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Fundamental Study on the Possibility Applying Peltier Device in the Air Conditioning System

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ABSTRACT

In the present scenario, Heating, Ventilation and Air Conditioning (HVAC) system commonly uses the efficient air conditioners but it has some demerits. The application of conventional system however, emits harmful gases such as freon, ammonia or carbon dioxide. The purpose of this study was to analyse the use of thermoelectric air conditioning system in cars to improve the Coefficient of Performance (COP) value. The simulation method was used to analyse the air flow through a chamber. The results showed with the current design, the COP value is able to achieve more than 2, which is significantly higher than previous studies. The temperature analyses at the outlet of the cooling chamber was done in order to calculate the COP value with varying the velocity of air flow. The outcome with higher base dimension of heat sink and higher number of fins resulted in better efficiency. This is because the heat sink strongly influences the COP value.

1. Introduction

Thermoelectricity was first studied between the year 1820 and 1920’s. Thermoelectricity was developed and introduced in western Europe by academic scientists 100 years before the world wars, with much of the activity concentrating in Berlin. The notion of thermoelectricity was developed and defined by Thomas Seebeck and Jean Peltier in the early nineteenth century. In 1821, Thomas Seebeck found that heating either side of a connection composed of two distinct cables might result in an electromotive force or a potential difference. After this electromotive force or potential difference, the Seebeck effect was named. Jean Peltier established that the Seebeck effect is a reversible phenomenon 13 years after Seebeck's discovery. To put it another way, one junction will be heated by putting an electric current across it, while the other side of the junction will be cooled. A thermoelectric module is generated whenever the variety of separate wires are physically coupled in line and electricity is series – connected [1].

Lord Kelvin (William Thomson) predicted and observed the Thomson effect in 1851. The Thomson effect can be described the heating or cooling of a current carrying temperature gradient conductor. With the current conducted through this gradient, a continuous element of the Peltier effect will occur [2,3].

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The thermoelectric (TE) effect is the transmission of changes in temperature to electrical charge and back using a thermocouple [3]. TE is commonly widely used for a variety of functions, including power generating, cooling and heating [1]. When the device is employed as a generator, another end of the mechanism is warmed to a hot concentration than the other, resulting in a voltage differential between the two sides. The Seebeck effect is the name for this phenomenon. When a device is regulated as a cooling or heating device, voltage is supplied across the device, resulting in a 2 temperature difference between the two sides. The Peltier effect is the name for this phenomenon [4].

1.1 Seebeck Effect

The Seebeck effect translates a difference in temperature through an electrical charge and from both ends of a thermoelectric material by creating free electrons and semiconductor holes. A current is created when electrons and holes flow across each other. A thermocouple is positioned between the semiconductor and the conductor, else a potential difference between both the cold and hot sides would be indicated [1]. The Seebeck effect is a typical case of an electromotive force (EMF), with a temperature-proportional, E_{emf} potential difference between cold and hot ends. The Seebeck effect is frequently reflected in the creation about an electric circuit force at a regional level,

$$E_{emf} = -S\Delta T \tag{1}$$

where, S is the Seebeck coefficient (also known as thermopower), ΔT is the difference in temperature between the thermoelectric material and the surrounding environment. The Seebeck coefficients change with temperature and are highly influenced by the conductor's composition [3].

1.2 Peltier Effect

Energy from one junction is expanded and absorbed at another junction whenever an electric current passes through a thermocouple circuit. As current runs through a junction between two conductors, heat must be constantly supplied or removed to keep the junction temperature constant [1]. The current flow direction varies depending on the application, from negative to positive, and between positive and negative voltage sides [5]. The amount of energy generated through the junction determines the current. The Peltier heat at the junction develops at a constant rate.

$$Q_{peltier} = (\pi_A - \pi_B)I \tag{2}$$

where, πA – πB are the Peltier coefficients of different conductors A and B, I is the electric current (from A to B) [3].

1.3 Thomson Effect

In some ways, the Thomson principle is similar to the Peltier effect, but the Thomson effect requires a difference in temperature and a moving energy. The temperatures of the Seebeck coefficient is really not constant in different materials because the Seebeck coefficient is a spatial gradient. A temperature gradient wire absorbs or releases heat as current passes through it, depending on the material and current location, resulting in a constant change of the Peltier effect.

The flow and temperature differential affect the rate of absorption of heat or release [1]. Heat transfer at the Thomson rate when a current density, J, is passed through a conductor, Q_{Thoms} is given by the equation.

$$Q_{Thoms} = -KJ\Delta T \tag{3}$$

where, ΔT is the temperature gradient, K is the Thomson coefficient [3].

1.4 Problem Statement

Automobiles play a critical part in human life, and transportation is essential for survival. The most immediate concern is the availability of electricity for automobiles [6]. There rely on two potential solutions available: Using renewable sources of energy and making the best use of the energy that is already available [7]. As most automobiles operate on fossil energy, their widespread use has resulted in resource depletion and increased poor air quality [8]. As a result, lowering automotive fuel usage is critical. Automobile HVAC systems play a critical role in lowering fuel usage. [9].

