Development of Car Cabin Cooler Based on Thermoelectric

Imansyah Ibnu Hakim[1], Ary Samgita[1]

[1]Departemen Teknik Mesin Fakultas Teknik Universitas Indonesia
Kampus Baru UI Depok 16424
E-mail : imansyah@eng.ui.ac.id

Abstract

The cars which are parked in the open space will have temperature increase in their cabin up to 56 ^{0}C. This is because the heat is transferred into car by radiation from the sun through the windows and also transferred by conduction and convection. High temperatures in the car cabin is not ideal for passengers and also can damage the electronic equipment and plastic dashboard. This problem is very dangerous to health because the air refreshers will evaporate and produce toxic gases. Car owners are always trying to reduce the heat that accumulates inside car cabin in various ways such as windscreen cover with a sheet of aluminium foil (windshield), by using window film, cooling fan, and others. A cabin cooler based on thermoelectric is developed to reduce the temperature increase inside the cabin. This cabin cooler based on thermoelectric is development from previous thermoelectric cabin cooler, which has same two surfaces, the hot side and the cold side but then completed with water jacket to reduce the temperature in the hot side of the thermoelectric. It is expected the cabin cooler based on thermoelectric can reduce the temperature inside the car cabin. The result showed that the use of the cabin cooler based on thermoelectric can reduce the temperature in car cabin from 50 °C to 42 °C.

Keywords**:** *conduction, convection, thermoelectric, car cabin cooler*

Introduction

When car is parked at an open space under direct sunlight as shown in Figure 1., the temperature inside the car cabin will increase drastically because of heat trapped and accumulated inside the car cabin and there is no air circulation inside the car cabin.

Figure 1. Car is parked in open space

The temperature inside the cabin can reach 50°C - 60°C as shown in Figure 2. This condition is not only dangerous for the passengers on board but also can damage the electronic equipment and the interior inside the car as shown in Figure 3. and 4.

Figure 2. Car cabin temperature and ambient temperature

Figure 3. Car refreshener, interior and electronic equipment and bottled beverage

Based on these conditions, a device is required to reduce the heat generated when the car is parked in the open area under direct sunlight. Then a device called "Cabin Car-Based Thermoelectric Cooling" is designed.

Figure 4. Cracked Dashboard Due to High Temperature Inside Car Cabin.

As common practice, to avoid high temperature inside the car cabin after the car is parked in the open space, the car user usually cover the front windscreen with windshield, a sheet of aluminum foil to block the sunlight.

However, this method is less effective to reduce heat build up inside the car because the heat has already trapped and can not get out.

Other methods to overcome these problems are solar protective film and the cooling fan. Branded Solar protective film is effective enough to reduce the heat inside the car cabin, but it is still relatively expensive.

While the cooling fan (Auto-cool) which using solar powered fan to exhaust the hot air from inside the car cabin is still not satisfactory because of security reason since the tool is placed on the car window which leaves a little gap in the window of the car.

Cabin Cooler was design as alternative to reduce the temperature inside car cabin. This cooling system is based on Thermoelectric Cooling and it is designed for City Car with the consideration that City Car has small cabin size so that the desired cooling temperature can be achieved.

The purpose of this research is to design a cabin cooler for cars parked in the open area in order to reduce the heat in the car cabin.

Theory

Heat inside the car cabin as shown in Figure 5. is strongly influenced by various external influences, among others :

a) Radiation from the sun.
b) The temperature in space.
c) Wind Speed.
d) The ambient temperature around the car.
e) The humidity of air around the car.

