermal analysis

Properties	Aluminum	Copper
ρ	2.7e-9	8.94e-9
E	68900	1.175e+5
ν	0.33	0.345
α	2.4e-5	1.7e-5
C	8.97e+8	4.5e+8
K	230	401

Method and Modeling

The simulation-driven design has largely replaced traditional prototyping and testing in the last decade to cut down on time and money spent developing products. Rather than spending time and money creating physical prototypes, engineers can instead use flexible simulation models to foresee how a product will perform. Not all time and money savings come from cutting down on individual design tasks, but rather from combining design teams, using concurrent engineering principles, and speeding up the entire design-through-manufacturing-through-maintenance process. To save significant time during the later stages of design, prototyping, and testing, a manufacturer may invest more time performing thermal analysis at the beginning of the design process.

Strict thermal analysis has the potential to lessen the number of malfunctions in the field as well. When compared to these time savings, the time spent on analysis or 3D design and assembly is negligible. Connecting the various MCAD, ECAD, and CAE (analysis) software programs used by engineers and designers presents a challenge (Man et al., 2010).

Technique for simulating heat transfer

The maximum temperature of 85 °C is used to model heat sinks in this analysis (Figure 3). Aluminum alloy and copper are being considered as heat sink materials. The research is simulated at the temperature of 0-85 °C with linear steady-state thermal analysis. The following are the parameters for the boundaries: properties of aluminum and copper are assigned as 85 °C heat source temperature. The heat source is transferring energy to the heat sink, which causes a heat flux to be exerted on the heat sink. Once the aforementioned boundary conditions have been applied, the simulation is run in both steady-state and transient modes.

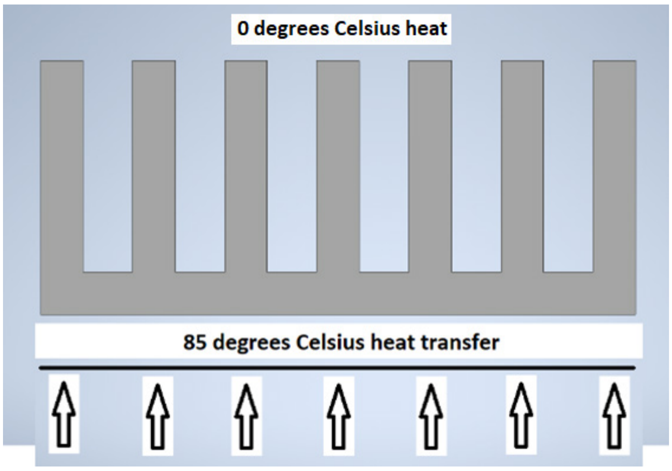


Figure 3. Heat transfer of a sample model

Construction of a heat sink Autodesk Inventor Pro is used to create five distinct fin designs, and then the Nastran analysis module is used to compare and contrast each design. Autodesk Inventor Pro's Nastran module offers thermal analysis to help predict how a design will react to different temperatures. Linear steady-state, nonlinear steady-state, and transient thermal analyses are all included in the simulation. Autodesk Inventor Pro's Nastran module offers thermal analysis to help predict how a design will react to different temperatures. Linear steady-state, nonlinear steady-state, and transient thermal analyses are all included in the simulation. Dimensions for all five heat sinks are presented in Figure 2. Both the bottom and the fin have the same thickness of 1 mm. Also, both aluminum and copper are used to construct the heat sink.

Results and Discussion

After comparing Copper and Aluminum in the package, it was discovered that the latter offered much better heat dissipation, reducing the likelihood that the board's CPU, RAM, and PCLe to USB 3.0 bridge would overheat (Figure 4 - 9). When we look at all models for Al and Cu materials, it is seen that model 'a' has the best cooling performance while model 'e' is the worst.

