

# Energy Harvesting from Household Heat Sources Using a Thermoelectric Generator Module

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**ABSTRACT:** Inefficiency in energy usage has led to the subject of energy harvesting which simply means recycling dissipated waste energy into another useful form of energy. This paper presents the harvesting of waste thermal energy from household heat sources (kerosene stove and generator exhaust pipe) as an electrical energy. Thermoelectric generator (TEG) modules (TGM-161-1.2-2.0) and aluminium heat sinks were constructed and placed close to the heat sources for waste heat harvesting. The hot and cold side temperatures of the TEG modules were measured along with the corresponding output voltages and currents, while the power and energy harvested were estimated. The harvesting of energy from the stove yielded means of  $1.532 \pm 0.091$  V,  $0.388 \pm 0.003$  A,  $0.597 \pm 0.039$  W and  $536.87 \pm 34.98$  J, subject to an average temperature difference of  $84.59 \pm 3.64$  °C. For the generator exhaust pipe, average values of  $1.28 \pm 0.074$  V,  $0.285 \pm 0.007$  A,  $0.367 \pm 0.029$  W and  $330.62 \pm 26.15$  J with an average temperature difference of  $62.31 \pm 4.88$  °C were achieved. The obtained results agreed with previous studies on energy harvesting using TEG modules. This work revealed the potential of waste heat energy harvesting using TEG technology.

**KEYWORDS:** Waste heat; temperature; thermoelectric generators; heat source; energy harvesting.

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## I. INTRODUCTION

Based on socioeconomic perspective, the level of energy consumption is directly related to the economic development and total number of population in a country. The increasing rate of population in the world is an indication that energy demand will be on the rise (Saidur et al., 2012). According to the World Health Organization (WHO), about 3 billion people cook in open fires by burning biomass like wood, animal dung, crop waste and coal (WHO, 2014). Over 4 million people die prematurely from illness due to the household air pollution by cooking with solid biomass fuels (Risha, *et al.*, 2015; WHO, 2014).

Globally, efforts have been directed toward improving fuel economy and efficiency, reducing emissions from primary energy resources and decreasing primary energy demand. Strategies employed in improving energy efficiency include investment in energy-efficient equipment and gadgets, production planning, energy recycling of industrial production process, excess energy recovery and reuse. It has been reported that 20 - 50% of the primary energy consumed industrially is released to the environment as waste heat and 25 - 30% of the energy contained in the fuel used in running automobiles is dissipated into the surrounding (Fang et al., 2013; Lian et al., 2009).

There are several potential energy sources (thermal, mechanical, solar, electromagnetic, acoustic, wind, human body, and wave) that can be appropriately harvested to replace traditional sources or to power electronic applications

(Saidur et al., 2012; Necula et al., 2014). Recovered energy can take its original form or be converted into other energy forms. The comparison and evaluation of five technologies for electricity generation from excess heat at temperatures between 200 °C and 500 °C was carried out by Bianchi and De Pascale (2011). These technologies are referred to as Organic Rankine Cycle (ORC), Micro Rankine Cycle, Stirling Engine Systems, Thermoelectric Generation (TEG) and Inverted Brayton Cycle. Law et al. (2012) conducted a review of technologies (ORC, Kalina cycle and TEG for electricity generation) for low temperature industrial excess heat recovery. Both articles concluded that the ORC was the most matured and tested technology of the lot, the Kalina cycle was said to need more industrial demonstration and TEG is reported to be the only one used to power low current equipment close to the heat source. In addition, Saidur et al. (2012) reported the possibility of incorporating TEG technology with other technologies such as a turbocharger, photovoltaic, and Rankine bottoming cycle.

Thermoelectric materials can play a crucial role in both primary power generation and energy conservation (waste heat harvesting). TEGs have emerged as a promising alternative to green technology due to their distinct advantages. Thermoelectric power generation offers a potential application in the direct conversion of waste heat energy into electrical power where it is unnecessary to consider the cost of the thermal energy input. The application of this alternative green technology can also improve the

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overall efficiencies of energy conversion systems. Several studies have been conducted on the various applications of TEG to generate electricity from different low-temperature waste heat sources (cook stoves, human body, motorcycle and vehicle exhaust, geothermal, micro-solar thermal collector, and air conditioning condenser (Schlichting et al., 2008; Champier et al., 2010; Ogbonnaya and Weiss, 2012; Faruk and Keith, 2014; Liu et al., 2015; Rinalde et al., 2010).

