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RESEARCH ARTICLE

Experimental Investigation of the Effect of Two-Stage Peltier Application on the Temperature of a Microprocessor

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ABSTRACT

Increasing the number of transistors to enhance the performance of processors leads to overheating, creating a need for cooling. Traditional cooling methods with copper pipes are becoming outdated and insufficient, prompting the development of alternative cooling methods. In this study, a two stage Peltier module cooler was designed using Peltier modules, and its performance in cooling the processor was evaluated. The two stage Peltier module was created by thermally connecting two Peltier modules in series and tested under different experimental conditions. In the first experiment, the manufactured two-stage Peltier module was placed in the experimental setup with its surfaces exposed to air. Both the cold and hot surfaces were in contact with air, allowing heat transfer through natural convection. Afterward, power was supplied, and the surface temperatures were observed, and with the application of power, it was observed that the temperature of the hot surface increased from 34.8°C to 110.2°C, while the temperature of the cold surface rise from 24.2°C to 67.1°C. In the second experiment, a heat sink and a fan were mounted on the hot surface of the two stage Peltier module to evaluate cooling performance. As a result of these experiments, it was observed that with the application of the cooler, the minimum cold surface temperature dropped to -2.3°C, while the maximum hot surface temperature reached 26°C. In the third experiment, the Peltier modules cooling performance was tested on a micro heater instead of air. In these experiments, four different powers were applied to the micro-heater, and at the maximum power of 9.9 W, the lowest cold surface temperature observed was 126.4 °C. Finally, the two stage Peltier module system was directly applied to a computer processor to observe its cooling performance under real-use conditions. The experiments showed that the two stage Peltier module cooler reduced the processor temperature. In addition, under the same ambient conditions, it was observed that computer cooler reduced the microprocessor temperature to 62°C, while the cooler using the two-stage Peltier module reduced the microprocessor temperature to 43°C at the same microprocessor clock speed.

It was determined that as power was supplied to the Peltier module, the temperature difference between the two surfaces increased, but there was no significant change in the temperature of the hot surface. Additionally, it was observed that the performance of the Peltier module varied with different power values. The article demonstrates that the two stage Peltier module can be used as an effective solution for processor cooling applications.

Keywords: Thermoelectric cooler, Processor cooler, Two-stage Peltier module, Temperature difference, Cooling method

1. Introduction

Computers have become an important part of our lives. They play a crucial role not only in our personal use but also in the development of technology. Engineering analyses, designs, and autonomous controls are performed using computers. Therefore, computers have both facilitated the advancement of technology and developed alongside it. One of the most important components of a computer is the processor, its brain. The processor determines the speed at which a computer processes data. Hence, to improve computers and make the operations faster, the speed of the processor needs to be increased. To accelerate processors, the number of transistors within them must be increased [1]. As the number of transistors increases, the electric current passing through the processor also increases, resulting in a rise in the amount of heat generated by the processors [2]. When this heat is not dissipated, the processor and other surrounding electronic components can be damaged. For this reason, the maximum operating temperature of processors has been set at 90°C [3]. When this temperature is reached, the processor speed decreases [4]. Cooling electronic components has always been one of the significant topics in engineering. Different methods are used to cool processors. The most common of these is the cooling technique using copper pipes. This method, with advancing technology, has started to become outdated and insufficient, leading to the emergence of alternative methods. Various methods, such as liquid cooling and compressors, have begun to be used. Cooling processors with thermoelectric methods is another area of study [5]. When power is applied to thermoelectric modules, which are made of p-

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and n- type semiconductors, one surface releases heat to the environment while the other surface absorbs heat, creating a temperature difference between the two surfaces [6]. This phenomenon is called the Peltier effect, and devices that operate in this way are called Peltier modules (PM) [7]. The absence of moving parts allows them to operate quietly and without vibration, requiring less maintenance and enabling long-term use [8]. In addition, the operating system can be easily controlled and can respond to small energy changes, such as 0.1 W, allowing more precise results in temperature control [9]. PM's are used in cooling applications across various fields. In the healthcare sector, they are used in cooling containers and tissue preparation applications, while in the military, they are used in areas such as night vision cameras and infrared detectors [10]. PM's are frequently used in the cooling of electronic components [11].