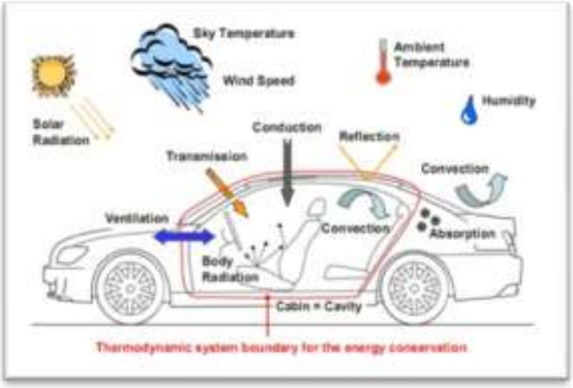

Figure 5. Heat Source Inside Car Cabin
Source: Paulke, Stefan, et al. 2007

The change of heat in the car cabin is influenced by several mechanisms, among others:

a) The Heat Transmission through the glass.
b) Conduction through the body of the car.
c) Convection of air in the car cabin.
d) Radiation emitted from the car's interior.
e) The air vents inside the car.

The heat transfer by conduction and radiation from the environment into the system (car cabin) is negligible, so that the process of heat transfer by conduction only occurs between the Peltier element, heatsink and coldsink.

Calculation of heat transfer in the cabin of the car based on the required power generated by a Peltier element. Eight Peltier elements are used and then arranged in parallel.

Peltier elements produced average temperarture 60°C. Characteristics of Peltier element can be determined as follow :

V = 12 Volt
I = 3 Ampere
ΔT = 30 ^{0}C

The performance Peltier element can be optimized, if the voltage and current supplied by 5 V and 20 A. The cabin cooler uses car battery to meet its electricity needs which has a voltage of 12 V and 40 A current, thus to lower the

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voltage and the current a converter is used. This converter will lower the voltage from 12 V to 5 V and limit the amount of current to 20 A. Thus, the power generated by the Peltier elements are :

$$P_{in} = V_{xy}\, I_{xy}$$

where :

V_{xy} = Voltage
I_{xy} = Ampere
P_{in} = Watt

$$P_{in} = \frac{V_{xy}^{\,2}}{R_{xy}}$$

where,

$$\frac{1}{R_{xy}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_n} = \frac{10}{2.5} = 0.25\ \Omega$$

$$R_{xy} = 0.25\ \Omega$$

so,

$$P_{in} = \frac{V_{xy}^{\,2}}{R_{xy}} = \frac{5^2}{0.25} = 100\ Watt$$

So the power generated by the eight Peltier element is 100 watts, or it can be said also that the heat produced by ten Peltier element is 100 Watt. Cold temperatures to be achieved is Tc = Th - ΔT = 60°C - 30°C = 30°C.

On the use of Peltier elements, one side will become hot. Where the temperature of the hot side can be determined by the following equation:

$$T_h = T_\infty + (\Theta)(Q_h)$$

where :
T_h = Temperature of Hot Side (°C)
T_∞ = Ambient Temperature (°C)
Θ =Thermal Resistant Peltier Element (°C/watt)

$$T_h = T_\infty + \left(\frac{\Delta x}{k\,A}\right)(Q_h)$$

$$60 = 50 + (0{,}01667)(Q_h)$$

$$Q_h = \frac{60 - 50}{0{,}01667}$$

$$Q_h = 600\ Watt$$

On the use of Peltier elements, one side will be the cold side. Where the temperature of the cold side peltier element can be determined by the following equation :

$$Q_h = Q_c + P_{in}$$

$$Q_c = 600 - 100$$
$$Q_c = 500\ Watt$$

Calculating temperature coldsink :

$$Q = -k\,.\,A\,.\,\frac{dT}{dx}$$

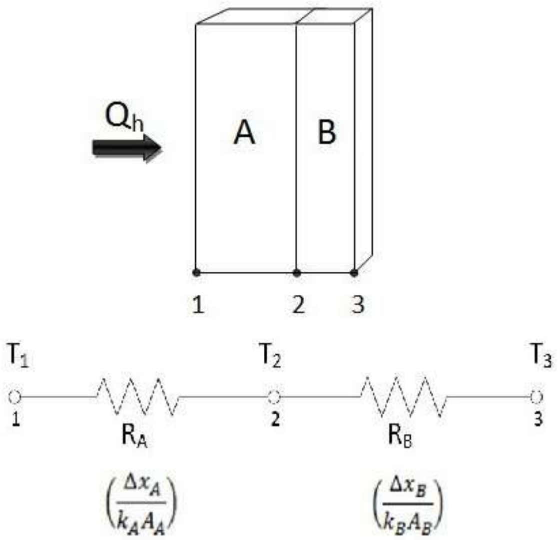

Figure 6. Schematic Heat Transfer and Thermal Resistance Circuit

$$Q = -k_A\,.\,A\,.\,\frac{T_2 - T_1}{\Delta x_A} = -k_B\,.\,A\,.\,\frac{T_3 - T_2}{\Delta x_B}$$