Champier et al. (2010) investigated the viability of using a TEG to improve a developed biomass-fired stove. They produced electricity which runs the fan in the stove and powered a light emitting device and thus increasing the combustion efficiency of the stove. Also, Rinalde et al. (2010) experimentally developed two prototypes of TEGs aimed at generating electricity for isolated rural homes through firewood home stoves. The developed TEG prototypes showed great potential as a low-cost green technology that can be replicated in local areas which can be of comparative advantage over photovoltaic solar systems. In order to possibly eliminate the alternator, waste heat energy was harvested from the exhaust of a motorcycle using a TEG module (Schlichting et al., 2008).

Although the power obtained from the module seemed inadequate to eliminate the alternator, the study showed the possibility of developing TEGs capable of doing so. In addition, a waste heat energy harvesting system using TEGs has been constructed and operated to convert the extracted heat from the exhaust pipe of an automobile to electricity (Liu et al., 2015). This work revealed the promising potential of using TEG system to harvest waste heat from the exhaust pipe of an automobile thereby enhancing the efficiency of the vehicle.

As electric power supply is erratic in Nigeria with around 40% of the population (over 180 million) connected to the national electricity grid and over 70% of the population living in rural areas, the use of electric generators has been the major alternative for electricity generation (Oyedepo, 2014). The present per capita power capacity (28.57 W) and per capita consumption of electricity (125 kWh) in the country is obviously inadequate even for domestic consumption (Oyedepo, 2014). The residential sector accounts for about 65% of energy use in the country and this is due to the low level of development in all the other sectors (Ley et al., 2015).

The main energy-consuming activities in Nigeria's households are cooking (91%), lighting (6%), and use of electrical appliances (3%) (Oyedepo, 2012). Gasoline and diesel consumption in standby electricity generators are responsible for half of the energy consumed in the residential sector. The extensive use of generators in the country has positioned her as the leading importer of generators in Africa and one of the highest importers globally (Ley et al., 2015).

In this present study, the use of TEG as a green technology to harvest waste heat energy from household

appliances in Nigeria was investigated. A TEG module was purchased and used to study the possibility of its application to convert waste heat from a cook stove and an electric generator to power portable electronic gadgets. Enormous heat is released into the immediate surroundings due to the use of generators and stoves.

## II. BACKGROUND OF THERMOELECTRIC GENERATOR

TEGs are devices that convert heat energy (subject to temperature gradients) into usable electricity. TEGs are thermoelectric modules which are solid-state integrated circuits that employ three established thermoelectric effects known as the Peltier, Seebeck and Thomson effects. TEGs require heat as an energy source and can generate electricity if there is a heat source such as gas or oil flame, stove, campfire, industrial machinery, and furnace (Faruk and Keith, 2014).

The "Seebeck" effect is coined after Thomas J. Seebeck, who first discovered the phenomenon in 1821 (Risha et al., 2015). Seebeck observed that when a loop of two dissimilar materials was heated on one side, an electromagnetic field was created. He stated that the electromagnetic field strength and the voltage are directly proportional to the temperature gradient between the hot and cold sides of the material. The amount of the Seebeck coefficient ( $S$ ) varies with material and temperature of operation as expressed in Eqn (1) (Jo et al., 2012; DiSalvo, 1999; John, 2014).

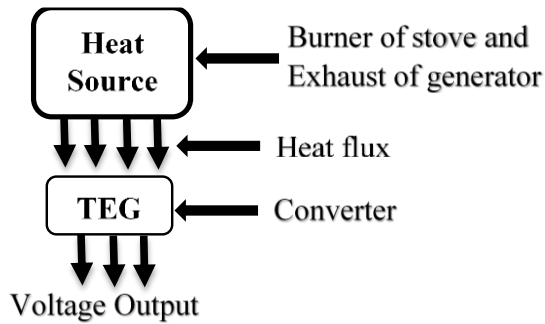
$$s = -n \left( \frac{\Delta V}{\Delta T} \right) \quad (1)$$

Where;  $n$  = number of modules,  $\Delta V$  = voltage difference between the hot and cold sides and  $\Delta T$  = temperature gradient between the hot and cold sides.

