



FORCED CONVECTION COOLING OF ELECTRONIC EQUIPMENT WITH HEAT SINK INCLUDING INCLINATION AND VIBRATION EFFECTS

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Abstract

The present investigation adopts Computational Fluid Dynamics CFD to analyze the problem of forced convection cooling of electronic equipment equipped with a heat sink, including inclination and vibration effects. Two fans were used to circulate the air inside the computer chassis. Three main components on the motherboard were used; Central Processor Unit (CPU), North Bridge, and South Bridge. These components generate heat at the rate of 3750, 2500, and 2222.22 kW/m³ respectively. Three different types of heat sink were used for CPU, these are: plate heat sink, radial heat sink without core, and radial heat sink with core. The other two main components on the motherboard used the same standard heat sink. The two fans are operated with different cases to specify the suitable operation. Inclination for the computer chassis and motherboard with vibration influence was also investigated. The power dissipation, fan flow rate, and ambient temperature are fixed. The results show that the radial heat sink with core enhances the heat transfer by reducing the temperature of the CPU. Also the influence of vibration has more effect in case of without heat sink, for other cases the influence of vibration is not affected in the investigated range. The effect of inclination angle for computer chassis also is not affected, just when the mother board inclination by 10° from top edge with vertical plane, the temperature reduction approximately 18°C in case without heat sink, 4.8°C with plate heat sink on CPU, 1°C in case with radial heat sink. The CFD analysis was validated with a thermal profile for real operation CPU, the results show good agreement with a mean deviation of (0.023). A radial heat sink with core reduce the temperature more than 114.5 °C compared without heat sink on CPU case.

Keywords:CFD, Forced Convection, Inclination and Vibration, Electronic Equipment Cooling, Heat Sink.

Nomenclature

t time, (s)

V velocity vector

P pressure, (N/m^2)

g acceleration gravity, (m/s^2)

T temperature, (K)

T_∞ Reference temperature, (K)

cfm Cubic foot per minute

V_v Maximum vibration velocity, (m/s)

f Frequency, (Hz)

a Amplitude, (mm)

Pr Prandtl number

G_k Turbulent kinetic energy due to the mean velocity gradients

G_b Turbulent kinetic energy due to the buoyancy

Y_M The contribution of the fluctuating dilatation in compressible turbulent to the overall dissipation rate

S source term

$C_{1\varepsilon}$, $C_{2\varepsilon}$, and $C_{3\varepsilon}$ Model constants

ρ density, (kg/m^3)

ν Kinematic viscosity, (m^2/s)

ρ_∞ Reference density, (kg/m^3)

β thermal expansion coefficient, K^{-1}

α Thermal diffusivity, (m^2/s)

μ_t Turbulent viscosity, ($kg/(s.m)$)

φ_{CA} Case to ambient thermal characterization, ($^\circ C/W$)

I. Introduction

Due to the rapid development in using the electronic equipment in all fields of life, the researchers focus on expanding the scientific research which cares about solving the increase in temperature for electronic equipment. The increase in

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temperature is one of the factors that cause damage to electronic equipment, in addition to other factors such as vibration, moisture, and dust. The thermal factor has influence reaches a ratio of 55%. Manufacturing and design of electronic equipment including great challenges, thermal one considers one of these challenges. Increasing in temperature leads not only to just damage for electronic equipment, but also reducing the efficiency of the system, and cause many logic errors in the system. So it is an important to design a cooling system suitable for the quantity of heat generated, and this system must be able to reduce the maximum temperature for equipment and make it not exceed (70-85°C). In (1960), the number of electronic equipment was within the limits (50-1000) in a single chip, while this number increases and reach to 10^9 in electronic equipment with (3cm*3cm) sizing. The quantity of heat dissipated from the electronic equipment specifies the method that must be used for cooling. There are many types of cooling such as natural convection with radiation, using direct air during forced convection, immersion the electronic equipment in special liquid during natural convection or forced convection heat transfer. Electronic equipment is found in many application starts from household appliance and toys and ending with big systems such as, missiles, aircraft, submarine, ships,..etc.[III]. Some previous researches study the cooling in electronic equipment and focus on some parameters during the study. Emre, 2004 [IV] investigated the heat sink with different size and geometry, place the heat sink above the CPU, and the temperature distribution evaluated numerically by using ANSYS fluent software. The results compared with different work having same parameter and showed good agreement. The study focused on the temperature distribution on the CPU heat sink. The turbulence, mesh resolution discretization and other factors investigated to get less computationally expensive scheme. The temperature results compared with the experimental one. The results numerically showed good agreement with experiment. Chiang et al. 2005 [XI] studied numerically the heat transfer from desktop computer, different locations of fans examined. The investigation focuses on the locations of fans on the wall and the inlet Reynolds number. The results showed that mode four is better than the other modes. Selin et al. 2009 [XIX] investigated the heat transfer and fluid flow in electronic system with CFD and the experimental work related with building promoters for cooling electronic system. The heat transfer coefficients are calculated in single circuit systems with different Reynolds numbers at laminar flow, different locations and geometries with several vortex promoters are used. Also studied the effect of the distance for heat sources. The results showed that when using single heat source, using different shapes of promoters, the maximum temperature decreased when using triangular vortex promoter, 320 K was the maximum temperature with this type. The rectangular promoter when placed after heat source this appeared that the heat transfer coefficient before the heat source is higher and lead to enhance in cooling for electronic system. When using two heat sources with different Reynolds numbers, the distance between two heat sources studied (30 mm and 10 mm) distance used; the results showed that the temperature increased when compared with single heat source. Konget al. 2010 [XVIII] studied the passive enhancement of heat transfer from the computer case. This investigation focuses on studying the parameters; orientations and locations of fans, and the opening of the computer case. The temperature over a heated element obtained

