Natural Convection Cooling of Electronic Enclosure

[1]Shrikant Chavan and Anilkumae Sathe,
[1]Student, 2Assistant Professor,
[1]Department of Mechanical Engineering, Dr. D. Y. Patil School of Engineering Academy Ambi, Pune, India
[2]Department of Mechanical Engineering, Smt. Kashibai Navale college of Engineering, Vadagaon (Bdr.), Pune, India

Abstract— The main function of enclosure is to protect electronic components and devices from aggressive media such as humidity, water, oil-contaminated ambient air, corrosive vapors and also dust in the ambient air. An electronic system is not complete without a rugged enclosure (a case or a cabinet) that will house the circuit boards and the necessary peripheral equipment and connectors, protect from the determinately effects of the environment, and provide a cooling mechanism. Natural convection cooling is the most widely used method of cooling electronic equipment. This can be attributed to its simplicity of design, low operating costs due to no extra power requirements, minimum maintenance, absence of noise due to no additional moving part, and very high reliability. In the experimental testing thermocouple wires attached on the surface of the enclosure components to measure the surface temperature. The temperature measurement is continuing up to steady state. Natural convection in electronic enclosures is studied by performing three dimensional numerical simulations. The effect of heat dissipation rate in the enclosure, inter-board spacing on heat transfer and flow field in the enclosure is illustrated by temperature contours, velocity vectors. Heat dissipation rate has strong impact on heat transfer and flow field in the enclosures.

Keywords— *Electronic Enclosure, ANSYS Icepak, Temperature Distribution, Velocity Distribution, Electronic Components*

I. INTRODUCTION

Electronic equipment has made its way into practically every aspect of modern life, from toys and appliances to high-power computers. The reliability of the electronics of a system is a major factor in the overall reliability of the system. Electronic components depend on the passage of electric current to perform their duties, and they become potential sites for excessive eating, since the current flow through a resistance is accompanied by heat generation. Continued miniaturization of electronic systems has resulted in a dramatic increase in the amount of heat generated per unit volume, comparable in magnitude to those encountered at nuclear reactors and the surface of the sun. Unless properly designed and controlled, high rates of heat generation result in high operating temperatures for electronic equipment, which jeopardizes its safety and reliability. (1)

An electronic system is not complete without a rugged enclosure (a case or a cabinet) that will house the circuit boards and the necessary peripheral equipment and connectors, protect from the determinately effects of the environment, and provide a cooling mechanism. In a small electronic system such as a personal computer, the enclosure can simply be an inexpensive box made of sheet metal of with proper connecters and small fan. But for a large system with several tens of PCBs, the design and construction of enclosure are challenges for both electronic and thermal designers.

Natural convection cooling is the preferred method of cooling for such enclosures, since, it is silent, reliable, and it is environmentally sound because no additional energy is used to remove the excess heat. On the other hand, natural convection cooling is more complicated to design because it may be challenging to identify if a certain application is suitable for fan-less cooling at the very early stage of the product development process. Computational fluid dynamics is one way of analysing this problem this but it is time consuming and not a feasible way of determination at the very early stage.

In electronic systems normally the heat generating bodies exit within the cavity. The effect of the presence of heat source on the mass flow rate and heat transfer is considered in present case for investigation. In order to verify the methodology of using fluent, the commercial software, the available problem in the literature is verified for parametric study on the location of heat source and its strength is considered for study. In present work, the given source is split into two parts and its effect on the flow rate and heat transfer is studied. An attempt is made for the best location of the heat source in the cavity so that it can be used in the electronic equipment generating heat.