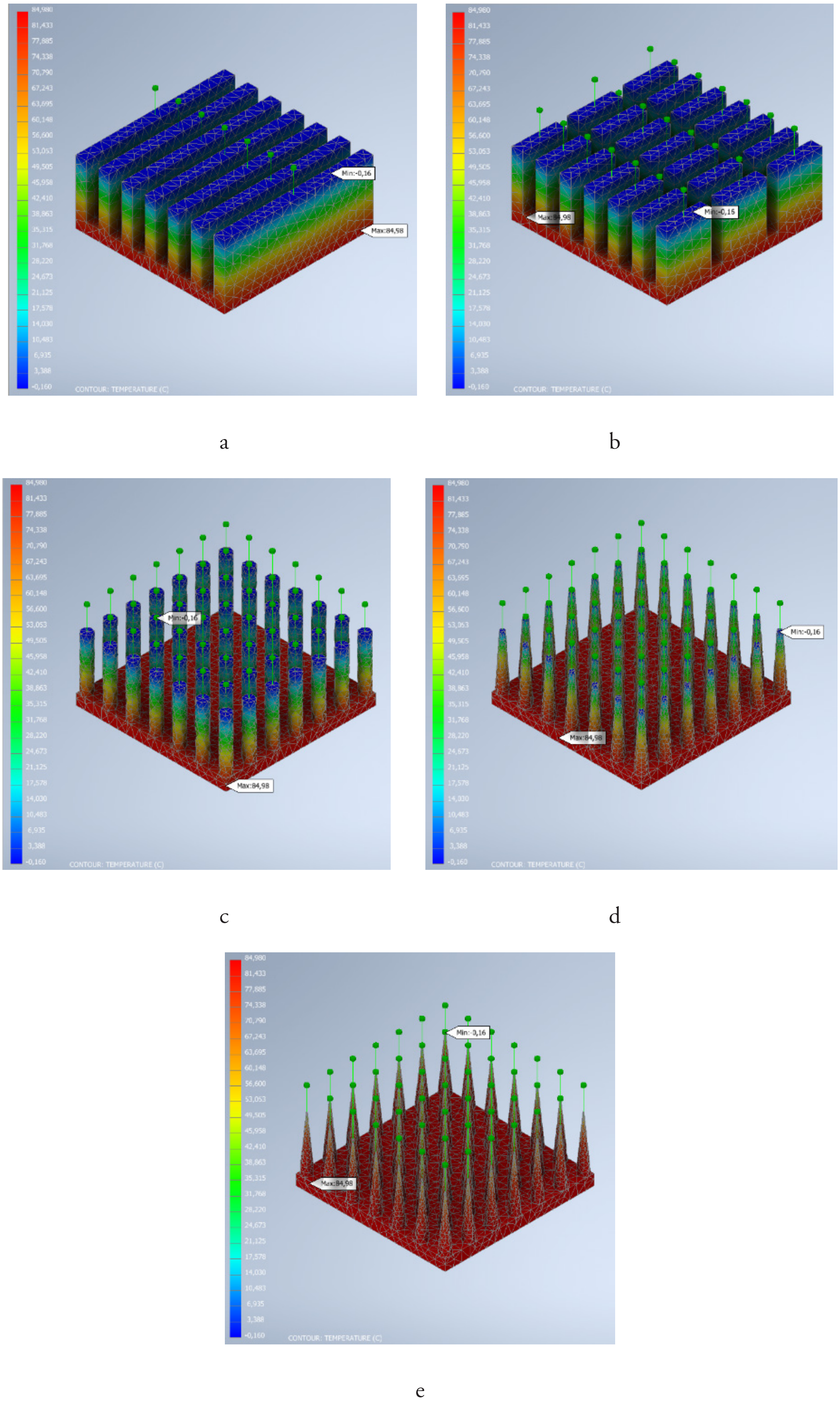
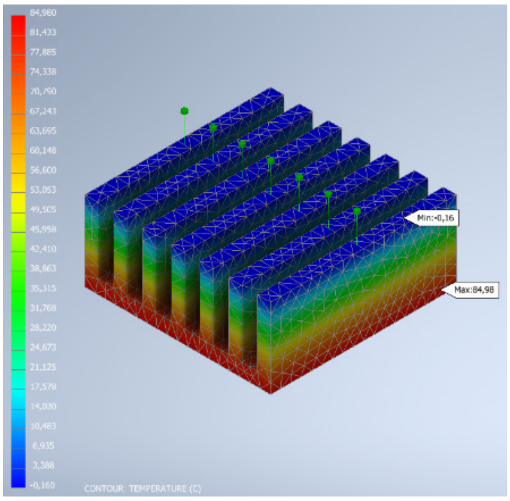
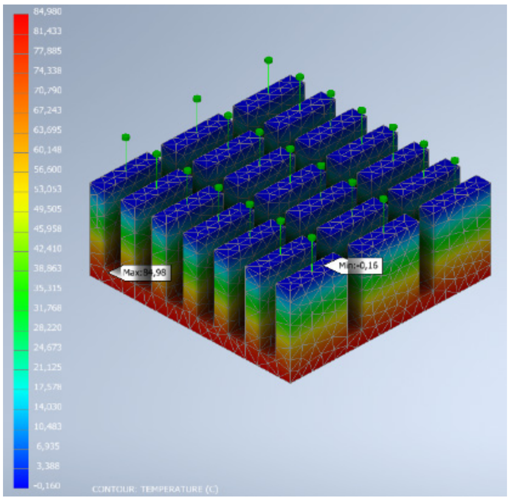


