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Received on: 25/04/2017

Accepted on: 23/11/2017

Numerical and Experimental Study of Cooling in Desktop Computer with Block Heat Sink

Abstract - This paper investigates numerically and experimentally fluid flow and heat transfer inside the desktop P.C.. The study of cooling considers the components; CPU, heat sink, power supply, motherboard, CD, HDD and fans. Three components have heat source (CPU, motherboard and power supply unit). There were two openings for air inlet and two for air outlet. The tested values of air inlet velocities were 1.2, 1.8 and 2.4 m/s. The work investigates the effect of inlet air velocity and powers ($P_{CPU} = 8.5$ W, $P_{PSU} = 24$ W, $P_{MO} = 12$ W) of multi-components (CPU, motherboard and PSU). The numerical results obtained (by finite volume method CFD) are found in a good agreement with the experimental results. The results show that the highest temperature for CPU with block heat sink was 88.1°C ($P_{CPU} = 8.5$ W, $P_{PSU} = 24$ W, $P_{MO} = 12$ W), the temperature of the heat generation components decreases linearly with increases of inlet air velocity. The CPU temperature increases with CPU power linearly. Motherboard temperature was the lowest one due to its position and area (52°C). Full details of flow field and temperature distribution are shown.

Keywords- CPU cooling, heat sink, active heat dissipation, P.C. cooling, forced convection, electronic cooling and computational fluid dynamics. .

How to cite this article: J.M. Jalil, E.H. Ali and H.H. Kurdi , "Numerical and Experimental Study of Cooling in Desktop Computer with Block Heat Sink," *Engineering and Technology Journal*, Vol. 36, Part A, No. 4, pp. 430-438, 2018.

1. Introduction

The rapid development of power electronics leads to processors with high power density. This leads to increased operating frequency and power consumption and decrease in sizes. At the same time, thermal solutions and better airflow become more limited within the same computer system. The result is the increasing importance of the system to make sure the thermal requirements of the system [1]. The CPU of the computer desktop must be cooled to the point of manufacture maximum allowable value, typical limit of CPU case ranging from 70°C to 85°C depending on different CPU packages. CPU cooling used heat sinks where it removes heat into the air by the fan. There are several ways to supply the air to the heat sink, such as active heat sink, in this way small fan attached to the heat sink, and this method considered best for cooling [2]. CPUs of the computers should be cooled to reduce the maximum operating temperature and remove heat generated by CPU. Although there are several methods for cooling, but the common method is forced convection air-cooling. In this way heat removed directly, fan with heat sink are fixed on the CPU. Air is pushed through the heat sink by the fan. By this method, the heat is removed and

transfer directly to the final medium, air [3]. The temperature problem in computer is continuous, this mean that the need for the CPU development, therefore cooling way is developed. For this reason, the study of computer desktop cooling needs more efficient cooling system. Chang, et al. [2] investigated the results of CFD analysis to cool 30-W CPU of a desktop PC with lower airflow rate and smaller heat sink size. This was done by using single fan air motion in the PC. This allowed extra 10°C reducing of the T_{CPU} . Mohan and Govindarajan [4] studied CFD for forced air cooling using heat sink in PC, which used 80W CPU, while this number shall increase from 70 W to 120W. The paper found optimum plate fin heat sink model and cylindrical plate fin heat sink model with changeable copper base to control the process of CPU heat sink. Wang et al. [5] found optimal shape for chassis heat dissipation in a passive fashion, by arranging the locations and directions of fans. It is concluded that optimal shapes in terms of heat dissipation of chip-based elements do exist with suitable conditions of the fan and openings. Maode et al. [6] studied the numerical simulation of temperature field on the motherboard by using thermal analysis software. From the results it appeared that the Northbridge, CPU and the

display card have higher power consumption. Their heat dissipation should be enhanced. The present work investigates experimentally and numerically desktop cooling to find the best way for cooling using block heat sink (made from copper). The experimental study includes the effect of changing inlet air velocity, CPU fan velocity and powers of multi-components (CPU, motherboard and PSU). The numerical study solves the main equations of continuity, momentum, energy and heat conduction for CPU, PSU, motherboard, block heat sink.

Nomenclature

- h_{MO} : Heat transfer coefficient for the air near motherboard ($W/m^2\text{°C}$)
- i,j,k : Unit vector in x-,y-,z- direction respectively (i,j,k)
- k_{MO} : Thermal conductivity of motherboard ($W/m\text{°C}$)
- Nu_L : Nusselt number
- CPU: Central processing unit
- PSU: Power supply unit
- MO: motherboard
- HS: Heat sink
- P_{CPU} : CPU power (W)
- P_{MO} : Motherboard power (W)
- P_{PSU} : PSU power (W)
- T_{∞} : Ambient temperature (°C)
- T_{air} : Air (inside PC) temperature (°C)
- T_{CPU} : CPU temperature (°C)
- W_{CPU} : CPU fan velocity (m/s)
- U_{in}, V_{in} : Inlet fan velocity in x, y directions (m/s)
- U,V,W: Velocities in x, y, z (m/s)
- μ : Dynamic viscosity of fluid (kg/m s)
- ρ : Density of fluid (kg/m^3)

