Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 15th International Scientific and Practical Conference. Volume III, 306-311

Cooling Glove Compartment of a Vehicle by Thermoelectric Coolers

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Abstract. **In this study, effects of the four different thermoelectric cooler (TEC) placements on the boundaries of the glove compartment have been numerically investigated under the effect of natural convection with Boussinesq approximation. The best cooling capacity has been observed for the top boundary TEC application for the investigated glove compartment geometry. It has also been observed that heat transfer is stronger at the beginning of the process as a result of the stronger convection currents. The absorbed heat from the glove compartment increases with the increase of the electric current applied.**

Keywords. Boussinesq approximation, glove compartment, natural convection, thermoelectric cooler

I. INTRODUCTION

Thermoelectric coolers (TECs) are used in many fields including cooling of electronic devices, refrigerator, air conditioning and building applications [1,2]. They work based on the Peltier effect. Peltier effect is the phenomena of when an electric current passes through a circuit consisting of different conductor, one of the joints is cooled and the other joint is heated. It is also possible to reverse the thermoelectric effect by heating the one tip of the same circuit, consequently it is possible to have electric current on the circuit (Seebeck effect) [3]. When Seebeck effect is applied they are called thermoelectric generators (TEGs) and they are also having wide rage of application fields such as space, building and automobile industry [1]. Although they have low coefficient of performance (COP) value, they have no moving parts, they are simple, low weighted and environmentally friendly [2].

Bismuth telluride (Bi_2Te_3) is the most used thermoelectric material in TECs. TECs consist of the p-doped and n-doped thermoelectric material legs which are connected thermally in parallel and electrically in series. While positively charged holes are responsible for the heat transfer in the current direction in the p-doped legs, negatively charged electrons take this duty in the opposite direction with current in the n-doped legs [4]-[5].

There are many studies related to cooling application by TECs in the literature. Zhou and Yu [6] developed a model for the optimization of TEC system based on the thermal conductance between the hot and cold sides. They presented the optimum cooling capacity and coefficient of performance (COP) depending on the allocation ratio for different total thermal conductance. Sarkar and Mahapatra [7] investigated the radiation effect from the heat sink in addition to the natural convection on the TEC performance. They conclude the result that the COP of the TEC improves with radiative heat fluxes and it is possible to operate TEC at lower value of current when emissivity is higher. Yushanov et al. [8] numerically solved thermoelectric field equations by implementing Seebeck-Peltier effect. They obtained simulational results for the temperature and electric potential. Chen et al. [9] performed a numerical and experimental study on the thermoelectric refrigerator under the effect of natural convection. According to their results, 12.2°C stabilized inside air temperature can be obtained in the case of 29°C outside air temperature and 10.8W input electric power. Jiang et al. [10] applied their analysis method on the water-cooled thermoelectric air-conditioner to verify their model experimentally. They presented the result that the corresponding input current density is 6.04 A/mm^2 regarding maximum refrigeration rate density and it is 0.62 A/mm^2 regarding the maximum COP at the cooling temperature difference of 5K. Kuşçu et al. [5] numerically investigated the natural convection in a square enclosure which is cooled by Peltier effect on the left wall, at high temperature on the right wall and also has adiabatic top and bottom walls. They observed the secondary circulation cell near the cold bottom corner at the beginning of the process and it develops with the increase of the electric current. Kuşçu and Kahveci [11] performed an experimental study related to water filled cubical container which is cooled by a Peltier device. They showed that

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2024vol3.8164

although temperature inside the container decreases slowly in the early stage of the process, as time progresses it becomes faster due to the strengthened convection.

In this paper, effect of the thermoelectric coolers on the glove compartment of a vehicle has been investigated numerically. Temperature simulations are obtained for bottom, side, rear and top cooling cases under the effect of natural convection with Boussinesq approximation by Comsol Multiphysics and Simulation Software.

II. MATERIALS AND METHOD

Three dimensional geometry of the glove compartment is given with dimensions in Fig. 1. These dimensions are very close to the dimensions of glove compartment of 1999 model Fiat Palio vehicle.

