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Cooling Computer Cabinet Using a Thermoelectric System, a Theoretical Study

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Abstract:

This paper is about cooling 95W socketed CPU of a desktop computer by a thermoelectric system. A Computational Fluid Dynamics analysis of this cooling system is provided in detail. The package used to perform the Computational Fluid Dynamics (CFD) analysis is ICEPAK R.18. The used computer cabin is HP Compaq dc5850. It includes all components that generate heat such as hard disk drive, CPU that has an attached heat sink, CD drive, memory cards, DVD, and power supply unit. Different thermoelectric cooling (TEC) models have been used to support transfer of heat from the 95W socketed CPU. The current study aims to present a thermoelectric cooling (TEC) model of a computer cabinet and to extend it to a module, to validate the accuracy of this model using a numerical simulation and an analytical solution, to identify the impact of using the TEC on the processor, and to study the influential factors that make the TEC efficient.

Keywords:

CFD, Thermoelectric, Electronic Cooling, Computer Cooling

1. Introduction

The thermoelectric modules consist of n and p elements of thermoelectric material placed between 2 ceramic plates, and they are connected in a series. These elements are heat pumps that are solid with no vibration and no noise. They transfer heat from one surface to another as soon as an electric current flows in them. When heat at the hot surface is dissipated to the surrounding environment through a heat sink, this structure is called a cooling unit. In addition to heat transfer, there are many other uses of thermoelectric modules; they are used to generate electricity by changing heat into electrical power. Thus, waste heat can be recovered. Lately, a lot of modern thermoelectric materials have been devised, helping considerably to raise the efficiency of power generation.

Moreover, the thermoelectric module is commonly used in medical, military, industrial, scientific, commercial, telecommunication and electro-optic fields for heating, cooling and producing power because it is small and light with no moving parts.

While operating Peltier elements, temperature limits have been found. The first limit is the maximum temperature of operation that is 200 °C, which is determined by the reflow temperature of sealing and solder. The second limit is the maximum difference between temperature of the hot side and temperature of the cold side in a Peltier element. In common applications, this difference is about 50 K in an element of a single stage.

A third limit has been found while using a Peltier element in thermoelectric cooling; the temperature rises once again when more current flows due to dissipation of power (I2R) in the Peltier element in case of applying a current more than Imax.

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This diagram of a thermoelectric system points out the components that are in the heat flowing path from the object to the surrounding air. It is a simple schematic diagram of objects that we assume their complete thermal insulation, i.e. the objects' temperature is not affected by convection. (Q stands for each object's thermal capacity.) [1]

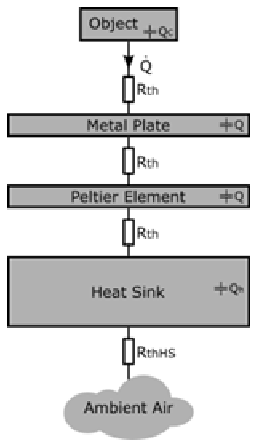

Fig.1 Simple schematic diagram of a cooling system

Scott Lee, [2] thought that generating thermoelectric energy can be a convenient source of power in space, particularly when other sources cannot be used. In addition, the photovoltaic cells are considered an alternative source of energy with greater efficiency of about 40% compared to about 5% for the thermoelectric generator.

However, the thermoelectric generator provides energy for deep-space missions where solar cells would not operate. Furthermore, the thermoelectric generator is comparatively inexpensive, robust and easy to use because it is a solid device that has no moving parts. Thereupon, electrical systems, such as robots, satellites and automobiles, can depend on thermoelectric generators.

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Suwit Jugsujinda*, Athorn Vora-ud et al.2010 [3] found that the thermoelectric cooling cold plate in TER used an electric current of 3.5 A. The temperature decreased from 30 ºC to – 4.2 ºC in one hour and to –7.4 º C in 24 hours. The TER was down from 30 ºC to 20 ºC in one hour and the temperature decreased slowly in 24 hours. The higher COP of TEC and TER were 3.0 and 0.65, respectively.

Prashant Gour and Tushar Arora 2012 [4] proved that when there is no cold plate, the convective transfer of heat is so low even if a fan is installed. The result was the decrease of only one degree Celsius in middle part of the chamber and nearly 10 degrees Celsius at the module's surface, not taking time into consideration. Even when fans were installed to decrease temperature more, this procedure was of no much help. To have more temperature difference in the middle part, there must be conduction first, then convection to the air regarding transfer of heat from the module's surface. To achieve this goal, a cold plate must be installed (a heat sink) on the module's surface to get conduction firstly and convection to the air secondly.