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numerically. The high vortices obtained poor heat dissipation; also the range of vortices was investigated. Farouq2015 [V] investigated the effect of natural convection using single phase fluid with the enclosure, and used forced convection to cool the electronic equipment. Water and air as working fluid used with an enclosure have a rectangular shape, the air passing through the device for computers. Fan installed at the outer side of the case that is found on the back of the computer. The maximum temperature level 85 °C and the enclosure design to keep the maximum value for temperature. Power dissipation from a CPU varies 15-40 W. The study investigated the problem experimentally and numerically. ANSYS-Icepack was used to investigate this study numerically, to simulate the temperature and flow distribution for the cooling system and computer. The experimental size for geometry has the same geometry for the numerical investigations. The results showed both the maximum temperature and heat transfer variation by changing the cavity size. The experimental results showed a good agreement with the results obtained numerically by variation approximately 3.5 %. The maximum temperature kept under 77°C. When using water as a working fluid and using a heat source 40 W, 65% of the CPU power for fan saved, also the vibration and noise reduced. Jalaletal. 2018 [X,XII], investigated experimentally the cooling in the desktop computer with heat sink. The heat sink used is blocked. The heat transfer and fluid flow inside the computer investigated experimentally and numerically. The cooling done under forced convection with flow velocity (1.2, 1.8, and 2.4) m/s. Focus on changing the magnitude of power and inlet air. The results showed good agreement between the experimental and numerical. The temperature of component decreased linearly with increasing the velocity of air. Also the same researcher studied the cooling of CPU with the finned heat sink. The results showed that pattern 1 have higher efficiency to dissipate heat. The vibration influence on natural convection heat transfer from wire was investigated by Robert 1955 [XVII]. Sreenivasan 1960 [XIII] studied the effect of vibration on heat transfer for cylinder under forced convection. The effect of vibration on heat transfer from a sphere, and also the effect of vibration on heat transfer from rectangular plate, fin arrays, vertical channel, and cylinder, was studied by Baxi et al. 1969 [II], N.D. etal. 1974 [XV], Nageetal. 1982 [XVI], Shung etal. [XX,XXI]. Hiba and Hussain 2019 [VIII] investigated numerically the cooling of PCB by natural convection with vibration and inclination effects. The study used the perforated fins heat sink. The study focused on cooling single component (CPU). Two types of heat sinks used, solid fins heat sink and other perforated fins. The CPU dissipated power approximately 30W. The results showed that the vibration and inclination effects led to reduce temperature.

The present work investigates the effect of fan operation cases (suction or blowing). Also, three types of heat sink, radial heat sink with core, radial heat sink without core and plate heat sink placed on CPU are examined under inclination and vibration effects, and compared with a case without a heat sink. The system used in the study is computer chassis with inclination and vibration effects. The PCB inside the computer chassis (motherboard) also examined with the inclination effect of its position.

II. Definition of the Problem

The present numerical study considers the computer chassis shown in fig.1. The model analysis is three dimensional. The study focuses on temperature distribution and evaluated the maximum temperature in the entire model, under the effects of vibration and inclination. Forced convection is created by using two fans, one on the outer wall side chassis and the other place above the CPU. The flow is considered turbulent. The working fluid is air with properties; thermal conductivity (0.0268 w/m.k), specific heat (1006 j/kg.k), density (1.134 kg/m^3) and viscosity ($1.88 \cdot 10^{-5} \text{ kg/m.s}$).

