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Citation for published version:
Al Musleh, M, Topriska, EV & Jenkins, DP 2017, 'Thermoelectric Modules Testing for Sustainable Buildings Applications', Paper presented at ISES Solar World Congress 2017, Abu Dhabi, United Arab Emirates, 29/10/17 - 2/11/17. https://doi.org/10.18086/swc.2017.35.01

Digital Object Identifier (DOI):
10.18086/swc.2017.35.01

Link:
Link to publication record in Heriot-Watt Research Portal

Document Version:
Publisher's PDF, also known as Version of record

Thermoelectric Modules Testing for Sustainable Buildings Applications

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Abstract

In order for buildings to be sustainable from an operational point of view, the basics are to save energy and maximize efficiency. This is only possible with the availability and around the clock collection of real-time data for energy use. These data can be collected via sensors installed all around the building which then feed back to the building management system or to the occupants. Transmitting data and powering those sensors remains a challenge. With today's wireless technologies and microcontrollers, transmitting is well developed, however, sensor power sources are still in the developing stage. This work describes the testing of Thermoelectric Generators (TEG) at the ultra-low temperature difference level (5°C and below). TEGs are used as energy harvesters that make use of the temperature difference within the building energy systems, to power wireless sensors, thus eliminating the need of a battery and the maintenance/operation costs that come with it.

Keywords: Smart Buildings, Sustainable Buildings, Thermoelectric, Wireless Sensing, Energy-Harvesting.

1. Introduction

Thermoelectricity is the direct conversion of a temperature gradient to electricity and vice versa. TEG modules are made of multiple Thermoelectric (TE) blocks connected electrically in series and thermally in parallel, to maximize power generation. This effect is known as Seebeck effect, where the generated electricity depends on the temperature difference between the two sides of the TEG module. The Seebeck coefficient of the blocks is used, as shown in the relationship of Equation 1:

$$E_{emf} = S\,\Delta T \qquad \text{(eq. 1)}$$

Where E_{emf} represents the generated electromotive force, S is the Seebeck coefficient which is material dependent, and ΔT is the temperature gradient difference (Ahıska and Mamur 2014). Figure 1 shows a schematic diagram of a typical TEG.

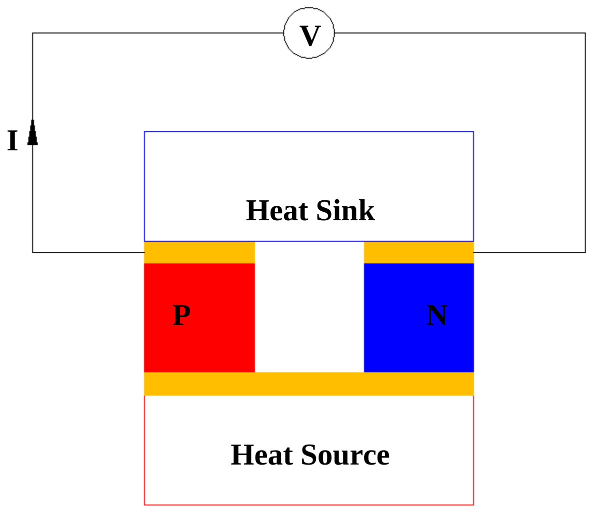
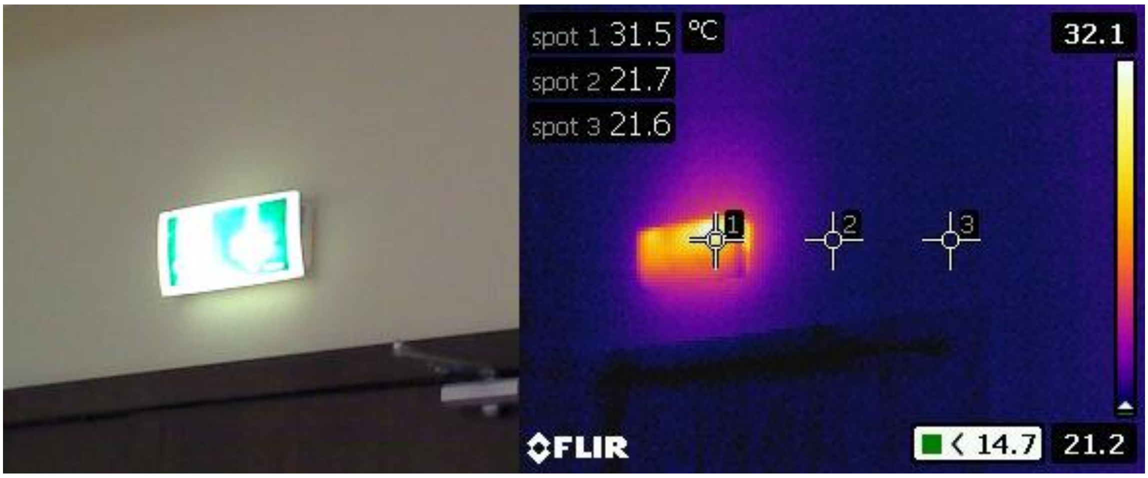


