Voltage Generation and Thermal Gradient Analysis of a Car Waste Heat using Thermoelectric Generator

A.M.Yusop[1], M.S.Sharuddin[1], R.Mohamed[2], A. Mohamed[2], N.A. Sulaiman[1] and S.I.Samsudin[1]
[1]Centre of Telecommunication Research and Innovation (CeTRI), Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
[2]Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia.
azdiana@utem.edu.my

***Abstract*— This study is conducted to analyse the behaviour of voltage generation and thermal gradient of a car waste heat when these conditions are applied; with no air conditioning system and with air conditioning system. The analysis of this behaviour is made possible by utilising a set of three cascaded thermoelectric generators (TEGs) in each condition. The harvested voltage is attained by placing the hot side of the TEG on top of the dashboard car. A series of data setup from a set of TEGs, temperature data logger and the data acquisition card is accomplished towards the end of the experiment. From the final analysis, it is found that the highest thermal gradient and voltage generation is obtained with the presence of air conditioning.**

Index Terms—Thermoelectric; Thermal Gradient; Voltage Generation; car waste heat.

I. INTRODUCTION

When a car is parked in direct sunlight for extended period of time, there will be no surprise to experience the dramatically increase to the temperature inside the car. When there is an available initiative to slightly roll down the car's windows to reduce to temperature, there is always be some heat that is still trapped inside the car. Thus, instead of sticking with the old mind set of complaining about the heat and let it gone by, it would be a far greater deed and more earth-friendly if the wasted heat is reuse in other beneficial applications.

Thermoelectric generators (TEGs) is used in this situation to convert thermal gradient produced in the car to electricity[1, 2]. In the previous report, thermoelectric has been used in several fields to convert waste heat energy into the form of electrical quantity such as in [3-5]. In the enclosed cabin, the temperature may rise. In [6], they calculated the rising temperature inside the cabin and modelled the output findings based on air temperature, global radiation and wind velocity. The model is developed because the heat inside the car may become dangerous to unattended children and pets that are being left in the car.

Hussain H. Al-Kayiem in his article in [7] has conducted both experimental and numerical analyses in order to study on the thermal accumulation and distribution inside a parked car cabin. The experimental results were obtained from measurements on a salon car parked in the unshaded area. Referring to this article, the spots with the highest temperatures recorded are located near the glass windshields; specifically, on the dashboard and on the back surface near the rear windshield. The result is classified into two cases; when all the windows are closed and another one for a similar condition but with the addition of sunshade on the front windshield.

B. Orr in their article in [8] had suggested the use of both TEGs and heat pipes to create a completely solid state and passive waste heat recovery system. The heat pipes are made as a complement to the TEGs due to its properties where it able to lessen the thermal resistance between the TEG and gases. It also can act as a temperature regulation of the TEGs. The heat pipes have its own restriction where they produce a maximum proportion of transferring heat. On top of that, heat pipes can only work in a certain temperature range.

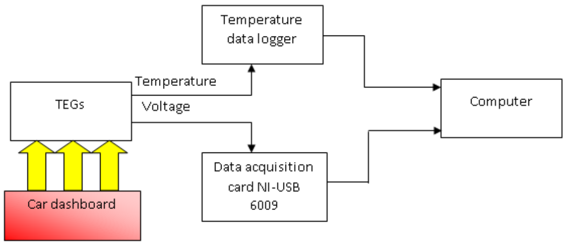
In this study, the dashboard is chosen as the spot for completing both objectives of this study. A basic configuration is established consisted of a set of three TEGs. This configuration is chosen based on our previous findings in [9, 10]. By applying different conditions and ran through different time on the same day, the voltage generation and thermal gradient of the TEGs are analysed.

II. EXPERIMENTAL SETUP

The block diagram and actual experimental connection of the layout of TEG testing in the car are shown in Figure 1 where the dashboard will act as a heat source of the TEG. Open circuit voltages for the TEG outputs are recorded using the NI-USB 6009 data acquisition card from the National Instrument.

