Thermal Analysis of CPU with variable Heat Sink Base Plate Thickness using CFD

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Abstract

The computational fluid dynamics is concentrated on the forced air cooling of the CPU using a heat sink. This paper utilizes CFD to identify a cooling solution for a desktop computer, which uses an 80 W CPU maximum whereas this number will be increased in the range of 70-120W in the forthcoming desktop computer systems. The design is able to cool the chassis with one fan with air blowing over heat sink attached to the CPU is adequate to cool the whole system and the power supply fan. This paper considers the optimal plate fin heat sink design and cylindrical fin heat sink design with variable copper base plate and the control of CPU heat sink processes. To have a better heat dispersion performance, a computational fluid dynamics is utilized to search for an optimal set of plate-fin or cylindrical fin shape parameters. Base plate thickness, fin thickness, fin profile and fin material parameters are to be handled together due to the frequently encountered space limitations. Three different thickness Plate and cylindrical heat sink designs with 2.5mm to 5mm thickness copper base plate are analyzed by using commercial CFD software packages Gambit and Fluent. The well converged, grid independent and well posed simulations are performed, and the results are compared with the experimental data. Especially, replacing aluminum with copper as base plate material improved the performance. This study will benefit the design engineers involved in electronic cooling and also help to reduce the significant increases in the sound power emitted by the CPU.

Keywords: Computational Fluid Dynamics, desktop computer, carbon - carbon composites (C-C) heat sink, Plate and cylindrical Heat Sink and copper base plate.

1. INTRODUCTION

TODAY’S rapid IT development like internet PC is capable of processing more data at a tremendous speed. This leads to higher heat density and increased heat dissipation, making CPU temperature rise and causing the shortened life, malfunction and failure of CPU. The failure rate of electronic components grows as an exponential function with their rising temperature. Power dissipation would be a major bottleneck to development of the micro electronic industry in the next 5 to 10 years. The performance level of electronic systems such as computers are increasing rapidly, while keeping the temperatures of heat sources under control has been a challenge. Many cooling techniques such as
cooling by the heat pipes, cold water, and semiconductor and even by liquid nitrogen were proposed and adopted. Liquid nitrogen cooling is very expensive and not suitable for conventional use. However many industries have had to begin looking to high capacity cooling technologies rather than air cooling. Liquid cooling has been used for many years by such companies as Cray, IBM and Honeywell. Technologies receiving a lot 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 constraints typically place heat pipes out of the running. Heat pipes are effective when the transport scale is large compared to package (computer) dimensions. For high volume manufacture, the heat sinks should be inexpensive, reliable and fit to other constraints in the manufacturing process. The modified fin geometry with air cooling is more effective and economic, since the water cooling requires water pump, a separate cooling system for coolant and a separate flow circuit. The air cooling technique is always significant and worthy of further study.

In recent years, as the heat loads have increased, better heat conductors such as copper plates are used to improve the spreading of heat from heat sources into the heat sinks. To meet the next generation, CPU needs the thermal requirements with a low profile heat sink. Therefore new heat sinks with larger extended surfaces, highly conductive materials and more coolant flow are keys to reduce the hot spots. To meet these constraints, CFD is a good approach to explore various design alternatives quickly with reasonable accuracy.

This research work stands to the challenges posed by increasing chip heat flux, smaller enclosures, and stricter performance and reliability standards. The thermal management of many systems that are likely to be developed in the next several years cannot be done with the current existing technology. While carrying out demanding tasks, this research work will provide a breakthrough for developing technology to give a solution to the problems of electronic industries. In this study, active heat sinks to cool central processing units (CPUs) of desktop computers are investigated.

