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EXPERIMENTAL INVESTIGATION OF THERMOELECTRIC POWER USING CANDLELIGHT

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Abstract*-This article presents a thermoelectric generator that used candlelight as a powering source. A thermoelectric generator produces electrical power from heat flow across a temperature gradient. In this case, the generator used the wastage heat from candle to produce electricity. This device consists of a thermopile, an upper heat sink, a lower heat sink, a glass chamber and a low voltage fan. Height and diameter of the candle were 5.5 cm and 2 cm respectively. Total height required for the device was about 30 cm. The candle was capable to light for 1.5 hours continuously and simultaneously we received maximum voltage 2.9 volts and power 2.75 watts. Hence, the generator produced 0.004125 KW/hr electricity within this time and the electricity passed directly to a fan connected to the output circuit of the device. Maximum air velocity produced by the fan is 1.2 m/s.*

Keywords: Thermoelectric generator, Thermopile, Seebeck effect, Candle.

1. INTRODUCTION

In recent years, thermoelectricity has become a popular term in both academic and industrial world, as traditional power generation resources, such as fossil fuels and nuclear fission, are either facing global shortage crisis or simply being quite costly. In contrast, the resources for thermoelectricity are either naturally present, for instance, the temperature gradient from the combustion engine, electromagnetic energy from communication and broadcast, motion from human movement or can be produced with little cost. As a result, nowadays lot of research is being made on energy harvesting like thermoelectricity. However, current technologies of energy harvesting are capable of producing only enough power to drive relatively low-power electronics. High volume applications of these technologies depend on further enhancement of the energy harvesting efficiencies.
According to the Bangladesh Energy Regulatory Commission (BERC), load shedding in Bangladesh takes severe form in the summer seasons. A statistics shows that highest load shedding in June-2013 was 766MW.**[1]**Most of the people are sufferer of the situation.

This establishes the necessity of thermoelectric device which can yield electricity utilizing wastage heat like heat from a candle light and which is not only easy to adapt in daily life but also cost effective. Besides, this sort of device is environment friendly as it uses up theunused heat from the candle.

2. WORKING PRINCIPLE

Thermoelectric (TE) generators consist essentially of three parts: a heat source, a heat sink and a thermopile. The heat source and heat sink provide the energy to the system by creating a temperature gradient across the thermopile. The thermopile serves to convert some of the thermal energy contained in the thermal reservoirs into electrical energy. The advantage of TE generators over other heat engines resides in their simplicity. This simplicity and lack of moving parts make TE generators a good target for miniaturization. A simplified picture of an ideal thermocouple is illustrated in Fig. [1]. When current flows through the circuit, heat is absorbed at the hot junctions and converted to electrical energy at a rate proportional to current times the Seebeck coefficient (a) for the material. Heat is generated within the thermo-element by Joule-heating, which is proportional to the dimensions of the structure. In parallel, heat is conducted down the length of the thermo-element at a rate inversely proportional to the dimensions of the structure. At the cold junction some of the electrical energy is converted back to heat, also due to the Peltier effect.

Two different materials with opposing Seebeck coefficients were needed to generate power from the circuit. A single pair of these thermo-elements (as shown in Fig. [1]) forms a thermocouple, with a net voltage at the terminals typically on the order of 300-500 mV per degree Kelvin for a highly efficient material system. In order to increase the terminal voltage to a useful range, thermocouples were often connected in series to form a thermopile, with a terminal voltage that was multiplied by the number of thermocouples.