In the hot environment and as a result of global warming, air conditioning in automobiles has become almost ordinary. In most cases, an automobile's air conditioning system is provided using the well-known vapor compression type system which includes among other things, driving the compressor unit with the vehicle's engine. Current air-conditioning systems in automobiles cause a variety of issues, including environmental pollution (Chlorofluorocarbon emissions), increased fuel consumption and decreasing engine efficiency [10].

The evaporator, compressor and condenser are the three main components of a classical cooling system. In the evaporator, the compressed refrigerant is allowed to expand, boil and evaporate. During the transition from liquid to gas, heat is lost. The compressor reacts as the refrigerants pump and recompress the gas into liquid. The condenser aids in the removal of heat absorbed into the atmosphere as well as heat emitted into the atmosphere *via* compression [11]. Because these systems generally require electrical, mechanical and fluid control systems to operate, they may result in excessive load, component complication, occupant of a large number of areas and the need for regular maintenance [9].

In automotive air conditioning, intermediate fluid is frequently used for cooling. The ozone layer is depleted as a result of the fluid leaks, resulting in global warming. These systems also have mechanical and moving components that put a lot of pressure mostly on engine and raise fuel usage. Acceleration was slowed by adding weight to the engine. Air pollution rises in conjunction with increased air fuel usage [9].

As a result, turning on the TE could be a big phase toward getting rid of standard car air conditioners. The development of an air conditioning system based on the TE couple will eliminate all of the current air conditioning system's drawbacks. Thermoelectricity has several disadvantages as well, such as high costs and limited efficiency [9]. Thermal conduction within the TE module, which is a Peltier unit, is 5 used to transfer heat from the heated side to the cool side. As the temperature difference widens, the mechanism becomes more effective. As a result, the heat effectively decreases as the temperature differential increases and the module becomes less useful [12].

The development of heat sinks must be considered to achieve performance enhancement by maintaining the system temperature differential with respect to essential heat removal in order to preserve the module's COP.

2. Literature Review

After studying the fundamentals of TE, it was discovered that a normal air-type TE device should be connected to a heat sink in order to optimise performance. As a result, finding a dependable approach that indicates how ideal heat sink condition parameters play a vital part in determining an effective optimal TE air conditioning system modelling is critical [1].

2.1 Thermoelectric Air Conditioning System (TEACS)

A variety of studies on the TEACS have been seen in the literature. Uemura [13] launched the first mention of the automotive TEACS beginning in 1958 in Japan, where Mr. Y. Kawai was involved in the TE experiment to be used in the manufacture of bulldozers for commercial use. At that time, contrary to his expectation, large-scale consumer TE cooling could not compete with vapor compression systems.

A conventional TE module is made up of a number of thermocouples placed between two ceramic substrate layers. The ceramic substrates should have a high thermal conductivity to ensure that there is little temperature decrease across the layer of the substrate, but a low electrical conductivity to prevent leakage current flow. A schematic of the construction of a typical TE module is shown in Figure 1 [14].

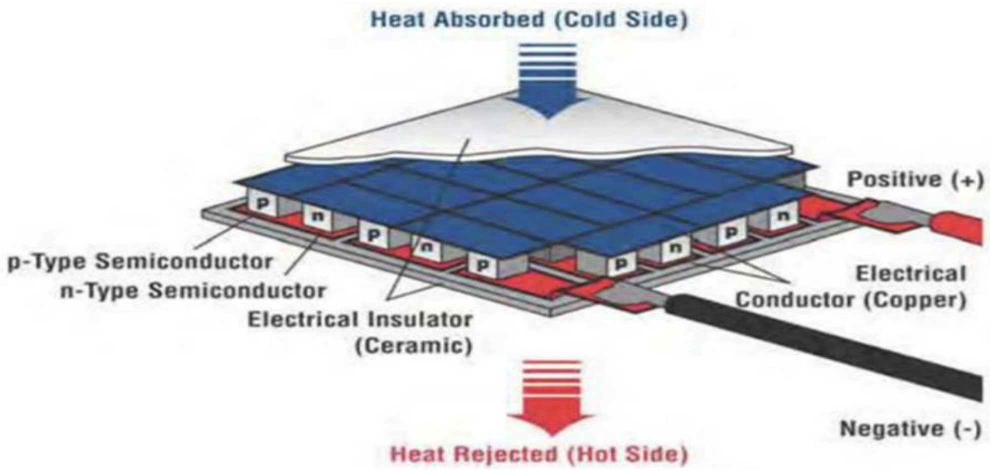

Fig. 1. Schematic construction of a typical TE module

An experimental analysis of TE air cooling for cars was performed by Manoj and Walke [15]. By replacing the current HVAC system with emerging new TE pairs or coolers operating on Peltier and Seebeck results, they are trying to resolve these disadvantages. Inside a small passenger car, they designed and tested a TEACS where the heat load for cooling the air is 222 W and it is acceptable for this experiment. Their system, consisting of six electrically linked TE cooler modules in series placed between two heat sinks, can lower the temperature in the cabin to as low as 7˚C. With the aid of a blower, the device is intended to recirculate the cold air to increase performance and have a cabin temperature of 25.8˚C where the ambient temperature is around 32˚C.

