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A Comparative Analysis of Energy Balance of Thermoelectric Power Generation vs. Fiberglass Insulation

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BY

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Statement of Purpose and Rationale

With the ever growing need for electrical energy and global warming, the need to find other ways to generate electricity is urgently needed. With the need to produce electricity without the need for additional non-renewable fuels, thermoelectric has the capability to provide power without the need for additional non-renewable fuels. The global warming crisis is an ever growing concern, and a green electrical production is needed now.

Thermoelectrical generation is an area of electrical energy production that has been discussed as a means to fill the gap of green energy production. Thermoelectrical generation is a non-mechanical way to generate electrical power from a heat by-product. With this area of electrical power generation, electricity can be generated with temperature differences. The purpose of this study is to see if the energy balance from thermoelectricity is a feasible way to generate electricity.

Introduction

The majority of electricity generation today is produced in and distributed from a centralized location with residential, commercial, and industrial buildings getting their electricity through electrical transmission and distribution lines. Integrating power generation into the building reduces the electrical demand to a power station

Thermoelectrical generators (TEG) produce electrical current using a semiconductor device that is made from an n-doped semiconductor and p-doped semiconductor. When heat passes from the n-doped side to the p-doped side of the semiconductor, electrons flow with the heat, thereby generating an electrical current. The two sides of the TEG is separated by a dissimilar material. By wiring to the two sides of a TEG a potential is created and allows the electrons to flow out and useable for a load that is connected. The generation of electricity by temperature differential is called the Seebeck effect. (Egli, 1958; Rowe, 2006)

When heat is applied to the hot side of a TEG, the temperature difference between the hot and cold side of a thermoelectric module causes the electrons from the n-doped semiconductor to flow to the p-doped semiconductor. The flow of electrons caused by holding the two ends of the thermoelectric module at different temperatures is called the Seebeck effect. The voltage that is produced from the temperature differential can be used to power a load that is connected to the thermoelectric generator. The voltage that is produced from one n-doped and one p-doped semiconductor is on the magnitude of microvolts. To generate enough voltage to be useful the module has many semiconductors connected. Residential buildings have many places where there is a temperature differential for example between the outside walls and the interior area of the building and the attic and basement and the rest of the buildings. Thermoelectric has the potential to generate electricity to small power systems in a building.

Hypothesis

This study is based on the hypothesis that the amount of energy that will be gained from a TEG will be greater than the amount of energy that will be lost from substituting fiberglass insulation with the TEG.

Literature Review

Thomas Johann Seebeck is the father of thermoelectricity. Seebeck was an Estonian-German physicist in the late 1700's to early 1800's. Seebeck did most of his work in Berlin. He discovered thermoelectricity in 1820 when he reported his discovery to the Berlin Academy of Sciences and wrote a paper on his discovery called “Ueber die magnetische Polarisation der Metalle und Erze durch Temperatur-Differenz.”(On the Magnetic Polarization of Metals and Minerals by Temperature Differences) (Velmre, 2007; William Francis Magie, 1963)

Seebeck’s experiments that lead to the discovery of thermoelectricity was not intentional. He was carrying out experiments on the activities of galvanic batteries. Seebeck noticed that when two metals were joined, there would be an induced magnetic field. He would then further investigate this phenomenon further to discover thermoelectricity.(D. K. C. MacDonald, 1962)

Seebeck’s experiments followed that from two pieces of different metals, that a magnetic field that would move a compass needle. He did several of these experiments first joining bismuth and antimony. In the first experiment, he laid a plate of bismuth on a copper plate. In Seebeck’s experiments that were conducted first, he would lay plates of bismuth or antimony on plates of copper. The results showed a magnetic field was created from the two dissimilar metals. The currents that were produced in the early experiments would deflect a needle. In later experiments, he would heat up a plate of copper and the needle would give a greater deflection.

Johann Seebeck would go on to come up with what is called the Seebeck effect. From Seebeck’s studies with thermoelectricity, the fundamental concept of thermoelectricity was derived. When two dissimilar metals are held at different temperatures, an emf would be produced in a circuit. The Seebeck effect is the basis on which thermoelectric modules are based on. From this effect, the Seebeck Coefficient was derived. The Seebeck Coefficient is proportional to the voltage and the temperature gradient of the two metals.(D. K. C. MacDonald, 1962; Egli, 1958; Rowe, 2006; William Francis Magie, 1963)

$$\alpha = \frac{V}{\Delta T} \tag{1}$$

Jean Charles Athanase Peltier was a watchmaker and part time physicist. Peltier was the second person to contribute to the field of thermoelectricity. In his findings, he found that if an electric current is passed through a thermocouple, then the thermocouple would produce a small heating or cooling effect. This effect is called the Peltier effect. The Peltier Coefficient (Peltier effect) is proportional to the current that is passed between the junction of two metals. This effect is described by the Peltier Coefficient(D. K. C. MacDonald, 1962; Rowe, 2006)

$$Q = \Pi\, I \tag{2}$$

William Thomson, later renamed to Lord Kelvin, was a Scots-Irish physicist that worked on thermodynamics and thermoelectricity in the mid-1800's. Kelvin contributed two major contributions to the field of thermoelectricity. Kelvin discovered what is called Thomson Heat and found a relationship between Thomson, Seebeck, Peltier effects. Kelvin's work is the fundamental relations to thermoelectricity.(D. K. C. MacDonald, 1962; Rowe, 2006)

In Kelvin's work, he discovered what is called Thomson Heat. Thomson Heat is a relationship between the heat in a conductor and its current density and temperature. When an electric current of density J_x is passing through a conductor and has a temperature gradient. The net heat that is produced per unit volume per second is given by Thomson Heat equation.(D. K. C. MacDonald, 1962)

$$Q = \frac{J_x^2}{\sigma} - \mu J_x \frac{dT}{dx} \tag{3}$$

This equation gives the amount of heat that a device will give or absorb. The Thomson heat that a device will produce is dependent on the Joule heat, which is the current density per electrical conductivity. The second term is which is the Thomson coefficient times the temperature gradient.

