



Thermal Resistance of Cascade Heat Pipe as CPU Cooling System to Maintain Safe Temperature for Computer

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ABSTRACT

Computer will overheat quickly if used in a state of full load continuously. One component on a computer that generates heat is the central processing unit (CPU) which is a key component on a computer where program instructions are processed. One of the right solutions to cool the CPU is the use of heat pipes as cooling system, using several size containers, loaded with a special liquid liquid to deliver the heat from the evaporator zone to the other end called condenser zone, but because the heat pipe condenser output temperature is still high therefore a cascade heat pipe was created to lower the output temperature. In this study there are four CPU cooling systems used namely single condenser cascade heat pipe and a double condenser cascade heat pipe, while others two cooling systems as a comparison namely non-cascade heat pipe and non-cascade heat pipe with fan. This study aims to find out the cooling performance of cascade heat pipe as CPU cooling system in a small form factor desktop PC by testing variations in workload, the workload given is idle load (12W) where the processor only runs the operating system without the software load so the processor utilization is only 1% -10%. Next is the medium load (30W) that uses 2 threads with processor utilization of 50% -90%. The last workload is full load (35W) with the number of threads used being 4 with processor utilization of 90% -100%. This research found that the thermal resistance of the cascade heat pipe tended to be higher than that of the non-cascade heat pipe, however the increase that occurred was not too large compared to the resulting performance of 60.2°C in the processor and 40.4°C in the heat sink for the cascade double condenser, the operating temperature of the CPU does not increase significantly as the thermal resistance increases on the cascade heat pipe.

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1. Introduction

Central processing unit or often called CPU is a key component on computer because there is where the instructions from program is being processed. High temperature on the CPU is a common problem that occurs in computers, the CPU gets hot quickly when used for a long time in a state of full load continuously [1]. Excessive heat can reduce CPU life and cause the processor to experience undervolting so that its performance decreases.

Technological developments encourage smart computer devices (smart devices) to be made smaller but also more powerful so that a smaller cooling system is needed [2]. Portable computers such as laptops, notebooks, etc. currently use forced air conditioning systems using heat sinks and fans, according to Kim *et al.*, cooling with such systems has poor performance, loud noise and a large weight when included in the computer with a small form factor. This weakness will certainly reduce the comfort of computer users themselves; heat pipe is one cooling system that can overcome the problem of limited space and power on a computer, therefore the heat pipe is suitable if used as a CPU cooler on the computer [3].

Heat pipe is a heat transfer technology using several size containers, loaded with a special liquid to deliver the heat from the evaporator zone to the other end called condenser zone [4]. Heat pipe cooling power is influenced by various variable among them is heat load, porosity, wick permeability, material, type and how much quantity of working fluid and the shape of the pipe used [5]. Various studies have also been done to improve the heat pipe cooling power, including some research on working fluid and wick conducted by Putra *et al.*, [6-8], but although the heat pipe cooling power increases the output temperature of the condenser remains high, to solve this problem a new heat pipe is created, namely cascade heat pipe by combining several heat pipes into one that was developed by Putra *et al.*, [9]. Next, the research about cascade heat pipe is continued by Septiadi *et al.*, [10] and Tnunay *et al.*, [11] who examined the temperature drop at the condenser with a cascade heat pipe cooling system, both found the utilization of cascade design affected the temperature drop on the condenser. Other studies have found a decrease in thermal resistance which proves that the cascade design will provide better heat transfer with lower condenser temperatures [12]. Based on this, this study was conducted to determine the performance of a cascade heat pipe on a computer with a small form factor and to determine the effect on thermal resistance if using a single and double condenser on a cascade heat pipe for computer cooling system.

2. Methodology

Figure 1 shows the design of Cascade heat pipe (CHP) which is a heat pipe design that has multilevel construction, combining several heat pipes into one system [9], each heat pipe is divided and named according to their level, first level heat pipe possesses the first evaporator and condenser and the name is continued by the next heat pipe that are connected to the first condenser and the list goes on according to their level [12].