According to Sandip Kumar Singh, Arvind Kumar 2015 [5], the cooling challenge has a new factor that is reducing temperature by thermoelectric solar refrigeration. Thermoelectric cooling (TEC) is considered a potential choice due to the great demand for enhanced cooling technology in order to improve performance and to reduce the operating cost. Devices of thermoelectric solar refrigeration can function as power generators, coolers, or thermal energy sensors. Therefore, technology of thermoelectric solar refrigeration has been commonly used in many fields such as aerospace, military, medicine, biology, commercial and industrial ones. With optimized operating conditions, it has been found that the temperature dropped by 12 ºC with no heat load, and by 10 ºC with 100 ml of water in the space of refrigeration with surrounding temperature of 24 ºC in the first half an hour.

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The project made by Ankit Kumar Mishra, Ankit Kumar Singh, et al 2017 [6], identifies the thermoelectric generator's performance under inconsistent conditions like limited working temperature and mismatched temperature distributions among the modules of series connection. The experimental data show the impact on electrical performance when modules operate under inconsistent conditions like mechanical load and inconsistent temperature. It is concluded that the electrical performance is improved by the suitable difference in temperature between both sides of the module. Based on the experimental results, it has been found that the loss of power in the modules in series connection is great. It is less than theoretical maximum power by 11% because of the inconsistent temperature conditions. Additional 2.3% can be reduced under the same conditions of working through thermal insulation of the modules and the power loss resulting from the mismatched temperature distributions. It is proposed that the thermal insulation is a new influential method to systematize the mismatch electrical features of the modules in the inconsistent conditions and to enhance the TEG system's performance with higher engine speeds.

The purpose of the study conducted by Rohitha Weerasinghe*, Thomas Hughes 2017 [7] is examining the benefit of CFD simulation in creating virtual thermoelectric cooling that is used to thermally manage downhole tools depending on the information of the data sheet and easy experimental techniques to determine the characteristics of the units at raised temperature. It has been found that the method of first-order linear approximation gives a steady-state solution comparable with the experimental data; the unit's resistance at raised temperatures can be gained from a lab experiment, and the values of Qmax and ΔTmax can be found based on values available in the literature.

Ma Ting, Xing Lu et al 2019 [8] found that thermoelectric modules used to generate electrical power are usually inserted between hot-side and cold-side exchangers of heat. However, the inserted structures are improper for recuperators as efficiency of heat transfer is considerably reduced by the huge thermal resistance resulting from the thermoelectric modules. To keep the efficiency of heat transfer and to produce more electrical power, a new perspective of thermoelectric generator is suggested. It includes fins that are made of thermoelectric materials other than steel. FLUENT software is used to develop a numerical model with User Defined Function codes.

The thermal-hydraulic performance of the new recuperator is similar to that of the conventional plate-fin recuperator. However, it produces more electrical power. The impacts of Reynolds number on internal resistance, open circuit voltage, output power, heat transfer, and pumping power are examined. The optimum velocity of hot gas is 1.5 m/s making a difference of 147.6 K in temperature. The open circuit voltage is 31.5 mV. The output power is 0.23 mW. For geometrical optimization, Taguchi method is used for designing numerical cases. It is found that the effective order is: channel width > TE fin thickness > TE fin height. The optimum values of channel width, fin thickness, and height are 1 mm, 3 mm, and 1 mm, respectively.

2-Description of the Problem and Way of the Solution

Computer chassis model is shown in Fig. (III-1). It is made as the real dimension of PC cabinet of model No. (HP Compaq dc5850).

The chassis was examined with different heat sinks in the previous study and the best one was selected. Now, thermoelectric cooling (TEC) will be added between the CPU and the heat sink that is considered the cold side on the CPU using various models. Each model's dimensions are 40*40 mm.

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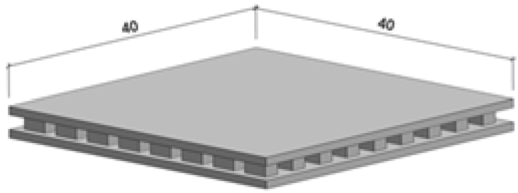

Fig.2 Schematic diagram of TEC geometry

2.1 Controlling equations

The flow inside the cabinet is steady-state and turbulent compressible with three dimensions. It is controlled by momentum, continuity and energy equations. These controlling equations are changed based on conditions of the case being simulated. Time-dependent parameters and viscous dissipation are omitted from the equations because the problem is supposed to be steady-state with low velocities. Thus, the equations are as follows:

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho \upsilon) = 0 \quad (3.1)$$

X-momentum:

$$\frac{\partial(\rho u)}{\partial t} + \nabla.(\rho u\, \bar{V}) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho f_x \quad (3.2)$$

Y-momentum:

$$\frac{\partial(\rho v)}{\partial t} + \nabla.(\rho v\, \bar{V}) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + \rho f_y \quad (3.3)$$

Z-momentum:

$$\frac{\partial(\rho w)}{\partial t} + \nabla.(\rho w\, \bar{V}) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + \rho f_z \quad (3.4)$$

Energy:

$$\frac{\partial(\rho e)}{\partial t}+\nabla.(\rho e\vec{V})=-p\nabla.\vec{V}+\nabla.(k\nabla T)+\Phi+q \quad (3.5)$$

Equation of state:

$$p=\rho RT \quad (3.6)$$

In the previous equations, ρ stands for density; u, v and ware components of the velocity in x, y and z respectively. V represents the vector of velocity. The body forces are fx, fy and fz, p stands for pressure, q represents heat flux that is a source term, R stands for gas constant, and shear stress is symbolized by τ that can be identified for Newtonian fluids.