Figure 4. Thermal analysis results of five different CPU heat sink models with aluminum material



a



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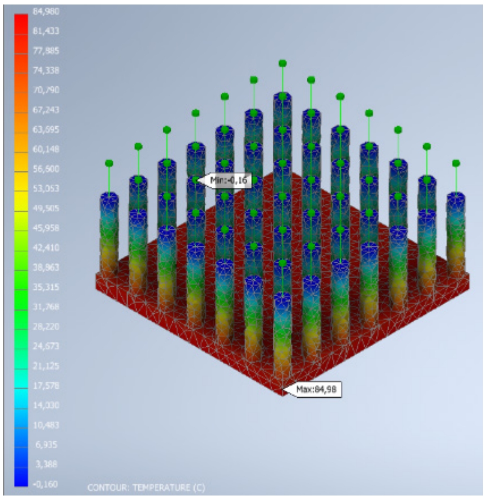

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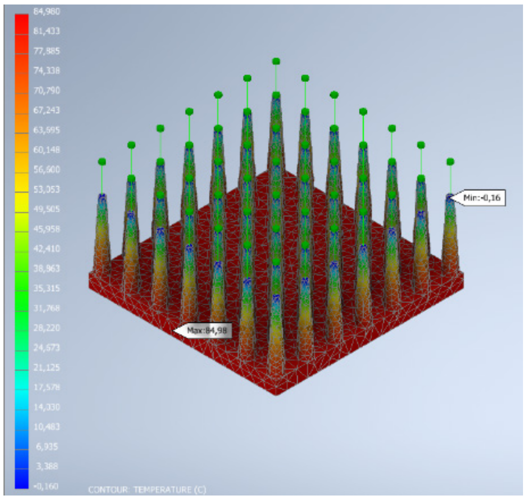

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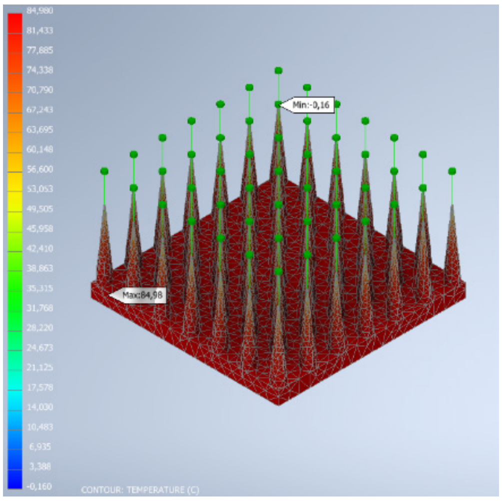

e

Figure 5. Thermal analysis results of five different CPU heat sink models with copper material

