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# Energy Harvester from Waste Heat using Thermoelectricity

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Currently there are many methods available to harvest energy from renewable sources. However, the method to harvest energy from waste heat sources still not fully explored. This paper focused on using thermoelectricity as a main component to utilized waste heat from household appliance especially from air conditioning system. The objective of this paper is to develop a thermoelectric generator system (TEG) based on heat release from compressor of the air conditioner system. Experimental data input was acquired from the compressor of the air conditioner system includes hot and cold side temperature. Then, Matlab SIMULINK has been used as a tool to analyse the acquired input data and output voltage, while current and power was calculated from the model. As result, maximum voltage obtained from the TEG system are 3.44 V with the temperature difference of 77.6 K at 16 °C, 0.73 A current, while power produced at 1.62 W. In conjunction to the power produced, the waste heat from air-conditioning system could light up the bulb in a room with the energy harvested using thermoelectric principle. The TEG system can also be utilize as an alternative energy sources for distributed energy generation (DEG) application.

## 1. Introduction

Nowadays, energy becomes the vital sources of the world. It used to increase the quality of life and yet energy consumption increases year by year. Energy comes from variety of sources and mainly generated from fossil fuels (Bell, 2008) leading to increasing levels of carbon dioxide emissions and challenging environmental problems in recent decades that directly or indirectly affects every country on this planet (Azmi & Tokai, 2016) However the wasted heat also can be recovered as an alternative energy source even though it's coming from small amount of energy production (Perry et al., 2008).

Thermoelectric terminology is used to describe harvested waste heat from machine production and convert it into electricity. It also can be defined as an alternative energy sources to reduce energy consumption on fossil fuels. Compact, flexible and high absorption of the thermoelectric system provide great advantages especially to the machinery application due to continuous operation of heat release (Fang et al., 2013).

Heating, ventilation and air-conditioning (HVAC) system is one of the machinery application that release wasted heat during operation. The air-conditioning system always tends to produce an excess of low temperature heat which usually called as "waste heat". The released waste heat can be harvest to generate the electricity (Snyder, 2008) using a device called as thermoelectric generator (TEG).

Practically, only one-third of fuels is used to generate electricity while another two-third is transformed into waste heat. It can say that around 20 % to 50 % of the energy is being lost to the environment as waste heat (Rosli, 2014). Waste heat is released during the operation of electrical powered machine. This situation indicates less efficient of electrical consumption due to more heat being waste rather than being used towards production.

Waste heat can be identified in household appliances (Rosen and Bulucea, 2009) such as the air-conditioning compressor system. The concept of air-conditioning system is to reduce the heat inside a building and then release it to the outside, thus to the environment. This will lead to negative impact especially towards climate change. Besides that, the heat trap within the building can lead to "Heat Island Effect" phenomena (Santamouris, 2001). It's very crucial to harvest the release heat from being wasted and contribute as an alternative energy sources to generate electricity for small energy consumer such as signal and sensors.

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This paper aims to develop a thermoelectric generator system (TEG) based on heat release from the air conditioning compressor system. It is very significant to the environment field as a response to the problem of climate change and reduce the impact of heat (Remeli et al., 2015). Moreover, thermoelectric devices helps in improving energy efficiency as it helps to reduce fossil fuel consumption.

## 2. Methodology

This paper aims to address this situation via quantitative analysis using Matlab SIMULINK software based on experimental design. Research hypotheses that waste heat from electrical appliances can be harvested to be used as an energy source (Rowe, 1999) from miniaturized equipment. Output is being measured by voltage, current and power. An experiment was conducted in this study in order to collect an input data of hot and cold side temperature. The temperature difference between the hot and cold side was the main key to the thermoelectric system (TEG).

Firstly, TEG prototype was developed and attached to the compressor of air-conditioner to obtain the temperature difference. The shape and circumference of the compressor was also measured. TEG will absorb heat and directly generate the electricity in the form of voltage which then will be supplied to load (breadboard). The current and power value will be obtained from the simple circuit (breadboard) using multimeter. Figure 1 shows the prototype of TEG system used in this study.

