Investigation of Heat Transfer Enhancement in Air Cooled Computer Processor Heat Sink

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Abstract – Every computer consists of a CPU and many other electronic components. Heat is by-product of CPU operation due to resistance offered by electronic circuits to electric current. As processors are getting smaller and faster day by day, this leads to higher heat density and increased heat dissipation, making processor temperature rise. This causes reduced processing speed, shortened life, malfunction or in some cases failure and thermal shutdown of processor. In this study, forced air cooling system consisting of heat sink and fan, mounted on processor is investigated. The heat removed in forced air cooling mainly depends on area of heat sink and convective heat transfer coefficient. In this study an attempt is made to increase convective heat transfer coefficient. The effect of various air inlet locations and air velocities on convective heat transfer coefficient and processor temperature is analysed numerically. There is close agreement between numerical and experimental results. It is found that, there is 3.4 times increase in average convective heat transfer coefficient, 31% reduction in thermal resistance of air cooling system and 14% reduction in maximum temperature of heat sink.

Keywords— CFD, Processor, Air Cooled, Convective Heat Transfer Coefficient, Heat sink

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INTRODUCTION

All electronic equipment rely on the flow of and control of electrical current to perform a variety of functions. Whenever electrical current flows through a resistive element, heat is generated. Regarding the appropriate operation of the electronics, heat dissipation is one of the most critical aspects to be considered while designing an electronic box. Heat generation in electronic components is an irreversible process and heat must be removed in order to maintain the continuous operation.

Like all electronic components, the CPU produces heat during its operation. Heat in excess, however, is not good and can even lead CPU to burn or to become unstable. The heat generated by an electronic device needs to be removed as soon as possible; otherwise its internal temperature will increase. Operating CPU above the maximum temperature threshold will lead to reduction in performance, random freezing, increased power consumption, random resets and physical damage to the CPU.

Commonly used cooling methods for processors are; air, water, thermo-electric and liquid nitrogen cooling. Also heat pipes are used to transfer heat in various zones of CPU cabinet. Liquid nitrogen cooling is very expensive and not suitable for conventional use. Technologies receiving lots of interest include liquid cooling using micro channel heat exchangers, heat pipes (in laptops and many non-electronics applications) and thermo-electric devices. Heat pipes are a sophisticated alternative, but cost, space and reliability typically constrain its application and also it only moves heat from one point to other and requires further air cooling system to remove heat. Water cooling requires a pump, a separate cooling system for coolant and a separate flow circuit. Air-cooling, which incorporates the use of fans and heat sink, is currently the prevalent method of cooling processors in computing environments. It has several advantages including low cost, ease of manufacturing, relatively low noise, and is free of piping elements, tubes and cables. The air cooling technique is always promising and worthy of further study.

There are mainly four components in air cooling system 1) Heat sink which increases the area exposed to air, 2) Fan which circulates air over heat sink (active cooling method), 3) Heat paste which is used to make perfect contact between heat sink and processor(without air bubbles to reduce thermal resistance), and 4) Assembly to hold heat sink and fan together over motherboard. Following diagram shows typical processor air cooling system,

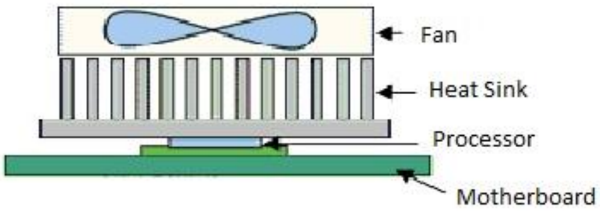


Fig. 1 Conventional Air Cooling System

From the performance point of view, air cooling system lags behind other cooling system due to low thermal conductivity of air, uneven flow of air and flaws in air flow directions.