Kelvin's next work in thermoelectricity is when he related the three effects. When Kelvin started to work on thermoelectric, Kelvin decided that there should be a thermodynamic relationship between the three effects. His first attempt at relating the three effects lead him to the erroneous equation that. The first attempt at the relationship of the three effect also lead Kelvin to the erroneous conclusion that. This lead Kelvin to the conclusion that there must be other thermoelectric effects that were not taken into consideration. The conclusion lead him to discover Thomson Heat. The discovery of Thomson Effect. The relationship that leads Kelvin discovered is called the Kelvin relations.(D. K. C. MacDonald, 1962)

Thermoelectric modules operate as a heat engine. The modules take heat from a source and convert the temperature difference between the hot and cold side of the module to produce a voltage. The efficiency of a module depends on the Carnot efficiency and the thermoelectric properties of the material that the module is made from. When the Carnot efficiency and the thermoelectric properties are combined, a new property is formed called the figure of merit zT. Thermodynamic efficiency is defined as the ratio of the power output to the thermal power input.

$$\eta = \frac{\text{electrical power to the load}}{\text{heat absorbed}} \tag{4}$$

Materials are judged on whether they are efficient based on its zT of the material. The zT of the material is based on the relationship between the Seebeck coefficient, its electrical resistivity, thermal conductivity, and the average temperature across the module. The zT of a material is defined as Eq. 5 and holds true for small ΔT.

$$zT = \frac{\alpha^2 T}{\rho \kappa} \tag{5}$$

It is clear from Eq. 5 that the biggest contributor to the efficiency of a material is the Seebeck coefficient. Since a TEG is a heat engine, it cannot exceed the Carnot efficiency of the system. To maximize the efficiency of a module materials with high Seebeck coefficient are needed. Thermoelectric materials the maximum efficiency is the product of the Carnot efficiency and the materials properties.

$$\eta_{max} = \frac{\Delta T}{T_h} \frac{\left(\sqrt{1 + zT} - 1\right)}{\sqrt{1 + zT} + \frac{T_c}{T_h}} \tag{6}$$

Thermopower is the conversation of heat into electrical potential. What drives a thermoelectric module or system is the Seebeck effect. When two dissimilar metals, n-doped and p-doped semiconductors, are held at different temperature the Seebeck effect drives the current in the system. The voltage output of a module is dependent on the Seebeck coefficient and the temperature difference between the hot and cold side of the module. The output voltage and current are defined as:

$$V = \frac{N\alpha(T_h - T_c)}{1 + \frac{2rl_c}{l}} \tag{7}$$

$$I = \frac{A\alpha(T_h - T_c)}{2\rho(n+1)(1+2rl_c/l)} \tag{8}$$

Where N is the number of thermocouples in the module, α is the Seebeck coefficient, ρ is the resistivity, T_h and T_c are the temperatures of the hot and cold side of the module, A is the cross-sectional area, l is the length, l_c is the thickness of the contact layer. From this, the power output of a module can be defined.

$$P = \left(\frac{\alpha^2}{2\rho}\right)\left(\frac{(AN(T_h - T_c)^2)}{2\rho(n + 1)(1 + 2rl_c/l)}\right) \tag{9}$$

Methodology

The methods that were used in this study were to test a module to see how much power will be generated from the module. The first step to answering the questions that this study investigates is to test out the module and measure its current and voltage output. The following methods will be used to determine the feasibility of power generation with thermoelectric. The study will be in three sections: single thermoelectric module, thermoelectric modules connected in series, and thermoelectric modules connected in parallel.

Section 1

To answer the question of how much power will be generated by a TEG module, experiments were conducted to determine the voltage and current output of a module. A metal tank was filled with water to act as a heat source. This tank was used to attach a TEG module so that measurements could be taken. A wooden box that had fiberglass insulation on the inside was used to protect and help with the heating up of the water that was inside. A thermostat was attached to the side of the metal tank. A water heater that was attached to a wooden lid that was laid on top of the tank. The water heater was used to heat the water up during the experiments that were conducted.

The first experiment that was conducted was to determine the power output of a single TEG module. The experiment was conducted with the module taped to the side of the tank. The temperature was taken with a thermometer. The placement of the thermistors was one was attached to the back, to the front, and one was set far enough away from the tank so that an ambient temperature could be taken. Two multimeters were used to take a volt and current reading. While the water was heating up a reading of voltage, current, temperature of the front, back and ambient temperature was taken every 1 min. The power output will be calculated from the measured voltage and amperage.

Section 2

The second experiment that was conducted was to determine the power output of a single TEG module. The experiment was conducted with four modules taped to the side of the tank. The temperature was taken with a thermometer. The placement of the thermistors was one was attached to the front of the first module, to the tank in between the second and third module, one was taped to the last module, and one was set far enough away from the tank so that an ambient temperature could be taken. Two multimeters were used to take a volt and current reading. While the water was heating up a reading of voltage, current, temperature of the front of the first, tank, and last module, and ambient temperature was taken every 1 min. The power output will be calculated from the measured voltage and amperage.

Section 3

The third experiment that was conducted was to determine the power output of a single TEG module. The experiment was conducted with three modules taped to the side of the tank. The temperature was taken with a thermometer. The placement of the thermistors was one was attached to the front of the first module, to the tank behind the second module, one was taped to the last module, and one was set far enough away from the tank so that an ambient temperature could be taken. Two multimeters were used to take a volt and current reading. While the water was heating up a reading of voltage, current, temperature of the front of the first, tank, and last module, and ambient temperature was taken every 1 min. The power output will be calculated from the measured voltage and amperage.

Results

The results of the first experiment are displayed in Table 1. The maximum voltage and current that was measured was 0.0780 V and 0.7630A. The maximum power output of the module was 0.0595 W. When comparing the voltage and power of the module to the temperature difference the results was and an average of 0.0077 V/□ and 0.0023W/□. The maximum voltage and power of the module when comparing to the temperature difference was 0.0092 V/□ and 0.0061 W/□. Figure 1 shows the graph of temperature difference and voltage output of the module. The results showed a linear trend with an R^2 of 0.9653. Figure 2 show the graph of temperature and power of the module. The results show a quadratic trend with an R^2 of 0.9745.