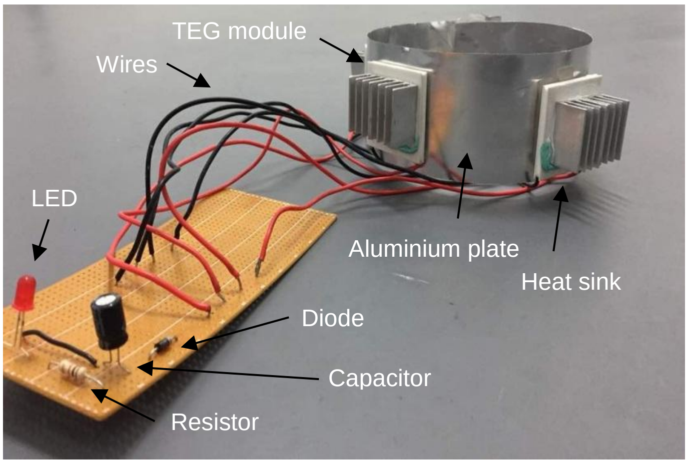


*Figure 1: Prototype of TEG system attached at the air conditioning compressor.*

An aluminum plate is used as a base for TEG attachment and act as heat spreader (Tan, 2013). This is due to make sure the TEG is performing at its highest and also serves as safety precaution. Additionally, TEG cannot be directly attached to the compressor because it could shorten TEG lifespan. The dimension of the aluminium plate is 5.5 cm x 38 cm with four TEGs attached and the hot side facing the aluminium plate.

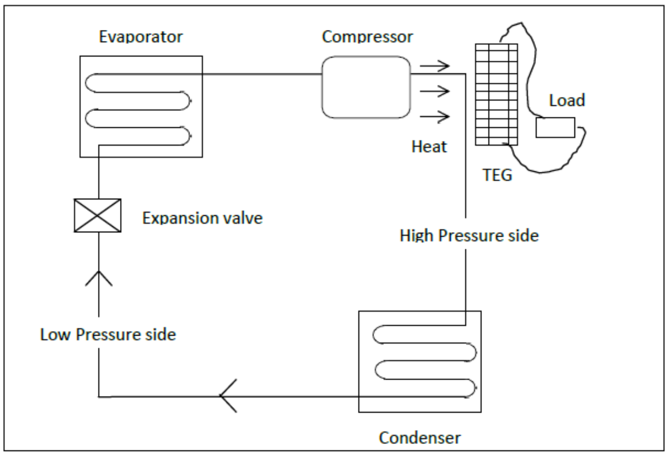


*Figure 2: TEG system installed at the air conditioning compressor.*

Due to the Seebeck principle; which TEG depends on the temperature different to generate electricity (Anitha et al., 2017), heatsink was used to absorbed heat from TEG. The heatsink is attached on the cold side of the TEG. Thermal paste is used in between TEG and heatsink as it act as a cooling agent (Wang et al., 2012) and glue between TEG and heatsink. Figure 2 shows the experimental design of this study.
As the prototype was attached to the compressor and input data was collected while the experiment was run. The input temperature data was collected using pyrometer. There are two temperatures acquired which are hot obtained from the compressor and cold temperature from the cold side of the TEG. The data is recorded from different temperature of thermostat which are at 16 °C, 18 °C, 20 °C, 22 °C and 24 °C. Each data are recorded for every15 minutes.
Let the resistance, $R$ is fixed at 10 ohm and assumed the Bismuth Telluride (Bi2Te3) thermoelectric modules (Lin et al., 2011) are used in this simulation. Then, the acquired input data was fed to Matlab SIMULINK where output voltage, $V$, current, $I$ and power, $P$ calculated from the formula:

$$V = S \triangle T + IR \quad (1)$$

$$I = S \triangle T/2R \quad (2)$$

$$P = I(S \triangle T - IR) \quad (3)$$

Where S is the Seebeck coefficient (de Boor and Müller, 2013), which

$$S = dV/dT \quad (4)$$

$dV$ is the Seebeck Voltage and $dT$ is the temperature.
The block diagram of Matlab SIMULINK is as shown in Figure 3. Temperature measured from the compressor was fed in the “hot_side_temperature” and “cold_side_temperature”. The output obtained from these equations was interpreted and analyzed.