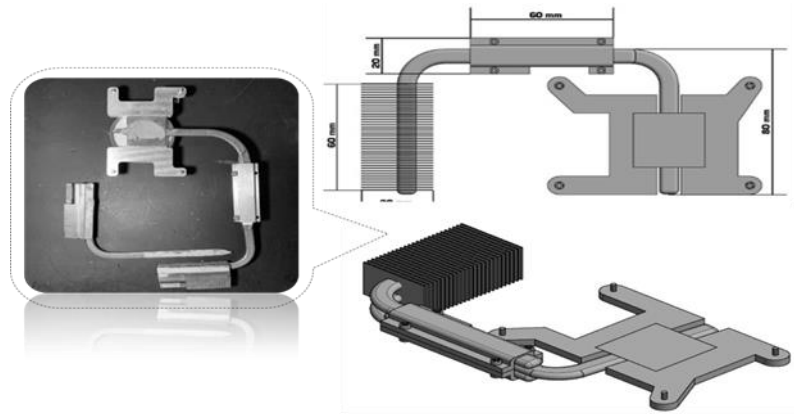


Fig. 1. Design of cascade heat pipe

The heat pipe used in this study is the cascade heat pipe that has a width of 8 millimeter, height of 4 millimeter, and 0.5 millimeter thick copper with a 0.5 millimeter wick thickness as for the wick this study use sintered powder using copper powder, lastly at the end of the second and third level heat pipe the condenser is fitted with a 20 mm thick finned heat sink. the design of the cascade heat pipe seen in Figure 1, for the cascade clamp the material used is aluminum same as in the place where the evaporator meets the processor.

2.1 Instrumentations

This study is using small form factor desktop mini PC M73 for the motherboard and other component including the DC Power Supply, this desktop pc is using a non-cascade heat pipe with fan for the stock cooling. For the monitoring this study use LabView software from National Instrument which is connected with Data Acquisition (DAQ) which is also connected to the thermocouple, the location of where the thermocouple is placed can be seen in Figure 2 as well as other instruments.

2.2 Methods

This research will be carried out by giving a continuous load (stress test) to the processor with workload given is idle at 12W, medium load at 30W and full load at 35W and also using several different cooling systems including: non-cascade heat pipe, non-cascade heat pipe with fan (stock cooling), single condenser cascade heat pipe and double condenser cascade heat pipe. Then the temperature on the processor and cooling system will be recorded by the DAQ consisting of the NI-9123 module and paired with cDAQ-9174l. Furthermore, the results of the data will be displayed and recorded in LabView software.