In the literature, Şahin and Işık (2023)[12] compared a liquid cooling system cooled by the Peltier method with a fan cooling system at a certain processor speed. The experiments used an AMD Athlon 4850E processor, a 12706 model PM with dimensions of 40x40, and a fan cooling system manufactured by AMD. Four different experiments were conducted at a room temperature of 24 °C. While the processor, running at full capacity, could be maintained at a temperature of 60 °C with the fan cooling system, the liquid cooling system designed with the PM could lower the temperature to 37 °C. Additionally, the cooling performance of the PM system was tested by operating it at 12V 2.85A, with the lowest temperature recorded as 20 °C and the highest as 28 °C. When the microprocessor was cooled using the PM, an increase in microprocessor performance of 40% was observed at the lowest processor speed, and 9.3% at the highest speed. Toren and Mollahasanoğlu (2022)[13] aimed to cool an oil-type transformer using a PM. A 5 kVA oil-type transformer was used in the study, and the results were compared with the cooling power of ester and naphthenic oils. The TEC1-12706 model PM was employed as the PM. As a result of the experiments, the PM reduced the temperature of the cabinet body by 15-20% compared to the oil cooling system. Ali Khan and others (2017)[14] compared the use of a heat pipe and a PM for cooling a laptop. Additionally, a second heat pipe was added, with the aim of dissipating heat from this pipe using the Peltier method. Experiments were conducted with a thermal design power of 35 W. As a result of the experiments, it was measured that the temperature of the second heat pipe decreased by 5 °C. It was also observed that the thermal design power decreased by 2.25 W. In the experiment conducted with both the heat pipe and the PM, the temperature was reduced by 2.3 °C, and the thermal design power decreased by 1.7 W. A cost analysis was conducted as a result of these findings. W. Y. Chen and others (2022)[15] conducted a comprehensive review of the advancements in state-of-the-art on-chip PM and summarized the related fundamentals, materials, designs, and system logic. Additionally, the power requirements for cooling microprocessors over the past five years were compared. The study focused on materials commonly used in both chips and PM and reviewed previous research. As a result, research was conducted to improve the design, performance, and applications of on-chip PMs in the future. Zaferani and others (2021)[10] conducted a review on the design, optimization, and development of PM as coolers for medical applications. In their study, they specifically researched the application of PMs in transport containers and wearable technologies. They noted that the features determining the thermal optimization of PMs include the use of efficient thermoelectric materials, effective heat sink and absorption design, especially the application of phase-changing materials and heat pipes, and the production of flexible thermoelectric devices. As a result, they highlighted that new PM technologies are gradually replacing traditional coolers due to their advantages, such as small size, flexibility, and pollution-free characteristics, particularly in wearable technologies and medical applications. Z. Liu and others (2022)[16] designed a two-stage PM to enhance its thermal performance. In their study, they compared the thermal performance of square-type, cubic-type, and pyramid-type two-stage PMs, finding significant improvements in cold-side temperature and the temperature difference between the two surfaces. The experimental results showed that the cubic-type two-layer PM could reach a low temperature of -49.5 °C, which is lower than the uninsulated pyramid-type two-layer PM (-34.3 °C) and the square-type two-layer PM (-38.6 °C).

In this study, the aim is to cool a computer processor using two stages PM. When we review the literature, various types of coolers have been used in studies on microprocessor cooling. Among these coolers, Peltier module research represents a small part. In addition, studies related to cooling have mostly been conducted on coolers with a single Peltier module. Theoretical analyses have been carried out on two-stage Peltier modules used as coolers, but experimental studies in this area are lacking. In this study, a cooler was designed using a two-stage PM. The performance of this cooler was evaluated through a series of experiments and finally applied to a microprocessor, where it was compared with the traditional microprocessor cooling method, the heat pipe. Additionally, the change in cooling performance was observed when a heat sink was mounted on the hot surface of the dual PM [17].

2. Materials and Methods

In the experiments conducted in the study, a 30 V_{DC}-30 A_{DC} DC power supply, a 14 V_{DC}-3 A_{DC} DC power supply, a 3 A_{DC}-30 V_{DC} DC power supply, a cooling system consisting of a heat sink and fan, a micro heater, a laptop, and an insulated experimental setup were used. A thermal camera and a thermometer were used as measuring instruments.

In the experiments, the TEC1-12709 model PM was used (Table 1). The key feature of this model is its maximum operating temperature of 135°C. Since it is known that the processor can't work temperatures up to 90°C, the PM's maximum operating temperature must be above this value; therefore, a PM model with a temperature rating higher than 90°C was selected.

Here, the two stage PM system is powered by a 30 V_{DC}-30 A_{DC} power supply, the fan by a 14 V_{DC}-3 A_{DC} power supply, and the micro heater by a 3 A_{DC}-30 V_{DC} power supply (Table 2). Since the PMs are used in a two-stage configuration, a maximum of 80 W power can be supplied. The fan operates at a voltage of 12 V and a current of 3 A. Although the micro heater is designed to handle a maximum power of 90 W, it is operated up to a maximum of 60 W due to the high surface temperature, which could cause damage to its surroundings.