2. CFD CHASSIS MODEL

A The CFD 3D chassis model is shown in figure 1. The chassis is modeled using standard dimensions of a common ATX chassis by hollow blocks and internal components are represented as lumped objects. During modeling, all the components inside the chassis are standard sized components and exact dimensions are obtained by measurement. The CPU is modeled as a 2D area which dissipates 80W. The 30mm x 30mm cross sectional area of CPU is taken which is commercially available AMD CPU. For simplicity, the motherboard, chipset card are modeled as zero thickness with heat generated uniformly. The CPU fan is modeled as a lumped parameter model and does not have blades. Ram cards are fixed on the motherboard. They are also heat sources and accurate dimensioning of space between ram cards is difficult. Therefore these things are not considered for study. Power supply is a very complex geometry which includes lot of electric components, wiring and heat sinks. It is assumed as a lumped media which exerts a resistance on the cooling air flow streams. SMPS (Switch Mode Power Supply) and few miscellaneous cards are modeled and lots of small electronic components on these cards are not modeled.
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The computer cases have small holes which are used to allow inlet air for cooling and discharge hot air through outlet. The modeling of these holes in accurate dimensioning is difficult and computationally expensive. Therefore it is modeled as a zero thickness flow resistance. The HDD (Hard Disk Drive), DVD, CD are modeled as solid blocks generating a specified amount of heat uniformly inside the volume.

### TABLE I
INTERIOR CONDITIONS

<table>
<thead>
<tr>
<th>Object Name</th>
<th>Material</th>
<th>Heat Dissipation Rate(w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>Silicon</td>
<td>80</td>
</tr>
<tr>
<td>CPU Heat Sink</td>
<td>Al – Cu, C-C</td>
<td>-</td>
</tr>
<tr>
<td>Chipset Heat Sink</td>
<td>Al</td>
<td>-</td>
</tr>
<tr>
<td>CD</td>
<td>Al</td>
<td>15</td>
</tr>
<tr>
<td>DVD</td>
<td>Al</td>
<td>15</td>
</tr>
<tr>
<td>HDD</td>
<td>Al</td>
<td>20</td>
</tr>
<tr>
<td>Power Supply</td>
<td>Porous</td>
<td>75</td>
</tr>
<tr>
<td>Miscellaneous Card</td>
<td>FR4</td>
<td>20</td>
</tr>
</tbody>
</table>

The closer view of geometric details of the CPU heat sink is shown in the Figure 1. The scope of this study is investigation of temperature distributions on CPU heat sinks. The thermal boundary conditions for the objects inside the chassis are listed in table1. A total of 225W of heat is dissipated.

The fans inside the domain are modeled as circular surfaces which add momentum source to the flow. The added momentum source is given as the pressure rise across the fan versus the flow rate curve. The relationship between the pressure and the flow rate is taken linearly.

### TABLE II
FAN CONDITIONS

<table>
<thead>
<tr>
<th>Name of the Fan</th>
<th>Pressure Rise</th>
<th>Heat Flow Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU Heat sink fan</td>
<td>30 Pa</td>
<td>30CFM</td>
</tr>
<tr>
<td>Case Fan</td>
<td>40 Pa</td>
<td>40CFM</td>
</tr>
</tbody>
</table>

The boundary condition for the power supply is different. The power supply is geometrically very complicated. Therefore it is modeled by simplifications. The power supply is a rectangular box which is a resistance to flow. The resistance is different in y-direction.

### 3. MODELING AND SIMULATION

In CFD calculations, there are three main steps.
1) Pre-Processing
2) Solver Execution
3) Post-Processing

Pre-Processing is the step where the modeling goals are determined and computational grid is created. In the second step numerical models and boundary conditions are set to start up the solver. Solver runs until the convergence is reached. When solver is terminated, the results are examined which is the post processing part.
A. Governing Equations

Time-independent flow equations with turbulence are solved. The viscous dissipation term is omitted. Therefore, the governing equations for the fluid flow and heat transfer are the following form of the incompressible continuity equations, Navier – stokes equations x-y and z direction momentum, and energy equations together with the equation of state.