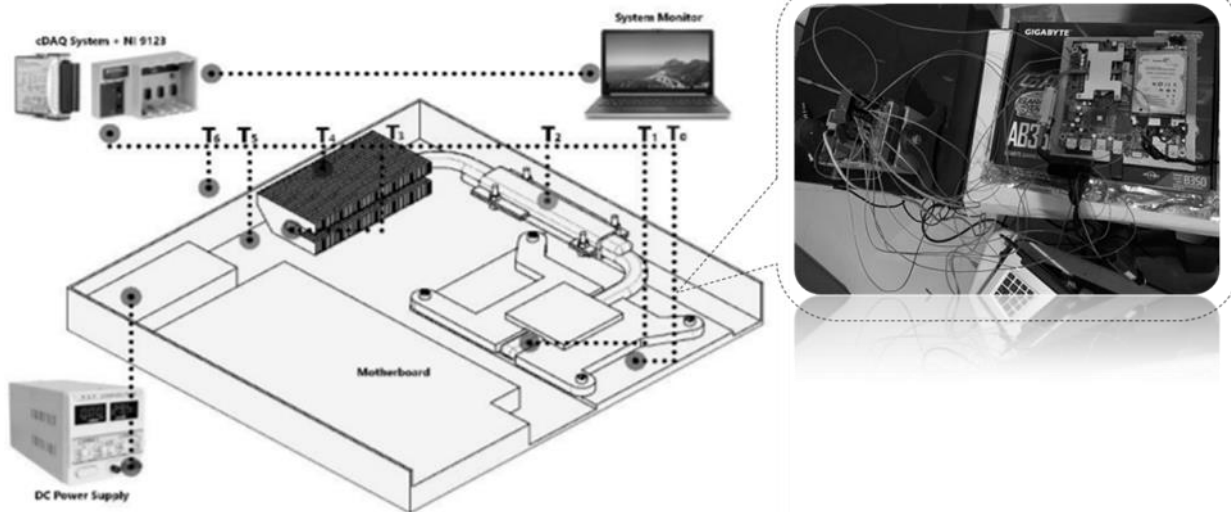


Fig. 2. Research schematic

The workload given to the core i5 processor is idle load, medium load and full load, on the idle load the processor only runs the operating system without being given a software load so that processor utilization is only 1% -10%, for medium load the number of threads used is 2 with processor utilization of 50% -90 %, whereas at full load the number of threads used is 4 with processor utilization of 90% -100%. The given workload is done by manipulating the power given to the processor using CPU-Z software to provide variations to give load on the processor and do a stress test for a few moments until the temperature is stable, to see the conditions on the processor can use the task manager and resource monitor applications. The temperature data that has been obtained is then calculated to know the thermal resistance using the equation

$$R = \frac{\Delta T}{Q} = \frac{T_e - T_c}{Q} \quad (1)$$

3. Results

Figure 3 shows that cascade double condenser is superior in maintaining CPU temperature at idle conditions with a lower temperature of 4.9% compared to stock cooling which shows a temperature of 42.4°C, although in other conditions the cascade double condenser shows a slightly higher temperature than stock cooling, this is because there is a fan on the stock cooling system, however the cascade double condenser cooling system can still be categorized as good for the CPU because the temperature is within the safe limits of the CPU's operation which is below 80°C [13].

Cascade single condenser cooling is proven to affect the heat pipe cooling process, indicated from the decrease in processor temperature by 9.6% at idle load condition, 9.28% under medium load conditions and 10.78% at full load when compared to the temperature of the processor that uses a non-cascade heat pipe as cooling system. In addition, the cascade double condenser cooling system has also been proven to affect cooling power of heat pipes, which is indicated by the decrease in processor temperature by 15.87% at idle load condition, 14,29% under medium load conditions dan 15,69% at full load compared to the temperature of the processor that uses a non-cascade heat pipe cooling system. The temperature decrease not only occurs in the processor but also occurs on the condenser and heat sink which is where the heat is discharged out.

All cooling systems except non-cascade heat pipes produce good output temperatures because they do not exceed the safe operating temperature limit of the computer which is below 50°C, whereas for non-cascade heat pipes the output temperature exceeds the safe operating temperature limit, this can cause the computer's environment temperature to be higher so that the computer is more at risk of failure.

