An Investigation of Liquid Cooled Air Blower Performance for Laptop Cooling System

Nicholas Pinenn and Jamilah Karim

***Abstract*—This work presents a study on the performance of custom design laptop's cooling system. Differ from existing external cooling solution for laptop which blows slowly ambient air to the laptop's ventilation, this system lowers the ambient air temperature then blows it into the laptop's cooling box and increase its internal air pressure. The internal pressure then used to force the extra air flow into the laptop's ventilation port and into the laptop's internal cooling system. Several tests has been conduct in order to prove the reliability of the design system. The data obtained from the test are analyzed by using numerical method which the new cooling method is giving significant cooling. The cooling system demonstrated the liquid cooled air blower system gives up to 8 percent cooler than stock cooling system and 5 percent cooler when compared with existing on market cooling pad when the CPUs are in continuous stress test.**

***Index Terms*— Cooling System, Liquid Cooling, Laptop Cooling**

I. INTRODUCTION

Following Moore's Law, microprocessor have driven a visible evolution in computing power, the semiconductor industry has successfully doubled transistor count same area of chip every 18-24 months and the microprocessor has been the flagship product, successfully exploiting the increased performance with each new technology generation along Moore's law [1]. Unfortunately, the consequences of increasing computing power associated with increase of heat power dissipation [1]. Heat is one of greatest enemy in computing world, it can burns the entire which renders it useless and malfunction. Due to this issue, computing power of Central Processing Unit (CPU) in computer mainly restrained by their operating temperature. Chip manufacture installs a fail-safe system which limit and reduce their product performance along with rising chip temperature as well as shut it down if exceed a predefined limit to prevent such catastrophic happened [2]. Still it does not enough as the needs of computing power demands exponentially in this modern day which leads to the birth of more powerful chip as well as its mortal enemy also getting stronger especially in mobile computing.

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To fight away such enormous amount of heat, mobile computer makers install their modern powerful chip like CPUs with heat disposal units called cooling fin that coupled with cooling fan in order to blow the heat away along with maintain both chips temperature below the operating limit temperature by limiting its computing power [3]. Yet this method is not effective for a long run due to many factors like shortening of laptop riser stand which limit the air flow rate, blockage of intake ventilation by dust and wear and tear of cooling fan which leads to the birth of external cooling solution by enhancing those laptop cooling power. Although, some computer maker came up with external liquid cooling system which compatible with certain model of their product and the price is high due to complexity. Due to this problem, varieties of external laptop cooling system product released in the market where not all of them is effective and some of them give no effects at all.

Typical operating temperature of CPU under heavy load is about 70 degree Celsius, beyond that the CPU's thermal protection system kicks in by lowering the computing power and if temperature keeps rising, the system will shut the CPU down. The stock cooling system in laptop usually able to keep the temperature not to reach temperature limit value but not for a long period of time. This is where these external cooling being used by placing them under the laptop called cooling pad which it blows in extra air into the inlet vent and some of them placed right in front of laptop cooling vents to suck the hot air out which is called as vacuum heat pump.

Numerous of studies has been conducted regarding air cooling method for CPU such that:

Copeland [4] has conducted an experiment regarding duct flow analysis for ideal type (infinite thermal conductivity) and real type heat sinks using analytic equations. In his work, he constructed the most ideal heatsink design by applying thermal radiation formula. Outcome from his work is to prove that there is mathematical equation to maximize the heat release to atmosphere cause by CPU during operating. However, the design cannot to be applied to modern mobile computer due to large size.

Bar-Cohen and Iyengar [5] introduced flow relations for isothermal parallel plates to define optimum heat sinks for least material and for maximum heat transfer. In this work the author varies the number of cooling fin number and each fin thickness to increase the heat release rate to atmosphere. The author also proposed the optimum fin number and thickness of mobile application which one of crucial characteristics is space saving.

Meanwhile, Culham and Muzychka [6] conducted a research on optimization of heat sink based on entropy generation. The proposed work was similar with work by Bar-Cohen except the author design the cooling fin based on heat generated by CPU and match it with ambient temperature. The paper focus more on chip power and fin design.