A. Domains Of Application

Natural convection in a confined environment is exploited in several activity areas. Electrical and electronic industries use it for the thermal regulation of components and devices used in various sorts of industrial equipment. Among other applications of free convection, one can cite: aeronautics, computers, automobile, nuclear energy, maritime transportation, civil engineering, solar, eolian, geothermal, heliometric and terrestrial equipment, as well as pharmaceutics, food industry and agriculture.(2)

Researchers have performed experimental and numerical analysis on natural convection of air in square enclosures with partially active side walls. The experimental study is carried out both through the holographic interferometry in order to obtain the average Nusselt numbers at different Rayleigh numbers. The temperature distributions in the air and the heat transfer coefficients are measured by a holographic interferometry and compared with the numerical results (3). Natural convection heat transfer and fluid flow of two heated partitions within an enclosure have been analysed numerically (4) the effects of position and heights of the partitions on heat transfer and flow field have been investigated also unsteady heat transfer and fluid flow characteristics in an enclosure are investigated (5) At initial times, the Nusselt number on hot wall is higher for higher width, but in the steady state region, the effect of width on Nusselt number is inversed. Also Nusselt number curves show steady state behaviour in lower times for lower width. Natural convection heat transfer in a square air-filled enclosure with one discrete flush heater is examined numerically (6)

II. EXPERIMENTAL SETUP

Figure 1; figure 2 shows the experimental layout and actual experimental set up respectively, J type thermocouple mounted on the different component. On the components thermocouple attached with the help of stick tape. Figure 2 shows the different thermocouple attached on the enclosure components. In this testing procedure A. C. supply is used and temperature measuring instruments are thermocouple with data logger and Infrared thermometer. The total procedure of testing is two and half hour to achieve steady state temperature condition.

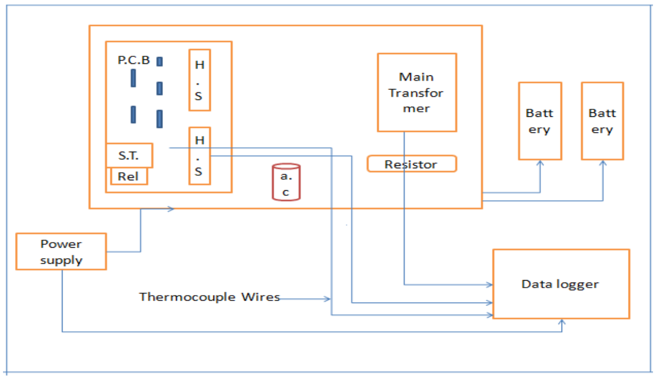


Figure1: Experimental layout

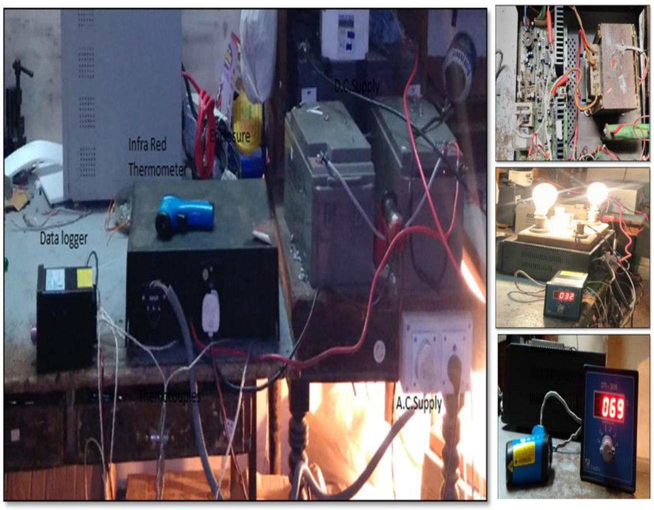


Figure2: Actual Experimental layout

In this experiment Electronic Enclosure is connected to D.C. supply and Enclosure output supply to bulb or another energy saving unit parameter. This photograph enclosure output energy is on bulb this bulb power is approximately 120-160 watt. Temperature indicator connects the thermocouple to enclosure different location to data logger. In this data logger six different locations which indicate the temperature. Infra-red thermometer is used to measure temperature at different places where thermocouple could not be attached. This infrared thermometer is manually handled.

III. CFD SIMULATION

ANSYS Icepak you can import board layout from a variety of EDA tools for efficient thermal simulation. Board dimensions, component layout information, and electronic trace and via information can all be incorporated into a thermal simulation. The ANSYS Icepack software among various CFD tool specifically tailored for use in the electronic industry to perform the board and system level thermal analysis. In icepack a variety of thermal limitation source elements are available, including heat dissipation, fixed temperature sources or heat flux sources. Typically electronic enclosure is housed in sealed case, and relies solely on free convection and radiation for cooling. The heat flow path in controller is a series of conduction, convection and radiation path, heat is transported through the case wall, and finally removed to the environment by free convection.

