DESIGN AND OPTIMIZATION OF HEAT SPREADERS

AND SELECTION OF FAN

IN LAPTOP

by

KRANTHI KUMAR MANNE SAMBAIAH

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To my parents for their belief in my education

and to my uncle for his constant

support and love

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ABSTRACT

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Technical advancements lead to the need for faster processors and reduced sizes in electronic systems. The urge for faster and compact systems leads to two major problems. Firstly over heating of chips which degrade the chip performance and secondly formation of heat spots on the surface which makes the user uncomfortable. Thermal management engineers, as a result have a major challenge in improving the cooling systems.

In this research project simulation using the thermal modeling tool selected is Icepak. The prototype model of the laptop is designed, boundary conditions are applied and

analysis is done. The results so obtained in this simulation give a detailed idea of the amount of the heat to be dissipated from the system and the locations of the hotspots. Graphite heat spreader is included in the design and simulated, the results interpret that the graphite heat spreader improves the thermal performance of the system. Graphite heat spreader forces the heat flow only through the plane which decreases the overall global temperature and also it reduces the hotspots in the system as heat spreader acts almost like insulator through the thickness. Graphite is very expensive so the size and shape of the heat spreader has to be optimized. Selection of a suitable fan is the next task; the system performance curve can be drawn from the above analysis for different values of airflow rate. This system curve is imposed on the fan performance curve which in turn gives the operating point. The fan which has its operating point nearest to its best efficient point (BEP) is selected.

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CHAPTER 1

INTRODUCTION

1.1 Introduction to thermal challenges in laptop

The modern technologies have tremendous urge for high performance laptops as they use new softwares and complex designs to be analyzed, this indeed arises a major problem for the thermal management engineers and this problem has been more difficult as the size of the laptop is reducing with time. In this process of increasing performance of these laptops, thermal engineers have a great challenge in improving the cooling systems. In high performance laptop the power density is very high resulting in high global temperatures and at few points the heating is localized resulting in the hotspots.

From past thermal engineers continue to investigate better methods to improve the performance of the system by maintaining its global temperature lower to the critical temperature. Certain methods are being implemented in this long run of time to overcome the above mentioned problems are stated below

1. Using a Heat sink directly on the chip; this can be used only in the traditional laptops where size was not a constraint and improves only the chip performance but the heat from other components will not be efficiently removed.

2. Using a Heat sink with exhaust fan and heat pipes which has an advantage over the method used previously as the heat pipe is used for transferring heat from chip to heat sink adiabatically to the heat sink and heat sink size can be increased as that is not located on the chip rather it is located closer to fan so the overall chip temperature will be reduced to level where the system performance will be better than former.
3. Using Heat spreaders, for conducting heat from chip to heat sink giving path for heat flow i.e. replacing the heat pipe. It can also be used to spread out heat at the surface as it again increases the in-plane surface area to reduce heat spots.

1.2 Brief account of Thermal Optimization

The present market requires most developed and faster notebook computers at much cheaper prices. This need for high performance laptops demand thermal engineers to design, develop and optimize the cooling devices so that they have high performance factor and inexpensive compared to past. Effective thermal management facilitates efficient removal of heat from device to the ambient environment. The ever shrinking size has also increased the burden placed on today's thermal management devices [1].

Engineering optimization can best be classified as a rigorous mathematical approach to identify and select a best candidate from a set of probable design alternatives [2].

A number of optimization methods are available to solve such problems. However, for engineers to apply optimization for their problem they need to understand the theory, the algorithm and the techniques behind these methods. This is because practical problems may require modifying algorithmic parameters, even scaling and adapting the existing methods to suit the specific application. Above all, the user may have to try out a number of optimization methods to find one that can be successfully applied. These methods are being used in the different fields of study, such as Electronics, Automotives, Buildings, Data centers. As the design complexity has been an issue of the optimization but the thermal modeling tools use computers to solve complex designs [3].

1.3 Introduction to Graphite heat spreader

As discussed in the previous section, there are certain complex problems that also have a weight constraint where the power density is increasing and the size, weight cannot be changed. Thermal management of the laptops is essential to have high performance. This challenge forces the thermal management engineers to go in search of a most efficient cooling system which has good conductivity and also is lighter in weight. This urge yields the requirement of heat spreaders which conduct heat laterally so there will be no localized heating and also it helps in directing the flow of heat

Graphite is an anisotropic material. The material most often used for heat spreaders are copper and aluminum if graphite is compared with these materials, its has almost the same conductivity as copper and in fact double to that of aluminum and graphite's density is much less. The other reason for selecting graphite is its anisotropic property as it has its thermal conductivity through the thickness almost 5% of the thermal conductivity in lateral, so almost it acts like an insulator through thickness. The only dis-advantage is that graphite is expensive.

1.4 Approach to the problem

This research study explains the Data matching of a technical paper by Martin [4]in which the method used is experimental and the simulation of the similar model with exactly same boundary conditions, same constraints and same design variables, which is done in a thermal design tool, Icepak.

Study also explains Optimization of graphite heat spreaders used in laptops to avoid the heat spots on the surface. The objectives are to optimize the size and shape of the Graphite Heat Spreader. Optimal surface temperature is the constraint. The chip power, laptop size, airflow rate are kept constant. A standard model of laptop is designed; boundary conditions are applied and thermal analysis is done. Then Heat Spreaders are introduced into the system and analysis is repeated again and results are noted and are compared with the results obtained in the analysis without heat spreader. These comparisons of both the results shows how heat spreaders improve the performance of the system but the graphite heat spreaders used here are very expensive which in turn increases the manufacturing price of the laptop, so the size and shape of the graphite heat spreader has to be optimized. Using the Optimization tool in ICEPAK 4.2 the size and shape of the heat spreader are optimized for maintaining the touch temperature on the surface optimal.

Finally it explains the steps for fan selection for the above designed system, the requirements of your system for selecting the right fan are system pressure drop, acoustic restrictions, and reliability. These all requirements may all play a role in your decision. The size of the fan will be determined by the flow rate of the air combined with the pressure drop through the system. Thermal modeling tool, such as Icepak, to simulate the exact conditions as in the real world model and also give us an idea of the resistance offered by the components of the systems to airflow. By measuring the pressure drop characteristics of the system at different flow rates gives the system curve. This system curve is superimposed with the fan performance curve which gives us the operating point which is the intersection of both the performance curves. This operating point should be nearest to the best efficient point (BEP) of the fan.

CHAPTER 2

OPTIMIZATION AND GRAPHITE HEAT SPREADERS

2.1 Definition and Applications

Optimization may be defined as the process of maximizing or minimizing a desired objective function while satisfying the prevailing constraints [5]. Decisions are made in every stage of design and modeling of engineering systems either to minimize the effort required or maximize the desired benefit. Since either of these goals in any physical situation can be expressed as a function of certain design variables, *optimization* may also be defined as the process of finding the conditions that give the maximum or minimum value of a function [2].

As there is no single method for solving all optimization problems efficiently so the engineers are compelled to develop a number of optimization methods for solving different types of optimization problem. But finally it is the decision of the design engineer to select which method is appropriate for his problem so as to get accurate and efficient solution.

The ever-increasing demand to lower the production costs due to increased competition has prompted engineers to look for rigorous methods of decision making such as optimization. As a result engineering optimization was developed to help engineers design systems that are both more efficient and less expensive and to develop innovative methods to improve the performance of the existing systems. Computer based simulation and analysis is used extensively in engineering for a wide variety of tasks. Despite the steady and continuing growth of computing power and speed, the computational cost of complex engineering analysis and simulations maintain pace.

2.1.1 Statement of an Optimization Problem

Majority of problems often involve constrained minimization. An example of such constrained minimization problem is finding the minimum resistance of the spreader subject to constraints on temperature and weight of heat spreader. Constrained problems may be expressed in the following general nonlinear programming form [6]:

$$\begin{aligned} &\text{minimize} && f(\mathbf{x}) && \\ &\text{subject to} && g_i(\mathbf{x}) \leq 0 && i = 1,\ldots\ldots., m \\ &\text{and} && h_j(\mathbf{x}) = 0 && j = 1,\ldots\ldots., l \end{aligned} \tag{2.1}$$

where $\mathbf{x} = (x_1, x_2, \ldots\ldots., x_n)^T$ is a column vector of n real-valued design variables. f is the objective function, g's are inequality constraints, and h's are equality constraints. The inequality constraints in Eq. (2.1) include explicit lower and upper bounds on the design variables. We may also express Eq. (2.1) in the form: minimize $f(\mathbf{x})$, $\mathbf{x} \in \mathbf{\Omega}$ where

$$\mathbf{\Omega} = \{\mathbf{x}: \mathbf{g} \leq 0, \mathbf{h} = \mathbf{0}\} \tag{2.2}$$

$\mathbf{\Omega}$ is the feasible region or feasible set. For unconstrained problems the feasible region is the entire space or $\mathbf{x} \in \mathbf{R}^n$. Objective function and constraints of linear programming problems involve linear functions of **x**, where as objective function in quadratic programming problems is a quadratic function of the variables while the constraints are linear.

The *design space or design variable space* in an optimization problem can be considered as an n-dimensional Cartesian coordinate space where each coordinate axis represents a design variable x_i (i=1,…..n). A design point is a point on the design space that may represent a possible or an impossible solution. Design variables cannot be chosen arbitrarily; they have to satisfy certain specific functional requirements to produce an acceptable design. These restrictions that must be satisfied in a design are called *design constraints*.

Design constraints are classified into two; one that represent limitations on the behavior or performance of the system and one that pose physical limitations on the design variables such as availability ,fabric ability, transportability etc. While the former is referred to as behavior or functional constraint, the latter is known as geometric or side constraints.

The values of the design variable belonging to the set **x** that satisfy $g_i(\mathbf{x}) = 0$ forms a hyper-surface on the design space called the *constraint surface*. This is an (n-1) dimensional subspace where n represents the number of design variables. The constraint surface divides the design space into two; one where $g_i(\mathbf{x}) < 0$ and the other in which $g_i(\mathbf{x}) >0$. Design points on the hyper-surface i.e. points that satisfy $g_i(\mathbf{x}) = 0$ satisfy the constraint $g_i(\mathbf{x})$ critically. Those lying on the region where $g_i(\mathbf{x}) >0$ are infeasible and unacceptable while those on the region belonging to $g_i(\mathbf{x}) <0$ are feasible and acceptable. The collection of all constraint surfaces i.e. $g_i(\mathbf{x}) = 0$, i=1,….m that separates the acceptable region is known as the *composite constraint surface*. A design point that lies on one or more constraint surfaces is known as a node point and its associated constraint as an *active constraint*. Those points that do not lie on the constraint surface are known as *free points*. Depending on the location of a design point on the design space, it can be classified into four as:

1. A free and acceptable point

2. A free and unacceptable point

3. A bound and acceptable point and

4. A bound and unacceptable point.

In general there will be more than one acceptable design point and our objective is to choose the best from the lot. This is obtained by specifying a criterion to compare the acceptable design and choosing the best one from it. This criteria or function is known as the *cost or objective function* of the optimization problem. When there are more than one objective function then the problem is known as a *multi-objective programming* problem. Like constraint surfaces, objective functions also form hyper-surfaces known as *objective function surfaces*. Once the objective function surfaces are drawn along with constraint surfaces on the design space, the optimum point can be easily located graphically as shown below [3].

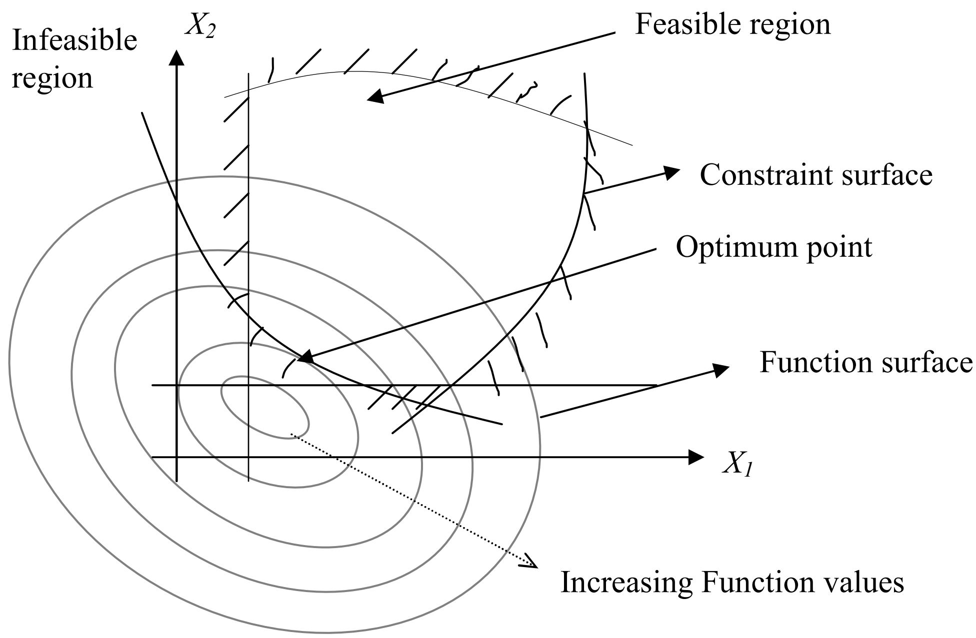


Figure 2.1 Function plot depicting optimum solution for a 2 design variable set

It can be observed that for a two design variable problem, the optimal point can be easily visualized and solved graphically. However when the number of design variables exceeds two then it becomes difficult to visualize the problem and can be only solved mathematically [1].

2.2 Graphite Heat Spreaders

Heat spreader is a sheet of a material which can conduct heat laterally and has high conductivity and lighter in weight.

Thermal management technology remains a vital part of electronics innovations as advanced electronic systems become faster, shrinking in size and weight.

Increasingly sophisticated high-density electronics demand higher thermal efficiencies, better performance, lighter in weight, greater reliability and inexpensive. Now a day's multi-chip packaging has its density increasing day by day and due to fast processors the heat produced is lot more compared to traditional single chip modules so that conventional heat sinks and coolants are becoming inadequate. As the heat is produced from an electronic chip so it is highly concentrated in localized areas. This is the situation where heat spreaders are used for efficiently dissipated the heat by creating the maximum effective surface area where heat is transferred into and carried away by the external cooling medium.

Heat spreaders are used at die level packaging to spread heat from the microprocessor chip into the packaging. Heat spreader can help to eliminate the need of fans, heat sinks, and heat pipes for thermal management. It also reduces the overall cost and weight of the system. Various methods of spreading heat are widely used in today's electronics. Spreaders are commonly used within electronic enclosures to move heat from discrete components to the walls of the enclosure. In some cases, a natural graphite heat spreader can replace a conventional thermal management system consisting of a heat sink and cooling fan in a low performance laptop [7]. To reduce the noise from the cooling fan and by keeping it from coming on for a certain time. This improves the working environment for people frequently using a laptop computer as the noise from the fan can be distracting at times.

The reliability and performance of these systems can be drastically decreased if heat is not properly removed from electronic systems. The reliability of electronic systems decreases 50% for every 20° C increase in junction temperature. When system's thermal densities and electronic packaging complexities increase the weight of the laptop will be a constraint so the heat sink size cannot be changed here the necessity for a lighter cooling system which has good heat conductivity.

2.2.1 Natural Graphite

Natural graphite is an anisotropic material which exhibits a high thermal conductivity in the plane of the sheet combined with a much lower thermal conductivity through the thickness of the sheet. Natural graphite sheet can be used as heat spreader to direct the flow of the heat from chip to the heat sink and it can also be used as insulator to eliminate localized hot spots decreasing the touch temperature in electronic components. The ability to direct heat in a preferred direction is an additional advantage of an anisotropic material [4].

When the heat dissipater is a thermally anisotropic material, the heat spreading coefficient has to be considered. Carbon and graphite based materials are attracting interest as anisotropic heat spreaders, with an additional advantage being their low density. **A** high degree of thermal anisotropy reduces the temperature gradient in the plane of the part and increases the effective heat transfer area, characteristics that are most desirable for electronics with high heat-intensity components. Most carbon and graphite-based materials used to date are based around carbon fibers. These are high cost by virtue of the need to conduct high temperature graphitization processes to develop the required thermal properties in the fiber [8].

Natural graphite flakes are a polycrystalline form of carbon comprised of layer planes containing hexagonal arrays of carbon atoms. These layer planes, referred to as graphene layers, are ordered so as to be substantially parallel to one another. The bonding forces holding the graphene layers together are only weak Vander Waals forces and hence the layers can be readily separated. Natural graphite flakes can be chemically treated to insert an intercalant ion into the interlayer spacing. The graphene layers can then be exfoliated by thermally vaporizing the intercalant in the graphite lattice. The intercalant within the graphite decomposes and volatilizes, which generates internal pressure between the graphene layers and forces the layers to separate as the intercalant escapes the graphite structure. The particles of intercalated graphite expand 100 times their original volume in an accordion-like fashion in the direction perpendicular to the graphene layers. The exfoliated graphite particles are vermiform in appearance, and are commonly referred to as worms. These expanded graphite flakes can then be consolidated together and mechanically formed, without binders, into a cohesive, flexible sheet of graphite material. Typically, continuous rolling operations are used to form the worms in sheets. [4]

Table 2.1, shows properties of different materials used to manufacture heat spreader. Density of natural graphite is 50% of aluminum and 20% of cooper ,so it is much lighter but the in-plane thermal conductivity of natural graphite is twice as of aluminum and almost equal as copper. Thermal conductivity of graphite through thickness is almost negligible compare to its in-plane conductivity so it acts like insulator through thickness avoiding hot spots.

Table 2.1
Thermal properties of Heat Spreader Materials

Property	Direction	Natural Graphite sheet	Aluminum alloy	Copper alloy
Density (g/cm3)		1.1-1.7	2.71	8.89
Thermal Conductivity (W/mK)	In- Plane	140-500	220	388
Thermal Conductivity (W/mK)	Thickness	3-10	220	388
Specific Heat Capacity (J/kgK)		846	904	385

There is another advantage of Graphite is the conversion of acoustic energy into heat as a result of the viscosity is the most important mechanism of sound absorption as sound propagation through the porous media is dominated by viscous forces and is proportional to the velocity of the fluid relative to the solid surface. The induced mass and friction drag lowers the sound speed relative to the free field. This indirect effect of heat transfer is accompanied by the direct effect of conversion of acoustic energy into heat. [9]

2.3 Graftech International Ltd.

The heat spreaders taken in this research are manufactured by Graftech International Ltd., which is one of the world's largest manufacturers of high quality synthetic and natural graphite and carbon products. It is the first company to offer heat spreaders manufactured from natural graphite materials. Compared to typical thermal management materials, eGraf materials offer thermal conductivities twice as effective as aluminum and rival the thermal conductivity of copper at substantially reduced weights. eGraf is one of the line of electronic thermal management products to meet the increasing thermal management demands created by the need for smaller, highly integrated and higher performing electronic devices. eGraf SpreaderShield is a natural graphite solution that distributes heat evenly in two dimensions, eliminating "hot spots", shielding components from heat sources and improving performance in consumer electronics. SpreaderShield thermal management products are custom designed for use in applications such as laptop computers, flat panel displays, portable projectors, digital video-cameras, wireless phones, and personal digital assistant devices. SpreaderShield is ideal for products where space for other cooling solutions is limited and weight is a critical factor. In many cases, SpreaderShield can eliminate the need for other thermal management solutions such as fans, heat sinks, and heat pipes resulting in both reduced cost and weight for the device." [7]

CHAPTER 3

FAN AND ITS ROLE IN THERMAL MANAGEMENT

3.1 Introduction

A fan can be defined as a low pressure air pump that utilizes power from a motor to generate a volumetric flow of air at a given pressure [10]. Airflow should be adequate to properly cool the high performance electronic products. For example, effective cooling of high-performance computer systems is vital, as its performance directly depends on the cooling rate [11]. Air cooling is a simple, in-expensive and most reliable approach, and can be done by using fans and blowers. Fan selection is an important decision, and is based on system requirements such as system pressure drop, acoustic restrictions, and reliability requirements. The Computational Fluid Dynamics (CFD) modeling tool like Icepak is used to identify a fan according to the specific requirements. [12].

3.2 Performance curve of fans[13]

The important characteristic of the fan is its performance. As the system in which fan is used is not empty. A power unit, a heat sink, a hard disk etc. constitute a system which put obstacles for the air flow from or into the fan. The real performance level can be much lower than the air flow rate which is usually specified on packages of fans. Fan also has one more important aerodynamic parameter - static pressure apart from performance. This value is measured in inches (or millimeters) of water, and actually represents the difference in pressure of an air flow from or into the fan and ambient pressure (atmosphere pressure).

The performance of the fan and static pressure of its air flow are inter-dependent. It is defined as the performance curve of a fan, which is basically a plot of both of them. [2]

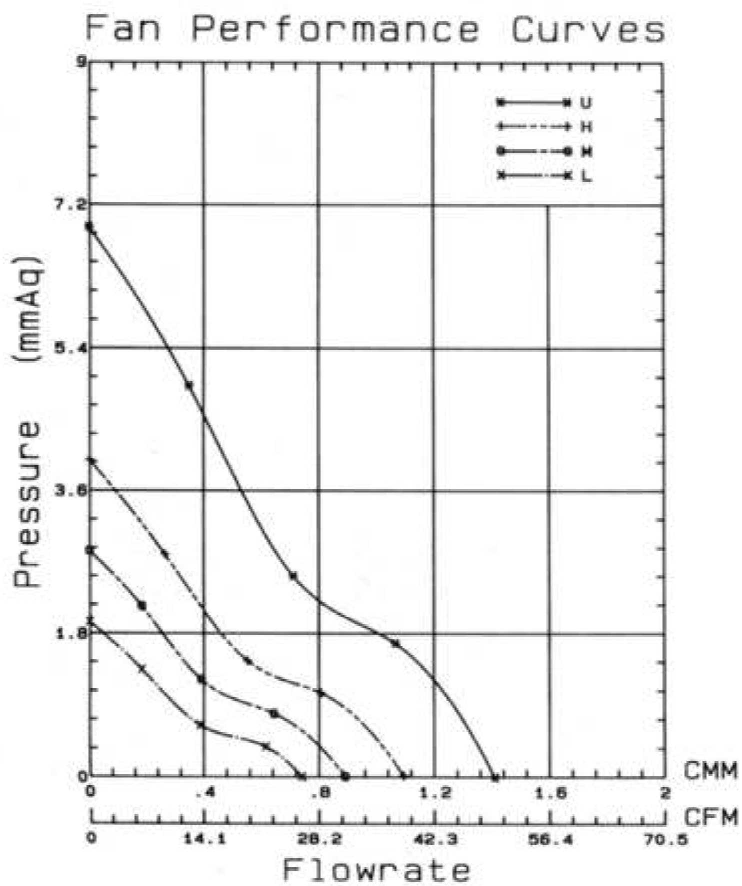


Figure 3.1 Fan Performance Curves

Pressure of the air flow at its zero volume rate (zero performance), i.e. when the fan runs idle. It happens when its flow resistance of the channel is so high that the fan is not able to pump air through this channel. Such situation never occurs in computer cooling, but it can take place in other spheres of application of fans. Volume flow rate at the static pressure equal to zero (i.e. when a fan works to its full capacity and gets no obstacles from the channel), is taken as performance.

3.3 Procedure for selecting a Fan

In a particular system, since a fan can only deliver one flow at one pressure, the "operating point" is determined by the intersection of the fan performance curve and the system performance curve. Figure 3.2 shows the operating points of both high and low resistance systems. It is best to select a fan that will give an operating point towards the high flow and low pressure end of the performance curve to maintain propeller efficiency. Each chosen electronic packaging system should be analyzed for possible reduction in the overall resistance to airflow [10].

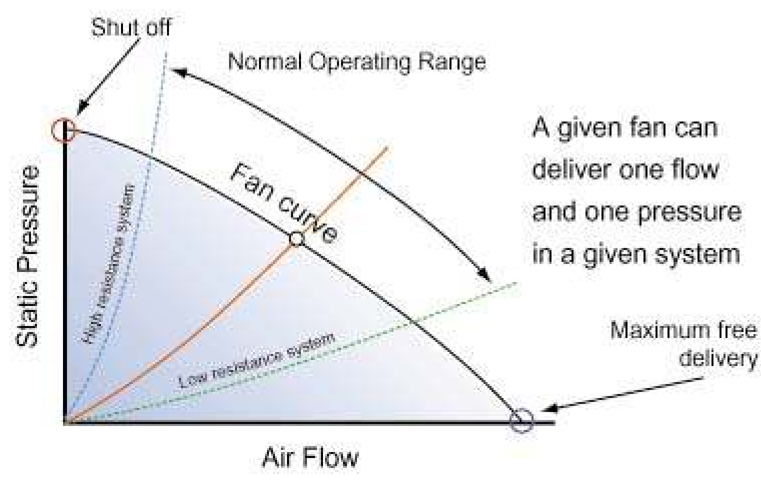


Figure 3.2 Fan/System Interaction [10]

Before selecting a fan, the amount of heat to be dissipated from the system can obtained as the overall system's internal temperature differential above the ambient temperature of air at the inlet is directly proportional to the heat dissipated. The basic heat transfer equation is:

$$Q = Cp \times m \times (DT) \tag{3.1}$$

Where:

Q = power to be dissipated (watts)

Cp = specific heat of air (J/kg °C)

m = mass flow of air (kg/s)

$DT = T_{air\ outlet} - T_{air\ inlet}$

To determine, how much air to be delivered by the fan can be calculated as shown below:

Since volumetric flow rate is related to mass flow rate,

$m = V_f \times r$

V_f = air flow rate (m^3/s)

r = air density (kg/m^3)

Thus, the equation can be rewritten to calculate the volumetric air flow rate:

$$V_f = \frac{Q}{(Cp \times r \times DT)} \tag{2.2}$$

The preceding steps indicated the necessary procedure to estimate the *required* airflow in order to obtain the desired overall air temperature rise d*T*. However, it was also indicated that the *actual* operating airflow is determined by the intersection of the fan curve and the system resistance curve.