An experimental analysis of the design method of the TE cooler was carried out by Huang *et al.*, [16]. The TE cooler is built and different variables are analysed. The performance test results are used to determine the physical properties and derive the empirical relation of the performance testing. The simulation of the device reveals that there is a cheaper heat sink for the model of a 0.2515 ˚C/W thermal resistance TE cooler. The simulation process is also shown to correlate with experimental results from a TE cooler. The combination theoretical and experimental analysis of TE materials and application was proposed by Yadav and Mehta [17]. The TE cooler device proposed is semiconductor material and current to transport energy such as heat from cold source to a hot source via n-type and p-type carriers. This device is fabricated by combining 11 the standard n- and p-channel solid-state TE cooler with a two-element device inserted into each of the two channels to eliminate the solid-state thermal conductivity. The cooling device is shown to have an energy transport per electron about 500 meV depending on concentration and field, while the good TE coolers is about 50-60 meV at room temperature.

2.2 Heat Exchanger

As shown in Figure 2, a typical TE device consists of a TE module and two heat exchangers or heat sinks connected to both the cold and hot side of the device. It has been shown that the researchers are trying to replace the traditional TE equations and equations of heat sinks and then optimize the geometric parameters of the heat sinks, where the analysis uses two-stage optimization to investigate the output [18].

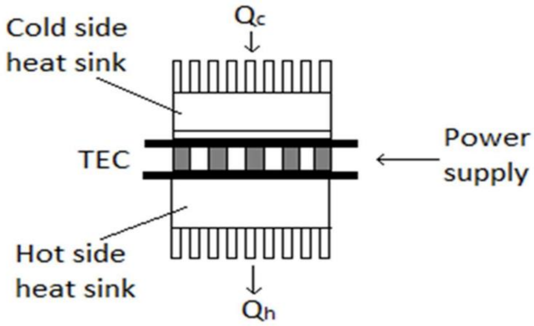

Fig. 2. Schematic diagram of TE cooler attached two heat sinks

In the literature, optimizing of heat exchangers or heat sinks is very well known and a detailed review on the optimization process is summarized in Lee [19]. Analytical correlation can be used for the accuracy of the Nusselt number, but it would be more consistent to provide an experimental analysis, particularly for more complex correlation shapes related to internally and turbulent fully formed flow [20].

An empirical correlation was therefore developed by Teertsta *et al.*, [21] to measure the Nusselt calculation based on flow in a parallel plate channel and a variation of developed and fully developed flow. The average Nusselt number can be calculated as a function of the heat sink geometry and fluid velocity. They evaluated the new correlation with experimental values after changing the Nusselt number correlation to include the fin results, which showed strong agreement. The resulting model is applicable for the full range of Reynolds number, 0.1.

In addition, Zhimin and Fah [22] employed two correlations to measure the number of Nusselt for thermal systems in both incompressible flows. The findings of the thermal resistances against other work were then verified. These heat exchanger improvement and Nusselt number connection studies can also be applied to a new study on the TE system, taking into account the effects of the heat sink tube's aspect ratio, the ratio of fin width to channel width, and the heat exchanger channel width's efficiency.

2.3 Improvement Efficiency of TE Cooler

The COP of a TE module is the optimum COP on the condition of optimum current varying the specific TE module is a function of module hot and cold side temperature, Th and Tc respectively. Increasing the Tc and decreasing the Th will improve the COP. For a fixed Th or Tc, the COP of a TE module typically decreases with increasing temperature difference between the module's hot and cold side [23].

Riff and Guoquan [24] performed a comparison analysis of TEACS versus vapor compression air conditioners (VCAC) and absorption air conditioners (AAC). Different kinds of domestic air conditioners and compact air conditioners were reviewed and made. The results show that VCAC is most efficient with COP of 2.6-3.0 whereas TE air conditioner is 0.38-0.45. But future research conducted can increase the value of COP.

The experimental analysis and new potential green refrigeration and air conditioning technologies were proposed by Manoj Kumar *et al*., [25]. They analyzed the cause and effect of an existing air-condition system. The conducted research for development of renewable energy-based TE refrigeration systems have been designed. Various studies indicate that only about 5-15 % of TE cooling systems are typically effective, relative to 40-60 % achieved by the traditional compression cooling system.

Matthieu Cosnier *et al*., [26] presented an experimental and numerical study of TE modules to cool or warm an airflow. The experimental results are in good agreement with the theoretical TE equations with the feasibility of cooling and heating air through TE modules with a good COP. By providing an electrical strength of 4 A and retaining the 5˚C temperature difference between both the hot and cold sides of the TE modules, they have achieved a cooling power of around 50 W per module, with a COP between 1.5 and 2.

A research on the analysis of TE refrigerator efficiency was conducted by Suwit Jugsujinda *et al*., [27]. The TE (TER; 25 × 25 × 35 cm^3) cooling system was manufactured using a TE cooler (TEC; 4 × 4 cm^3) and 40 W of electrical power was implemented. To evaluate the cooling point at different places, the temperature of the TE refrigerator was calculated at ten points. For 1 hour, the TER reduces from 30˚C to 20˚C and the temperature drops steadily for 24 hours. TEC and TER had a combined COP of 3.0 and 0.65, respectively.