LITERATURE REVIEW

Deepak Gupta et al [1] carried out CFD and thermal analysis of processor heat sink for fin profiles. There are mainly two types of fin profiles viz., rectangular fins and circular pin fin. Results show that the total heat transfer rate of rectangular plate fins is greater than cylindrical pin fins with applying same dimensions. R. Mohan et al [2] carried out experimental as well as numerical analysis on processor heat sink for parameters such as fin geometry, fin pitch and fin height. It was observed that stacking too many fins is not a solution for decreasing the hot spots on the heat sink since they prevent the passage of air coming from the fan to the hottest centre parts of the heat sink. Channamallikarjun [3] investigated heat sink performance for two types of heat sink, base plate materials i.e., copper and aluminium. Results show that, thermal resistance of the heat sink is decreased when base plate material was copper as compare to aluminium. Also when base plate thickness increased, heat sink performed better. Todd M. Ritzer et al [4] discussed the effect of fan orientation on heat sink performance. In case of processor heat sink there are two ways in which air can flow over heat sink, by pushing air over heat sink or by pulling out air from heat sink. For heat sink that was investigated (rectangular fin), pushing air gives better performance. M. Anandakrisshanan et al [5] studied flow fields inside a desktop personal computer cabin. Results show that increasing fan speed will reduce average temperature of heat sink. Sivapragasam, A.et al [6] studied the effect of fan distance from top of the heat sink. Results show that 5 mm fan distance is the optimum fan distance for getting maximum heat transfer. Increasing fan distance does enhance heat dissipation significantly but beyond 5 mm, heat sink performance decreases. Subhas. L. Hunasikatti et al [7] investigated mixed convections air flow in CPU cabinet. This study suggests that horizontal case shows average motherboard temperature 0.1 ^{0}C and chipset average temperature 0.2 ^{0}C less than that in the vertical case. Also study suggests air inlet locations should be on left or bottom side of CPU cabinet. Emre Ozturk et al. [8]studied on fluid flow and temperature fields inside the CPU cabinet and processor heat sink. Three different commercial heat sink designs were analysed by using commercial computational fluid dynamics software packages Ice-pak and Fluent. Results show that for all types of heat sinks that are commercially used there is hot spot at the centre of heat sink. This is due to heat source, i.e., processor is located at centre. Even if all heat sink designs were optimized, there is still centre hotspot due to fan motor hub which is exactly on top of centre of heat sink. Hence, there is need for further investigation to improve heat transfer rate from the centre of the heat sink to remove the hotspot.

THEORETICAL BACKGROUND

Heat removed by a fluid flow over flat plate is given by,

$$Q = h_{avg} A(T_{avg} - T_{atm}) \qquad (1)$$

For a turbulent fluid flow over flat plate, average convective heat transfer coefficient is given by following relation

$$h_{avg} = 0.0028\, \frac{k}{l}\left(\frac{ul}{\mu}\right)^{4/5} (Pr)^{1/3} \qquad (2)$$

At a particular temperature, for any fluid *k*, *μ* and *Pr* are constant. Above equation can be reduced to,

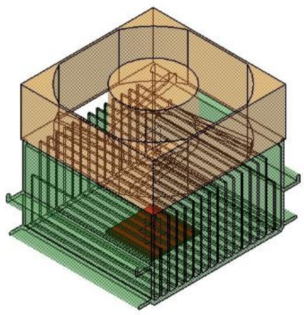
$$h_{avg} \propto \frac{u^{4/5}}{l^{1/5}} \qquad (3)$$

Hence convective heat transfer coefficient can be enhanced by increasing air velocity and reducing leading edge distance.

CFD ANALYSIS

CAD modelling

A solid model of CPU air cooling system is made in modelling software CATIA V5 and exported to ANSYS-fluent. Fan is modelled as lumped model in order to reduce computational effort. Fig .2 shows, a CAD model of conventional air cooling system used for CPU cooling.