A. Simulation Modelling

The following enclosure is overheated when enclosure power supply long time activated and loaded condition in enclosure components. Due to the overheating of Enclosure control system not working properly and some components are damaged due to overheating and the temperature range is -10^0C to 75^0C. Without increasing its volume, cooling required for the following enclosure. Present system in the electronics enclosure contains main Transformer, Sensing Transformer, Resistor, Relay, 2 Rectangular type's Heat sink, PCB board, and different type of I.Cs. And vent for cooling purpose. The complete system has got a main transformer whose temperature rise is to 70°C and Heat sink whose temperature is 55-60°C.

The following enclosure is overheated when enclosure power supply long time activated and loaded condition in enclosure components. Due to the overheating of Enclosure control system not working properly and some components are damaged due to overheating and the temperature range is -100C to 750C. Without increasing its volume, cooling required for the following enclosure.

Present system in the electronics enclosure contains main Transformer, Sensing Transformer, Resistor, Relay, 2 Rectangular type's Heat sink, PCB board, and different type of I.Cs. And vent for cooling purpose. The complete system has got a main transformer whose temperature rise is to 70°C and Heat sink whose temperature is 55-60°C.

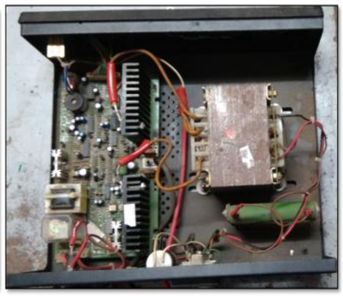


Figure2.*Electronic Enclosure* Figure3. *Electronic enclosure With all components*

Inverter shown in figure2 photograph is completely enclosed by enclosure. It is a very important device which controls all the home and industrial appliances. The four bolts are used to fix this enclosure. Entry of moisture and dust inside the inverter is prevented by enclosure. Also enclosure restricts high air flow over components inside the inverter as per EURO norms.

The following table gives the dimensions of the different component which are placed inside the enclosure. These are heat generating component in enclosure.

Table1: Enclosure components and their dimension

Component	Simplification	Dimension
Main transformer	Block	0.115 x 0.098 x 0.07 m
Sensing transformer	Block	0.0335 x 0.026 x 0.041 m
Resistor	Block	101mm× Φ11mm
Relay	Block	0.0315 x 0.0445 x 0.03471 m
A.C. Capacitor	Block	52.62 mm× Φ15mm
MOSFETs	Heat source	0.01 x 0.009 m
PCB	QFP	0.23 x 0.0016 x 0.13 m
Enclosure	Block	0.307× 0.117 ×0.355m

The enclosure made up of aluminium with 2 mm thickness. The enclosure is simplified into cuboid shape for analysis purpose. The components inside the enclosure are closely fitted in enclosure as per their exact positions. The model in ICEPAK is constructed which is approximate to the real geometry. Thermal contact resistance is considered in the model. Heat and mass transfer through the enclosure is allowed.

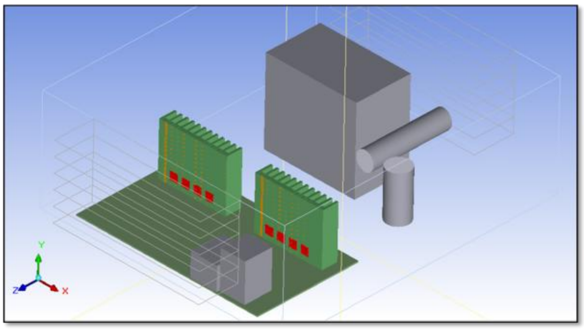


Figure 4: CFD model of Enclosure

The figure shows the computational model of Enclosure. The material of Enclosure is made up of aluminium. In an enclosure eight components are present, in which main transformer is most heat generating component then resistor, heat sink, sensing transformer, relay, a. c. capacitor and PCB with MOSFETs and I.C. The finite volume method is adopted for converting governing equations to algebraic equation that can be solved normally. The simple algorithm is used to solve the pressure and convection - velocity coupling term. Discretization method is first order upwind scheme. In the solution domain the maximum size of element in three mutually perpendicular directions is less than 1/20 of every domain dimension.