Table 1. Peltier Module Properties

Model	V_{max}(V)	A_{max}(A)	T_{max}(°C)	Dimension (mm)	P_{max}(W)
TEC1-12709	9	14	135	40x40	80

Table 2. Power Supplies Properties and Usage Area

Model	V_{max}(V)	A_{max}(A)	P_{max}(W)	Usage area
30 V_{DC}-30 A_{DC}	30	30	900	Peltier Module
14 V_{DC}-3 A_{DC}	14	3	42	Fan
3 A_{DC}-30 V_{DC}	3	30	90	Micro heater

The cooling equipment was used to dissipate heat from the hot surface of the PM. It consists of a fin and a fan as components. The fin is used as a heat sink (Table 3), while the fan is used to increase the heat transfer rate through forced convection. Fan diameter is 120 mm, and the air flow speed is 1.25 m/s with the fan. The aim is to enhance the performance of the PM by dissipating heat from its hot surface.

Table 3. Heat Sink Properties

Properties	
Material	Aluminum
Fin number	88
Fin width (mm)	4
Fin thickness (mm)	0.4
Fin length (mm)	34

In the experiments, two different measuring devices were used. One of these is a thermal camera, the UNI-T UTI brand model 720E (Table 4). The thermal camera was used to measure the surface temperatures of the PM in experiments involving a two-stage PM and a cooled two-stage PM. The other measuring device was a Cem brand datalogger and thermocouple (Table 5). The thermometer was passed through the insulated surface in the experiments conducted on the microheater to measure the surface temperature of the microheater. Since the thickness of the microheater was less than 10 mm, the temperature difference between its two surfaces was neglected, and the temperature obtained from the thermometer was accepted as the cold surface temperature of the PM in these experiments.

Table 4. Thermal Camera

UNI-T UTI 720E – Technical properties	
IR resolution (Pixel)	256×192
Screen	3.5"IPS (640×480)
Thermal sensitivity (NETD)	≤50mK
Frame rate	≤25Hz
Temperature measuring range	-20 °C ~ 550 °C
Digital camera resolution	2MP
USB	C type
Dimensions	260mm×97mm×99mm

Table 5. Datalogger and Thermometer

CEM – Data logger and thermocouple technical properties	
Temperature sensitivity	±1°C
Temperature resolution	0.1°C
K type thermocouple temperature measurement range	-200°C ... +1372°C
J type thermocouple temperature measurement range	-210°C ... +1100°C
Memory capacity	18.000 units per thermocouple input
Operating temperature	0°C ... +50°C
Power supply	Battery

In the experiments, the HP PAVILION DV2 model was used. The experiments were conducted on a processor of the AMD Athlon™ Neo MV-40 model, which has a thermal design power of 15 W (Table 6). The experiments were conducted at the processor's maximum speed of 1.6 GHz.

Table 6. Processor Properties

Model	Clock (GHz)	Thermal design power (W)
AMD Athlon™ Neo MV-40	1.6	15

In the first part of the experiments, the hot surface of one of the two PM was placed in contact with the cold surface of the other, mounting them thermally in series. Thermal paste was used to increase the contact area between the surfaces. Then, power was supplied to the two stage PM, and the temperatures of the hot and cold surfaces were measured. In this part, the performance of the PM was evaluated when heat transfer was carried out by natural convection. In the second part, a cooling fin and fan system were mounted on the hot surface of the two stage PM system, and experiments were conducted to evaluate the effect of heat dissipation from the hot surface on the cooling performance of the PM. In both experiments, the two stage PM was initially supplied with a current of 1 A, which was increased by 1 A increments up to the maximum temperature value of the PM. As the surfaces were exposed, their temperatures were measured with a thermal camera.

In the third part of the experiment, tests were conducted on a designed micro heater before testing the PM on a processor (Figure 1). Looking at the experimental setup, the heat starts from the micro heater, then proceeds through the 1st PM, the 2nd PM, and finally reaches the finned surface. Since processors can easily malfunction at high temperatures, the experiments began on the micro heater, which served as a prototype for the processor. Here, the heat emitted by the processor was simulated on the surface of the micro heater to test the two stage PM system's ability to dissipate heat from this surface. In the insulated system created, one surface of the micro heater was insulated while the other was in contact with the cold surface of the PM. With this design, most of the power supplied to the system was dissipated as heat from the surface where the micro heater was in contact with the PM. To measure the temperature of the surface where the PM and the micro heater were in contact, measurements were taken from the insulated surface; a thermometer was passed through the insulation to contact the surface of the micro heater. Since the micro heater was thin, the temperature difference between its two surfaces was considered negligible.

Test parameters and conditions are listed in table 7. These parameters and conditions used in experiments.