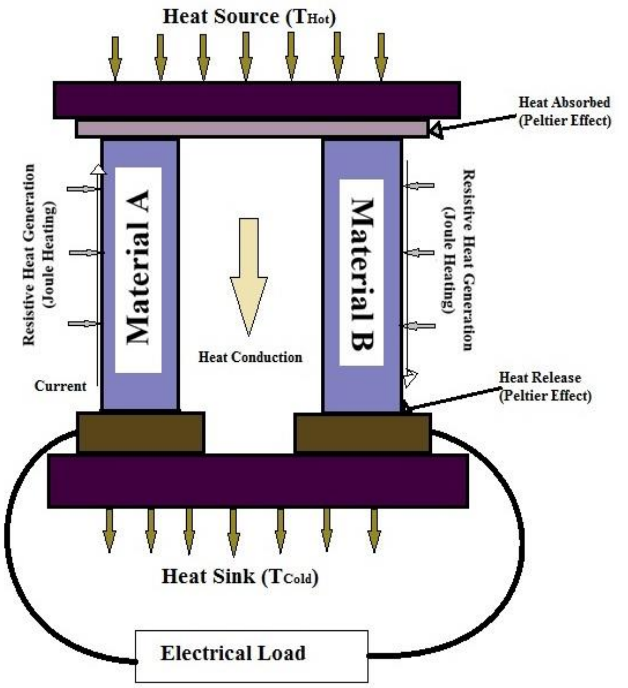

Fig.1: Thermoelectric generation.

To maximize power-generation efficiency, the temperature differential between the hot and cold sides of a TE generator should be as large as possible. As material properties vary with the temperature, they exhibit optimum performance over a relatively narrow temperature range. As a result, in order to maximize the efficiency of power generation modules, individual TE elements are usually formed from two and sometimes three different TE materials laminated together in the direction of current flow to form segmented elements. Each TE material in the laminate structure is chosen for its superior performance over the range of its temperature exposure.

When the parasitic conduction of the support structure and resistance of the contacts and leads are included, the maximum efficiency is obtained when the effective load resistance (*R*) and efficiency (*H*) are, respectively [2]

$$R_{max}=r_D\sqrt{1+Z_D\,.\,T_{ave}} \qquad (1)$$

$$\eta_{max}=\frac{(T_{H\,Ave}-T_{C\,Ave}).(\sqrt{1+Z_D\,.T_{ave}}-1)}{T_{H\,Ave}\,(\sqrt{1+Z_D\,.T_{ave}}+\frac{T_{C\,Ave}}{T_{H\,Ave}})} \qquad (2)$$

The Device Figure of Merit is obtained by Eq. (3).

$$Z_D=\frac{\alpha^2E_{ff}}{r_D.K_{Eff}} \qquad (3)$$

A thermopile is shown in Fig. [2], It is a pile of thermocouple connected in series so that voltage produced by each of the couple addsup. The output from a thermopile is large enough to run electrical devices such as low voltage light and fan. Number of thermos couples present in a thermopile depends on how much electricity is needed. The thermopile used here contains 127 thermocouples.

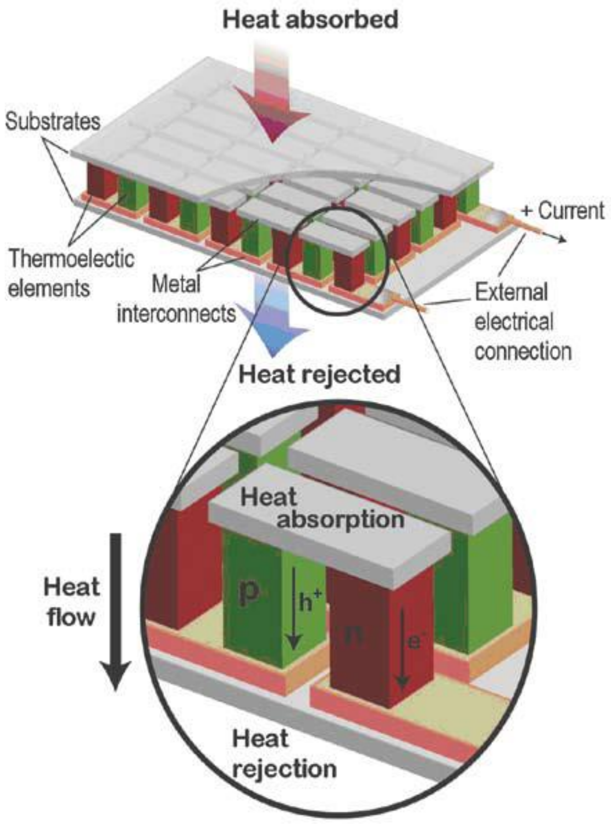

Fig.2: Schematic of a thermopile [3].