	V	A	W	V/□	W/□
Average	0.0329	0.3107	0.0134	0.0077	0.0023
Max	0.0780	0.7630	0.0595	0.0092	0.0061

Table 1 One Module

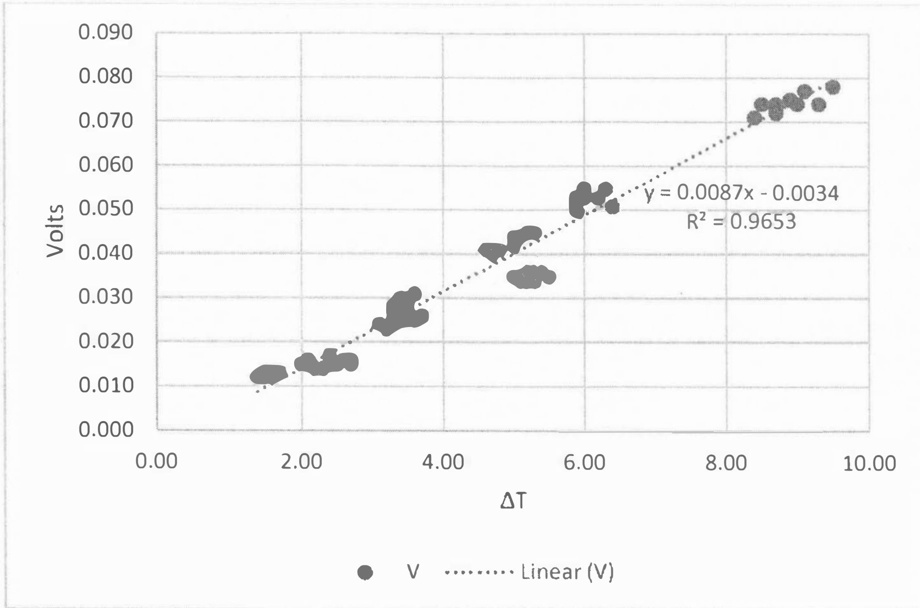

Figure 1 Voltage vs Change in Temperature for One Module

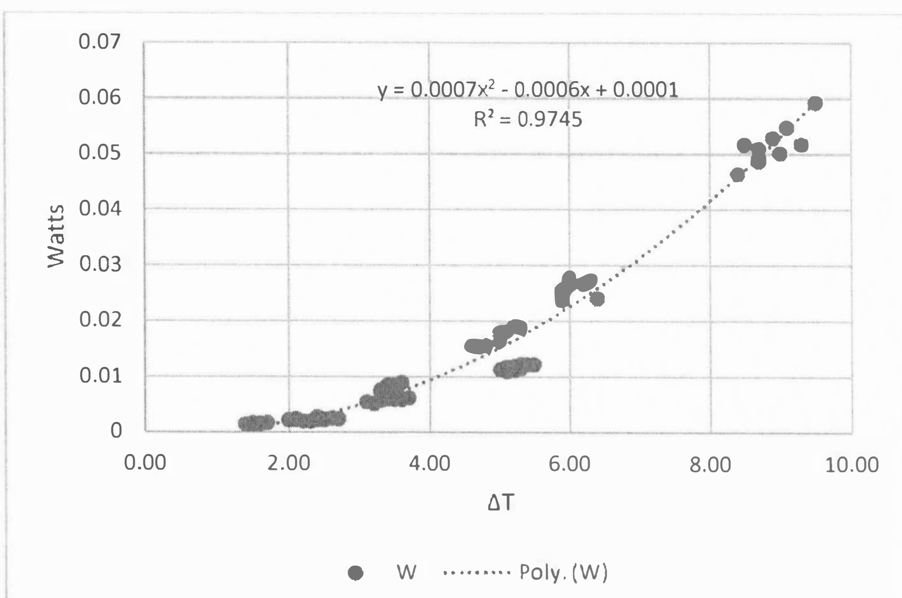

Figure 2 Power vs Change in Temperature for One Module

The results of the second experiment are displayed in Table 2. The maximum voltage and current that was measured was 0.3330 V and 0.1370 A. The maximum power output of the module was 0. 0108W. When comparing the voltage and power of the module to the temperature difference the results was and average 0.0993 V/°C and 0. 0038W/°C. The maximum voltage and power of the module when comparing to the temperature difference was 0.4033 V/°C and 0.0100 W/°C. Figure 3 and Figure 4 show the graphs for the voltage and power output of the modules when comparing the measurements to the difference in temperature. The graph shows no correlation in the data.

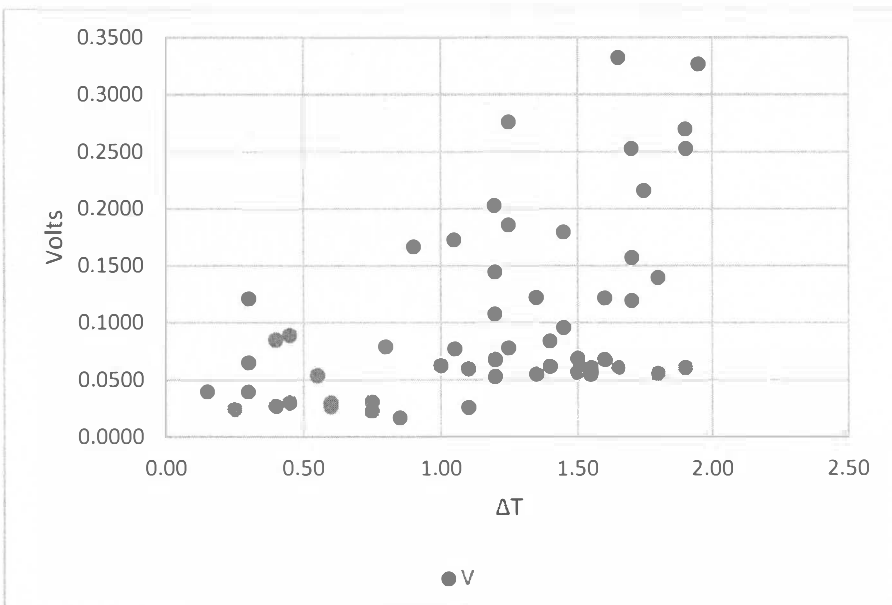

Figure 3 Voltage vs. Change in Temperature for 4 Modules in Series

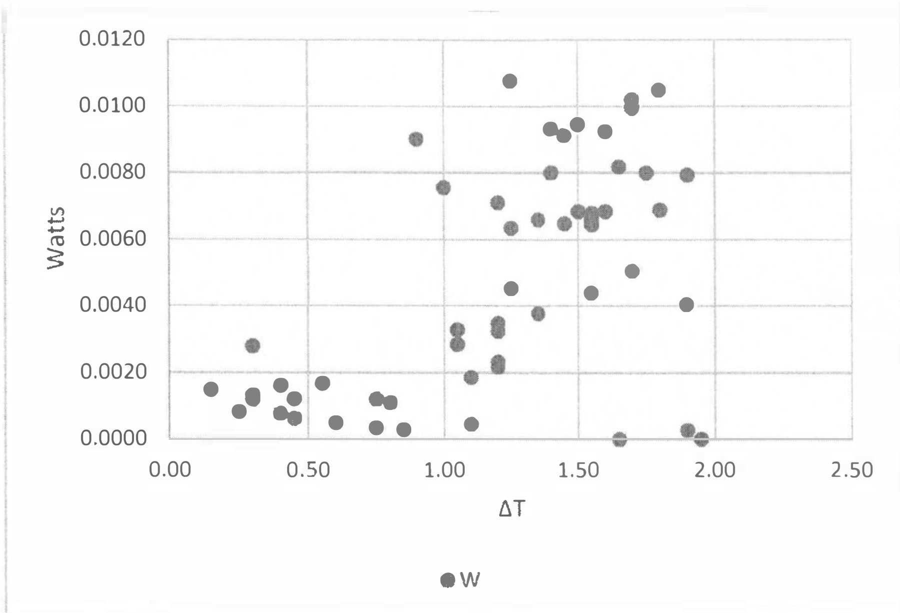

Figure 4 Power vs. Change in Temperature for 4 Modules in Series

	V	A	W	V/□	W/□
Average	0.1046	0.0546	0.0045	0.0993	0.0038
Max	0.3330	0.1370	0.0108	0.4033	0.0100