2. Mathematical and Numerical Analysis

I. Governing Equations (laminar flow)

For flow of air inside the P.C. in Figure 1, laminar (the value of Reynolds number of the air inlet is 2069) 3-D, forced convection, steady, incompressible with Cartesian Coordinates is assumed. The Navier Stokes equations (continuity, momentum and energy) are as follows [7]:

Continuity equation

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

Momentum equation

U-Momentum (x-direction)

$$\frac{\partial}{\partial x}(uu) + \frac{\partial}{\partial y}(uv) + \frac{\partial}{\partial z}(uw) = -\frac{1}{\rho} \frac{\partial P}{\partial x} + \nu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right) \tag{2}$$

$$\frac{\partial}{\partial x}(vu) + \frac{\partial}{\partial y}(vv) + \frac{\partial}{\partial z}(vw) = -\frac{1}{\rho} \frac{\partial P}{\partial y} + \nu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \right) \tag{3}$$

W-Momentum (z-direction)

$$\frac{\partial}{\partial x}(wu) + \frac{\partial}{\partial y}(wv) + \frac{\partial}{\partial z}(ww) = -\frac{1}{\rho} \frac{\partial P}{\partial z} + \nu \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2} \right) \tag{4}$$

Energy equation

$$\frac{\partial}{\partial x}(uT) + \frac{\partial}{\partial y}(vT) + \frac{\partial}{\partial z}(wT) = \frac{k}{\rho C_p} \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) \tag{5}$$

The transport equations for continuity, momentum and energy all have the general form [9]:

$$\begin{aligned} \frac{\partial}{\partial x}(\rho u\phi) + \frac{\partial}{\partial y}(\rho v\phi) + \frac{\partial}{\partial z}(\rho w\phi) &= \frac{\partial}{\partial x} \left(\Gamma_{\phi} \frac{\partial \phi}{\partial x} \right) + \frac{\partial}{\partial y} \left(\Gamma_{\phi} \frac{\partial \phi}{\partial y} \right) \\ &+ \frac{\partial}{\partial z} \left(\Gamma_{\phi} \frac{\partial \phi}{\partial z} \right) + S_{\phi} \end{aligned} \tag{6}$$

Where ϕ the dependent variable, and S_{ϕ} is the source term which has different expressions for different transport equations. Table (1) gives the expression for the source term S_{ϕ} for each dependent variable, which is likely to be needed in solving fluid flow problems.

Table 1: Source term in the transport equations for laminar flow

Equation	ϕ	Γ_{ϕ}	S_{ϕ}
Continuity	1	0	0
x-momentum	U	ν	$-\frac{\partial P}{\partial x}$
y-momentum	V	ν	$-\frac{\partial P}{\partial y}$
z-momentum	W	ν	$-\frac{\partial P}{\partial z}$
Energy	T	α	

Where:

$$\alpha = \frac{k}{\rho C_p}$$

II. Steady Heat Conduction

The heat transfer within solid PC components is numerically calculated. If the system is in a steady state, then the heat flow in the x, y and z

directions may be calculated from Fourier equation:

$$q = -kA \frac{\partial T}{\partial x} \tag{7}$$

Energy balance methods were used and can be described as the summation of heat in and out equals to zero and were applied over small elements, the element has six faces. These elements in heat generation components [9, 10 and 11]:

1. CPU.
2. PSU.
3. Motherboard.

For example; node details of motherboard as shown in Figures 2 and 3. The motherboard has (40×48×1) nodes, all these nodes have one face which is insulated and the opposite face has convection except the nodes with the CPU:

$$\sum q_{\text{all faces}} = 0$$

$$\sum q_{\text{all faces}} = q_{e-x} + q_{w-x} + q_{n-y} + q_{s-y} + q_{t-z} + q_{b-z} + P_{MO} = 0 \tag{8}$$

$$A_e = \Delta y \Delta z, A_w = \Delta y \Delta z, A_n = \Delta x \Delta z, A_s = \Delta x \Delta z, A_t = \Delta x \Delta y, A_b = \Delta x \Delta y \tag{9}$$

$$q_{e-x} = \frac{-k_{MO} A_e}{\Delta x} (T_{MO(i,j,k)} - T_{MO(i+1,j,k)}) \tag{10}$$

$$q_{w-x} = \frac{-k_{MO} A_w}{\Delta x} (T_{MO(i,j,k)} - T_{MO(i-1,j,k)}) \tag{11}$$

$$q_{n-y} = \frac{-k_{MO} A_n}{\Delta y} (T_{MO(i,j,k)} - T_{MO(i,j+1,k)}) \tag{12}$$

$$q_{s-y} = \frac{-k_{MO} A_s}{\Delta y} (T_{MO(i,j,k)} - T_{MO(i,j-1,k)}) \tag{13}$$

$$q_{t-z} = h_{MO} A_b (T_{MO(i,j,k)} - T_{air}) \tag{14}$$

$$q_{b-z} = 0 \text{ (insulated)} \tag{15}$$

The temperature is given by:

$$T_{MO(i,j,k)} = \frac{C_e T_{MO(i+1,j,k)} + C_w T_{MO(i-1,j,k)} + C_n T_{MO(i,j+1,k)} + C_s T_{MO(i,j-1,k)} + C_t T_{air} + P_{MO}}{C} \tag{16}$$