$$Q = \frac{T_3 - T_1}{\frac{\Delta x_A}{k_A A_A} + \frac{\Delta x_B}{k_B A_B}}$$

$$600 = \frac{T_3 - 60}{\frac{(4x10^{-3})}{(150)(1,6x10^{-4})} + \frac{(6x10^{-4})}{(202)(0,0576)}}$$

$$T_3 = 49.97^0 C$$

Where,
Q_h = 600 Watt
T_1 = 60^0 C
$k_{peltier}$ = 150 Watt/m K
$k_{alumunium}$ = 202 Watt/m K
$x_{peltier}$ = 4 mm = 4 x 10^{-3} m
$x_{alunumium}$ = 0.6 mm = 6 x 10^{-4} m
$A_{peltier}$ = 1,6 x 10^{-3} m^2
$A_{alumunium}$ = 0,0576 m^2

Heat generated at the hot side is 600 watts and produce heat temperature 60°C. Peltier elements are arranged on the side of the coldsink, so the heat transfered by

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conduction. Value of T3 is the temperature at the outer side of the coldsink facing toward driver, while the value of T1 is the temperature on the hot side of the Peltier element. So coldsink temperatures generated by heat conduction through Peltier element is 49 .97° C.

Heat transfer by convection is heat transfer follow by displacement of particles / molecules of the object or in other words the mass flow rate occurs on the object / substance.

Calculating the convection value :

- Pr Value

  Prandtl number is a parameter that connects the relative thickness of the boundary hydrodynamic and thermal boundary layers. The average temperature after taking data on the car cabin is 50° C or 323 K.
  On the Annex 1 List A-5 Properties of Air at Atmospheric Pressure, we can find the value of Pr using interpolation method at T = 323 K. So, will get the value of Pr = 0.703, ν = 18.09 x 10-6 m2 / s, and k = 0.02798.

- Re_x Value

  $$Re = \rho D \, v/\mu$$

  where:
  Re = Reynolds Number
  v = Fluids Velocity (m/s)
  μ = Fluids Dynamic Viscosity (Nm/s^2)
  ρ = Fluids Density (kg/m3)
  D = Boundary Layer Distance (m)
  Value u ∞ is the free-flow fan speed value used in cabin cooler, which has a flow rate of 51 cfm or 3.77 m / s. While the value of x is the perpendicular to the direction of arrival of forced convection by fan along the aluminum plate that covers the Peltier element. Distance from the boundary layer to the flat plate covering the peltier hot side is 340 mm.

$$Re_x = \frac{\left(3,77\,\frac{m}{s}\right) x\,(0,34\ m)}{\left(18,09\ x\ 10^{-6}\,\frac{m^2}{s}\right)} = 70856,87$$

- Nu_x Value

  Pr and Re values that have been obtained from the previous calculation, then these values will be used in the equation Nuβelt :

$$Nu = \frac{0,3387\,(70856,87)^{\frac{1}{2}}(0,703)^{\frac{1}{3}}}{\left[1 + \left(0,\frac{0468}{0},703\right)^{\frac{2}{3}}\right]^{\frac{1}{4}}}$$

$$Nu = 77,16$$

Convection Coefficient Value :
Nuβelt value obtained is then used to calculate convection coefficient (h) that occurred in the car cabin air after using a car cabin cooler

$$h = \frac{Nu.k}{x}$$

$$h = \frac{Nu\,k}{x} = \frac{(20,93)(0,02798)}{0},34 = 6,35\,\frac{W}{m^{2\,o}C}$$

