Energy Conservation: Harnessing Excess Thermal Energy and Converting to Electricity by Use of the Thermoelectric Effect

Katie Shideler, Dr. Susan Y. Lehman, Dr. R. Drew. Pasteur
The College of Wooster

Abstract

The dynamics of thermoelectric energy were studied throughout this research. A device comprised of thermoelectric generators (TEGs) was placed onto various heat sources across the College of Wooster campus. The TEGs could harness the wasted heat given off by the heat source and convert the temperature gradient into a usable voltage. The energy recycled from our prototype device proved to be insignificant. The cost of making a device to power everyday tasks was far greater than the cost of electricity. Balancing the cost of the device with the cost of electricity per year when both are supplying equal amounts of energy was determined 30 years minimum. Improvements must be made to our model to increase the efficiency and energy recycled. We must increase the current generated by the TEGs or add to the number of operating TEGs on our device to make reasonable adjustments to recycle a significant amount of energy. With these adjustments, thermoelectric materials have the potential to greatly increase energy conservation on the college campus.

Introduction

Energy Conservation: the prevention of the wasteful use of energy.

- Example: harness energy wasted in one form and convert to another form.
- Convert excess energy into electricity.
- Heat is an unintended biproduct of various electrical and mechanical systems.
- Process of converting thermal energy to electricity is what is known as the thermoelectric effect.
- A thermoelectric generator (TEG) is a module which uses a temperature gradient to generate a voltage via the thermoelectric effect.
- The voltage is generated by charge carriers moving within the TEG.