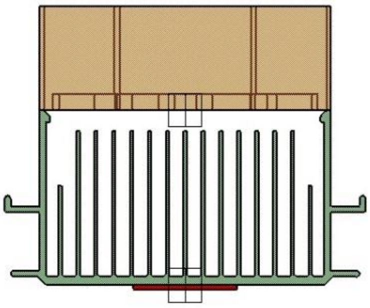


Fig. 2 : CAD model of CPU air cooling system

In order to increase air velocity and decrease leading edge distance modification is done in conventional air cooling system as shown in ***Error! Reference source not found.***3.The variables of funnel are; width of air outlet of funnel (length is fixed to width of heat sink) and distance of air outlet from base of heat sink. CFD analysis is carried out for these parameters keeping all other parameters constant.

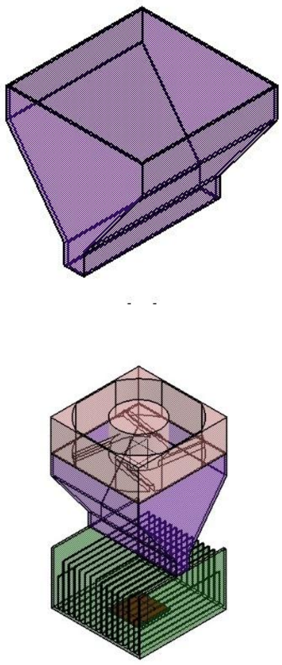


Fig. 3 : Air cooling system with funnel

Meshing

A high quality unstructured mixed mesh (tetra and hexa) is generated before the solution of the governing equations. Mesh is non-conformal in order to decrease the total number of cells in the computational domain. The air domain was meshed with the unstructured grid, while the solid domain was meshed with the structured grid accounting for isotropic thermal conductivity of the aluminium.

Boundary Conditions

Three boundary conditions are specified for the analysis. Air inlet and outlet conditions are at atmospheric pressure and temperature. Air velocity is calculated from fan flow rate and area of fan for particular fan speed (4.46 m/s @ 2870 RPM) from fan laws. Heat input is the third boundary condition with constant heat flux given over area as per processor rating.

Equations Solved

Time-independent flow equations with turbulence were solved. The viscous dissipation term is omitted. As flow in this analysis is considered as turbulent flow, standard k-ε turbulence model is used for turbulence modelling.

EXPERIMENTAL ANALYSIS

Experimental setup consists of a processor air cooling system, a heater as heat source, temperature sensors, rpm sensor and data acquisition system. Cooler-Master A73 is selected as air cooling system consisting of heat sink and fan mounted on it. Heat sink dimensions are 70 × 70 × 25 mm with rectangular fins having thickness 0.8 mm and 4 mm pitch. Fan dimensions are 68 × 35 mm with rated speed of 3300 ± 10 RPM and 30 CFM flow rate at 12V DC. Heater is made of mild steel block of 40 × 40 mm, inside of that heater element is fitted. Thermal compound is placed between heater and heat sink, in order to enhance heat transfer. For temperature measurement resistance temperature detectors (PT-100) are used, while to measure fan rpm infrared rpm sensor is used. Both sensors are interfaced with data acquisition system, which consists of 8-bit microcontroller, 6-channel 10-bit analog to digital converter. Data acquisition system is connected to desktop computer via USB port.

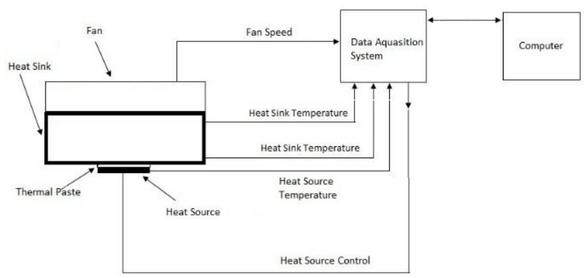


Fig. 4 : Experimental Setup

Test setup is an open domain; the atmospheric temperature is the temperature of the air blown to the heat sink. Fan outlet mass flow rate and air velocity is calculated from fan rpm and cross-sectional area. Temperatures were measured with thermocouples and temperature data was collected at the locations upstream of the heat sink, and at the base of the heat sink. The experiments were conducted under steady state conditions. The maximum base temperature of the heat sink and the bulk mean inlet temperature were used to calculate the thermal resistance of the heat sink.

