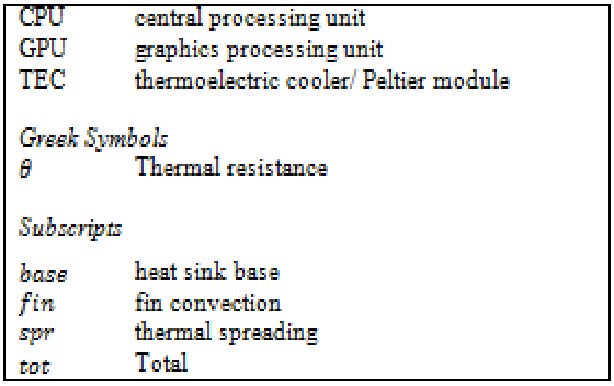
Design and Testing of A Thermoelectric Cooling System For Laptops Using Peltier Module

Ved Soni[1]**, Jay Maradiya**[2]**, Anubhuti Mishra**[3]
[1, 2, 3] Dept of Mechanical Engineering
[1, 2, 3] Sardar Patel College of Engineering, Andheri West, Mumbai-400058, Maharashtra, India

Abstract- *Majority of laptops currently available in the market rely on heat pipes and forced convection by fans as their primary thermal management technique. When these devices are subjected to computationally and graphically intensive tasks such as simulations or gaming for extended periods of time, the CPU and GPU junction temperatures rise which necessitates an external cooling system in addition to the stock one. The currently employed external cooling systems generally consist of multiple fans placed at strategic locations to enhance the cooling rate. In the present study, a rudimentary thermoelectric cooling system is developed which consists of a Peltier module, heat sink,andan axial fan. The system is designed, fabricated and tested to optimize the cooling provisionwith processor junction temperatures as parameters.Results indicate that the proposed system can provide a reduction of 9°C on an average in the CPU junction temperature for a module voltage of 5.44 V. Also, the experiments are repeated with a 'heat sink only' system for comparison.*

Keywords- electronic cooling, laptop cooling, Peltier module,thermal management, thermoelectric cooler

NOMENCLATURE



CPU	central processing unit
GPU	graphics processing unit
TEC	thermoelectric cooler/ Peltier module
Greek Symbols	
θ	Thermal resistance
Subscripts	
base	heat sink base
fin	fin convection
spr	thermal spreading
tot	Total

I. INTRODUCTION

For the last two decades, the miniaturization of electronic devices has been the prime research focus of electronics industry. Consequently, smaller devices have higher power densities and operate at elevated temperatures which drastically undermine their performance [1] besides reducingsafety and reliability [2].Pedram and Nazarian [3] reported that more than 50% of integrated circuit failures are related to thermal issues.Thermoelectric cooling can provide enhanced cooling rates and can resolve the concern of thermal management of compact electronics [4].Although Peltier modules are available in the market, the current commercial external laptop cooling systems (cooler pads) do not employthem and instead rely on only a set of axial fans which cause inadequate decrement in CPU/GPU junction temperatures [1].The aim of this study was to develop an effective and practical TEC-based cooling system for laptop computers.

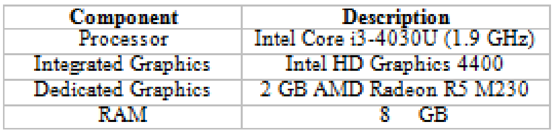
Research on the application of TECs for thermal management of electronics began with mathematical modeling of TECs and their subsequent performance assessment and optimization depending on various parameters [5-7]. However, little effort has been dedicated to incorporate TECs in physically confined electronic devices such as laptops. Bou-Rabee et al. [1] used a TEC to cool air and supply it to fan inlet of a laptop. Temperatures of various components in the laptop were measured at several ventilation conditions, with and without the TEC in conjunction. However, since the air cooled by TEC was passed through an enclosed ducting, it resulted in a large pressure drop and thereby poor convection, resulting in only 1°C temperature drop in GPU relative to acommercial external cooling system. Khan et al. [8] attached a TEC directly to the CPU die and a secondary heat pipe is used to cool the hot side of the module. The final cooling load of the secondary heat pipe is borne by the laptop's existing forced convection cooled heat sink. This restricts the TEC from operating at higher cooling capacities and consequently, the CPU junction temperature drop witnessed was only 2.3°C as compared to the stock cooling system.