Wei He *et al*., [28] carried out a numerical analysis of analytical and empirical investigations of a solar-powered TE cooling and heating system. In summer, when electrical power supply by photovoltaic/thermal (PV/T) modules is added to it, the TE system acts as a Peltier cooler. In winter, the voltage applied on TE device is reversed. The experiment was conducted in a model room whose volume is 0.125 m^3 in summer condition using a solar panel whose area is 0.5 m^2. The minimum temperature 17˚C is achieved, with COP of the TE device higher than 0.45. Then comparing the simulation result and experimental data.

Astrain, *et al.,* [29] performed a COP examination on the enhancement of heat dissipation in TE refrigeration. It is described in TE cooling based on the concept of a thermosyphon with phase change. A thermosyphon model with a thermal resistance of 0.110 K/W was produced during the research optimization process, dissipating the heat of a Peltier pellet with a size of 40 × 40 × 3.9 mm^3. TE domestic refrigerators are two prototypes designed, one with the developed device and the other with a traditional dissipator of fins. Experimental approach proved that the use of thermosyphon with phase change increases the COP up to 32 %.

Shen, Xiao *et al*., [30] investigated a novel TE radiant air-cooling system (TERAC). The system employs TE modules as radiant panels for indoor cooling, as well as for space heating by easily reversing the input current. A case study of the TERAC system presented compared with conventional air conditioning systems in terms of cooling and heating capacities, energy consumption and operation reliability. They reached a maximum cooling COP of 1.77 when adding an electrical current of 1.2 A, and preserving the cold side temperature at 20°C on the basis of the study of a commercial TE module.

3. Methodology

3.1 Flowchart

The methodology used for this work is summarised in the following flow chart in Figure 3.

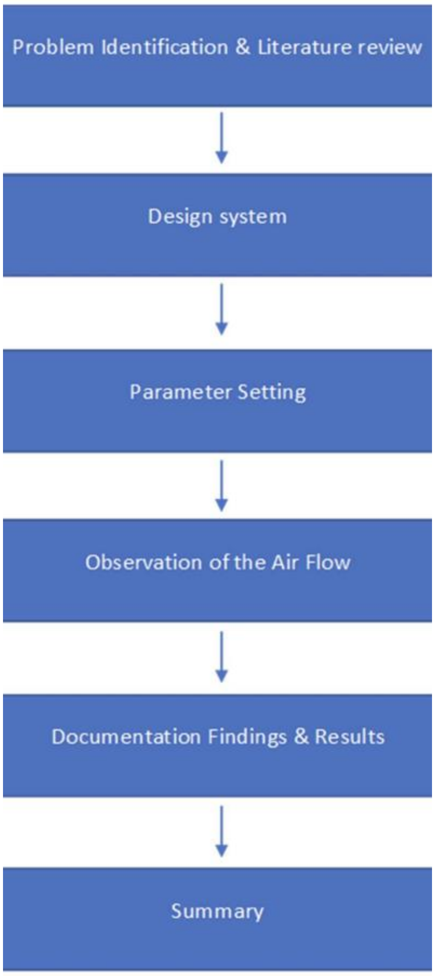

Fig. 3. Flow diagram of methodology

The research used a structured system analysis and design methodology approach. Figure 4 depicts the project's block analysis process with the use of a simple block diagram. The blower blows ambient air through a duct to the TEC.

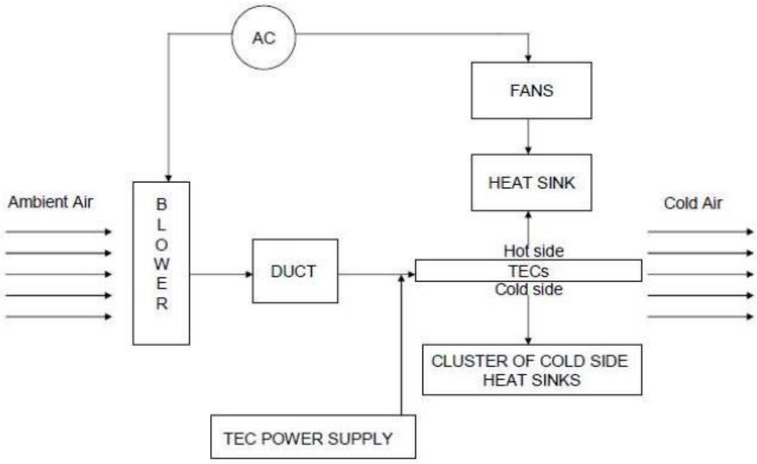

Fig. 4. Block diagram of the TE cooling

The following modules make up the cooling system: Vehicle blower, which serves as the major supply of air.

1. The duct that transports the air from the blower.
2. Heat sink has been installed to absorb heat.
3. A resource of energy for the fan blower.

A TEC, or solid state electrically driven heat exchanger, is used to achieve a good TE cooling design. The polarity of the applied voltage influences this. When TEC is used for cooling, it absorbs heat from the surface to be cooled and transmits it to the fin *via* conduction, where it is eventually dissipated into the surrounding ambient air by convection.

3.2 Design System

SOLIDWORKS 2021 is used to create a concept modelling prototype. To investigate the process of temperature fluctuation chamber input and chamber exit, this concept modelling process begins with designing a three-dimensional (3D) geometry for the cooling system, as shown in Figure 5. The temperature fluctuations in this system will be studied by observing the airflow inside the chamber.