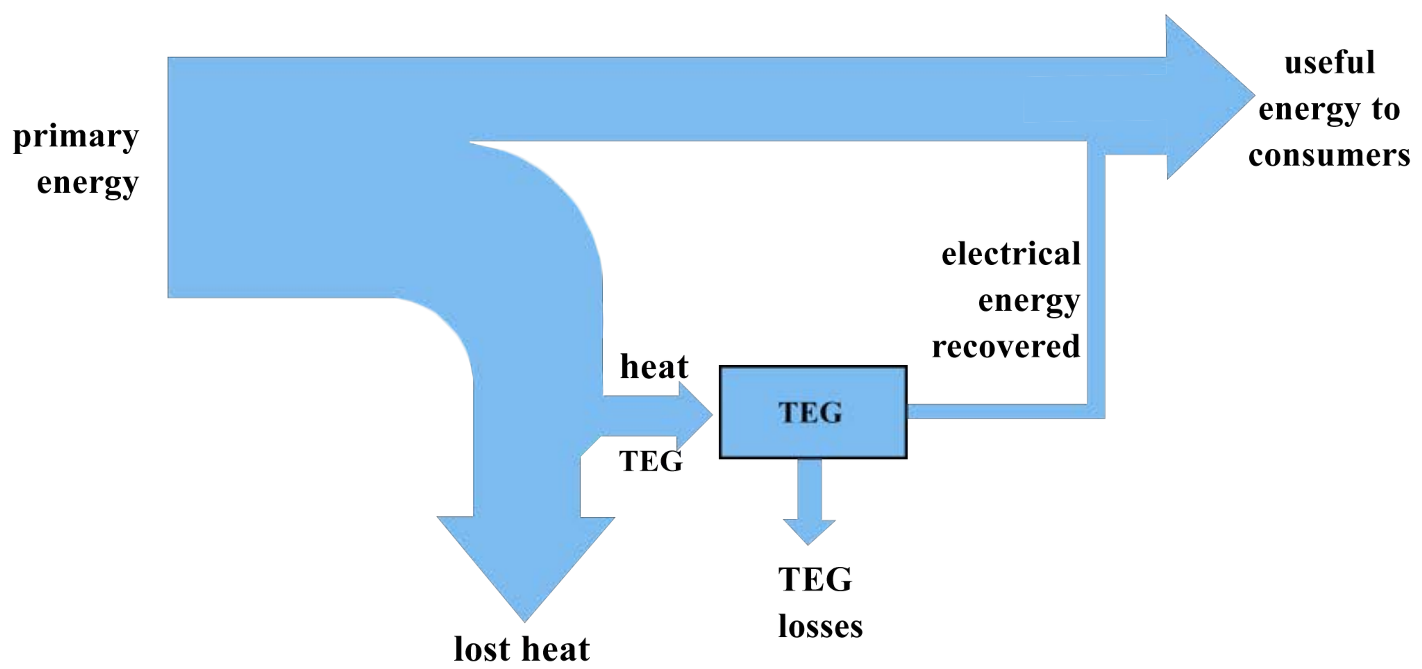

Figure 1. The harnessing of wasted heat and reusing it in the form of electrical energy. The conversion of energy is done by a thermoelectric generator (TEG).

Overview

- An apparatus consisting of TEGs is built to study how much thermal energy can be recycled.
- Apparatus used to investigate various locations on the campus of the College of Wooster.

The Apparatus

- Device consists of three main parts: the thermoelectric generators, the plastic base, and the data acquisition device (DAQ).
- Four TEGs embedded in plastic base, connected electrically in series.
- Device has one thermistors at each surface of the TEGs to measure temperature on each TEG plate.
- TEGs and thermistors inserted into DAQ where measurements are digitized to be read in LABView.
- Images of the device are seen in Fig. 2 and Fig. 3.

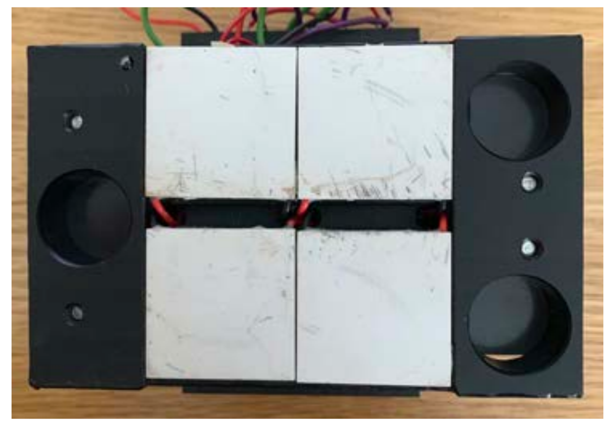

Figure 2. Top view of apparatus showing the four TEGs embedded in the plastic base.

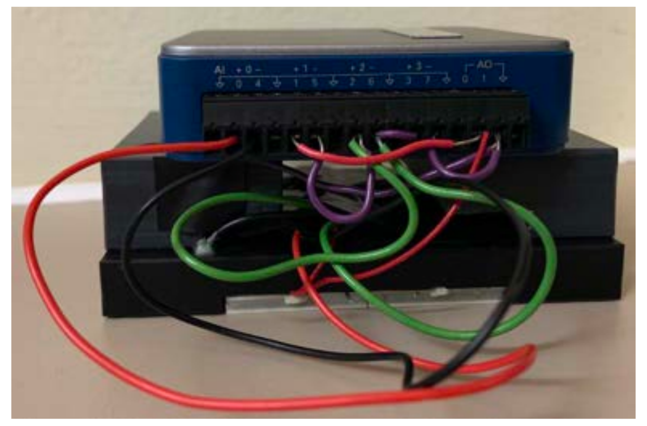

Figure 3. Side view of apparatus showing the wiring into the DAQ.

Procedure

- Device is placed onto various surfaces in which substantial amounts of heat are lost.
- Locations include a clothes dryer, an oven, a toaster, a toaster oven, a window, a charging laptop, the school's steam lines and an electric motor.
- Measurements taken and recorded include the maximum voltage produced by the TEGs, the temperature difference between the TEG plates, and the duration the maximum voltage is maintained.
- Values recorded and shown in Table 1.