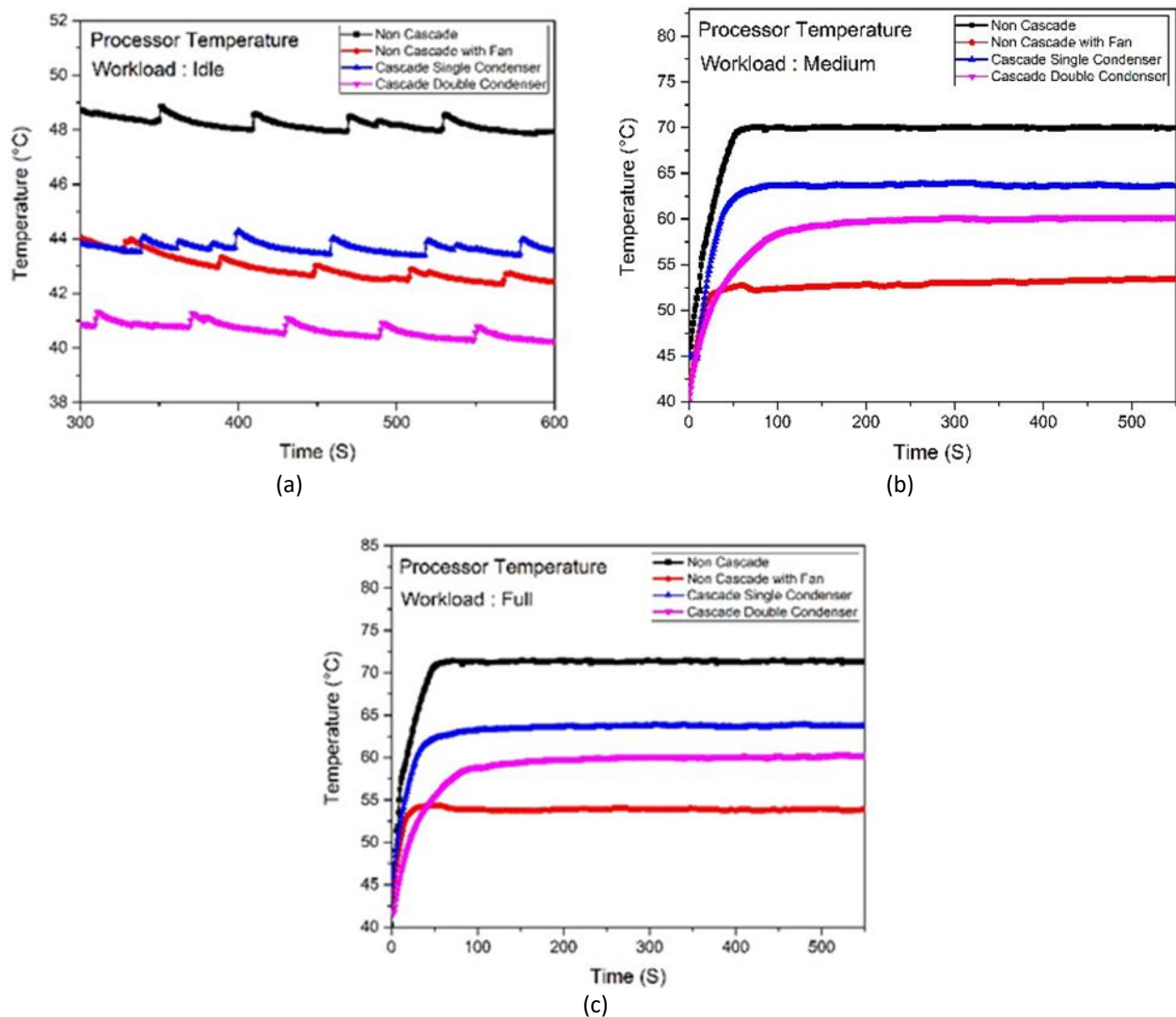


Fig. 3. Processor temperature on condition idle (a), medium (b), full (c)

Figure 4 shows that heat pipe non-cascade with fan (stock cooling) has the lowest temperature compared to a fanless cooling system, this happened because in the absence of a fan, the condenser and heat sink heat transfer occurs by natural convection so it only depends on the phenomenon of natural heat transfer, whereas in stock cooling with the presence of a fan the heat transfer becomes forced convection which speeds up and increases the heat transfer rate, so that the rotation of the working fluid through evaporation and wick in the heat pipe occurs faster causing heat to be absorbed by the evaporator from processor is larger, but to reach the optimal point the fan must spin quickly so that it produces a loud sound and requires more power. The double condenser cascade heat pipe cooling system has the closest result to stock cooling results with a temperature of 40°C only differing 8°C when given a full workload carried out continuously.

From economical view, the cascade heat pipe cooling systems can be far more economical than non-cascade with fan (stock cooling) because they do not require additional power for fans and

making it more efficient to the power source, by reducing the use of fans in computer cooling systems can save a total energy of more than 600 million kW/h per year globally [14].