Table 7. Test Parameters and Conditions

Test conditions		Test parameters
Ambient temperature (°C)	23	Current (A)
Fan speed (RPM)	1500	Power (W)
Contact surface conductivity (W/m.K)	8.5	
CPU usage rate (%)	100	

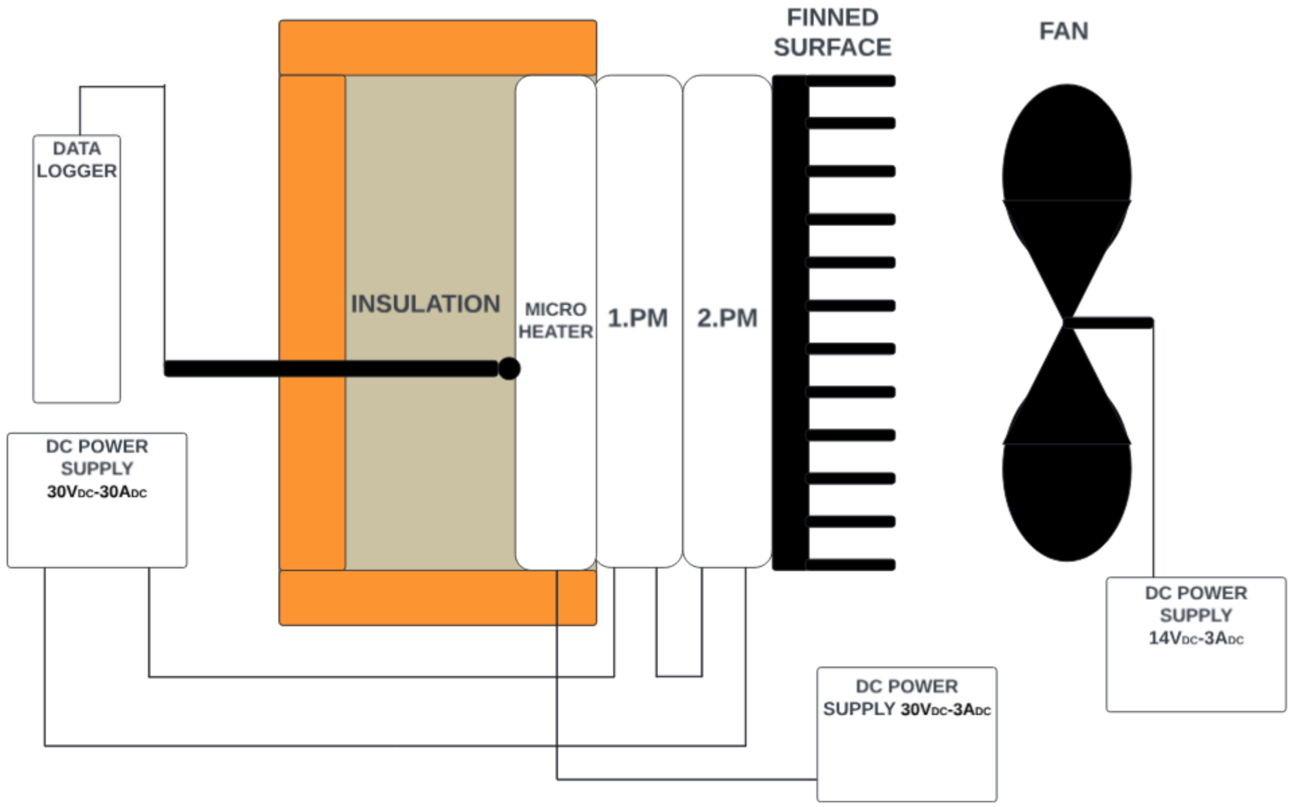

Figure 1. A Schematic Diagram of a Two Stage PM on Micro Heater Experiment

In the fourth and final part of the experiments, the two stage PM system was applied to a computer processor, and the processor temperatures were observed (Figure 2). In this part, the experiments were conducted with the graphics card of the computer being cooled by its own cooling system, while the processor was cooled by both a cooling system consisting of fins and a fan, and the two stage PM and cooling system. It was observed that when the processor was cooled only with the two stage PM, the computer shut down about 5 minutes after being turned on due to high temperatures. Therefore, the experiments were conducted with a cooling fin and fan system mounted on the hot surface of the two-stage PM. In this part, the experiments began without supplying power to the two stage PM; the power supplied to the system was increased in 1 W increments, and the experiments were concluded with a final power supply of 6 W. The AIDA64 program was used to apply maximum load to the processor, and the processor temperature was observed with The AIDA64. The experiments were successfully conducted, and the results were evaluated.