Author in [7] and [8] used liquid cooling fan to cool down the CPU in the desktop computer. They believed this is the best cooling method thus far. However, this system requires larger space and not suitable for laptop.

More researches on liquid cooling have been conducted recently. [9] in his work introduce the heat pipe embedded on top of the heat sink. The heat pipes were used to ensure a uniform temperature distribution. However, this system too requires larger space and not suitable for laptop.

Besides using normal water to cool the air, [10] introduced new cooling fluid to cool the CPU. His work proved that this new cooling fluid can cooled the CPU temperature better than water. However the size of the CPU cooling devices used is not suitable for the laptop.

Due to limited space of laptop's constructions, the manufactures facing the problems to cool their products as well as with the problem that has been determined for aftermarket cooling pad:

- Stock copper heat dissipater is small added with low air flow rate due to small ventilation fan which restrict the removal excess heat generated by chips efficiently under heavy load for long period of time.
- Aftermarket product like cooling pad shows minute cooling effects compared with stock cooling system.
- Constructing a cheaper and more reliable external cooling system and compatible to variety model of laptop.

There are two methods to lowering CPU temperature, either forcing extra air to flow into the inlet vent which commonly method use by third party computer cooling solution or by lowering the temperature of air that flow into the inlet vent which then flows into the laptop's cooling system. For the cooling pad and vacuum heat pump, they both forcing extra air flow through the cooling system either by blowing and sucking, this method got limitation as the inlet vent has dust trap which restrict the amount of air flow into the cooling system. For cooling pad case, extra unblown into air due to dust trap just flow around the back case of laptop while for vacuum heat pump will sucking air at limit of the air flow rate of the laptop's cooling system.

Due to those constrains, this project proposed a cooling system that apply both methods mentioned above and aided with pressure difference flow assist technique which gives a new name as cooled air cooling to cool down the CPU operating temperature. This newer method of cooling is not yet existed in market and the comparison of this method with cooling pad and stock cooling is done under variety of test variables which focusing on these objectives to proof the reliability of this new cooling method:

- Intrroducing new air cooling method of external induced cooling system for laptop.

Combining both forcing extra air to flow into the inlet vent and by lowering the temperature of air that flow into the inlet vent methods aided with pressure difference flow assist technique to cool down the laptop's under heavy load temperature.

- To analyze and proof the efficiency of the new air cooling method by comparing with stock and cooling pad cooling system

Setting up a suitable tests and data analysis techniques for the three methods of cooling (stock cooling system, cooling pad and cooled air method) and compared each data to each other. At the same time proving that cooled air method is better that the other two methods.

- Construct a much cheaper and compatible to variety of laptop brand and model

As mention above, some computer maker came up with their own external cooling system, unfortunately the cost of such cooling system is expensive and only compatible with their own certain product only. Therefore, one of aim for this project is constructing a cheaper and compatible wide external cooling system

II. METHODS

A. System Description

Figure 1 shows the block diagram of the working the cooling system. Laptop is placed on top of a cooling box (used shoe box) with ventilation holes (intake and blow out).

1. Cooler Blower and Water Block module: It contains a Peltier cooler unit sandwiched blower fin and water block placed inward at intake vent which serve to cool the incoming air. Then the blower fan attached on the blower fin blow the cooled air toward the laptop intake cooling vent via blow out hole of the box.
2. Power supply module: A modified computer power supply unit is used to power up the Peltier cooler and cooler blower.
3. Radiator module: A compartment which a continuous tube packed tight together to give largest surface area that being used to remove heat from water flows in it.
4. Reservoir & Pump module: A container filled with water and water pump which pumping the water towards the entire system.