The continuity Equation

\[ \nabla \cdot (\rho \nabla) = 0 \]

The X, Y, Z Momentum Equations

\[ \nabla (\rho u) = -\frac{\partial P}{\partial x} + \frac{\partial (\tau_{xx})}{\partial x} + \frac{\partial (\tau_{yx})}{\partial y} + \frac{\partial (\tau_{zx})}{\partial z} + B_x \]

\[ \nabla (\rho v) = -\frac{\partial P}{\partial y} + \frac{\partial (\tau_{xy})}{\partial x} + \frac{\partial (\tau_{yy})}{\partial y} + \frac{\partial (\tau_{zy})}{\partial z} + B_y \]

\[ \nabla (\rho w) = -\frac{\partial P}{\partial z} + \frac{\partial (\tau_{zx})}{\partial x} + \frac{\partial (\tau_{zy})}{\partial y} + \frac{\partial (\tau_{zz})}{\partial z} + B_z \]

The Energy Equation

\[ \nabla (\rho h) = -\rho \nabla T + \nabla (k \nabla T) + \phi + S_h \]

Equation of state

\[ P = \rho RT \]

Where \( \rho \) is the density, \( u, v \) and \( w \) are velocity components, \( \nabla \) is the velocity vector, \( P \) is the pressure, \( B \) terms are the body forces, \( h \) is the total enthalpy and \( \tau \) terms are the viscous stress components.

B. Heat sink selection

The plate heat sink in two arrays and cylindrical heat sink of different thickness profiles have been used to cool the CPU. Unfortunately, significant modeling and run time is needed to represent small pins with complex meshing. In the course of preliminary numerical simulation work, three different thickness geometries of same base area, same fin height, and same fin pitch are simulated. Base plate thickness accounts for the uniform distribution of heat through the base of heat sink, since electronic components are generally smaller than the heat sinks. Although base plates are generally square, they can also be rectangular, round or irregular in shape. If the base plate thickness increases then the fin length can be shorter. The 54mm x 65mm heat sink rectangular base plate size is selected for this work. The different shape of extruded fins and a 3.5mm thick base plate is finished of aluminum materials. In addition to enhance the heat transfer 2.5mm and 5mm thick copper base plate has been provided as a spreader to conduct heat from CPU processor. For all fin geometries 2.5mm fin pitch, 40mm fin height, 54mm x 65mm heat sink base plate, 5mm clearance between the power supply and the fin tips of the heat sink at the flow rate of 30CFM. The thermal performance of the heat sink is modeled using gambit. The heat sink solid model in the chassis numerical model is done and the CFD software solves the heat transfer problem for the heat sink. The flow of air is parallel to the heat sinks and vertical flow of air is pulled upward by a fan mounted at the top of the heat sink with clearance.

C. Convergence Issues

The persistent results are obtained from only a well converged, well posed and grid independent simulation. The order of magnitude residuals drop is used for convergence. Two different convergence tolerances are compared, one is 10\(^{-3}\) for flow and 10\(^{-7}\) for energy, and the other is 10\(^{-4}\) for flow and 10\(^{-8}\) for energy. Running the solver such that residuals fall one more order of magnitude means that more iteration is done to improve the solution quality. It should be noted that, convergence criteria must assure that the results do not change as the iterations proceed. There is a common way of implementing this. Scalar change of some
values like temperature is displayed as well as the residual monitors. When the scalar values stay at a certain number and do not change as the iterations continue, then it can be stated that the solution is converged. It was seen that this trend is achieved when the momentum residuals fell below $10^{-4}$ and energy residual fell below $10^{-8}$. Therefore in this paper all the models use the convergence criteria of $10^{-4}$ for the flow variables and $10^{-8}$ for the energy. Emre Ozturk and Ilker Tari was used the convergence criteria of $10^{-4}$ for the flow variables and $10^{-7}$ for the energy.