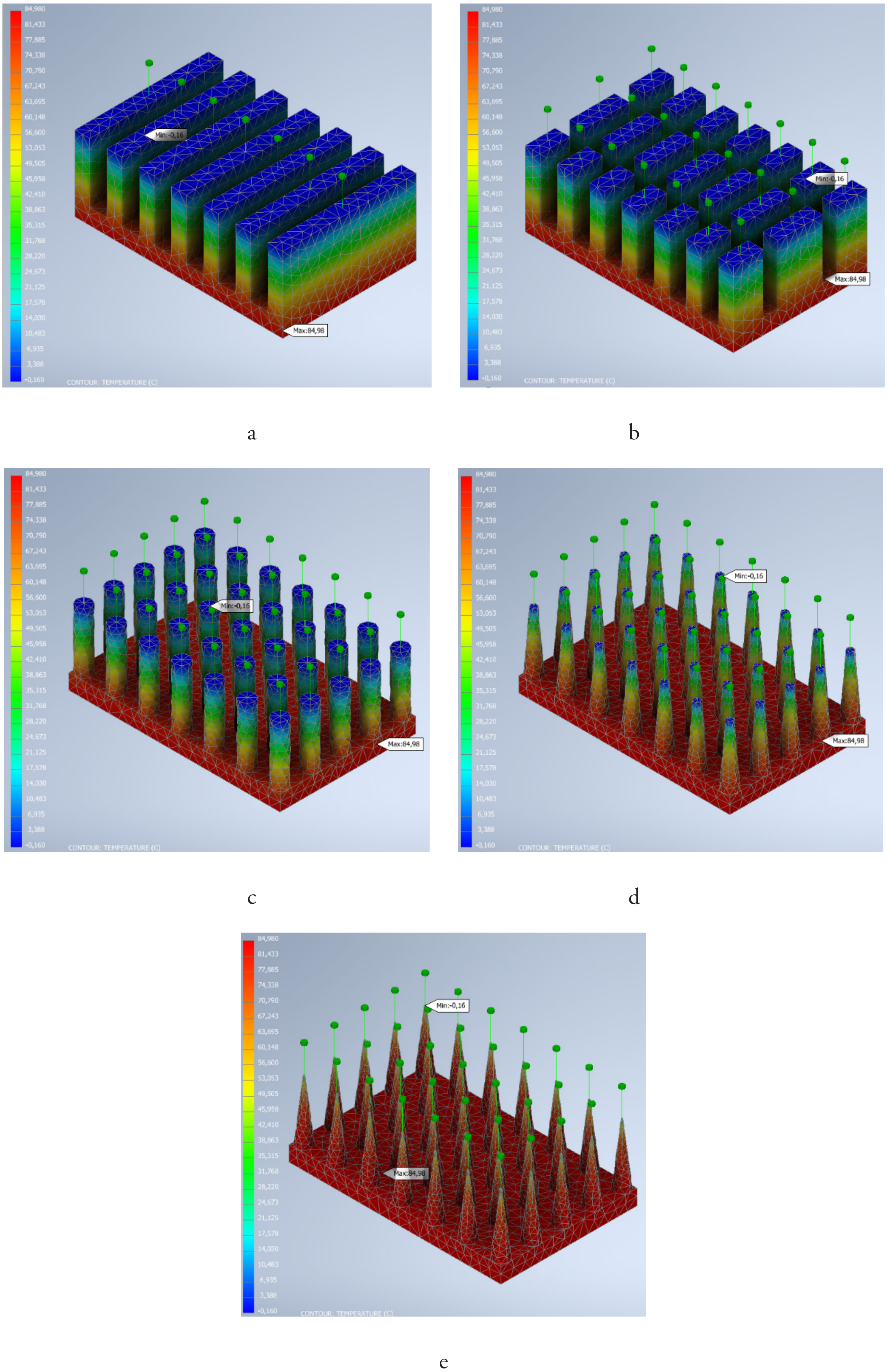

Figure 6. Thermal analysis results of five different RAM heat sink models with aluminum material