The negative sign is due to the negative charge of the electron, and the direction of current flow. For a negative Seebeck coefficient, electrons are the dominant charge carriers (n-type), whereas, for a positive Seebeck coefficient, holes are the dominant carrier (p-type) in materials. The major charge carriers move away from the hot (heated) side toward the cooler side while the minor charge carriers move in the opposite direction, but at a slower rate as a result of phonon drag and charge carrier diffusion rate (Snyder and Toberer, 2008). Hence, both n-type and p-type materials are required to realize current flow in a TEG module. The efficiency of a TEG module is expressed in Eqn (2) (John, 2014; Liu et al., 2015).

$$\eta_{max} = \left( \frac{T_H - T_C}{T_H} \left( \frac{\sqrt{1 + ZT} - 1}{\sqrt{1 + ZT} + \frac{T_H}{T_C}} \right) \right) \quad (2)$$

Where;  $\eta_{max}$  = maximum efficiency,  $ZT$  = figure of merit,  $T_H$  = hot side temperature,  $T_C$  = cold side temperature, and  $T$  = mean of hot and cold side temperatures ( $^{\circ}$  C).



**Figure 1: Schematic diagram for energy harvesting.**

Maximum generation of power requires the minimization of the thermal conductivity while maximizing the Seebeck coefficient and electrical conductivity. Notable advantages of TEG over other technologies include: extreme reliability as they have no mechanical moving parts, considerably less maintenance, very small size and weight, requires less space, very cheap, conversion of waste heat (at low temperature) to electricity and operates at high temperatures, and finally, it is a green technology.

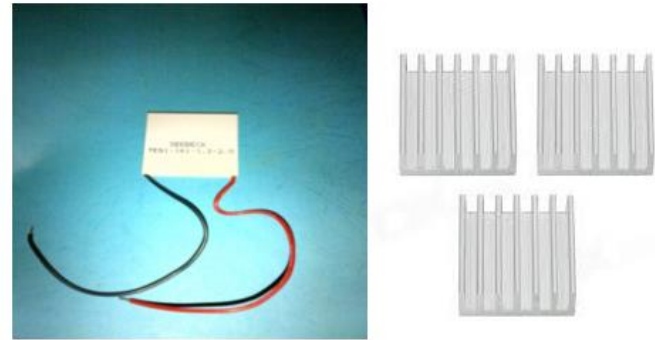
### III. METHODS AND MATERIALS

#### A. Equipment and Materials

The materials used in this work were: heat sources (burner (kerosene stove) and generator exhaust pipe (Petrol generator; Sumec Firman SPG 3000E2)), TEG modules (TGM-161-1.2-2.0, Russia), lead wire, plier, electrode, aluminium heat sink. The commercially available TEG module was purchased from Amazon (online shopping site; www.amazon.com) – United States of America. The equipment used was a thermometer (infrared non-contact; AR360A+; accuracy =  $\pm 2\%$ ; temperature range =  $-50\text{ }^{\circ}\text{C}$  –  $360\text{ }^{\circ}\text{C}$ ) – to measure temperature, welding machine, soldering iron and multimeter (DT-830D digital multimeter; current accuracy of  $\pm 1.2\%$ ; voltage accuracy of  $\pm 0.5\%$ ; China) – to measure the current and voltage.

#### B. Selection and Fixation of TEG Module

The heat sources utilized in this study were kerosene stove and exhaust pipe of a gasoline-powered generator



**Figure 2: TEG module and aluminium heat sink.**

(Sumec Firman SPG 3000E2). These heat sources were chosen due to their prevalence in most households in the country. TEG is a transducer that functions as a heat engine; however, it is less bulky and has no revolving parts. In this study, two TEG-161-1.2-2.0 modules were used. The TEGs were selected because they are readily available, and the hot side can operate between the temperature range of  $200\text{ }^{\circ}\text{C}$  and below, and the cold side between the temperature  $-40\text{ }^{\circ}\text{C}$  and above, which covers the range of the temperatures of the heat sources selected and investigated. A TEG module was used for each heat source. Figure 1 presents the schematic diagram of this study.