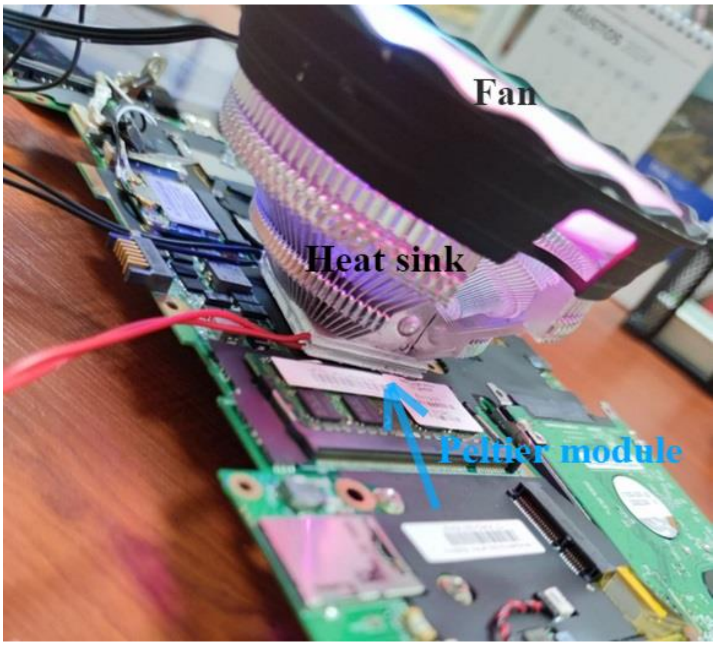

Figure 2. Two Stage PM Module with Heat Sink and Fan Applied to Microprocessor

3. Results and Discussions

In the experiments, the performance of both the two stage PM without cooler and the two stage PM with the cooler applied to the hot side was initially evaluated. In the experiments conducted, how the power supplied to the system affected the surface temperatures of the two stage PM was examined. The obtained results were presented, and finally, results from the experiments conducted on the processor were obtained.

The first experiment observed the temperature changes on the hot and cold surfaces of the two stage PM were measured at different powers applied to the PM (Figure 3). The power supplied to the system is the total power consumed by the two PM's. In the first experiment of this section, a total of 0.8025 W power was supplied to the PM's, and the hot surface temperature was measured as 34.8°C. The hot surface temperature continued to increase with the power supplied to the system and reached 110.2°C when 7.8 W of power was applied. The experiment was concluded at this point as it approached the maximum temperature the PM could withstand. In the initial experiment, the cold surface temperature was measured as 24.2°C, which is above the room temperature of 23°C. Subsequently, the cold surface temperature continued to increase with the power supplied to the PM. In the two stage PM experiment, the temperature difference between the two surfaces increased as the power supplied to the system increased. When 0.8025 W of power was supplied to the system, the temperature difference between the two surfaces was 10.6°C; when 2.2 W was supplied, it was 17.6°C; at 4.11 W, it was 29.6°C; and at 7.8 W, it was 43.1°C.

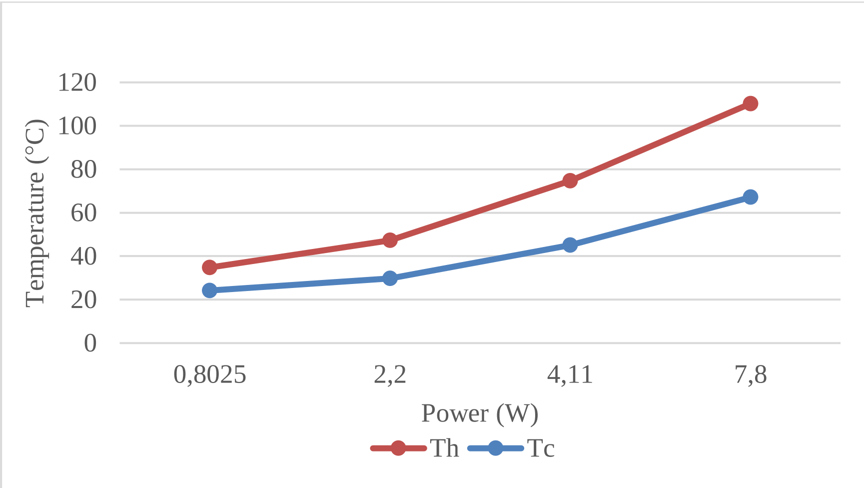

Figure 3. The First Experiment, Hot and Cold Surface Temperatures with the Power (W) Applied to the Two Stage PM

In the second part of the experiments, a cooling fin and fan system was applied to the hot surface of the PM. The two stage PM experiment began with a power of 0.4825 W supplied to the system (Figure 4). At the starting point, the hot surface temperature was measured at 23.7°C, and the cold surface at 13.2°C. As the power supplied to the system increased, the temperature difference between the two surfaces also increased, reaching the highest temperature difference of 28.3°C at a power level of 5.38 W. Furthermore, the lowest measured temperature value of -2.3°C was obtained when 5.38 W of power was supplied to the system. The hot surface temperature increased as power was supplied to the system; while the temperature difference between the first two measurements was 0.5°C, it was 1.1°C between the last two measurements. This indicates that the hot surface temperature did not increase linearly but rather showed an increasing slope.