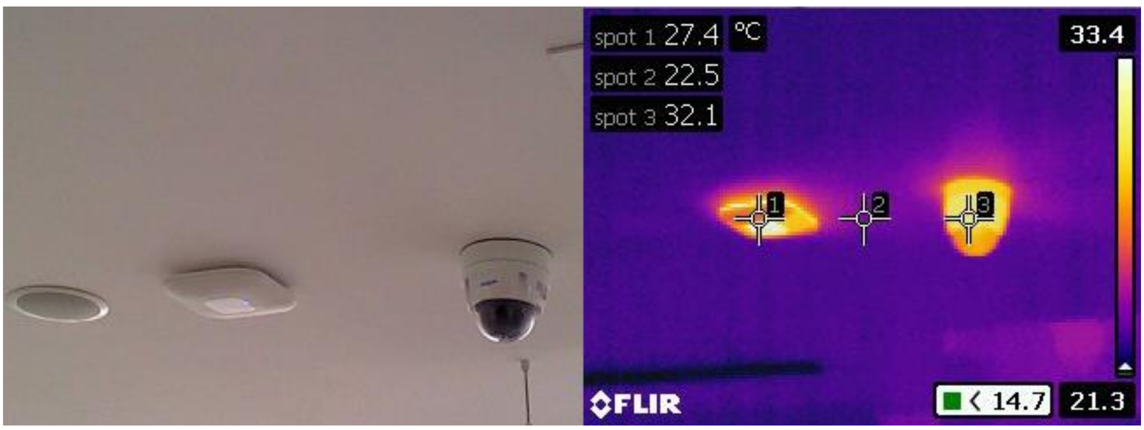
Figure 1 schematic diagram of a typical TEG.

doi:10.18086/swc.2017.35.01 Available at http://proceedings.ises.org

To run building resources and energy systems at a more sustainable level, systems feedback is required. This feedback is achieved using a network of sensors distributed around the building. Such sensors can measure building temperature, indoor light intensity, air quality, etc. and are either wired or wireless. Wireless sensors are often referred to as wireless sensor network (WSN). WSN could use batteries as a power source but the maintenance stays as a challenge from an operational point of view. Using ambient energy harvesters to power such sensors is a feasible option and TEGs are one of the techniques used for energy harvesting to power sensors. However, most of the commercially available TEG based energy harvesters require high-temperature difference, which is targeting industrial applications. Within the built environment low-temperature difference applications are common, if heating and hot-water systems are excluded. Typical examples of built environment applications are the temperature difference of an exterior wall surface, of a cold air duct with respect to the surroundings temperature, the heat emitted from a light fixture, the heat emitted from information technology (IT) equipment such as wireless routers, or security equipment such as surveillance cameras. Figure 2a shows a thermal image highlighting the heat emission from lighting fixture, where measured temperature difference is about 10ºC. Figure 2b shows a thermal image of two different IT and security equipment, a wireless communication router and surveillance camera. The wireless router temperature is measured to be about 5ºC above surroundings, while the surveillance camera measured at 9.6ºC above surroundings. TEG used as power source for WSN has an increasing research interest but researchers in the field often face difficulties of the availability of TEG performance test data at very low-temperature difference. Therefore, the aim of this study is to provide such performance data and ultimately develop a universal test setup for TEG at this temperature range. (Salerno 2010) (Snyder 2008) (Moczygemba 2015) (Huang et al. 2011) (He et al. 2015) (Wang et al. 2013) (Wellington City Council 2017).