3. THERMOELECTRIC MATERIALS

For well over 50 years, researchers have been unable to produce a high-efficiency thermoelectric material. Because of conflicting material characteristics, previous TE generators have long been too inefficient to be cost-effective in most applications. They need materials that are both good electric conductors (else electron scattering generates heat on both sides of the barrier and throughout the materials) and poor thermal conductors (or the temperature difference that must be maintained between the hot and cold sides will produce a large heat Backflow).

But now with the invention of Nano-technology, these problems are solved to some fine limit. The best performance is achieved with materials such as heavily doped semiconductors, such as bismuth telluride or silicon germanium. Finally, for semiconductors, it is desirable to have a base material that can be both p- and n-type doped, so that the same material system can be used on both sides of the junctions [4].

Commonly used thermoelectric materials are:

- Bismath-Titenium (Bi_2Te_3)
- Zinc-Antimony (Zn_4Sb_3)
- Lead-Tellurium (PbTe)
- Silicon-Gallium (SiGe)
- Bismath-Antimony (BiSb)

Efficiency of these materials varies with temperature as shown in figure 3. Hence selection of material defends on the working temperature of the thermopile. The materials of the thermopileused in the device are Ceramic Substrate Sb, Bi, Se, Te, tin and non-ferrous materials Wire.

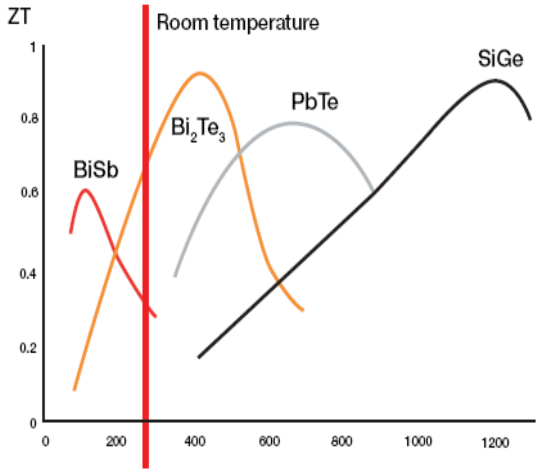

Fig.3: Efficiency of different TE materials [5].

4. CONSTRUCTION AND FABRICATION

4.1 Components

Lots of components are used to build the device. Following is a brief description of essential parts of the TE:

4.1.1 Glass Chamber

Figure 4shows the glass chamber which was made of commercial or soda-lime glass so that it can withstand high temperature produced by long term burning of candle and limit the transfer of heat from the chamber to the surrounding. Dimensions of the chamber are150 mm×140 mm ×110 mm(L x W x H) with a square chasm at top and a door at front.

4.1.2 Thermopile

Only one thermopile (shown in Fig. 5) was used in the device and the model of the thermopile is TEC1-12703 which has 127 couples. Normally this kind of thermopile is used as cooler and has maximum current and voltage of 3 A and 15.4 V respectively. But in this case, it was used as anelectricity generator using the reciprocal property.

4.1.3 Low Voltage Fan

As the output voltage of the generator was very low, we needed to use a low voltage fan with a sufficient air flow rate. For this reason we used a centrifugal radial fan with slightly inclined blade. The fan contains three metal blades, each 70 mm long. Operational voltage of the fan is 5 V and power consumption rate is 2.5 ± 0.25 W.

4.1.4 Hot End

An Aluminum plate was used to absorb heat from the candle and it transferred heat to the thermopile. The dimensions of the plate are 80 mm ×67 mm ×33 mm (L x W x H).

4.1.5 Cooler

To maintain a temperature difference between two ends of thermopile a cooler is attached at the cold end. It’s a pile of aluminum plates which reject heat and keep it cool.