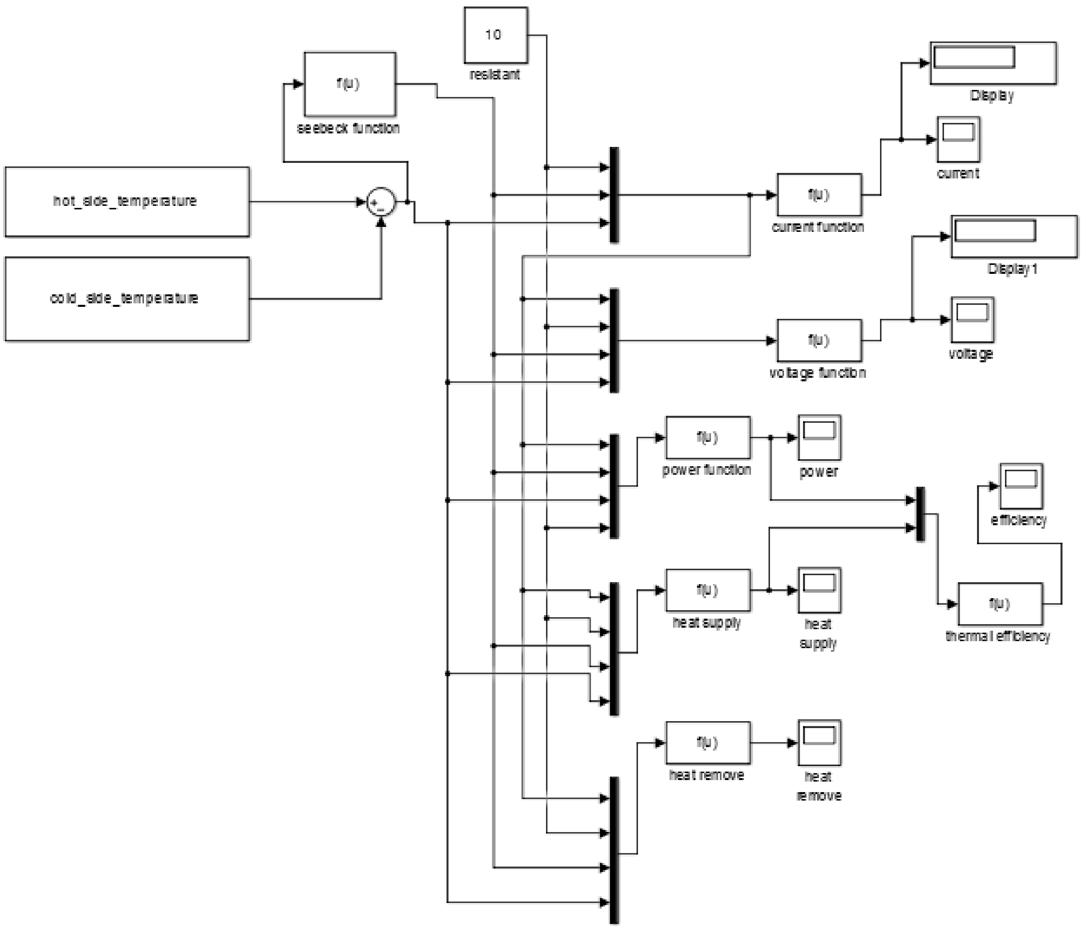


*Figure 3: Block diagram simulation using Matlab SIMULINK*

## 3. Results and discussion

There are two different temperatures that was collected during the experiment of TEG system at air-conditioner compressor. The hot temperature is collected at the compressor while cold temperature is collected at TEG module. The temperature difference was then measured between the hot and cold temperature where it will create electrical potential difference. Figure 4 shows the temperature difference collected between the compressor and TEG module respectively.