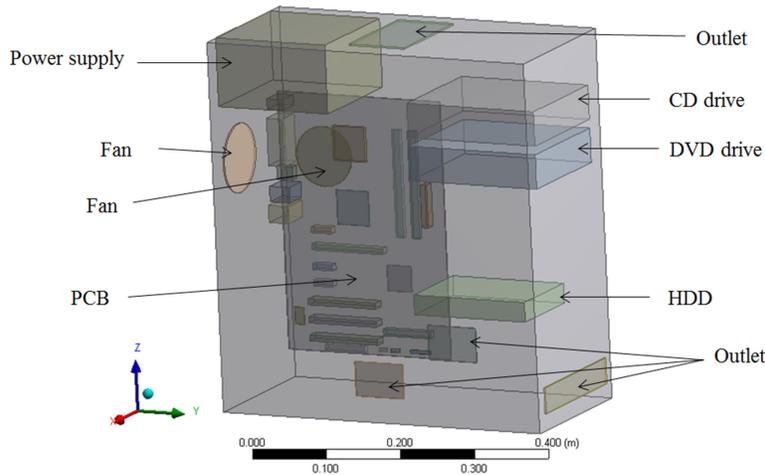


Fig.1: Schematic of the computer chassis

The dimensions and materials for the important parts are shown in table 1 and material properties shown in table 2.

Table 1: Dimensions and materials for some important part of the model

Component	Lenght*Width*Hieght (cm)	Material
Computer case	40*18*43	Aluminum
Motherboard	20.5*0.2*30	Fr-4
CPU	4*0.5*4	Silicon
North bridge	4*0.2*4	Silicon
South bridge	3*0.2*3	Silicon
CD&DVD-room	16*14*4	Aluminum
Hard disk drive	14*10*2.3	Aluminum
Power supply	13.8*14*8	Aluminum

Table 2:Material properties for model

Material	Thermal conductivity [w/m.k]	Specific heat [j/kg.k]	Density [kg/m ³]
Aluminum	202.4	871	2719
Silicon	150	710	2300
Fr-4	0.35	1300	1250

The motherboard type (GA-EP31-DS3L) is used, the heat dissipation from the important parts of CPU, North Bridge, and South Bridge are 3750, 2500, and 2222.22kW/m³ respectively. All the other parts remain off and placed in the analysis to show the effect of fluid flow on heat transfer. The simulation is done with 35°C for ambient temperature. The fans are modeled as a lumped system with a circular shape. The fan operation was done with different cases and then specified the best case for future study. The fan in the computer wall operation is in case of suction or blowing, the flow case of the CPU fan is blowing because the air at the domain cannot be heated too much in comparison with the sucking fan. Two cases for the motherboard are examined; without and with heat sink. The second case consists of three types of heat sinks; plate heat sink on the CPU, radial heat sink without a core on CPU, and radial heat sink with a core on the CPU, all are made of Aluminum. The study used the same heat sink geometry on both south bridge and north bridge components. The objects with these different types of heat sinks become very complicated, thus it takes more time to complete the analysis. Both of the north bridge heat sink, south bridge and CPU heat sink geometries are recreated by measuring the dimensions of the actual heat sink for these parts, as shown in (fig. 2).

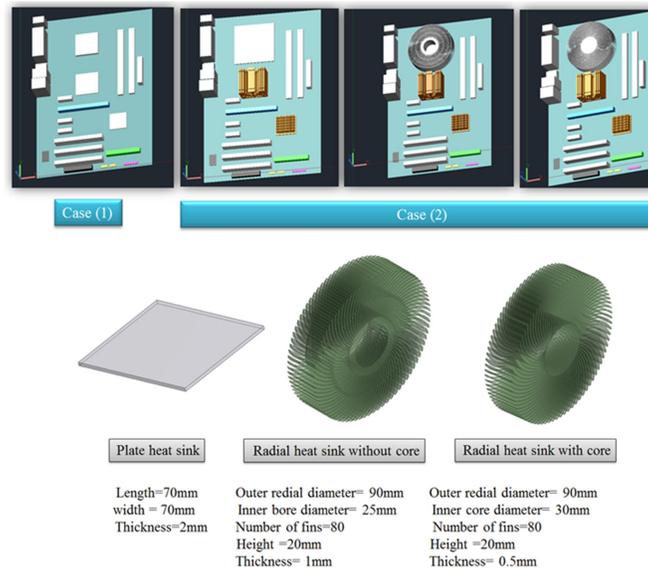


Fig.2:Schematic of the motherboard cases and CPU heat sinks

III. Mathematical Model and Governing Equations

Steady state, incompressible ideal gas, negligible radiation, three dimensional and turbulent flow are assumed. The elasticity of parts during vibration is neglected to simplify the solution.

The governing equations are continuity, momentum, and energy equation for the problem are listed below;

$$\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right) = 0 \tag{1}$$

Where; (u,v,w) are the velocities in x,y,z directions.