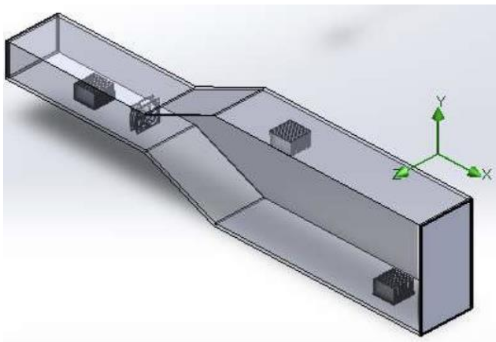

Fig. 5. 3D geometry cooling system

3.2.1 Design of parts

The cooling chamber, heat sink or heat exchanger and axial fan that were used in this research were all designed using SOLIDWORKS 2021.

3.2.1.1 Cooling chamber

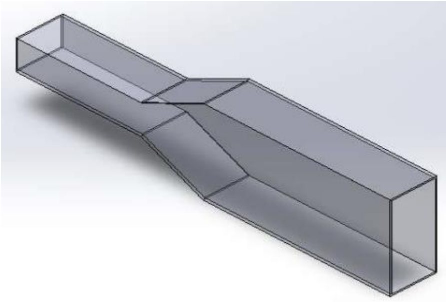

Fig. 6. CAD model of cooling chamber

Each operational procedure has the same cooling chamber dimensions, which are 60 mm x 15 mm x 30 mm for the inlet and 40 mm x 15 mm x 10.5 mm for the outflow. This is due to the need to keep the area inside the cooling chamber cool. Figure 7 illustrates a sectional image of the cooling chamber that was used in this study. The air will enter through the right side of the chamber and exit through the left side of the chamber.

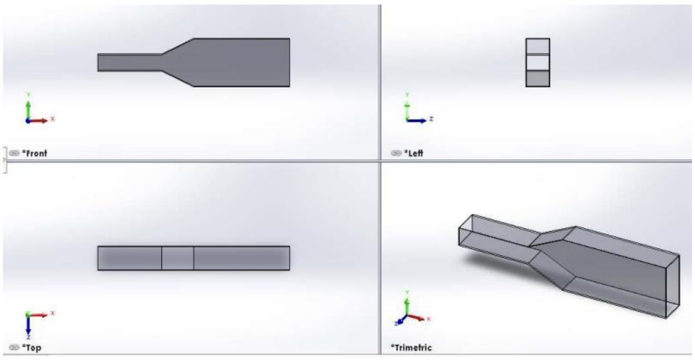

Fig. 7. Sectional view of cooling chamber

3.2.1.2 Heat sink or heat exchanger

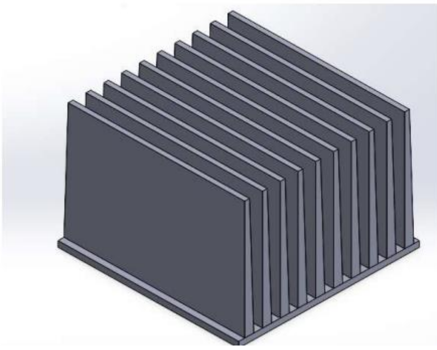

Fig. 8. CAD model of heat sink

The dimensions used for the heat sink vary. The purpose of changing the dimension of the heat sink in this study is to increase the heat transfer rate from the fins. Six heat sink or heat exchanger designs have been created. Heat sinks with base dimensions of 6 mm x 6 mm x 0.2 mm, 10 mm x 6 mm x 0.2 mm and 15 mm x 6 mm x 0.2 mm were utilised. Following that, the number of fins changes from 10 to 20. The design of the heat sink is summarized in Table 1. Figure 9 depicts a sectional view of one of the heat sink kinds. To meet the performance requirement, heat sink development must be considered.

Table 1
Summary of the designing heat sink

Type	Characteristic
Type 1	Base dimension:6mmx6mmx0.2mm Number of fins:10
Type 2	Base dimension:10mmx6mmx0.2mm Number of fins:10
Type 3	Base dimension:15mmx6mmx0.2mm Number of fins:10
Type 4	Base dimension:6mmx6mmx0.2mm Number of fins:20
Type 5	Base dimension:10mmx6mmx0.2mm Number of fins:20
Type 6	Base dimension:15mmx6mmx0.2mm Number of fins:20

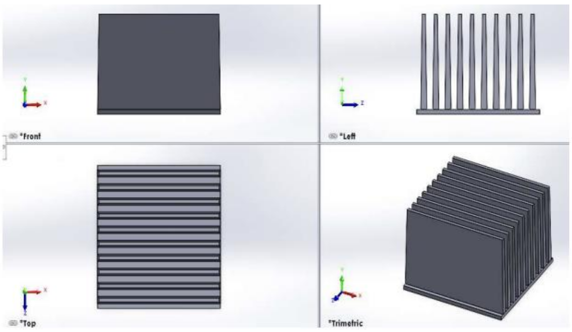

Fig. 9. Sectional view of heat sink

3.2.1.3 Axial fan

The CAD model of an axial fan is shown in Figure 10. The axial fan's dimensions were designed to fit inside the cooling chamber. The main aim of an axial fan is to create forced convection to repulse the heat produced by TE. Figure 11 shows a sectional view of the fan in this arrangement.