There are three types of approach available for estimating this operating point: (1) experimental measurement using a thermal/mechanical mockup of the system, (2) calculation of the operating point using airflow network methods, or (3) calculation of the system airflow using computational fluid dynamics software (available from commercial software companies). The experimental measurement can be used to measure the total airflow for specific fans. Then, it requires an engineer to superimpose the selected fan performance curve and system resistance curve to obtain the operating airflow. The airflow network methods provide adequate results when the geometry is simple, and geometry systems and the flow path within the system are known.

The ability of CFD simulation to predict the fan performance for a wide range of flow rates is more precise and accurate compared to all other methods. The CFD analysis can be done for systems to be optimized, at much lower cost compared to traditional "cut and try" methods. The CFD simulation also provides fluid velocity, pressure and temperature values throughout the system with any complex geometries and boundary conditions. As a part of the analysis, a user can change the geometry of the system or the boundary conditions such as inlet velocity, flow rate, rotational speed, etc., and view the effect on the flow. The CFD is an effective tool for generating detailed parametric studies, making it possible to evaluate far more design alternatives than the build and test method and thereby providing opportunities for optimization [14]. The simulation software is allowed to determine the system resistance and operating point. CFD works by numerically solving the governing equations of flow and heat transfer in three dimensions, and considers the effects of turbulence and gravity as well. CFD can also be used to study the performance of fans in series and parallel arrangements as well as optimize the location with respect to other objects inside the cabinet.

System resistance curves may usually be expressed as a non-linear expression of pressure vs. airflow:

$$P = K\, r\, V_f^N \qquad (3.3)$$

where

P = system pressure loss

K = a load factor specific to the system

r = density of air

V_f = airflow rate

N = a constant which varies between 1 and 2 depending on whether the flow is completely laminar (N=1) or completely turbulent (N=2)

Thermal modeling tool, such as Icepak, can be utilized to find the resistance offered by the system on the air. System curve can be obtained by plotting the system responses in terms of pressure drop for different values of the air flow from the fan (Figure 3.3).

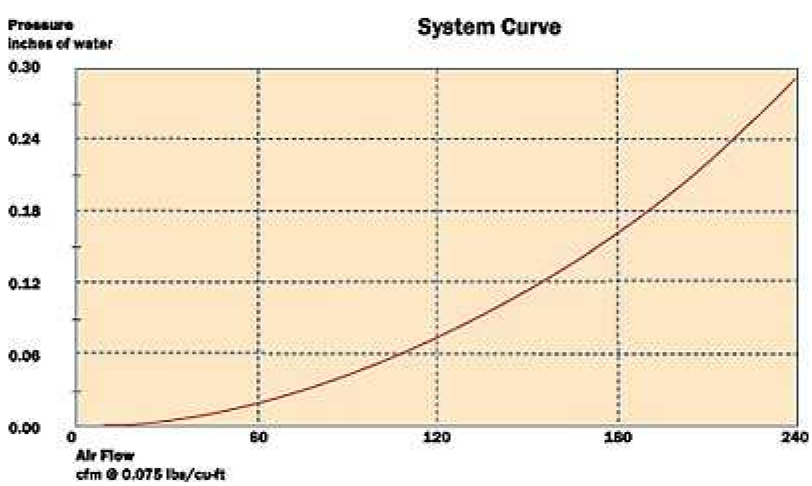


Figure 3.3 Representative flow-versus-pressure characteristic of system air path [15].

Second step is to combine the airflow derived with the system pressure drop to determine the size of the fan. The system curve is then super imposed by the fan performance curve which in return shows the operating point (figure3.4) of the fan, which can be altered to the point nearest to the best efficiency point (BEP).The intersection of the pressure drop and the required airflow should be in the zone of the fan impedance curve where the airflow rate is more but static pressure is less.

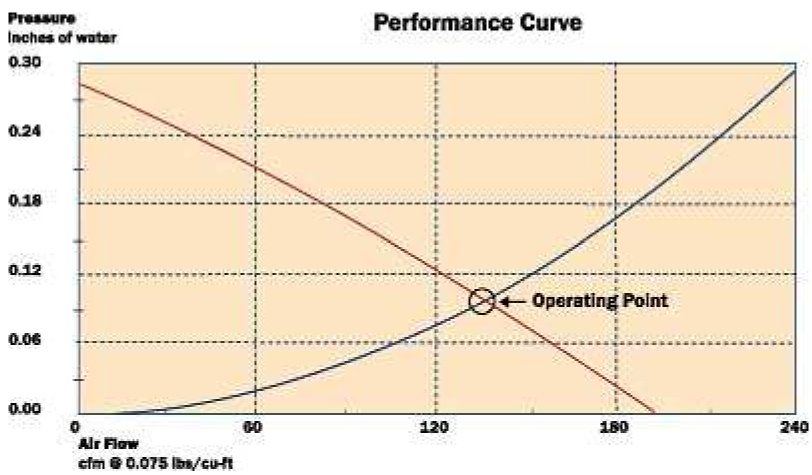


Figure 3.4 Graph of the system curve and fan curve super imposed [15]

Other important considerations are: location of the fan; and the direction in which it moves the air through the system, as the life of the fan depends on these two conditions For example, intake fan should be kept in the coolest place in the system to have a longer life. Complex system geometry in front of a blowing fan can cause turbulent flow where as a fan pulling air out of the system provides more uniform airflow throughout the system. If the acoustic noise level is important, it should be noted that an obstruction on the suction side of a fan will cause noise an order of magnitude higher than an obstruction on the force side. If an obstruction is too close to the fan, the fan may not function properly or may have a shortened life.

The system requirements will often drive the fan location and whether it needs to work in suction mode or exhaust mode. Impeller's speed is also an important characteristic of a fan, measured in rotations per minute (rpm). The faster the impeller rotates, the higher the fan's performance. Volumetric air flow rate is the fan's performance which is measured in cubic feet per minute (CFM). The higher the fan's performance, the more effectively it pumps air through a heat sink reducing its thermal resistance. As a rule, the bigger the fan, the higher its performance. A noise level can vary from 20 to 50 dBA. Typically, humans consider a fan quiet if its noise level doesn't exceed 30-35 dBA. A failure detection method is incorporated into the design of some of the advanced fan heat sinks through a signal interface which connects to the system microprocessor. The processor clock the pulses from fan and recognize the speed of the fan, and when fan gets older and its performance go low, then it auto shuts off as a safety mode.

3.4 Airflow and System Characteristics

Air flow characteristics in a laptop resemble pressure, velocity and temperature of the air. Laptop is not an empty cabinet; it consists of hard disk, chip, heat sink, battery, DVD drive and PCMCIA. These components act as obstruction in the way of thheye air flow. There are various considerations has to be taken to keep the airflow rate maximized. The important one is the location of the above mentioned components inside the cabinet, then it will be the fan location and the type used. There are three types of fan available which can be used in a laptop which are intake, exhaust and internal fan. If it is an intake fan, its location has to be at the hottest point in the cabinet. Internal fans usually located over the processor. The components around the fan affect the air flow characteristics. Modeling tool, such as Macroflow is used for analyzing the airflow inside the cabinet. The modeling in this tool is like a network which exactly shows the route of the airflow. The results can be interpreted after the analysis which shows the change in the airflow characteristics with the change in the type of the fan. Change in characteristics of the airflow with different types of the bends, intersections, distributors and obstructions in the path of airflow which in turn have an effect on the system curve. Basically from all this analysis gives the relation of the system curve with obstructions and a free flow.

System characteristics are represented as a curve which is drawn as pressure drop in y-axis and airflow rate in x-axis. The operating point of the fan can be interpret from the graph in which system curve and fan performance curve are superimposed and plotted i.e. intersection of the performance curves. The fan which has the operating point nearest to the BEP is the best fan for the respective system. This selection can be done in two ways 1) changing the system impedance and 2) changing the fan size.

The system impedance can be changed by altering the grill opening but there is a constraint in selecting this method that is system impedance is not supposed to be increased. Combination of both the methods is the best one and the procedure is that the system impedance is decreased as a result the pressure drop for the same amount of airflow rate is reduced. At this point decision should be made to select the diameter of the fan so that the operating point will be nearest possible to BEP. This will be the best fan for that particular system. This can be better illustrated in the example taken from [16].

3.4.1 Technical Example

The air performance curve for a typical cooling fan is shown as Figure 3.5. It is customary in the trade to plot the air flow rate as an abscissa, with static pressure as the primary ordinate and speed, power and electrical current flow plotted on a secondary axis.

Application of this fan at Operating Point A would deliver 70 CFM of air if the package resistance imposes a pressure drop of 0.14 inches of water on the air stream.

If the package is modified in some way to reduce its flow resistance so that 70 CFM corresponds to a pressure drop of only 0.04 inches of water (Point B), the fan could be expected to deliver an air flow rate of more than 70 CFM. It also follows that a higher flow rate through the package will increase the pressure drop in the air stream.

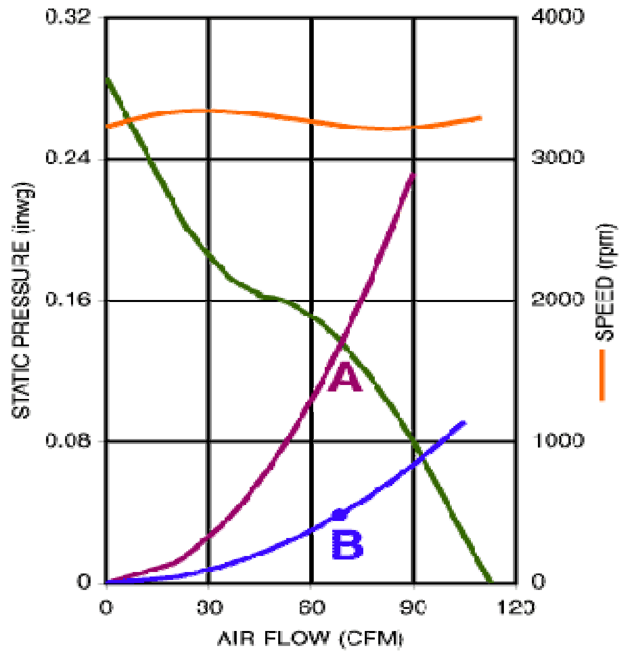


Figure 3.5 System Characteristics

In most cases of forced air cooling, the relationship between the air pressure drop and the air flow rate is a simple parabola:

$$P = krQ^2 \text{ (Q Squared)}, \tag{3.4}$$

Where

P = Pressure Drop
Q = Air Flow Rate
R = Air Density

The pressure drop/flow rate parabola, often called the system resistance curve, is shown in Figure 3.6 through Point B. It indicates that a reduction of the package pressure drop from 0.14 to 0.07 inches of water increases this fan's air flow delivery to 92 CFM. At that point, the package requires and the fan provides a pressure of 0.07 inches.

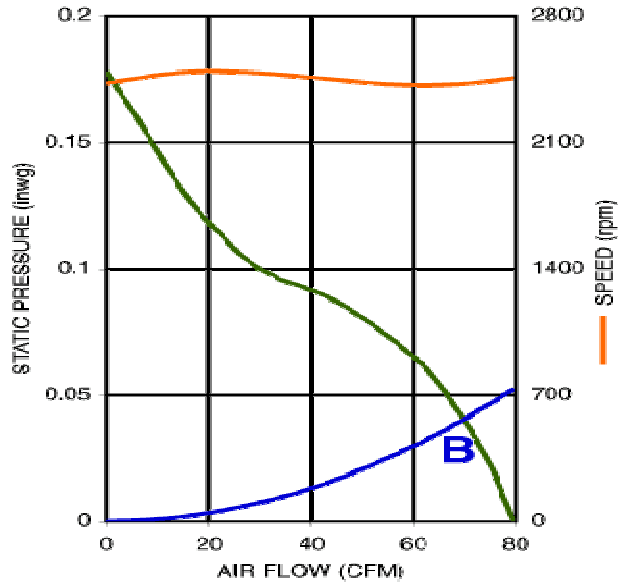


Figure 3.6 Improved Operating Point

Figure 3.7 summarizes the change from one fan to the other.

In some cases, it may be possible to specify a physically smaller fan with lower air flow ratings if package resistance is sufficiently reduced.

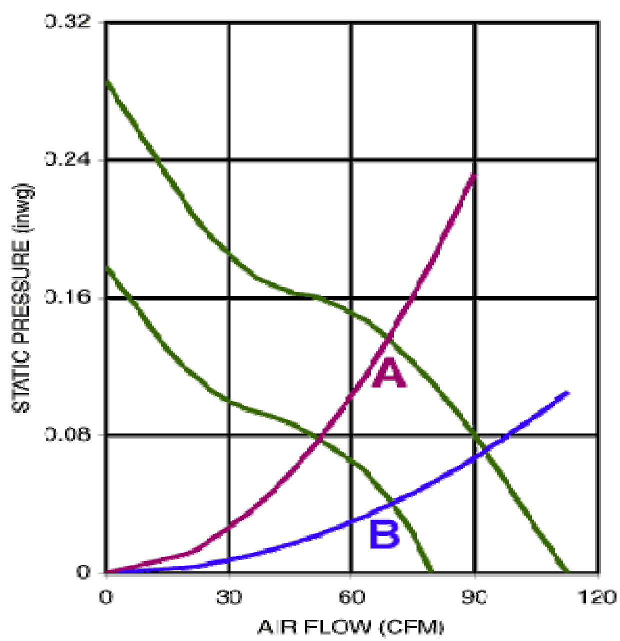


Figure 3.7 B E P

CHAPTER 4

SIMULATION OF THERMAL MANAGEMENT PROCESS

4.1 Introduction

A *simulation* is an imitation of some real thing, state of affairs, or process. The act of simulating something generally entails representing certain key characteristics of a selected physical system. The formal modeling of systems has been by a mathematical model, which attempts to find analytical solutions to problems which enable the prediction of the behavior of the system from a set of parameters and initial conditions. Computer simulation is often used as a substitution for, modeling systems for which simple closed form analytical solutions are not possible. There are many different types of computer simulation; the common feature they all share is the attempt to generate a sample of representative scenarios for a model in which a complete enumeration of all possible states of the model would be prohibitive or impossible. Several software packages exist for running computer-based simulation modeling that makes the modeling almost effortless and simple

4.2 Simulation of Toshiba Laptop

In this research study the simulation is carried in a thermal management tool, Icepak due to its complex geometry and boundary conditions. Firstly it starts with the modeling of the Toshiba laptop then followed by assigning their respective properties to all the components and setting the initial and boundary conditions as shown in table 4.1

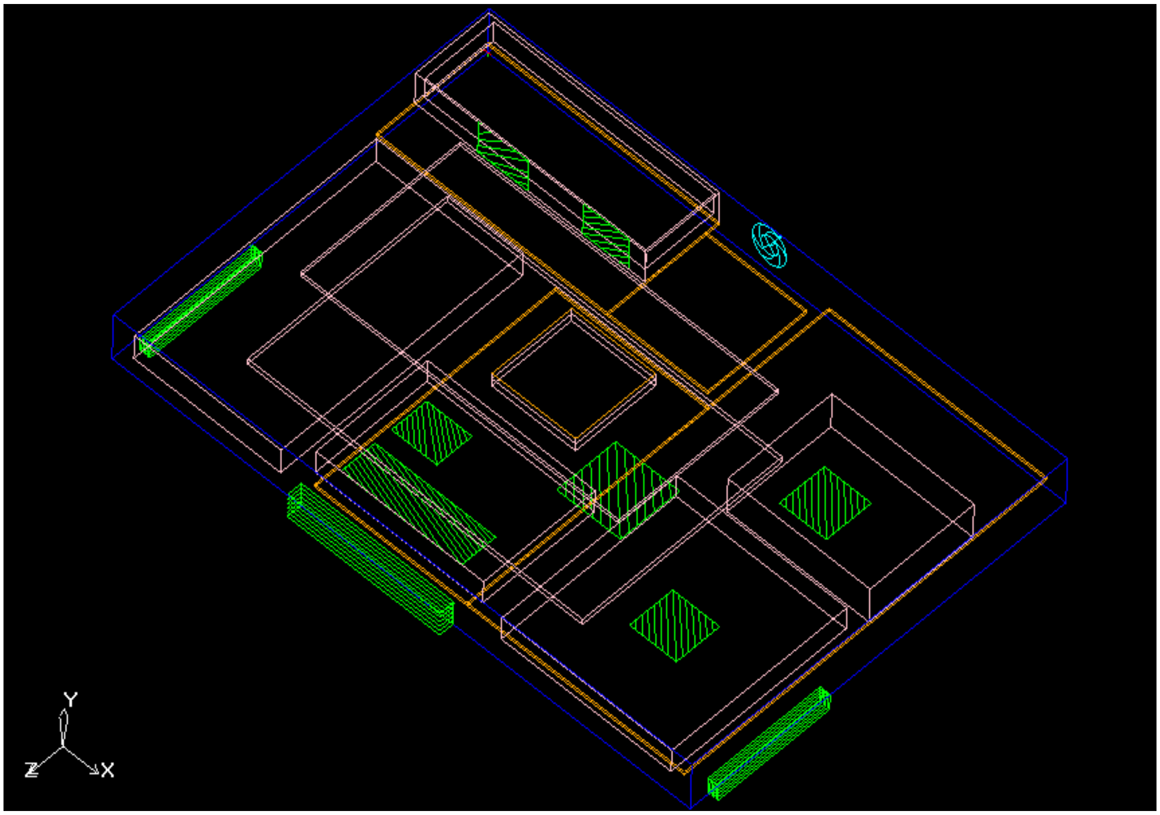


Figure 4.1 Layout of medium performance Toshiba laptop

Table 4.1 Properties of the components

Components	Power(W)
CPU	20
Hard Drive	10
Battery	10
DVD Drive	5
PCMCIA	2
Total Power	47

The model so created is solved and results so obtained are analyzed to find the amount of more heat which has to be removed from the system to improve the chip performance and the location of the Hotspots.

Instead of Heat sink and Heat pipe, a Graphite heat spreader is used as a cooling system. Due to its anisotropic property it spreads the heat from the chip to cooler region by increasing the effective heat transfer by increasing the area. The heat spreader can also be used on the surface of the system to spread out the heat and avoid the Hotspots by reducing the touch temperature.

This analysis is specifically done to show that the effectiveness of the Graphite heat spreaders in cooling a laptop as for the medium performance systems they replace the bulky cooling systems consisting Heat sink and Heat pipe combination. If system selected is a high performance system then a combination of all three of them can be used as the size if the spreader can be change for further increase in its power with out much increase in the weight of the system.

4.3 CFD Model of DELL 610

The model selected for further analysis is Dell 610, a high performance system. The standard dimensions of this laptop are taken from Dell Website [16]. The orientation of all the components, properties and boundary conditions are taken from the paper [1]. The power dissipation by each components are stated in the table 4.2

Table 4.2 Properties of the Components in DELL

Components	Power(W)
CPU	35
Hard Drive	20
Battery	20
DVD Drive	10
PCMCIA	5
Plate	10
Total Power	100

A detailed model consisting of all the components in the cabinet will become very complex and difficult for the computations and analysis. To reduce the complexity in the geometry of this model creating and analyzing tasks, a simplified model is obtained by following considerations-

1. Only the components with larger size and high power dissipation are included.
2. Hard Drive, DVD Drive and other components of complex and unknown geometry are considered as rectangular solid blocks.
3. Circular and Cylindrical shapes are approximated to squares and rectangular shapes.
4. The Keyboard and Display are excluded in this simplified model.
5. Heat dissipation from smaller components are shown as sources.

A schematic diagram of the physical configuration of the system is as shown in fig 4.2

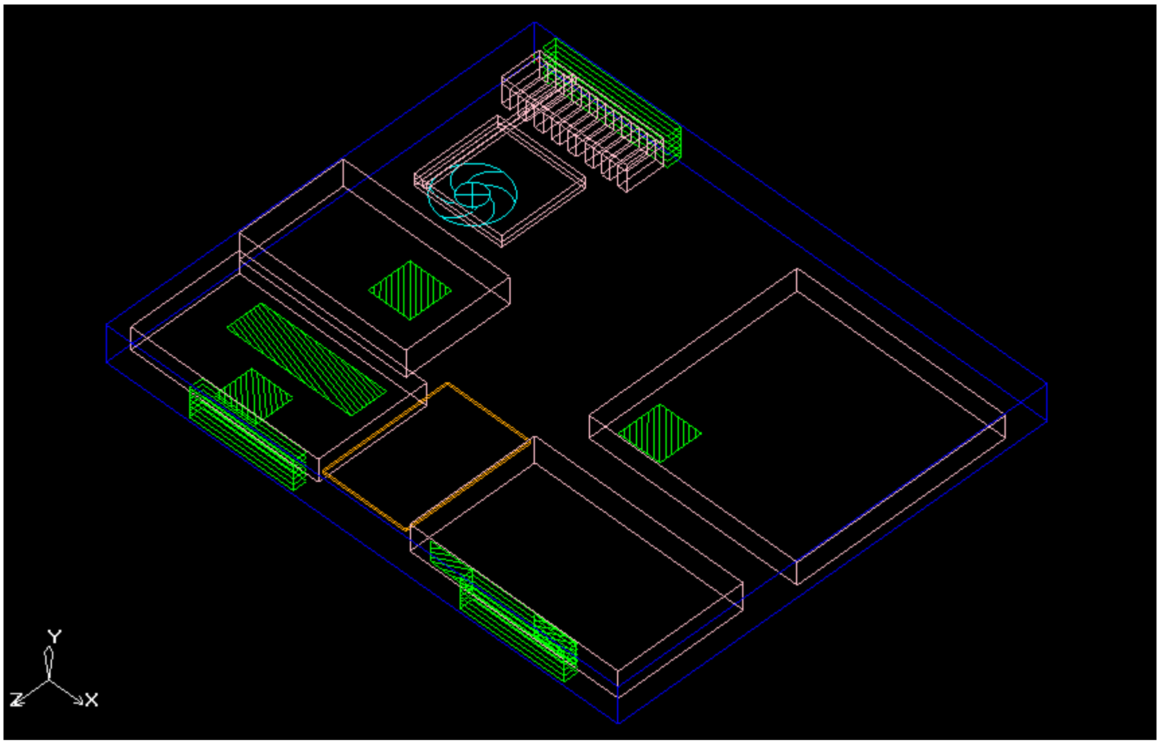


Figure 4.2 Layout of the DELL 610 Laptop

4.4 Experimental Measurements to Validate the Simulation Model

A typical Dell 610 laptop computer is shown in Figure 4.3, while the internal layout of components directly below the keyboard and case are shown in figure 4.4, Major components include the heat sink, the heat pipe above the CPU chip, the fan, the slot for the PCMIA card, the hard drive, the battery, and the bay for the DVD drive. There is a well-designed thermal solution cooling the CPU, but there is no explicit thermal solution employed to cool the hard drive. A particular feature of this design is the placement of the hard drive under the left palm rest and the battery under the right.

High hard drive operating temperatures can result in uncomfortable palm rest touch temperatures.

Figure 4.3 Typical laptop computer

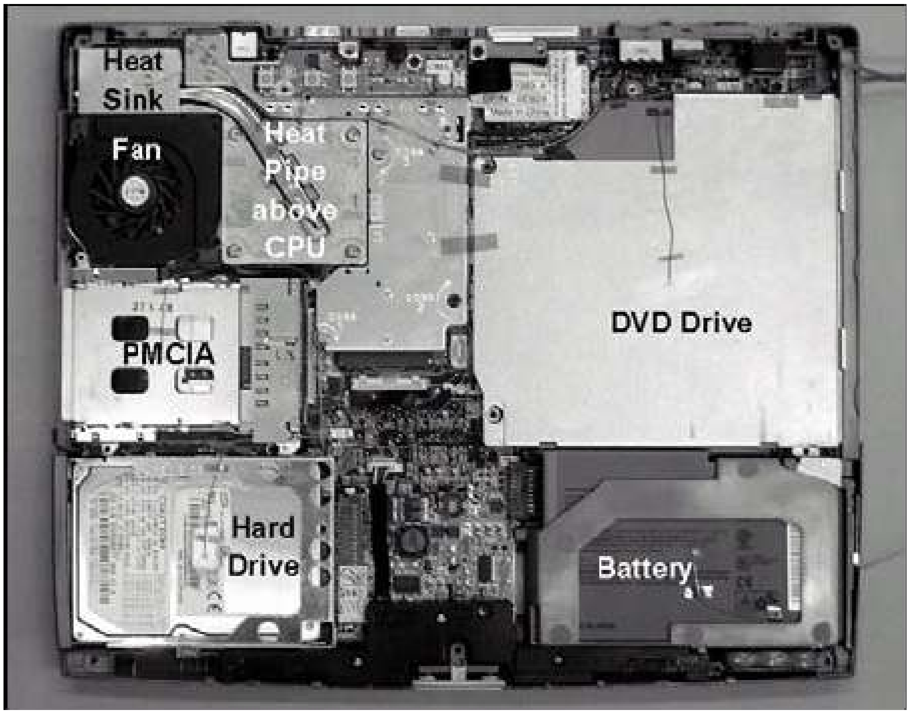


Figure 4.4 Internal components located immediately under the case and keyboard

To determine maximum hard drive temperature, an AVI file, loaded onto the hard drive, was run continuously for 2 hours and on-board software was used to access a temperature sensor built into the hard drive. An infrared thermal image of the laptop case taken at the end of this period is shown in Figure 4.5. The image was made with an Infra-Red Solutions Inc., Flex Cam model FLX-031115. Four areas of the image were highlighted and the average temperatures within those areas were determined using Flex View V1.0.16 Image Analysis Software. Area A1 is the area of the left palm rest, A2 the mouse pad, A3 the right palm rest, and A4 an area on a flat black, insulating surface adjacent to the laptop that was used to obtain an ambient temperature measurement. The average temperature in each area was determined and the average temperature rise relative to ambient, ΔT_{avg}, determined.