Where:

$$C_e = \frac{k_{MO} A_e}{\Delta x}, C_w = \frac{k_{MO} A_w}{\Delta x}, C_n = \frac{k_{MO} A_n}{\Delta y}, C_s = \frac{k_{MO} A_s}{\Delta y}, C_t = h_{MO} A_t \tag{17}$$

And

$$C = C_e + C_w + C_n + C_s + C_t + C_b \tag{18}$$

And i,j,k to represents X,Y,Z respectively, The temperatures of the other components (CPU, Heat sink, PSU) were solved in the same method. The equations solved (by finite volume method CFD) with 1000 iteration at 15 minutes using Fortran 90.

3. Experimental Apparatus

The experimental rig was constructed to study the fluid flow and heat transfer in box similar to the computer case. The idea of the study was to find the effect of changing the powers multi-components (CPU, PSU, and motherboard) and the inlet air velocity with the change air velocity of CPU fan for block heat sink. The photograph of experimental apparatus is shown in Figure 4, which consists of:

1. Pyrex box.
2. Four heaters: one heater used to represent CPU, one heater to represent motherboard and two heaters to represent the front face and lower face of PSU.
3. Heat sink: block heat sink made from copper.
4. Fans.
5. Voltage regulator (Variac).
6. DC power supply: to change the velocity.
7. Measurement units.

- a. Temperature recorder: it used to measure the temperature of the main components.
- b. Hot wire anemometer: it used to measure the velocity.
- c. Digital power clamp meter: it used to measure the power.

Experiments were done to measure the temperature change of the three main components (CPU, MO and PSU) of the desktop computer, the temperature of heat sink, temperature of air inside the P.C. and temperature of air inlet and outlet with the change of velocity and experiments to measure the temperatures change with the changing the powers of the three main components. The number of experiments is 15, the measurements to find temperatures using thermocouples were connected from one side to the place that measured its temperature and from other side to temperature recorder. The measurements were drawn and compared with the theoretical readings to find the appropriate temperatures.

4. Results and Discussion

1. Experimental Results

1. Effect of Inlet Velocity

The maximum temperatures of CPU and other components in P.C. obtained at the maximum power for CPU, PSU and motherboard with copper heat sink at minimum inlet air velocity (1.2 m/s) and ($T_{\infty} = 33^{\circ}\text{C}$) are given in Table 2. Figure 5 illustrates the variation of temperatures of the components with inlet velocity at $P_{\text{CPU}} = 8.5 \text{ W}$, $P_{\text{PSU}} = 24 \text{ W}$, $P_{\text{MO}} = 12 \text{ W}$. The temperature is decreased with increasing inlet velocity; the slope of the decreasing has same trend for CPU and HS and same trend for PSU1, PSU2 and MO. The temperature of CPU is higher than the others; it varies between 88.1°C at minimum inlet air velocity 1.2 m/s and 74.1°C at 2.4 m/s. The MO temperature is the lowest one. It varies between 51.5°C at minimum inlet air velocity 1.2 m/s and 44.8°C at 2.4 m/s. The temperature range in Fig. 5 was set by limitation maximum allowable temperature (standard operating temperature) for CPU (70°C to 85°C), for MO maximum allowable was 48°C and 70°C for PSU. The power of the components in this graph represents the maximum allowable powers to reach the temperature limits. The velocity of CPU fan was chosen in relation to inlet velocity to achieve allowable temperature of CPU. The temperature of PSU depends on the cooling; the lower face temperature is lower than the front face due to the position of this face near the CPU fan and inlet from one side and inlet from another side. The temperature of CPU and power supply faces great affected by the velocity, motherboard temperature and little affected by the velocity of air. From these results and to keep the CPU within allowable temperature limit, the power should be reduced lower than (8.5 W) or by increasing the inlet air velocity and CPU fan velocity, the CPU power varies according to usage and the type of CPU; it starts from 30 W to 130 W. In this research a suitable power was used to reach the temperature of the heater to the standard operating temperature of the CPU.