2.2 Turbulent Modeling

Algebraic Turbulence Model is the default model of turbulence for all calculations. This model is a two-equation one and is the easiest computationally because there are no additional equations are solved except for continuity, momentum and energy. Moreover, results of the algebraic model must be validated by turbulence models of higher-order so that they can be depended on. The used test case is K-ε model. A comparison has been made between velocity fields and temperature distributions and acceptable agreement has been found. Thereupon, it is suitable to use Algebraic Turbulence Model.

2.3 Geometry under consideration

Fig.1 shows the layout of the CFD model in the used computer. The current study presents a modelling of all major components of the PC chassis. Air is circulated through the cabinet by fan and grilles. The fan is installed opposite to the heat sink and is used only for cooling the CPU. In addition, an exhaust fan is used to cool the power supply unit. There is a main intake grille and another opposite exhaust grille.

All components of the cabinet represent the actual components. A sufficiently fine mesh that describes each component's details would lead to a disproportionately great number of mesh points, which can not to be traced by the limited computational resources. The mesh has been created using Icepak preprocessor.

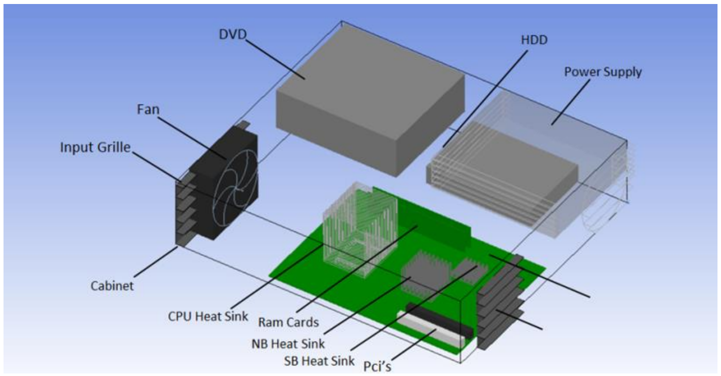

Fig.3 The model of computer chassis (L×W×H) in (Z×X×Y) directions

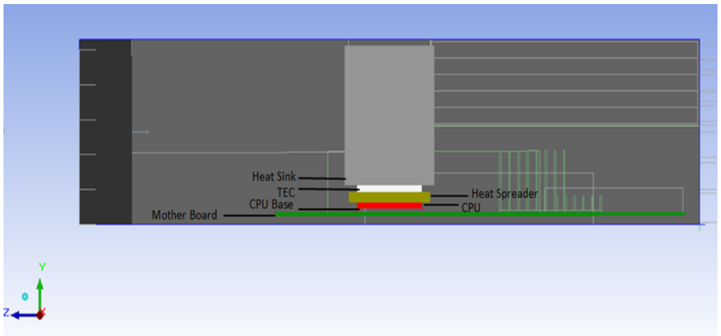

Fig.4 The cabinet from a side view showing the CPU's cooling system

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Dimensions of the cabin and all components have been determined based on a standard PC cabinet. The cabin is an aluminum rectangular enclosure. Its dimensions are: a width of 335 mm, a height of 380 mm, and a depth of 90 mm. The area of the thermo-electrics is 40x40 mm with different depth. Table (2) shows the specifications of these models. The heat sink and the heat spreader are put on the thermo-electrics for heat distribution. Coolant thermal conductive grease is used for good contact.

2.4 Boundary conditions:

Fig. 2 shows a schematic diagram of the thermoelectric geometry. A couple includes n-type semiconductor, a p-type semiconductor, a ceramic and copper. The ceramic acts as an electric insulator but copper is a conductor of electricity. The material, used in the junction where copper and the leg are soldered, is characterized by electric contact resistance. This resistance is very important as it helps to calculate the module's cooling power. In the current numerical model, radiative heat transferred from the thermoelectric system and the sink is negligible. The CPU die is 38×38 mm square. It is connected to the heat spreader's base plate. The internal fan is circular with a diameter of 45 mm, and it has a special performance curve. All the remaining components are modeled such as the solid blocks that uniformly generate a certain amount of heat in the volume. Resistance of Icepak is used for modeling the power supply. The effect of the resistance acts as a pressure drops via its volume.