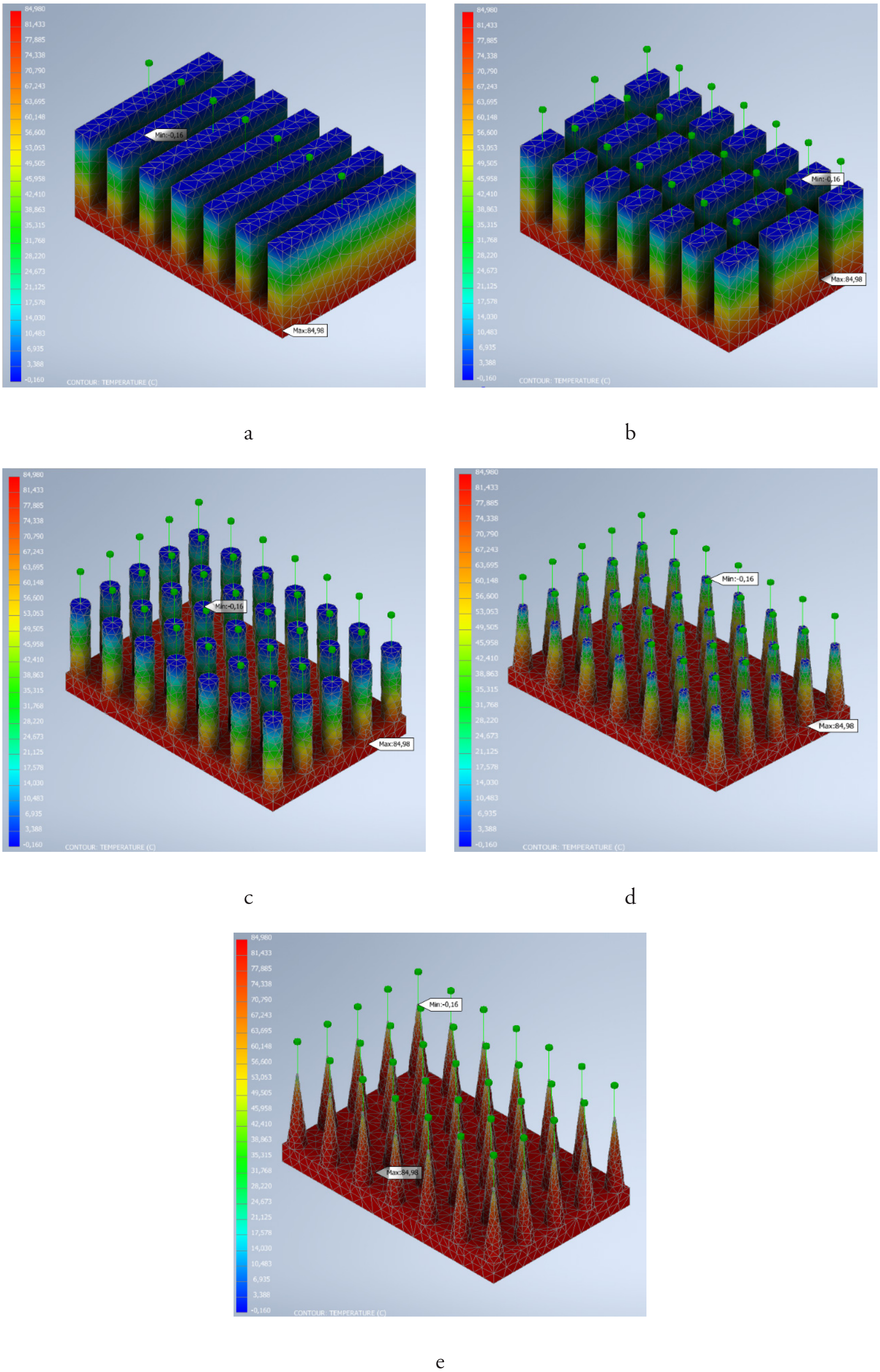

Figure 7. Thermal analysis results of five different RAM heat sink models with copper material