A bracket made of aluminium plate was welded on the kerosene stove burner to hold the TEG module in place close to the heat source at 3 cm from the surface of the burner. For the generator, the TEG module was also placed near (5 cm) to the exhaust pipe but without a bracket on the exhaust pipe as the vibration from the generator was observed to affect the TEG and its performance. An aluminium heat sink was firmly fastened to the cold side of each TEG module as the hot side was to be placed close to the heat source. The heat sink was utilized to cool the cold side of the TEG module for effective heat dissipation into the surrounding. The TEG module and the aluminium heat sink are shown in Figure 2.

#### C. Experimental Procedures

The surface temperatures of the kerosene stove burner and the generator exhaust pipe were measured for a period of 15 minutes using the infrared non-contact



**Figure 3: Pictorial representation of energy harvesting from stove.**

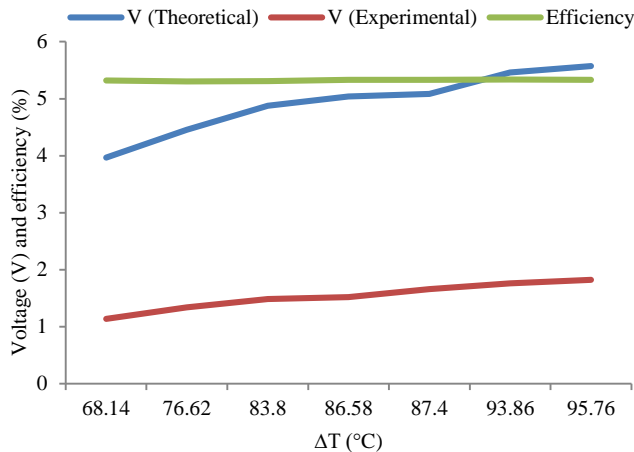
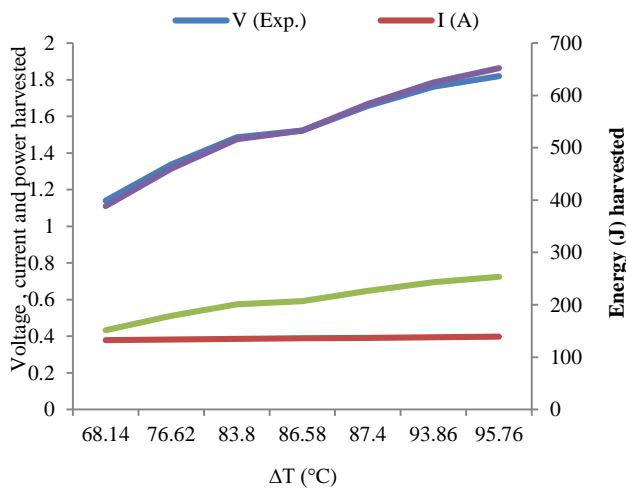


**Figure 4: Pictorial representation of energy harvesting from generator.**

**Table 1: Temperatures from TEG modules.**

Time (minutes)	Stove			Generator		
	T <sub>hot</sub> (°C)	T <sub>cold</sub> (°C)	ΔT	T <sub>hot</sub> (°C)	T <sub>cold</sub> (°C)	ΔT
2	107.7	39.6	68.14	81.4	33.3	48.1
4	119.3	42.7	76.62	85.6	36.4	49.2
6	130.7	46.9	83.80	93.7	40.1	53.5
8	140.7	54.2	86.58	106.5	43.9	62.6
10	148.1	60.7	87.40	113.8	46.9	66.9
12	156.5	62.6	93.86	121.4	48.1	73.3
15	161.6	65.8	95.76	133.3	50.8	82.5
Mean	137.8	53.2	84.59	105.1	42.8	62.3
SD	19.69	10.33	9.64	19.20	6.4	12.9
MSE	7.44	3.90	3.64	7.26	2.43	4.88

Note: SD = Standard deviation; MSE = Mean standard error

**Figure 5: Voltage and efficiency against temperature difference (stove).****Figure 6: TEG module parameters for waste heat harvesting from stove.**

thermometer after lighting the stove and running the generator, respectively. For the first six measurements, a two-minute interval was maintained with three minutes interval observed for the last (seventh) measurement. The ambient temperatures around both the stove and the generator were also determined. This was carried out in triplicates and the mean temperatures recorded. The hot side of each TEG module was placed near the surface of each heat source

which provided the high temperature before operating the generator and lighting the stove.