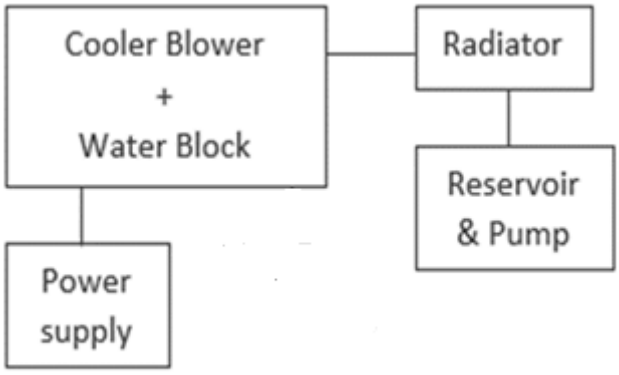

Figure 1: Cooling System Block Diagram

B. Project Description

Cooling system is crucial for microprocessors as it remove out generated heat cause by the computation carried out by the processor. Therefore, there are several sub-system modules involve to completes the new cooling method for this project. Figure 2 shows the hardware of the cooling system. Figure 3 is load test software used to set up and begin the test, and Figure 4 is data logging software which is used to collect all the test data. A software called CPUID HWMonitor Pro is used, where it also one of commonly used hardware operating logging software worldwide due to its advance and detail logging results.

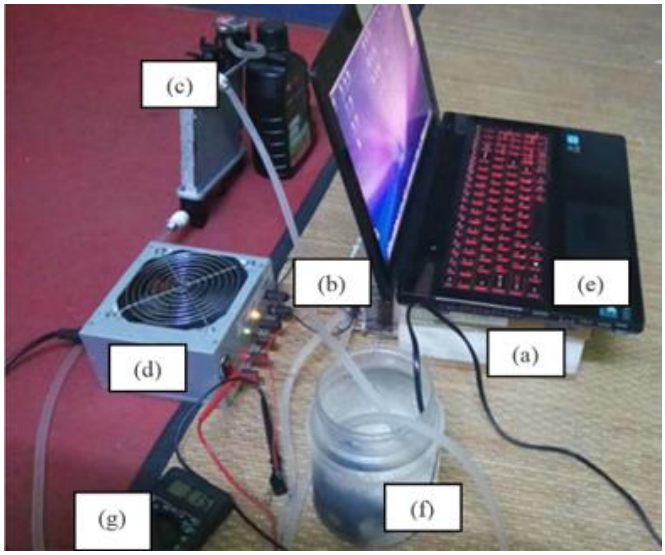

Figure 2: Cooling System setup for experiment

Figure 3: Project load test software setup

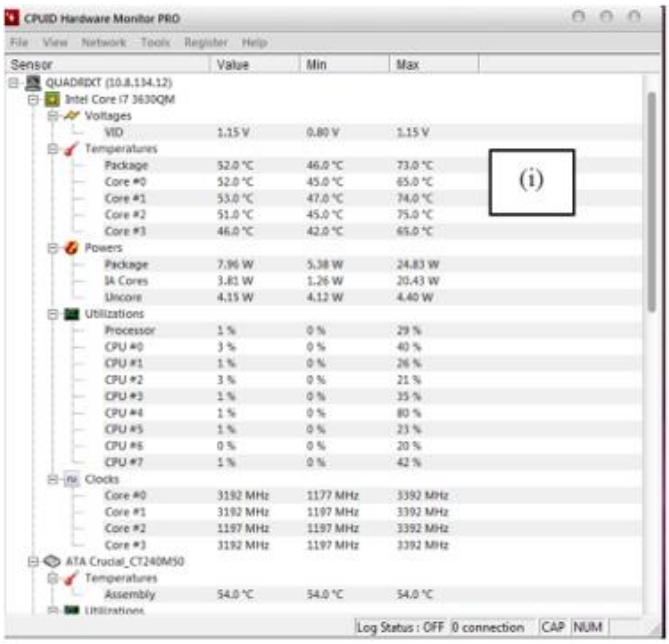

Figure 4: Project Data logging Software Setup

(a) Cooling Pad

An aftermarket cooling solution which its function is to enhance the cooling capacity by blowing more ambient air volume towards the base of laptop. Sometime the extra cooling capacity "provided" by it is confused by the extra lift on the inlet vent of the laptop which also allows more air to flow into the laptop's cooling system. Due to this confusion, the test compares it with setup without the cooling pad to see the difference.

(b) Cooler unit blower

A Peltier cooler unit sandwiched blower fin and water block with water hose attached which its purpose is to cool down suck in ambient air to lower temperature and blow it towards the cooler inlet ventilation of the laptop. The attached water hose serve as the heat removal agent from the Peltier cooler unit pump by water pump and radiate out the heat contain to atmosphere via radiator.