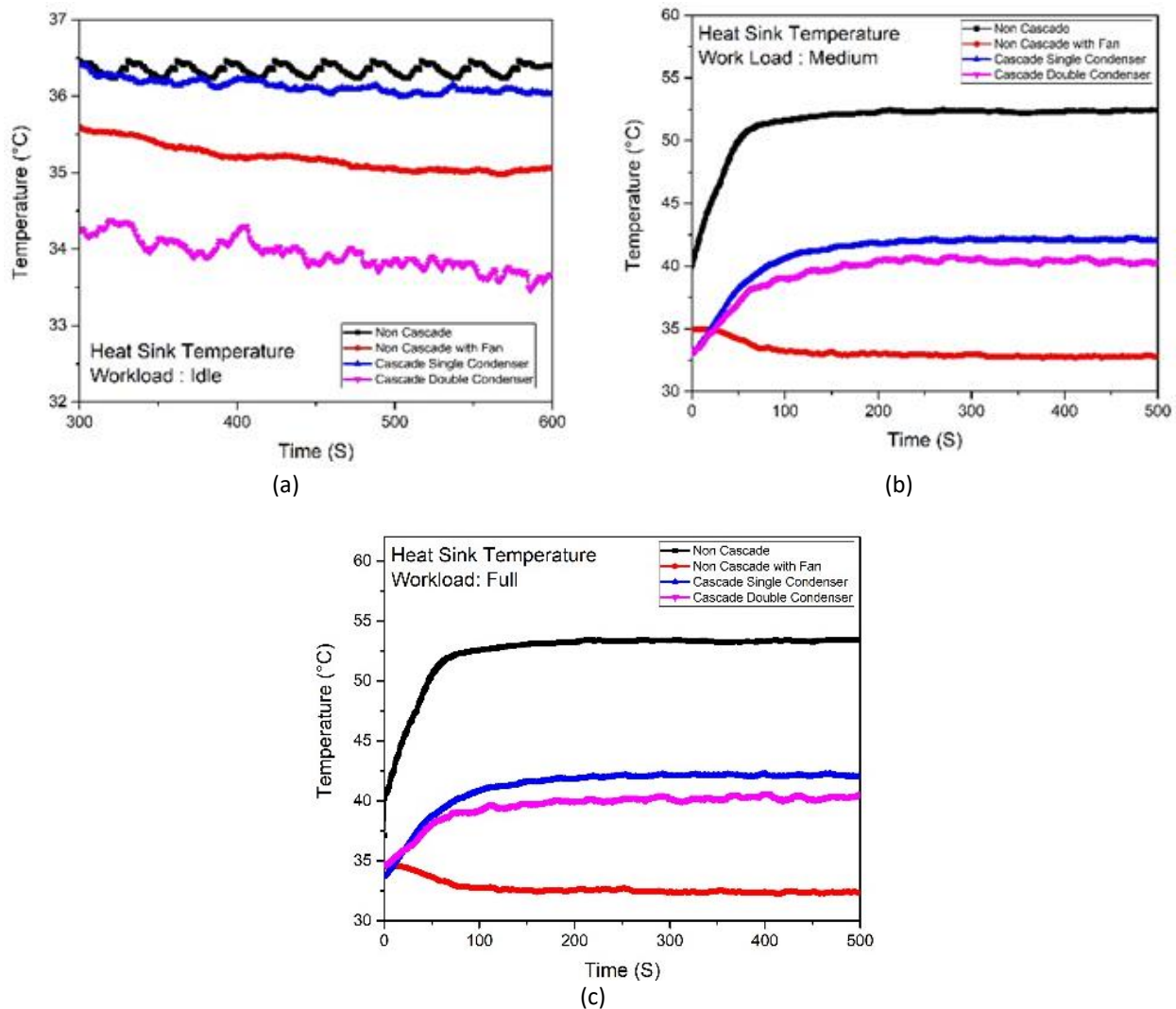


Fig. 4. Heat sink temperature when given idle load (a), medium load (b), full load (c)

The comparison of thermal resistance is shown at figure 5, from the figure it can be seen that cascade heat pipe tends to be have higher thermal resistance than non-cascade heat pipe, this is natural because the addition of heat pipes will add thermal resistance due to thermal contact. However, the increase that occurred was not too large compared to the resulting performance produced which is 60.2°C on the processor and 40.4°C on the heat sink for cascade double condenser. From the results there we can find out that CPU operating temperature did not increase significantly along with the increase of thermal resistance on the cascade heat pipe cooling system.

Single condenser cascade heat pipe cooling system on average has a lower thermal resistance of the first level heat pipe compared to the double condenser. Thermal resistance at level I heat pipe for cascade heat pipe single condenser when given an idle, medium and full loads respectively 0.13009°C/W, 0.18223°C/W and 0.15826°C/W. In the other hand thermal resistance of the first level heat pipe for cascade heat pipe double condenser has a value of 0.19915°C/W at idle load, 0.21724°C/W on medium load condition and 0.1666°C/W when given full load.