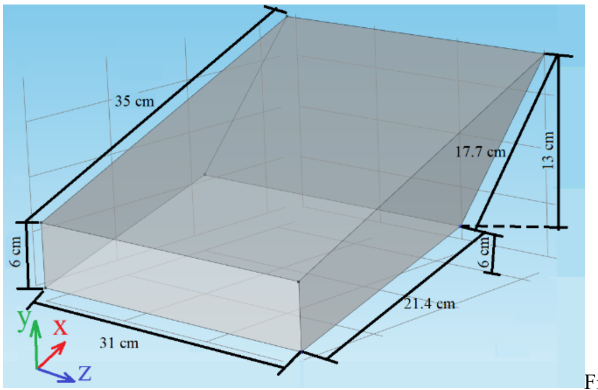
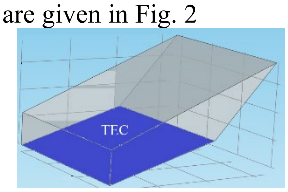
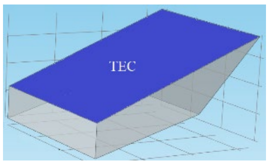


Fig. 1. Dimensions of the glove compartment

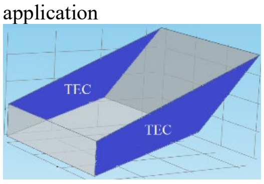
Thermoelectric coolers inserted on the bottom, top, rear and side boundaries of the glove compartment, except 17.7 cm length cover. The investigated four different cases are given in Fig. 2



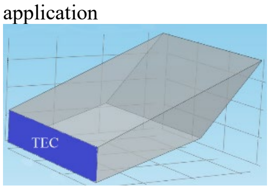
(a) Bottom boundary TEC application



(b) Top boundary TEC application



(c) Side boundary TEC application



(d) Rear boundary TEC application

Fig. 2. TEC placements on the glove compartment

The Newtonian working fluid is air and thermophysical properties are taken constant at 10°C as given in Table I.

TABLE I THERMOPHYSICAL PROPERTIES OF AIR [12]

Explanation	Property	Value
Thermal conductivity	k_{air} (W/mK)	0.02439
Density	ρ_{air} (kg/m^3)	1.246

TABLE I THERMOPHYSICAL PROPERTIES OF AIR [12]

Explanation	Property	Value
Specific heat	c_p (J/kgK)	1006
Dynamic viscosity	μ_{air} (kg/ms)	$1.778 \cdot 10^{-5}$

Governing equations have been solved under the Boussinesq approximation. They are given in Eqs.(1)-(10) with the initial and boundary conditions. No slip condition is applied on boundaries as given in Eq. (6). When heat flux boundary condition is applied on the boundary covered with TEC or Peltier elements, other boundaries are adiabatic. Glove compartment is initially at 25°C as stated in Eq. (10).

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

$$\rho_{air}\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial P}{\partial x}+\mu_{air}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right) \quad (2)$$

$$\rho_{air}\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial P}{\partial y}+\mu_{air}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)+\rho_{air} g\beta(T-T_{max}) \quad (3)$$

$$\rho_{air}\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial P}{\partial z}+\mu_{air}\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right) \quad (4)$$

$$\rho_{air} c_{p,air}\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)=k_{air}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right) \quad (5)$$

$$u|_{boundary}=0, \quad v|_{boundary}=0, \quad w|_{boundary}=0 \quad (6)$$

$$\dot{q}_w|_{TEC}=-k_{air}\frac{\partial T}{\partial n} \quad (7)$$

$$-k_{air}\frac{\partial T}{\partial n}=0 \quad \text{for boundaries not coated with TEC elements} \quad (8)$$

$$u|_{t=0}=0, \quad v|_{t=0}=0, \quad w|_{t=0}=0 \quad (9)$$

$$T|_{t=0}=25^{\circ}C \quad (10)$$

where u, v, and w are the velocity components on x, y and z directions respectively, t is time, P is pressure, g is gravitational acceleration, T is temperature, β is thermal expansion coefficient, which is equal to 1/T(K) in this study for an ideal gas. T_{max} is the maximum air temperature inside the glove compartment. n is the direction normal to the surface. TEC1-12730 [13] having the square cross section with 62mm length is used as Peltier device for this study. Heat flux function $\dot{q}_w$ for TEC1-12730 is derived from the datasheet [13] for the case of hot side temperature of the TEC is 25ºC. The corresponding heat absorption $\dot{Q}_c$ is presented in Fig.3. Investigations in this study are performed for 6A, 18A and 30A electric current values.