(c) Radiator

As its name suggest, it radiates out heat energy content within the water flows within it, the efficiency of it can be elevated by increase the surface area of chambers swirling on it and increase the air flow via the radiator.

(d) Power supply

A modified desktop power supply so it can supply power to the Peltier cooler correctly without burning itself due to low resistance of the Peltier cooler.

(e) Laptop

This project would not called as project without its test subject. The laptop is equipped with one unit Intel Core i7 CPU, renders this laptop a suitable subject as the chips are high power units which able to produced significant results when under tests

(f) Water Pump

The heart of the external cooling system which circulating water from the reservoir to Peltier cooler water block to radiator and circulate back to reservoir.

(g) Multi-meter

A device which use to measure the electric current used by the Peltier cooler to cooled down the air for entire tests. Eventually we able to calculate the power consumption of the Peltier cooler.

(h) Load test software

The load test software called Unigine Heaven Benchmark where the software is one of famous benchmarking software used by performance computer builder worldwide.

(i) Data logging software

A software called CPUID HWMonitor Pro is used, where it also one of commonly used hardware operating logging software worldwide due to its advance and detail logging results.

C. Flow chart

• Test environment selection: A stage of selecting the stress test software on computer which being used for testing.
• Apparatus setup: A stage of setting up all modules into one system and tested whether it function properly or otherwise.
• Software setup: A stage of setting up the stress test configuration like resolution, test time and sampling size.
• Test and data logging: A stage where all system is started, the cooling system is start to cools the CPU, the test software is start its stress test on computer and data logging is started as well.
• Data analysis: Stage where numerical form of data are transcript to graphical form for ease of presentations.
• Record: The graphs form results are stored to prevent confusions.
• Result comparison and conclusion: stage where all mode of cooling test results are obtained and their data are compared to each other to determine which one cooling method is the best.

Figure 5:Flow chart

D. Test flow

For this project, a stress test is done for each cooling method (cooled air method, cooling pad method and stock cooling system) to prove each cooling method effectiveness. For each method test, the setup apparatus is required to run for about one minute in idle mode before starting the test with data logging phase for minimum of 220 seconds. This is to ensure the temperature of chips is stabilized with each cooling method setup therefore avoiding inaccurate results. For data analysis, each test gives us sampling values which then plotted on a graph for ease of comparison of each cooling method and conclusions.

For this projects, total of 3 repetitive tests is done to prove the new cooling system effectiveness compared to existing cooling solution and stock cooling system.

III. RESULT AND DISCUSSION

To evaluate the performance of the working system, the following analysis was conducted:

Software analysis method- To analyze the data, a software that log CPU conditions is used. The sampling time is adjusted at proper interval which is 0.5 seconds, at this sampling time a sharper graph able to be obtained and reducing the possibilities of interval sampling loss. The sampled data then plotted to be a graph of variables versus time.

Numerical analysis method- As the sampling time is small, it creates noisy data look. Therefore, by applying numerical analysis on the data using Microsoft Excel, the summarized data are presented in much clearer view and look neat as well.

As hypothesized, the cooled air-cooling system has a significant cooling effect compared to the cooling pad and stock cooling system during stress tests. Figure 6, 7 and 8 shows the temperature versus time for cooled air-cooling system, cooling pad and stock cooling system respectively.

From figure 6, the minimum temperature during test is around 49.7 to 52.7 degree Celsius while maximum temperature at 220 second (at the end of test) is at 67.4 degree Celsius. It is noticed that the graph keeps rising and remain constant for entire test time which indicate the CPUs are working at full capacity for entire test time.

