Demonstration of Thermoelectric Glass

Wolf Fruh and Mohamed Al Musleh
Heriot Watt University Engineering and Physical Sciences, Edinburgh, UK
Email: {w.g.fruh, m.al-musleh}@hw.ac.uk

***Abstract*—This paper investigate the feasibility of embedding thermoelectric generator modules within buildings external glass in places where high temperature difference is present between indoor and outdoor, such as areas with extreme hot or extreme cold weather, these modules will work as small individual electrical generators, which then get electrically connected in parallel or series depending on the required voltage, and/or current, the electricity generated can then be used as any other renewable source. This paper describes a prototype design, build, test, and the actual results while testing during the hot summer of Dubai, UAE, where exterior temperature was in the range of 40s C^o while indoor temperature in the range of 20s C^o, then discuss the challenges involved in the setup, and its feasibility in this part of the world.**

***Index Terms*—thermoelectricity, renewable energy, Seebeck effect, Peltier effect**

I. Introduction

With the increasing demand on energy over the globe, the introduction and development of green polices, and the requirements of carbon footprint reduction, there is need for new, emission free, sustainable, energy source, at least to satisfy a small fraction of the total energy supply, this will contribute to the reduction of dependence on fossil fuels, and add to the global energy mix.

Thermoelectricity is promising source of renewable energy, limitations are there with respect to the overhaul efficiency and its dependence on high temperature differences, however, the recent developments on both materials manufacturing technologies, and the processes of manufacturing such as micro structures, nano technology, 3D printing opened new doors for such old concepts to be studied again, in order to produce more efficient, and more practical applications with less cost, which eventually helps in commercializing them.

It is forecasted that interest is going to continuously rise in thermoelectricity, and its applications to reach a market of $750 Millions by 2022. [1]

This paper focuses on the electricity generation applications of thermoelectricity, in which the modules are known as thermoelectric generator (TEG).

II. Thermoelectricity

Thermoelectricity is the conversion of heat to electricity and vice versa, it was reported during 1821 for the first time by Thomas Seebeck where he found heating one side of a junction made of two different metals produces a magnetic field which deflects a compass placed nearby, refer to Fig. 1 below. [2], later it was discovered that magnetic field was due to electrical current flow.

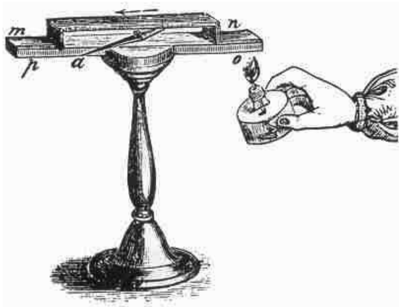

Figure 1. Seebeck experiment setup. [2]

From that time there was many enhancements and developments to the understanding of that phenomenon, modeling it, and the technologies involved in manufacturing such devises, and applications during the mid of the 1950s semiconductors were introduced, and got involved in thermoelectricity, farther developments affected the thermoelectricity generation like other industries, that period witnessed the first commercial thermoelectric generator shown in Fig. 2 below where a kerosene burning lamp was the heat source, and a radio was the load. [2]-[4]

Figure 2. Early commercial TEG. [3]

From that time the development of such devices had some fluctuations, due to feasibility, practicality, and efficiency limitations, during the recent few years a lot of research was going on getting benefit from new material developments, and manufacturing technologies, many commercial products were introduced to the market, new applications are being introduced every now and then, all this seems promising, Fig. 3 shows one of the recent commercial products, portable Thermoelectric generator

Manuscript received January 4, 2015; revised September 23, 2015.

doi: 10.18178/ijoee.3.4.248-251

designed to be used during emergency situation, camping, and in rural areas where TEG uses biomass as fuel to cook and charge gadgets. [5]-[7]

Figure 3. BioLite stove. [5]

Due to the advantages of TEGs of quiet electricity, no moving parts and no working fluid, they were used for long time to generate electricity for a variety of applications, such as industrial components, military equipments, domestic applications, and space missions, the most important unmanned mission nowadays mars Curiosity is powered by some sort of high tech Thermoelectric generator, which is considered the most sophisticated up to date, it uses plutonium to produce heat as energy source, and TEG modules to generate electricity for years to come. [8], [9]

III. HOW TEGS WORK

At the early beginning TEGs used a junction of two different metals to produce current, nowadays they are based on junction of semiconductors of different type based on the application and the operating temperature range, the TEG produce electricity from heat flow through a heat gradient, as the heat flow charged carriers within the semiconductor material flow with it, by connecting semiconductors in series a voltage is produced which can be supplied to a load, in order to get a sensible voltage, more junctions are connected in series to make a TEG. [6]-[8]