4. RESULTS AND DISCUSSIONS

The chassis model with three different heat sinks with and without base plates is analyzed by CFD simulations. The results have been obtained by varying the heat sink model and keeping the entire computational domain same. The different heat sink models are considered with and without base plate, the temperature distributions are as shown in figure 2-7. For all of the heat sinks, it is viewed that their centers are the hot spots since the heat source corresponds to the closeness of the base center. The fans installed on the heat sinks are identical with dimensions. The fans have hubs where air cannot pass through and it makes the center parts hotter. In the current simulations, the swirl of the fan is not modeled since the fans are lumped parameter models. For real cases, the center would not be as hot as the present simulations predict, due to the swirl. It is observed that the upper right and left part of the heat sink has lower temperature when compared to centre part of the heat sink. This is due to more air flow circulation in sides of heat sink and also exhaust fan sucks the hot air which is nearer to side of the heat sink. The cooling becomes less efficient at other sides of the heat sink.

Although the heat sink dimensions are same, C-C heat sink gives higher heat transfer rates. Without copper base plate 1.5 mm thickness C-C heat sink performance is tremendously well when compare to 1.5mm thickness Al heat sink model with copper base plate. The performance of plate fin heat sink model is better when compared to all cylindrical fin heat sink models. The 3.5 mm thick cylindrical fin model with 5 mm copper base plate only performs well than other models. It is observed that 1.5mm thickness heat sink model performs well than other two thickness heat sink model. Even though it has less the number of fins it performs well. It is noticed that instead of increasing number of fins by increasing the thickness of fins the performance of heat sink is increased. Even if the heat sink dimensions are same for all three cases, the heat sinks with base plate enhance the heat transfer rate. Copper base plate heat sink performs well when compared to aluminum base plate heat sink. By increasing the base plate thickness and changing the material of base plate the performance of heat sink is enhanced. It is also observed that by adding the base plate increases the heat conduction rate instead of increasing the fin height.

![Fig 2.1 Plate Heat sink without base plate 0.5mm thickness](image1)

![Fig 2.2 Plate Heat sink without base plate 1mm thickness](image2)
Fig 2.3 Plate Heat sink without base plate
1.5mm thickness

Fig 3.1 Plate Heat sink without base plate
0.5mm thickness

Fig 3.2 Plate Heat sink with 2.5mm base plate and 0.5mm thickness

Fig 3.3 Plate Heat sink with 5mm base plate and 0.5mm thickness

Fig 4.1 Plate Heat sink without base plate
1mm thickness

Fig 4.2 Plate Heat sink with 2.5mm base plate and 1mm thickness

Fig 4.3 Plate Heat sink with 5mm base plate and 1mm thickness

Fig 5.1 Plate Heat sink without base plate
1.5mm thickness
Fig 5.2 Plate Heat sink with 2.5mm base plate and 1.5mm thickness

Fig 5.3 Plate Heat sink with 5mm base plate and 1.5mm thickness

Fig 6.1 Cylindrical Heat sink with 2.5mm base plate and 2.5mm thickness

Fig 6.2 Cylindrical Heat sink with 2.5mm base plate and 3 mm thickness

Fig 6.3 Cylindrical Heat sink with 2.5mm base plate and 3.5mm thickness

Fig 7.1 Cylindrical Heat sink with 5 mm base plate and 2.5mm thickness

Fig 7.2 Cylindrical Heat sink with 5 mm base plate and 3 mm thickness

Fig 7.3 Cylindrical Heat sink with 5 mm base plate and 5mm thickness

Fig. 2-7 CFD Prediction of Temperature distribution on different CPU Heat Sinks
Table III
Temperature for plate heat sinks for 80 W CPU Heat Dissipation