Table 2 Modules in Series

The results of the third experiment are displayed in Table 3. The maximum voltage and current that was measured was 0.0480 V and 0.1410 A. The maximum power output of the module was 0.0066 W. When comparing the voltage and power of the module to the temperature difference the results was and an average of 0.0058V/□ and 0.0005 W/□. The maximum voltage and power of the module when comparing to the temperature difference was 0.0074V/□ and 0.0008 W/□. Figure 5 shows the graph of temperature difference and voltage output of the module. The results showed a linear trend with an R^2 of 0.9938. Figure 6 show the graph of temperature and power of the module. The results show a quadratic trend with an R^2 of 0.9919.

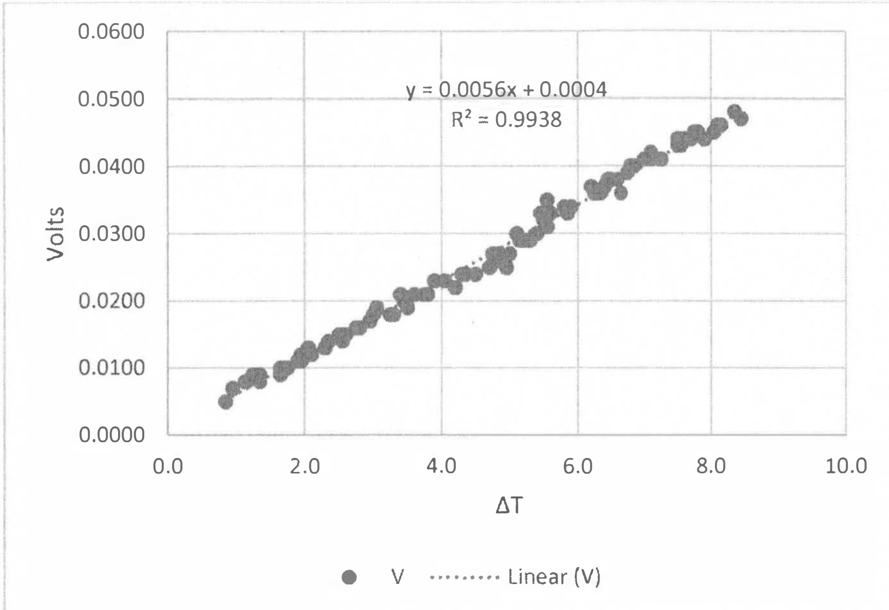

Figure 5 Voltage vs. Change in Temperature for 3 Modules in Parallel

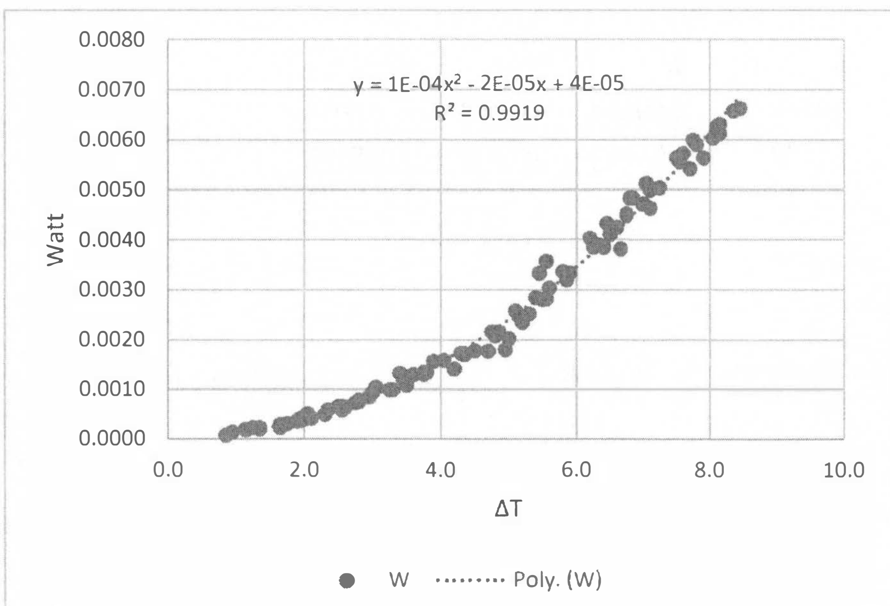

Figure 6 Power vs. Change in Temperature for 3 Modules in Parallel

	V	A	W	V/□	W/□
Average	0.0266	0.0789	0.0025	0.0058	0.0005
Max	0.0480	0.1410	0.0066	0.0074	0.0008

Table 3 Modules in Parallel

Comparing the results from one module to the results of the rest. The single module and the modules in parallel showed the similar correlation in both voltage and power output. When connecting the modules in series, the data showed no correlation. The observation for series was that sometimes the voltage and current would fluctuate drastically. Further experiments and tests should be done to see if this is true or a normal result from connecting the modules in series. Parallel the results showed that of what a single module demonstrated with a linear trend for the voltage and a quadratic trend for the power curve.