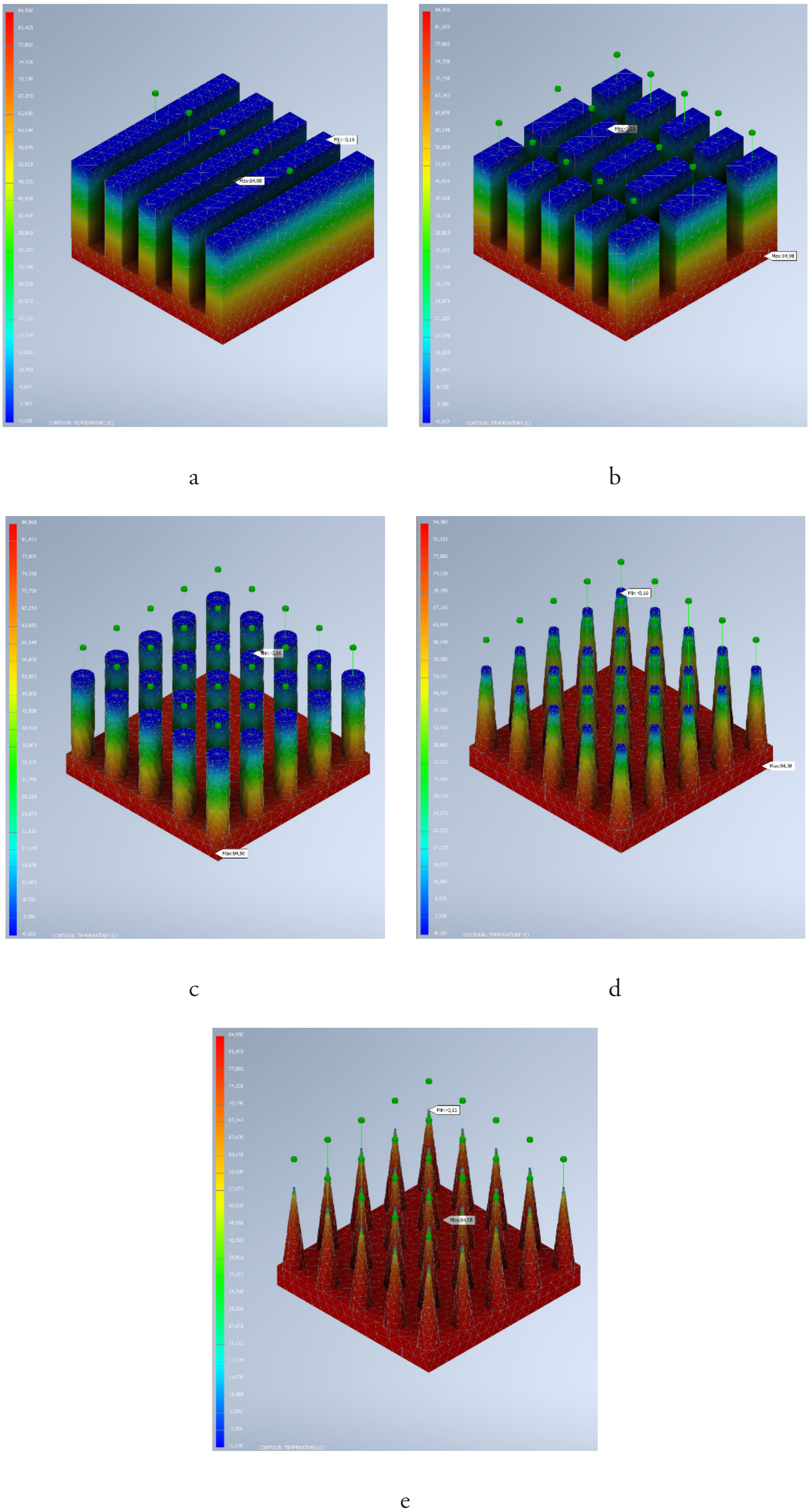

Figure 8. Thermal analysis results of five different PCLe to USB 3.0 Bridge heat sink models with aluminum material