<table>
<thead>
<tr>
<th>Study</th>
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<th>1 mm</th>
<th>1.5 mm</th>
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<tr>
<td>Base plate thickness</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Fin Material</td>
<td>Al</td>
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<td>Al</td>
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</tr>
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<td>CFD Simulation Work</td>
<td>Temperature Difference</td>
<td>26</td>
<td>23</td>
<td>19</td>
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<tr>
<td>Experimental Work</td>
<td>Temperature Difference</td>
<td>24.5</td>
<td>22</td>
<td>17.8</td>
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</table>

Table IV
Temperature for plate heat sinks with base plate for 80 W CPU Heat Dissipation

<table>
<thead>
<tr>
<th>Study</th>
<th>Parameters</th>
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<th>3 mm</th>
<th>3.5 mm</th>
</tr>
</thead>
<tbody>
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<td>2.5 mm</td>
<td>2.5 mm</td>
<td></td>
</tr>
<tr>
<td>Fin Material</td>
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<td>Al/ Cu</td>
<td>Al/ Cu</td>
<td></td>
</tr>
<tr>
<td>CFD Simulation Work</td>
<td>Temperature Difference</td>
<td>22</td>
<td>19</td>
<td>17</td>
</tr>
<tr>
<td>Experimental Work</td>
<td>Temperature Difference</td>
<td>20.9</td>
<td>18.1</td>
<td>16.2</td>
</tr>
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</table>

Table V
Temperature for Cylindrical heat sinks with base plate for 80 W CPU Heat Dissipation

<table>
<thead>
<tr>
<th>Study</th>
<th>Parameters</th>
<th>2.5 mm</th>
<th>3 mm</th>
<th>3.5 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base plate thickness</td>
<td>.5 mm</td>
<td>5 mm</td>
<td>5 mm</td>
<td></td>
</tr>
<tr>
<td>Fin Material</td>
<td>Al/ Cu</td>
<td>Al/ Cu</td>
<td>Al/ Cu</td>
<td></td>
</tr>
<tr>
<td>CFD Simulation Work</td>
<td>Temperature Difference</td>
<td>19</td>
<td>17</td>
<td>15</td>
</tr>
<tr>
<td>Experimental Work</td>
<td>Temperature Difference</td>
<td>18.3</td>
<td>15.8</td>
<td>13.4</td>
</tr>
</tbody>
</table>

5. CONCLUSION

In this paper, the CPU cooling performances of a computer chassis with rectangular, pin fin heat sinks with varying thickness and carbon carbon composite heat sinks were investigated and the results were compared. The heat sink temperature difference results have been compared with an experimental result to find out best heat sink designs. The number of fins, the fin profiles, fin thickness and the base plate thickness were investigated for enhancing
the heat dissipation rate from CPU, and some thermal improvements as well as space reduction and material savings were attained. Improvements on heat sink designs are possible by the use of CFD. Eventually it is possible to finish up with a new heat sink design which has better thermal performance and uses less material. The influence of the mesh resolution, turbulence model choice, convergence criteria, and discretization schemes were investigated to find the best model with the least computational cost. In the current study, it is observed that stacking too many fins is not a solution for decreasing the hot spots on the heat sink since they may prevent the passage of air coming from the fan to the hottest centre parts of the heat sink. It was shown that the improvements on heat sink designs are possible with the help of CFD. In this paper, different thickness of heat sinks with base plates are selected and analyzed. From which the optimal design of heat sink is selected which gives more heat transfer rate. If base plate material is selected to be copper rather than aluminum, then the thermal resistance of the heat sink decreases as expected. However, this makes the heat sink more expensive and heavier. The heat sink fin thickness is also a parameter for improvement. When the base plate thickness was increased, the heat sink performed better. However, there are space limitations for every heat sink in a computer. Therefore, the total height of the heat sink should be considered together with the space limitations when increasing the height of the base plate. In this study a complete computer chassis with different heat sinks has been investigated and the performances of the heat sinks are compared. This study will benefit the design engineers involved in electronic cooling.

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International Journal of the Computer, the Internet and Management, Vol. 18 No.1 (January-April, 2010), pp 27-36