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2.5 Boundary conditions:

The adiabatic boundaries are the cabin's top, side and bottom. The thickness of the enclosure's wall is negligible. In the modeling, the DVD, hard disk drive, memory cards and CD drive are considered lumped components that have uniform volumetric generation of heat inside them. The card slots and the motherboard force some restrictions on the airflow inside the cabin. However, no heat is supposed to be generated from them. Air intake is achieved through an inlet grille that has a certain loss coefficient. The pressure drop through the vent must be taken into account. The pressure drop across the vent is supposed to be proportionate to the fluid's dynamic head with an experimentally identified loss coefficient. In other words, the pressure drop differs according to the normal component of velocity across the vent, u:

$$p = \frac{1}{2} k_l \rho u^2 \qquad (3.6)$$

K_L represents the non-dimensional loss coefficient of the current study. Temperature of the surrounding air is supposed to be 25°C. All properties of air are assessed at this temperature. The CPU die has a square area of 38 mm by 38 mm at the bottom of the heat sink. A uniform heat flux is calculated according to the sum of heat dissipation value. Regarding heat sinks, boundary conditions—related to temperature continuity and heat flux—are provided. However, an interface exists between the fluid and the fin.

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2.6 Solution procedure

ANSYS Icepak is used for modeling electronic systems, conducting fluid flow, and simulations of heat transfer as it is CAE software. ANSYS Fluent CFD solver engine is used by ANSYS Icepak. It is used to solve partial differential equations in a control volume according to the method of finite volume with SIMPLE algorithm. In all chosen geometries, the flow is assumed to be turbulent. ANSYS Icepak's turbulence models use Reynolds averages of the controlling equations. Variables of the solution in the instantaneous Navier-Stokes equation are dissociated into the fluctuating and the mean components.

ICEPAK R18 is used for solving the controlling equations for the solid regions and the fluid. In this study, the solution algorithm is the segregated solver. It is used to solve the three controlling equations in this order: mass, momentum, and energy.

2.6 Model validation study

A.E.Kabeel, A.Khalil, G.I.Sultan* and M.I.El-Hadary (2019) have offered CFD models to calculate the cooling effect factor (CEF) using different heat sinks. Table (2) compares between TECs and CEF results with both heat sinks.

3. RESULTS AND DISCUSSION

3.1 Grid Independence

To get a grid independent solution, a study of grid independence in the system cabin with thermoelectric cooling was conducted. The used meshing was a hexahedral unstructured one. The resulting mesh took into consideration the non-uniform distribution; an approximation was made of half a million hexahedral elements, except for the walls of the fin in the portion near to the base where the cell ratio was 1.025. Figs. 3 and 4 show the computational mesh adopted in the current study regarding a typical case.

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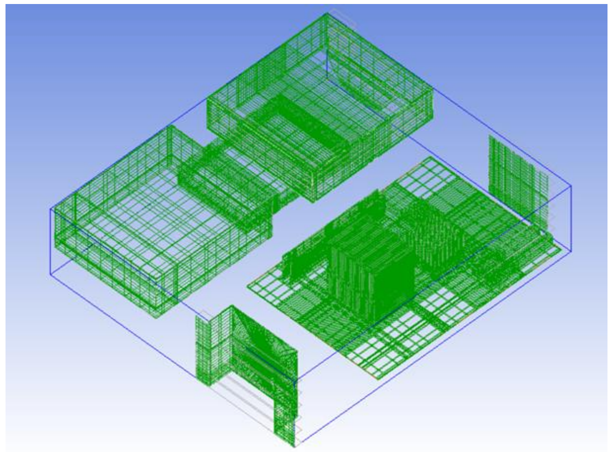

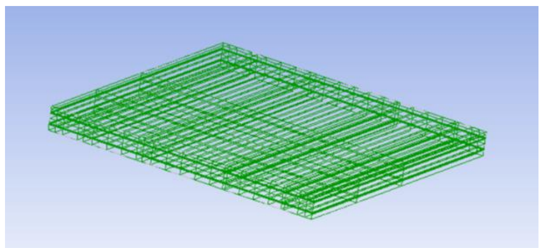

Fig. 5 (a) The cabin’s computational mesh
(b) Computational mesh of some components of the desk top computer

3.2 Distribution of Temperature:

Table (1) shows the highest temperature of the CPU case and system’s components. They are gained from simulations performed for a 95W processor with thermoelectric cooling and a heat sink that is vertical and straight. The values of the highest temperature of CPU case match well with the values found in the data sheet of the manufacturer. Other components’ temperatures are good within their operating values.