Height	0.04000 m
Width	0.04000 m
Thickness	0.00368 m
Area	0.00160 m^2

Table 4 Dimensions of Module

Using the data from Table 4 and $\overline{\alpha}$ the amount of voltage per square meter for every °C can be determined.

$$\alpha = \frac{V}{°C} \tag{10}$$

$$\beta = \frac{\alpha}{m^2} \tag{11}$$

$$\gamma = \frac{W}{°C} \tag{12}$$

One module with an area of 0.00160 m (Table 4) and an $\overline{\alpha}$ of 0.0077 V/□ can produce a β of 4.8 V per (°C times m^2). The same method of determining the amount of V/□/m^2 can be done with the amount of power of the module, the same module with an area 0.0016 m^2 can produce 1.44 W/□/m^2.

$$\frac{V/_{°C}}{m^2} = \frac{.0077\ V/_{°C}}{.0016\ m^2} = \frac{4.8\ V/_{°C}}{m^2}$$

$$\frac{W/_{°C}}{m^2} = \frac{.0077\ W/_{°C}}{.0016\ m^2} = \frac{1.44\ W/_{°C}}{m^2}$$

Thermal conductivity is the ability for a material to conduct heat. The higher the thermal conductivity of a material, the more heat that can pass through an object. Some common thermal conductivity of some materials ranges from fiberglass with is 0.04 W/(m °C) to iron which has a thermal conductivity of 43 W/(m K). The material that the module that was used was AlN and Al_2O_3. The thermal conductivity of AlN is 18 W/(m °C)0 and Al_2O which is 25 W/(m °C). The total thermal conductivity of the module is the sum of the thermal conductivity of the two materials which is 205 W/(m °C).

$$Thermal\ Conductivity\ (k)\ \ k_{total} = k_{Al_2O_3} + k_{AlN}$$

The R-value of a material is defined as the ability to resist heat flow through a given area. R-value is the inverse of the thermal conductivity. To calculate the R-value, the thickness of the material is divided by its thermal conductivity. All materials resist heat flow in some way. In buildings fiberglass insulation, is put into the walls to keep the heat inside or to prevent heat from entering a building. A common insulation material is fiberglass insulation. Fiberglass insulation has a thermal conductivity of .04 W/(m °C). For an 11.5 cm thickness, an R-value would be 0.2875 °C m^2/W.

$$R - Value = \frac{l_t}{k}$$

$$R - Vlaue_{fiberglass} = \frac{.0115\ m}{\frac{.04\ \mathrm{W}}{\mathrm{m\ °C}}} = \frac{.2875\ \mathrm{°C}\ m^2}{W}$$

The R-value of a module with 3.8mm thickness has and R-value of 0.000018°C m^2/W. With the thickness of a module being 11.5 cm then the R-value will be 0.0000560 °C m^2/W.

$$R - Vlaue\ Module = \frac{.038\ m}{\frac{205\ \mathrm{W}}{\mathrm{m\ °C}}} = \frac{0.000018\ \mathrm{°C}\ m^2}{\mathrm{W}}$$

$$R - Vlaue\ Module = \frac{.115\ m}{\frac{205\ \mathrm{W}}{\mathrm{m\ °C}}} = \frac{0.000056\ \mathrm{°C}\ m^2}{\mathrm{W}}$$

The rate of heat loss is defined as the amount of heat that is lost through a wall in a building through its materials. The amount of heat that is lost through a material is the area of the wall times the difference between the inside and outside temperature divided the R-value.

$$Q = kA\frac{\Delta T}{l_t}$$

$$R = \frac{l_t}{k}, k = \frac{l_t}{R}$$

$$Q = A\frac{l_t}{R}\frac{\Delta T}{l_t}$$

$$Q = \frac{A\Delta T}{R} \tag{13}$$

Using a one °C temperature difference between the outside and inside, and through a $1m^2$ Area, with equation 13, the heat transfer is the following

$$Q_{insulation} = \frac{.0016m^2 * 1°\text{C}}{.2875\ m^2°\text{C}/W}$$

$$Q_{insulation} = .00557\ W$$

$$Q_{Thermoelectric\ module} = \frac{.0016m^2 * 1°\text{C}}{.000018\ m^2°\text{C}/W}$$

$$Q_{Thermoelectric\ module} = 88.9\ W$$

With the R-value calculated out to be .000018 °C m^2/W the average amount of heat loss was 583.333 kW/m^2. The average amount of power that was produced with the module was 58.906 W/ m^2. Fiberglass insulation the average amount of heat loss was 36.5 W/m^2. When comparing the two together fiberglass insulation loos a significantly less heat than the thermoelectric module does.

Delta T	Area	R value	W Output	W/m2	Q lost	Q lost /m2	Net
1.00	0.0016	0.000018	0.0002	0.125	88.89	55555.56	-55555
2.00	0.0016	0.000018	0.0017	1.063	177.78	111111.11	-111110
3.00	0.0016	0.000018	0.0046	2.875	266.67	166666.67	-166664
4.00	0.0016	0.000018	0.0089	5.563	355.56	222222.22	-222217
5.00	0.0016	0.000018	0.0146	9.125	444.44	277777.78	-277769
6.00	0.0016	0.000018	0.0217	13.563	533.33	333333.33	-333320
7.00	0.0016	0.000018	0.0302	18.875	622.22	388888.89	-388870
8.00	0.0016	0.000018	0.0401	25.063	711.11	444444.44	-444419
9.00	0.0016	0.000018	0.0514	32.125	800.00	500000.00	-499968
10.00	0.0016	0.000018	0.0641	40.063	888.89	555555.56	-555515
11.00	0.0016	0.000018	0.0782	48.875	977.78	611111.11	-611062
12.00	0.0016	0.000018	0.0937	58.563	1066.67	666666.67	-666608
13.00	0.0016	0.000018	0.1106	69.125	1155.56	722222.22	-722153
14.00	0.0016	0.000018	0.1289	80.563	1244.44	777777.78	-777697
15.00	0.0016	0.000018	0.1486	92.875	1333.33	833333.33	-833240
16.00	0.0016	0.000018	0.1697	106.063	1422.22	888888.89	-888783
17.00	0.0016	0.000018	0.1922	120.125	1511.11	944444.44	-944324
18.00	0.0016	0.000018	0.2161	135.063	1600.00	1000000.00	-999865
19.00	0.0016	0.000018	0.2414	150.875	1688.89	1055555.56	-1055405
20.00	0.0016	0.000018	0.2681	167.563	1777.78	1111111.11	-1110944
		Average	0.094	58.906	933.333	583333.333	-583274.427