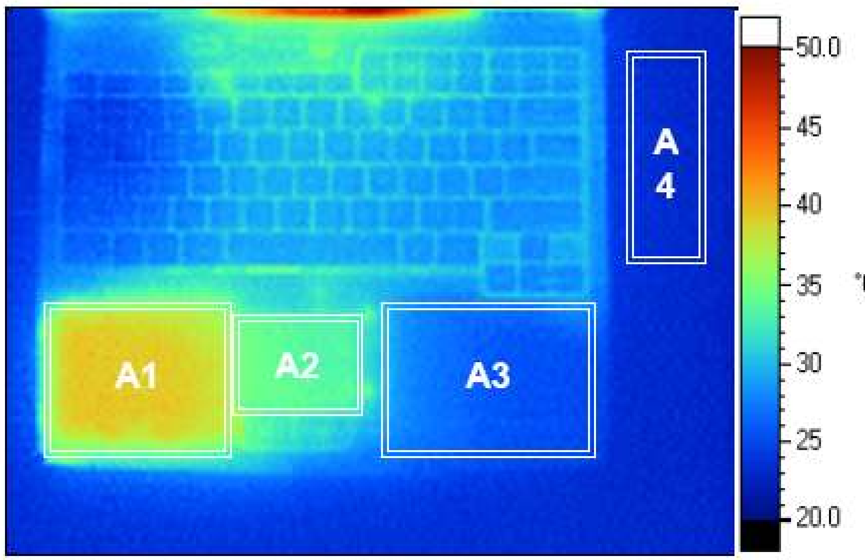


Figure 4.5 Thermal image of the laptop cover and keyboard taken after running an AVI file continuously for 2 hours

These results are shown in Table 4.3, along with the increase in hard drive temperature from the internal sensor.

Table 4.3
Hard Drive and Laptop Case Temperature

Average Temperature Rise Above Ambient (°C)				Ambient (°C)
Hard Drive	A1 Left Palm Rest	A2 Mouse Pad	A3 Right Palm Rest	
30.0	14.1	9.9	3.0	23.9

This test shows that significant temperature gradients exist in laptop computers. The remainder of this paper will examine how a natural graphite heat spreader can be used to reduce these temperature gradients. To determine the effect of graphite spreaders on the heat distribution within the laptop, thermal tests were conducted on the laptop in Figure 4.3 with and without spreaders. Although the thermal imaging camera was used to provide basic case temperature data, thermocouples were used for primary measurements of component, spreader, and case temperatures. Four types of heat spreaders are selected with the following properties shown in table 4.4.

Table 4.4
Properties of Graphite Spreader Material

Test Variable		Graphite Thickness	k_i Graphite Only		k_t Graphite Only
Thickness	k_i	(mm)	Mean (W/m°K)	Standard Deviation (W/m°K)	(W/m°K)
Low	Low	0.27	234	9	4.51
High	Low	0.52	275	8	4.94
Low	High	0.26	393	13	3.81
High	High	0.51	369	14	3.33

Then again the thermocouples are used to measure the temperature on the heatsink, CPU, PMCIA, Hard Drive, DVD Drive and Battery and listed in the table 4.5 below. The temperatures shown in the table are differential temperature to ambient.

Table 4.5 Temperature Rise of Hardware Components					
Spreader Material	None	0.27 mm 234 W/mK	0.52 mm 275 W/mK	0.26 mm 393 W/mK	0.51 mm 369 W/mK
Heat Sink	9.0	10.5	10.4	10.4	10.3
CPU	9.6	11.0	10.9	10.9	10.8
PMCIA	7.3	11.5	13.0	11.2	11.6
Hard Drive	27.8	23.8	22.8	22.6	21.9
Battery	4.8	8.1	9.3	7.8	9.0
DVD Drive	9.9	10.3	10.9	9.8	10.7

From the above table the temperatures are compared and the best among the four is selected and the results of the best heat spreader and the results obtained without the spreader are compared to each other in the table 4.6 below.

Table 4.6 Thermal Performance of Laptop-Thermal Imaging Data					
Spreader	Average Temperature Rise Above Ambient (**°C)**				A4 Ambient
	A1 Left Palm Rest	A2 Mouse Pad	A3 Right Palm Rest	ΔT Left to Right Palm Rest	
None	14.1	9.9	3.0	5.9	23.9
0.51 mm 369 W/mK	8.8	7.6	5.9	2.9	23.7

<u>4.5 Optimization and Analysis of the CFD model</u>

The model created in Icepak is analyzed for all the standard cases done in the experimental measurements. These results so obtained are compared to ones obtained in experimental measurements.

The model with the best heat spreader is now selected to optimize the resistance and the size of the heat spreader. Optimization Tool in the thermal management tool, Icepak is used. The length and breadth are the design variables selected for this technique, the resistance of the spreader is the objective function and the constraints are the global maximum temperature less than 60 and the touch temperature less than 45. In the optimization phase, the number of iterations, the upper and lower bounds of the design variables and the limits on constraints are specified. The process converges within the specified iteration if a minimum value of objective function has been found that obeys the given constraints. If it does not converge a second iteration has to be setup with a new starting point. This goes on until a convergence is met within the specified constraints.

For the Icepak, the procedure for simulation and optimization can be summarized in the following steps.

1. Modeling is done with the exact dimensions. Properties of all the components are assigned.
2. Initial conditions and Boundary conditions are set.
3. Define Design variables and the solution is run to know the minimum and maximum values of the design variables.
4. Define design objectives and constraints for the optimization.
5. Create new design points through sequential solutions following all the constraints.
6. Select the best candidate/candidates from study points.

4.6 Fan Selection

The final step after the optimization is the selection of the best suitable fan the particular system being used for the analysis. The selection process goes in the procedure explained in the previous chapter. The airflow rate required for removal of the heat dissipated by the laptop is calculated and the fan which has flow rate slightly more that the required value is selected and the solution is run for different values of the airflow rate through the system which in fact gives the static pressure in the system. The system curve is drawn from the pressure values obtained previously. This system curve drawn is super imposed with the fan performance curve to get the operating point. The best fan for a system is selected by observing the operating point which should be as close as possible to the BEP of that particular fan. In the graph the BEP should be toward the right of the operating point if not so, the diameter of the fan is varied to get BEP right to operating point. So that the system curve can be easily moved to the right just by reducing the resistance of the system, this is done by increasing the grill inlet ratio.

4.6.1 Tutorial on Macro flow

Figure below shows the main design window of the Macro Flow, shows all the design tools on the top and left side of the design window.

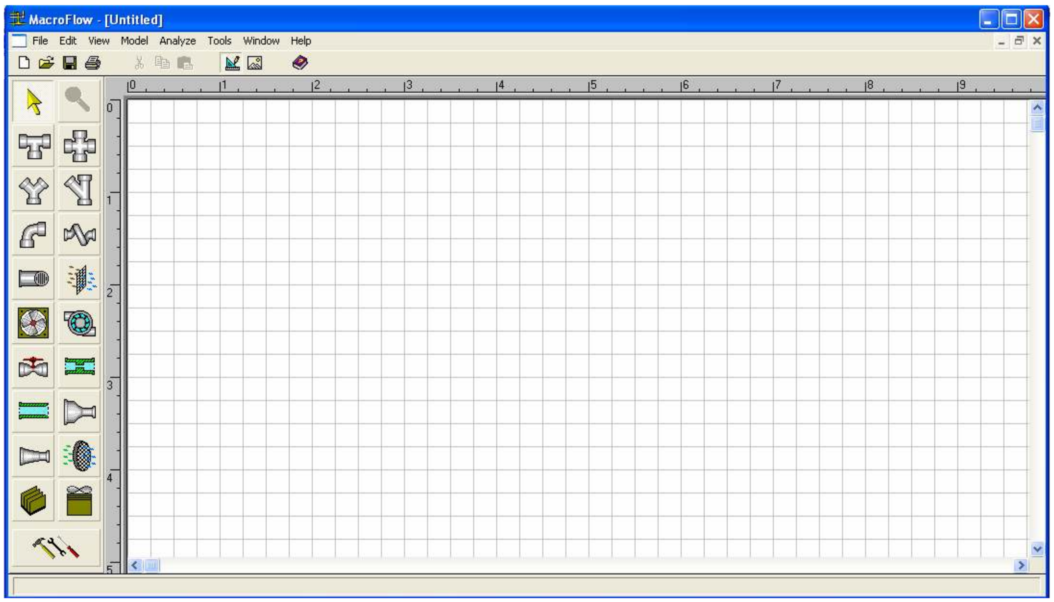


Figure 4.6 Design Space

The create tool for the heat sink is selected and heat sink is located in the design window shown below.

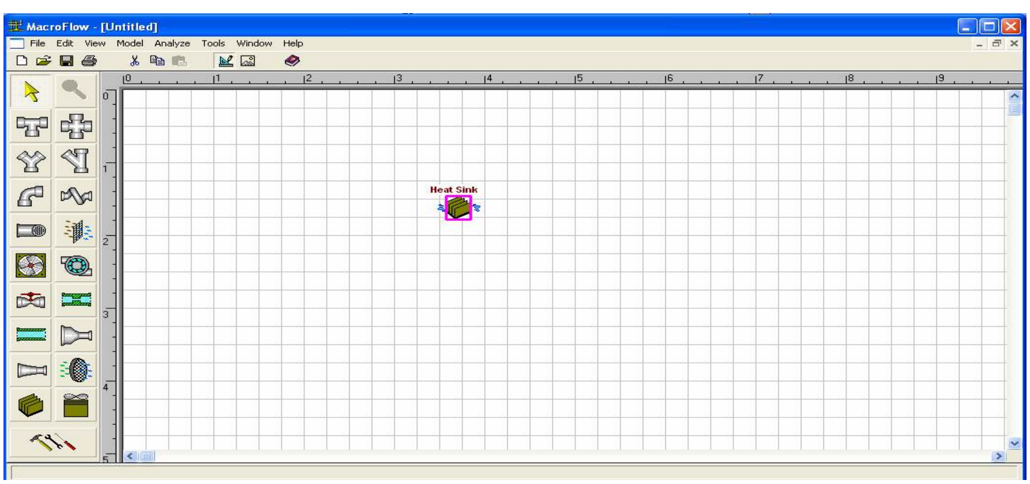


Figure 4.7 Create Heat Sink

Select model from the main menu and scroll through model menu and select heat transfer.

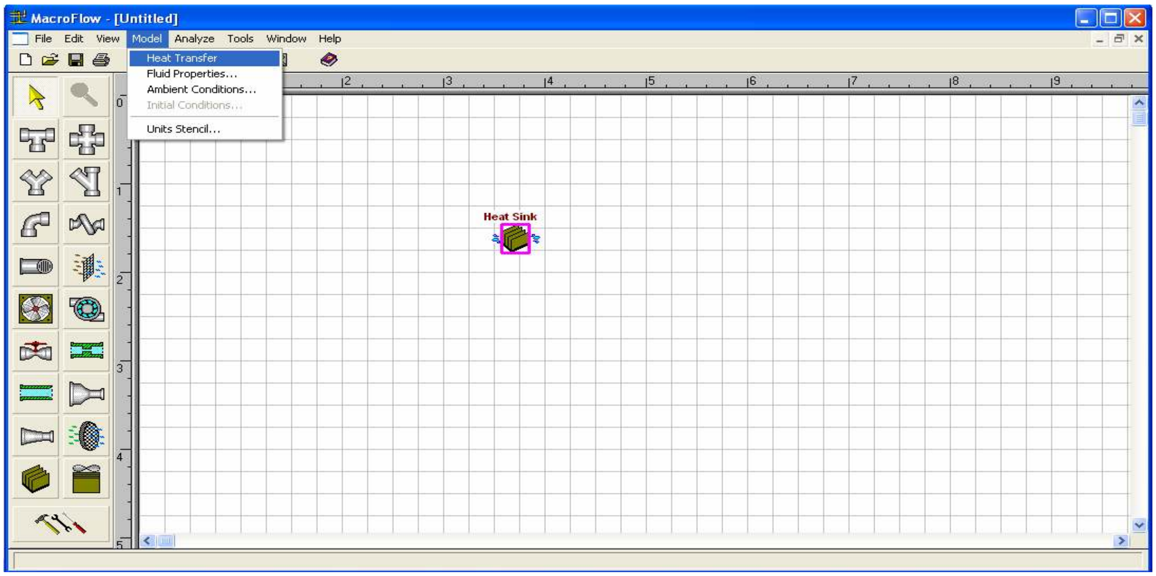


Figure 4.8 Heat Transfer Options

Open the heat sink window, select general tab and select standard correlation type

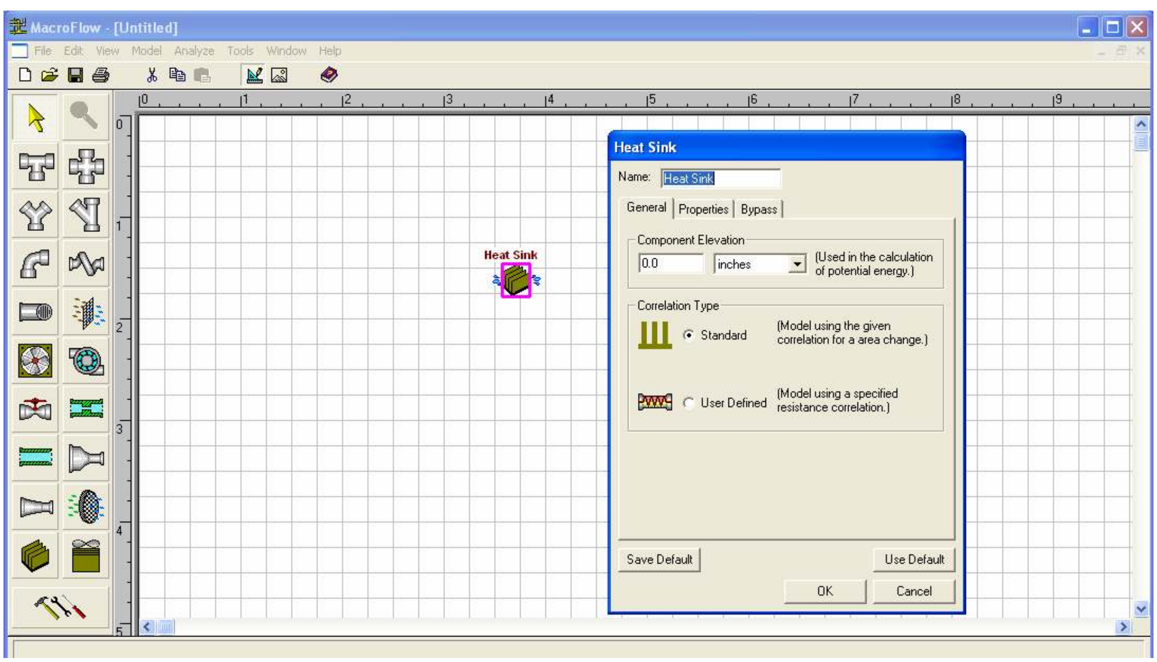


Figure 4.9 Heat Sink Properties

Select properties tab and put all the values of the heat sink dimensions.

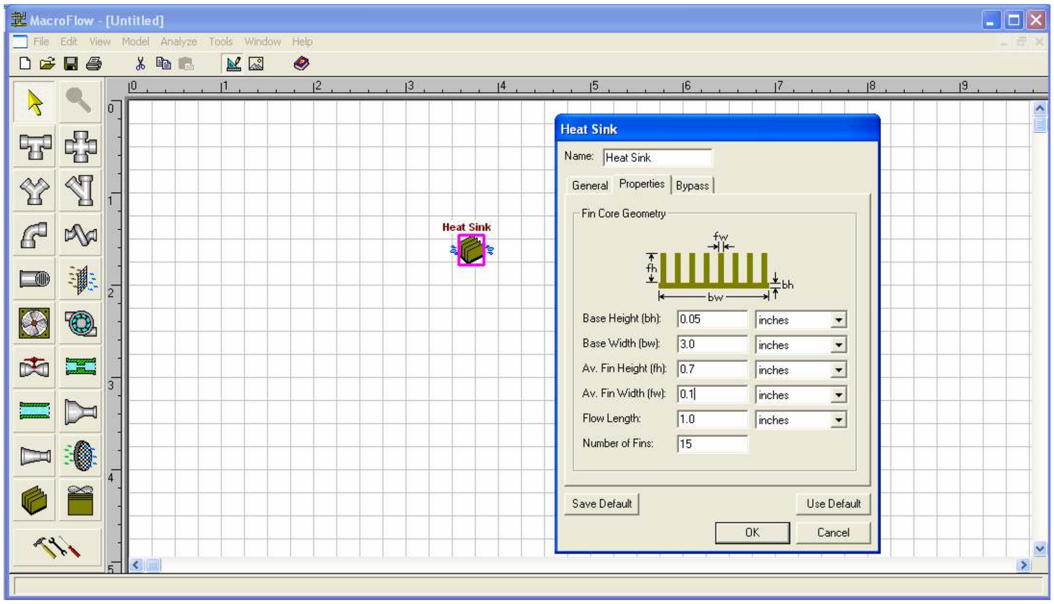


Figure 4.10 Heat Sink Properties

Select heat transfer tab and select appropriate values for the thermal conductivity and heat dissipation.

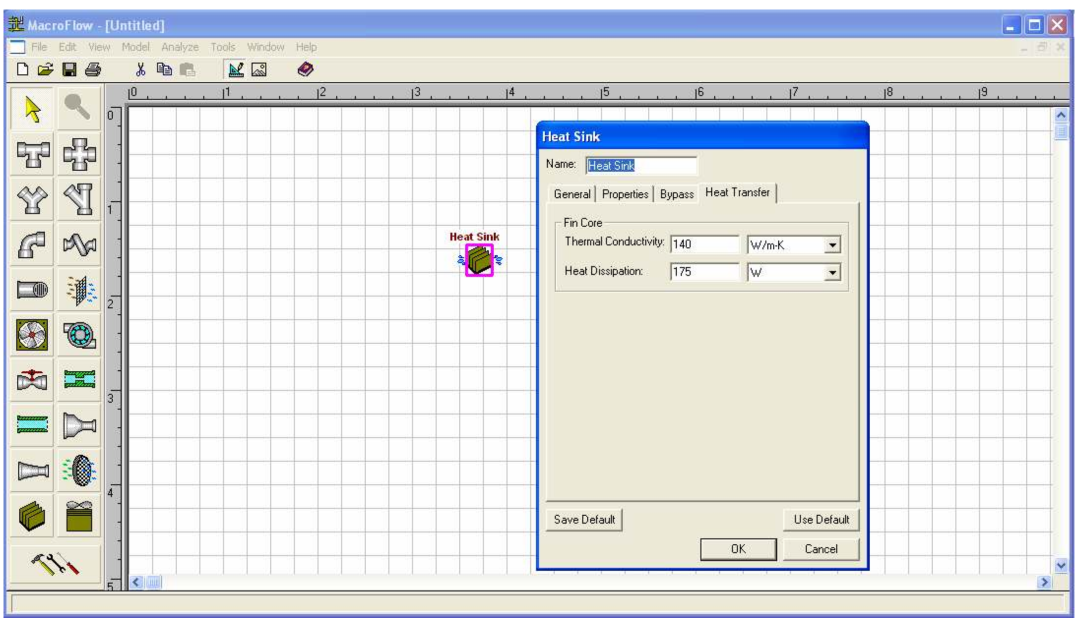


Figure 4.11 Heat Sink Thermal Properties

Create fan in the design window. Open the properties window, select library on general tab and turn on the fan.

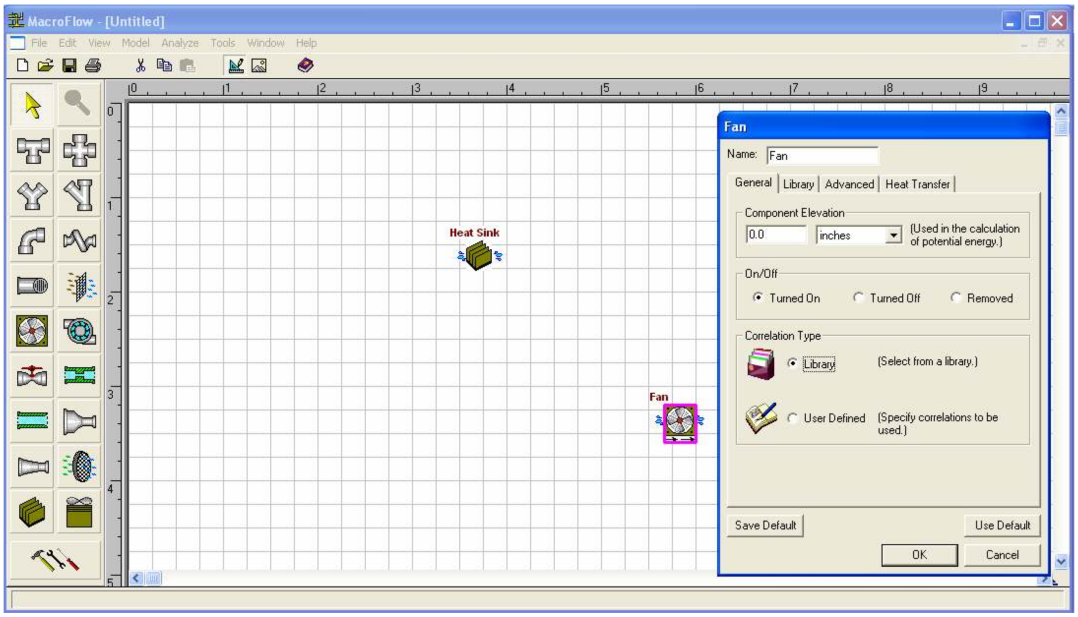


Figure 4.12 General Properties of Fan

Select library tab and select Comair rotron flight 1190 FN-12B3 type fan

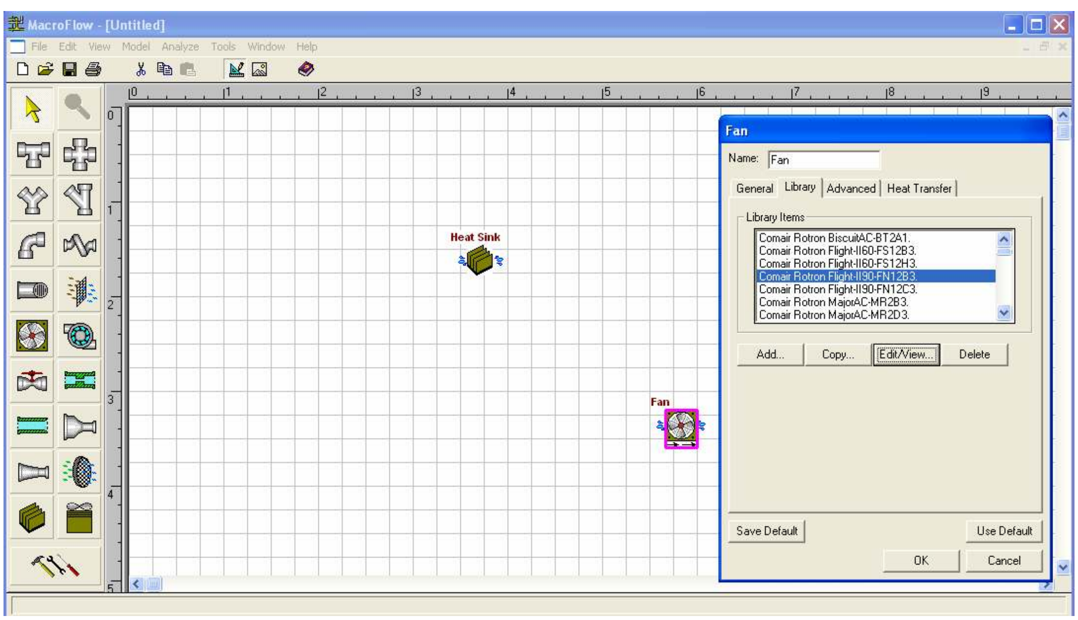


Figure 4.13 Type of Fan

Selected fan specifications are shown below

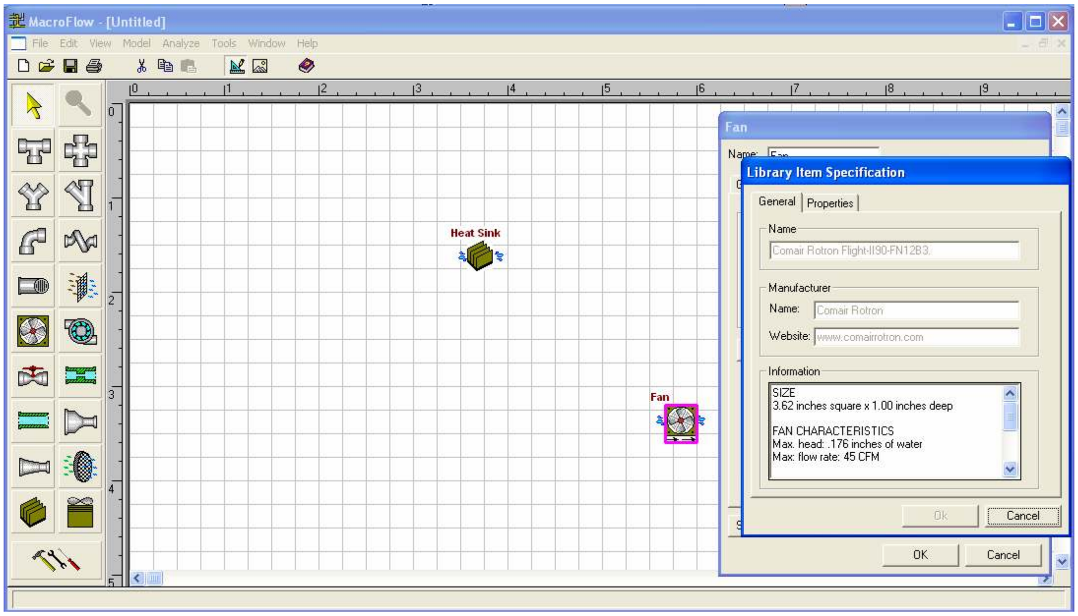


Figure 4.14 Fan Specifications

Select advanced tab and select speed dependent option.