RESULT AND DISCUSSIONS

Following graphs show the effect of nozzle opening, leading edge distance on temperature of heat sink.

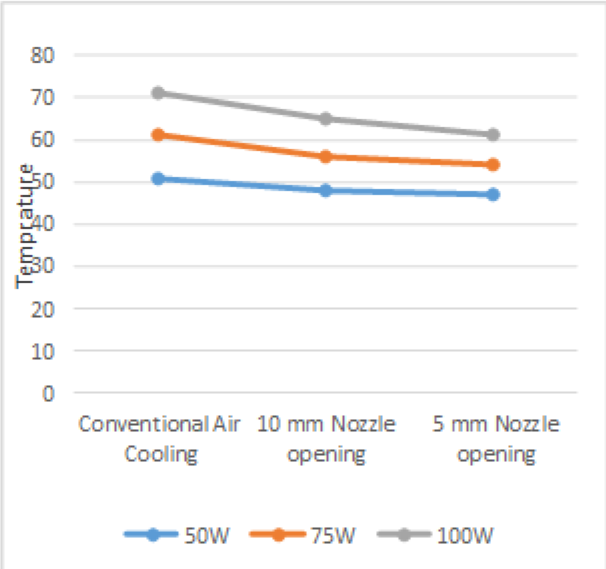


Fig. 5 : Effect of nozzle opening on temperature

Fig. 5 shows the effect of nozzle opening on temperature of heat sink for a leading edge distance of 40 mm. It is observed that, reducing nozzle opening will reduce temperature of heat sink because of increase in velocity of air, increasing CHT and heat removal.

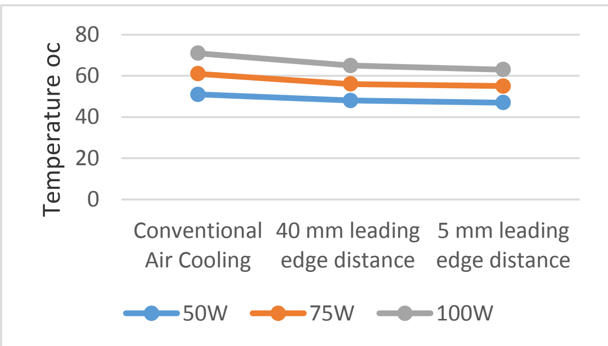


Fig. 6: Effect of leading edge distance on temperature (10mm Nozzle opening)

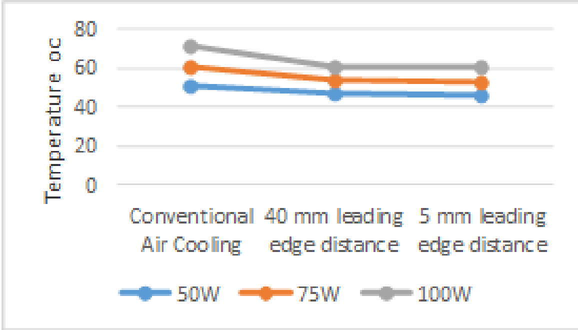


Fig. 7 : Effect of leading edge distance on temperature

Fig. 6 and Fig.7 show the effect of leading edge distance on heat sink temperature. It is seen that, by reducing the leading edge distance, temperature of heat sink is reduced. This is due to increased convective heat transfer coefficient. Following contours show the distribution of convective heat transfer coefficient over heat sink for all the cases considered.