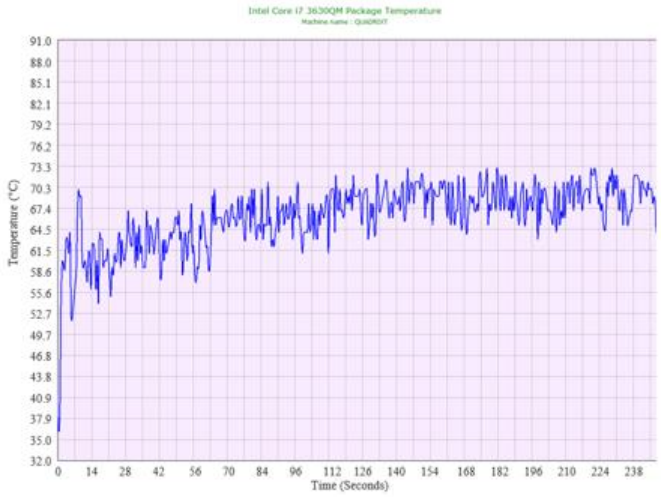

Figure 6: Temperature versus time of stress test using cooled air cooling system

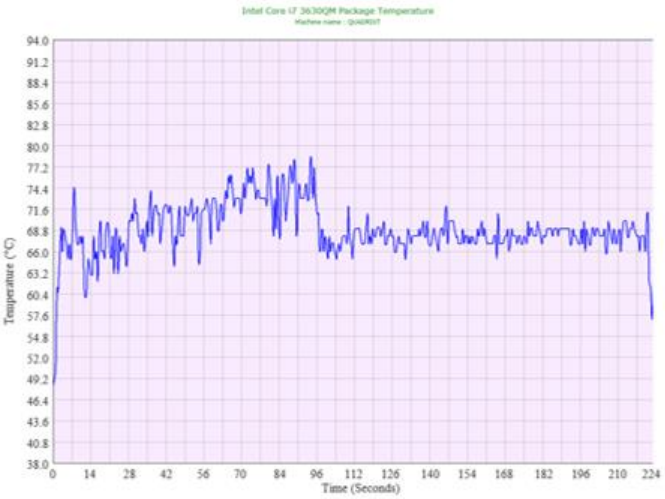

Figure 7: Temperature versus time of stress tets using cooling pad

From figure 7, the minimum temperature during test is around 57.6 to 60.4 degree Celsius while maximum temperature at end of test is around 68.8 to 71.6 degree Celsius. From figure 8, the minimum temperature during test is around 62.0 degree Celsius while maximum temperature at end of test is around 75.8 degree Celsius. From these two results, it is noticed that there is sudden drop of temperature after the CPUs reaching approximately 75 degree Celsius. This is happened as the CPUs reaching thermal warning level and signaling itself to lowers the computing power which results in drop in temperature.

From the graphs of temperature versus time for each stress test below, the time taken for CPU temperature for cooled air method rises much slowly compared to the other two, which prove the effectiveness of the new cooling system. This is cause by lowered ambient air vented into the cooling system which by lowering the ambient temperature, the capacity of cooling increase, which also follows the equation 1 below:

$$P_D = P_{D(\max)} - \frac{P_{D(\max)}}{T_{J(\max)} - T_{C0}} [T_A + P_D(\theta_{CS} + \theta_{SA})] \qquad (1)$$

Where P_D is permissible power dissipation, $P_{D(\max)}$ is maximum power dissipation, $T_{J(\max)}$ is maximum junction temperature, T_{C0} is casing temperature, T_A is ambient Temperature and $\theta_{CS} + \theta_{SA}$ is thermal resistance (constant)

From the mathematical equation above, by lowering the ambient temperatureT_A , the permissible power dissipation value also increases which allow the chip to dissipate more heat power into the flowing cooled air within the cooling system. Therefore, lowering the rate of temperature rising cause by chip operation.

Therefore, the proposed cooling system can reduce the CPU temperature by 7.9 degree Celcius and 12.3 degree Celcius compared cooling pad and stock cooling system respectively.

It is proven that by lowering the temperature of air to 22 degree Celsius that flow into the laptop's cooling system increase of cooling capacity. Thus, the time taken for CPU reaching thermal protection system value also increase. Figure 6 shows that is somewhere 74 degree Celsius, which after that the CPU lowering its clock speed to reduce heat.

From the results shows at Figure 9, 10 and 11, the amount of time CPU operating at maximum clock cycle (approximate 3.2Ghz) is the longest without lowering its clock speed for the cooled air method (Figure 9) while for the other two, it spends for a short amount of time at maximum clock speed before thermal protection system kicks in and lowers the computing power hence gives out lower performance (Figure 10 and 11).