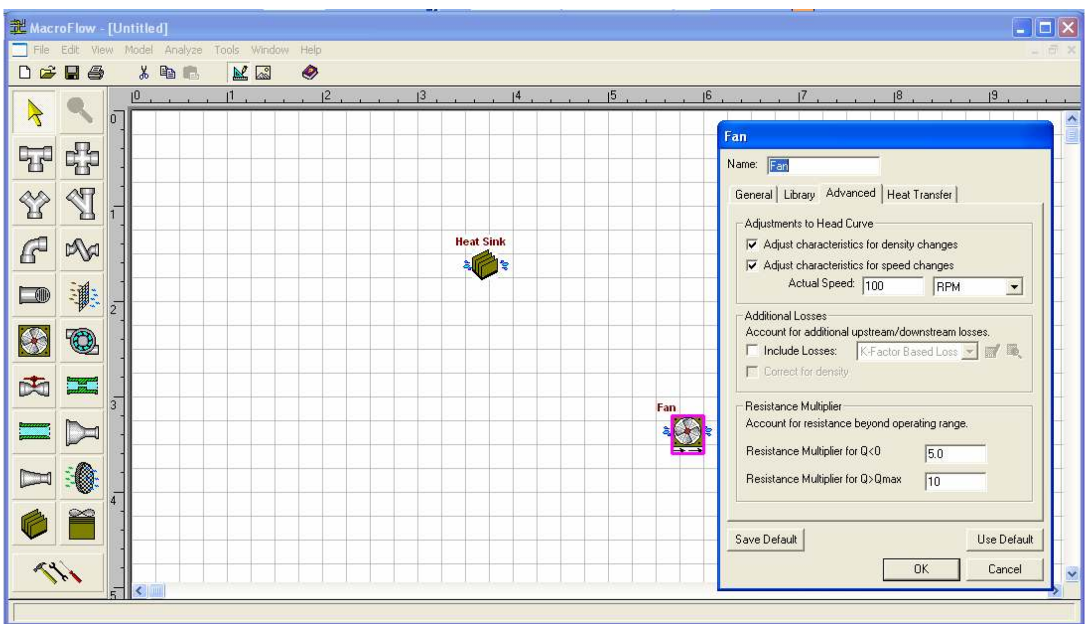


Figure 4.15 Advanced Properties of Fan

Create a bend and select a standard type option.

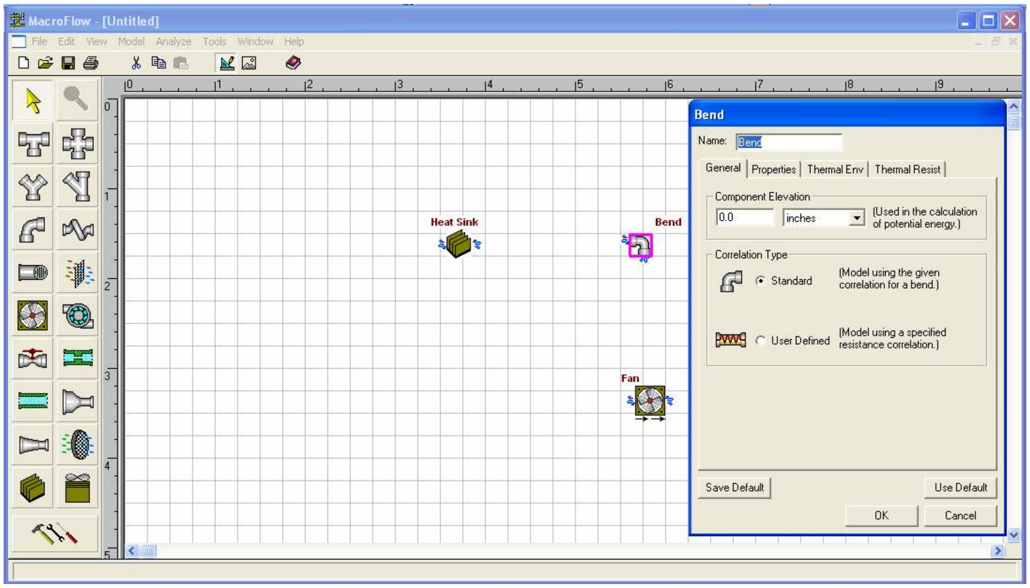


Figure 4.16 Thermal Properties of Fan

Select properties tab and change the surface type.

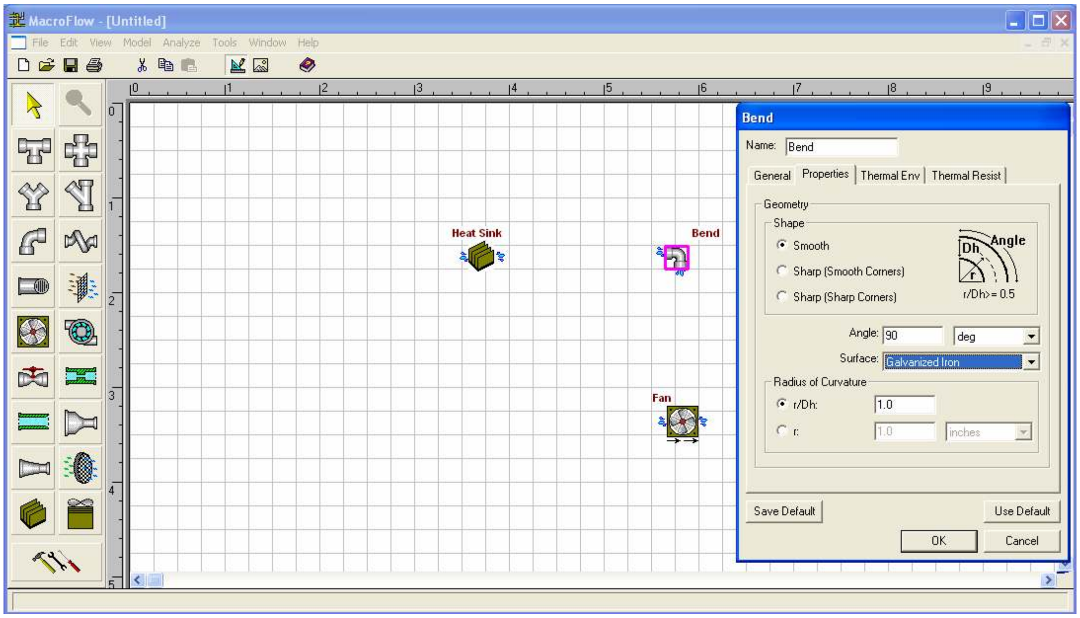


Figure 4.17 Bend Properties

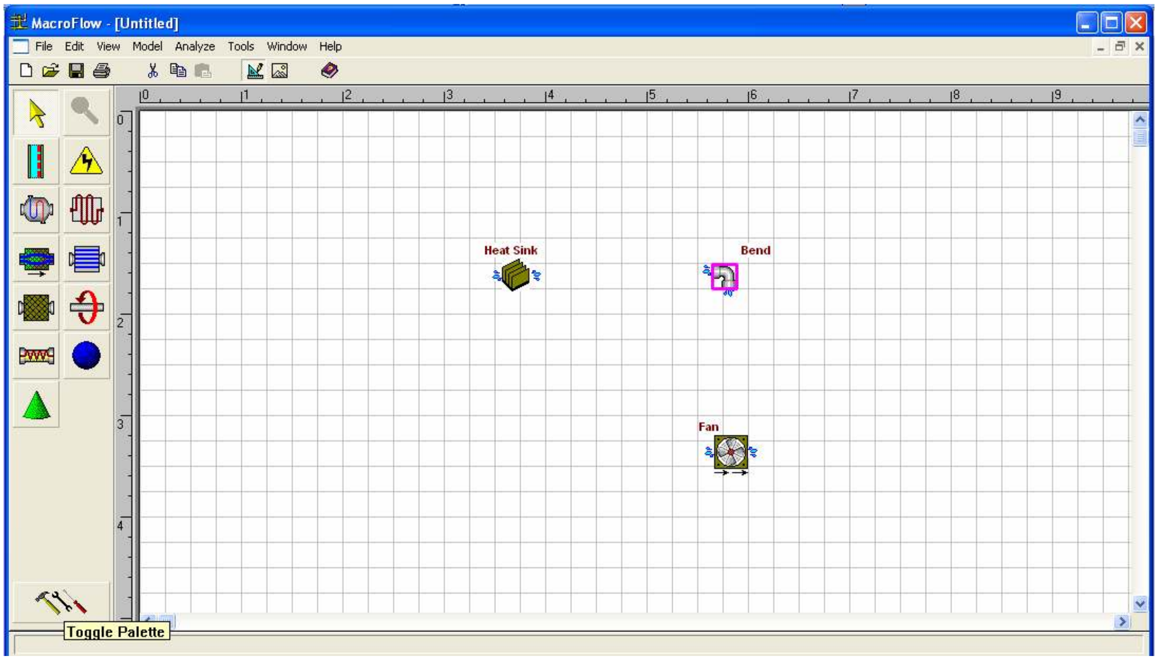


Figure 4.18 General Orientation

Create two boundary nodes and change the values as ambient under the state tab.

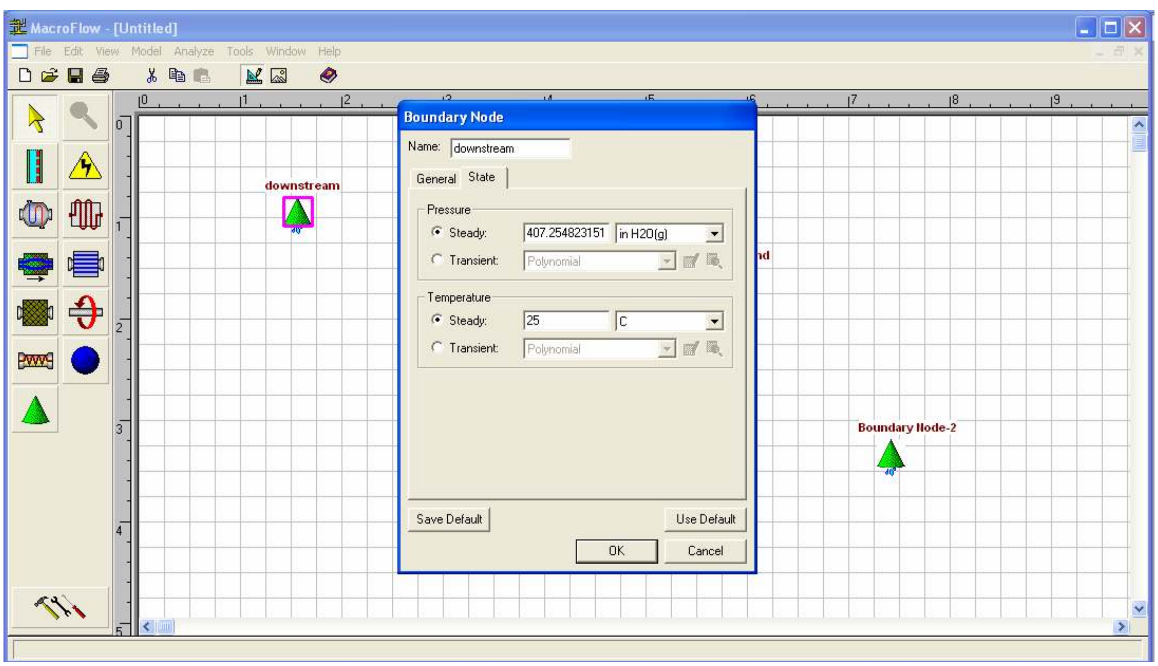


Figure 4.19 Boundary Conditions

Connect the network using the links.

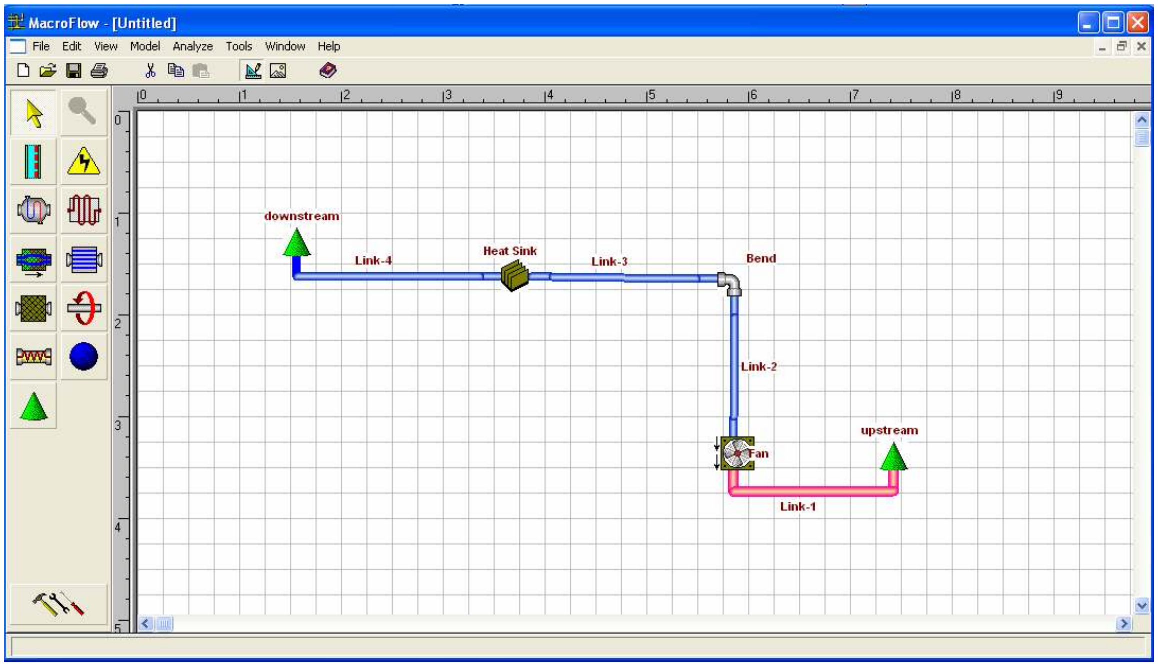


Figure 4.20 Air Flow Path

In link 1 and 4 select zero resistance pipe and also select the diameter as 3 inch.

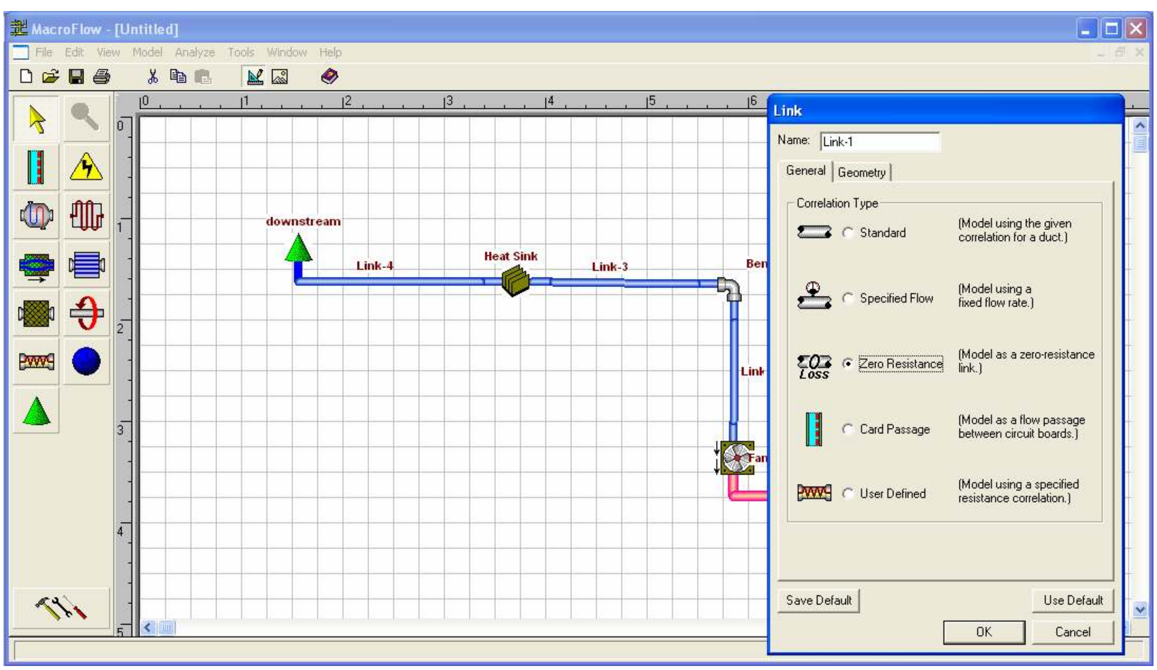


Figure 21 Link 1 Specifications

For link 2 and 3 select standard pipe type.

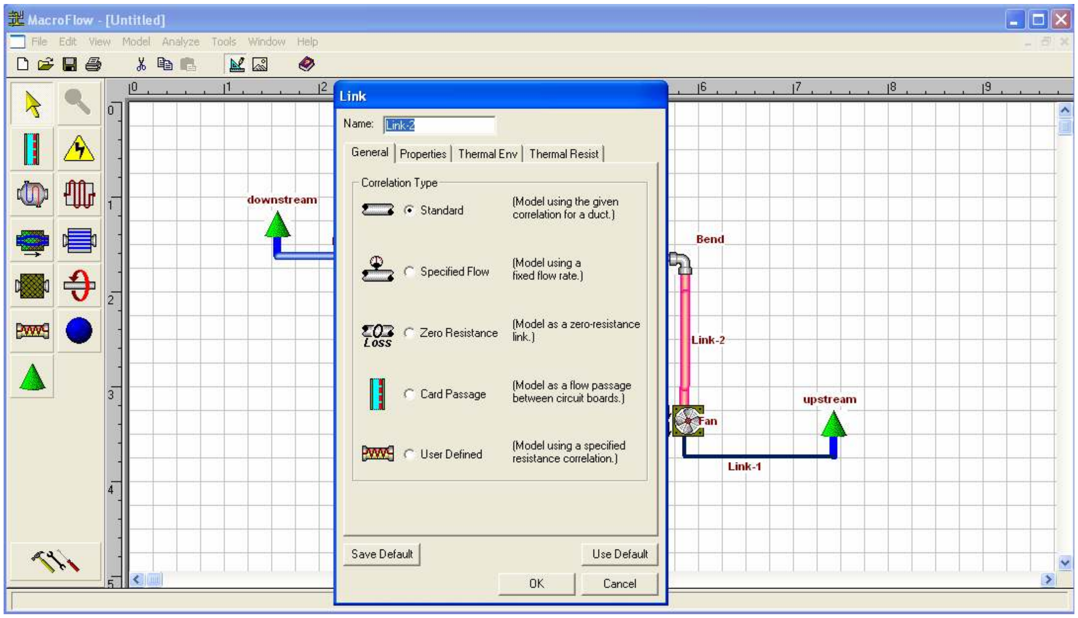


Figure 4.22 Link 2 Specifications

Select the properties tab for link-3 and select shape and dimensions.

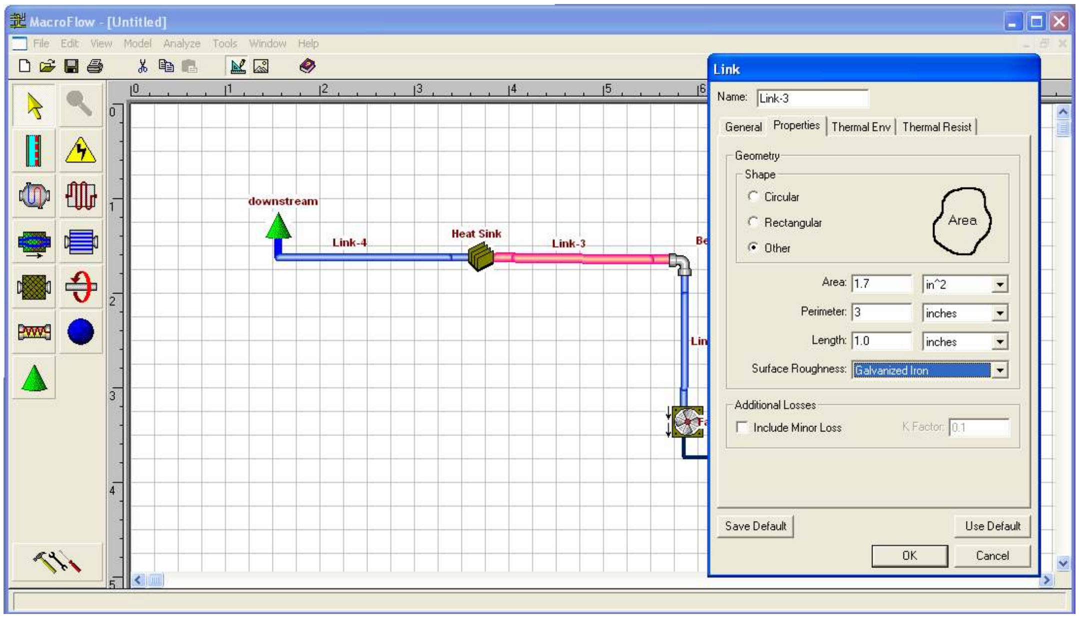


Figure 4.23 Link 3 Specifications

Go to main menu and select analyze, scroll down and select all the variables in the results.