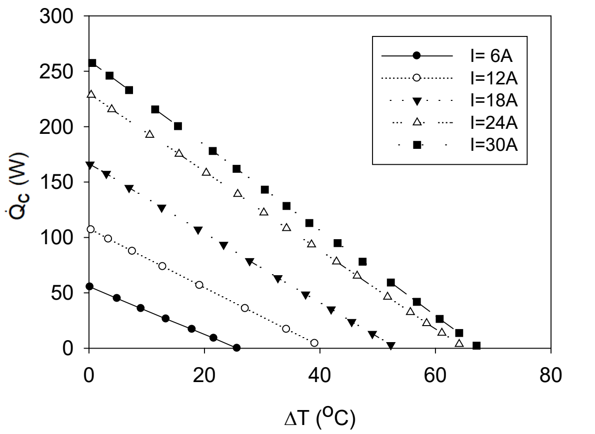


Fig. 3. Performance curves derived from TEC1-12730 datasheet [13]

Derived heat flux function for different electric current values are presented in Table II. ΔT corresponds to ''25ºC-T'' because of the 25ºC hot side temperature of the TEC and R^2 is the coefficient of determination.

TABLE II HEAT FLUX FUNCTION

$\dot{q}_w(W/m^2)$	R^2	I(A)
$-(55.5291-2.1598\Delta T)/(62\cdot 62\cdot 10^{-6})$	0.9999	6
$-(166.5319-3.1356\Delta T)/(62\cdot 62\cdot 10^{-6})$	1	18
$-(259.7302-3.8357\Delta T)/(62\cdot 62\cdot 10^{-6})$	1	30

Verification of the code has been performed by the study of Kuşçu et al. [5]. As it has been show in Fig. 4, results are compatible with the literature. T_{ave} is the average temperature of the enclosure.

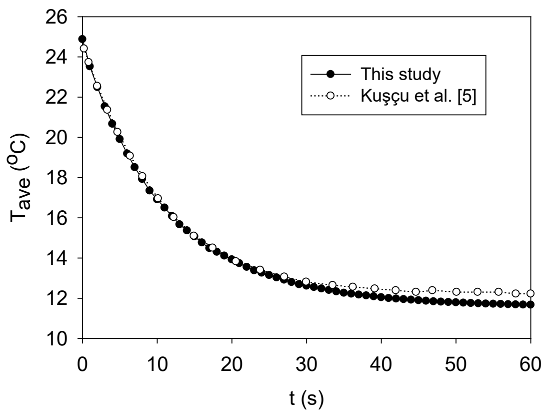


Fig. 4. Verification of the code

Mesh dependency analysis for this study has also been performed for top boundary cooling condition and 6A of electric current. Corresponding results are given in Fig. 5. Two dimensional results with ''extremely fine mesh'', which is the default mesh with highest quality in Comsol Multiphysics and Simulation Software are also presented in Fig 5. Regarding the computational time and accuracy, 37420 elements has been used for the three dimensional analysis, in this study.

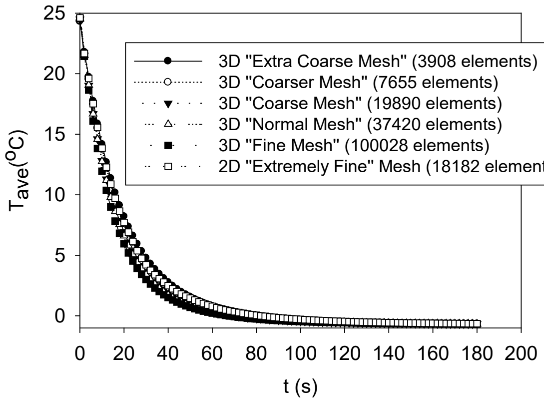
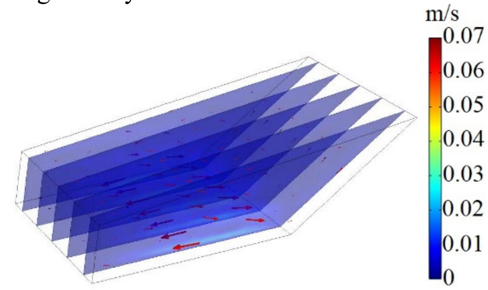