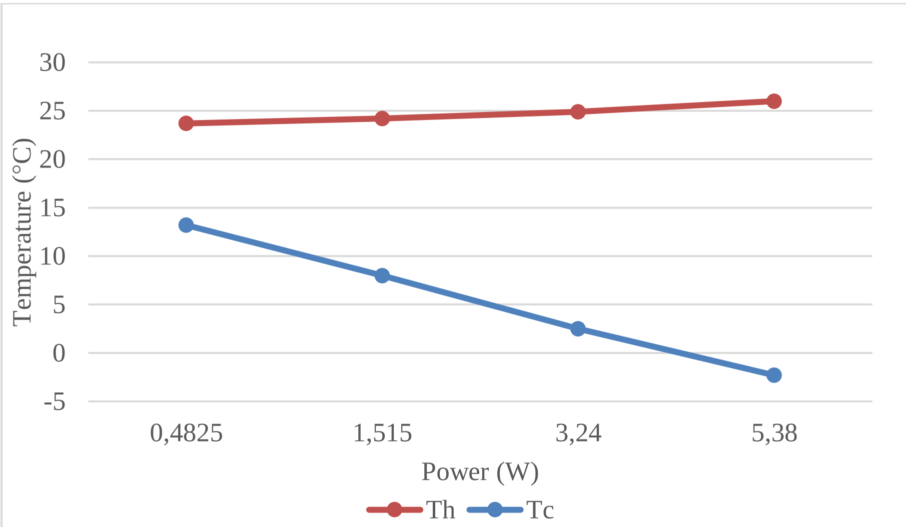

Figure 4. Hot and Cold Surface Temperatures with the Power (W) Applied to the Two Stage PM at Second Experiment

Another part of the study is PM cooler applied to micro heater. Micro heater experiments were conducted because microprocessors degrade above 90°C, and the behavior of a two-stage PM cooler was observed on the micro heater. However, since microprocessor temperatures change more rapidly compared to the micro heater, experiments were also conducted on the microprocessor after the micro heater tests. This allowed the performance of the two-stage PM cooler applied to the microprocessor to be clearly demonstrated. In the third experiment using two stage PM as the cooler, it was observed that the cold surface temperature increased as the power supplied to the micro heater increased (Figure 5). The power (W) values here represent the heat dissipated from the surface of the micro heater, while the current (A) values indicate the total current supplied to the system. As the current applied to the PM increased, the cold surface temperature reached its lowest point at the current value of 5 A, and the temperature began to rise as the current value continued to increase.

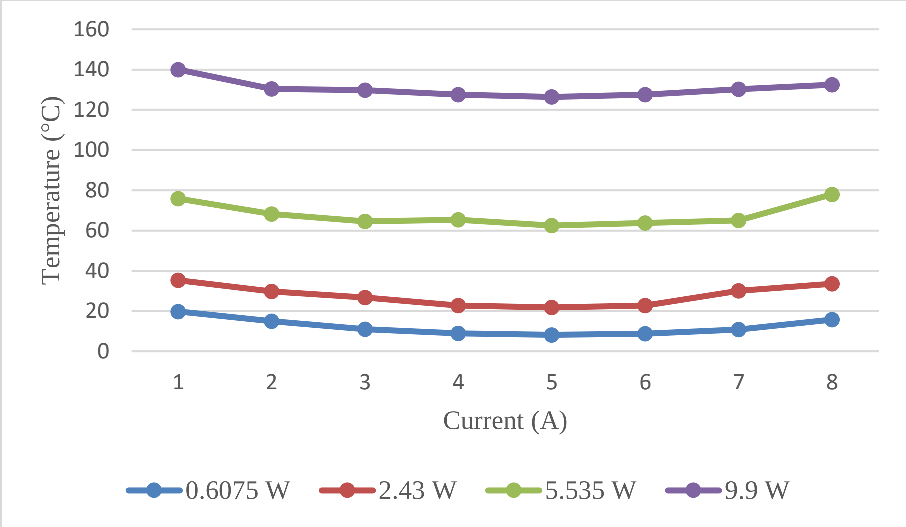

Figure 5. Cold Surface Temperatures of Cooled Two Stage PM's at Different Micro Heater Power

When examining the hot surface temperatures of the two stage PM, the highest temperature value was measured at 95.8°C when 9.9 W of heat was dissipated from the micro heater and 8 A of current was applied to the PM (Figure 6). When comparing these four experiments, the highest temperature was 95.8°C at a power level of 9.9 W on the micro heater, while the lowest temperature was measured at 79.5°C when 0.6075 W of power was applied to the micro heater.