The average value of heat transfer coefficient is twice the convection coefficient value above :

$$\bar{h} = (2)(6,35) = 12,7\,\frac{W}{m^{2\,0}C}.$$

Then the heat flow values

$$Q = \bar{h}\,A\,(T_s - T_\infty)$$

If the assumed depth of the unit in the z direction in the car cabin is 0.4 m.

$$Q = (12,7)(0,4)(50 - 49,97) = 0,1524\ Watt$$

So the calculation of heat transfer by convection inside the car cabin as far as 0.4 m from the cabin cooler in the driver's seat, the calorific value of the driver's seat in the cabin is at 0.1524 Watt.

Car Cabin Cooler Design

Basic concept for the car cabin cooler based on thermoelectric cooling is to reduce the temperature inside the car cabin, especially on the driver’s side. The calculation used is based on the literature related to the heat transfer process.

Previous Cabin Cooler consists of 6 major components is reduced to 5 components: Coldsink, Fan, Heatsink, Thermoelectric cooler (TEC) and The waterline. Pictures of previous car cabin air can be seen in Figure 7. while the new developed car cabin cooler can be seen in Figure 8.

In the new design cabin cooler still uses 2 fan on the coldsink to circulate cool air into the cabin of the car. The difference is to dissipate the heat from Heatsink, cabin cooler equipped with water cooling system and also uses only 8 pieces thermoelectric cooler (TEC).

Heatsink serves to take the heat generated from TEC hot side and water function of dissipate hot water that occurs in from the heat sink.

Coldsink made of aluminum material aluminum material which has a high conductivity about 202 Watts / m K.

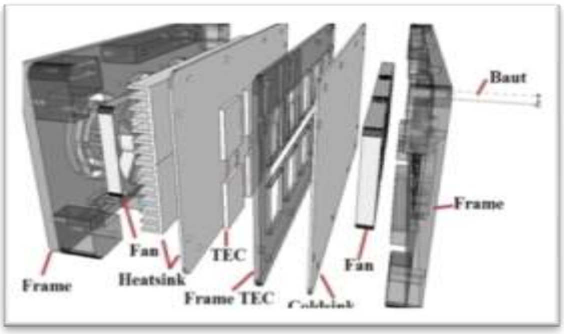

Figure 7. Previous Design Thermoelectric Based Car Cabin Cooler

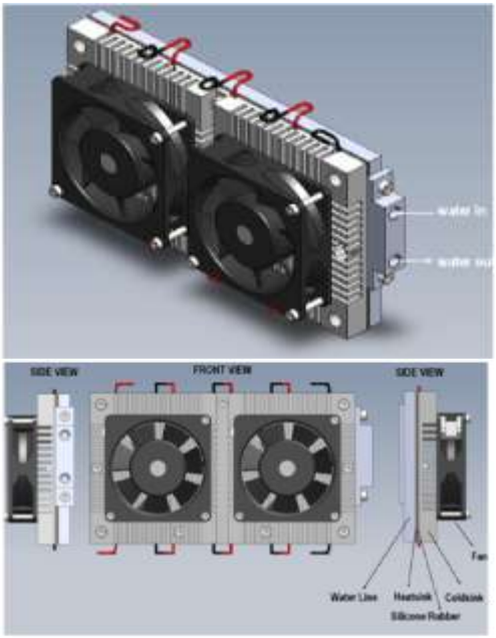

Figure 8. New Developed Thermoelectric Based Car Cabin Cooler

Installation of car cabin cooler is in the driver's side and attach on the sun visor, ie eye protection from the sun as shown in Figure 9.

Figure 9. Installation Layout for Cabin Cooler

Car Cabin Cooler is powered with 12 volts 40 Amperes car battery. But before connected to cabin cooler the car battery is pass through converter as shown in Figure 10. It is intended that the desired voltage and current not exceeding desired. Desired output of the inverter is 5 Volts and 18 Amperes.