In the present study, a TEC is physically integrated with the stock cooling systemand its performance is gauged by the temperature drop produced in CPU/GPU junctions. SectionII outlines the design process of the TEC and also the experimentation methodology followed.The experimental results and their detailed analyses are presented in sectionIII and are further summarized in section IV.

II. DESIGN AND EXPERIMENTAL METHODOLOGY

The laptop used for the study is Lenovo G50-70 and has following specifications:

Table 1: Laptop Specifications



Component	Description
Processor	Intel Core i3-4030U (1.9 GHz)
Integrated Graphics	Intel HD Graphics 4400
Dedicated Graphics	2 GB AMD Radeon R5 M230
RAM	8 GB

A. *TEC component design and selection*

The TEC selected was TEC1-12706 due to its commercial availability.The maximum heat dissipation through laptop was found to be 10.22 W (as logged by ‘CPUID’ software) during ‘OCCT 4.5.1’software’s power supply test and was verified using the correlation provided by Mozumder et al. [9]. From TEC datasheet [10], the operating voltage was decided to be varied under 6 V to match the laptop’s heat dissipation.

Considering manufacturability, aparallel plate-fin heat sink subjected to forced-convective cooling by an axial fan was selected for dissipating heat fromTEChot side. Sixteen heat sink geometries with varying fin thickness, fin spacing,and base size were analyzed for their cooling performance in conjunction with five cooling fans with different flow rates available in the market. As seen in Eq. 1, the total thermal resistance (θ_{tot})consists of three components: fin resistance (θ_{fin}) considering forced convection of air; base resistance (θ_{base})due to conduction through the aluminium base; and spreading resistance (θ_{spr}) which is considered whenever the heat sink base size exceeds the TEC surface area to account for thermal spreading.

$$\theta_{tot} = \theta_{base} + \theta_{fin} + \theta_{spr} \qquad \text{(Eq. 1)}$$

Fig. 1illustrates a plot between heat sink thermal resistances against their fin thickness, spacing configurations for different base sizes where the heat sink is used in conjunction witha high CFM fan for minimizing thermal resistance. As seen, the thermal resistance reduces drastically with increasing base size but doesn’t vary appreciably with change infin configuration. A low value of heat sink thermal resistance is to be preferred as it will dissipate more heat with a lower temperature gradient across the sink base and ambient air. After considering space constraints and manufacturing feasibility, a heat sink having 62.5 mm x 62.5 mm base size and 2.5 mm thick fins with 2.5 mm spacing was selected (indicated in Fig.1 by dropped lines) (heat sink-fan assembly pressure drop, heat transfer coefficient and thermal resistance calculations were adopted from [11-13]).

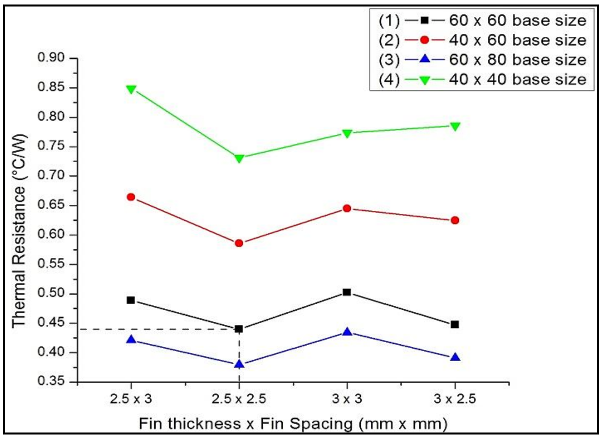


Fig. 1: Thermal Resistance of heat sink geometries for different base sizes for a selected fan

A 5V 5A SMPS power supply which suppliesconstantvoltage in the range of 2.5 to 5.5 V is used to power the TEC and axial fan. Allied components designed for the system include an aluminium extender block (Fig. 2), which conducts heat from laptop’s stock heat pipe to the TEC cold side, and a wooden stand to contain the cooling system, SMPS and also to support the laptop. A thermal grease is used as a thermal interface material between TEC hot and cold sides, the extender block and heat sink. Fig. 3 shows the entire cooling system assembly.