Besides these, some other materials like candle, electrical wires, metal frame, nut and bolt etc. are also used

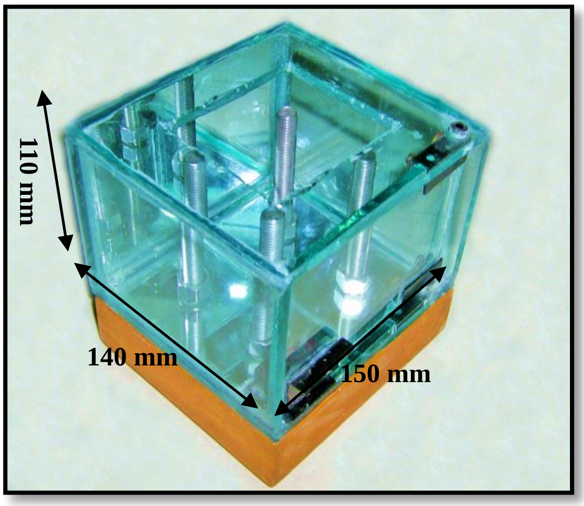

Fig.4: Glass chamber

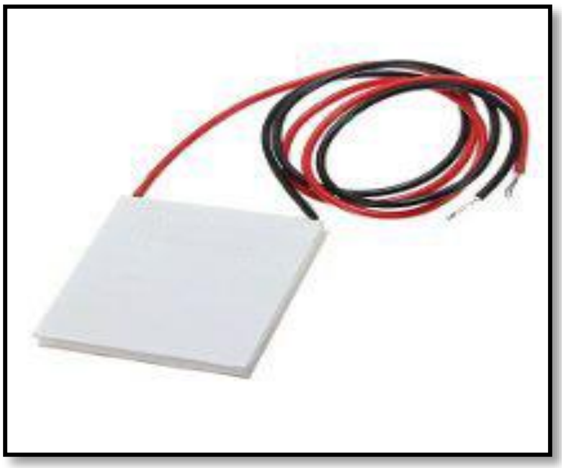

Fig.5: Thermopile

4.2 Construction of Thermoelectric Generator

Thermopile was used between hot end and cooler like a meat in a sandwich. With the help of thermal glue, it was then attached with the two end. This setup was placed over four vertical column inside the glass chamber. It is essential that the cooler should remain outside the chamber (as shown in Fig. 6), otherwise it would be too hot to stop the function of the generator. The low voltage fan was fitted with a metal frame and the frame is placed at the top of the glass chamber. Positive and negative sides of the thermopile were connected with the respective sides of the fan via electrical wire. The whole thing was placed over a wooden base.

5. RESULT AND DISCUSSION

A candle was kindled and put inside the glass chamber. It was found that the fan didn’t just start to rotate immediately, rather it took 3-5 minutes to start. This was happened because at the beginning the temperature difference between the hot and cold end of the thermopile was very lowhence voltage generation was also small in amount. As time passed, the temperature difference and voltage generation increased. When the thermopile generates enough electricity which was around 2.5-2.75 Watt, the fan started to move.

Temperature of the hot end increased with the time but after a certain stage it stopped increasing and remained constant. The highest temperature range of hot end was 140-150 degree Celsius.

In the case of cold end, temperature also increased with time but it didn't reach as high as the hot end. For this end maximum temperature range that was attained in our experiment was about 70-75 degree Celsius. That was almost half of the hot end highest temperature. Our experimental room was closed and there was no air flow other than the fan. But if the thermoelectric generator was kept in the open air then there would be air flow and hence cold end temperature would also decrease which will increase the temperature difference. As a result power generation will also increase.

It's also noticeable that the fan doesn't stop immediately after the extinguishment of the candle light. As one end of thermopile is still hot and there is temperature difference, so it generates electricity. It's seem that the fan stops 2-3 minutes later.