The input temperature is taken using temperature data logger TC-08. From the study in [7], it is found that the temperature on the dashboard will vary from the varied heat. The temperature value of the dashboard is interconnected with the car's outdoor temperature and will experience the highest heat at noon. The determination was carried out in this study where the experimental time is taken from 12.30 pm to 1.30 pm as all car windows are closed.

The analysis is also done by taking into account the effects of ventilation in producing electricity. The main purpose of this study is to evaluate the effect of ambient temperature on the changes of TEG's temperature gradient.



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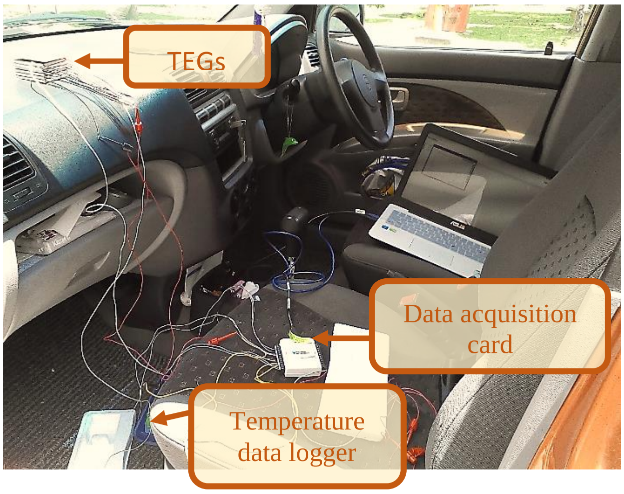

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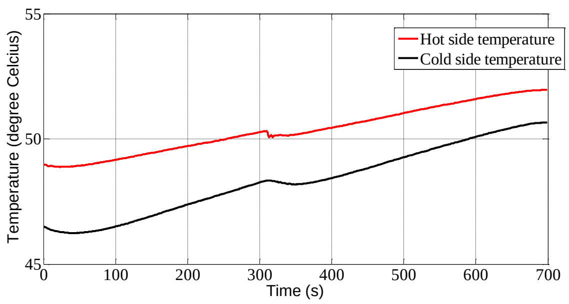
Figure 1: TEGs arrangement in a car

III. Experimental Analysis

The analysis is divided into two parts. The first part is the analysis with the air conditioning and the second part with the presence of air conditioning system.

A. Analysis without air conditioning

In this part of the experiment, the temperature of both sides of TEGs is recorded with no air conditioning. The temperature is taken at 12.30 pm, 1.00 pm and 1.30 pm which lasts for 700 s depending on the measuring device's capacity. This analysis has been carried out for several days at the same time every day and then diminished before the temperature on both sides of the TEG is plotted in the same diagram. Through Figure 2 it is found that the temperature of both sides of the TEG increases as the cold side temperature follows the heat side temperature. At 1.00 pm, there is a situation where cold-side temperatures overtake heat-side temperatures. Subsequently at 1.30pm, at the analysis time 422 s onwards, the thermal side temperature has been overcome by cold side temperature. It is found that the higher the temperature on the dashboard, the TEG's temperature gradient will become smaller. This condition will cause the TEG's output voltage tends to decrease. This can be seen further in Figure 3.



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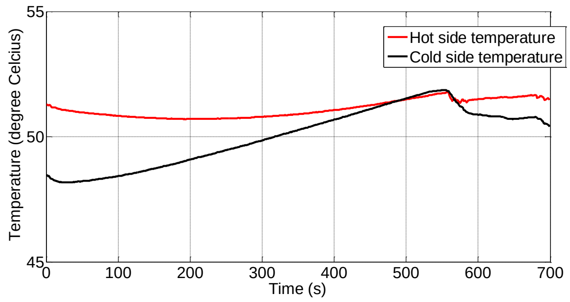