2. Effect of Power Dissipation

Figure 6 shows the variation of temperature of components with CPU power at inlet velocity 1.8 m/s, $P_{\text{PSU}} = 16 \text{ W}$ and $P_{\text{MO}} = 8 \text{ W}$. The temperature increased with increasing CPU power. The slope of the increasing has same trend for CPU and HS. In addition, the slope is same trend for PSU1, PSU2 and MO. The temperature of CPU is higher than the others. It varies between 57.3°C at 3.7 W and 74.1°C at 8.5 W. MO temperature is the lowest and varies between 41.5°C and 43.4°C . The temperatures of CPU and HS are greatly affected by the change of the CPU power, while the temperatures of other components are slightly

affected. The CPU may not dissipate maximum power all the time, this depend on kind of P.C. and the operation. The other components are less sensible to P_{CPU} change; their temperatures increase about two degrees for PSU faces and about one degree in motherboard temperature. Fig. 7 shows the variation of CPU temperature with the variation of inlet air velocity, at $P_{\text{PSU}} = 16 \text{ W}$, $P_{\text{MO}} = 8 \text{ W}$ for different powers of CPU. The CPU temperature increases with increases of the power and decreases with increases of the velocity of inlet air. The higher CPU temperature was 83.4°C at the power equals to 8.5 W and velocity of 1.2 m/s, the lowest CPU temperature was 54.2°C at the power equal to 3.7 W and velocity equals to 2.4 m/s. These temperatures decrease with the power and velocity as shown in Table 3. Fig. 8 shows the variation of CPU temperature with the variation of inlet air velocity at $P_{\text{CPU}} = 8.5 \text{ W}$ for different powers of MO and PSU. The slopes of temperatures have the same trend. The higher temperature of CPU is 88.1°C at $P_{\text{PSU}} = 24 \text{ W}$, $P_{\text{MO}} = 12 \text{ W}$ and 1.2 m/s, the lower temperature equal to 68 at $P_{\text{PSU}} = 8 \text{ W}$, $P_{\text{MO}} = 4 \text{ W}$ and 2.4 m/s. From Figures 7 and 8, it appears that the temperature of CPU is affected by the change of CPU power greater than by the change in MO and PSU powers.

Table 2: Maximum temperatures of CPU and other components

Component	Maximum temperature ($^{\circ}\text{C}$)
CPU	88.1
Heat sink	70
PSU front face	75.6
PSU lower face	70.1
Motherboard	51.5

Table 3: CPU temperature variation with P_{CPU} and inlet air velocity

Inlet air velocity (m/s)	Temperatures ($^{\circ}\text{C}$)		
	8.5 W	6.1 W	3.7 W
1.2	83.4	74.1	62.2
1.8	74.1	66.9	57.3
2.4	69.8	62.9	54.2

II. Numerical Results

1. Effect of Inlet Velocity

Figure 9 shows the variation of temperatures with the variation of inlet air velocity at $P_{\text{CPU}} = 8.5 \text{ W}$, $P_{\text{PSU}} = 24 \text{ W}$, $P_{\text{MO}} = 12 \text{ W}$. The temperature

decreases with increasing of inlet velocity, the slopes of decreasing have the same trend for CPU and HS and same trend for PSU1, PSU2 and MO. The temperature of CPU is higher than the others. It varies between 85.23°C at minimum inlet air velocity 1.2 m/s to 79.18°C at 2.4 m/s. The MO temperature is the lowest one, it varies between 54.4 °C at minimum inlet air velocity 1.2 m/s to 48.27°C at 2.4 m/s.

2. Effect of Power Dissipation

Figure 10 shows the variation of temperatures with CPU power at $P_{PSU}=16$ W, $P_{MO}=8$ W, inlet velocity 1.8 m/s and $W_{CPU}=3$ m/s. The temperature increased with increasing CPU power, the slope of increasing has the same trend for CPU and HS and the slope was same trend for PSU1, PSU2 (front face and lower face of power supply respectively) and MO.

III. Isothermal Distribution in P.C.

Figure 13 illustrates 3D plots of the isothermal contours with different directions at $P_{CPU}=8.5$ W, $P_{PSU}=24$ W, $P_{MO}=12$ W, $V_{in}=U_{in}=1.2$ m/s, $W_{CPU}=2$ m/s, (a) 3D, (b) CPU at $z=20$ cm, (c) block heat sink at $z=15$ cm, (d) motherboard at $z=20$ cm, (e) PSU1 at $x=26$ cm, (f) PSU2 at $y=31$ cm. the three dimensional plot shows the temperature distribution inside the box. To show the details of temperatures in the domain, a 2d surface plots are used. In b, $z=20$ cm, the red area shows the highest temperature of CPU. The internal area of the CPU temperature is nearly 85°C. In c, the HS temperature was nearly 69°C. In d, the motherboard temperature at $z=20$ cm, the temperature close to 50°C, it increased in area of CPU and decreased near the position of outlet. In e and f, the two faces of power supply were shown.

IV. Flow Field Distribution

Fig. 14 shows the flow field in PC at $P_{CPU}=8.5$ W, $P_{PSU}=24$ W, $P_{MO}=12$ W, $V_{in}=U_{in}=1.2$ m/s, $W_{CPU}=2$ m/s. The figure shows the outlet openings at $y=x=0.2$ m. In b, the figure shows the flow field at $z=0.1$ (high processor fan velocities). In c, four x surfaces are shown; the white areas represent the positions of HDD, CD and PSU. In d, four levels of y are shown, in the third level, the fan velocities against the processor are clear.