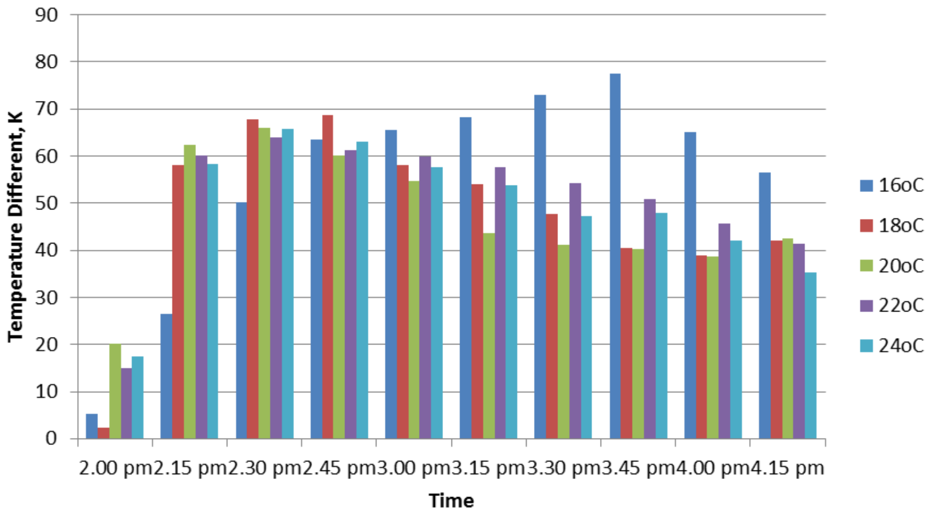


*Figure 4: Temperature difference collected for every 15 min at different thermostat's temperature*

All the data collected at the same time to ensure the temperature from the outside and inside of the room is in constant. In Figure 4, it is noticed that the highest temperature different obtained is 77.6 °C with the thermostat at 16 °C. Meanwhile, the lowest temperature different obtained is 2.3 °C with the thermostat at 18 °C which is the temperature collected at the first period. The inflation of the temperature different is contrasting at every temperature set by the thermostat. This phenomenon was due to the stoppage of the compressor when the room temperature reached its set thermostat. According to Navaro-Peris (XXX), the compressor operation depends on the setting from the thermostat and on the weather of the surrounding environment. Figure 4 shows that the graph of temperature difference varies according to the temperature set. It also indicated that at temperature at 16 °C has the longest rise in temperature difference between hot side and cold side. This is due to the compressor at 16 °C have the longest operation compared to other temperature settings. Thus, the lowest temperature set by the thermostat will cause the compressor to keep operating until the room reaches the optimum temperature. As the compressor keeps on operating, the heat released from the compressor will increase and it brings benefit to the TEG as the module required temperature different between hot side and cold side to generate voltage.

Input temperature difference was fed to the Matlab SIMULINK to calculate the output voltage (V) and current (I) produced. Figures 5 and 6 shows the results of output voltage and current respectively at different thermostat's temperature.

From Figures 5 and 6, it can be seen that the highest voltage and current produced is 3.44 V and 0.73 A respectively with temperature different of 77.6 °C between hot side and cold side of TEG module at 16 °C. The voltage will be produced when there is temperature difference between hot side and cold side of TEG module. Also, the voltage and current produced will increase when the temperature different rise. Temperature difference at 16 °C has the highest energy potential compared to temperature at 18 °C, 20 °C, 22 °C and 24 °C, causing the highest production of voltage and current.

The different temperature set by the thermostat has resulted in different amount of power produced. This is because air conditioner will make sure the optimum temperature is achieved according to the temperature set by the thermostat. Once optimum temperature is reached, the compressor will stop working until room temperature increases again.

The lowest temperature set by the thermostat, the longest compressor will work until the room reaches the optimum temperature. The power was calculated using Matlab SIMULINK and highest peak of power produce is 1.62 W at 16 °C. While the lowest peak of power produce is 1.01 W at 22 °C. The power starts to decrease as the compressor has stop working after the room reached the optimum temperature. Produced power of

1.62 W is enough to light up a 1 W single mini LED light. However, this is applied for a single unit of TEG model. If more TEG units are present, more power can be harvested thus capable to be applied to other appliances such as sensors and indicators.