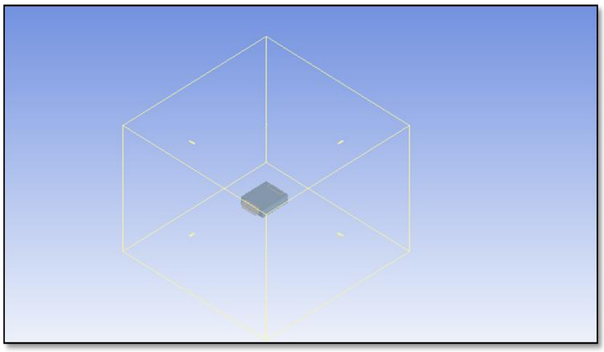


Figure 5: Solution domain

Once the modelling of the enclosure is done then it requires putting it in domain under study. The figure 4 shows the complete computational domain of the CFD problem. The solution domain consists of the whole solution domain with six open faces. The dimensions of the domain are 0.7 x 0.5 x 0.7 m.

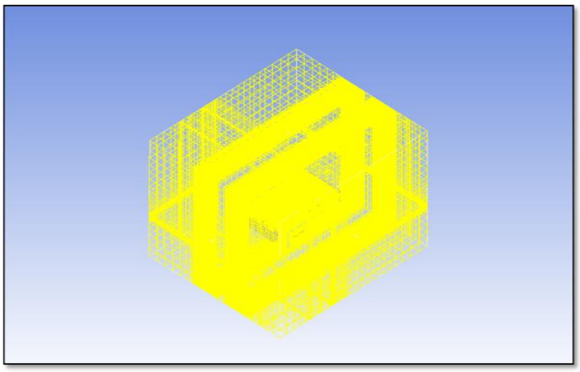
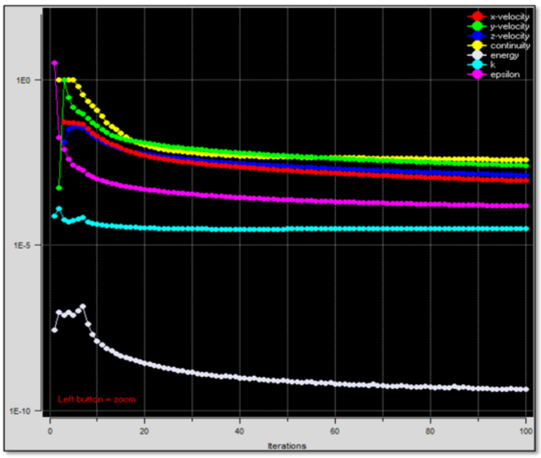


Figure 6: Unstructured Hexahedral Meshing

Figure 6 shows the meshing distribution of whole domain. The computational domain is discretized into unstructured hexahedral meshes that have a number of nodes and number of element are 637936, 622914 respectively. The numbers of quads are 78049, and faces + solids are 281. The face alignment quality is 0.17, which is desirable value in CFD. The mesh elements are smaller near objects, to take accounts thermal and velocity gradient that are often present near the boundaries of an object. By contrast, the open spaces between objects are meshed with large elements, to minimize computational costs.



Graph 1: Residual graph for CFD calculation

After number of trials 100 iterations are sufficient to calculate the given domain. Convergence criteria for flow, energy, turbulent kinetic energy and turbulent dissipation rate is 0.001, 1e-7, 0.001, 0.001 respectively. Based on the physical characteristic of the above model as defined, the calculated Prandtl number is 0.7085. The graph shows the x, y, z velocity, continuity, energy, k and epsilon. The 100 iterations are sufficient to calculate the above problem. Prior to solving the model, ANSYS Icepack will determine whether the flow will be dominated by forced or natural convection. For flows dominate by natural convection means buoyancy driven flow , ANSYS Icepack computes approximates value of the Rayleigh number and the Prandtl number If the Rayleigh number is greater than 5E + 7 and the Prandtl number is around is 0.71, the turbulent model with natural convection will be recommended. Based on the physical characteristic of the above model as defined , the calculated Rayleigh number and Prandtl number by software are 4.6090E + 9 and 0.7085 respectively

IV. RESULT AND DISCUSSION

The following table shows the experimental and computational values.