Data on the temperatures of the hot and cold sides of the TEG modules, and the terminal voltage and current were measured for 15 minutes. The terminal current and voltage were determined using the multimeter. This was repeated five times and the average values reported herein. The waste heat from the heat sources flowed via radiation, convection and partial conduction to the TEG modules, heat sink and finally to the surrounding. The temperature differential across the TEG modules produced a potential difference which led to the flow of direct current (DC) as measured between the TEG terminals. After obtaining the data, the harvested power through the TEG module was used to light LED bulbs. The waste heat energy from the stove and generator exhaust pipe with relatively low temperature was harvested and converted into electricity for immediate use. The schematic diagram of this study is presented in Figure 1. Figures 3 and 4 represent the experimental setup for the stove and generator, respectively.

#### D. Estimation of Parameters

The measured hot and cold side temperatures from both heat sources were used to evaluate their theoretical voltage and efficiency using Eqs. (1) and (2), respectively. Seebeck coefficient of 0.05818 V/K was used for the TEG module (TEG-161-1.2-2.0) as obtained in the literature (Everdrronics, 2016). The harvested power and energy from the waste heat via the use of the TEG modules for both heat sources were estimated using Eqs (3) and (4).

$$P = V \times I \quad (3)$$

$$E = P \times t \quad (4)$$

Where; P = power (W), V = voltage (V), I = current (A), E = energy (J), and t = time (s).

#### E. Statistical Analysis of Study

The use of a statistical tool (Microsoft Excel (2013)) to calculate the mean, standard deviation, and mean standard error of the measured temperature (hot and cold sides of TEG), voltage, current, power, and energy was conducted. Also, the correlation between the obtained theoretical and experimental values was carried out in addition to the analysis of variance (ANOVA) performed on them to check for the significance of the garnered data during this study.

## V. RESULTS AND DISCUSSION

### A. Energy Harvested from the Stove

Energy was harvested from the waste heat of the kerosene stove burner using the TEG module. Table 1 shows the measured temperature of the cold and hot side of the module and the temperature difference for the stove. The average temperature of the hot side of the module was  $137.81 \pm 7.44$  °C with a temperature range of 107.7 to 161.56 °C while that of the cold side of the module was  $53.21 \pm 3.90$  °C. The mean of the temperature difference between the module (hot and cold side) was  $84.59 \pm 3.64$  °C. It is apparent from Table 1 that all the measured temperatures were noticed to increase progressively from the start of taking the readings in

the experiment to the end (15 minutes). With the average value of the cold side temperature being considerably higher than the ambient temperature (25 °C), it is, therefore, possible to further reduce the cold side temperature by increasing the aluminium heat sink which would increase the temperature gradient.

Figure 5 depicts the harvested theoretical and experimental voltage from the stove waste heat and the efficiency of the TEG module as against the temperature differential between the module. The theoretical voltage was estimated using Equation (1) as illustrated by a moderately increasing straight line whereas the experimental voltage was determined with the use of a digital multi-meter and it is represented by a slightly increasing straight line, all as a function of the temperature gradient. Mean values of both theoretical and experimental voltage were  $4.92 \pm 0.21$  V and  $1.53 \pm 0.09$  V, respectively. From Figure 5, the values of theoretical voltage were conspicuously higher than the experimental values due to the low efficiency associated with the use of TEG modules as reported in the literature (Champier et al., 2010; John, 2014). This is corroborated by the relatively constant efficiency of the module estimated to be  $5.32 \pm 0.005\%$  on the average. The efficiency of TEG modules is generally around 10% (maximum) and this is not due to low-power generation but high-power generation (John, 2014).