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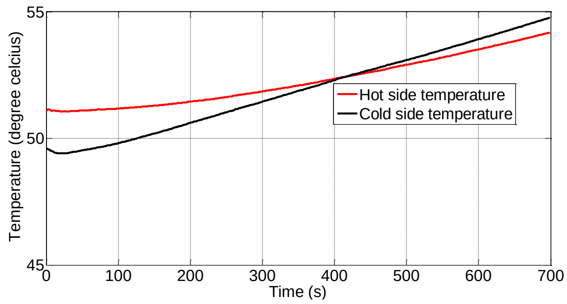
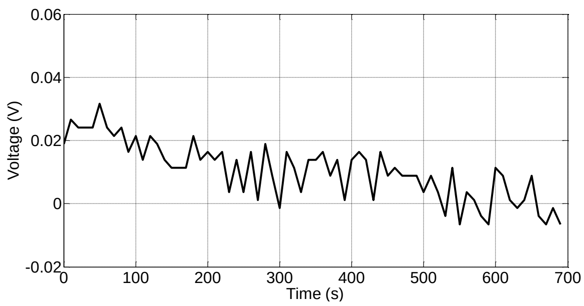


(c)

Figure 2: TEGs temperature profile on the dashboard without the presence of air conditioning (a) 12.30 noon (b) 1.00 pm (c) 1.30 pm

Figure 3 (a) shows that the TEGs output voltage is decreasing, where this condition occurs because the temperature on both sides as seen in Figure 2 (a) is increasing. This will cause the temperature gradient to decline which in turn causes the TEGs output voltage to decrease. From Figure 3 (b), although it is initially showing decreased voltage values but at analysis time of 500 s to 566 s, the cold side temperature reading has surpassed the hot side temperature. This has resulted in a slight negative gradient and the resulting voltage decreases. It is found that after 566 s the temperature of the hot side temperature returns back to the cold side temperature and this causes the output voltage of TEGs to rise.



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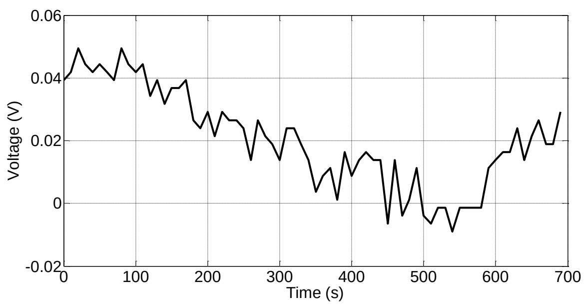

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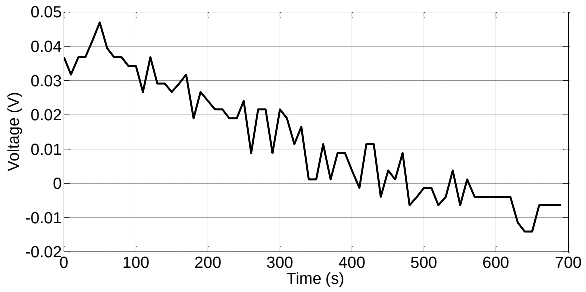

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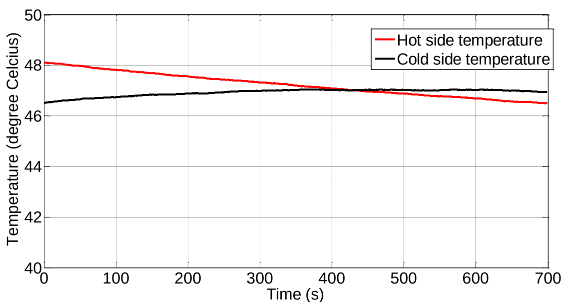
Figure 3: TEG's output voltage when placed on the dashboard without the presence of air conditioning (a) 12.30 noon (b) 1.00 pm (c) 1.30 pm

Next in Figure 3 (c) the voltage generated by TEGs decreases drastically compare to Figure 3 (a). This condition occurs due to the increasing slope of temperature during the experimental process. This temperature gradient is smaller due to the increasing heat of the car's external temperature, which causes the temperature of the cold side of the TEGs to follow its hot side temperature and although at one point the cold side temperature greater than the hot side temperature but due to the small temperature gradient effect, the TEGs output voltage still decreasing.