Momentum equation;

$$\rho (V \cdot \nabla V) = g - \nabla p + \nu \nabla^2 V \tag{2}$$

Boussinesq approximation also accounted in this analysis;

$$\rho = \rho_\infty [1 - \beta(T - T_\infty)] \tag{3}$$

Energy equation;

$$V \cdot \nabla T = \alpha \nabla \cdot (\nabla T) \tag{4}$$

The k-ε model was used for turbulence.

Turbulent kinetic energy k;

$$\frac{\partial}{\partial t} (\rho k) + \frac{\partial}{\partial x_i} (\rho k u_i) + \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{Pr_k} \right) \frac{\partial k}{\partial x_j} \right] + G_k + G_b - \rho \varepsilon - Y_M + S_K \tag{5}$$

And the turbulent dissipation rate ε;

$$\frac{\partial}{\partial t} (\rho \varepsilon) + \frac{\partial}{\partial x_i} (\rho \varepsilon u_i) + \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{Pr_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + C_{1\varepsilon} \frac{\varepsilon}{k} (G_k + C_{3\varepsilon} G_b) - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k} + S_\varepsilon \tag{6}$$

$$C_{1\varepsilon} = 1.44, C_{2\varepsilon} = 1.92$$

$$C_{3\varepsilon} = \tanh \left| \frac{V}{u} \right|$$

$$G_k = -\rho \overline{u_i' u_j'} \frac{\partial u_j}{\partial x_i} \tag{7}$$

$$G_b = \beta g_i \frac{\mu_t}{Pr_t} \frac{\partial T}{\partial x_i} \tag{8}$$

The turbulent Pr for k and ε are given by $\sigma_k = 1$ and $\sigma_\varepsilon = 1.3$

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$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \tag{9}$$

The flow rate for fans are taken as 55 cfm (0.026 m³/s) with 90mm diameter. The air outside the computer chassis is considered stagnant, the temperature for all walls of computer chassis is taken as 35°C, the outlet pressure is atmospheric.

The investigated vibration frequencies are (0, 2, 5, 9, and 16Hz) and 3mm amplitude. All parts of the computer chassis move under maximum vibration velocity, whose magnitude is evaluated as Wu-Shung [XX,XXI];

$$\text{Vibration velocity; } V_v = 2\pi f a \cos(2\pi f t) \tag{10}$$

$$\text{Maximum vibration velocity; } V_v = 2\pi f a \tag{11}$$

IV. Numerical Simulation

An ANSYS FLUENT software program was used to analyze the problem. The grid was generated by dividing the model into small cells and high quality. Polyhedral mesh was used, this type of mesh has good accuracy and suitable for complex geometries. When compared between three types of mesh hexahedral, tetrahedral and polyhedral in convergence, accuracy, element account and time required to complete run, the polyhedral mesh is the best [XIV,I,VI,VII]. The grid selected is fine with high roughness. The grid independence test is shown in (fig.3). The number of elements is (2725963) cells in case without heat sink, at which the value of maximum temperature for CPU does not change.

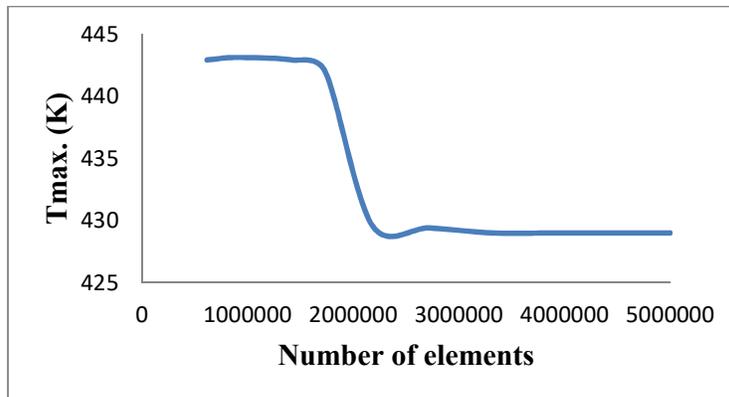


Fig.3:Grid Independency Test GIT

V. Validation of the Numerical Scheme

No direct results or correlation founds for validation the software code for this complex model. The validation does with the thermal profile data for CPU found in the data sheet [IX]. Thermal profile plots between the maximum temperature and power dissipation from CPU. CPU with dimensions (37.5*37.5*5)mm, the heat sink specification taken from the data sheet, the ambient temperature 38°C, and range of

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power dissipation (20-100)W. The volume flow rate equal to 25 cfm, the volume flow rate of the fan selected under the case to ambient thermal ($\phi_{CA} = 0.29 \text{ }^\circ\text{C/W}$).

$$\text{Where; } \phi_{CA} = \frac{T_{max} - T_{\infty}}{P} \quad (12)$$

Fig. 4 shows the deviation between thermal profile data evaluated and data founded from the data sheet.