V. Comparison between numerical and experimental results

Figures 11 and 12 show the comparison between numerical and experimental results for distribution of surface temperature with inlet air velocity of CPU and MO at $P_{CPU}=8.5$ W,

$P_{PSU}=24$ W, $P_{MO}=12$ W. A good agreement is shown between the numerical and experimental results and it can be observed that both numerical and experimental results have the same behavior. It was found that the numerical results are greater than the experimental results.

5. Conclusions

The conclusions that can be drawn from the present study are:

1. The temperature of the heat generation components decreases linearly with increases of inlet air velocity.
2. The CPU temperature increases with CPU power linearly.
3. The temperatures of other components affected little by CPU power.
4. The CPU temperature is slightly affected by the power of other components.
5. PSU2 temperature was less than the PSU1 temperature due to its position close to inlet, outlet CPU fan.
6. Motherboard temperature was the lowest one due to its position and large area.

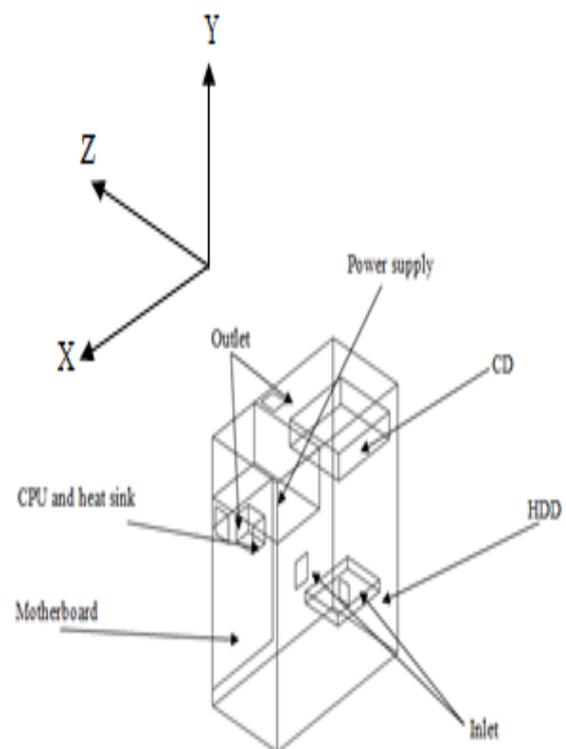