Table 5 Power output and heat loss of various delta T

Delta T	Area	R value	W Output	W/m2	Q lost	Q lost /m2	Net
1.00	0.0016	0.287500	0.0000	0.000	0.01	3.48	-3
2.00	0.0016	0.287500	0.0000	0.000	0.01	6.96	-7
3.00	0.0016	0.287500	0.0000	0.000	0.02	10.43	-10
4.00	0.0016	0.287500	0.0000	0.000	0.02	13.91	-14
5.00	0.0016	0.287500	0.0000	0.000	0.03	17.39	-17
6.00	0.0016	0.287500	0.0000	0.000	0.03	20.87	-21
7.00	0.0016	0.287500	0.0000	0.000	0.04	24.35	-24
8.00	0.0016	0.287500	0.0000	0.000	0.04	27.83	-28
9.00	0.0016	0.287500	0.0000	0.000	0.05	31.30	-31
10.00	0.0016	0.287500	0.0000	0.000	0.06	34.78	-35
11.00	0.0016	0.287500	0.0000	0.000	0.06	38.26	-38
12.00	0.0016	0.287500	0.0000	0.000	0.07	41.74	-42
13.00	0.0016	0.287500	0.0000	0.000	0.07	45.22	-45
14.00	0.0016	0.287500	0.0000	0.000	0.08	48.70	-49
15.00	0.0016	0.287500	0.0000	0.000	0.08	52.17	-52
16.00	0.0016	0.287500	0.0000	0.000	0.09	55.65	-56
17.00	0.0016	0.287500	0.0000	0.000	0.09	59.13	-59
18.00	0.0016	0.287500	0.0000	0.000	0.10	62.61	-63
19.00	0.0016	0.287500	0.0000	0.000	0.11	66.09	-66
20.00	0.0016	0.287500	0.0000	0.000	0.11	69.57	-70
		Average	0.000	0.000	0.058	36.522	-36.522

Table 6 Heat Loss of Fiberglass Insulation

Delta T	TEG Net	Fiberglass Net
1.00	-55555.4	-3.47826
2.00	-111110	-6.95652
3.00	-166664	-10.4348
4.00	-222217	-13.913
5.00	-277769	-17.3913
6.00	-333320	-20.8696
7.00	-388870	-24.3478
8.00	-444419	-27.8261
9.00	-499968	-31.3043
10.00	-555515	-34.7826
11.00	-611062	-38.2609
12.00	-666608	-41.7391
13.00	-722153	-45.2174
14.00	-777697	-48.6957
15.00	-833240	-52.1739
16.00	-888783	-55.6522
17.00	-944324	-59.1304
18.00	-999865	-62.6087
19.00	-1055405	-66.087
20.00	-1110944	-69.5652

Table 7 Comparing TEG vs Fiberglass Insulation

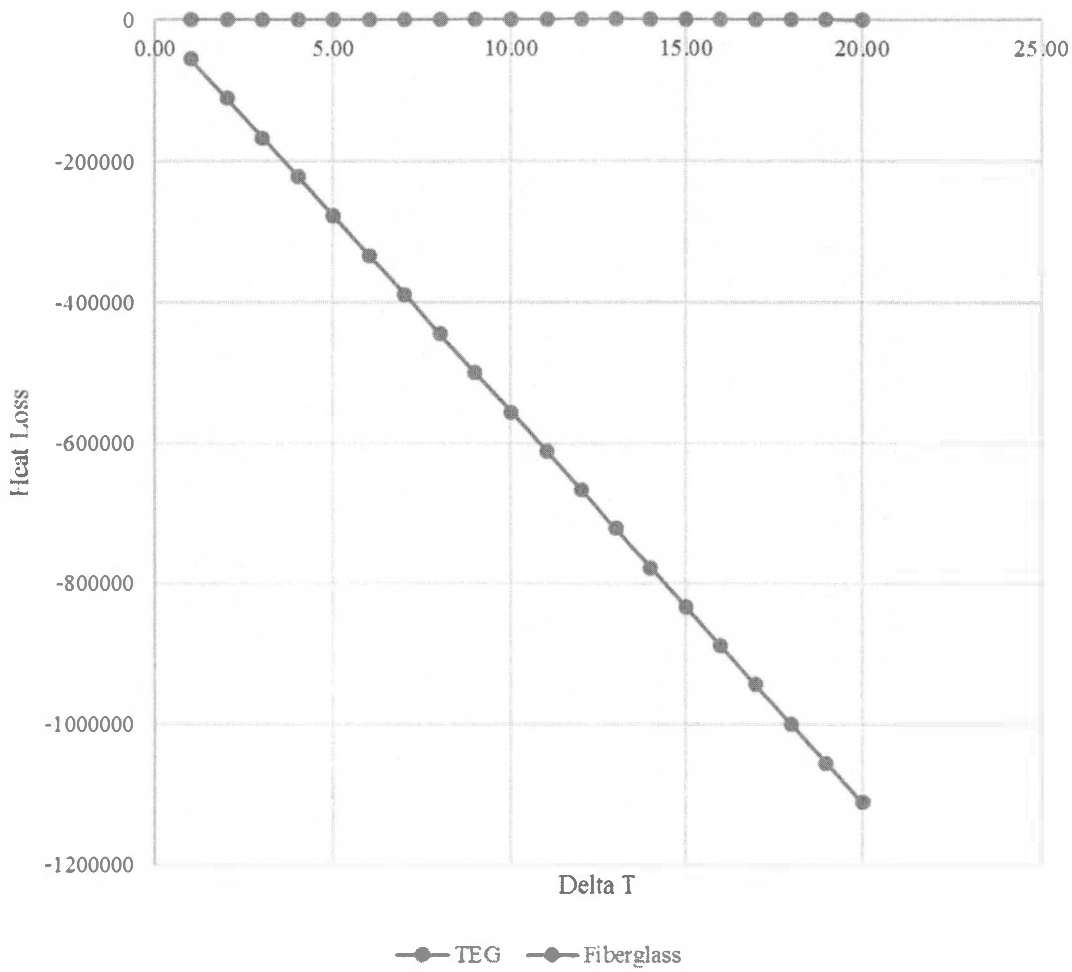

Figure 8 Heat Loss of TEG vs Heat Loss of Fiberglass Insulation

Conclusion

Fiberglass insulation loses less heat than that of a module. The module does produce some energy but loses far more energy than it produces. The net amount of energy for the thermoelectric module is negative. With a negative amount of energy that the module produces, the conclusion is that in this application, replacing fiberglass with thermoelectric power generators, it is not worth it. In this application, the replacement of fiberglass insulation with thermoelectric power generators, the amount of energy that needs to be replaced due to heat loss would outweigh the amount of energy that is produced.

Further research is needed to increase the modules energy output and decrease the amount of heat is lost in the modules. Using the modules in other application is an area that needed to be further researched. The application of using modules in interior walls and not the outside walls. Using the modules in other areas such as using the waste heat, for example, a water heater, radiators and other such appliances in a home. Other materials that have a higher Seebeck coefficient are also another area of further research. The investigation into using these modules in other areas of a residential building could be viable, but further research needs to be done with other applications. These applications could be putting these modules on the outside of a water heater, radiators, and heat pipes.