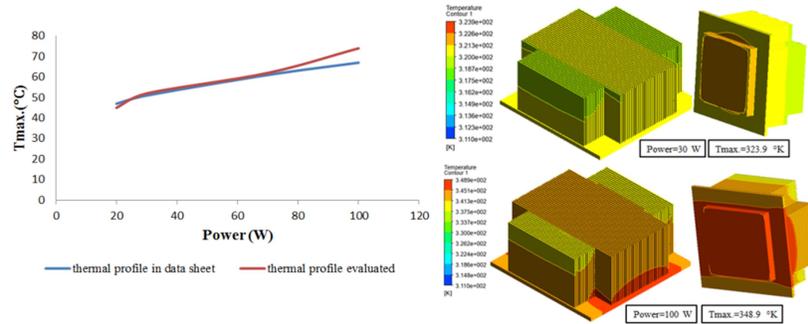


Fig.4: Comparison between thermal profile data from the data sheet and data evaluated by ANSYS code with some contours

The deviation was calculated to be approximately (0.023) by using the following expression;

$$\text{Deviation} = \sqrt{\frac{Q}{K}} \quad (13)$$

$$Q = \sum_1^K (\log x_{data\ sheet} - \log x_{evaluated})^2 \quad (14)$$

Where; Q: sum of the squared errors and K: number of data

VI. Results and Discussions

• Effect of fan operations

The computer chassis was analyzed with different types of fan operations. Two fans used in this model, one on the computer chassis wall and the other above CPU. Two types of flow were investigated, parallel flow generated by the fan in the computer chassis wall and impinging flow generated by the fan above CPU. Fig.5 shows the results of five fan operations, in case without any heat sink above the component on the PCB. When the outer fan blowing the air inside the computer chassis, and the CPU fan with impinging flow on, the results show a reduction in the maximum temperature inside the computer chassis, this is due to the resistance for distributing air flow compared to other cases. Also in this case lead to more exchange in air flow and more disturbance. Accordingly, this case is adopted for future study.

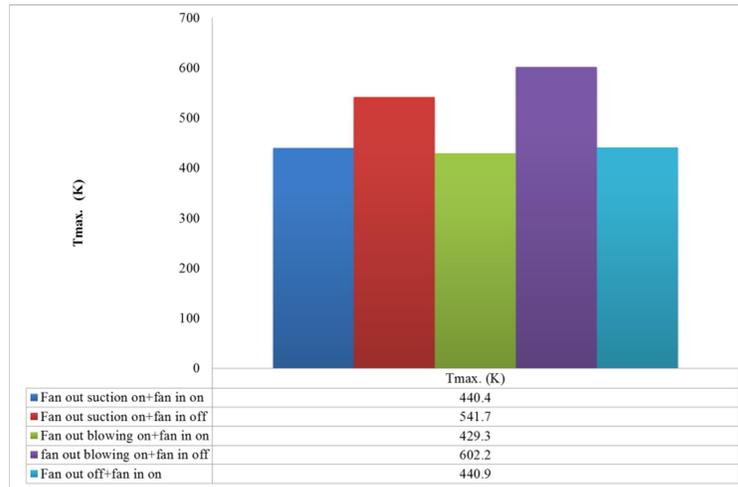


Fig.5:Relation between fan operation cases and maximum temperature of motherboard in case without heat sink

- **Effect of Inclination and Vibration**

The computer chassis with vibration and different inclination angles (0° , 60° , 90° , and 120°) is analyzed. The motherboard inside the computer chassis was examined under two cases, one without heat sink on any components on the motherboard, and the other case with heat sink. Thenorth bridge and south bridge cases are not changed. Three types of heat sink were replaced on the CPU, plate heat sink, radial heat sink without core and 1mm thickness fins, and radial heat sink with core and 0.5mm thickness fins.