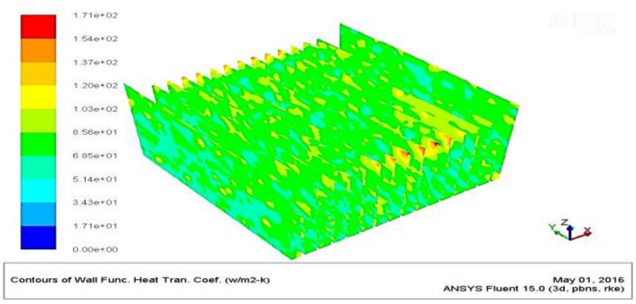


Fig. 8 : Conventional Air cooling system

Fig. 8 shows distribution of convective heat transfer coefficient over heat sink for conventional air cooling system. It is seen that lowest value of convective heat transfer coefficient is at centre bottom region of heat sink and maximum value is observed at top sides of heat sink.

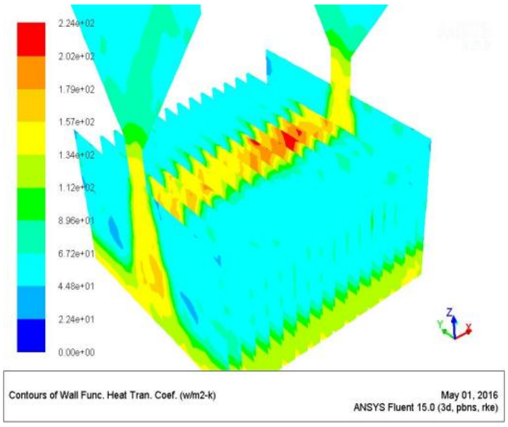


Fig. 9 : Modified Air Cooling system (Nozzle opening = 10mm, Leading Edge distance = 40mm)

Fig. 9 shows distribution of convective heat transfer coefficient over heat sink with nozzle attached at a distance of 40 mm away from processor and nozzle opening is 10 mm. Due to this all air is passed through centre part of heat sink, producing maximum heat transfer coefficient at centre location.

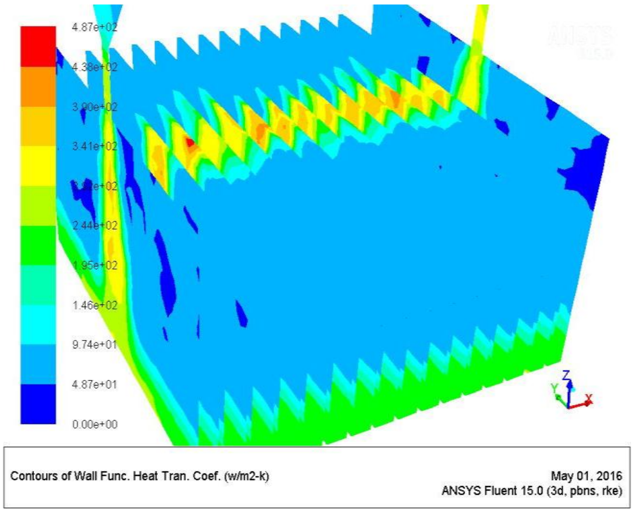


Fig. 10 : Modified Air Cooling system (Nozzle opening = 5mm, Leading Edge distance = 40mm)

Fig.10 **Error! Reference source not found.**shows distribution of convective heat transfer coefficient over heat sink with 5 mm nozzle opening. The reduction in nozzle opening, increases air velocity, which further increases convective heat transfer coefficient.