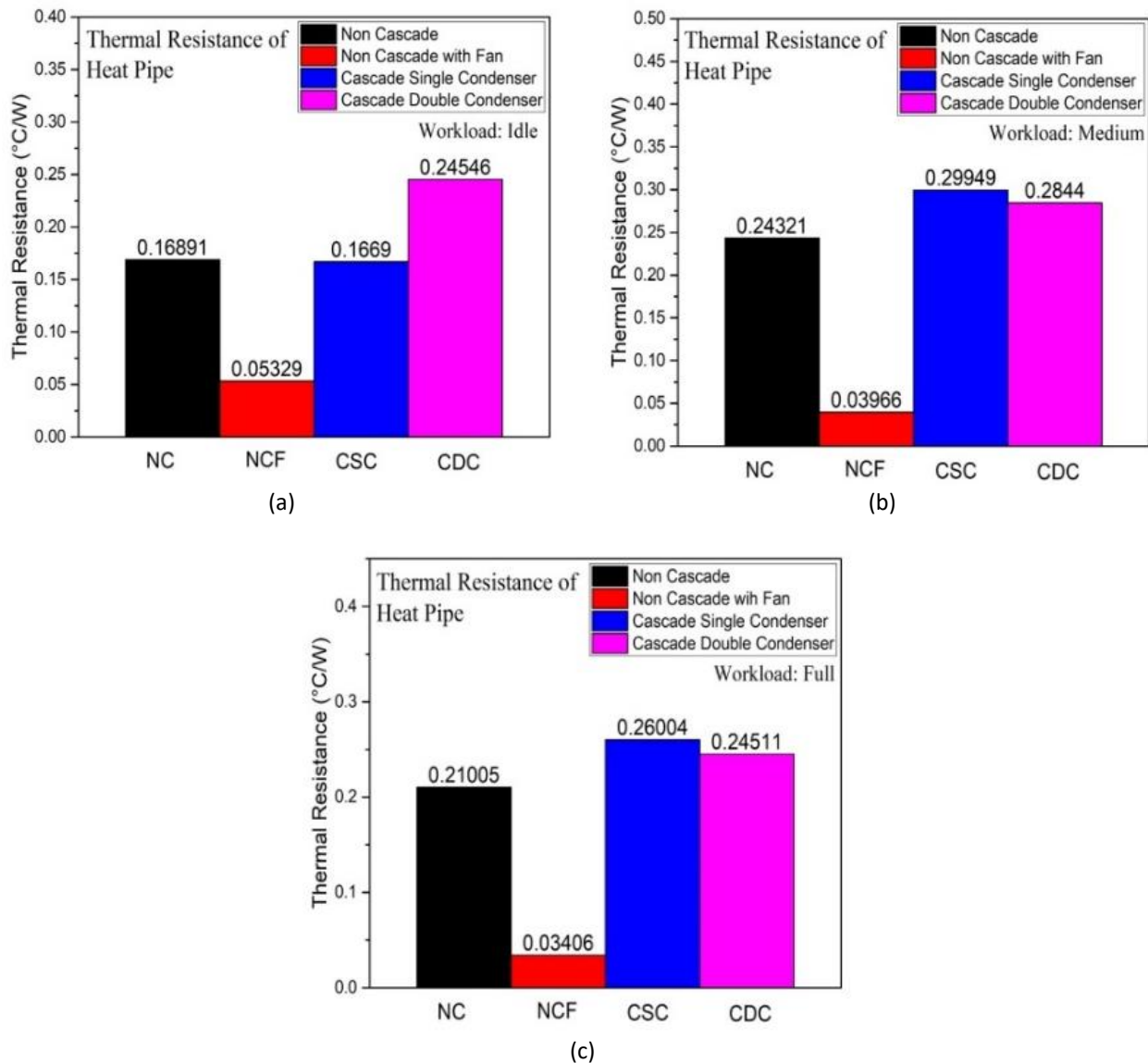


Fig. 5. Heat pipe thermal resistance when the workload conditions in idle (a), medium (b), full (c) load

Figure 6 shows that the thermal resistance of level I heat pipe for the cascade heat pipe cooling system is lower compared to the thermal resistance of the first level heat pipe on non-cascade cooling system, this is caused by the addition of heat pipe with cascade configuration on the level I heat pipe condenser part causing multilevel evaporation, so that the thermal resistance of the level I heat pipe in the cascade heat pipe is lower than that of the non-cascade heat pipe cooling system.