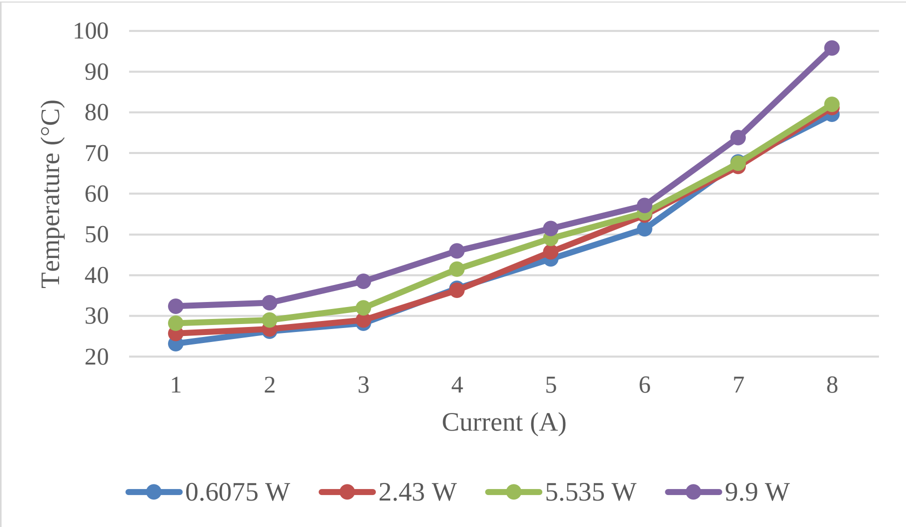

Figure 6. Hot Surface Temperatures of Cooled Two Stage PM's at Different Micro Heater Power

This section we made third experiment, two stage PM and cooler equipment (finned surface and fan) applied to micro heater. The experiment started by applying 0.66 W of power to the PM, and the hot surface temperature was measured at 32.4°C, while the cold surface temperature was 140°C (Figure 7). It was observed that as the power supplied to the PM's increased, the hot surface temperature increased, but the cold surface temperature reached its lowest point of 125.9°C at a power of 33.6 W and then started to rise again. Additionally, at this point, the increase in the hot surface temperature was observed to accelerate. The power level of 33.6 W represents the optimum point for the two stage PM system to cool a surface emitting 9.9 W of heat, and the temperature decreased to 125.9°C; beyond this point, the temperature began to increase as more power was applied.

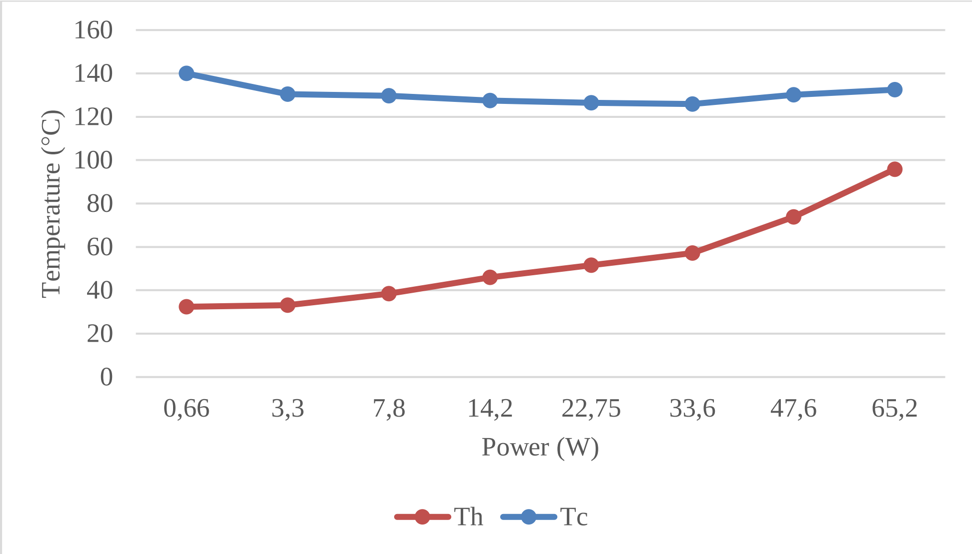

Figure 7. In the Third Experiment, PM Surface Temperatures with the Power (W) Applied to the Two Stage PM with Cooler in the Micro Heater (9.9W)

A series of experiments were conducted on the processor. Both the computer's original cooler and the designed two stage PM cooler were used in the experiments (Figure 8). One of the boundary conditions of the experiment was to apply maximum load to the processor using the AIDA64 program, resulting in 100% CPU utilization at maximum speed. Another boundary condition was that all experiments were conducted in an environment with an ambient temperature of 23°C. Initially, the experiment was performed using the computer's original cooler, which consists of a copper pipe, fin, and fan system, keeping the computer processor at a temperature of 62°C. The experiments then continued with the two stage PM cooler. Heat was dissipated from the hot surface of the PM using a fin and fan system. In the experiments, power was supplied to the two stage PM starting from 0 W, increasing by increments of 1 W. When no power was supplied to the PM, the processor temperature was measured at 72°C. It was observed that as power was supplied to the PM, the processor temperature decreased, reaching as low as 43°C when 6 W of power was supplied. At the start of the experiment, when power was supplied to the system, the temperature dropped from 72°C to 56°C, and after this point, the temperature decreases lessened with each step. When 5 W of power was supplied to the system, a temperature of 45°C was measured, and at 6 W, a temperature of 43°C was observed. The experiments were concluded at this point due to the temperature difference being only 2°C.