Figure 1: PC case

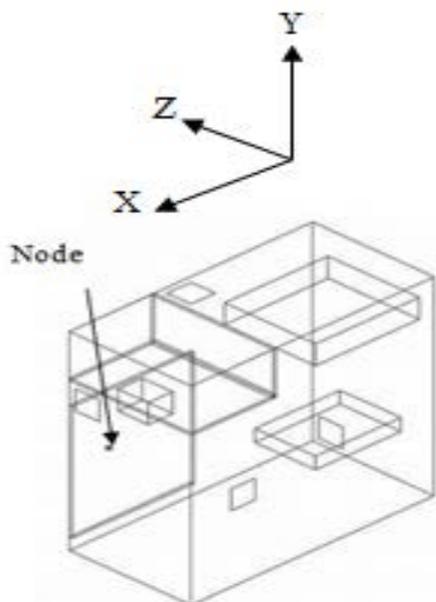


Figure 2: Motherboard Node

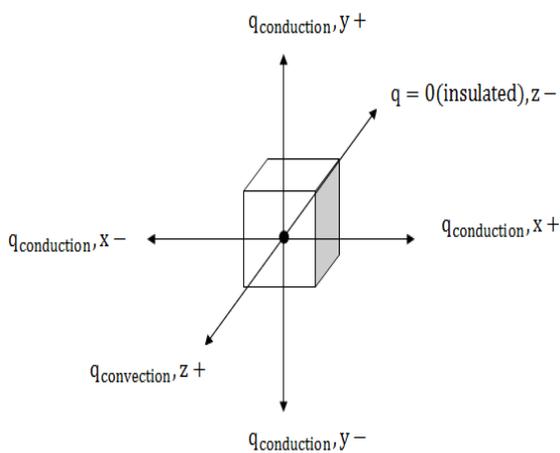


Figure 3: Energy balance for nodes on motherboard

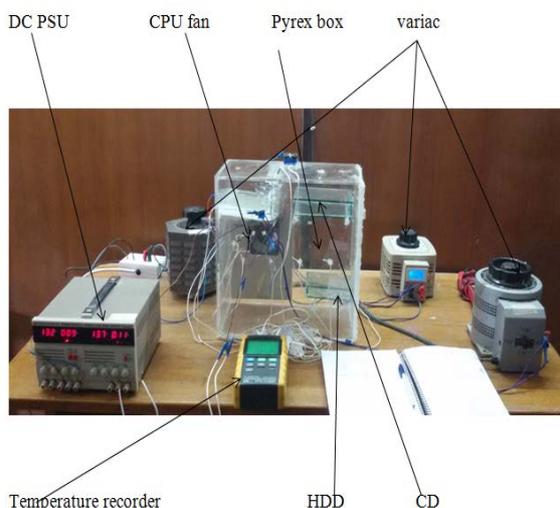


Figure 4: Photograph of experimental apparatus

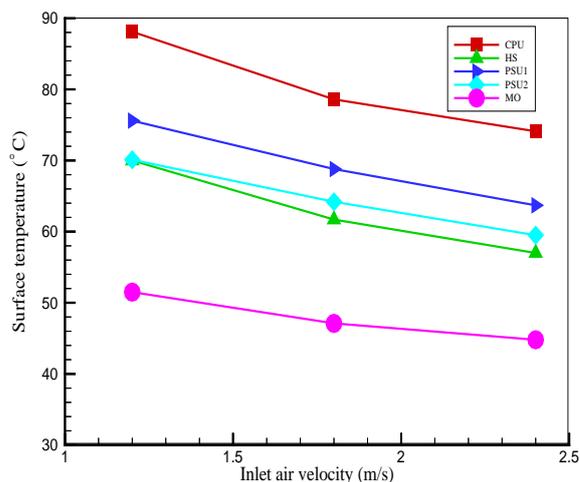


Figure 5: Variation of temperatures with inlet air velocity at $P_{CPU} = 8.5 \text{ W}$, $P_{PSU} = 24 \text{ W}$, $P_{MO} = 12 \text{ W}$

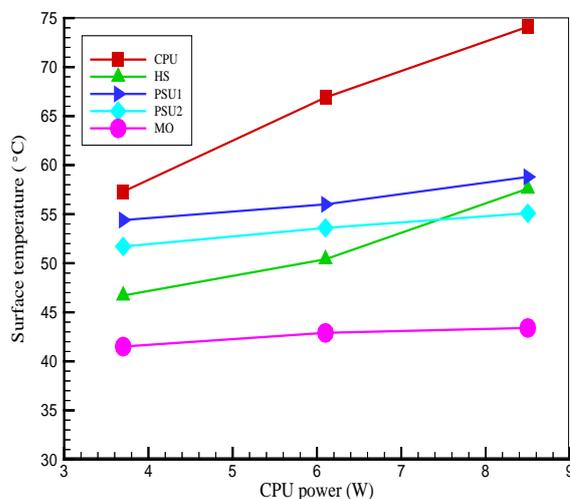


Figure 6: Variation of temperatures with CPU power at $P_{PSU} = 16 \text{ W}$, $P_{MO} = 8 \text{ W}$, inlet velocity 1.8 m/s and $W_{CPU} = 3 \text{ m/s}$

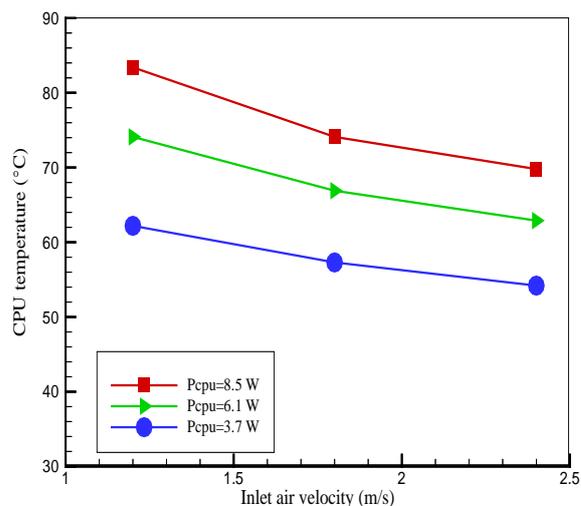


Figure 7: Variation of CPU temperature with inlet air velocity, at $P_{PSU} = 16 \text{ W}$, $P_{MO} = 8 \text{ W}$

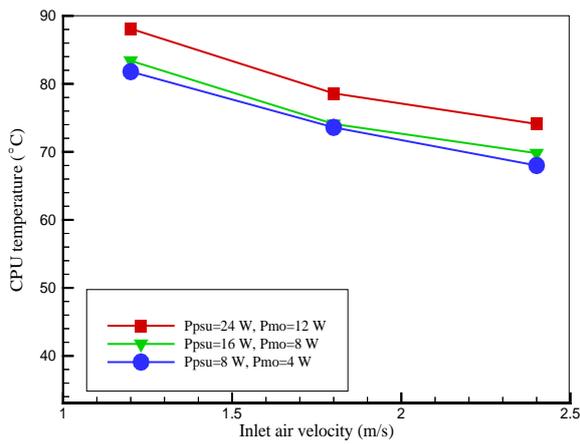


Figure 8: Variation of CPU temperature with inlet air velocity, at $P_{CPU} = 8.5 W$

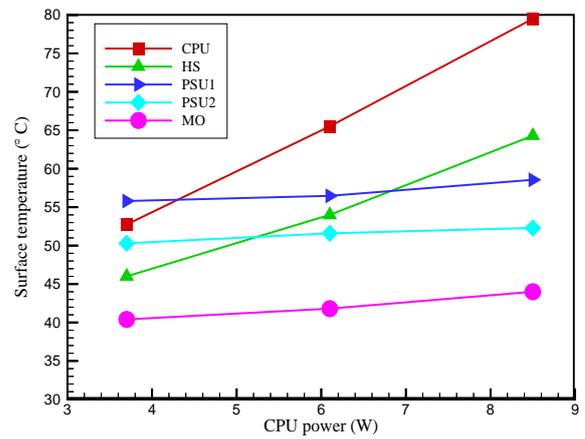


Figure 10: Variation of temperatures with CPU power at $P_{PSU} = 16 W$, $P_{MO} = 8 W$, inlet velocity 1.8 m/s and $W_{CPU} = 3 m/s$