The behavior of thermoelectric material can be described using one or a combination of the following effects: Seebeck, Peltier, and Thomson effects. TEGs are considered as heat engines in which the efficacy is limited by Carnot efficiency, this paper does not discuss the mathematical model of the TEGs. [8], [10], [11]

IV. THE EXPERIMENTAL SETUP

The setup was basically a sandwich of two layers of 4mm thick glass with TEGs in between, thin layer of thermal paste was used at each side of the TEG, the thermal paste layer thickness was limited to 0.2mm using a plastic gasket, two types of TEGs were used; the first one is a module designed to be generator from Marlow Industries which is a Single-Stage Thermoelectric Module (RC12-2.5) as shown in Fig. 4, while the other one was a general purpose module from HB Corporation (TEC1-12710).

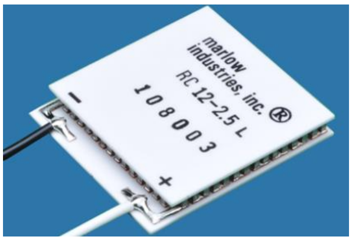

Figure 4. The generator module RC12-2.5. [12]

Two types of modules were used in order to study whether designing the module based on the actual application has noticeable effect on the performance or not, two of each of the above mentioned modules were used in order to reduce the error which might result of using only one, the four modules were aligned horizontally with 10cm spacing between them. Thermocouples were installed at the different sides of the glass panels' i.e. external, internal and intermediate (Both sides of the air gap) where the TEGs get into contact with the glass, thermal conductive paste and thermal tape were used to fix the thermocouples in place, the experimental setup was then installed instead of one of the actual windows of the electronics laboratory of Heriot Watt University Dubai Campus which was facing 145^{o} South-East with all the electrical output wires from the TEGs, and thermocouples wires to indoor, the experimental setup is shown if Fig. 5 below.

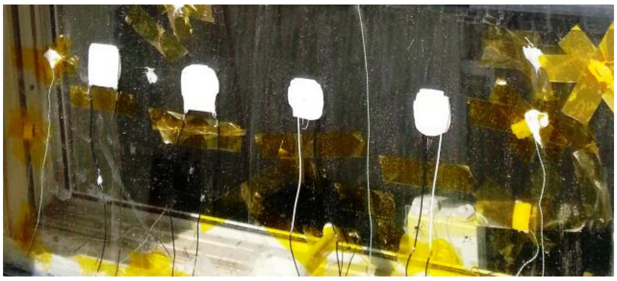

Figure 5. Photo of the experimental setup as it looks from the outdoor.

V. RESULTS

The experiment took place during the hot summer of Dubai, and during one of the hottest months "August-2014", results produced from this experiment are divided into two parts, thermal results which include the thermocouples logged data, and electrical results which includes the voltage, current, and power output from the different TEGs.

A. Temperature Data

Data logger (Pico Log USB-8) was used to log temperature values from all the thermocouples every minute for 24 hours period.

Then the temperatures of the two sides of the double glazing air gab was extracted, this temperature difference is the one responsible for the power generation in the TEGs, it is the most important difference for this experiment, both air gab sides temperatures is shown in the graph below in Fig. 6 where Blue refers for the outdoor side, and Red for the indoor side.

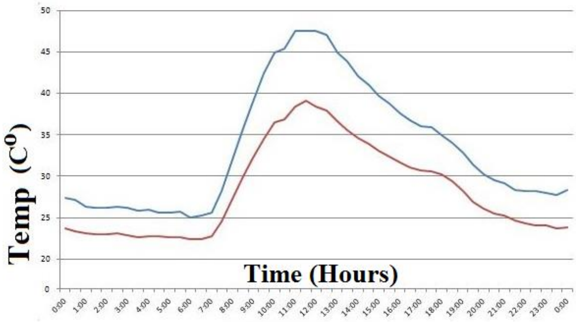

Figure 6. Logged temperature values from the two sides of the double glazing air-gab for 24 hours.

But the actual difference is what force a power generation in the TEGs regardless the temperature values, so a graph shows the actual difference (Tout-Tin) was produced as shown in Fig. 7, it was found that even during night there is a noticeable temperature difference of about 6 C°, while this value doubles during the day to more than 12C°.