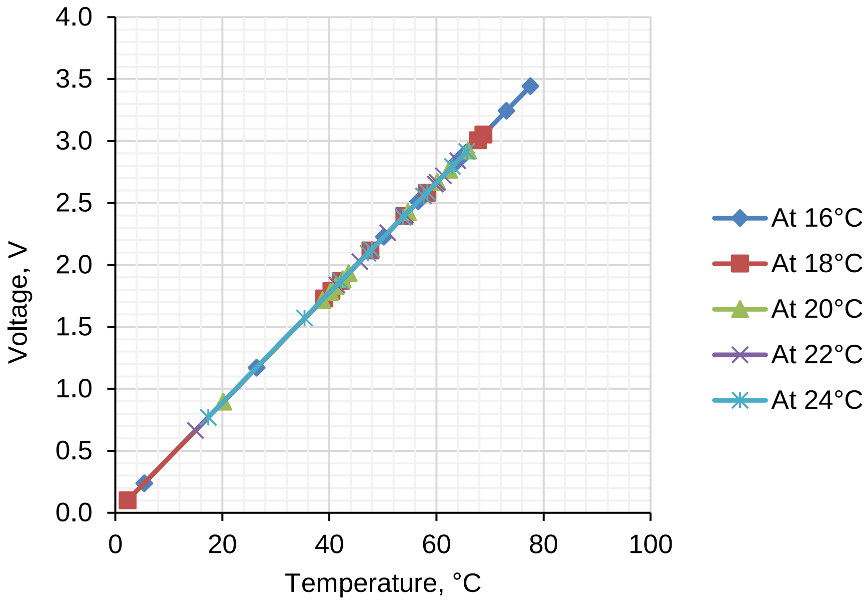


*Figure 5: Output Voltage versus Temperature Difference at different thermostat's temperature setting*

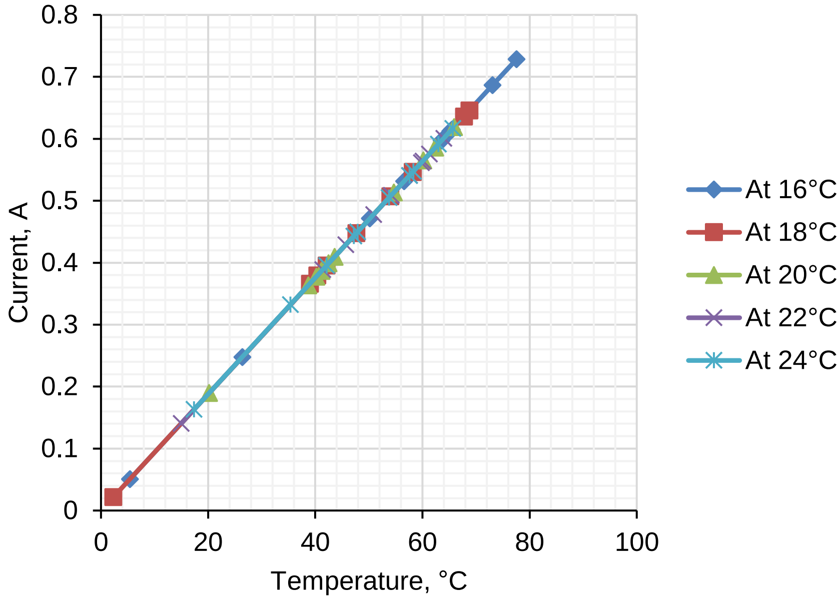


*Figure 6: Output Current versus Temperature Different at different thermostat's temperature*

## 4. Conclusions

TEG is one of the green technology approach and alternative energy saving especially at residential and industry. This research could give benefit to industry which can reduce fossil fuel consumption. Plus, industry nowadays seeks green technology as collective effort to reduce risk of climate change. The thermoelectric generator system (TEG) has been developed based on heat released from the air conditioning compressor system previously wasted. The results showed that the higher the temperature difference on TEG module, the higher the voltage, current and power generated. Maximum voltage obtained from the TEG system are 3.44 V with the temperature difference of 77.6 °C with the thermostat at 16 °C and the current is 0.73 A while power produce is 1.62 W.

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