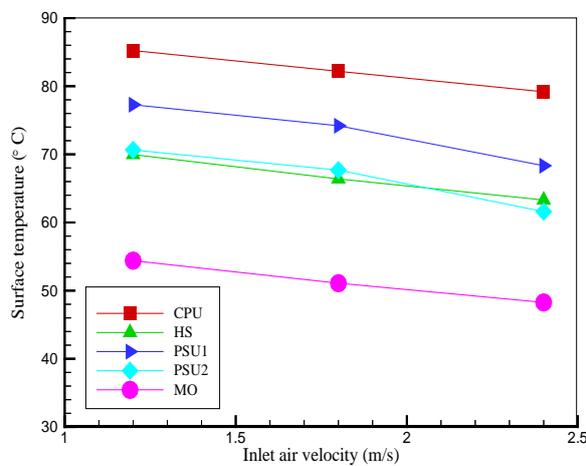


Figure 9: Variation of temperatures with inlet air velocity at $P_{CPU} = 8.5 W$, $P_{PSU} = 24 W$, $P_{MO} = 12 W$

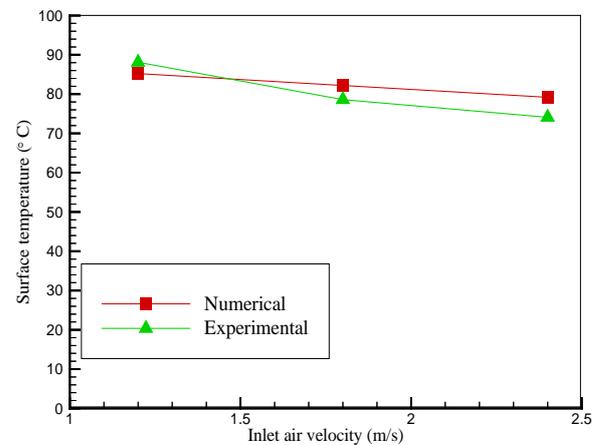


Figure 11: Comparison between numerical and experimental results for surface temperature with inlet air velocity of CPU at $P_{CPU} = 8.5 W$, $P_{PSU} = 24 W$, $P_{MO} = 12 W$

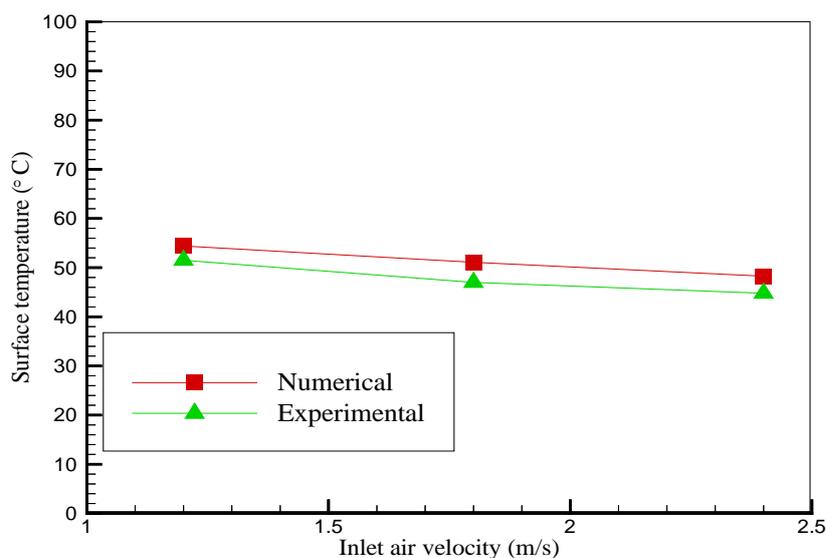


Figure 12: Comparison between numerical and experimental results for surface temperature with inlet air velocity of MO at $P_{CPU} = 8.5 W$, $P_{PSU} = 24 W$, $P_{MO} = 12 W$