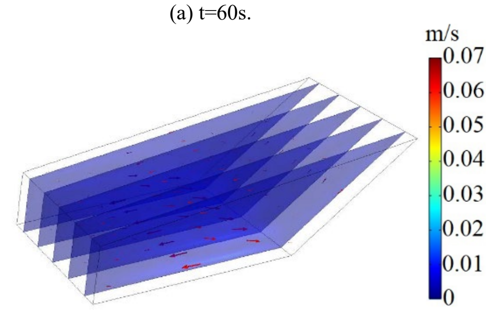
Fig. 5. Mesh dependency analysis

III. RESULTS AND DISCUSSION

Temperature and velocity simulations (Figs. 6-13) have been presented in this study only for electric current of 6A. As it has been seen from these figures that convection is stronger at the beginning of the process due to the body force, which is related with the temperature difference inside the glove compartment, in the momentum equation (Eq.(3)). There are two factors effecting the cooling capacity. They are the physical mechanism of the natural convection and heat transfer surface area. When the thermoelectric coolers are placed on the top boundary, the cooled air sinks and also the largest heat transfer surface for this case enhances the heat transfer considerably. As a result, the top boundary TEC application has the highest cooling capacity for the investigated geometry.

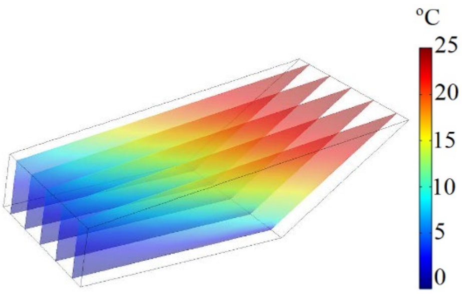


(a) t=60s.

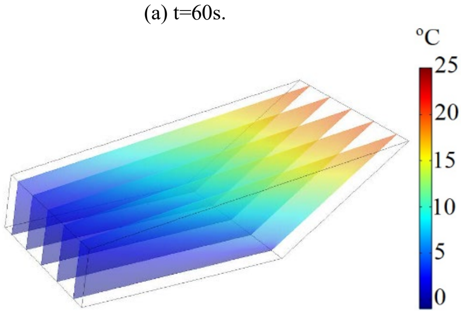


(b) t=120s.

Fig. 6. Velocity simulations for bottom boundary TEC application (I=6A)

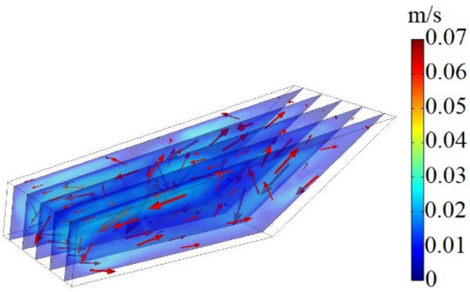


(a) t=60s.

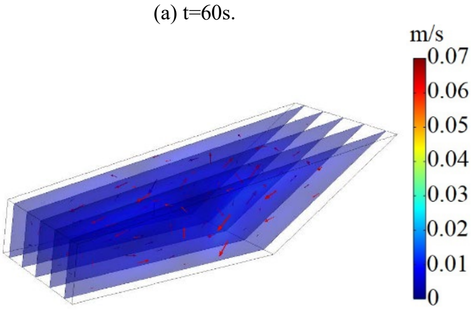


(b) t=120s.

Fig. 7. Temperature simulations for bottom boundary TEC application (I=6A)

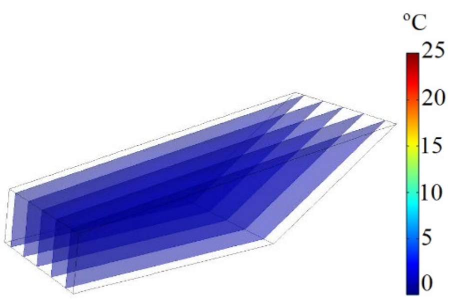


(a) t=60s.