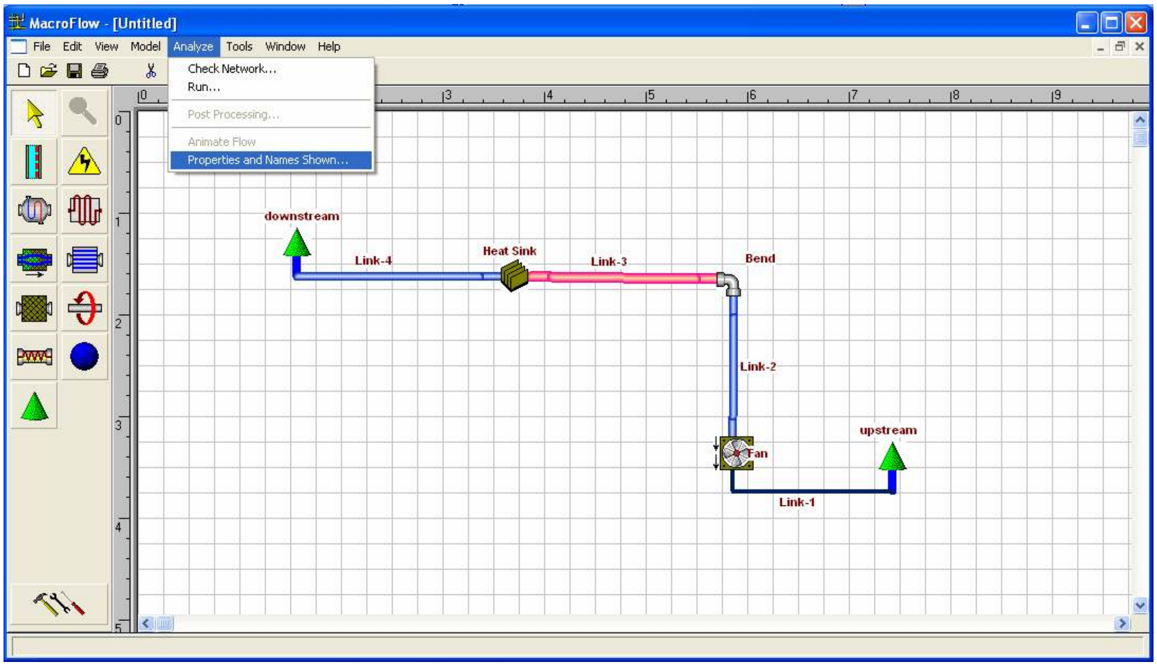


Figure 4.24 Solution Settings

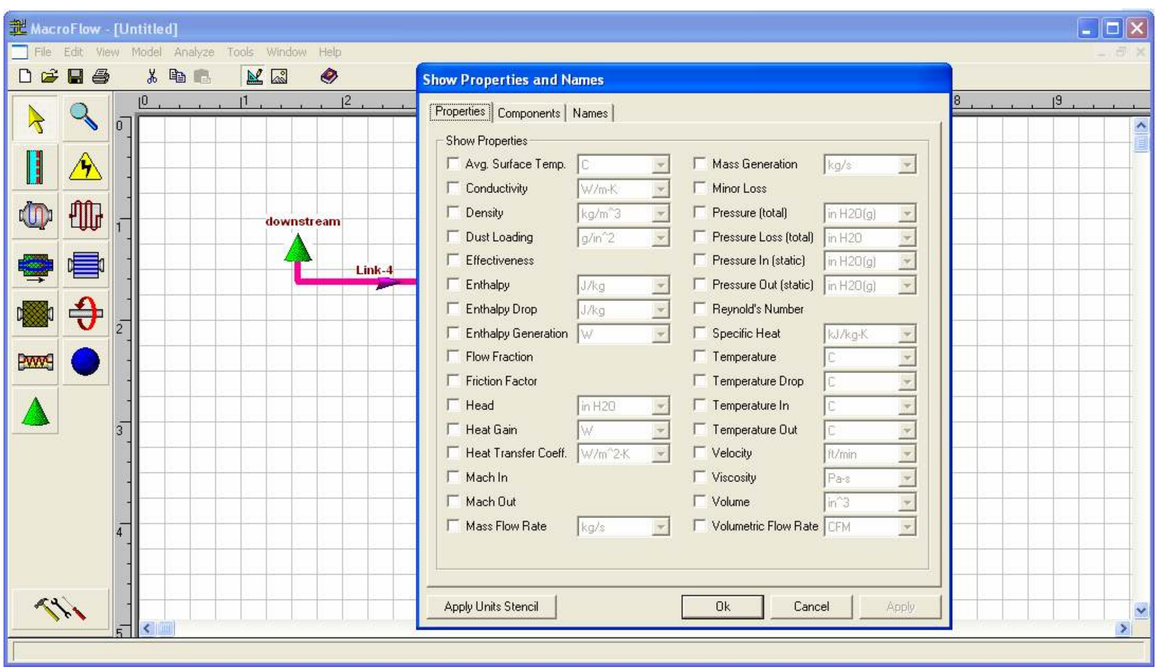


Figure 4.25 Result Settings

Run the solution by selecting proper relaxation factors and convergence relations

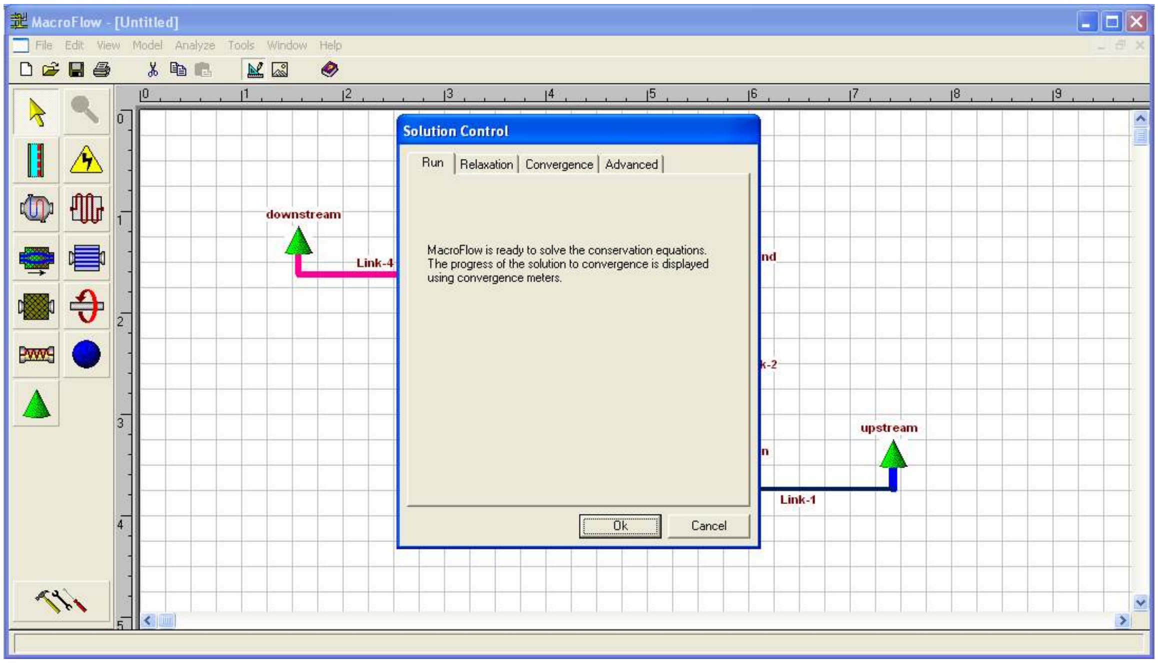


Figure 4.26 Run Solution

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Introduction

In this section we will discuss the results obtained by simulation in the thermal management tool, Icepak for two different models of laptop. The application problems studied are

1. Heat spreaders used in Toshiba replacing the complex cooling system consisting heat sink and heat pipe.
2. Simulation of a DELL 610 laptop and validation on the CFD model with the experimental measurements.
3. Optimization of the resistance and size of the heat spreader in the DELL 610 laptop.
4. Selection of a perfect Fan for the above optimized model.

The first two problems need the modeling of the laptop model with certain approximation mentioned in the previous section. The results obtained solving the these simulation problems using the thermal management tool, Icepak. In first one, it shows how the heat spreader replaces the heat sink in low performance laptops and it can be inferred that heat spreader will be included in the cooing system with heat sink so that performance of the cooling system can be improved with a little increase in weight. In the second problem the simulation model is validated using the experimental measurements.

However the DELL laptop designed previously is used in the optimization tool of Icepak, which is a conventional optimization method where the true functions (Objective and Constraints) are used for the optimization. The objective function, constraints and variables are assigned to the model to get the analysis. The selection of the Fan is done in modeling tool, Macroflow the model is created without any obstructions and with obstruction are created and analyzed. The results of this problem give the air characteristics inside the laptop and the relation of the system curve in different obstructions with the straight flow.

5.2 Toshiba laptop

The results shown in the figure 5.1 is the temperature of the system when there is no cooling system is used, so the heat transferred here is only due to the fan.

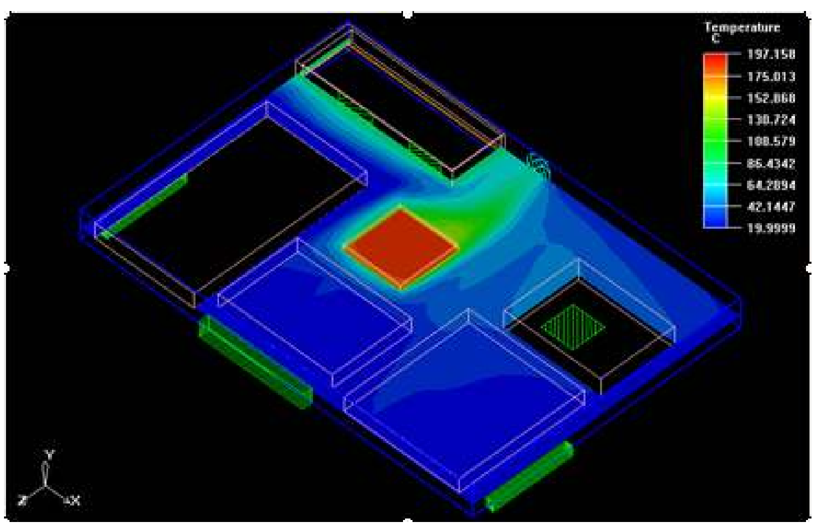


Figure 5.1 Only Forced Convection.

Figure below shows the temperature contour of the system when heat sink is used as cooling system, its shows almost 107 ^{o}C decrease in the global temperature. As the system here used is a medium performance laptop, the cooling as to be improved.

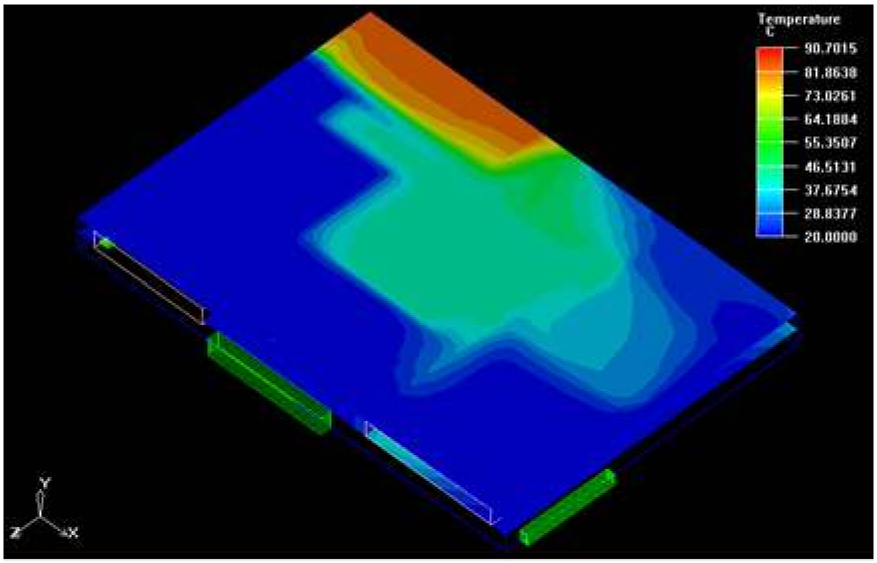


Figure 5.2 Heat Sink

Heat spreaders are used instead of heat sink as it reduces the weight of the system, from the results in the table state that the Graphite heat spreaders also decrease the global temperature by 104 oC, which is almost equal to the performance of the heat sink. It can be inferred that in low performance laptops heat spreaders can replace the complex heat sink and heat pipe combination. For medium and high performance laptops a combination is used to keep the weight of the system low and still the performance of the cooling system can be improved.

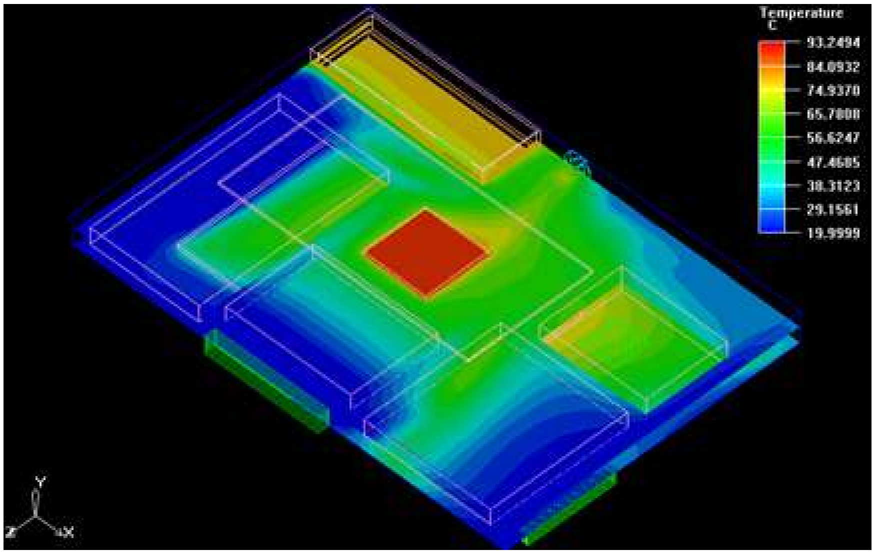


Figure 5.3 Heat Spreader

5.3 DELL 610 Laptop

The results by solving the model created in the procedure explained in the previous section. Temperature contours below show the exact temperatures on the three areas left palm rest, mouse pad and right palm rest. It can be noticed that the maximum temperature is at the left palm rest and it decreases while we move to the right.

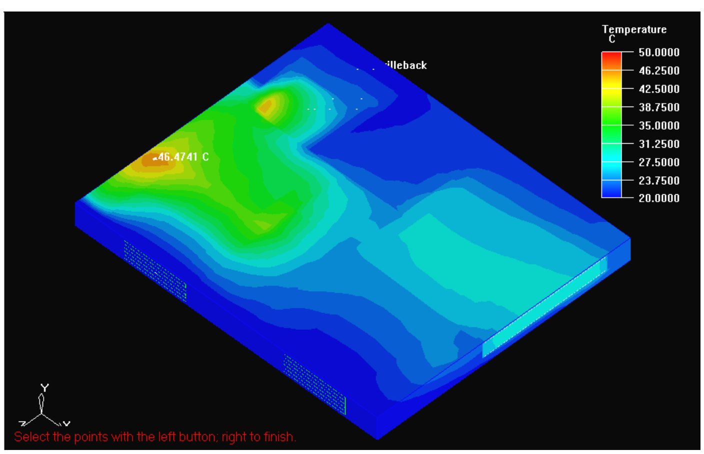


Figure 5.4 None A1

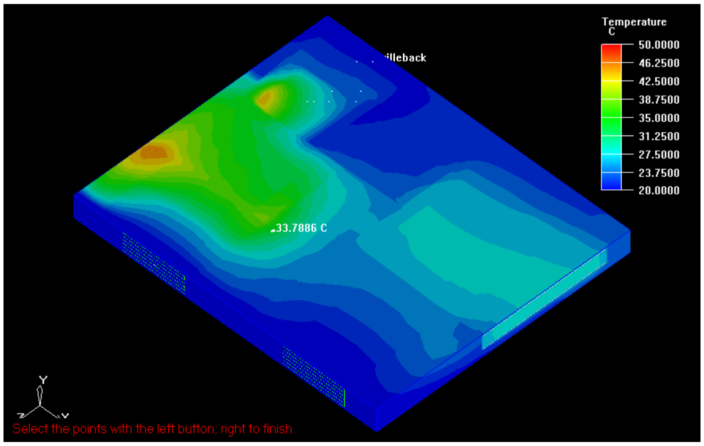


Figure 5.5 None A2

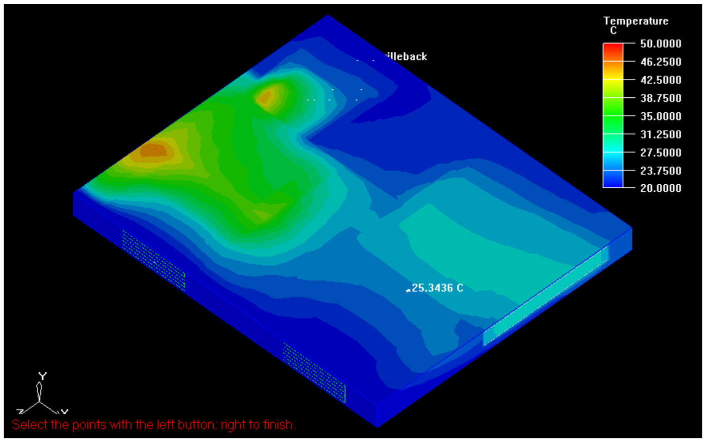


Figure 5.6 None A3

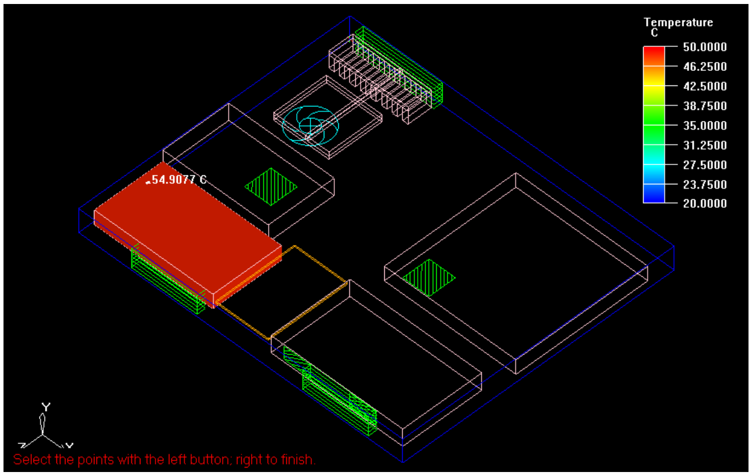


Figure 5.7 None Hard Drive

These temperatures so obtained in the results are tabulated which can be validated by the measurements shown in the table 5.1

Table 5.1 Hard Drive and Laptop Case Temperature				
Average Temperature Rise Above Ambient (°C)				Ambient (°C)
Hard Drive	A1 Left Palm Rest	A2 Mouse Pad	A3 Right Palm Rest	
34.9	26.7	13.8	5.3	20

Graphite heat spreader is introduced in the design for better heat transfer rate. Analysis is carried out on all the four types of heat spreaders with different thickness and different thermal conductivities. These results are then compared to each other and the best of them is selected for the final analysis.