The voltage (experimental), current, power, and energy harvested from the waste heat from the stove against the temperature difference are provided in Figure 6. The average values of the measured current and estimated power and energy were  $0.388 \pm 0.003$  A,  $0.597 \pm 0.0389$  W and  $536.87 \pm 34.98$  J, respectively. The range of these values was 0.379 A - 0.398 A for current, 0.432 W - 0.724 W for power and 388.85 J - 651.92 J for energy harvested. Except for the current that appears relatively constant, all the three parameters were observed to increase with an increase in temperature difference between the module. This can be attributed to the fact that temperature gradient is directly proportional to voltage and power harvested from the waste heat using TEG (Liu et al., 2014; 2015). Also, temperature difference has been identified as the parameter with the most impact on the utilization TEG for energy harvesting (Liu et al., 2015).

A comparison of the results obtained in this present study showed that the power, current, and voltage were slightly lower than those of a previous work on the harvesting of heat from a cook stove to improve the stove's efficiency (Champier et al., 2010). These slightly higher values of power (1.7 W), current (0.75 A), and voltage (2.27 V) can be attributed to the significantly high temperature difference of 160 °C, which is close to double the value obtained in this study. The obtained efficiency for this work is slightly higher than that reported in the study of Champier et al. (2010). The difference in the types of modules engaged in both works may be responsible for the discrepancy in the efficiency. In another study, 500 W (0.833 W per module) and 160 W (0.267 W per module) with 4% efficiency were harvested

from a geothermal energy source using 600 TEG modules at 200 °C and 80 °C, respectively (Liu et al., 2014). Our results were found to be within the range of values they achieved in their works. Also, Dandekar et al. (2016) generated 3.2 W (0.4 W per module) from household induction stove waste heat using eight TEG modules with a temperature gradient of 25 °C. This harvested power is found to be slightly lower than the value obtained in this work.

### B. Energy Harvested from Tail Pipe of Generator

The measured temperatures (hot, cold, and temperature difference) in the energy harvesting from the exhaust pipe of the generator are presented in Table 1. The average measured temperature for the cold and hot side of the TEG module was  $105.09 \pm 7.26$  °C and  $42.78 \pm 2.43$  °C, respectively. The temperature range for the cold side was 33.26 °C - 50.8 °C while the one for the hot side was 81.40 °C - 133.34 °C. The temperatures of the hot and cold side gave an average temperature difference of  $62.31 \pm 4.88$  °C ranging from 48.14 °C - 82.54 °C (see Table 1). It can be noticed that the measured temperatures (hot, cold, and temperature difference) for the stove were moderately higher than those of

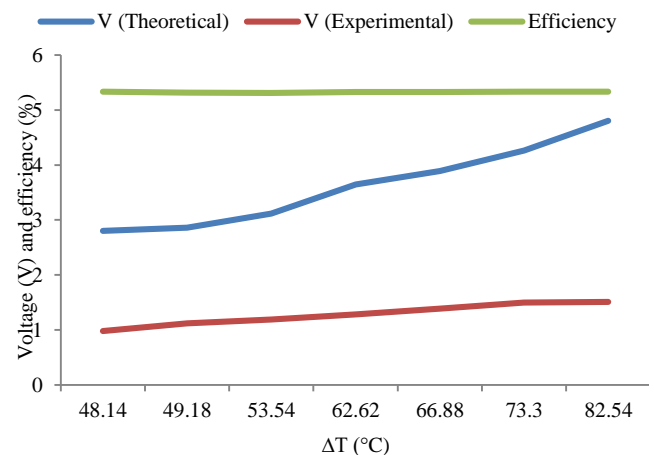


Figure 7: Voltage and efficiency against temperature difference (generator)