The output power from the converter is then connected to the cabin cooler as shown in Figure 10.

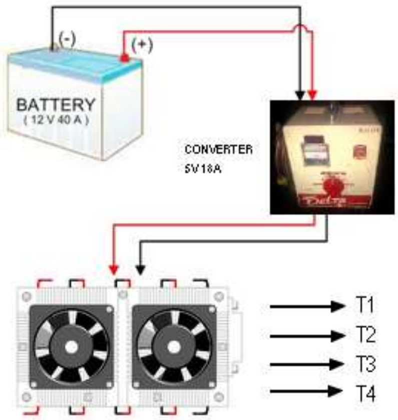

Figure 10. Data Collection Scheme

Result and Discussion

Data collection is determined inside the car cabin and it represents the human body that has a high level of sensitivity to temperature. Consideration is that driver's body must be in a comfortable temperature inside the cabin of the car and the driving position as shown in Figure 11.

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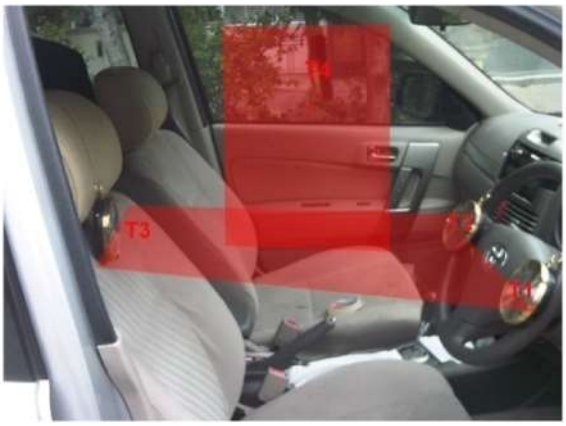

Figure 11. Data collection represents the human body that is sensitive to temperature

Figure 12. shows the car cabin temperature without using the cabin cooler. Cabin temperature can reach 56 ^{o}C.

Figure 13. shows the temperature decrease inside the car cabin, but the temperature drop is not too significant. This is because the cabin cooler is not effective to reduce the heat inside car cabin.

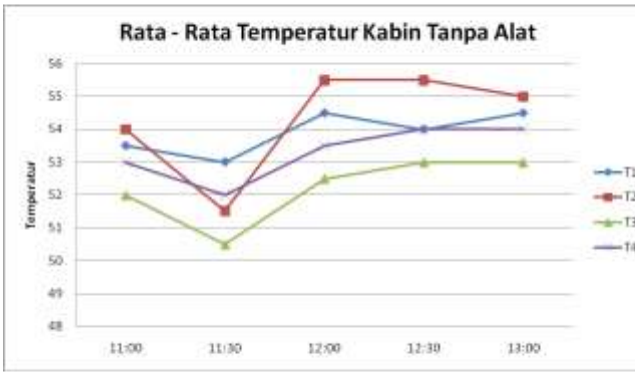

Figure 12. Car cabin temperature without using cabin cooler

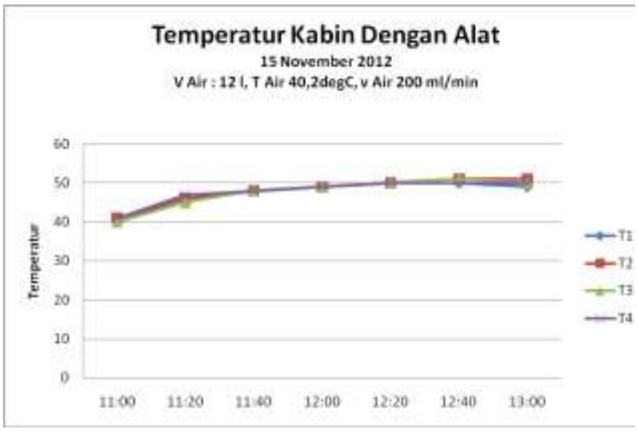

Figure 13. Car cabin temperature with and without cabin cooler

To verify the effectiveness of the cabin cooler experiment is conducted to determine optimum voltage and current which result the biggest ΔT between Th and Tc.