Results for heat spreader with 0.51mm thickness

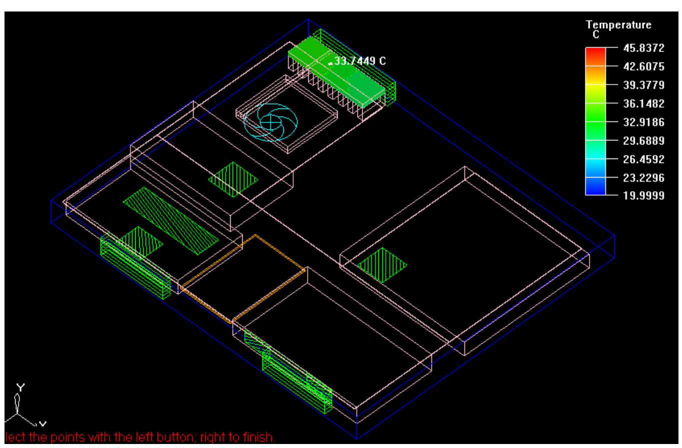


Figure 5.8 0.51mm Heat Sink

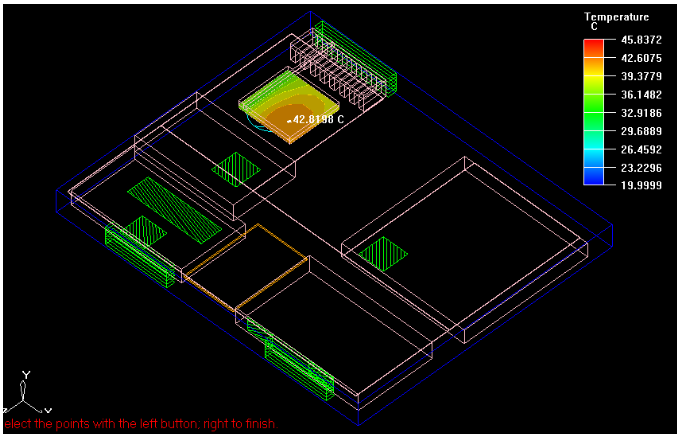


Figure 5.9 0.51mm Chip

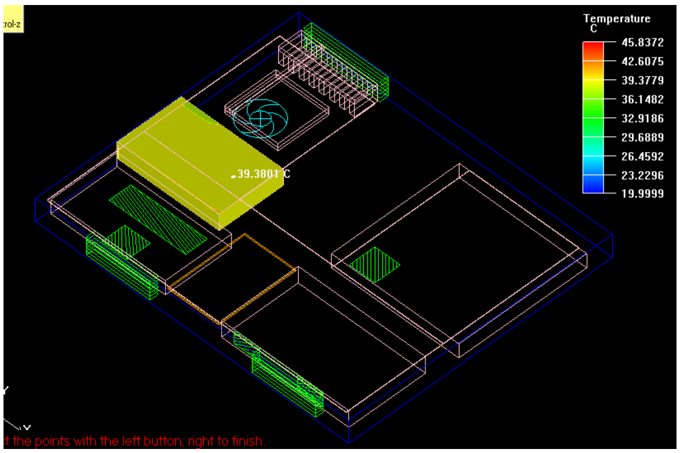


Figure 5.10 0.51mm PCMCIA

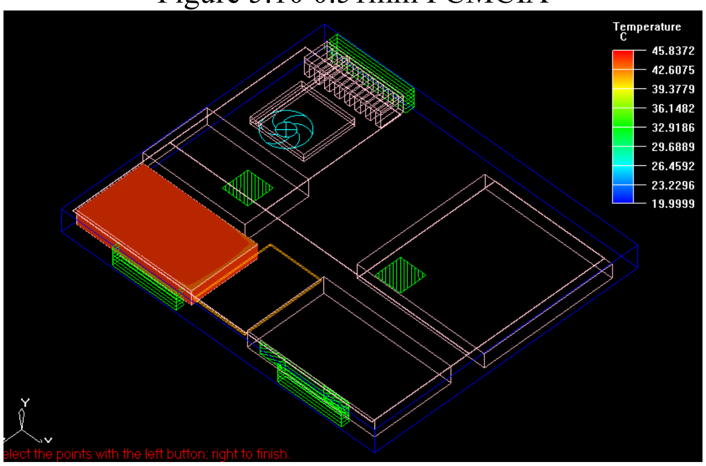


Figure 5.11 0.51mm Hard Drive

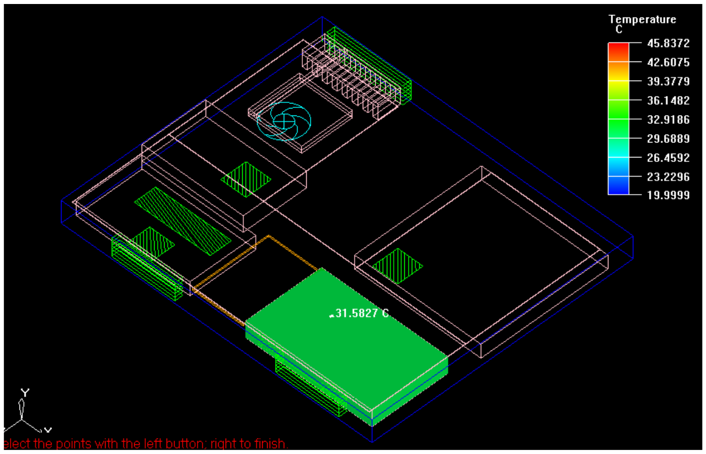


Figure 5.12 0.51mm Battery

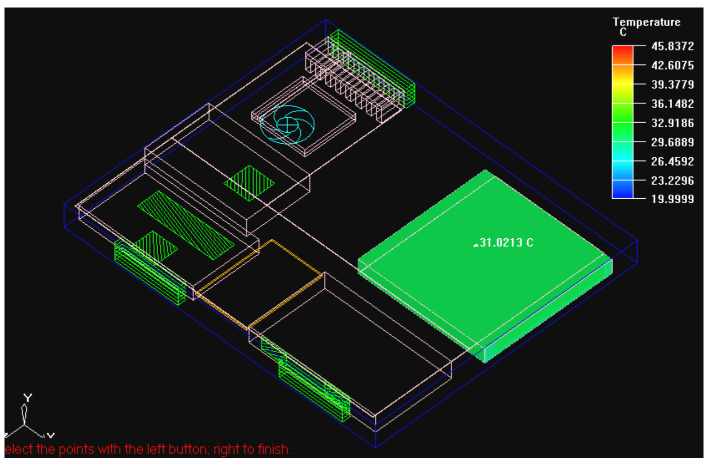


Figure 5.13 0.51mm DVD Drive

Results for heat spreader with 0.26mm thickness

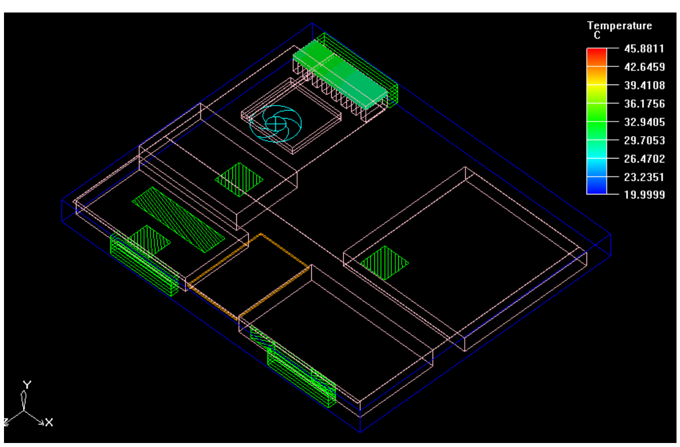


Figure 5.14 0.26mm Heat Sink

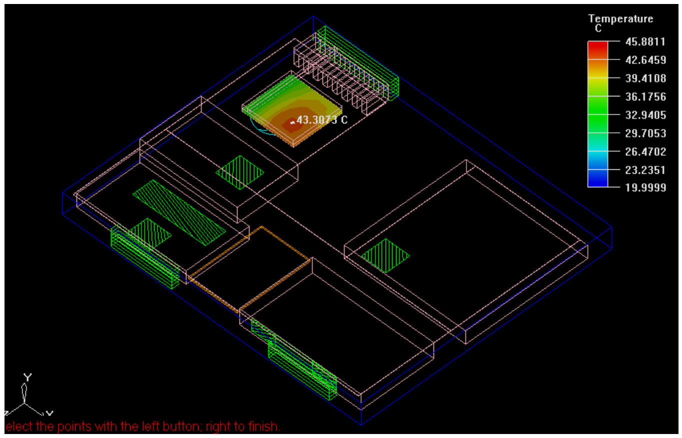


Figure 5.15 0.26mm Chip

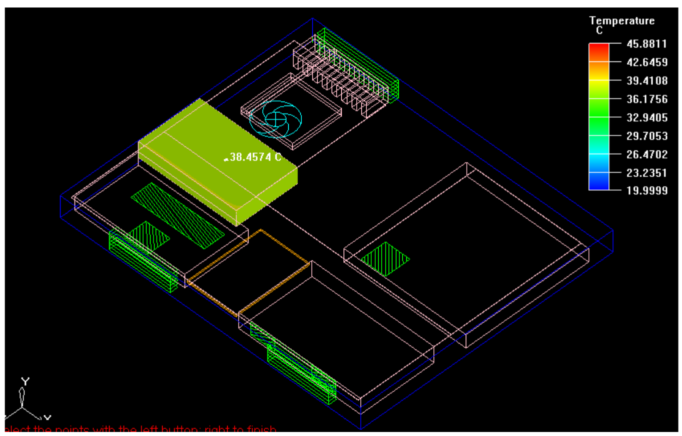


Figure 5.16 0.26mm PCMCIA

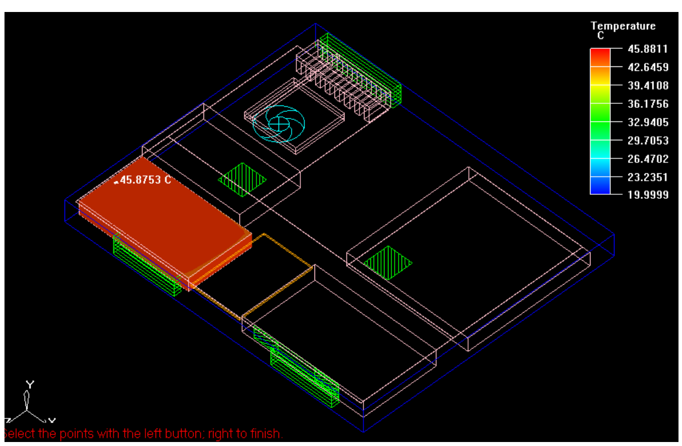


Figure 5.17 0.26mm Hard Drive

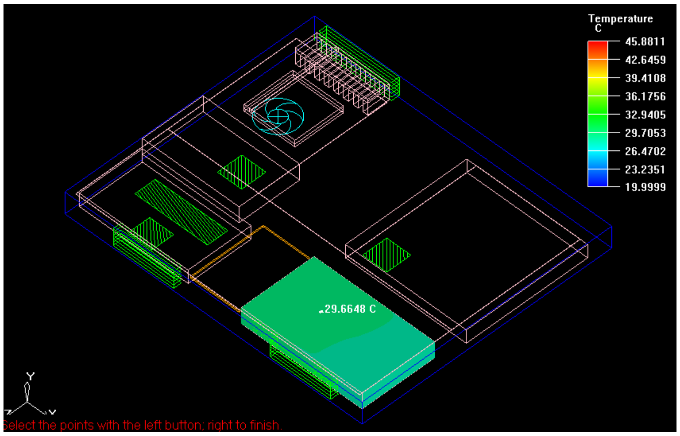


Figure 5.18 0.26mm Battery

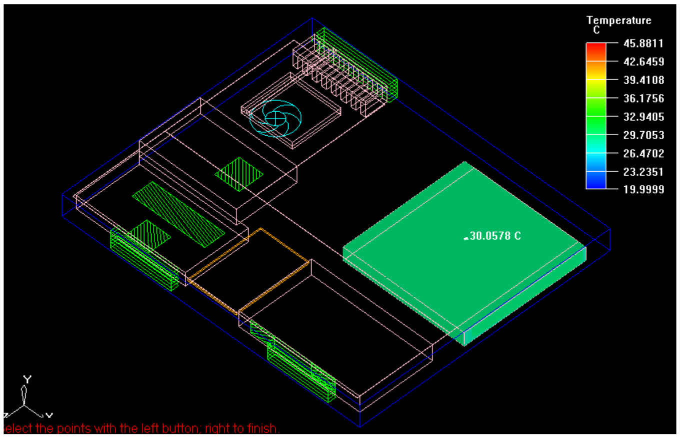


Figure 5.19 0.26mm DVD Drive

Results for heat spreader with 0.27mm thickness

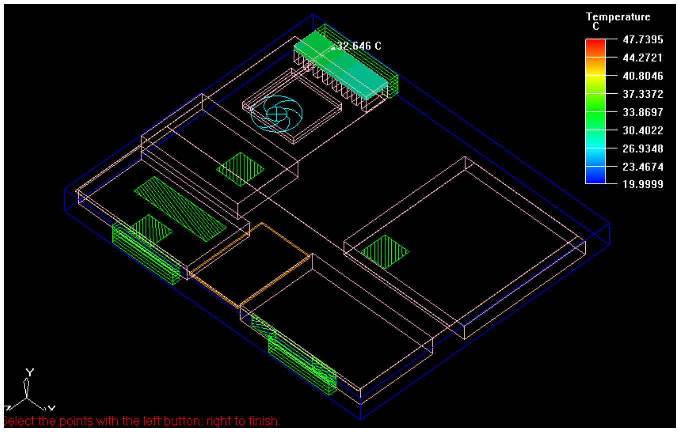


Figure 5.20 0.27mm Heat Sink

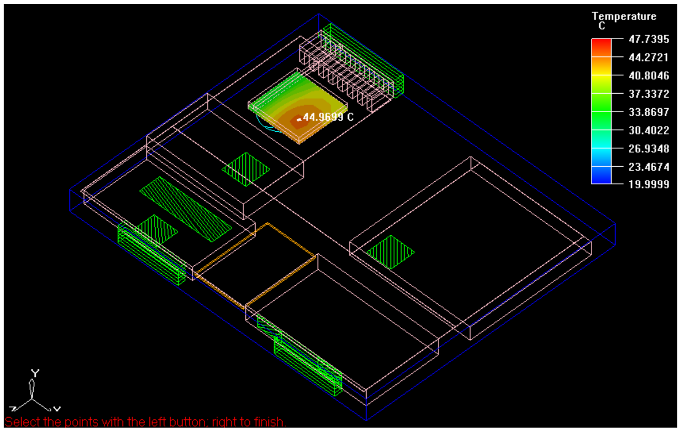


Figure 5.21 0.27mm Chip

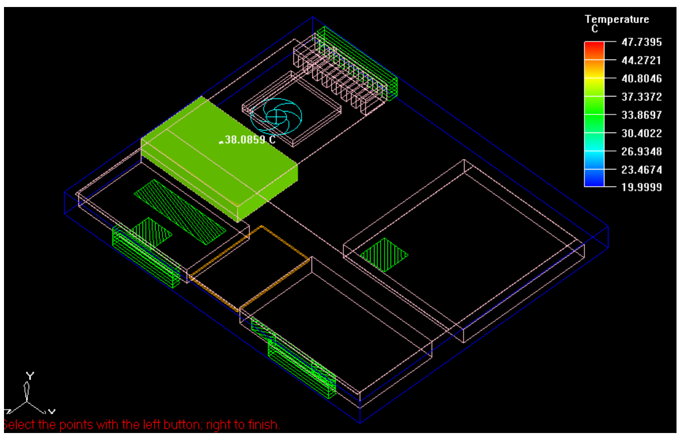


Figure 5.22 0.27mm PCMCIA

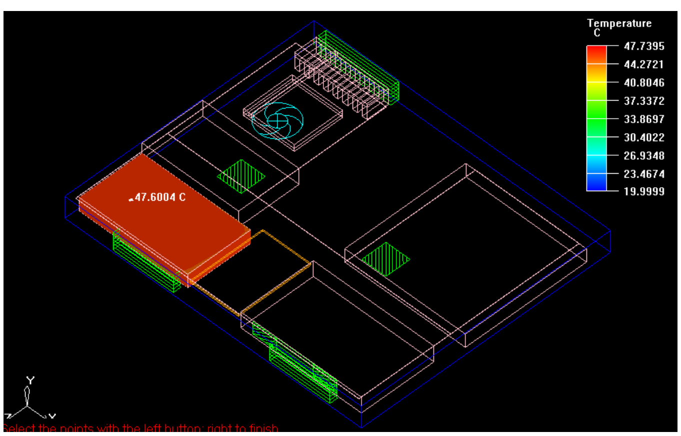


Figure 5.23 0.27mm Hard Drive

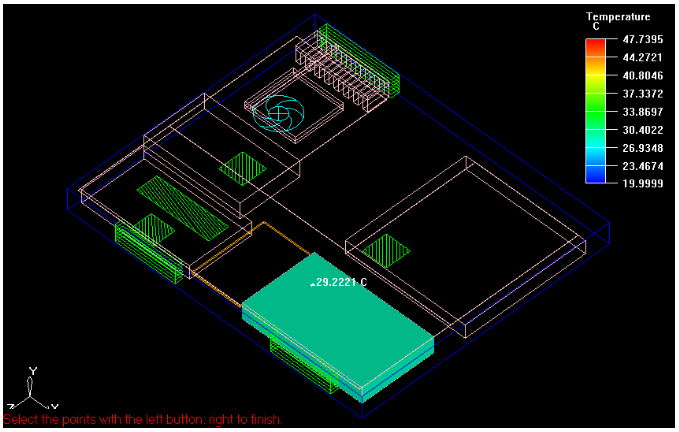


Figure 5.24 0.27mm Battery

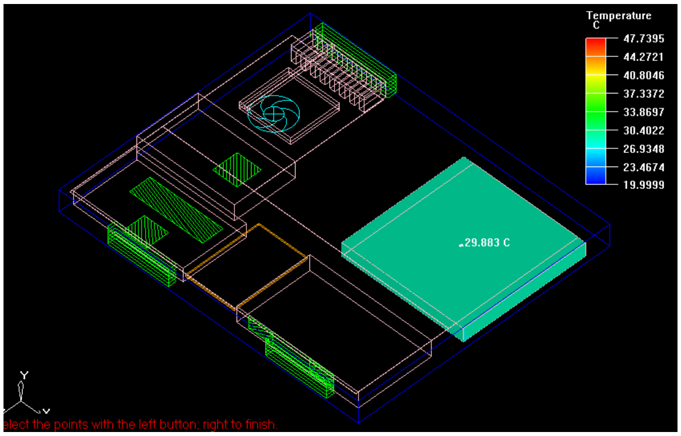


Figure 5.25 0.27mm DVD Drive

Results for heat spreader with 0.52mm thickness

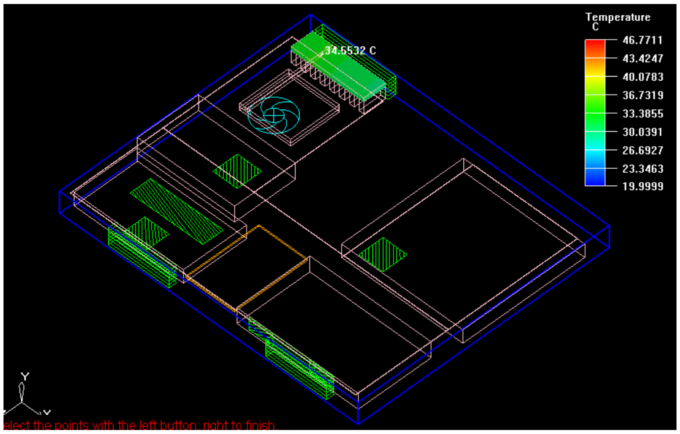


Figure 5.26 0.52mm Heat Sink

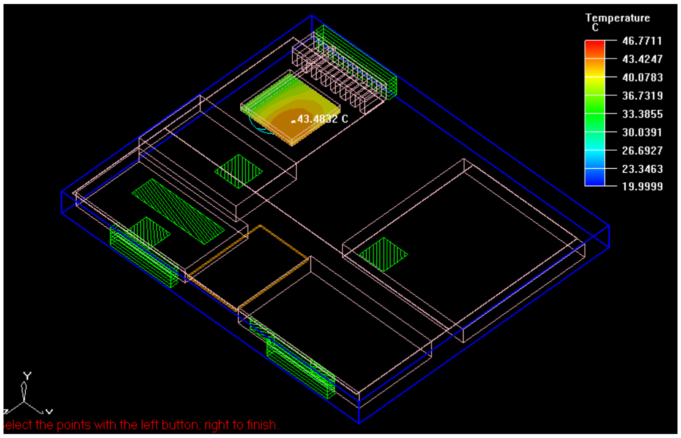


Figure 5.27 0.52mm Chip

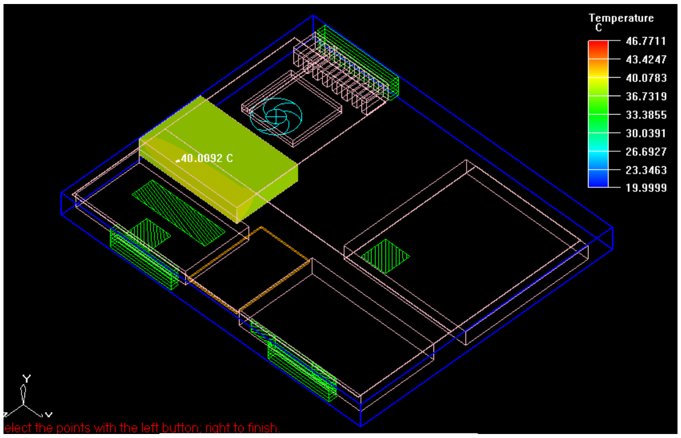


Figure 5.28 0.52mm PCMCIA

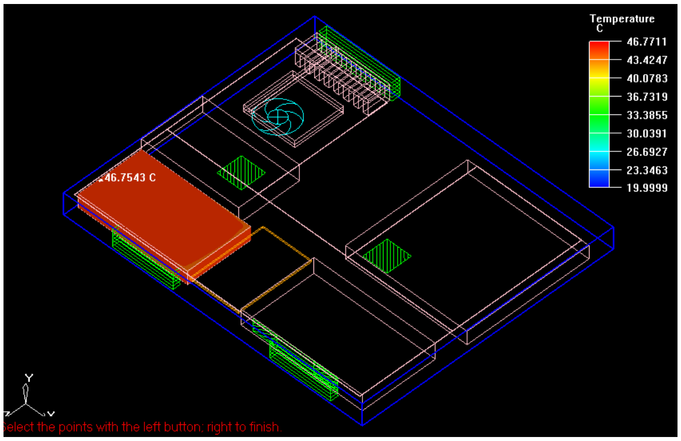


Figure 5.29 0.52mm Hard Drive

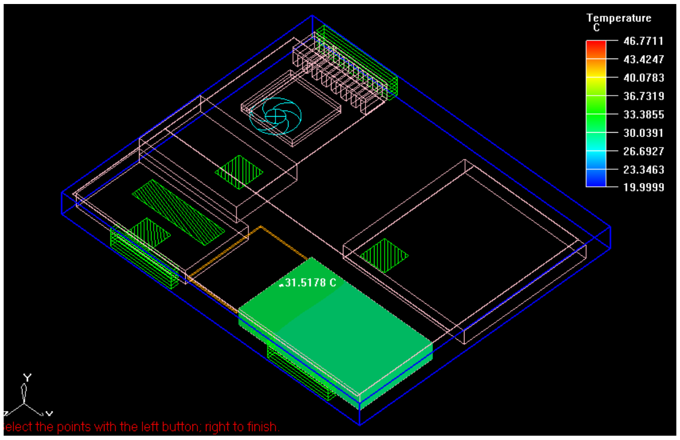


Figure 5.30 0.52mm Battery

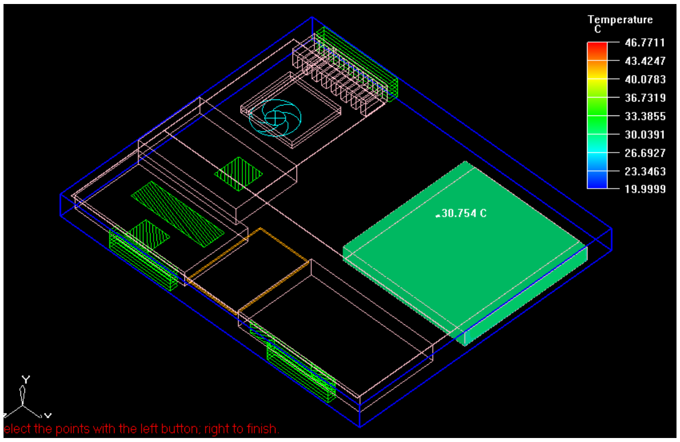


Figure 5.31 0.52mm DVD Drive

Results for without heat spreader

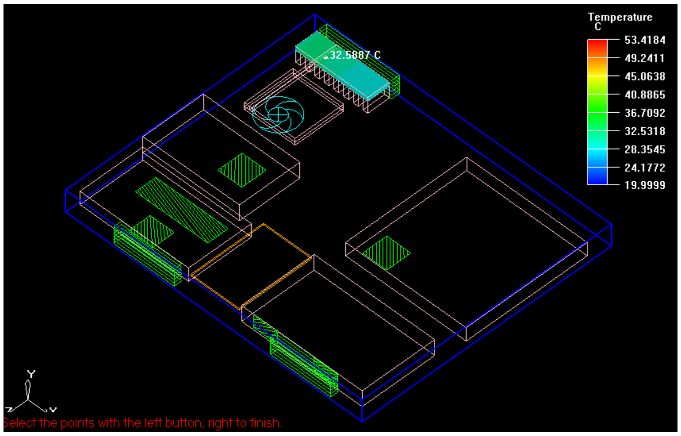


Figure 5.32 None Heat Sink

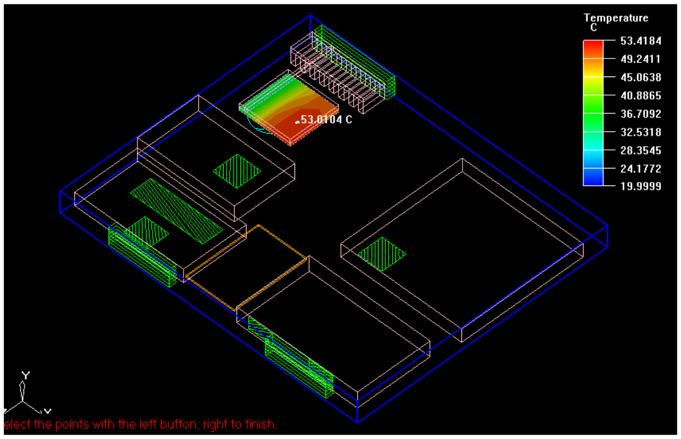


Figure 5.33 None Chip

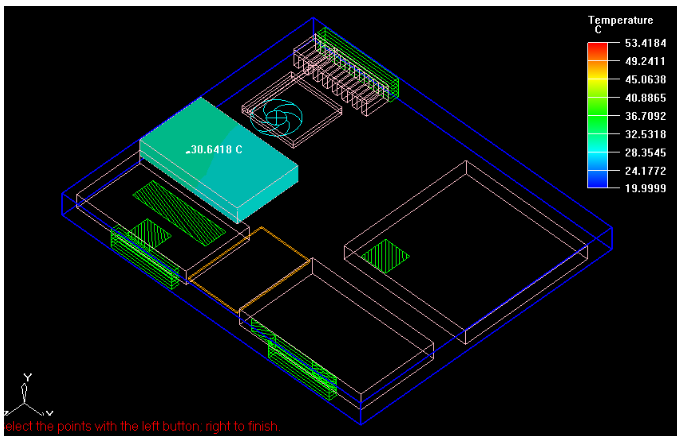


Figure 5.34 None PCMCIA

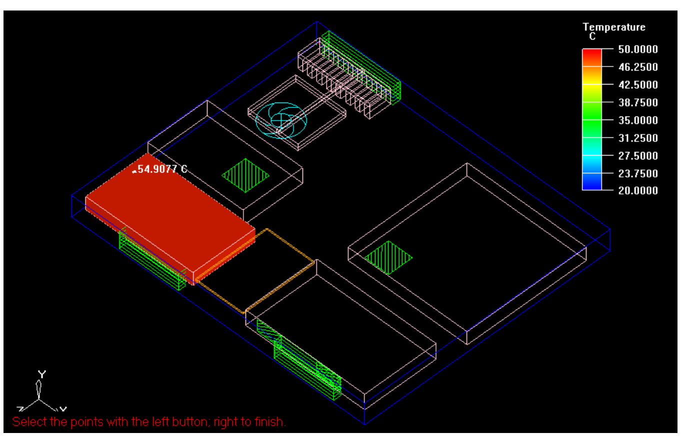


Figure 5.35 None Hard Drive

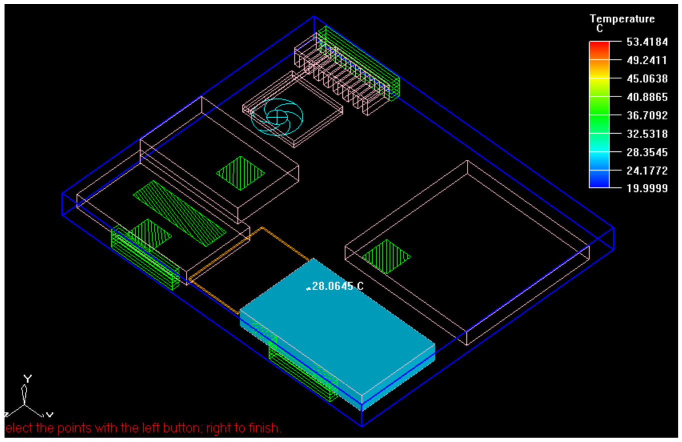


Figure 5.36 None Battery

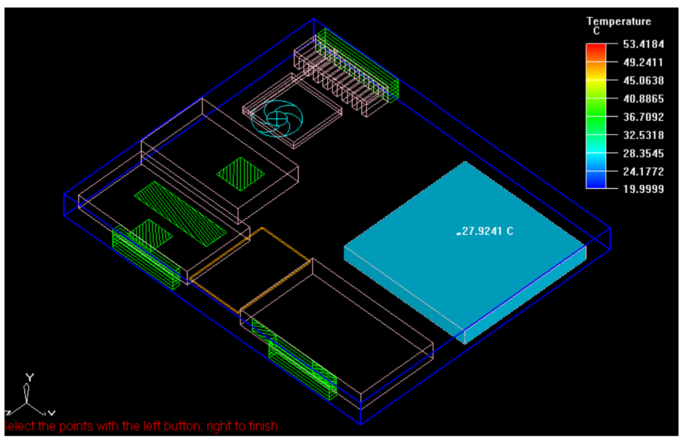


Figure 5.37 None DVD Drive

The table 5.2 shows all the results obtained and ca be compared easily. The temperature on different components in each case taken from the temperature contours are tabulated and compared to the table 4.5 in previous section to validate the results.

Table 5.2 Temperature Rise of Hardware Components					
Spreader Material	None	0.27 mm 234 W/mK	0.52 mm 275 W/mK	0.26 mm 393 W/mK	0.51 mm 369 W/mK
Heat Sink	12.5	12.6	14.5	13.1	13.8
CPU	23.0	25.0	23.5	23.3	22.8
PMCIA	10.6	18.0	20.0	18.4	19.4
Hard Drive	34.0	27.6	26.8	25.9	25.6
Battery	8.0	9.2	11.5	9.6	11.6
DVD Drive	7.9	9.8	10.7	10.0	11.0

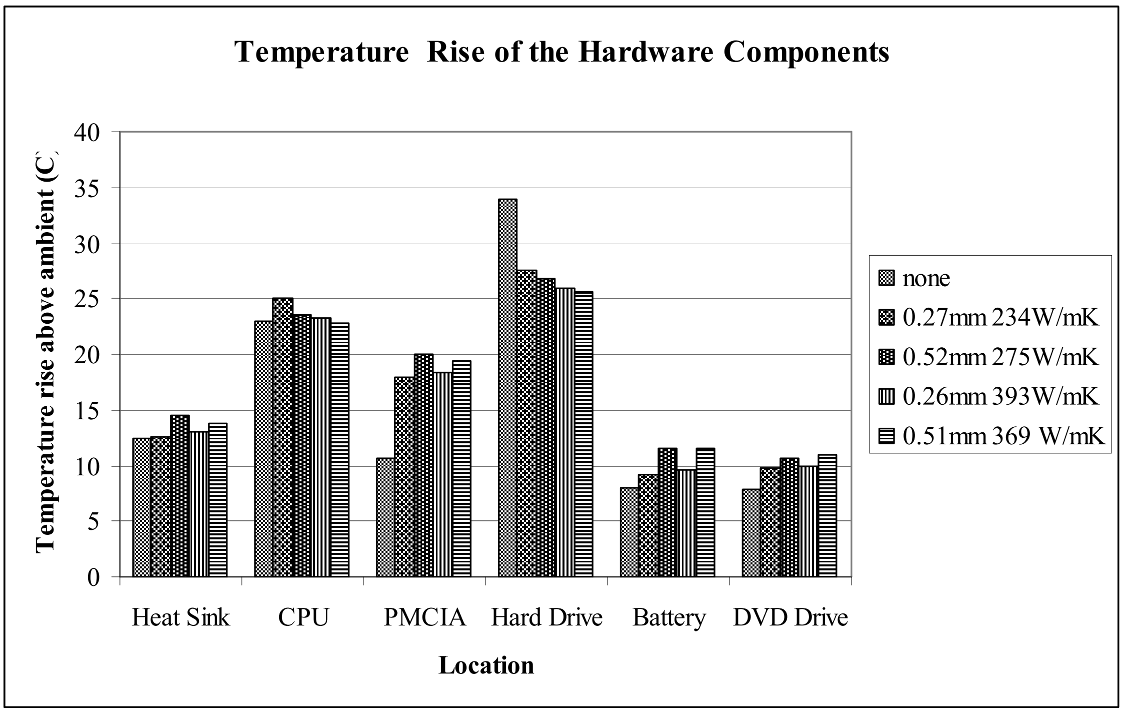


Figure 5.38 Temperature Rise on Hardware Components

From the previous results in the table 5.2 show that the best performance is by the heat spreader with thickness 0.51mm and thermal conductivity 369 W/mK. Then the temperature contours below show the temperature at three areas explained earlier.