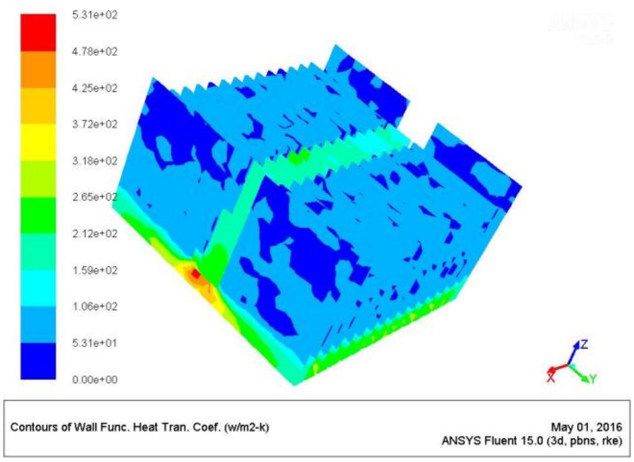


Fig. 11 : Modified Air Cooling system (Nozzle opening = 10mm, Leading Edge distance = 5mm)

Fig. 11 shows distribution of convective heat transfer coefficient over heat sink with nozzle inserted into heat sink, without disturbing geometry of heat sink. This reduced the leading edge distance, producing maximum convective heat transfer coefficient at bottom-centre part of heat sink.

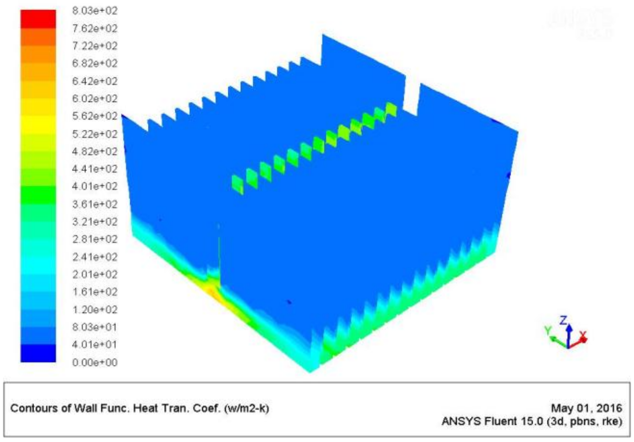


Fig. 12 : Modified Air Cooling system (Nozzle opening = 5mm, Leading Edge distance = 5mm)

Fig.12 shows distribution of convective heat transfer coefficient over heat sink with nozzle inserted into heat sink and reducing nozzle opening to 5 mm. This effect increases air velocity as well as reduce leading edge distance, aiding to increase convective heat transfer coefficient.

CONCLUSIONS

In this study, CPU cooling has been investigated using air cooling system with different air inlet locations and air velocities. Performances of the heat sinks are compared and following conclusions are made,

1. In current study, it is seen that in conventional processor air cooling system hub at centre of heat sink obstructs air over centre part of heat sink, this produces hotspot at centre and increases processor temperature. Also in conventional air cooing system air inlet locations are away from high temperature zone, which reduces convective heat transfer coefficient, which reduces net heat transfer. Increasing air velocity will increase convective heat transfer coefficient, but for conventional air cooling system, the only way to increase air velocity is to increase fan speed, which in turn increases noise. Hence, it not a feasible solution.

2. With use of new innovative design air cooling sytem presented in this study, air velocity can be increased without increasing fan speed, which increases convective heat transfer coefficient and net heat transfer. Also it diverts air flow on centre hot-spot of heat sink, which further reduces heat sink temperature and area of hot-spot.

3. A decrease in leading edge is achieved by proposed new design of air cooling system as fresh air at atmospheric temperature first flows over high temperature region and then passes over other parts of heat sink. As temperature difference is more in this case than conventional design, heat transfer is more, which cools heat sink better. Also from results it is seen that, with new design of air cooling system, there are low pressure zones created on the sides of heat sink, which causes atmospheric air to flow over heat sink. So additional air is blown over heat sink, aiding to reduce temperature of heat sink further without additional power.

4. In conventional air cooling method average convective heat transfer coefficient is 94 W/m^2k, while average convective heat transfer coefficient value with proposed method is 421 W/m^2K which is 3.4 times higher than conventional air cooling method.

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