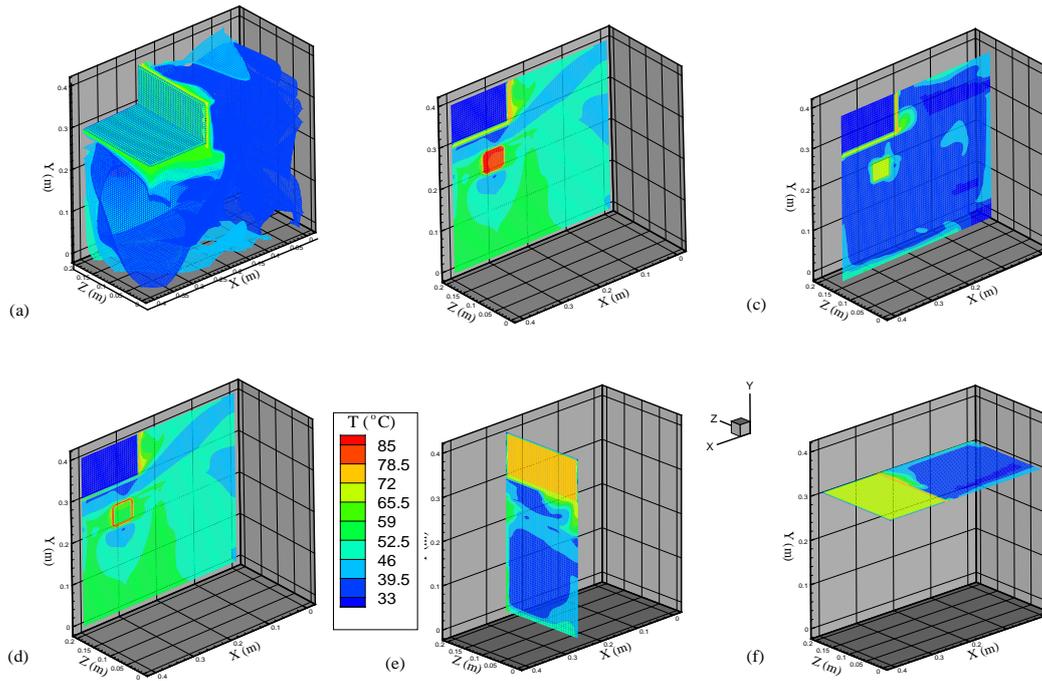


Figure 13: Isothermal distribution at $P_{CPU} = 8.5$ W, $P_{PSU} = 24$ W, $P_{MO} = 12$ W, $V_{in} = U_{in} = 1.2$ m/s, $W_{CPU} = 2$ m/s, (a) 3D, (b) CPU $z = 20$ cm, (c) block heat sink $z = 15$ cm, (d) motherboard $z = 20$ cm, (e) PSU1 $x = 26$ cm, (f) PSU2 $y = 31$ cm

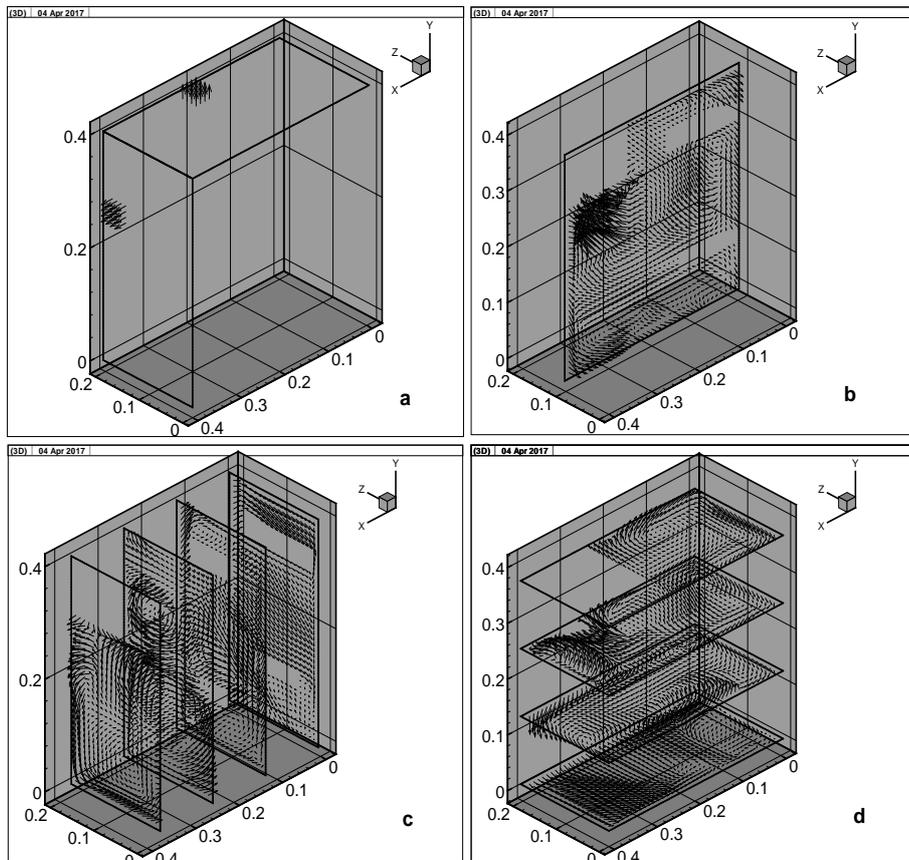


Figure 14: Flow field in PC ($P_{CPU} = 8.5$ W, $P_{PSU} = 24$ W, $P_{MO} = 12$ W, $V_{in} = U_{in} = 1.2$ m/s, $W_{CPU} = 2$ m/s), a) outlet openings, b) $z = 0.1$ m, c) different x surfaces, d) different y levels

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