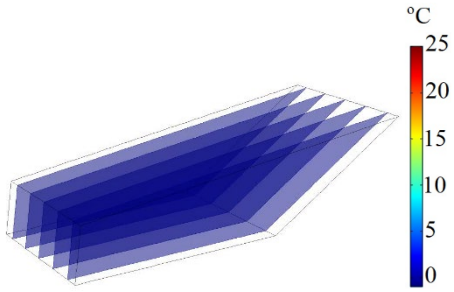


(b) t=120s.

Fig. 8. Velocity simulations for top boundary TEC application (I=6A)

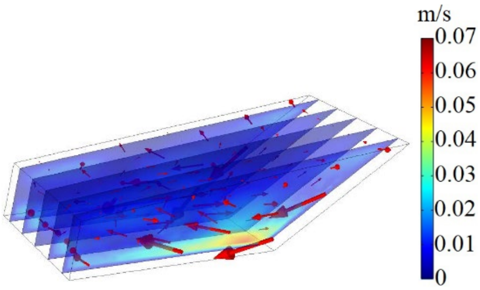


(a) t=60s.

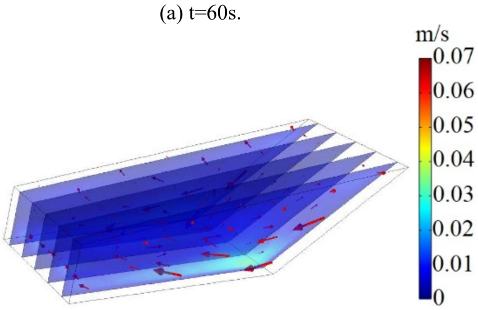


(b) t=120s.

Fig. 9. Temperature simulations for top boundary TEC application (I=6A)

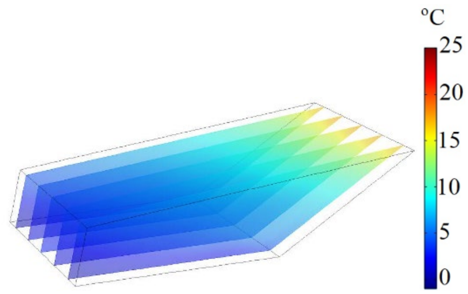


(a) t=60s.

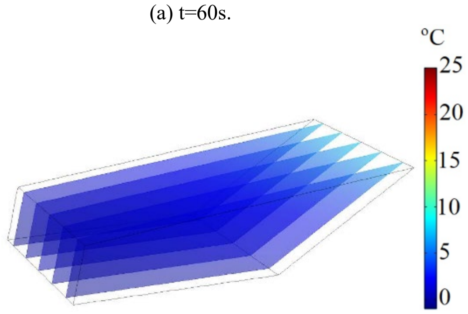


(b) t=120s.

Fig. 10. Velocity simulations for side boundary TEC application (I=6A)

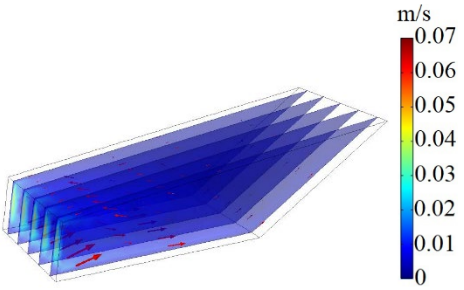


(a) t=60s.

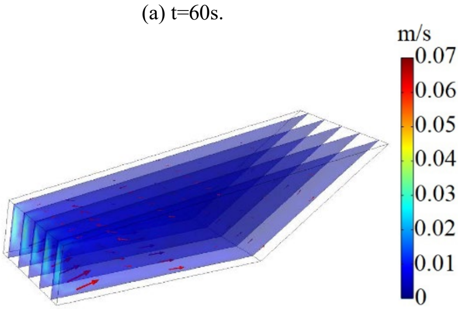


(b) t=120s.

Fig. 11. Temperature simulations for side boundary TEC application (I=6A)

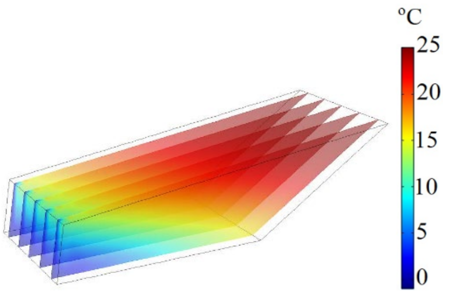


(a) t=60s.