Component	Experimental values	CFD Values
Main transformer (core portion)	70	68
Main transformer (upper portion)	68	66
Heat sink	57	54.50
PCB	45	43.45
Sensing transformer	43	42
Inside	43	42
IC	42	41.10
Enclosure	45	44.50

The maximum error between experimental and computational is 4.56 on the PCB. Figure7 shows the temperature distribution on the enclosure. The temperature range is 23.42^{0}C to 68.14^{0}C. In the experimental measurement only surface temperature of different electronic enclosure is measured and in CFD analysis temperature inside the enclosure is also detected. Figure7 shows also surface temperature of the electronic enclosure for validation purpose. Once the normal condition temperature is validating with the CFD calculated temperature the loaded condition apply on the board in different result plotted with the help of ansys icepack

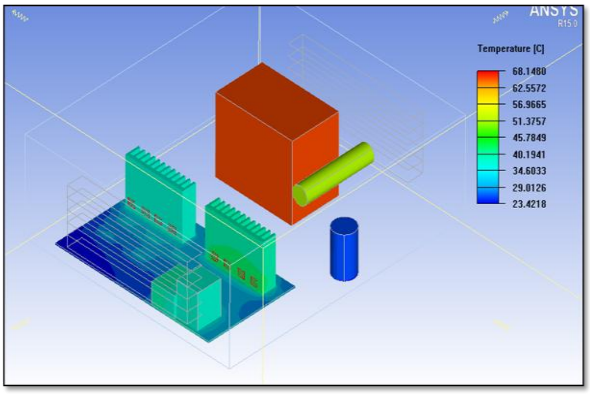


Figure 7: Temperature distribution at normal condition

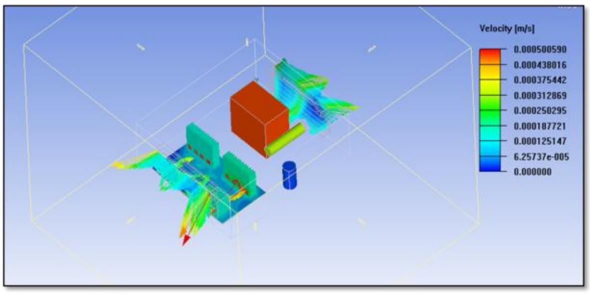


Figure 8: Velocity domain

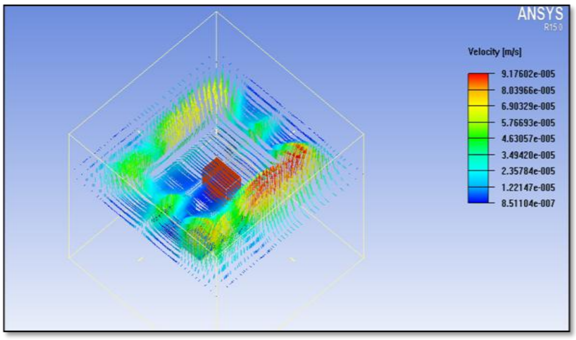


Figure 9*:* Velocity of air above the enclosure

The velocity of the domain is constant because of the natural convection is recommended. The velocity is changing from lower region to upper region because of buoyancy force. The above figure8 shows the velocity region near the component of Enclosure. Since the velocity of air is very negligible, so the conduction cooling is required for cooling purpose. Velocity increases when we move from the components which are more at the grill side due to the buoyancy force and figure9 indicates the animation of velocity contours from bottom to upper region of enclosure cabinet. How to density difference effect on enclosure to velocity difference.

A. Effect of Component Placement on Electronic Enclosure

The component placement is very effective and chipest technique in electronic cooling. Figure10 indicating the well component placed electronic Enclosure. After the component placement temperature decrease from 3 to 6^{o}c in this Enclosure.