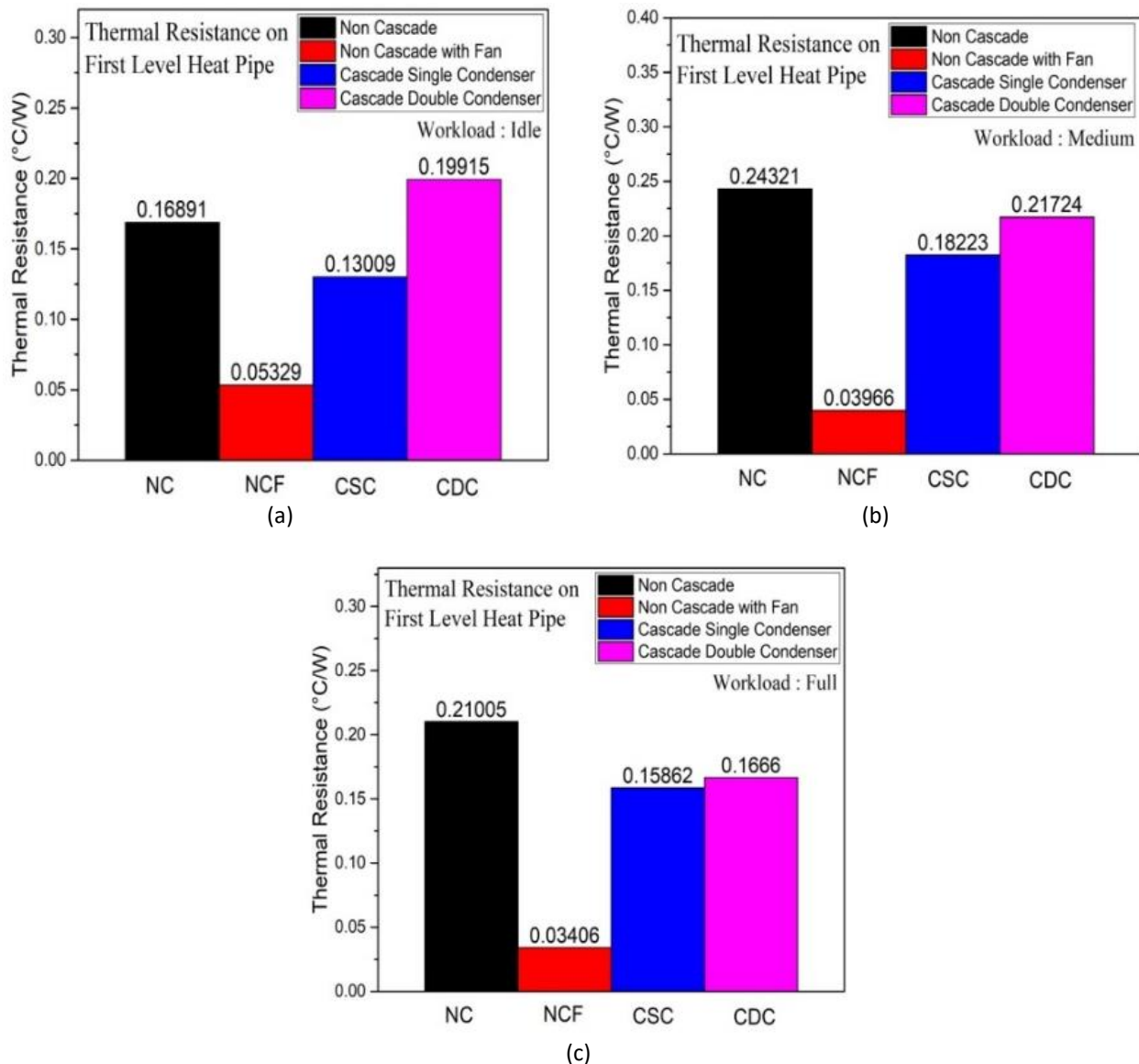


Fig. 6. Heat pipe thermal resistance on workload conditions: idle (a), medium (b), full (c)

4. Conclusions

From the discussion above, it can be concluded that the use of cascade heat pipe has an effect on the performance of a heat pipe with decreasing temperature not only on the processor but also on the condenser, although the use of cascade increase the thermal resistance on the heat pipe, the performance that's given is still better than a non-cascade heat pipe, on the other hand the use of cascade also reducing the thermal resistance at first level heat pipe which means the use of cascades increases the performance of the heat pipe.

In term of usability despite of not using fan for the cooling process, the cascade heat pipe cooling system can maintain the safe operating temperature for processor and condenser. The cascade heat pipe cooling system can approach the performance cooling system with a fan without the need for additional energy.

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