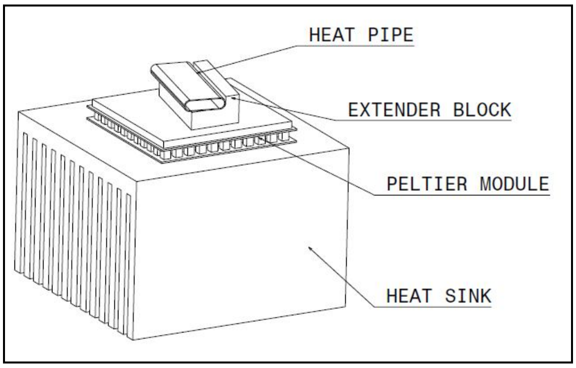


Fig. 2:TEC Components

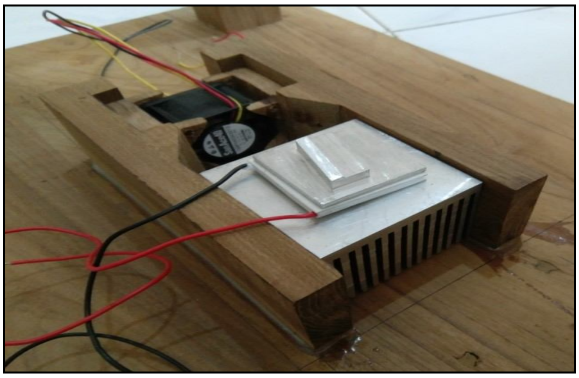


Fig. 3: Cooling System Assembly

B. *Experimentation procedure*

Drop in CPU/GPU junction temperature is selected as the main parameter to evaluate TEC performance. The junction temperatures are measured using 'OCCT 4.5.1' software while the laptop is subjected to OCCT's power supply test. Four experiments are conducted: In the first experiment, junction temperatures are recorded without the TEC, while the laptop undertray is in place. The second experiment involves repeating this procedure while the undertray is removed and the laptop is mounted on the wooden stand. In the third experiment, the setup and data gathered is same as that in second experiment, but the proposed cooling system is brought into operation at a TEC voltage of 5.44 V. Also, the junction temperatures are measured along with variation in voltage across the TEC from 5.44 V to 2.85 V by adding electrical resistances in series with the TEC. In the final experiment, a 'heat sink only' system, without the TEC is used for comparing the performance of the proposed system with a conventional one.

III. RESULTS AND DISCUSSION

This section presents the results in a graphical form and also provides their detailed analysis.

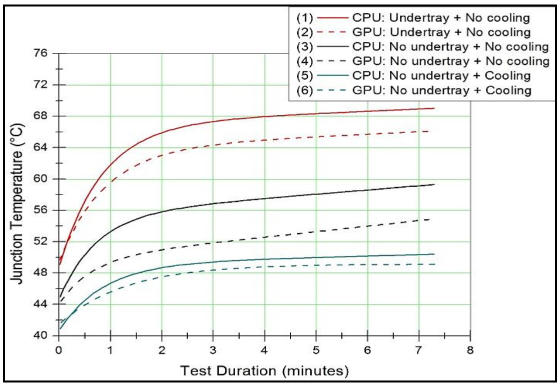


Fig. 4: Junction temperature v/s test duration for different setup conditions

Fig. 4 represents the timeplot of CPU and GPU junction temperatures for experiments 1, 2 and 3. As seen for all the curves in Fig. 4, the temperature rise is logarithmic in nature, which is explained by the heat transfer version of Newton's law of cooling [14]. In experiment 1, the CPU junction temperature rises andstabilizes at 69°C (Fig.4, curve 1), which reduces to 59°C in the second experiment (Fig.4, curve 3) and further to 50°C in the third experiment (Fig. 4, curve 5).

Thus, the effective temperature drop achieved by the proposed cooling system is 19°C. However, more than half of this temperature drop, i.e. 10°C is achieved just by undertray removal and raising the laptop by placing it on the wooden stand, both of which result in an increased heat transfer to surroundings. After bringing the TEC into operation, a further average drop of 9°C at a module voltage of 5.44 V is experienced.