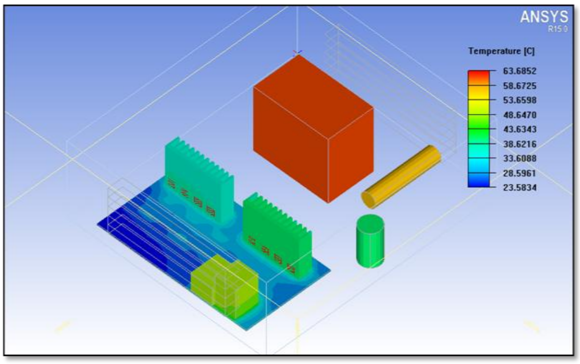


Figure10: Temperature of enclosure component after component placement

The main transformer, resistor and heat sink are main heating component in the enclosure due to that concentration of temperature increases in that particular region. Component placing temperature of the board decreases from 68^{0}C to 63^{0}C. This is not final optimum placement of the enclosure. Taking number of trials temperature will decrease for electronic enclosure.

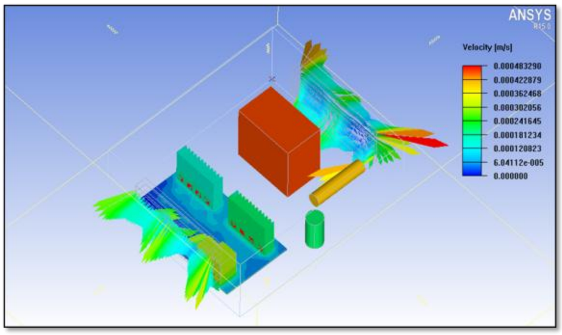


Figure 11*:* Velocity Domain of Enclosure after component placement

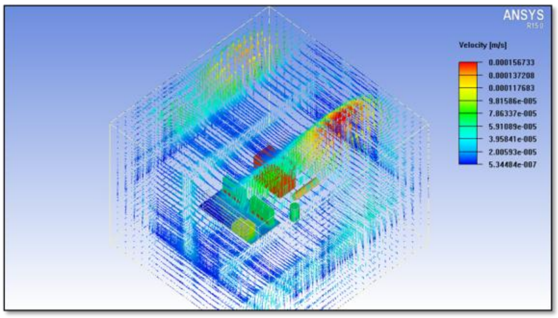


Figure12: Velocity domain of whole cabinet after component placement

After providing the component placement to the enclosure the velocity of the air is increases and varies from 0.00 to 0.000483290, after providing the component placement on enclosure natural convection current increases. The velocity of streamlines travelling to under the component as well as above the component. The velocity of air increases when passing through the grills. In figure11 show the velocity of all cabinet is varies from 5.3448e-007 to 0.000156733.

B. Effect of Grill Placement on Electronic Enclosure

Grill is the only component gives good natural ventilation over components in enclosure. Grills are placed at the upper side of enclosure and exactly above the main transformer since it is main heat source in enclosure. These grills provide effective natural convection.

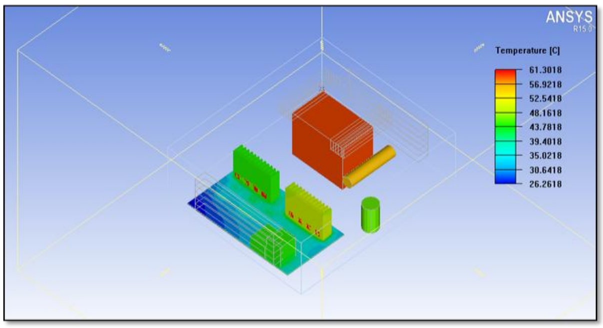


Figure 13: Temperature of enclosure component after grill placement

As the size of grill increases, thermal connectivity of enclosure increases and resulting into decrease in temperature of components. Above figure shows the temperature of the enclosure decreases due to grills used in enclosure. The temperature of enclosure after grill placement ranges from 26.26^{0}C to 61.30^{0}C.

In figure14 we can observe the streamlines of the air due to natural convection, the velocity of the air increases due to the heated component. The grills is provided exactly on the main transformer in previous model air is not freely move inside the enclosure due to that air get trapped inside the enclosure and temperature increases continuously.