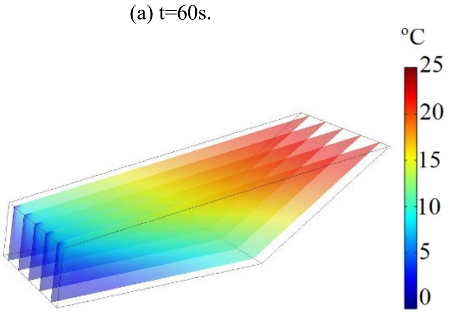


(b) t=120s.

Fig. 12. Velocity simulations for rear boundary TEC application (I=6A)



(a) t=60s.



(b) t=120s.

Fig. 13. Temperature simulations for rear boundary TEC application (I=6A)

Time depending variations of the average air temperature inside the glove compartment for 6A, 18A and 30A electric current values have also been presented in Figs. 14-16, respectively. Heat transfer is stronger at the beginning of the process due to the stronger convection currents. As it has been observed from these figures that, as being compatible with the simulations given in Figs. 6-13, when the top boundary TEC application has the highest cooling capacity, that of the rear boundary TEC application is the weakest. One more important result obtained is that, applied electric current to the TECs significantly improves the cooling capacity.

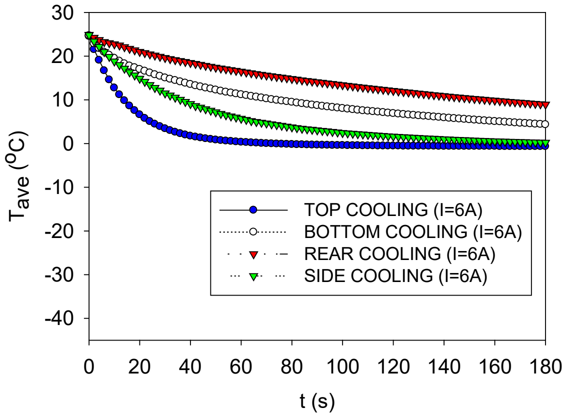


Fig. 14. Average temperature of the air inside the glove compartment for I=6A

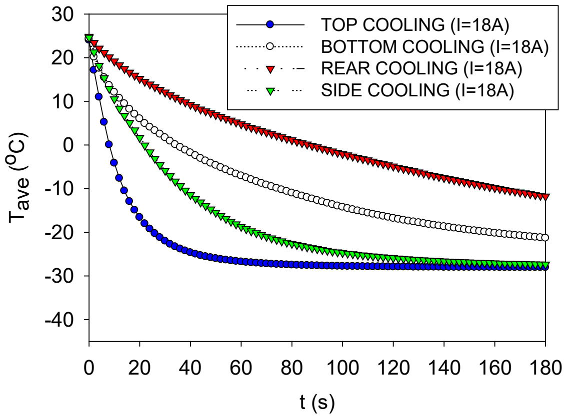


Fig. 15. Average temperature of the air inside the glove compartment for I=18A

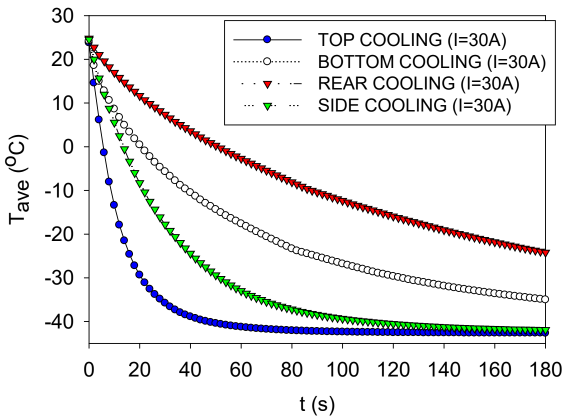


Fig. 16. Average temperature of the air inside the glove compartment for I=30A

IV. CONCLUSIONS

In this study, the effects of the four different TEC placements on the glove compartment have been investigated numerically by Comsol Multiphysics and Simulation Software. Numerical results have been obtained under the effect of natural convection with Boussinesq approximation. It has been concluded that top boundary TEC application cools the investigated glove compartment much more rapidly than other cooling conditions. Heat transfer is stronger at the beginning of the process as a result of stronger natural convection. Cooling capacity also enhances significantly with the applied electric current.

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