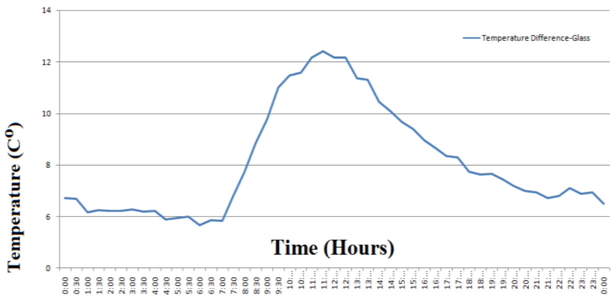

Figure 7. Temperature difference applied to the TEGs over 24 hours.

B. Electrical Data

This part covers the logged data of open circuit voltage, loaded voltage, and produced power at optimum load resistance, the electrical voltage was recorded for all the four modules every 30 minutes for 24 hours, the following graph in Fig. 8 shows the generated open circuit voltage of both types of modules Blue is for the generator type, and Red is for the universal module.

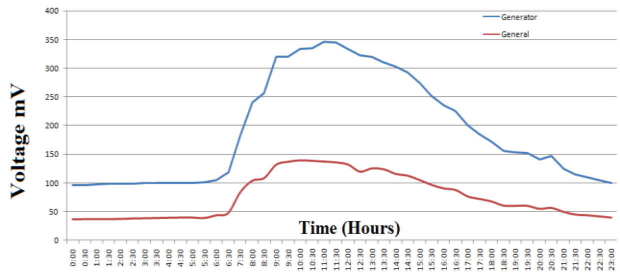

Figure 8. Open circuit voltage of the two model types with respect to time.

A large difference is clear from the graph, during night the universal module generates about 50mV while the generator one produces about double that value to produce around 100mV, this highlight the importance of the design parameters of the module in the first place, and designing modules based on the actual application has a great impact on the device performance, due to that power and load results shall be provided to the generator module.

In order to produce figures of generated power, it's important to test the modules with load, and record the loaded voltage, for this purpose the load selected is a 7 Ohms resistive load, which is matching the load resistance for optimum efficiency from the manufacturer data sheet as shown in Table I below. [12]

TABLE I. TEG MODULE POWER GENERATION PERFORMANCE DATA [12]

Hot Side Temperature (℃)	85	55	35
Cold Side Temperature (℃)	27	27	27
Optimum Efficiency, η (%)	2.53	1.28	0.37
Optimum Power (W)	0.410	0.100	0.008
Optimum Voltage (V)	1.805	0.861	0.243
Load Resistance for Opt η (Ω)	7.95	7.42	7.05
Open Circuit Voltage, VOC (V)	3.16	1.51	0.43
Short Circuit Current (A)	0.53	0.27	0.08
Thermal Resistance (℃/W)	3.58	3.58	3.57

Loading the module decrease the generated voltage as expected, the new generated voltage values with respect to the time of the day is as shown in Fig. 9 below.

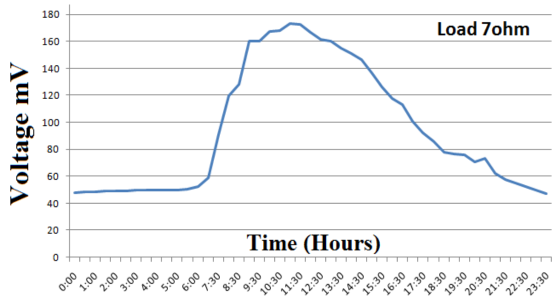

Figure 9. The generated voltage values with respect to time with 7 Ohms load for 24 hours.

As the load resistance is known, and the voltage over the time was measured, it is possible to calculate the actual generated power over the time, using the equation:

$$P = (V^2/R)*(N)\ \mathrm{W/m^2}$$

where P is the power per square meter, V is the generated voltage from one module, R is the load resistance, and N is the number of modules per square meter. In order to get a comparable figure the power per square meter was calculated considering the area of the module, and assuming having a cretin number of modules to cover a complete square meter, the following graph on Fig. 10 shows the calculated power values over the time for 24 hours.

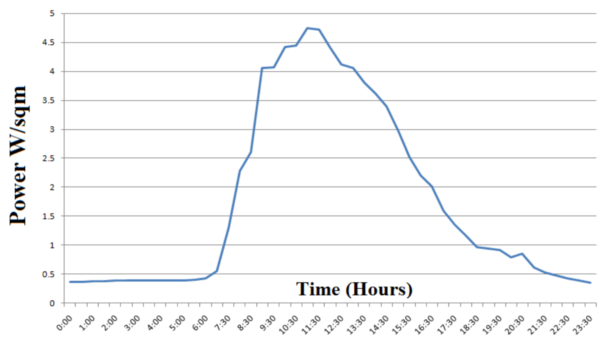

Figure 10. Generated power values over the time for 24 hours.