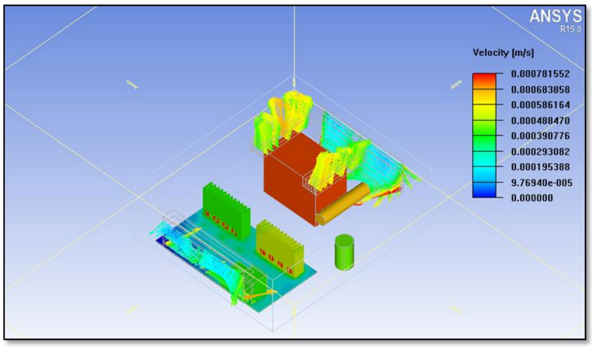


Figure 14: Velocity domain of enclosure after grill placement

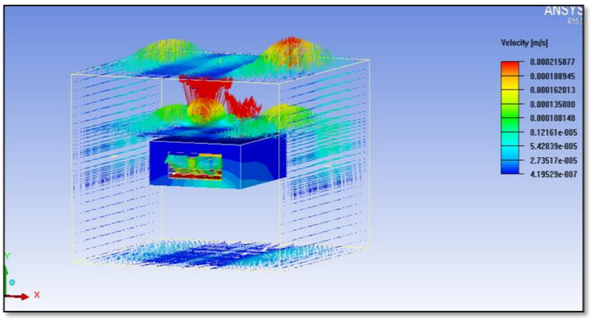


Figure15: Velocity domain of whole cabinet after grill placement

After providing the grills to the enclosure the velocity of the air is increases and varies from 0.00 to 0.0000781552 m/s, after placing grills on enclosure natural convection current increases In figure14 it's clearly indicated that velocity varies from 4.19529e-007 to 0.000215877.

CONCLUSION

Thermal management and thermal management design in Electronic enclosure has long been a challenging issue as its compact on the devices reliability and endurances. The electronic component faces the same challenge of thermal management as the industry in general .A thermal analysis model for electronic enclosure is demonstrated in this paper, the main conclusion are summarised as the following,

The grill placement is a very effective technique to decrease the temperature of component as well as enclosure. Grill size is maintained minimum such that it can avoid the entry of dust inside the enclosure also to avoid accidental injury by human mistakes. The grill replacement technique provides good natural convection over the components. By providing grills on enclosure the temperature of heated component decreases inside the enclosure. The temperature of components is reduced by 3^{0}C to 5^{0}C.

Component placement is also an important factor for the enclosure component temperatures. Multiple trials for components location can be performed in order achieve an optimal thermal design effect. The temperature of component is reduced by 3^{0}C to 6^{0}C.

References

[1] Thermal management of electronics : a review of literature. Shanmuga Sundaram Anandan , Velraj Ramalingam, s.1.: thermal science, 2008, vol. 12.

[2] A review on natural convection in enclosures for engineering applications. The particular case of the parallelogrammic diode cavity. A. Bairi a, E. Zarco-Pernia a, J.-M. Garcia de Maria b. s.l. : Applied Thermal Engineering, 2014, Vol. 63. 304-322.

[3] A numerical and experimental analysis on natural convective heat transfer in a square enclosure with partially active side walls. M. Paroncini, F. Corvaro, A. Montucchiari, G. Nardini. s.l. : Experimental Thermal and Fluid Science, 2012, Vol. 36. 118-125.

[4] Natural convection heat transfer by heated partitions within enclosure. Oztop, Dagtekin and H.F. s.l. : Inr. Comm. Hear Mass Transfer;, 2001, Vol. 28. 823-834.

[5] Unsteady natural convection in an enclosure with vertical wavy walls. Rostami, Javad. s.l. : Heat Mass Transfer, 2008, Vol. 44. 1079-1087.

[6] Laminar Natural Convection in a Square Enclosure with Discrete Heating of Vertical Walls. Radhwan, Abdulhaiy M And Zaki, Galal M. Jeddah , Saudi Arabia : Eng. Sci., 2000, Vol. 12. 83-99.