From Figure 14. it is known that at voltage 5V and 18 Ampere can be obtained the highest ΔT between Th and Tc in range 30-35 ° C.

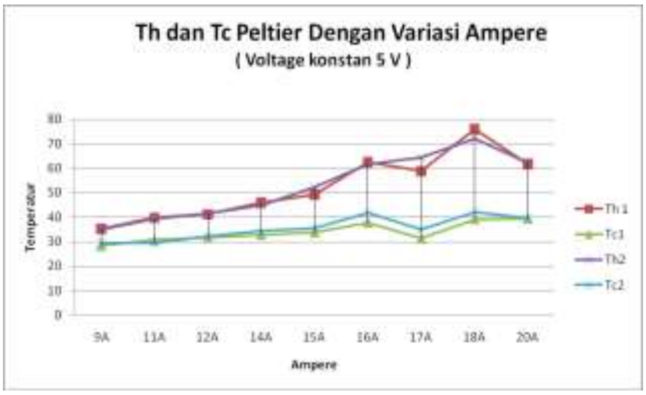

Figure 14. Graphs of Th and Tc with different ampere

In the next experiment, in Figure 15. and 16. there is significant decrease in temperature. This is because the cooler is quite effective in cooling the car cabin with appropriate Voltage and Ampere.

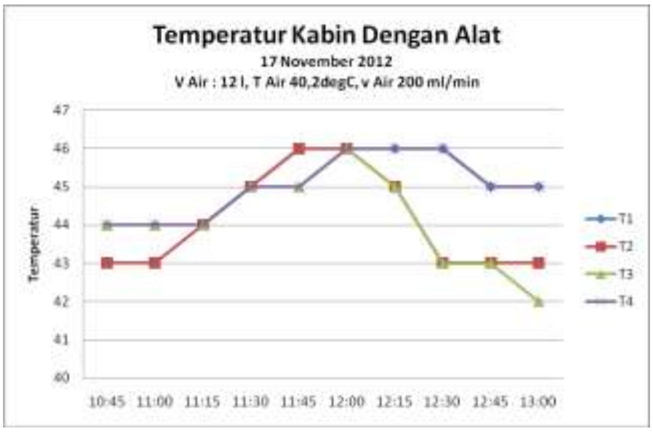

Figure 15. Car cabin temperature with cooler

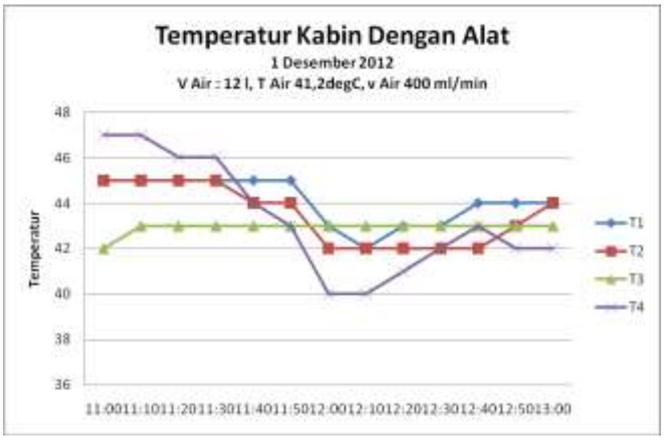

Figure 16. Car cabin temperature with cooler

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Conclusion

From all data from the testing and research that has been done some conclusion as follows :

1. Temperature inside car cabin which is parked in open space with direct sunlight can reach 56°C.
2. Car cabin temperature after using the car cabin cooler can reach minimum 42°C.
3. Efficiency of the cabin cooler is 19.235%.
4. The temperature inside the car cabin influenced by several factors, but the most significant effect on the temperature rise inside the car cabin is the ambient temperature of the environment around the car.
5. In this research, data collection performed on different days with the same car so it can be bias because of possible difference in outside air temperature and solar heat intensity.

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