(a)



(b)

Figure 2 Thermal Image of (a) a lighting fixture and (b) IT equipment

2. Experimental Setup

A TG12-4 TEG module was acquired for this test, which is a Marlow Industries Inc. product. This is designed as a universal TEG, rated at 4 watts at a temperature difference of 180°C (Marlow Industries). The experimental setup consisted of a high precision temperature controlled hotplate, which acted as a heat source. The hot side of the TEG was placed on top of the hot plate using thermal paste to maximize heat transfer and a K-type thermocouple was placed between the TEG and the hotplate to measure the hot side temperature. On the other side of the TEG a heat sink was used to dissipate the heat and an electric fan was attached to the heat sink to ensure cooling via forced convection. Another K-type thermocouple was placed between the TEG and the heat sink to measure the cold side temperature. Schematic diagram of the test setup is shown in Figure 3. Both thermocouples were connected to a temperature data logger shown at the left of the test setup photo in Figure 4. A digital multimeter was used to measure the generated open-circuit voltage (V_{OC}) and short-circuit current (I_{SC}) of the TEG. The complete experimental setup is shown in Figure 3 below.

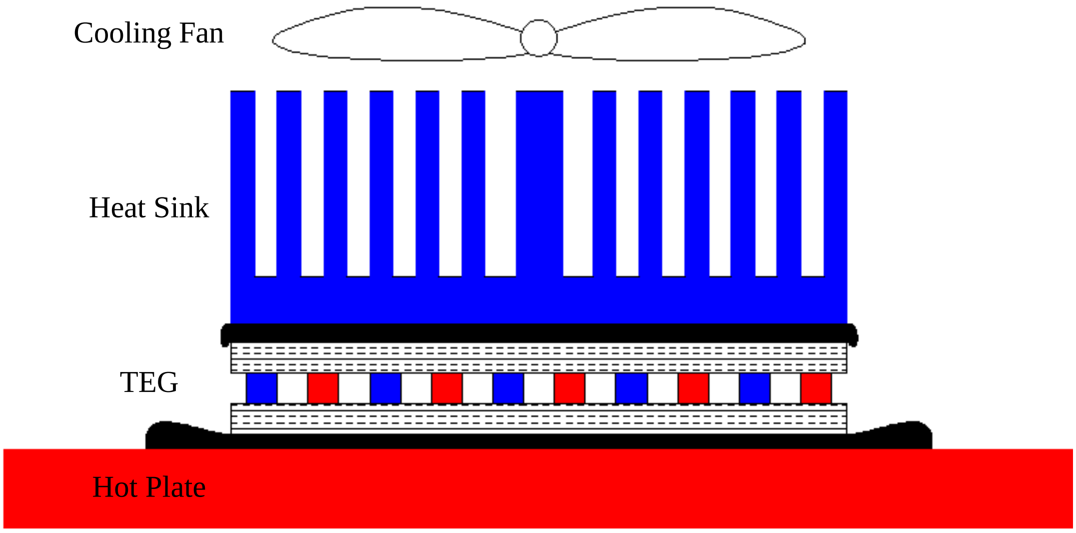


Figure 3 schematic diagram of the experimental setup.