Results for heat spreader with 0.51mm thickness

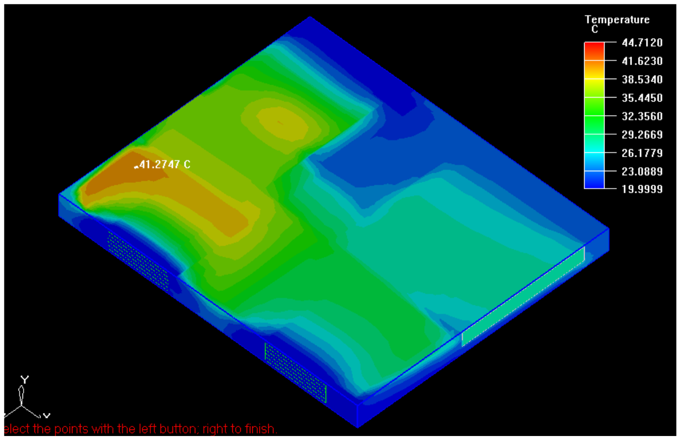


Figure 5.39 0.51mm A1

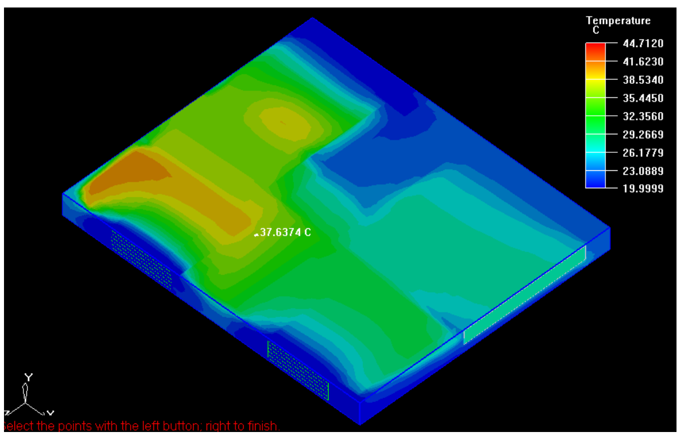


Figure 5.40 0.51mm A2

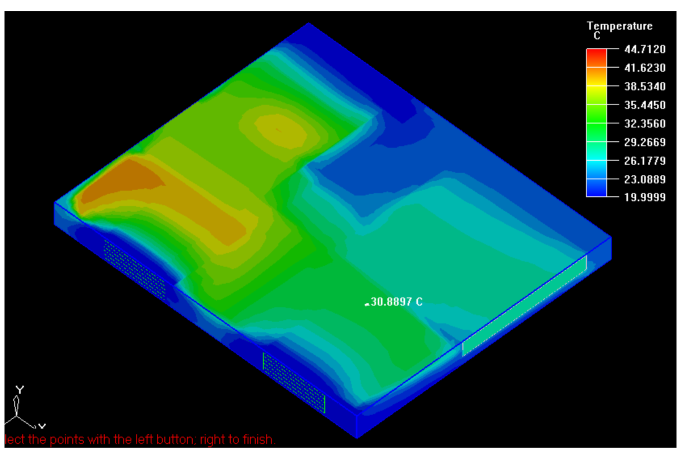


Figure 5.41 0.51mm A3

The results are tabulated combined with the values in table 5.1, which compares and shows the improvement in the thermal management of the laptop using heat spreaders. The table clearly shows the decrease in the temperature gradient from left to right, as this infers that the heat transfer is efficient and uniform using heat spreader.

Table 5.3
Thermal Performance of Laptop-Thermal Imaging Data

Spreader	Average Temperature Rise Above Ambient (°C)				A4 Ambient
	A1 Left Palm Rest	A2 Mouse Pad	A3 Right Palm Rest	ΔT Left to Right Palm Rest	
None	26.4	13.7	5.3	21.1	20.0
0.51 mm 369 W/mK	21.0	18.0	10.8	10.2	20.0

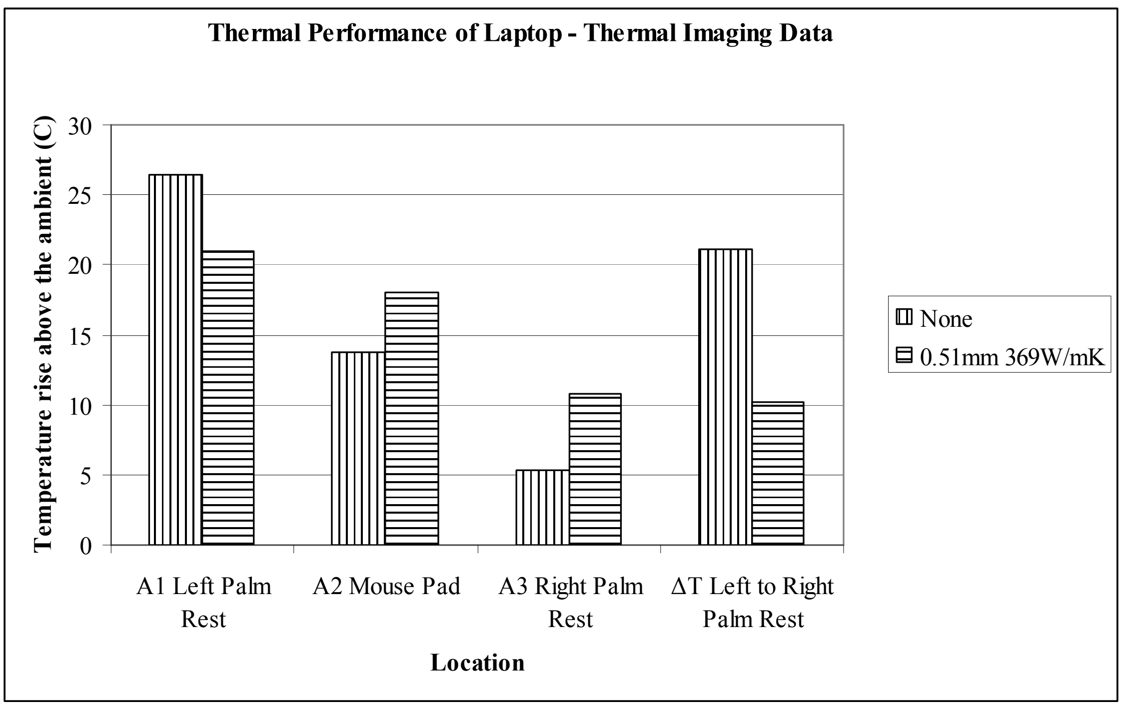


Figure 5.42 Thermal Performance of Laptop

As the material used for the heat spreader i.e. Graphite quiet an expensive so the size of the heat spreader so selected previously is modified from the shape show in fig 5.43 to the shape shown in the fig 5.44, in which again two heat spreaders are used one on the CPU Chip and other on the hard drive and battery but both having same properties. This modified model is analyzed and compared to the previous one

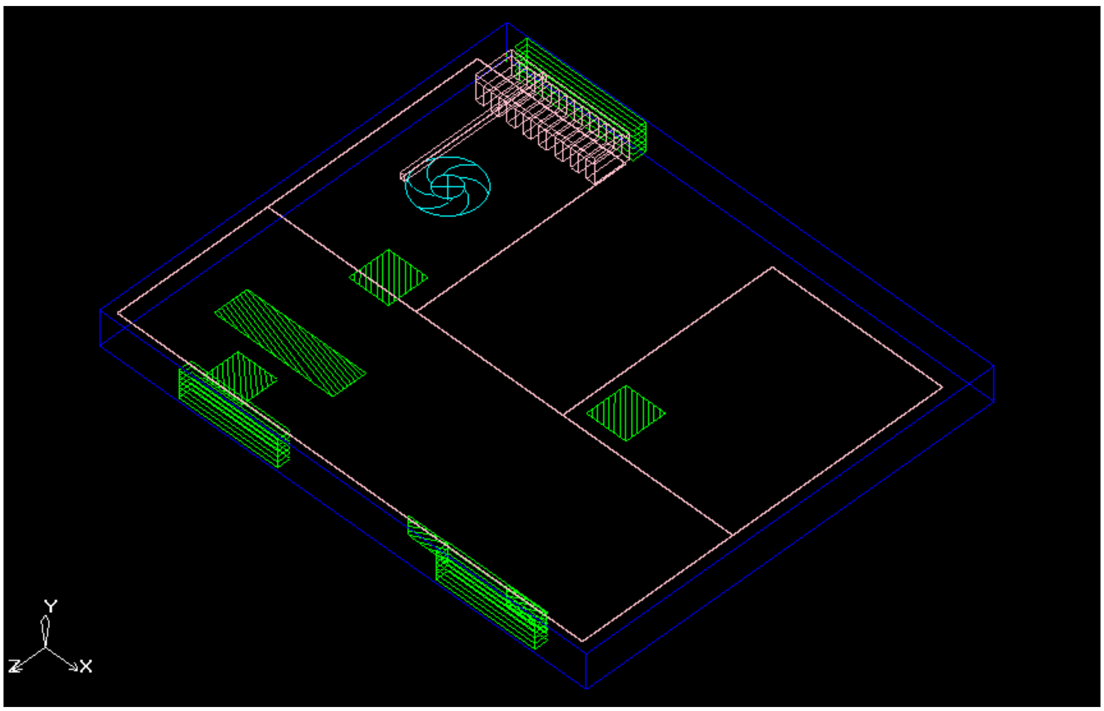


Figure 5.43 U- Shape

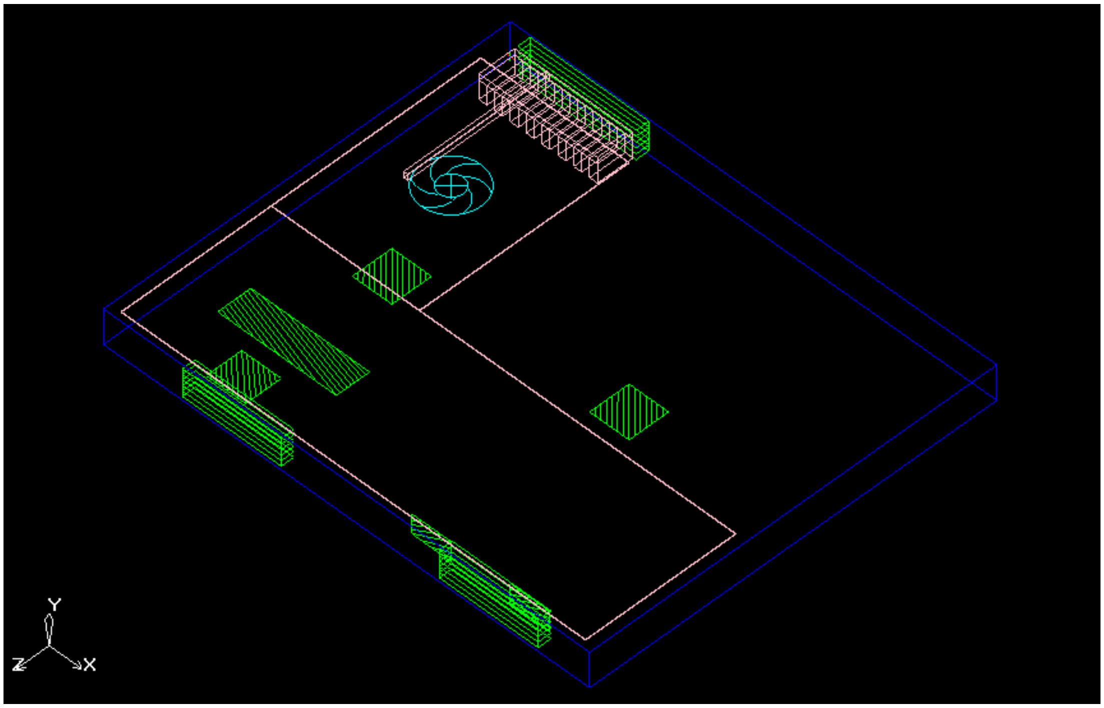


Figure 5.44 L-Shape

. Contours below give the results on modified laptop.

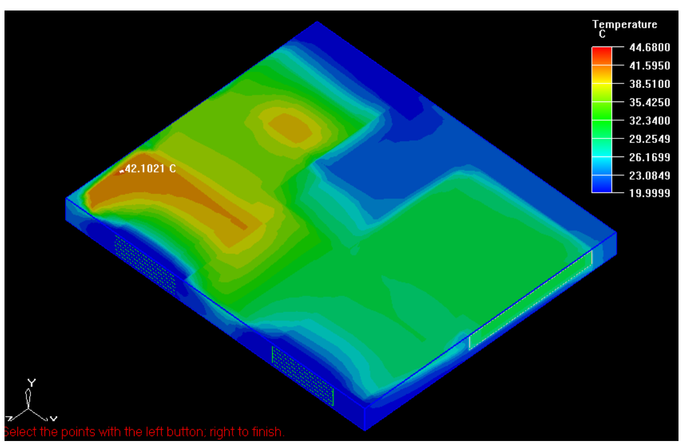


Figure 5.45 Modified A1

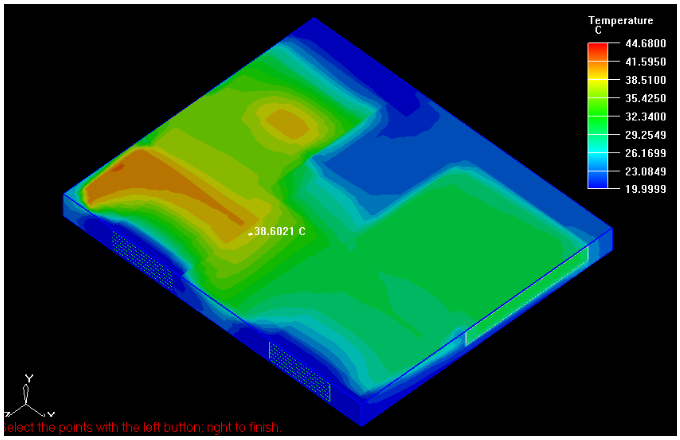


Figure 5.46 Modified A2

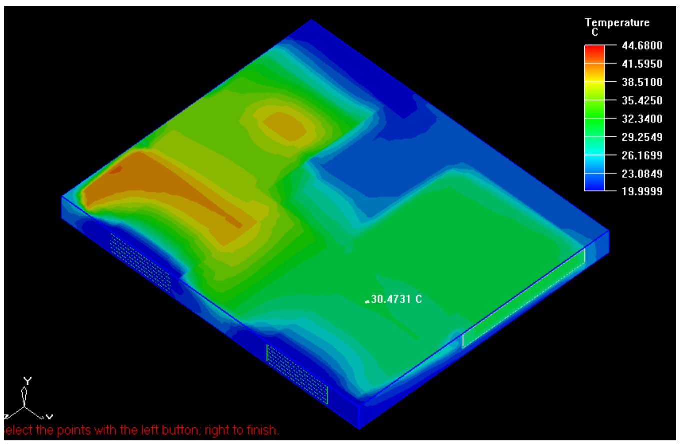


Figure 5.47 Modified A3

Temperature contours on the component bodies

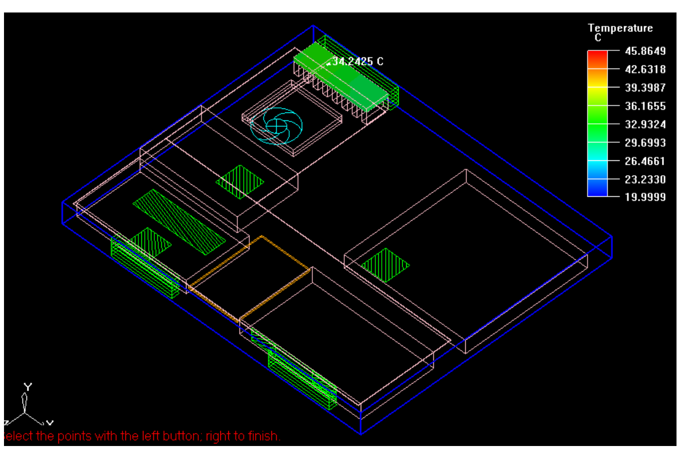


Figure 5.48 Modified Heat Sink

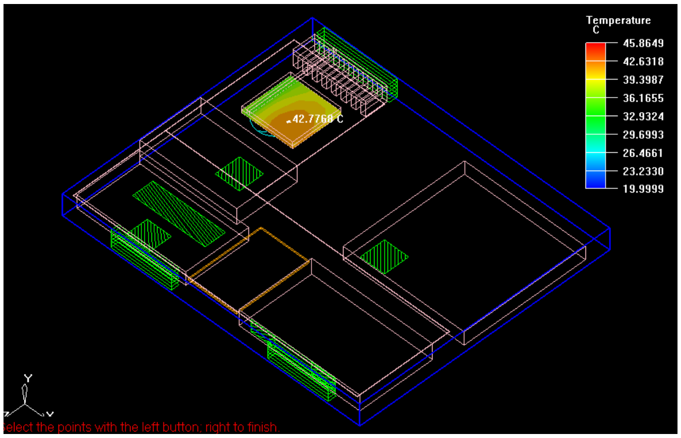


Figure 5.49 Modified Chip

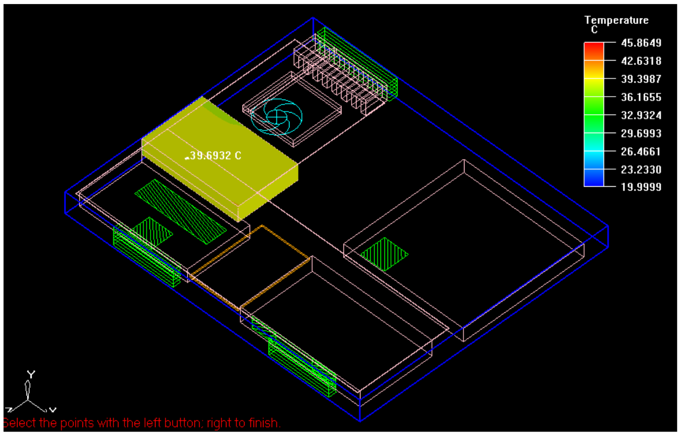


Figure 5.50 Modified PCMCIA

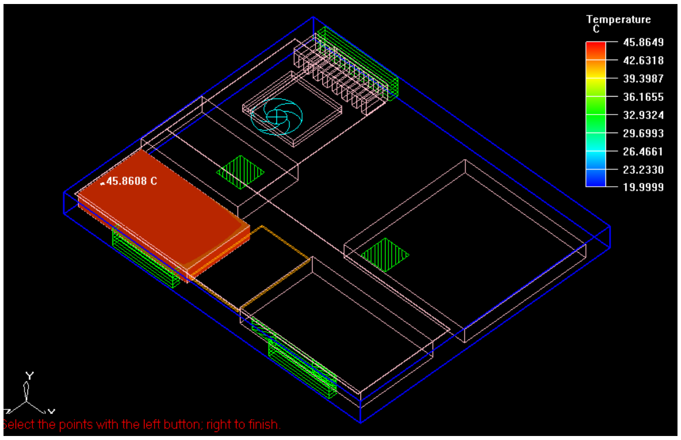


Figure 5.51 Modified Hard Drive

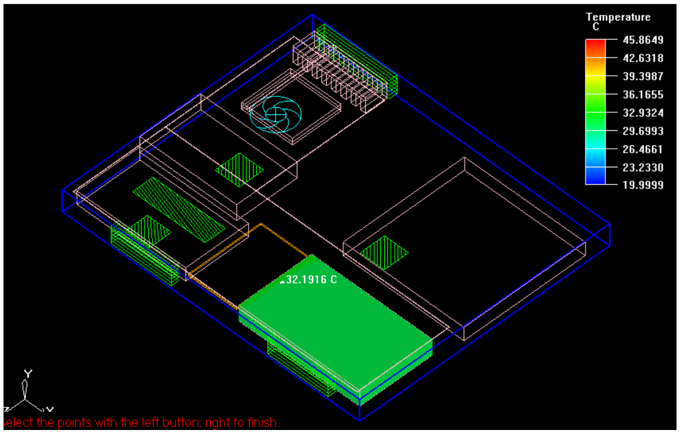


Figure 5.52 Modified Battery

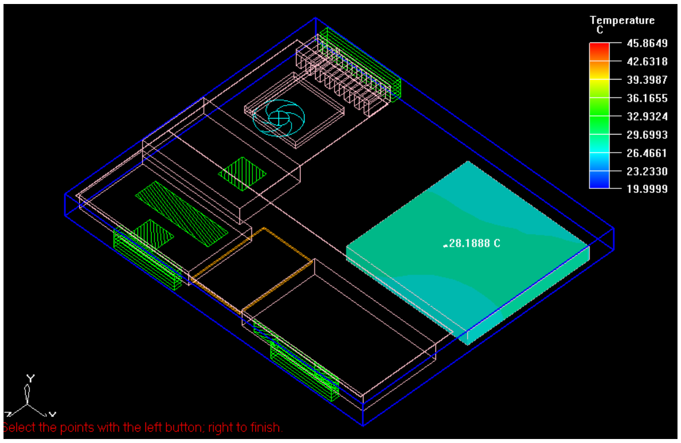


Figure 5.53 Modified DVD Drive

The tables below show the comparison between both the results. Finally the modified can be selected in the place of the older model as the results show that there is no much difference in the heat transfer if we reduce the spreader size, which is clear from the following tables.

Table 5.4 Thermal Performance of Laptop-Thermal Imaging Data					
Spreader	Average Temperature Rise Above Ambient (°C)				A4 Ambient
	A1 Left Palm Rest	A2 Mouse Pad	A3 Right Palm Rest	ΔT Left to Right Palm Rest	
0.51 mm 369 W/mK	21.0	18.0	10.8	10.2	20
Modified 0.51 mm 369 W/mK	22.1	18.6	10.4	11.7	20

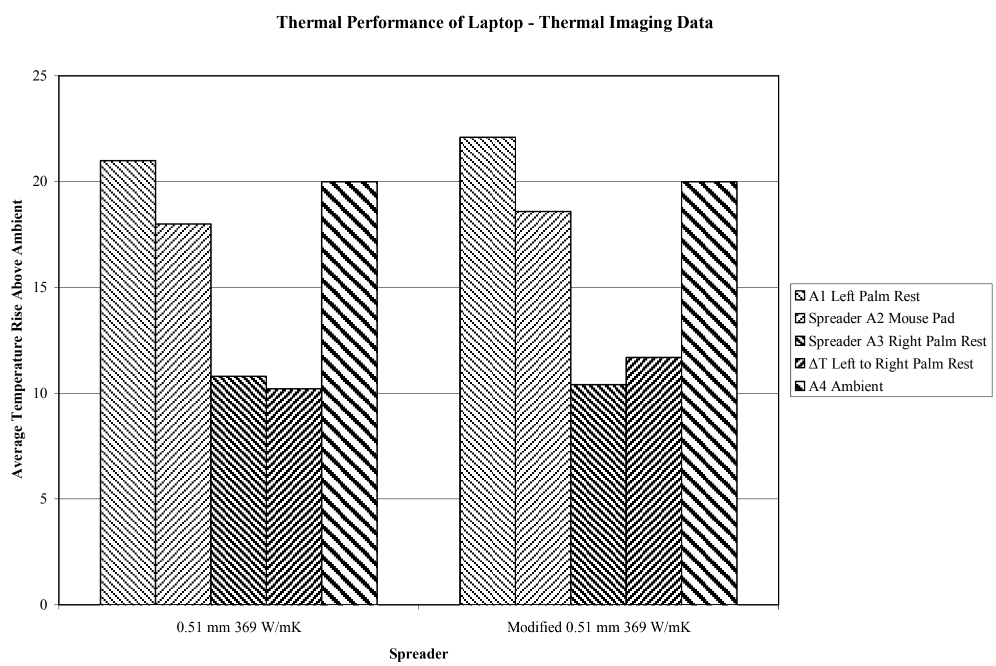


Figure 5.54 Comparison chart

Table 5.5 Temperature Rise of Hardware Components			
Spreader Material	None	Modified 0.51 mm 369 W/mK	0.51 mm 369 W/mK
Heat Sink	12.5	14.2	13.8
CPU	23	22.8	22.8
PMCIA	10.6	19.7	19.4
Hard Drive	34	25.9	25.6
Battery	8.0	12.2	11.6
DVD Drive	7.9	8.9	11.0

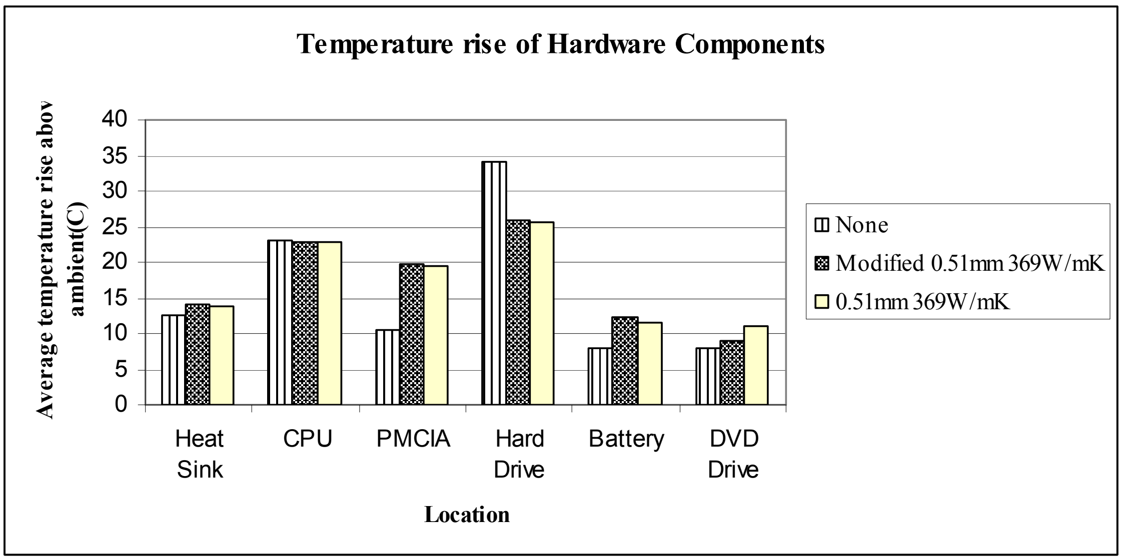


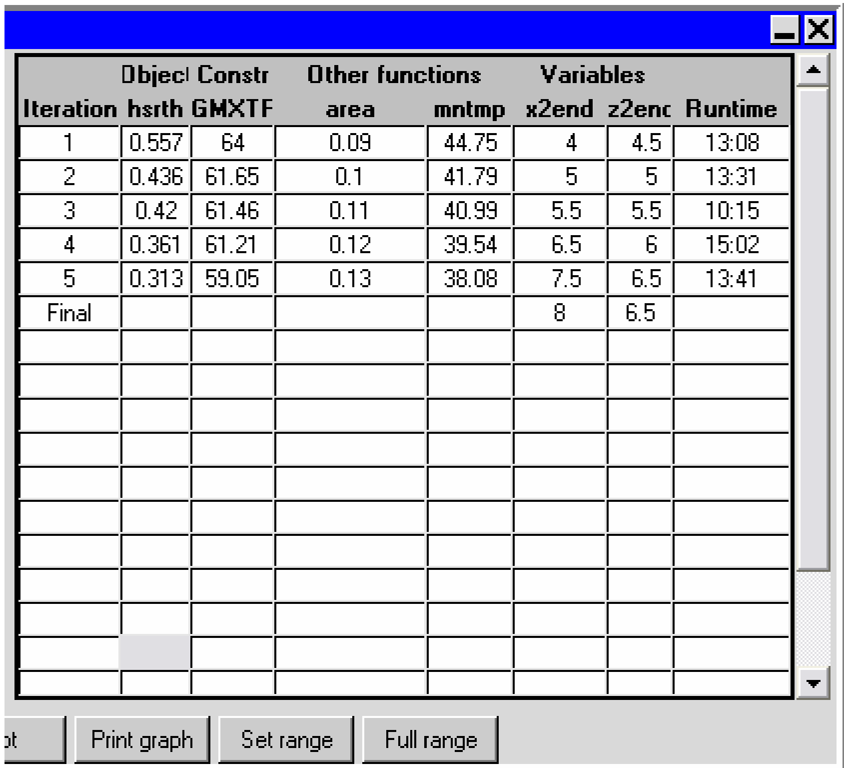
Figure 5.55 Temperature Rise on Hardware Components

5.4 Optimization of DELL 610

The model which is designed before is taken which has two heat spreaders in the design. The length and breadth of the heat spreader which is on hard drive and battery are kept constants. The length and breadth of the second heat spreader are defined as design variables. The global temperature of the system, spreader size and the touch temperature are the design constraints and the main objective function or goal is to minimize the resistance in the heat spreader.