B. Analysis with air conditioning

In this second analysis, TEGs behavior over the dashboard is analyzed with the presence of air conditioning. The purpose of this analysis is to see how the use of air conditioning can change the TEGs output voltage behavior. The experimental process is similar to the previous analysis where the only difference is that air conditioning system will be on along this test. TEGs temperature change profile with the presence of air conditioning can be seen more clearly in Figure 4.

It is found that TEGs hot side temperature is very different from the no-air conditioning analysis where it decreases throughout the experimental time. The cold side temperature remains to follow the hot side temperature until certain intersection point looks that the cold side temperature will overtake the hot side temperature as shown in Figure 4 (a). Referring to Figure 4 (b) at 1.00 pm when the temperature is recorded it is found that the hot side temperature is decreasing and the cold side temperature also decreases according to the behavior of the hot side temperature of TEGs. At 1.30pm, the hot side temperature decreased drastically and followed by a decreasing in cold side temperature. However, at time 174 s, it can be seen that the cold side temperature had overcome the hot side temperature of TEGs. This shows that with the presence of air conditioning, the temperature gradient of the TEGs will increase throughout the experimental process even though the outdoor condition of the car is getting hotter.



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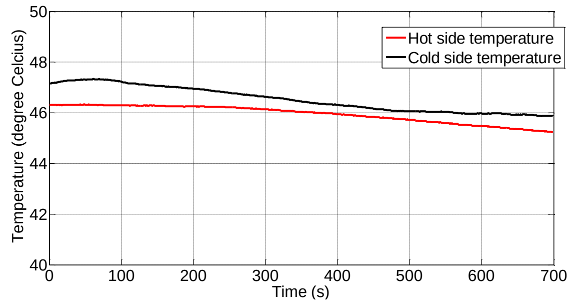

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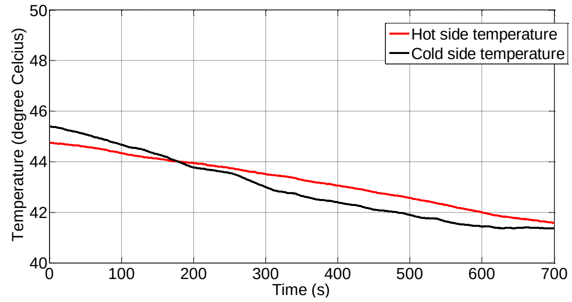

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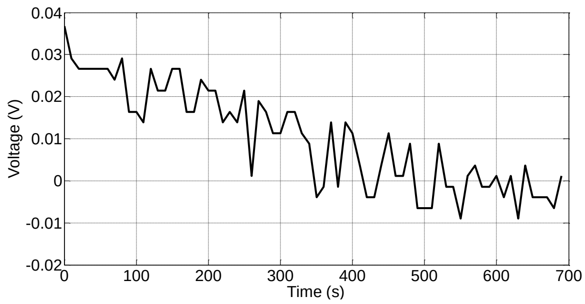
Figure 4: TEGs temperature profile on the dashboard with the presence of air conditioning (a) 12.30 noon (b) 1.00 pm (c) 1.30 pm

Furthermore, it can be seen from the TEGs output voltage plot from Figure 5, at the beginning of the test at 12.30 pm, as soon as the air conditioning system is on at this first 700 s interval, its impact has not yet affected the TEGs output voltage. At this time, the TEGs output voltage still decreases during the experimental period. At 1.00 pm, the TEGs output voltage pattern is relatively stable and subsequently increases at 1.30pm. From the results shown, it is clearly seen that the analysis with air conditioning system has succeeded in increasing the TEGs temperature gradient and increasing the output voltage of TEGs. This condition allows TEGs to be used as a device for waste heat harvesting on the car dashboard and subsequently converted into electricity. This is clearly different from the analysis without air conditioning which, the cold side temperature will always follow the hot side temperature and thus lower the temperature gradient. As a result, the resulting output voltage decreases.