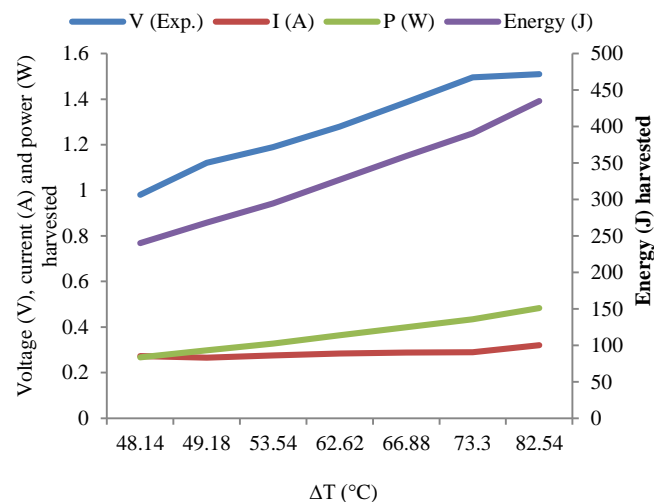


Figure 8: TEG module parameters for waste heat harvesting from generator.

the generator (Table 1). This is probably because the TEG module for the stove was placed closer to the flame while the module for the generator was slightly far from the combustion chamber. Also, the temperatures obtained via the burning of the stove (flame) and the running of the generator (combustion chamber) could be different.

Both the efficiency and voltage (theoretical and experimental) of the TEG module used for harvesting energy from the generator was plotted against the temperature gradient is provided in Figure 7. In this study, the estimated voltage (theoretical) was  $4.80 \pm 0.28$  V while the measured voltage (experimental) was  $1.5 \pm 0.07$  V, all on an average basis. From Figure 7, the voltages (theoretical and experimental) are illustrated by straight lines which increase with respect to an increase in the temperature difference. This showed a relatively linear relationship between both the theoretical and experimental voltage and temperature gradient.

The gap between the voltage lines revealed the measure of efficiency recorded in the use of the TEG module, which agreed with previous studies (Liu et al., 2014). In addition, the estimated efficiency for the TEG module as shown in Figure 7, gave a straight line implying no change in efficiency with an increase in the temperature gradient. An average value of  $5.33 \pm 0.003\%$  was evaluated as the efficiency for the TEG module used on the generator for energy harvesting. The same value of efficiency was obtained

239.90 J - 434.88 J, respectively. An average current, power, and energy of  $0.285 \pm 0.007$  A,  $0.367 \pm 0.029$  W, and  $330.62 \pm 26.15$  J, respectively, with a temperature difference of  $62.31 \pm 4.88$  °C was obtained. As can be noticed in Figure 8, the temperature gradient has a significant effect on voltage, energy, power, and current. This observation is in line with previous studies that temperature difference has the most effect on electricity generation using TEG technology (Schlichting et al., 2008; Champier et al., 2010; Liu et al., 2014).

In this study, the harvested power (average) from the exhaust of the generator was slightly lower than 0.4694 W (with a temperature difference of 48.73 °C) reported by Schlichting et al. (2008) using a TEG module to generate electricity from the exhaust system of a motorcycle. Ogbonnaiya and Weiss (2012) harvested 9.15 mW ( $V = 0.129$  V and efficiency = 2.87%) from a micro solar thermal collector with a temperature difference of 7 °C. The power reported is considerably lower than the power generated in this work using waste heat from a generator, though at a moderately high temperature.

### C. Statistical Analysis of Data

The correlation coefficients of measured parameters (voltage, current, cold and hot side temperature) from the use of stove as a heat source for energy harvesting is presented in Table 2. The range of the correlation coefficients was from

**Table 2: Correlation coefficients of parameters (stove).**

Parameters	T <sub>hot</sub> (°C)	T <sub>cold</sub> (°C)	Voltage (V)	I (A)
T <sub>hot</sub> (°C)	1			
T <sub>cold</sub> (°C)	0.9870	1		
Voltage (V)	0.9923	0.9689	1	
I (A)	0.9915	0.9802	0.9826	1

**Table 3: ANOVA result (stove).**

Source of Variation	Sum of squares	Decree of freedom	Mean square	F <sub>observed</sub>	P-value	F <sub>critical</sub>
Between Groups	87619.84	3	29206.61	236.0994	6.09E-18	3.01
Within Groups	2968.914	24	123.7048			
Total	90588.76	27				