Table (1) Maximum temperature of CPU and other components using TEC

Components	Max. temperature (°C)
CPU Case	23.23
HDD	39.3
DVD	24.2
Power Supply	53.4
RAM-1	46.7
RAM-2	45.4

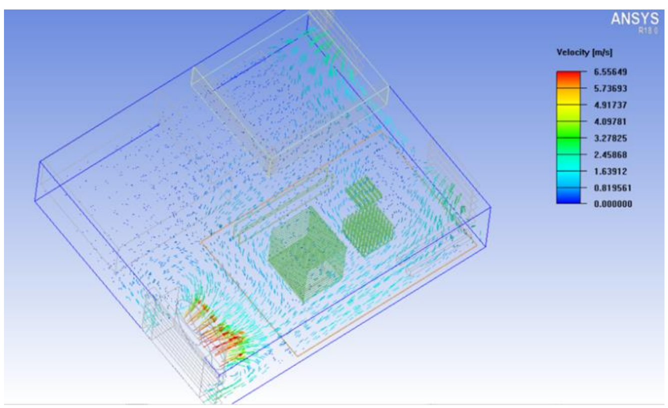

Fig.6 Velocity vectors plan at a parallel section to motherboard in the system enclosure (95W CPU).

Fig. 6 shows the airflow's velocity vectors at a parallel section to motherboard in the system enclosure. The pattern of the airflow shows that there is a strong flow via the heat sink, on the motherboard, and in places of the grilles. However, this flow becomes weaker at places away from the motherboard. Through the intake grille, air flows into the cabin with an average velocity of 2.4 m/s. The highest velocity of airflow via the fin of the heat sink is approximately 3.7m/s.

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Fig. 7.a compares the contours of airflow temperature at a section over the motherboard before and after TEC with 126.4 W and highest ampere of 24. Temperature of air on entering the system is 25 °C. This temperature rises along the path of airflow. Over the CPU, it increases to 50 °C so it is considered the hottest portion of the cabinet. However, as shown in Fig. 7.b, the processor has the minimum temperature by the impact of TEC.

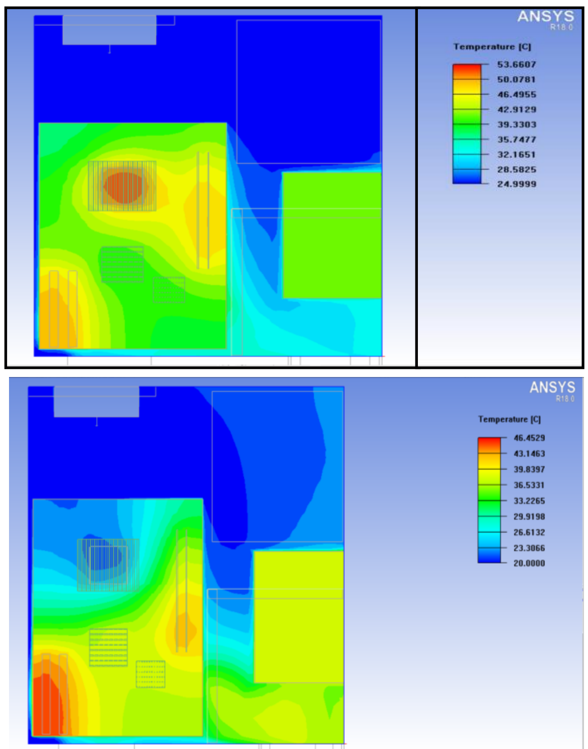

Fig.7 Static temperature's contours at a section over the motherboard after and before using TEC in the 95 W CPU

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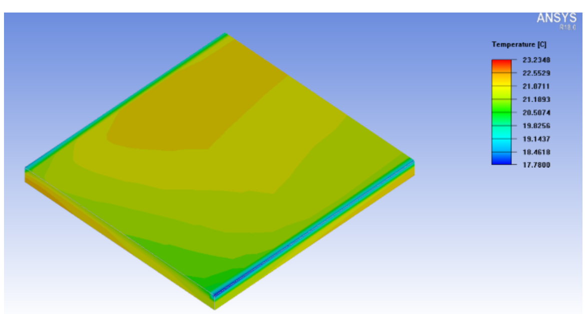
3.3 Impact of TEC on cooling the processor

Table (2) Specifications of various TEC models

NO	MODEL	
1	07111-5M31-24CQ	Qmax126.4. Vmax8.5,Imax24
2	12711-5L31-04CQ	Qmax33.4, Vmax15.4,Imax4
3	12711-5L31-07CQ	Qmax60, Vmax15.4,Imax7
4	12711-5L30-25CQ	Qmax22.6, Vmax15.4,Imax2.5
5	12711-9L31-05CQ	Qmax47.1, Vmax15.2,Imax5
6	12711-9L31-09CQ	Qmax77.1, Vmax15.4,Imax9
7	12711-9L31-12CQ	Qmax100.1, Vmax15.4,Imax12
8	19911-5L31-06CQ	Qmax88.5, Vmax24,Imax6
9	12711-5P31-12CQ	Qmax113, Vmax15.4,Imax12
10	TEC1-12706	Qmax60, Vmax15.2,Imax6

Fig.8 The figures show the cooling impact of TEC on CPU from 1 to 10 respectively