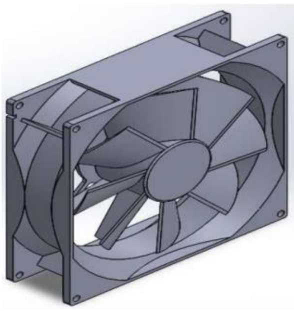

Fig. 10. CAD model of fan

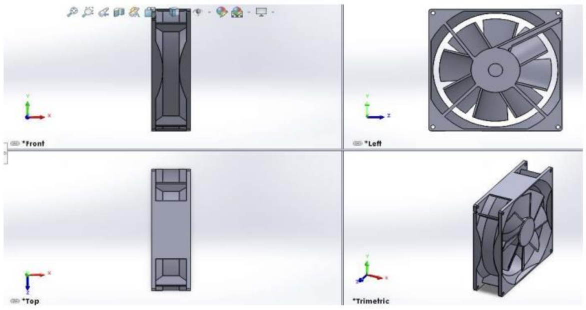

Fig. 11. Sectional view of fan

3.2.2 Assembly cooling chamber

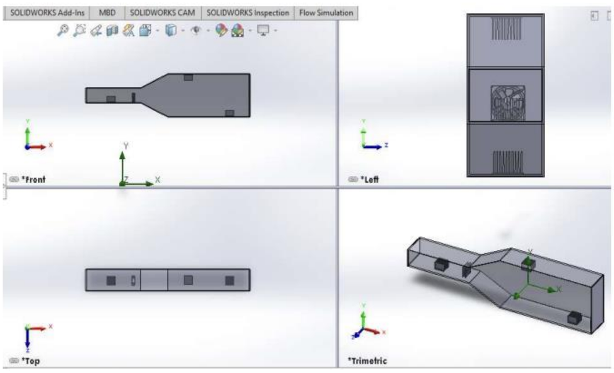

Fig. 12. Sectional view of the assembly cooling chamber

The process of temperature variation in the chamber outflow was investigated in this study, which took place in the cooling chamber. The temperature changes in this system were studied using the Computational Fluid Dynamics (CFD) approach. The surface was chosen as the location of TE. The walls have been ignored in this design and just the air flow, heat sinks and system input and output regions have been addressed. For each observation, three heat sinks of the same type are mounted, and the placement of the three heat sinks is also fixed.

3.3 Parameter Setting

3.3.1 Cooling system parameter

The variable temperature and air velocity for the inlet chamber will be included as parameters. The study will be compared for each air velocity, and the type of air flow must be described using Reynold numbers. For varied air velocity inlets, the temperature at the output air chamber will be analysed. The heat sink must be considered in this study in order to reduce thermal resistance. The base dimension of the heat sink and the number of fins will be taken into account. Wf denotes the width of the base heat sink, Lf denotes the length of the base heat sink, Tf denotes the thickness of the fin and Zf denotes the fin spacing as illustrated in Figure 13.

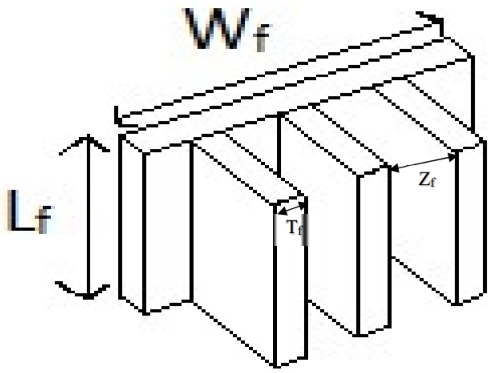

Fig. 13. Schematic diagram of heat sink

3.3.2 Boundary conditions and fluid properties

Eq. (4) was used to compute the system's air velocity because the air flow velocity was measured at the channel output,

$$Q = A \times V \tag{4}$$

where, Q = flow rate (m^3s^{-1}), A = channel outlet area (m^2) and V = air flow velocity (ms^{-1}). The simulation's flow type should also be defined. The Reynolds number was used to determine the flow type, as illustrated in Eq. (5).

$$R_e = \frac{\rho \times V \times D_h}{\mu} \tag{5}$$

where, ρ = density of air at the desired temperature (kgm^{-3}), V = air flow velocity (ms^{-1}), Dh = hydraulic diameter (m) and μ = dynamic viscosity (Nsm^{-2}). The hydraulic diameter is obtained from Eq. (6).

$$D_h = \frac{4A}{P} \quad (6)$$

where, A = the area (m^2) and P = input channel perimeter (m).

The Flow Simulation in SOLIDWORKS 2021 software was used to numerically simulate the computational domains of the cooling systems evaluated in this study. The fluid flow and heat transmission in cooling systems were simulated using the 3D K-ε turbulence model. Constant heat flux is used as a boundary condition in this study to analyze the system.