About 5 watts per square meter was the peak generated power during the test period, it might be considered as minimal, but the most important point at this stage is to show that there is a power generation from this setup, and what is noticeable from the graph is the generation during night of about $0.5W/m^2$ which is about 10% from the peak value.

VI. Side Effects

As expected embedding TEGs in the exterior glass has its effect on the glass characteristic which will reflect on internal space, in this section the effect on glass U value, and the Air Conditioning shall be discussed, the effect on lighting, and glass transparency is not going to be discussed, assuming that TEGs can be produced to be transparent, and/or can be used in windows without effecting the daylight.

A. Effect on Glass U Value

Changing the nature of the double glazing gap has an effect on the overall U value, the thermal resistance of the TEG module is given by the manufacturer to be $3.57C^o/W$ as shown in Table I, from that it is possible to calculate the U value of the 4mm layer of TEG, while a 4mm layer of typical glass has a U value of $5.8W/m^2k$ (Source: Dubai Municipality AC guide). Having a sandwich of two 4mm layers of glass and TEG in the middle has a total U Value of $5.6W/m^2k$. While a typical double glazing panel has a U value of $3.327W/m^2k$ [Source: Dubai Municipality AC guide].

B. Effect on Air Conditioning

This part discuss the effect of the glass U value on the Air conditioning due to the change in the solar gain, in case of the original glass was a single glazing the TEG will reduce the U value from 5.8 to $5.6W/m^2k$ i.e. the solar gain from 555 to $530W/m^2$ which is a slight positive impact.

While if the original glass was double glazing the TEG will increase the U value from about 3.5 to $5.6W/m^2k$ i.e. solar gain will increase from 335 to $530W/m^2$ which is a large negative impact.

For the above figure HAP design software was used assuming the actual glass panel location and orientation.

VII. Conclusion

Utilizing general use commercial TEG modules is not feasible but very much possible for this application, as the temperature difference is present, and available all over the day, however, the low efficiency of the used modules at that low temperature difference is not major, employing the latest technologies is essential for the useful use of TEG in such applications, such as producing a transparent high efficient module using nanotechnology, and employing 3D printing advancements for such applications, farther investigation with different variables is important to produce a final statement on this field.

References

[1] H. Zervos, "Thermoelectric generators: A $750 million market by 2022," *Energy Harvesting Journal*, 2012.

[2] California Institute of Technology. Brief history of thermoelectrics. [Online]. Available: http://thermoelectrics.caltech.edu/thermoelectrics/history.html

[3] The self site. Thermo-electric generators. [Online]. Available: www.douglas-self.com

[4] R. Brink, "Development of miniature personal thermoelectric generator," thesis submitted to Dublin City University, 2004.

[5] Biolite. Biolite camp stove. [Online]. Available: www.biolitestove.com

[6] Y. Zhou, "Energy harvesting using a thermoelectric generator and generic rule-based energy management," thesis submitted to Case Western Reserve University, 2008.

[7] E. Koukharenko, *et al.*, "Towards a nanostructured thermoelectric generator using ion-track lithography," *Journal of Micromechanics and Microengineering*, vol. 18, no. 10, 2008.

[8] I. Sateikis, R. Ambrulevicius, and S. Lynikiene, "Investigations of a micropower thermoelectric generator operating at a low temperature difference," *Elektronika Ir Elektrotechnika*, vol. 106, no. 10, pp. 113-116, 2010.

[9] Multi Mission Radioisotope Thermoelectric Generator, NASA facts, National Aeronautics and Space Administration, October 2013.

[10] G. J. Snyder. (2008). Small thermoelectric generators. *The Electrochemical Society Interface*. [Online]. Available: www.electrochem.org

[11] K. W. Engelke, "Novel thermoelectric generator for stationary power waste heat recovery," thesis submitted to Montana State University, 2010.

[12] *Product Technical Datasheet RC12-2.5*, Marlow Industries Inc.

Mohamed Al Musleh was born in Baghdad, Iraq in 1982. He graduated from Nahrain University, Iraq in 2003 with B.Sc. in electronics and communications engineering, and from Heriot Watt University, UK in 2014 with Master of Energy. He currently works as engineering laboratories' in-charge for Heriot Watt University - Dubai Campus, Dubai, United Arab Emirates.