Case 1

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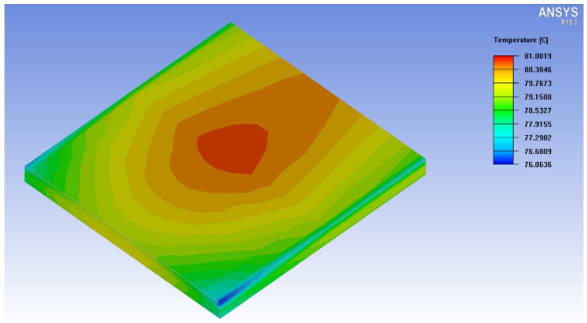
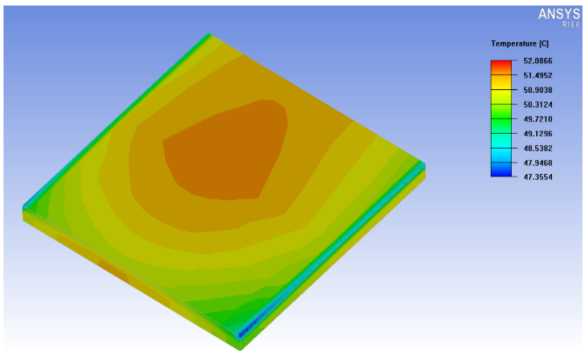
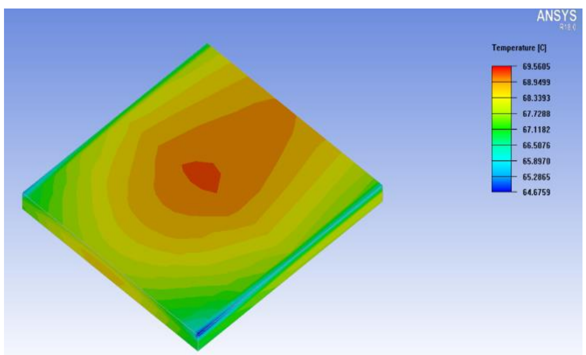


Case 2



Case 3



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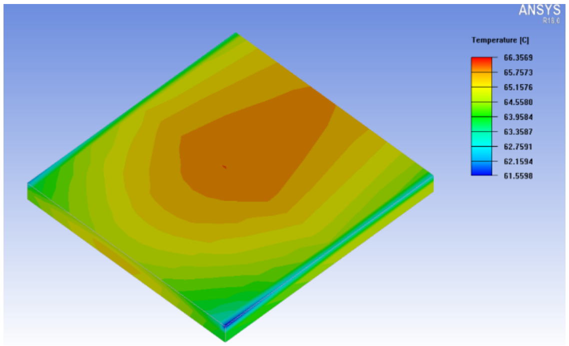
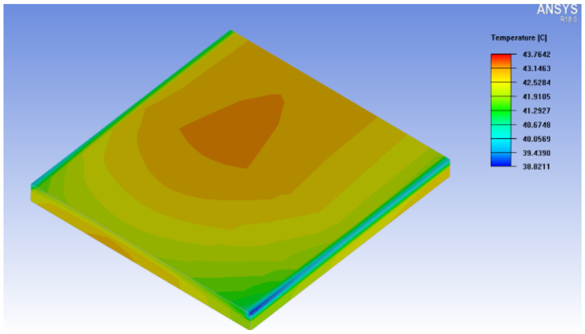
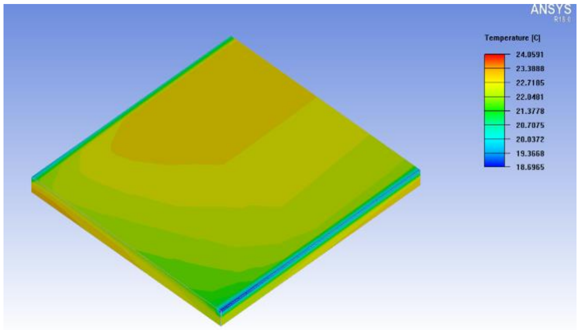


Case 5



Case 6



Case 7

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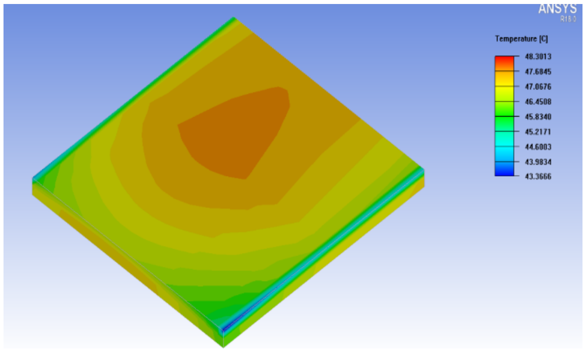
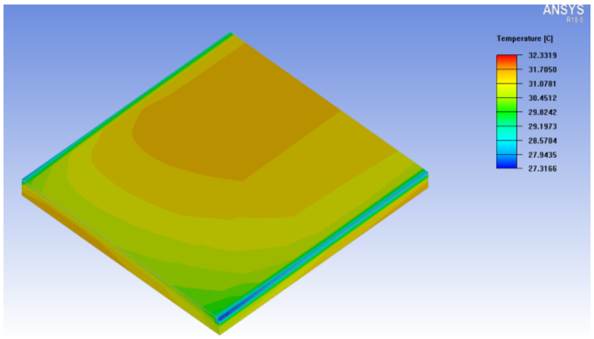