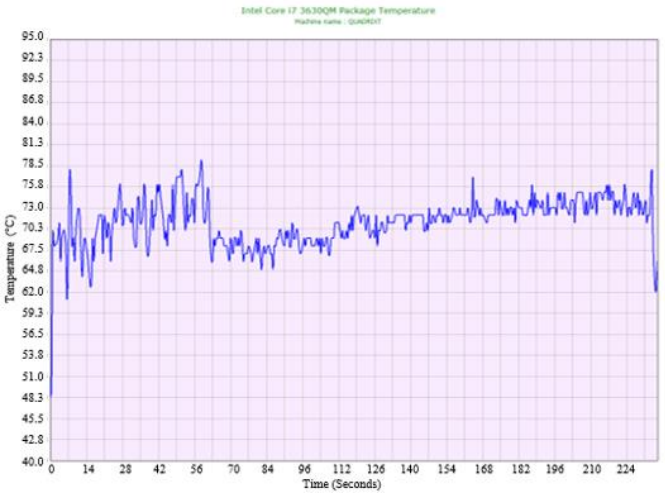

Figure 8: Temperature versus time of stress test using stock cooling system

From the results shows at Figure 9, 10 and 11, the amount of time CPU operating at maximum clock cycle (approximate 3.2Ghz) is the longest without lowering its clock speed for the cooled air method (Figure 9) while for the other two, it spends for a short amount of time at maximum clock speed before thermal protection system kicks in and lowers the computing power hence gives out lower performance (Figure 10 and 11).

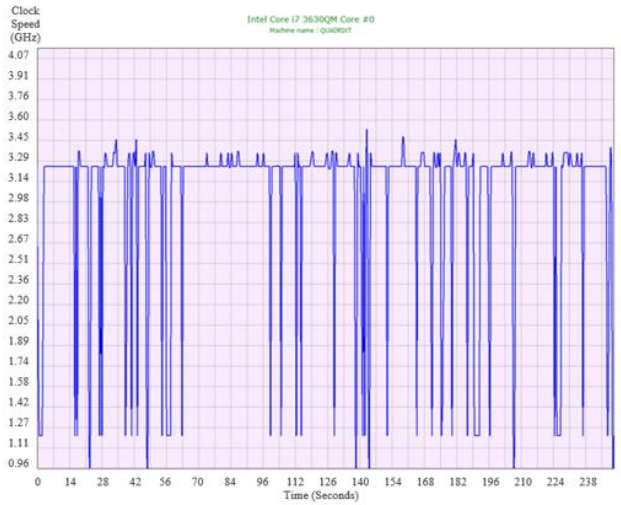

Figure 9: Clock speed versus time of stress test using cooled air cooling system. The CPU clock speed maintain at 3.2GHz for entire test time

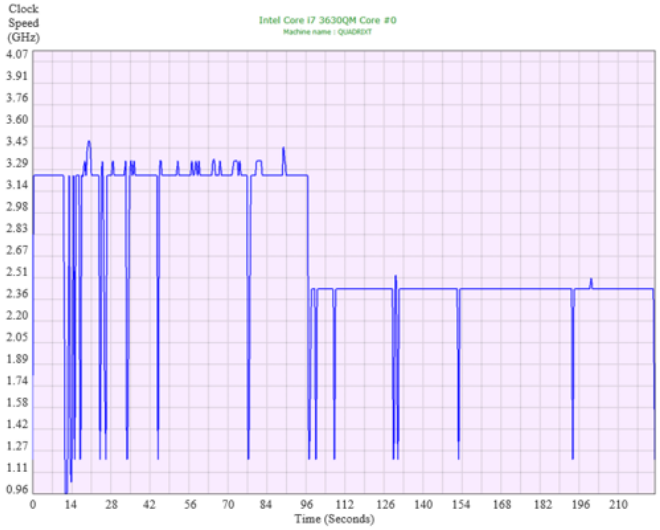

Figure 10: Clock speed versus time of stress test using cooled air cooling system. The CPU clock speed maintains at 3.2 GHz for 98 seconds then drop to 2.4 GHz until end of test