Fig.6 shows the results for these cases. In case without heat sink on any component on the motherboard, the change of angle of inclination from 0° to 90° leads to decrease in maximum temperature about 2°C , Also the effect of vibration velocity from $(0 - 0.3 \text{ m/s})$ leads to decrease the temperature about $(2 - 4^\circ\text{C})$, the vibration in the case with angle 90° is more effective than the other angles of inclination, this is due to the disturbance happens in the boundary layer in the direction of the buoyancy effect which is greater in the vertical case, also the direction of vibration become longitudinal leading to transfer heat from two sides of the PCB in suitable way when compared with vibration happens in another angle of inclination. In case when using plate heat sink on the CPU and standard heat sink for north bridge and south bridge, the effect of angle of inclination becomes small and can be neglected, because the buoyancy effect decreases due to a reduction in temperature inside the computer chassis, and the effect of turbulent flow become larger. Also the effect of vibration is very small due to the disturbance in the boundary layer happens in a place far from the heat source. The disturbance happens near the surface of the heat sink and becomes subjected to air stream directly and this influence leads to reduce temperature. Also the geometry of heat sink and the shape with distributed fins and when the air impinging on it lead to increase the turbulent intensity and as a result the

influence of vibration and inclination is not significant. Also the temperature difference between the ambient and the component is approximately 10°C, thus the effect of inclination is weak. At this place, the disturbance generated by the turbulent flow is greater than the disturbance generated by the velocity of vibration. The same behavior is found in the case when using radial heat sink without core and radial heat sink with core. But the results show a minimum temperature for CPU incase when using radial heat sink with core having 0.5 mm thickness fins. The temperature decreases from 431.3 K as maximum temperature in motherboard to 331K in case of radial heat sink with core, this temperature appeared in the south bridge component. When compared to two types of radial heat sink, the radial heat sink with core and have 0.5 mm thickness fins gives good results and reduce the temperature more than the other radial heat sink, this is due to the spacing between fins more than the other type, this led to enhancement in heat transfer by convection and as results reduce the temperature.

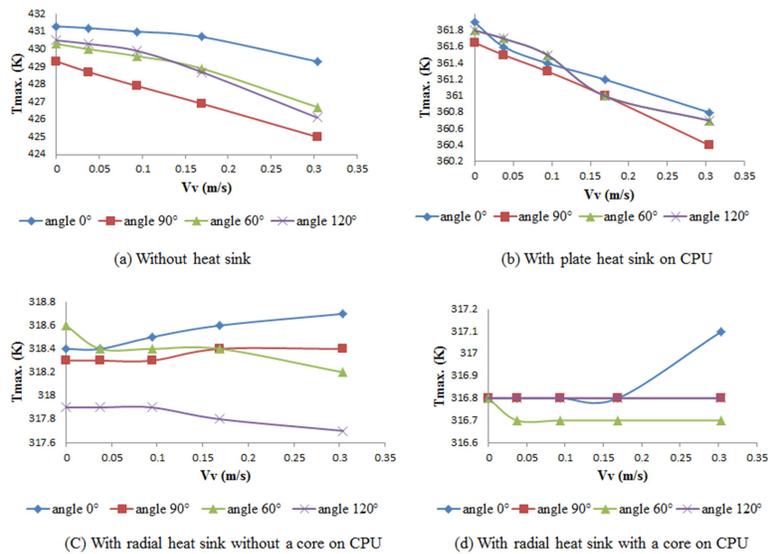


Fig.6:Maximum temperature vs. vibration velocity with different heat sink cases and inclination angle of computer chassis.

• **Effect of PCB Inclination with Vibration**

Two cases for PCB(Printed Circuit Board) inclination was analyzed, the first case is the inclination of the top edge of PCB by 10° from the vertical plane. The second case is the inclination of the bottom edge of PCB by 10° from the vertical plane, these two cases are examined under the vibration effect with and without heat sink. Fig.7 shows the results in case without heat sink and with plate heat sink on the CPU, the case with an inclination for top edge of PCB gave reduction in temperature compared to other case, the reason is that the air flow from the fan in the computer chassis impacting and mixing with the air flow generated from the interior fan, the

circulation of the air flow appeared and lead to decrease the temperature about 30°C in case without heat sink, and about 5°C in case with a plate heat sink on the CPU.