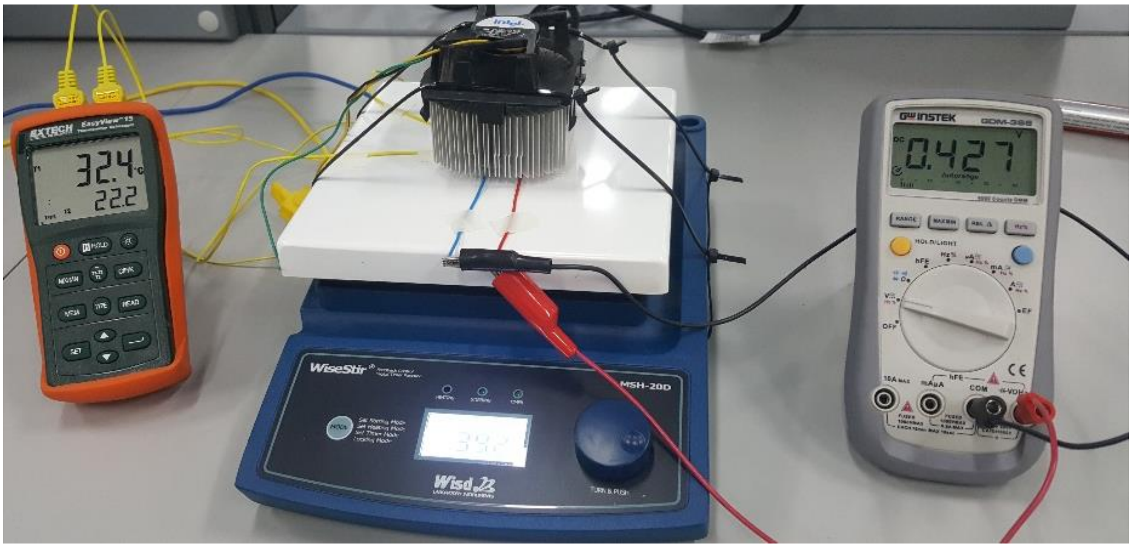


Figure 4 The complete setup of the experiment showing the temperature data logger at left, the hotplate with the TEG mounted on it below the heat sink, and the multimeter at the right.

As cooling was performed using an air-cooled heat sink, it was rather complicated to estimate the heat dissipation from the TEG. To further investigate the heat flux through the TEG and device efficiency it was found appropriate to use water blocks on both sides of the TEG. The all copper water block is shown in Figure 5 were sourced out for this test.

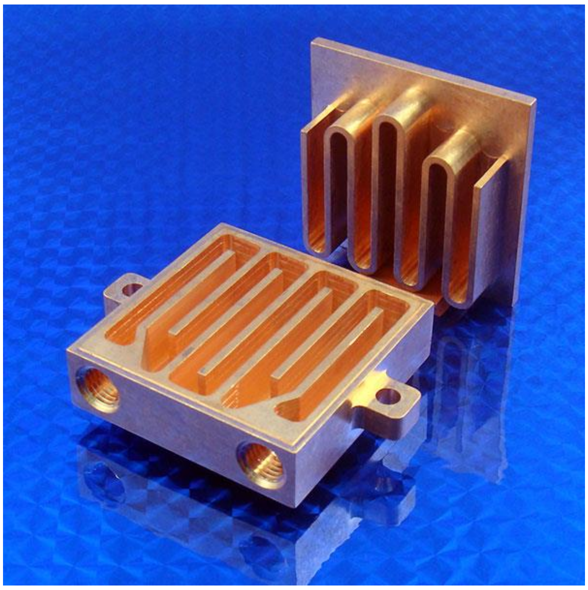


Figure 5 The all copper water block which was sourced out for the test.
(Image source: customthermoelectric.com)

One block for the hot water cycle attached to the TEG hot side and the other for the cooling water cycle on the cold side. 3D designed and printed holders were used for holding the water block in place and to make sure that TEG is always in the center. The complete setup of the TEG installed on the water block is shown in Figure 6.

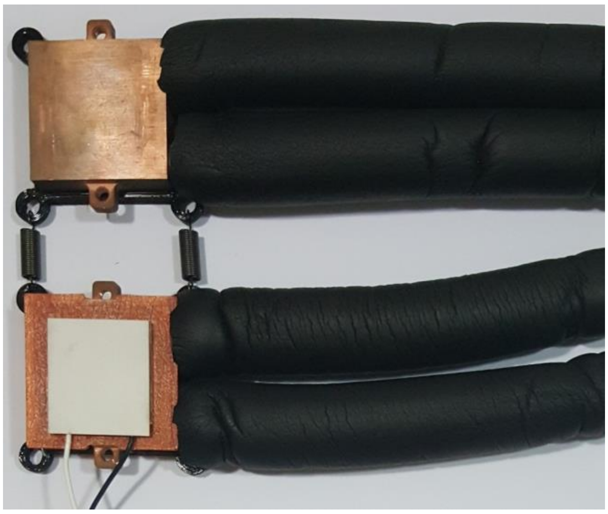


Figure 6 the TEG installed on one side of the water blocks.