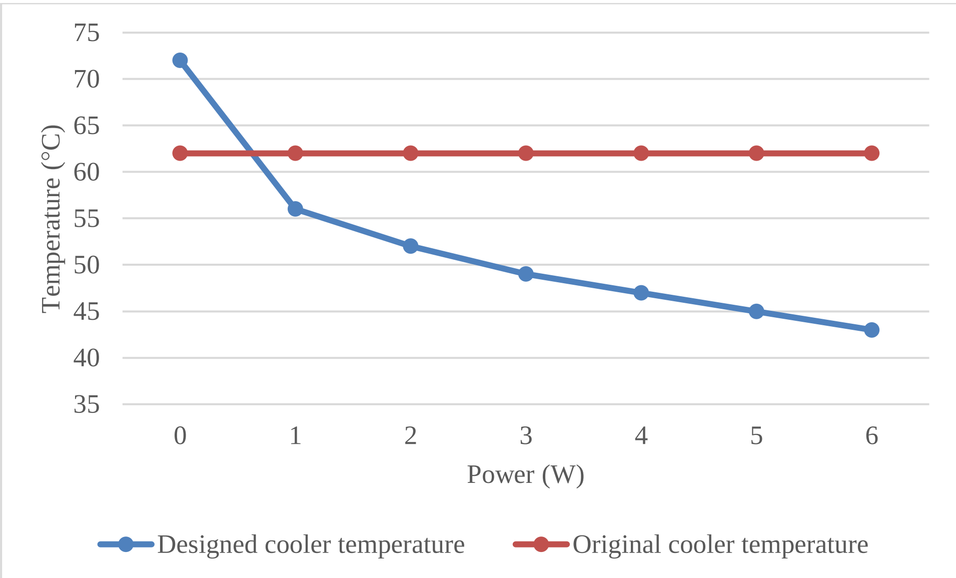

Figure 8. Experimental Results of PM Cooler on the Microprocessor

The use of two stage PMs provides an alternative solution in cooling systems, shedding light on PM studies. In this study, the cooler designed with two stage PM demonstrates that it can effectively cool electronic components that generate high heat, such as processors, while offering valuable insights to researchers on enhancing the performance of the two stage PM through a heat sink. Additionally, this study will provide researchers with insights into the advantages and cooling performance of the two stages PM.

4. Conclusion

In the study conducted, a cooler was designed using a two stage PM and applied to a computer processor, yielding the results. For the cooler design, two PMs were thermally mounted in series, allowing heat to be dissipated from the hot surface using fins. In the experiments conducted solely on the PM, it was observed that as the power supplied to the PM increased, the temperature difference between the two surfaces also increased. Initially, when 0.8025 W of power was supplied, the temperature difference was 10.6°C, which rose to 43.1°C when 7.8 W was supplied to the system. When heat was dissipated from the hot surface using fins and a fan, the temperature difference between the two surfaces increased, but there was no significant change in the temperature of the hot surface. A temperature difference of 2.3°C occurred on the hot surface between the beginning and the end of the experiment. However, there was a decrease in the cold surface temperature, dropping from an initial temperature of 13.2°C to -2.3°C by the end of the experiment. Additionally, forced convection was achieved by blowing air onto the fins with a fan. As a result of the experiments conducted in this section, it was determined that the cooler applied to the hot surface of the PM increased the cooling performance of the PM. Subsequently, the designed cooler was tested by being applied to a micro heater before use. The PM was tested for different power values supplied to the micro heater, and it was observed that the PM reached its limit temperatures when 9.9 W of power was supplied. Finally, experiments were conducted on the processor. In these experiments, it was observed that the PM-equipped cooler lowered the processor temperature to a greater extent compared to the computer's original cooler.

This study provides a foundation for determining the optimal operating temperature of the microprocessor and for future work aimed at maintaining the microprocessor temperature at its optimal value. Additionally, it can be used as a basis for investigating the effect of P and N material leg heights on cooling performance. Furthermore, it supports efforts to reduce the negative impact of electrical conductors on cooling performance.

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It is declared that during the preparation process of this study, scientific and ethical principles were followed, and all the studies benefited from are stated in the bibliography.

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