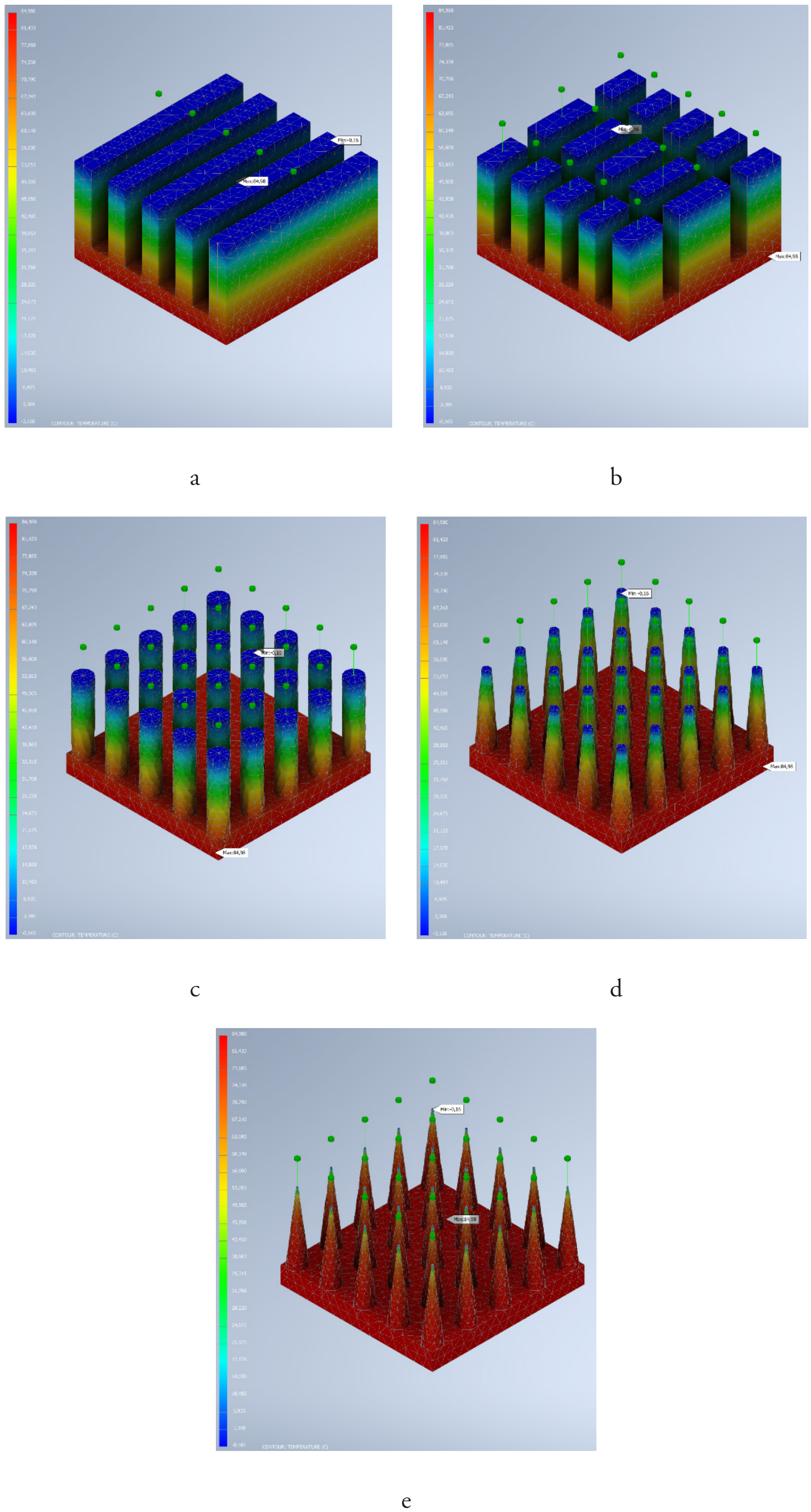

Figure 9. Thermal analysis results of five different PCLe to USB 3.0 Bridge heat sink models with copper material

In figures 4-9, it is seen that the thermal gradient changes between 0 to 85 °C, in models 'a', 'b', 'c', and 'd' the thermal value decrease to 0 °C, with the surface area increasing the efficiency of the heatsink increasing in the models, respectively. Between these models in Figure 4-9, it is also seen that the critical point starts in the model 'e' at every figure. Because in model 'e' the heatsink thermal value increases at 85 °C, it is seen that there is no efficient cooling application at each of 'e' models in the figures. The simulation results show that there is no significant thermal efficiency difference between materials based on the small models.

There is evidence from Seo et al. (2012) that using a copper spreader reduces heat sink temperature by about 3 degrees celsius compared to not using one. Within an error of 2 degrees celsius, both the simulated and measured temperatures agree very closely with one another. The simulations' efficacy is plain to see.

Özdilli and Şevik (2020), suggest that the cylindrical-concave type provided the best performance, while the cylindrical-convex type provided the worst performance. When compared to other cooler shapes, the cylindrical-concave cooler was superior because of its large surface area, high fin ratio, and low filling volume.

It has been noted by Pal (2014) that the performance of fins and heat sink is heavily dependent on thermal mass, exposed surface area, and geometric placement of fins. The optimal performance of a heat sink for an LED depends on its material, fin structure, ambient fluid temperature, orientation concerning gravity, and the color, texture, and conductivity of the interface layer used.

According to the simulation analysis results and designed small model dimensions and the maximum 85 °C heat level, it can be implied that between Al and Cu heat sink models, there is no significant difference between Al and Cu heat sink models related to the ability of better heat transfer. As the main result, it can be said that the simulation analysis results show that the cooling achievement is directly related to the correct heatsink design and enough surface area. Additionally, low price levels and material properties of heat sinks that give resistance to environmental conditions are the other significant factors for heat sink production and selection.