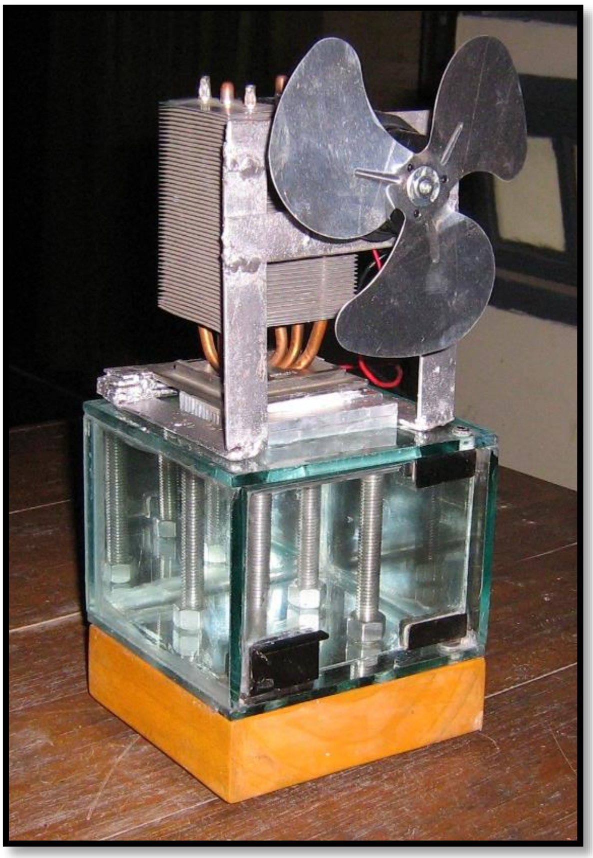

Fig.6: Thermoelectric Generator

5.1 Result

Table [1] shows the experimental data that was found during the experiment.

Table 1: Experimental data

Temperature		Difference of Temperature ΔT(℃)	Voltage Generated, Volt	Air velocity m/s
Cold end Tc (℃)	Hot end Th(℃)			
29	40	11	1.1	0
28	50	22	1.6	0
38	70	32	2.2	0
51	84	33	2.4	0.7
50	90	40	2.5	0.85
52	90	38	2.566	1.1
65	96	31	2.534	1.1
66	110	44	2.61	1.1
67	122	55	2.72	1.1
68	135	67	2.8	1.15
71	140	69	2.9	1.2

5.2 Graphs

Thermoelectric generator starts to generate electricity at very low temperature difference and as the temperature difference increases voltage generation also increases which is shown in Fig. 7. It was found that at lowest temperature difference of 11^o Celsius, voltage was 1.1 volt and at 69^o Celsius temperature gradient voltage was 2.9 volt.

Figure 8 shows the relation between air velocity and temperature difference between hot and cold end. It's seem that as temperature difference increases voltage generation increases and hence velocity of the air in front of the fan increases. At the very beginning upto 33 ℃ there is no air velocity because fan was not running but after then there is a sharp increase in the fan speed upto 40℃. And then velocity of the air examines a slow increase.

Figure 9 shows the relation between cold end temperature and voltage generated. At 29 ℃ TEG starts to generate voltage and with the increase of cold end temperature voltage also increases. It's notable that initially cold end temperature increases rapidly buy as the fan starts this temperature growth slows down because fan enhance the air supply around the upper heat sink.

Relation between hot end or lower heat sink temperature and voltage generated is shown in Fig. 10. When the heat sink is at room temperature no electricity will be generated. But as the temperature rise to 40 ℃ small amount of voltage is produced but it's not enough to run the fan. The fan will start to rotate at 84°C when the generator generates abound 2.4 volts electricity. Maximum voltage we found in this project is 2.9 volt and it's found at 140°C.

Figure 11 shows how air velocity changes with the cold end temperature. Up to 30°C there was no air velocity because the fan hadn't started yet. When the temperature reaches around 40°C, the fan starts slowly and then as temperature rises, speed of the fan also rises. Maximum air velocity that can be obtained from this fan is 1.2m/s.
Figure 12 shows how air velocity changes with hot end temperature of the thermopile. In this case also we don't get any air velocity initially as the fan is stopped. When the temperature reaches 84°C the fan starts to rotate and velocity increases sharply. But after 90°C it rises moderately because the fan reached its limit by then.