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Appendix

Data for One Module

T1 Temp of back Side of TEG □	T1 Temp of Front Side of TEG □	T1 Ambient Temp □	ΔT	V	A	W	V/ΔT	W/ΔT
26.40	23.80	14.50	2.60	0.0160	0.1530	0.0024	0.0062	0.0024
26.20	23.60	14.20	2.60	0.0160	0.1540	0.0025	0.0062	0.0024
26.30	23.60	14.30	2.70	0.0160	0.1530	0.0024	0.0059	0.0022
26.20	23.50	14.30	2.70	0.0150	0.1550	0.0023	0.0056	0.0021
26.20	23.90	15.30	2.30	0.0140	0.1380	0.0019	0.0061	0.0026
26.20	23.90	15.10	2.30	0.0140	0.1370	0.0019	0.0061	0.0026
26.10	23.90	14.90	2.20	0.0140	0.1370	0.0019	0.0064	0.0029
26.10	23.60	14.70	2.50	0.0150	0.1420	0.0021	0.0060	0.0024
26.00	23.60	14.70	2.40	0.0150	0.1440	0.0022	0.0063	0.0026
26.00	23.50	14.50	2.50	0.0150	0.1450	0.0022	0.0060	0.0024
26.70	24.30	14.60	2.40	0.0170	0.1600	0.0027	0.0071	0.0030
26.60	24.50	14.90	2.10	0.0160	0.1490	0.0024	0.0076	0.0036
26.60	24.50	15.10	2.10	0.0150	0.1440	0.0022	0.0071	0.0034
26.60	24.50	15.00	2.10	0.0150	0.1470	0.0022	0.0071	0.0034
26.50	24.50	14.80	2.00	0.0150	0.1420	0.0021	0.0075	0.0038
26.50	24.40	14.70	2.10	0.0150	0.1460	0.0022	0.0071	0.0034
26.70	24.30	14.70	2.40	0.0150	0.1490	0.0022	0.0063	0.0026
26.30	24.30	14.60	2.00	0.0150	0.1460	0.0022	0.0075	0.0038
26.30	24.20	14.50	2.10	0.0150	0.1460	0.0022	0.0071	0.0034
32.60	29.20	14.60	3.40	0.0260	0.2410	0.0063	0.0076	0.0022

32.60	**29.20**	**15.00**	**3.40**	**0.0250**	**0.2410**	**0.0060**	**0.0074**	**0.0022**
32.50	**29.20**	**14.60**	**3.30**	**0.0250**	**0.2400**	**0.0060**	**0.0076**	**0.0023**
32.50	**29.20**	**14.90**	**3.30**	**0.0250**	**0.2310**	**0.0058**	**0.0076**	**0.0023**
32.40	**29.10**	**15.20**	**3.30**	**0.0240**	**0.2380**	**0.0057**	**0.0073**	**0.0022**
32.20	**29.10**	**15.30**	**3.10**	**0.0240**	**0.2270**	**0.0054**	**0.0077**	**0.0025**
32.30	**29.10**	**15.00**	**3.20**	**0.0230**	**0.2210**	**0.0051**	**0.0072**	**0.0022**
32.20	**29.00**	**15.20**	**3.20**	**0.0230**	**0.2260**	**0.0052**	**0.0072**	**0.0022**
32.10	**28.90**	**14.90**	**3.20**	**0.0230**	**0.2210**	**0.0051**	**0.0072**	**0.0022**
32.00	**28.80**	**14.80**	**3.20**	**0.0230**	**0.2230**	**0.0051**	**0.0072**	**0.0022**
34.10	**30.80**	**15.50**	**3.30**	**0.0270**	**0.2600**	**0.0070**	**0.0082**	**0.0025**
34.20	**30.80**	**15.30**	**3.40**	**0.0270**	**0.2530**	**0.0068**	**0.0079**	**0.0023**
34.10	**30.60**	**15.10**	**3.50**	**0.0270**	**0.2590**	**0.0070**	**0.0077**	**0.0022**
34.00	**30.60**	**15.10**	**3.40**	**0.0270**	**0.2530**	**0.0068**	**0.0079**	**0.0023**
33.70	**30.20**	**15.30**	**3.50**	**0.0250**	**0.2420**	**0.0061**	**0.0071**	**0.0020**
33.60	**30.20**	**14.90**	**3.40**	**0.0250**	**0.2390**	**0.0060**	**0.0074**	**0.0022**
33.50	**29.80**	**15.10**	**3.70**	**0.0260**	**0.2380**	**0.0062**	**0.0070**	**0.0019**
33.40	**29.80**	**15.00**	**3.60**	**0.0250**	**0.2400**	**0.0060**	**0.0069**	**0.0019**
33.30	**29.80**	**14.80**	**3.50**	**0.0250**	**0.2360**	**0.0059**	**0.0071**	**0.0020**
33.20	**29.60**	**14.80**	**3.60**	**0.0250**	**0.2330**	**0.0058**	**0.0069**	**0.0019**
40.20	**34.90**	**14.90**	**5.30**	**0.0360**	**0.3420**	**0.0123**	**0.0068**	**0.0013**
40.10	**34.90**	**14.70**	**5.20**	**0.0360**	**0.3310**	**0.0119**	**0.0069**	**0.0013**
40.00	**34.90**	**14.80**	**5.10**	**0.0350**	**0.3370**	**0.0118**	**0.0069**	**0.0013**
39.90	**34.60**	**14.90**	**5.30**	**0.0350**	**0.3360**	**0.0118**	**0.0066**	**0.0012**
39.80	**34.40**	**14.80**	**5.40**	**0.0360**	**0.3400**	**0.0122**	**0.0067**	**0.0012**
39.70	**34.60**	**14.60**	**5.10**	**0.0340**	**0.3230**	**0.0110**	**0.0067**	**0.0013**
39.50	**34.50**	**15.20**	**5.00**	**0.0350**	**0.3230**	**0.0113**	**0.0070**	**0.0014**
39.30	**33.80**	**14.70**	**5.50**	**0.0350**	**0.3490**	**0.0122**	**0.0064**	**0.0012**