Case 8



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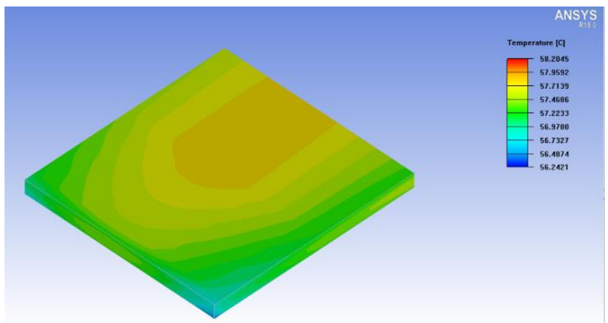

Case 10

3.4 Cooling effect factor

Based on the studies cases, as shown in Table (V-3), and after comparing the cooling effect factor (CEF) of various models of heat sinks, it has been found that the most influential model has a CEF of 0.79. However, in thermoelectric cooling case, it is increased to 1.17 for the most influential model. It is case (1) in the first group where alpha heat sink is used.

Heat sinks	
Case	**CEF**
1	0.70923
2	0.585995
3	0.792225
4	0.6124025
5	0.53821

Thermo-electrics	
Case	**CEF**
1	1.179535
2	0.4527
3	0.817375
4	0.5973125
5	0.6375525
6	0.9217475
7	1.169475
8	0.8639025
9	1.0651025
10	0.73941

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$$ZT = \left(\frac{T_{\mathrm{h}} - T_{\mathrm{c}}(1-\eta)}{T_{\mathrm{h}}(1-\eta) - T_{\mathrm{c}}} \right)^2 - 1$$

The next procedures are necessary for designing a TEC application:

First, assess the heat load of the object that is going to be cooled. Second, identify the range of working temperature for both the object and the heat sink. Third, select the Peltier element that meets these requirements. Fourth, select a thermoelectric cooling controller that has an appropriate power range. Fifth, select a heat sink suitable for the Peltier element. Sixth, it is preferable to select a fan to cool the heat sink (optional). Seventh, select a sensor for the object's temperature and another optional one for the heat sink. Finally, select a TEC controller's power supply.

A significant criterion is the amount to heat that has to be absorbed by the TEM's cold surface or Peltier element from the object (QC [W]). Based on the application, various kinds of heat load must be considered namely radiation, power dissipation, and convective/conductive dynamics (dQ/dt). The heat load QC summarizes these loads. It is transferred from the cold side to the hot one where the heat sink is placed. A temperature difference results from the Peltier element. This difference is due to the current flow between both sides of the Peltier element. The Coefficient of Performance (COP) is a significant parameter while selecting a Peltier element. COP is defined as the absorbed heat at the cold side; it is divided by the Peltier element's input power: COP = QC / Pel.

The maximum COP results in the minimum input power of the Peltier element. Hence, heat sink dissipates the minimal total heat. (Qh = QC + Pel). Thereupon, an operating current must be found through combination between an optimum COP and a specific dT.

An assessment of Qmax helps us to select a Peltier element. A design margin is added by: selecting a Peltier element that has heat pump capacity more than required, designing a system that has an operating current much less than Imax of the Peltier element, using a heat sink of a bigger size, or putting a fan to maintain the temperature of the hot side low. Consequently, a change in the active heat load or surrounding temperature does not result in a thermal runaway.

Heat Sink

The heat load is absorbed by the heat sink at the Peltier element's hot side, and it is dissipated to the ambient air. Some reserve must be added when determining the dimensions of the heat sink so as not to get a very high temperature of this heat sink. The next diagram shows that the heat Qh, i.e. the heat that the Peltier element rejects, can rise to 2.6 times Qmax because of the internal heat produced during heat pumping in the Peltier element. Thus, the overall heat that must be dissipated at the heat sink includes the object's heat and the Peltier element's internally produced heat.