Design variables are defined with a minimum, base and a maximum value. The increments are also assigned to them. Primary and compound functions are defined and the constraints are assigned for these functions. The objective function is among these functions which are minimized or maximized upon the constraints.

Design variables i.e. length has 4mm as minimum and maximum as 9 and breadth has 4.5 mm as minimum and maximum as 6.5, the increment multiplier is set as 0.5. Primary functions defined as Global temperature with maximum value constraint to 60 and mean temperature of the heat spreader. Compound functions defined as area of the heat spreader related as breadth multiplied to thickness and resistance of the heat spreader which again related as temperature gradient multiplied by the fraction of area to length. Then the solution is run to get the following results in figure 5.56



	Objec	Constr	Other functions		Variables		
Iteration	hsrth	GMXTF	area	mntmp	x2end	z2enc	Runtime
1	0.557	64	0.09	44.75	4	4.5	13:08
2	0.436	61.65	0.1	41.79	5	5	13:31
3	0.42	61.46	0.11	40.99	5.5	5.5	10:15
4	0.361	61.21	0.12	39.54	6.5	6	15:02
5	0.313	59.05	0.13	38.08	7.5	6.5	13:41
Final					8	6.5	

Figure 5.56 Optimization Results

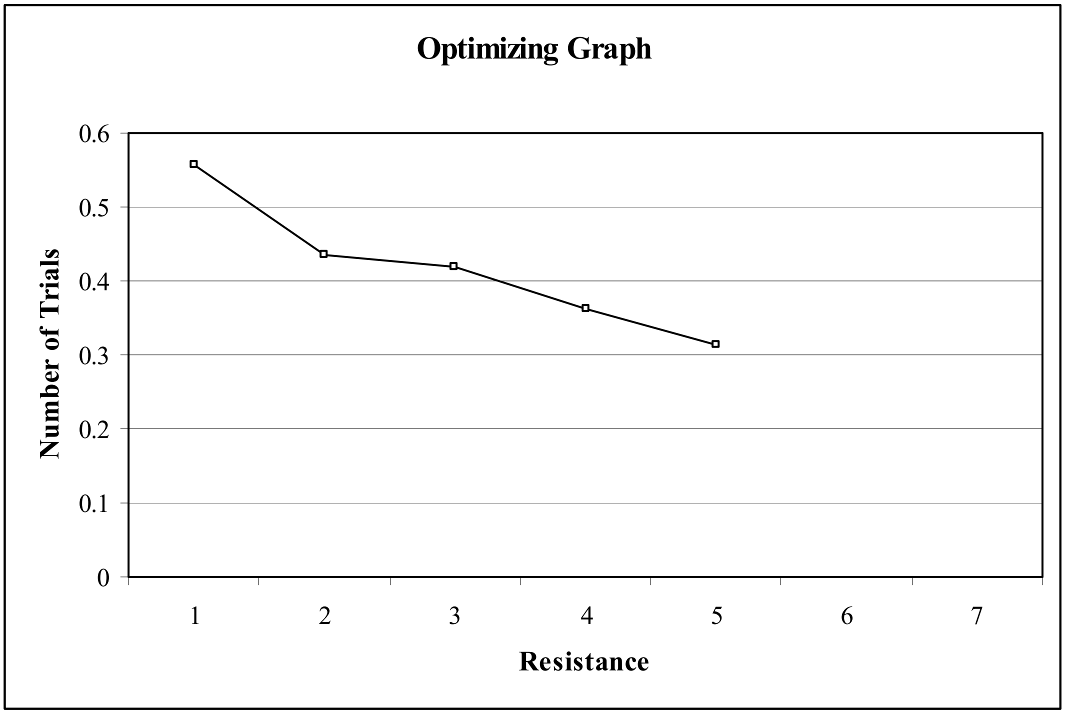


Figure 5.57 Optimization Graph

The above results show that the solution is convergent. In the 5th iteration the global temperature goes below the constraint value, this value is selected as the best one because the size should be as less as possible also. The optimum size of the heat spreader is 7.5 mm* 6.5mm* 0.87mm. The optimum value of the resistance of heat spreader is 0.313 ^{o}c/W.

5.5 Selection of Fan

The selection of the procedure is stated in the previous chapter. So if it goes in the same sequence the heat should be dissipated will be 140 W

Considering the equation (3.1)

r (sea level) = 1.225 kg/m^3

Cp = 1005 J/kg °C

We can use DT = 20°C. This gives us an airflow calculation as follows:

$$VF = \frac{140 \text{ watts}}{1005 \text{ J/kg °C} \times 1.225 \text{ kg/m}^3 \times 20 \text{ °C}}$$

$= 0.00567 \text{ m}^3/\text{sec} = 12 \text{ CFM}$

A Fan with its maximum rated airflow more than the required airflow rate and the solver is run for the different values of the air flow rate and the static pressure is taken as the results which in turn gives the system performance curve shown in figure 5.58.

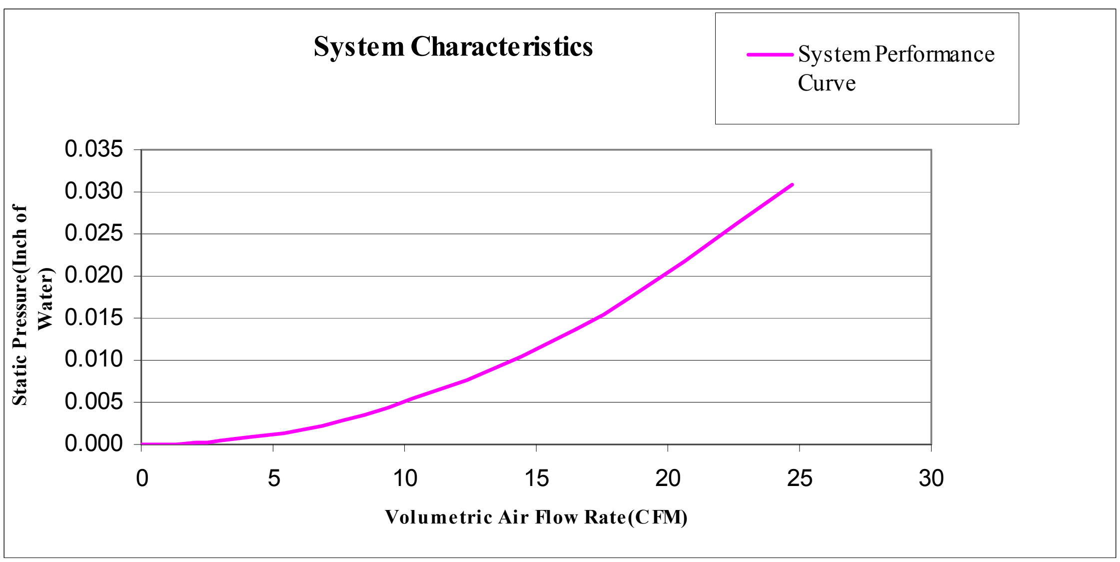


Figure 5.58 System Characteristics

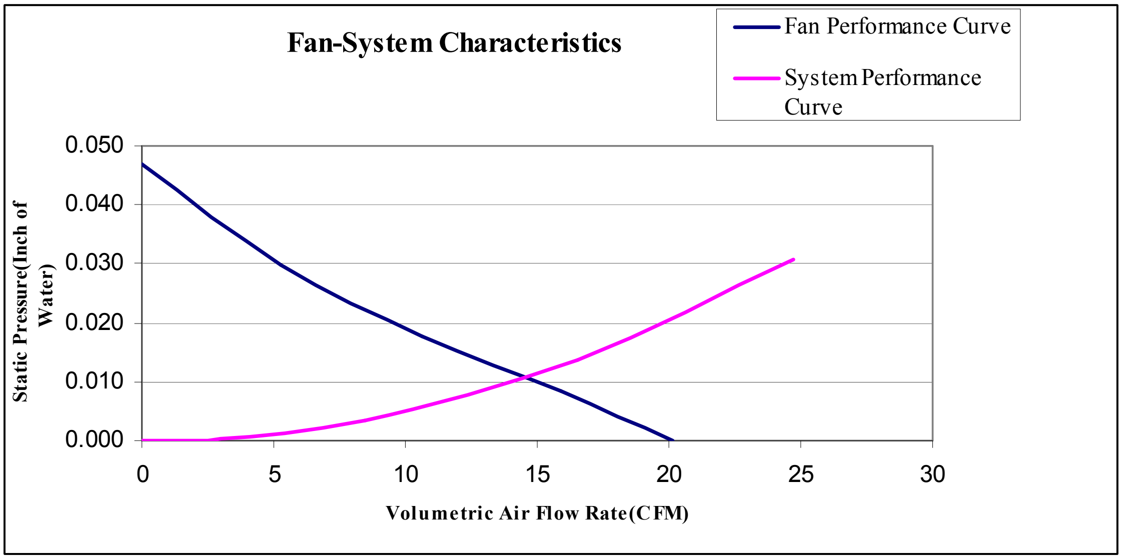


Figure 5.59 Fan System Characteristics

The curve above is super imposed by the fan performance which is shown in figure 5.59. As the operating point should be in the quarter where the static pressure is less and the flow rate should be more i.e. close to BEP. The system curve is shift to right by increasing the grill opening.

5.5.1 Relation of obstructions in the flow path of air

Macroflow is the tool used to find the air characteristics and how they change with an obstruction in the path. Figure 5.60 shows the result of the non-obstructed air flow in the system.

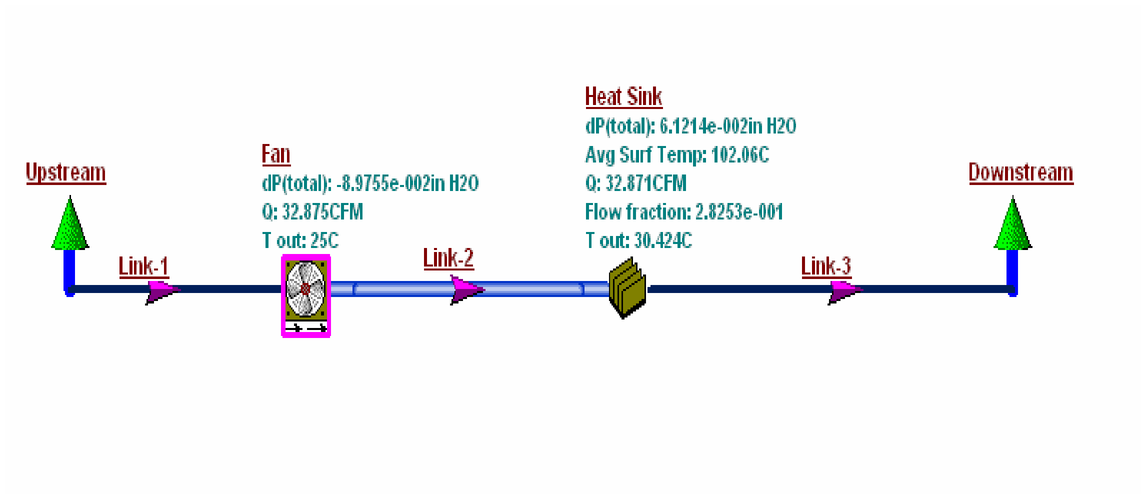


Figure 5.60 Free Flow

If the bend is placed in the path of the airflow as an obstruction and analyzed, the results are shown in the figure 5.61 below.

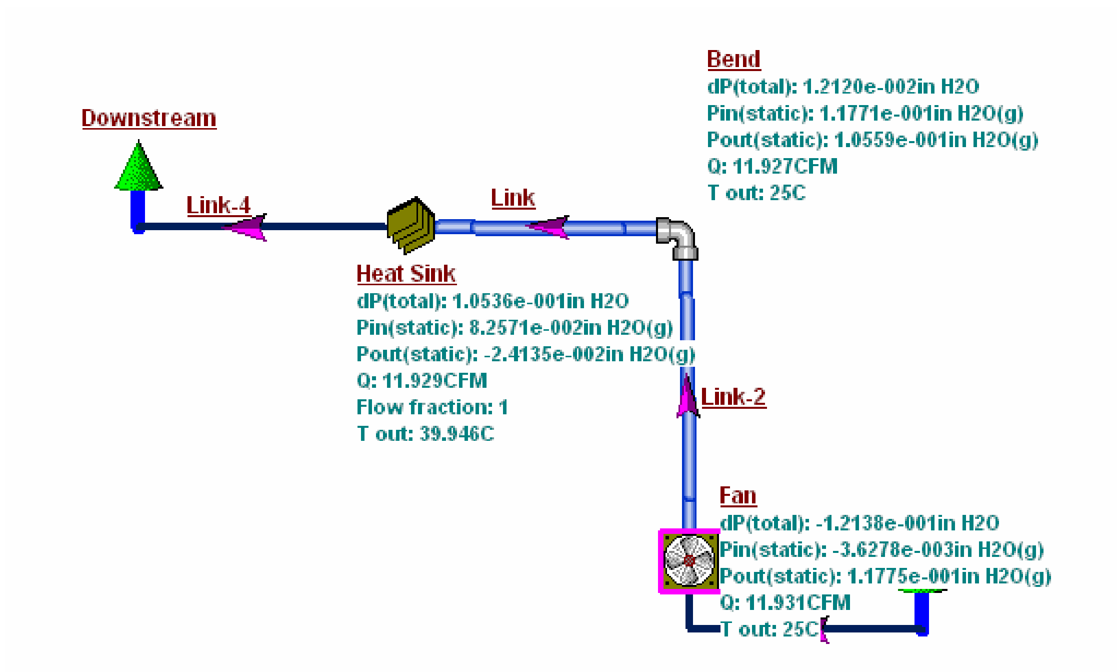


Figure 5.61 Flow Through Bend

The graph in Figure 5.62 shows how the system curve changes with obstruction (bend). It shows that the airflow rate reduces for the same amount of static pressure. So the airflow gradient is increasing as the value of the static pressure is increasing, as shown in Table 5.6

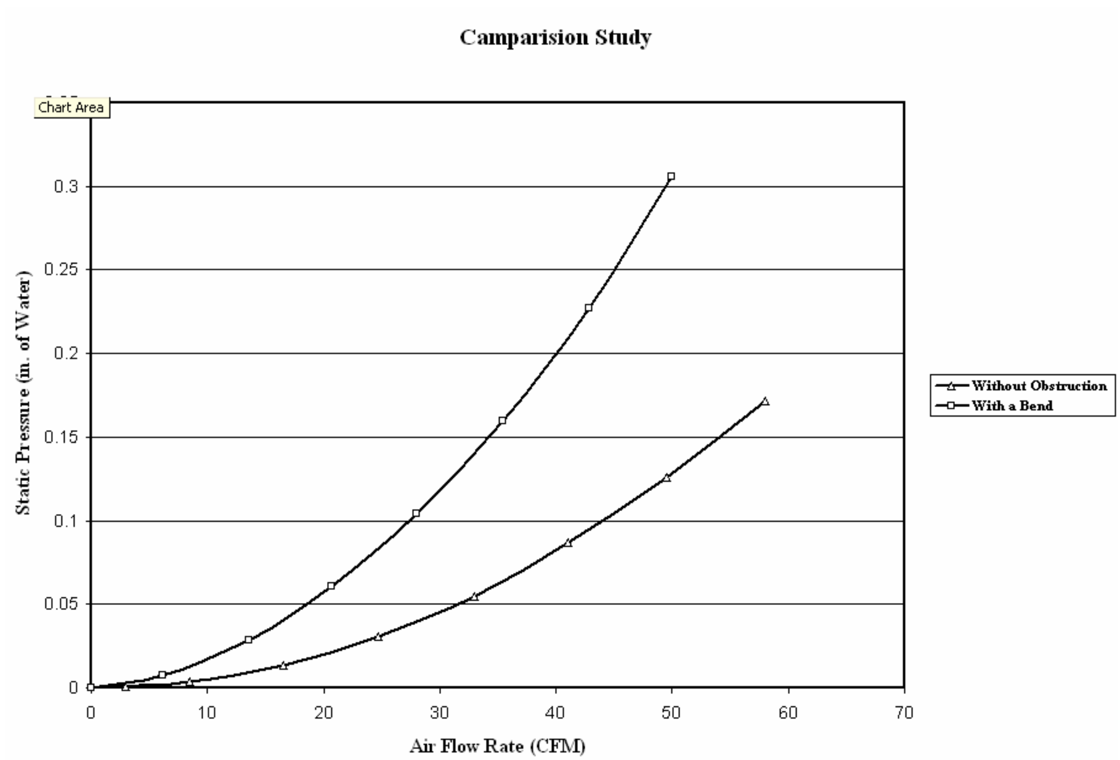


Figure 5.62 Comparison Study

Table 5.6 Airflow Characteristics			
Static Pressure (in of water)	0.05	0.1	0.15
Airflow Gradient (CFM)	14	16	20

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

The main objective of this work was to define a design thermal management for a laptop. Optimization of the heat spreader resistance and size is another goal of this research study. Icepak, a powerful computational fluid dynamics solver is used in this analysis for simulation and optimization. The simulation model is validated by the experimental measurements. Air flow rate characteristics are compared by the tool Macroflow.

6.1.1 Conclusions

Graphite is the best material for the heat spreader compared to the aluminum and copper as the graphite conductivity is same as copper and twice as aluminum, and the density of Graphite is much lesser compared to both aluminum and copper. Anisotropic property is also very important characteristic of Graphite which makes it the best of three. The thermal conductivity of the heat spreader will be almost equal to the standard heat sink used in a laptop. In low performance laptop Graphite heat spreader can replace a complex heat sink and heat pipe combination. In medium and high performance laptops these heat spreaders can be coupled with heat sink and heat pipe as the performance of the whole cooling system can be improved with out increasing the weight of the system. The results of all the heat spreaders used in the

DELL 610 are compared and the best heat spreader is selected on the basis of thickness and its in-plane thermal conductivity as they both should be high simultaneously as the resistance is inversely proportional to both the properties. CFD analysis was utilized to optimize the thermal performance of a Graphite heat spreader in thermal modeling tool, Icepak. Icepak is used to reduce the design complexities and time which ultimately result in reduction of the development cost and the introduction of a fully optimized heat spreader into the laptop marketplace [s3].

In selection of the fan, the best fan should have its operating point, which is the intersection point of the system performance and fan curves should be nearest possible to the BEP i.e. fan should deliver more air at lesser values of static pressure. If there is any obstruction in the airflow will increase the system resistance so the system curve moves towards left. The system resistance can be lowered by increasing grill openings.

6.1.2 Recommendations

1. Multi-disciplinary optimization can be used to improve the heat spreader performance.
2. The algorithm can be modified for parallel implementation and can be experimented to solve complex laptop design problems efficiently.
3. By optimizing heat sink and heat spreader simultaneously to solve optimization of complex laptop systems problem which in return increases the performance of the laptop and cooling system.
4. Other meta-modeling techniques that can handle large number of design variables should be explored.

REFERENCES

[1]. Martin Smalc, Gary Shives, Gary Chen, Shrishail Guggari and Julian Norley, "Thermal Performance Of Natural Graphite Heat Spreaders" IPACK2005-73073, ASME interPACK 2005.

[2]. Bob dehoff, Dr. Chong-Sheng wang and David Fast, "Thermal Optimization of a Radial Folded Fin Heat Sink for Desktop Computer Applications" Tyco Electronics.

[3]. S. Rao, Engineering Optimization – Theory and Practice. NY: John Wiley & Sons, Inc., 1996.

[4]. A. Menon, "Structural Optimization Using ANSYS and Regulated Mulquadratic Response Surface Model" AIAA 2005

[5]. Ashok D Belligundu and Tirupathi R. Chandrupatla, Optimization Concepts And Application in Engineering. Prentice Hall India

[6]. T. W. Simpson, A. J. Booker, D. Ghosh, A. A. Giunta, P. N. Koch and R.-J. Yang, "Approximation Methods in Multidisciplinary Analysis and Optimization-A Panel Discussion," Structural and Multidisciplinary Optimization, vol. 27, pp. 302-313, July. 2004

[7]. www.egraf.com

[8]. R. J. Gaeta, "The SDound Absorbing Potential of Carbon-Graphite Foam" 12th AIAA/CEAS Aeroacoustics Conference, AIAA 2006-2405

[9]. Ingard, U. Notes on Sound Absorption Technology, Noise Control Foundation, Poughkeepsie, NY, 1994.

[10]. Mike Turner, "All you need to know about fans" Electronics Cooling Online.

[11]. Vitaly Krinitsin, "Cooling Systems. Part 3: Complex Approach to Computer Cooling"

[12]. Vivek Mansingh, Chris Chapman, "System Fan Selection- A Little Planning Yields Big Results"

[13]. Vitaly Krinitsin, "Cooling systems. Part 2: fans, technical details"

[14]. Frankiln Kelecy, "Study Demonstrates that Simulation Can Accurately Predict Fan Performance" JA108

[15]. Roger Dickinson, "Low noise axial fan application" Torrington Research Company.

[16]. www.coolingzone.com

[17]. www.icepak.com

[18]. www.flentinc.com

BIOGRAPHICAL INFORMATION

Kranthi Kumar Manne Sambaiah was born on May 23rd, 1982 in Hanamkonda, India, the eldest son of Sambaiah Manne and Rama Devi Manne. He enrolled in National Institute of Technology Karnataka, Surathkal, Karnataka, India in 1999 and earned his B.E . (Bachelor in Engineering) in Mechanical Engineering in June 2003.In his senior year; he undertook an internship at the Electronics Corporation of India Ltd in India

Kranthi Kumar Manne Sambaiah had started his M.S. (Master of Science) degree in Mechanical Engineering at The University of Texas at Arlington, Arlington, Texas in August 2004 and earned M.S. Degree in Mechanical Engineering in December 2006 with a 3.25 G.P.A. His thesis was based on the development of a design and optimization using thermal design tool ICEPAK. His current research interests are electronic packaging, heat transfer, finite element methods and computer aided design.