Fig. 5 is a plot of cooling rates obtained by using the proposed system by varying the voltage across TEC. The effective cooling rate was calculated by measuring the junction temperature drop achieved after using the system for five minutes, by which time the junction temperatures stabilize. As seen in Fig. 5, the graphs for the cooling rate of both CPU and GPU are similar in shape to the cooling capacity v/s module voltage curve provided in the module datasheet [12]. Also, the curves 2 and 4 in Fig. 5 represent the cooling rate of the 'heat sink only' system, which is approximately 1.44 °C/min on average.

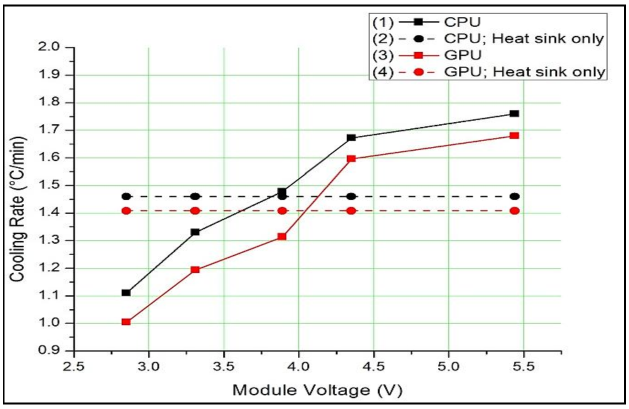


Fig. 5: Cooling rate v/s module voltage for CPU and GPU and its comparison with the cooling rate for heat sink only system

Consequently, it is justified to invest in the proposed cooling system, only if the desired cooling rate is above 1.44 °C/min. Below this rate, the use of a 'heat sink only' system will suffice the cooling requirement besides being less expensive and simpler in construction.

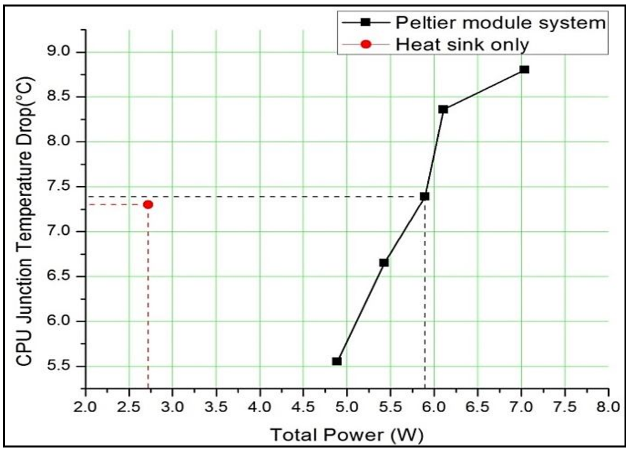


Fig. 6: Drop in CPU junction temperature v/s total power consumed by the proposed cooling system and by the heat sink only system

Fig. 6 depicts the CPU junction temperature drop obtained against the total power utilized by the proposed cooling system. The total power consists of two components: the power consumed by the TEC and that consumed by the axial fan. As seen, the temperature drop increases by a large amount with a small increase in power supplied. Moreover, the red point indicates the power consumption of the 'heat sink only' system i.e. the power consumed by the axial fan.

The 'heat sink only' system consumes less than half the total power consumed by the TEC system for providing the same temperature drop of approximately 7.35°C. Hence, from the perspective of temperature drop, it would be judicious to use the proposed cooling system when the desired temperature drop is more than 7.35°C, below which the use of a heat sink only system will serve the purpose.

IV. CONCLUSION

Thermal management of laptops is a crucial predicament faced by the electronics industry. While resolving this issue using external cooling systems, their effectiveness and pragmatism are two primary concerns. The proposed TEC-based cooling system provides a drop of 9°C on an average at a module voltage of 5.44 V, but its use is only justified when the desired cooling rate and CPU junction temperature drop are above 1.44°C/min and 7.35°C respectively. Further investigation of the proposed system is required to standardize its performance with respect to TEC parameters as well as the laptop used. Also, ergonomic improvement and compaction are the other matters needing attention.

V. ACKNOWLEDGEMENT

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