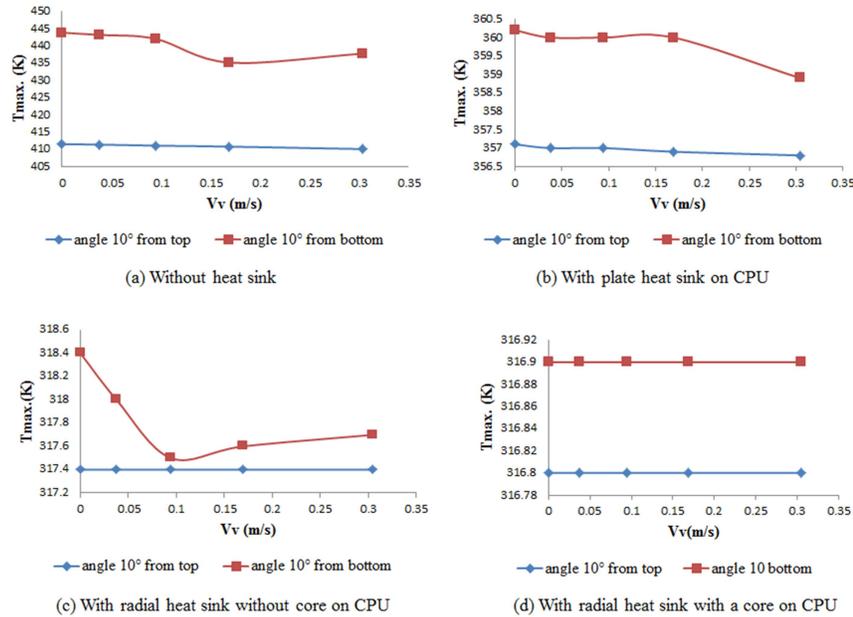


Fig.7: Maximum temperature vs. vibration velocity with different inclination angles for PCB(motherboard) and heat sink cases.

The large effect returns to the air flow impinging on the surface of heat source, and the high temperature difference between heat source surface and ambient temperature. But this effect appeared low in the case when using the radial heat sink, and the effect of vibration is not significant (approximately 0.6°C) and can be neglected in the range of vibration velocity used in this study, this is due to the high turbulent intensity on PCB as a result of circulating airflow inside the computer chassis.

• **Analysis of Simulation Results**

The simulation results are shown in fig.8, in this figure the temperature distribution of model in case with radial heat sink without a core placed on CPU is presented, angle of inclination for the computer chassis 90° and without vibration effect. The results show the temperature distribution for each heat sink. A maximum temperature of 318.3 K in the middle of CPU is clear from contours, minimum temperature on the CPU heat sink is greater than the ambient temperature by 5.7 degrees. In the north bridge with heat sink the maximum temperature in the bottom is higher than the side near from CPU heat sinks, this return to the air flow from the CPU fan rejecting the heat from this area and lead to a reduction of the temperature in this position. In the south bridge with heat sink the temperature reaches to 332.4 K, at the same time this value considered as maximum temperature in the motherboard.

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From temperature contours, the maximum temperature appeared higher on the bottom part and this part subjected to a small quantity of air flow than the top part.

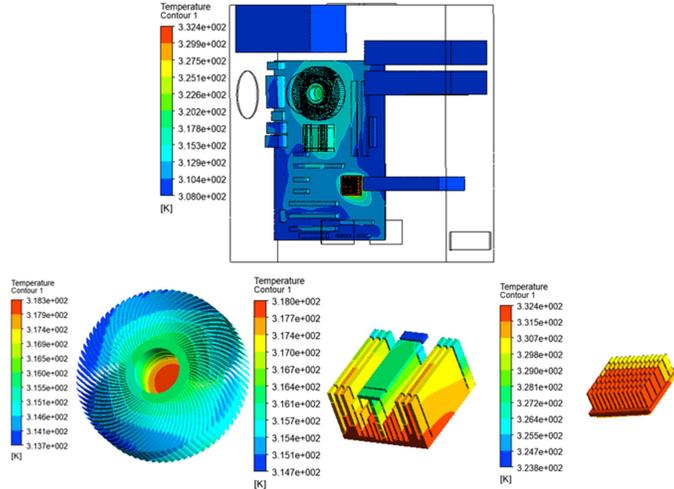


Fig.8: Contours of temperature for computer chassis and important parts heat sink without vibration effect.

At maximum vibration velocity range 0.3m/s as shown in fig.9, the temperature of CPU and North Bridge is not affected and this change is very small, but for south bridge the maximum temperature reaches to 329.9 K, the temperature in this case is less than without vibration by approximately 2.5 degrees.

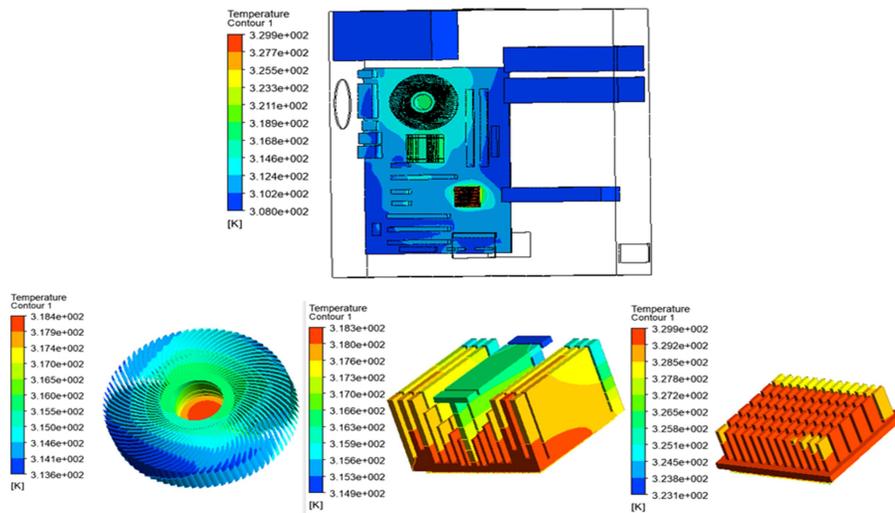


Fig.9: Contours of temperature for computer chassis and important parts of heat sink with maximum vibration effect.