3.4 Observation of the Air Flow

At speeds of 0.18 m/s, given that ReD >2300, the airflow was considered to be turbulent in this simulation. System evaluation variables are shown in Table 2, there are assumptions included in the simulation. First, the outer surface of the desired system was assumed to be adiabatic. Second, the outlet pressure was assumed to be ambient air pressure.

Table 2
Velocity and temperature inlet

Inlet velocity, m/s	Inlet temperature, K
0.18	300.69
0.57	293.20
0.7	315.67
0.44	308.18
0.31	323.15

4. Results and Discussion

The numerical set up of an air conditioning system to investigate at the outlet of the cooling chamber and their effect on the COP system. Based on the data recorded, the COP value was calculated.

4.1 Inlet and Outlet Relationship

These values were taken for various velocity and temperature value. The relationship of inlet and outlet of the chamber is shown in Table 3. The value of outlet temperature is varied for each type of heat sink. The graph shown in Figure 14 for type one of the heat sink at the inlet velocity 0.18, the outlet temperature is high and the type six of heat sink at the inlet velocity 0.18, the outlet temperature is low. It shows that the higher the length of the heat sink and the number fin, the efficiency of the heat sink is higher. If the efficiency of the heat sink is high, the temperature difference between the hot and cold side of the TE cooling system may be reduced significantly and the COP will be increased. If the efficiency of the heat sink is low, the temperature difference between the hot and cold side will be greater and the COP will be lower.

Table 3
Inlet and outlet cooling chamber

Base heat sink (l x w), m	Inlet velocity, m/s	Inlet temperature, K	Outlet temperature, K	
			Number of fins	
			10	20
	0.18	300.69	174123.4	166789.6
	0.57	293.20	184060	172359.7
6 x 6	0.7	315.67	180238	168836
	0.44	308.18	170412.5	163594.4
	0.31	323.15	172683.7	170436.4
	0.18	300.69	163506.8	162578.9
	0.57	293.20	156397.2	145680.2
10 x 6	0.7	315.67	169882.5	175434.1
	0.44	308.18	158841.7	135603.4
	0.31	323.15	173046.2	171138.2
	0.18	300.69	161181.1	158025.2
	0.57	293.20	156825.5	160531.9
15 x 6	0.7	315.67	160741.1	167478
	0.44	308.18	173713.4	179136.6
	0.31	323.15	171042.8	167480