Overall, it is found that in a certain period TEGs cold side temperature will override the hot side temperature where this condition occurs because the cold side of the TEGs has been directly involved with the solar radiation. This condition has contributed to the rise in temperature on the cold side which initially only is impressed with the temperature from the hot side crossing the cold side and the ambient temperature inside the car. This phenomenon has resulted in the smaller TEG's temperature gradient and the reduction of the harvested voltage generation.



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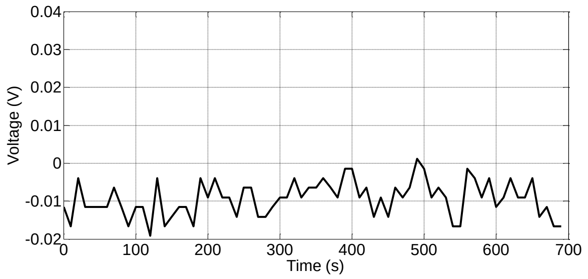

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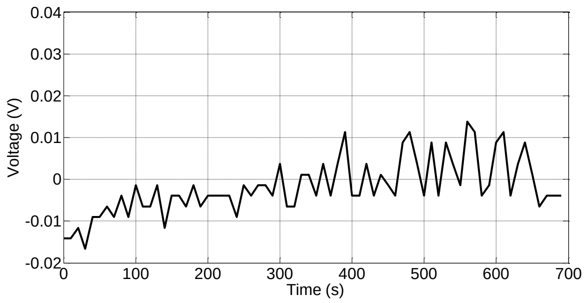

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Figure 5: TEG's output voltage when placed on the dashboard with the presence of air conditioning (a) 12.30 noon (b) 1.00 pm (c) 1.30 pm

With the presence of air conditioning, it was found that the temperatures on both sides of the TEGs began to decrease where the air conditioning system had managed to lower the ambient temperature of the car. This has helped in reducing the TEGs cold side temperature rise contributors. The entire TEGs experimental data on the car dashboard is recorded in Table 1.

Table 1
Summary of the experimental data of TEGs inside the car

Parameter	Time 12:30		13:00		13:30	
	Without A/C	With A/C	Without A/C	With A/C	Without A/C	With A/C
Hot side temp, Th (ºC)	50.66	45.23	50.40	46.94	54.18	43.58
Cold side temp, Tc (ºC)	51.97	45.87	51.46	46.50	54.76	41.37
Temp gradient, Th – Tc (ºC)	-1.31	-0.64	-1.06	0.44	-0.58	2.21
Output voltage (V)	0.0005	0.0015	0.0020	0.0088	0.0070	0.014

The ventilation is represented by an A/C symbol. It can be seen that the highest output voltage was harvested at 1.30 pm with the presence of air conditioning with a mean value of 0.014 V. The temperature gradient of this condition also highest at 2.21 °C. The lowest output voltage was produced in the condition without air conditioning at 12.30 pm with only 0.0005 V. It is also found that the hot side temperature is currently quite high at 50.66 °C compared to the hot side temperature with the presence of air conditioning.

IV. Conclusion

Observation of the actual situation and system for TEGs has been successfully implemented which includes the use of TEGs in the car. As a result, it is found that the TEGs temperature gradient has a very significant effect in producing its output voltage. Noteworthy explanations can be seen in experiments without air conditioning where the output voltage decreases throughout the experimental period. This is in fact contrary to the experimental results with air conditioning where the value of the generated voltage increases even though the external temperature of the car is getting hotter. It is found that the highest voltage value is successfully harvested with the presence of air conditioning is 0.014 °C.

Acknowledgment

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