Conclusion

The design, manufacturing, and maintenance processes can all be streamlined with computer-aided design (CAD) and simulation software. However, prototyping and testing are essential to the design process. This is a reliable method for obtaining precise outcomes. The final design was created and refined using data obtained from the Nastran module of the Autodesk Inventor Pro software. Model refinement in the future should lead to more precise estimates of thermal coefficients. Generally, in the markets when they are selling small Al and Cu heatsink models, they claim that Cu heat sink models can better heat transfer from Al heat sinks. But the simulation analysis results show that this is not diretcly true. It could be true looking at the material properties, but focused on the small dimensions and desing shapes, also high price levels, and resistance to environmental conditions the results are changing. The cooling achievement is directly related to the correct heatsink design and enough surface area in this heat level. In the research, it is implied that the agriculture drones have their own set of restrictions. Some of these include pilot involvement; average image quality; average implementation costs; stability; maneuverability; reliability; standardization; engine power; limited power sources; limited flight duration; etc. to access to agriculture. In this way, based on the results one more restriction is explained and analyzed in addition to the literature, and in the future better designs can be done and sold in the market and heatsinks to give us a chance to use electronic circuits and board more efficiently to improve the agricultural application success.

Authors' Contributions

All authors contributed equally to the article.

Conflicts of Interest Statement

The authors declare that they have no conflicts of interest.

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