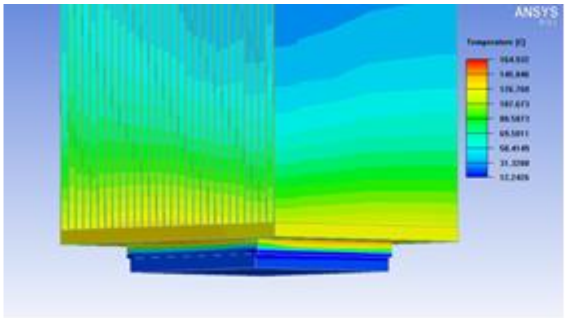

Fig.9 Temperature change after CFD analysis

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3.5 Parametric Study

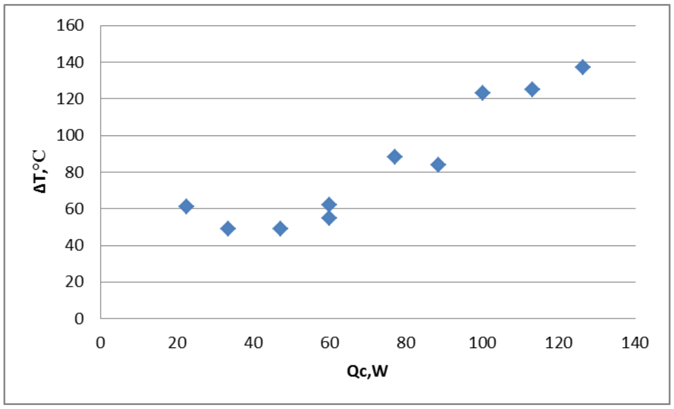

Fig. 10

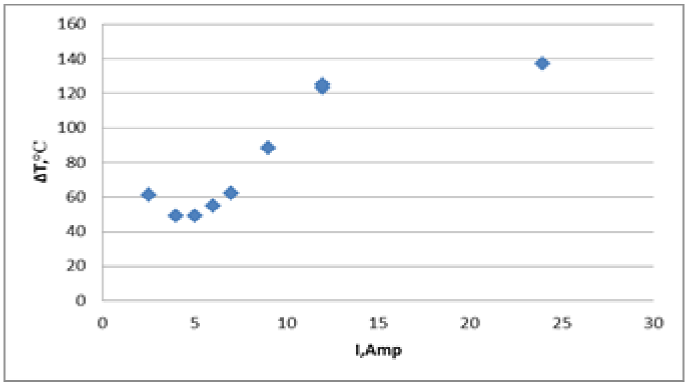

Fig. 11

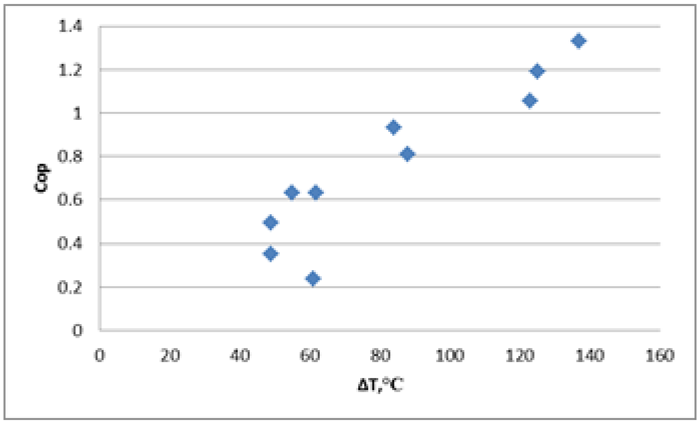

Fig. 12

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Fig. 10 points out the relation between QC of various models and ΔT. The difference in temperature increases as every QC increases. Hence, with huge dT, the heat sink dissipates a huge amount of heat compared with a little amount of heat absorbed at the Peltier element's cold side.

In addition, Fig. 11 shows the relation between ΔT and the current. It points out that the temperature difference increases when the current increases.

To determine the suitable TEC system, our purpose is to find a Qmax which is huge enough to cover the required QC and which results in the best Coefficient of Performance (COP) as in Fig. 12. COP has an influential role in QC as there is an obvious relation between them.

4. Conclusion

This study presents a numerical simulation of heat transfer and fluid flow inside a computer set using thermoelectric cooling (TEC) enclosure. It is found that the cooling offered to the processor, which dissipates 95W of heat, is not enough for cooling a processor with high heat dissipation. Thereupon, various models of thermoelectric cooling fins are used. A parametric study has been conducted to examine the impact of different parameters on the maximum temperature of CPU case and of other components.

Based on this study, the significant conclusions that can be reached are as follows:

1- Thermoelectric cooling (TEC) has an influence on decreasing the CPU temperature by approximately 16°c comparing with the heat sink.
2- With absorbed heat and current, the resulted ΔT from TEC increases.
3- By increasing ΔT, the TEC COP increases.

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5. TERMENOLOGY

TEC	
TO	object temperature (cold side temperature) [°C]
THS	heat sink temperature (hot side temperature) [°C] = Tamb + ΔTHS
dT	The difference between TO and THS is known as dT (ΔT or deltaT) [K]: dT = THS - TO = Tamb + ΔTHS - TO
QC	the amount of heat to be absorbed from the object by the cold surface of the TEM or Peltier element.
COP	Coefficient of performance
CEF	Cooling effect factor

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