**Table 4: Correlation coefficients of parameters (generator).**

Parameters	T <sub>hot</sub> (°C)	T <sub>cold</sub> (°C)	Voltage (V)	I (A)
T <sub>hot</sub> (°C)	1			
T <sub>cold</sub> (°C)	0.9843	1		
Voltage (V)	0.9743	0.9875	1	
I (A)	0.9229	0.8590	0.8212	1

**Table 5: ANOVA result (generator).**

Source of Variation	Sum of squares	Decree of freedom	Mean square	F <sub>observed</sub>	P-value	F <sub>critical</sub>
Between Groups	51061.95	3	17020.65	166.10	3.49E-16	3.01
Within Groups	2459.33	24	102.4719			
Total	53521.27	27				

for the TEG modules because they are the same product.

The voltage, current, power, and energy obtained in this work from the generator are plotted against the temperature difference as presented in Figure 8. All the parameters (except for the current), illustrated in Figure 8 are linear in nature with progressive and slight increase as the temperature difference increases. The current, power and energy harvested from the waste heat of the generator using the TEG module ranged from 0.172 A - 0.32 A, 0.267 W - 0.483 W, and

0.9689 - 0.9923; showing positive and very strong correlation existing between all the parameters. The analysis of variance (ANOVA) test was carried out on all the garnered experimental data relating to the harvested energy from the stove using the TEG module. The data were found to be statistically independent of one another as  $F_{observed} (236.49) > F_{critical} (3.0088)$  (see Table 3). Since the p-value is  $\ll 0.05$  at 95% confidence level, the measured data obtained in this study can be said to be significant.

Table 4 shows the correlation coefficients between the measured parameters as sourced using TEG module to harvest waste heat from the generator. The correlation coefficients between the parameters were positive and very strong with the exception of current and  $T_{\text{cold}}$  (0.8590) and, current and voltage (0.8212) which were positive and moderately strong. The ANOVA test showed that the data were not statistically the same with  $F_{\text{observed}}$  (166.10) >  $F_{\text{critical}}$  (3.01) (see Table 5). And the data were significant to this study with a p-value of less than 0.05 at 95% confidence level.

#### D. Utilization of Harvested Energy

The harvested power via the TEG modules from the heat sources was not stored but used. In order to check the feasibility of using the harvested energy to power or operate portable home appliances, it was used to light some light emitting devices (LEDs). An electric DC-DC converter was also incorporated into the setup before using the harvested power from both heat sources to lighten the LEDs. This is to further increase the voltage level of the harvested current.

A bright light was obtained for 5 minutes of using the harvested power (from each of the heat sources) to operate the LEDs to show the possibility of the modules producing electricity. Based on the achievement recorded in this work, a future work on improving the magnitude of harvested power using TEG technology to generate electricity for immediate use and storage is ongoing. To achieve this, the cold side temperature is to be lowered and made steady, the number of modules is to be increased, high capacity TEG modules are to be used and the possibility of stepping up the voltage is also to be investigated.

#### V. CONCLUSION

Energy harvesting in form of electrical energy from household heat sources (stove and exhaust pipe of a generator) using TEG modules has been carried out. TEG modules and aluminium heat sinks placed close to the heat sources were employed to harvest the waste heat. Parameters such as the hot and cold side temperatures, output voltages and currents were measured while the power and energy harvested were estimated for each heat source. Average voltage, current, power, and energy harvested from the stove was  $1.532 \pm 0.091$  V,  $0.388 \pm 0.003$  A,  $0.597 \pm 0.039$  W and  $536.87 \pm 34.98$  J, respectively, with a mean temperature difference of  $84.59 \pm 3.64$  °C. The exhaust pipe of the generator gave a voltage of  $1.28 \pm 0.074$  V, a current of  $0.285 \pm 0.007$  A, a power of  $0.367 \pm 0.029$  W and an energy of  $330.62 \pm 26.15$  J, with temperature differential of  $62.31 \pm 4.88$  °C.

These results were in good agreement with earlier works on the utilization of TEG modules for energy harvesting. TEG technology seems to have the potential to generate electricity that can be used to power portable household gadgets due to erratic supply of electricity in the country.

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