The test setup is planned to be attached to a heat exchanger supply unit. The unit will supply to two separate water cycles, one is hot and the other is cold. Both cycles have inlet and outlet temperature recorders along with recording the water flow rate.

3. Experimental Results

The temperature of the hotplate was increased in steps of 0.5°C above the room temperature, allowing enough time for both sides of the TEG to reach a steady state temperature. Both V_{OC} and I_{SC} were measured at each step and the recorded values are shown in Figure 7 below.

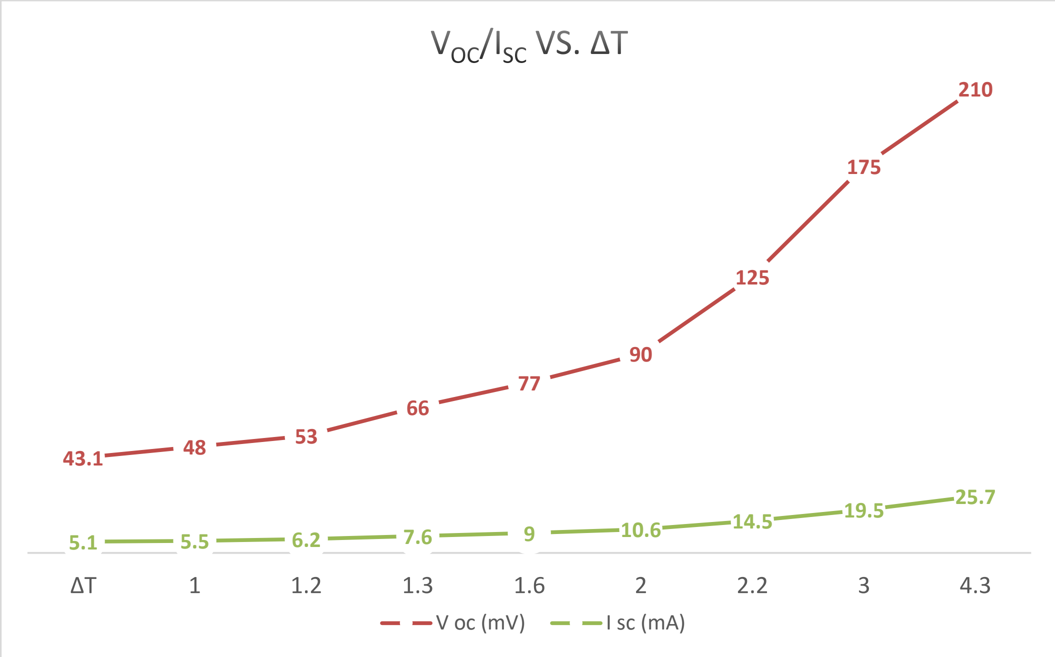


Figure 7 Open-circuit voltage (V_{OC}) and short-circuit current (I_{SC}) vs. temperature difference (ΔT)
Using hot plate and air cooled heat sink.

The temperature deference covered a small range of 1-5 C°, which is considered as very low-temperature difference in TEG applications. This range was investigated being the most commonly available range within buildings. The open-circuit voltage and short-circuit current were observed to be directly proportional to the temperature difference, and closely following the increase in the TEG hot side temperature as shown in Figure 7. Using the measured values and using Equation 1, the Seebeck coefficient was calculated, to an average of 40.72 mV/C° over the test range.

A similar test was performed using the heat exchanger unit and the water blocks. Both cycles were set to a water flow of 2 liters per minute. An important observation using this setup is that precise control can be applied to the temperature difference (ΔT). ΔT across the TEG was increased from 0°C up to 7°C. V_{OC} and I_{SC} were measured at various temperature differences as shown in Figure 8.