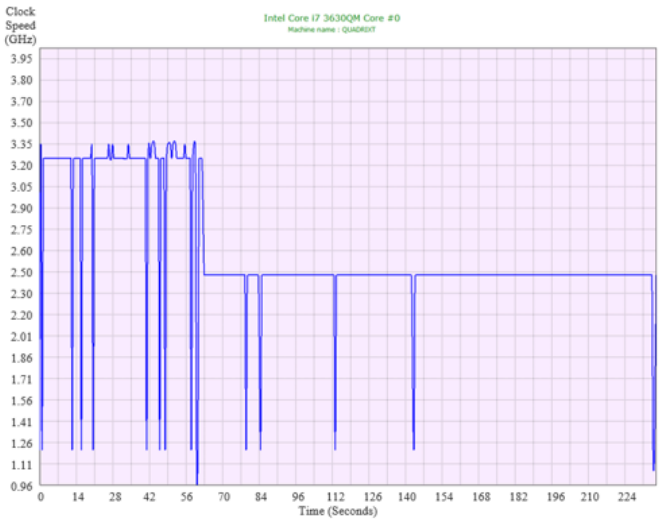

Figure 11: Clock speed versus time of stress test using cooled air cooling system. The CPU clock speed maintains at 3.2 GHz for 63 seconds and drop to 2.4 GHz until end of test.

From all the graph above, it is shown that different cooling method gives different CPU performance which cooled air cooling method gives the best cooling performance among three followed by cooling pad and stock cooling system.

IV. Conclusion

From the results, it is proven that the cooled air cooling method has significant cooling effect towards laptops cooling system. By lowering the ambient temperature flow into the laptops cooling vent, the cooling capacity increase significantly. The new cooling system also manage to maintain the temperature of CPU operating under stress below thermal protection value (75 degree Celsius), hence delivering peak performance for entire test time.

References

[1] B. G. E. Moore, “Cramming more components onto integrated circuits,” *Electrnics*, vol. 38, no. 8, p. 4, 1975.

[2] Intel, “Intel ® Pentium ® 4 Processor on 90 nm Process,” 2005.

[3] B. R. Mahajan, C. Chiu, and G. Chrysler, “Cooling a Microprocessor Chip,” in *Proceeding of the IEEE*, 2006, vol. 94, no. 8, pp. 1476–1486.

[4] D. Copeland, “Optimization of Parallel Plate Heatsinks for Forced Convection ww,” in *Sixteenth IEEE SEMI-THERM Symposium*, 2000, pp. 266–272.

[5] A. Bar-cohen and M. Iyengar, “Design and Optimization of Air-Cooled Heat Sinks for Sustainable Development,” *IEEE Trans. Components Packag. Technol.*, vol. 25, no. 4, pp. 584–591, 2002.

[6] J. R. Culham and Y. S. Muzychka, “Optimization of Plate Fin Heat Sinks Using Entropy Generation Minimization,” *IEEE Trans. Components Packag. Technol.*, vol. 24, no. 2, pp. 159–165, 2001.

[7] M. R. Hidayat, Nur, Reza Fauzi Iskandar, “Temperature Control Personal Computer Using Liquid Cooling System Based PID Control,” in *2015 International Conference on Automation, Cognitive Science, Optics, Micro Electro-Mechanical System, and Information Technology (ICACOMIT), 2015*, 2015, no. 2, pp. 4–6.

[8] M. Vuckovic and N. Depret, “Impacts of local cooling technologies on air cooled data center server performance: Test data analysis of Heatsink, Direct Liquid Cooling and passive 2-Phase Enhanced Air Cooling based on Loop Heat Pipe,” in *Annual IEEE Semiconductor Thermal*

Measurement and Management Symposium, 2016, vol. Part F1214, pp. 71–80.

[9] Y. Wang, B. Wang, K. Zhu, H. Li, W. He, and S. Liu, "Energy saving potential of using heat pipes for CPU cooling," vol. 143, no. July, pp. 630–638, 2018.

[10] T. Dbouk, "A new technology for CPU chip cooling by concentrated suspension flow of non-colloidal particles," vol. 146, no. October 2018, pp. 664–673, 2019.