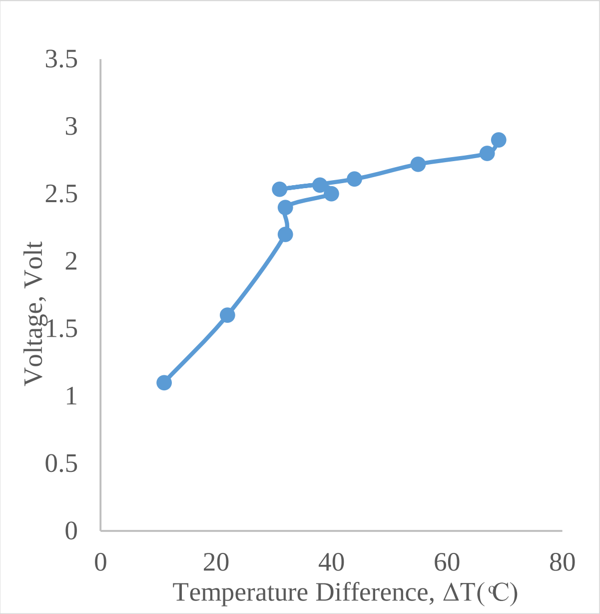

Fig.7: Temperature Difference Vs Voltage

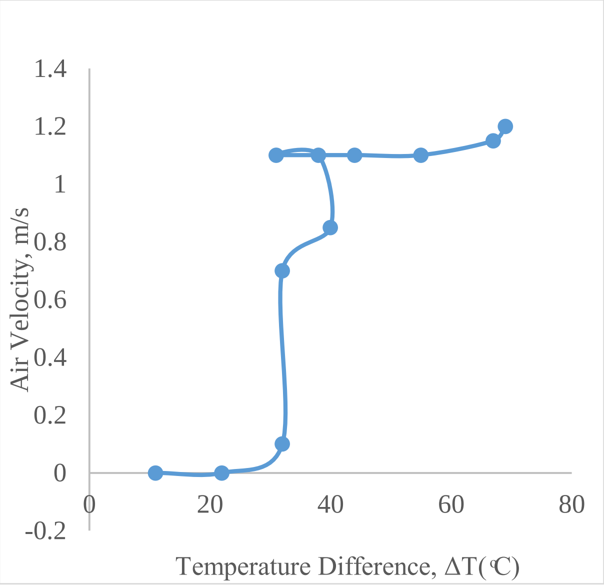

Fig.8: Temperature Difference Vs Air Velocity Graph

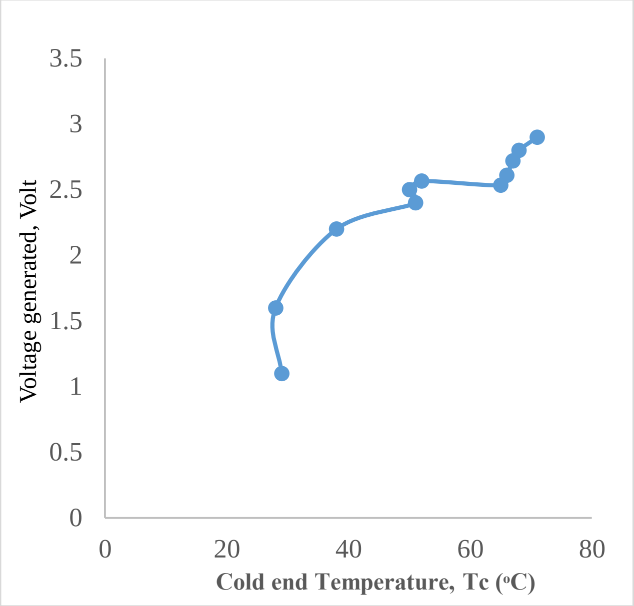

Fig. 9: Cold End Temperature Vs Voltage Graph

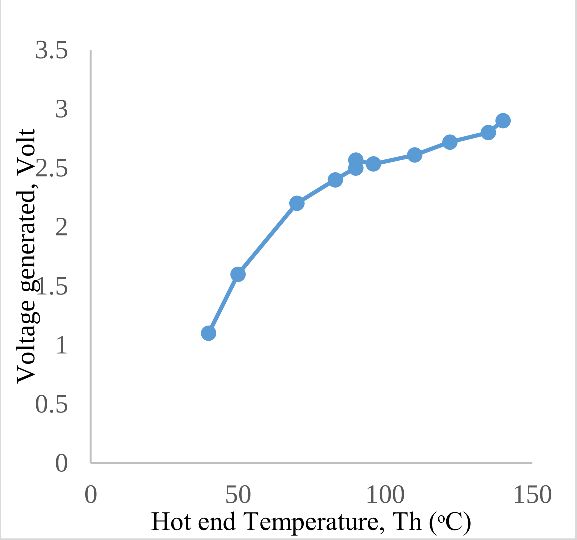

Fig.10: Hot End Temperature Vs Voltage Graph

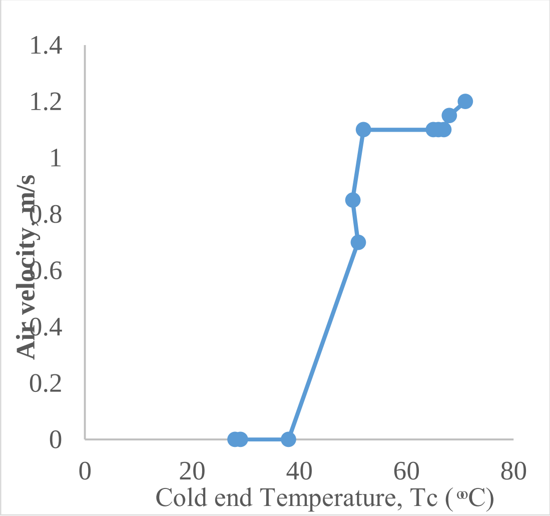

Fig.11: Cold End Temperature Vs Air Velocity Graph

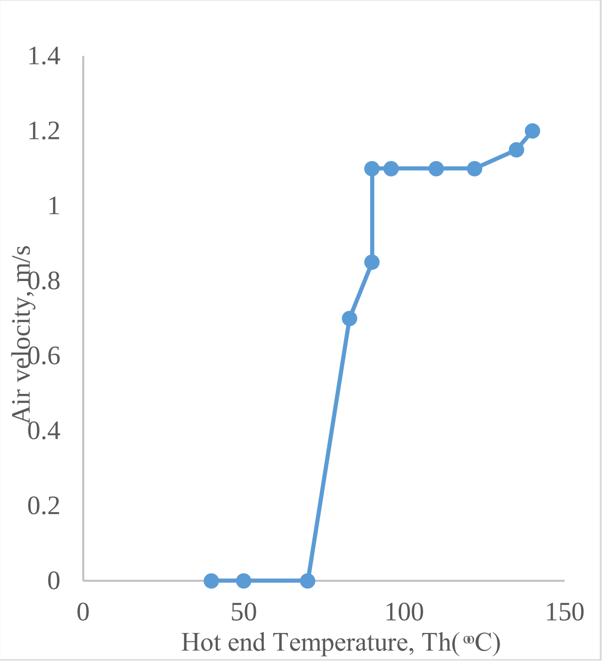

Fig.12: Hot End Temperature Vs Air Velocity Graph

6. CONCLUSION

This device makes it feasible to use only a single candle to provide electricity to operate a fan along with the natural light of candle. If we simply light a candle in a closed room for a long time, the temperature of the room increases. In that case thermoelectric generator curtails the surrounding temperature by relinquishing only a small fraction of heat. The device is a great assist to the rural area where electricity is yet to reach and to the area where load shedding is a big problem. It can be utilized for the production of more electricity, simply by adding some more thermopile and connecting these modules in series. Thermoelectric generator can be used for both domestic and industrial purpose, though modification is necessary for these kind of usages.

7. ACKOWLEDGEMENT

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9. NOMENCLATURE

Symbol	Meaning	Unit
r_D	Total resistance of the device	(Ω)
R_{max}	Maximum Resistance	(Ω)
η_{max}	Maximum Efficiency	Dimension less
$T_{H\ Ave}$	Average temperatures at the hot junction	(K)
$T_{C\ Ave}$	Average temperatures at the cold junction	(K)
T_{ave}	Average of $T_{H\ Ave}$ and $T_{C\ Ave}$	(K)
K_{Eff}	The effective conductivity of the structure	(S/m)
A_{Eff}	The effective Seebeck coefficient	(V/K)