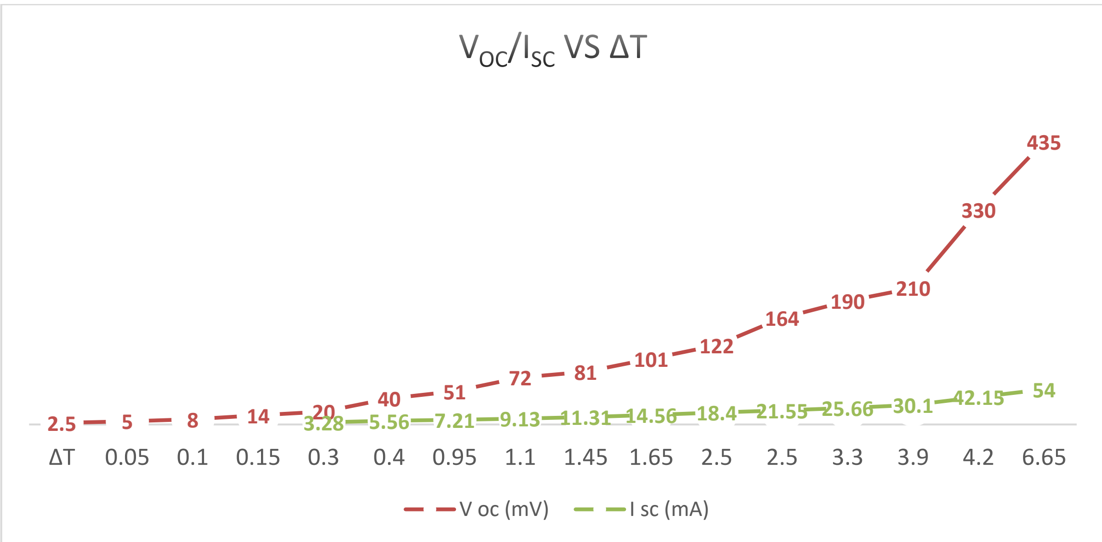


Figure 8 Open-circuit voltage (V_{OC}) and short-circuit current (I_{SC}) vs. temperature difference (ΔT)
Using heat exchanger unit and water blocks.

Comparing the two sets of results highlighted much higher power generation with the water blocks setup at similar

ΔT. This variation requires further investigation, but could be due to one or more of the following:

- Nonuniform cooling of the heat sink in the air-cooled experiment.
- Nonuniform heating by the hot plate.
- The better thermal conductivity of the all copper water blocks.
- Improved heat dissipation from the TEG cold side with water blocks.
- The elimination of thermocouples between the TEG and hot/cool sides in the water blocks experiment.

4. Conclusions and Future Recommendations

The experimental results highlight a good indication of the TEG energy harvesting capabilities at the very low-temperature difference. It was difficult to estimate the overall device efficiency due to the fact that the first setup used an air cooled heat sink. Closed water cycle setup to cool the TEG was developed and tested. The continuous monitoring of the inlet temperature, the outlet temperature, and the flow rate will allow more accurate estimation of the heat dissipation and overall efficiency. The V_{OC} and I_{SC} are used as an indication for power output data. For more accurate electrical generation characterization connecting a load or I-V tracer is essential. Testing of TEG electrical output using I-V tracer is planned for future research and publication. I-V tracer will provide under load test for accurate load current and voltage. In addition to that programable I-V tracer simulate dynamic load setup which continuously adjust the virtual load impedance to match TEG internal impedance. Impedance matching is essential to track the maximum power point of generated power. It was clearly noted that the TEG performance was much better using the water blocks setup. Further investigation is required to identify the reasons. Possible reasons are that the pure copper water blocks offer enhanced uniform heat transfer on both sides and the continuous water flow continuously removing large amounts of heat from the cold side compared to the air-cooled heat sink of the first test. Current tests were run using 30mmx30mm TEG, while the second test used 40mmx40mm water block, a future test is planned using a purpose made 40mmx40mm TEG designed for extra low temperature applications. The matching size of 40mmx40mm will minimize error sources when it comes to accurately measure thermal energy or input power to the TEG for accurate efficiency evaluation. A computer model is under development using COMSOL Multiphysics, the model will use the experimental data as a basis of calibration in order to develop accurate model to be used for virtual testing if TEGs.

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