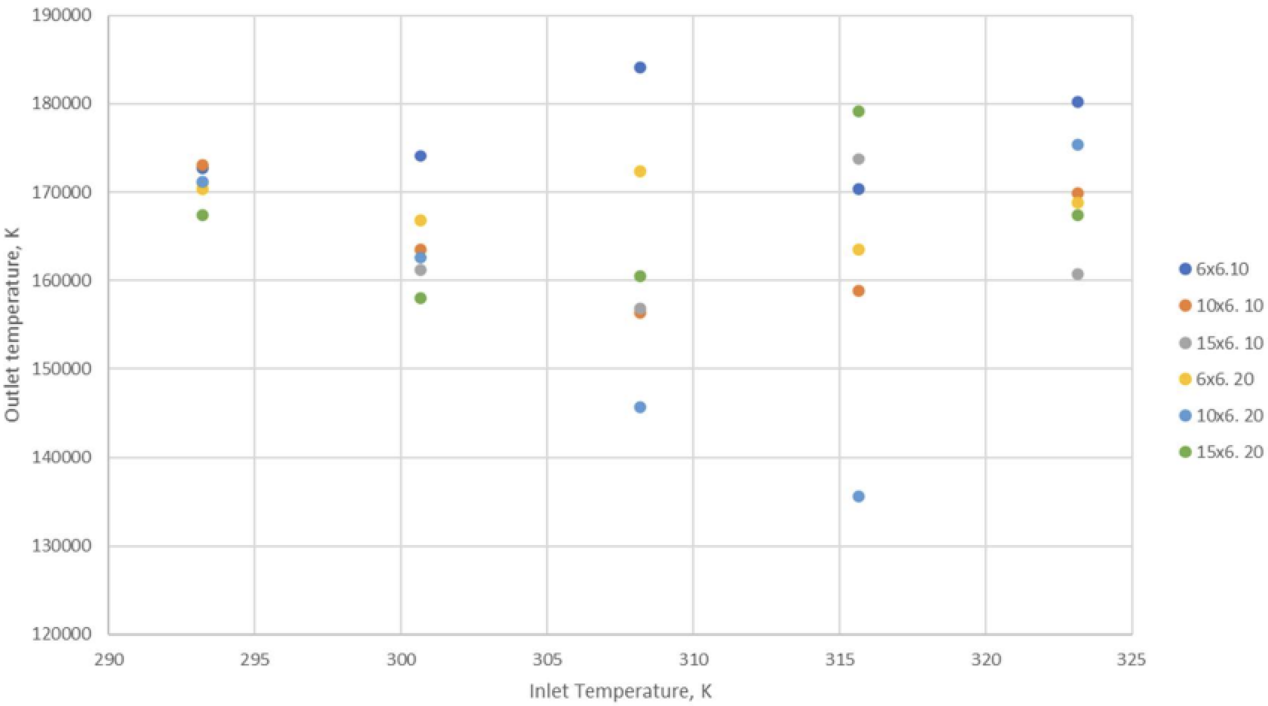

Fig. 14. Temperature difference

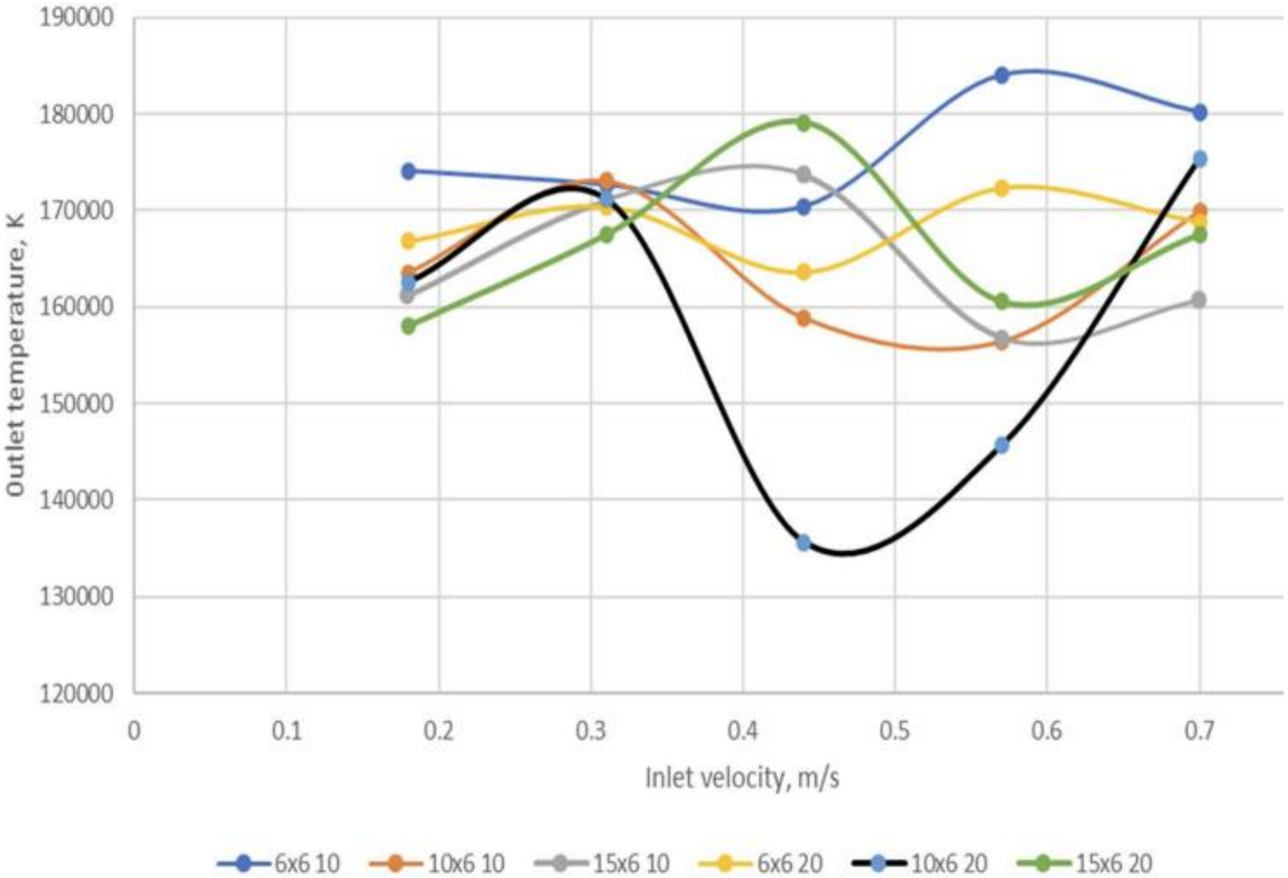

Fig. 15. Graph for the inlet velocity *vs* outlet temperature

4.2 COP Value

For a TE system, the COP of a TE module which is thermal efficiency, must be addressed. The COP factor will also be used to determine which TEC to use. The TEC's COP is the ratio of its thermal output power to its electrical input power. The COP is computed by dividing the quantity of heat absorbed on the cool side by the input power.

$$COP = \frac{Therm \quad Power}{Electric\ Power} \tag{7}$$

The electrical power is fixed to 22 kW. As shown in Table 4, for each type of heat sink is, the C value is varied. For conventional air conditioning systems, the current COP value is generally less than 2 but it depends on many factors such as inner load, ambient condition for temperature and humidity and many else.

Table 4
The coefficient of performance value

Type	COP
1	0.69
2	1.97
3	2.09
4	0.76
5	2.07
6	2.13

5. Conclusions

TE is an alternative method to replace the conventional air conditioning system. A TE air cooling for car was designed and simulate that can be used for personal cooling inside the car. The TE systems should be explored to compete with conventional air conditioning systems. The contribution of this study are listed as follows: (a) The first contribution related to the TE study. The TE study was based on numerical analysis. To improve the development of this study, the designing must be considered inside the cooling chamber. (b) The second contribution is related to COP value. The performance will be increased if the optimal design of heat sink is developed. The performance increases the efficiency of the heat, ventilating and cooling in car.

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