Fig.10 shows the same behavior when using radial heat sink with core, but the maximum temperature for the CPU is reduced by 1.6 degrees, the effect of vibration is not significant in this case.

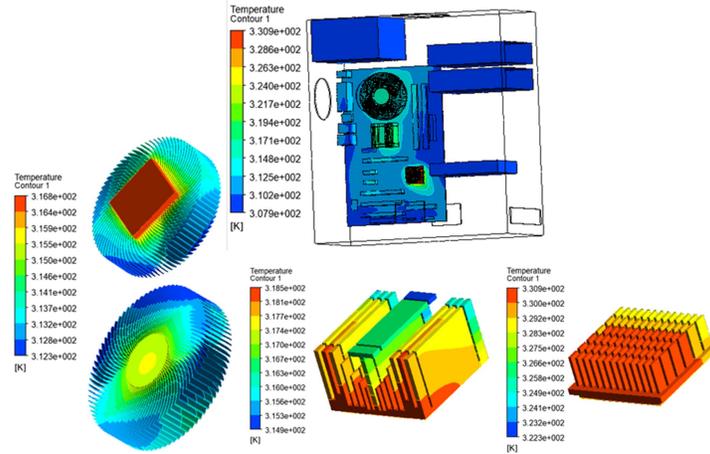


Fig.10: Contours of temperature for computer chassis and important parts of heat sink

In fig.11, when the motherboard inclination angle is 10° from the top edge, the maximum temperature for motherboard shows reduction in value compared with other cases studied. The effect of vibration is very small and maximum effect when the velocity of vibration is 0.3m/s which lead to increase in maximum temperature compared with the case without vibration, this increase is about 0.6 degrees, because when the motherboard vibration led to prevent the boundary layer moving in the direction of buoyancy, and the model started to heat itself and lead to increase in maximum temperature.

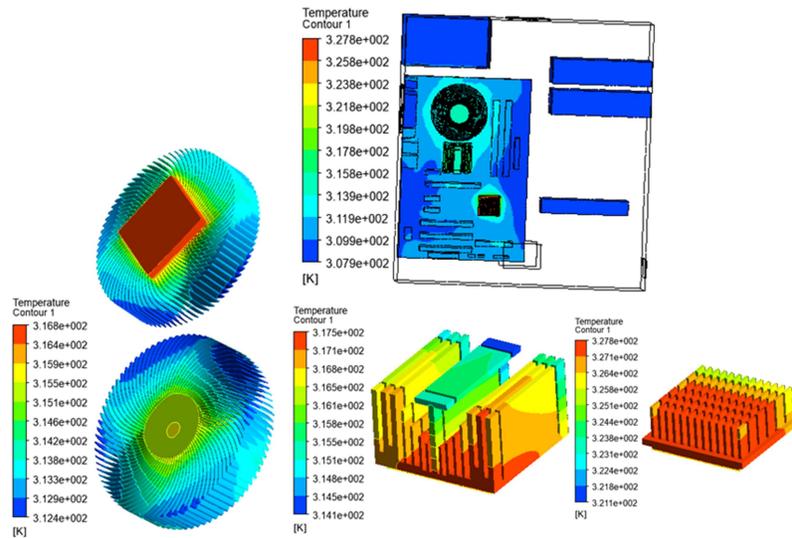


Fig.11: Contours of temperature for computer chassis and important parts of heat sink with maximum vibration effect

VII. Conclusions

The developed numerical scheme of the present work was capable of calculating the forced convection cooling of electronic equipment with different types of heat sinks, including the inclination and vibration effects. The results demonstrated the effectiveness of using radial heat sink with core in reducing the CPU temperature. The effect of vibration was very small because the disturbance of turbulent flow was greater than the disturbance generated by vibration. The influence of angle of inclination ($0^\circ, 60^\circ, 90^\circ$, and 120°) for the computer chassis was not significant due to the high disturbance of flow generated by fans which exceeds the buoyancy effects. The influence of inclination the motherboard by 10° between the top edge and vertical plane reduces the maximum temperature compared to that with inclination by 10° from the bottom edge and vertical plane. Validation was done through a comparison with the thermal profile for real CPU, and the comparison shows good agreement.

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