Table 1. Measurements made by the apparatus. The asterisks * implies the run ended before the voltage decreased from the maximum value.

Data Collection Location	V_{max} (V)	ΔT_{max} (°C)	Time (s)
Clothes Dryer Window	0.97	2.0	11.9
Clothes Dryer Window (2nd Trial)	0.96	1.1	8.3
Clothes Dryer Vent	0.30	--	*>28.4
Oven	0.67	1.3	12.4
Toaster	1.44	7.7	17.6
Toaster Oven	4.50	13.1	15.7
Window	-0.54	-2.9	8.7
Charging Laptop	0.42	1.3	9.7
Galpin Steam Line	1.05	4.3	*>64.8
Scheide Steam Line	0.76	1.9	*>35.0
Holden Electric Motor	0.95	4.6	13.5
Feed Water to Campus	1.29	4.2	*>32.4

Results

- Goal is to calculate how much energy can be recycled and power generated with our device.
- Need to relate energy and power to our measured maximum voltage and time the voltage is maintained.
- $P = IV$
- With voltage, we need current I to calculate power P.
- In thermoelectric materials, it is common that some output voltage is lost at large currents – known as voltage droop.
- Need to experimentally measure current generated by TEGs.
- We measure current with various resistors connected to our TEGs and calculate which current generates maximum power.
- The relationship between output voltage and current is linear and the relationship between power and current is parabolic.
- The data is plotted in Fig. 4 where the maximum power shown occurring at 66 mA of current.
- With current, we can now calculate potentially generated power.
- $E = Pt$
- Energy that can be recycled is calculated .

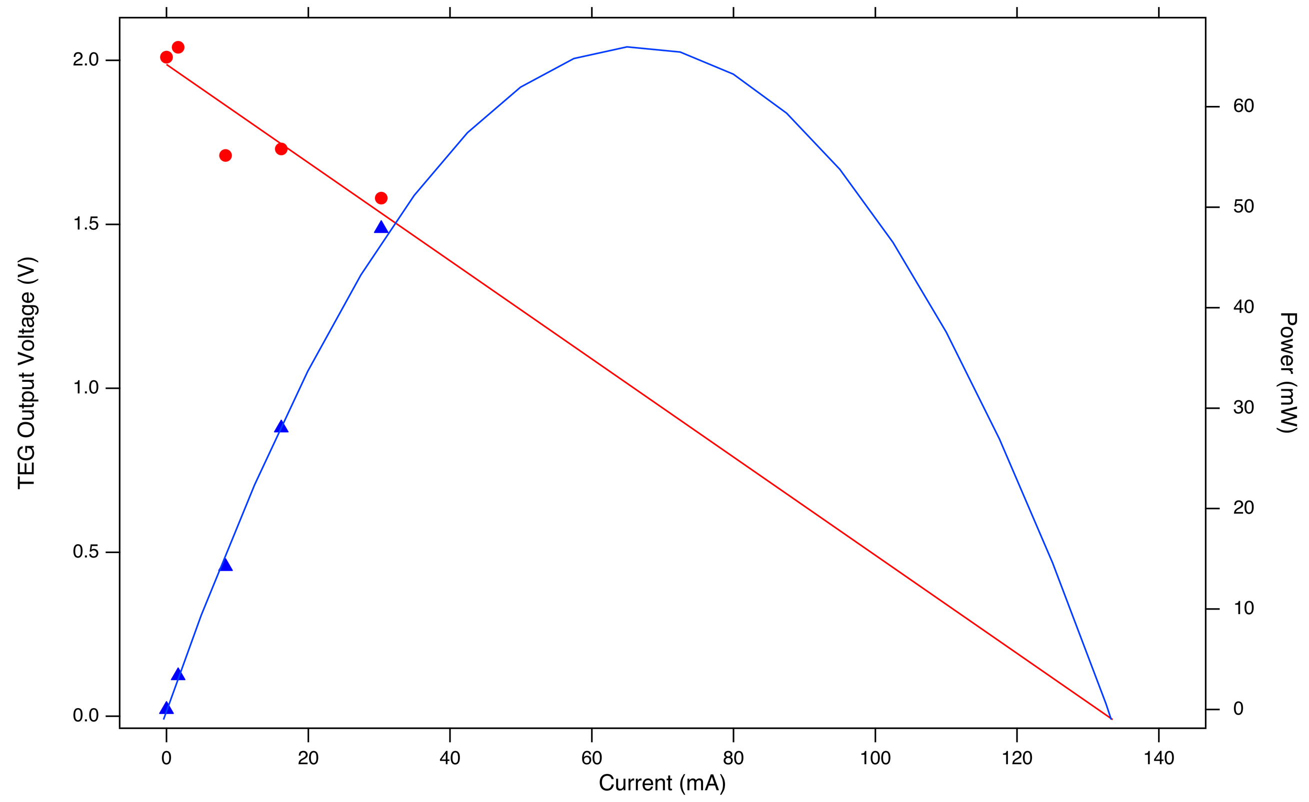

Figure 4. Output voltage vs current is plotted in red and power vs current is plotted in blue. The maximum power occurs at a current of 66 mA.

- Power and energy recycled is calculated for each location using a current of 66 mA.
- The average power generated was 0.077 W and the average energy recycled was 0.45 mWh.
- Improvements need to be made to the device in order to obtain more realistic numbers to be able to power everyday appliances.
- Improvements could include adding to the number of TEGs on the device to generate a substantial amount of power.
- Improvements could also include improving the thermoelectric device to tolerate generating a higher currents without significant loss of output voltage.
- The number of TEGs required to power various devices (using typical power values for those items) is calculated both for our current of 0.066 A and a higher value of 1.5 A.
- Results of these calculations are reported in Table 2.

Table 2. The number of modules needed to power various devices of certain powers and the surface area those modules would occupy is calculated..

Device	Power	Current	Voltage per TEG (V)	# of Modules	Area (cm²)
Cell Phone	5 W	66 mA	0.30	253	2,300
			1.13	67	600
Laptop	29 W	66 mA	0.30	1,464	13,200
			1.13	391	3,500
Range Hood	185 W	66 mA	0.30	9,343	84,100
			1.13	2,492	22,400
		1.5 A	0.30	411	3,700
			1.13	109	1,000

Cost-Benefit Analysis

- The number of TEGs needed to power every day objects is substantial.
- The surface area this amount of TEGs is large, and the cost of this number of TEGs is unfavorable from a monetary perspective.
- Thermoelectric energy is uncommon when electricity is a cheaper and more efficient alternative.
- A comparison is done between the price of buying TEGs and paying for electricity when both are suppling the same amount of power.
- The years required to equate the cost of the TEG modules with the cost of electricity is calculated in Table 3.

Table 3. The cost-benefit analysis between the cost of the modules compared to paying for electricity. The cost of the modules is calculated as well as the years to equate that cost with the cost of paying for electricity yearly.

Device	Power	Electricity Cost ($/year)	Typical Time use	Current	# of Modules	Cost	Years
LED Lights	8 W	$2.40	8 hrs/day	66 mA	404	$1,616	673
				1.5 A	18	$71	30
Range Hood	185 W	$23.40	10 hrs/week	66 mA	9,343	$37,374	1,597
				1.5 A	411	$1,644	70

Conclusions

- Minimal power and energy was recycled using our prototype device.
- Improvements such as a higher generated current or increasing the number of TEGs used are needed for substantial results.
- Number of TEGs needed to power studied appliances is immense.
- The cost and surface area of the large number of modules is unfavorable when compared to the cost and efficiency of electricity.
- Number of years required to equate the cost of the device with the cost of paying for electricity is large (30 years minimum for LED lights).
- These numbers and timelines show why there are millions of washers and dryers in the world, and very few use thermoelectric energy.

Acknowledgements

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