39.30	34.00	14.80	5.30	0.0340	0.3380	0.0115	0.0064	0.0012
39.10	33.90	14.80	5.20	0.0340	0.3290	0.0112	0.0065	0.0013
24.20	22.60	14.80	1.60	0.0120	0.1200	0.0014	0.0075	0.0047
24.10	22.60	14.90	1.50	0.0120	0.1180	0.0014	0.0080	0.0053
24.20	22.60	14.40	1.60	0.0130	0.1190	0.0015	0.0081	0.0051
24.10	22.40	13.90	1.70	0.0130	0.1300	0.0017	0.0076	0.0045
24.10	22.40	14.00	1.70	0.0130	0.1270	0.0017	0.0076	0.0045
24.20	22.60	14.60	1.60	0.0130	0.1220	0.0016	0.0081	0.0051
24.00	22.50	14.80	1.50	0.0130	0.1210	0.0016	0.0087	0.0058
24.10	22.60	24.80	1.50	0.0120	0.1130	0.0014	0.0080	0.0053
24.10	22.70	14.40	1.40	0.0120	0.1140	0.0014	0.0086	0.0061
24.00	22.50	14.20	1.50	0.0130	0.1230	0.0016	0.0087	0.0058
33.70	30.10	13.80	3.60	0.0310	0.2880	0.0089	0.0086	0.0024
33.60	30.20	14.40	3.40	0.0300	0.2850	0.0086	0.0088	0.0026
33.50	30.10	24.70	3.40	0.0290	0.2880	0.0084	0.0085	0.0025
33.50	30.20	14.80	3.30	0.0280	0.2740	0.0077	0.0085	0.0026
33.40	30.10	14.40	3.30	0.0280	0.2630	0.0074	0.0085	0.0026
33.40	30.00	14.30	3.40	0.0280	0.2750	0.0077	0.0082	0.0024
33.30	29.80	14.00	3.50	0.0290	0.2790	0.0081	0.0083	0.0024
33.30	29.80	23.80	3.50	0.0290	0.2840	0.0082	0.0083	0.0024
33.30	29.90	13.80	3.40	0.0300	0.2670	0.0080	0.0088	0.0026
33.10	29.60	13.90	3.50	0.0300	0.2820	0.0085	0.0086	0.0024
41.20	36.00	14.10	5.20	0.0450	0.4260	0.0192	0.0087	0.0017
41.00	35.70	13.80	5.30	0.0450	0.4210	0.0189	0.0085	0.0016
40.80	35.80	13.80	5.00	0.0440	0.4100	0.0180	0.0088	0.0018
40.70	35.60	13.90	5.10	0.0440	0.4160	0.0183	0.0086	0.0017
40.60	35.90	14.80	4.70	0.0400	0.3910	0.0156	0.0085	0.0018

40.70	36.00	14.70	4.70	0.0410	0.3790	0.0155	0.0087	0.0019
40.70	36.10	14.70	4.60	0.0410	0.3810	0.0156	0.0089	0.0019
40.60	35.60	14.40	5.00	0.0420	0.3910	0.0164	0.0084	0.0017
40.50	35.50	14.00	5.00	0.0440	0.3950	0.0174	0.0088	0.0018
40.40	35.60	13.90	4.80	0.0410	0.3840	0.0157	0.0085	0.0018
46.90	41.00	14.70	5.90	0.0520	0.4790	0.0249	0.0088	0.0015
46.90	40.90	14.70	6.00	0.0530	0.5050	0.0268	0.0088	0.0015
46.70	40.70	14.20	6.00	0.0550	0.4860	0.0267	0.0092	0.0015
46.20	40.20	14.10	6.00	0.0550	0.5060	0.0278	0.0092	0.0015
46.40	40.10	13.70	6.30	0.0550	0.5000	0.0275	0.0087	0.0014
46.40	40.20	13.80	6.20	0.0530	0.5060	0.0268	0.0085	0.0014
46.20	40.30	14.30	5.90	0.0530	0.4860	0.0258	0.0090	0.0015
46.20	40.30	14.70	5.90	0.0500	0.4770	0.0239	0.0085	0.0014
46.10	39.70	15.10	6.40	0.0510	0.4740	0.0242	0.0080	0.0012
45.90	39.90	14.40	6.00	0.0540	0.4880	0.0264	0.0090	0.0015
57.00	47.50	13.80	9.50	0.0780	0.7630	0.0595	0.0082	0.0009
56.70	47.80	13.80	8.90	0.0750	0.7070	0.0530	0.0084	0.0009
56.80	47.70	14.10	9.10	0.0770	0.7140	0.0550	0.0085	0.0009
56.40	47.10	14.60	9.30	0.0740	0.7020	0.0519	0.0080	0.0009
56.30	47.80	14.60	8.50	0.0740	0.7010	0.0519	0.0087	0.0010
56.20	47.50	14.20	8.70	0.0720	0.6820	0.0491	0.0083	0.0010
55.90	47.50	14.00	8.40	0.0710	0.6560	0.0466	0.0085	0.0010
55.60	46.90	13.80	8.70	0.0740	0.6920	0.0512	0.0085	0.0010
55.40	46.40	13.70	9.00	0.0740	0.6800	0.0503	0.0082	0.0009
55.20	46.50	13.70	8.70	0.0730	0.6700	0.0489	0.0084	0.0010

Data for 4 Modules in Series

Reading	Lead T1 Front TEG 1 □	Lead T2 Front TEG 4 □	Lead T3 Tank Between TEG 2 & 3 □	Lead T4 Ambient Temp □	ΔT	V	A	W	V/ΔT	W/ΔT
1.00	26.30	26.50	26.80	14.50	0.40	0.0270	0.0029	0.0001	0.0675	0.0002
2.00	27.00	27.30	27.40	14.40	0.25	0.0240	0.0034	0.0001	0.0960	0.0003
3.00	27.50	27.80	28.40	14.30	0.75	0.0310	0.0039	0.0001	0.0413	0.0002
4.00	28.30	28.50	28.70	14.40	0.30	0.0400	0.0030	0.0001	0.1333	0.0004
5.00	29.30	29.60	29.90	14.40	0.45	0.0300	0.0040	0.0001	0.0667	0.0003
6.00	29.90	30.00	30.10	14.40	0.15	0.0400	0.0037	0.0001	0.2667	0.0010
7.00	30.40	30.60	30.80	14.50	0.30	0.0650	0.0043	0.0003	0.2167	0.0009
8.00	31.10	31.40	32.30	14.50	1.05	0.0770	0.0037	0.0003	0.0733	0.0003
9.00	32.00	32.20	32.50	14.30	0.40	0.0850	0.0019	0.0002	0.2125	0.0004
10.00	32.50	32.80	33.20	14.60	0.55	0.0540	0.0031	0.0002	0.0982	0.0003
11.00	33.30	33.60	34.30	14.50	0.85	0.0170	0.0017	0.0000	0.0200	0.0000
12.00	34.20	34.50	34.80	14.40	0.45	0.0890	0.0007	0.0001	0.1978	0.0001
13.00	34.90	35.30	35.40	14.70	0.30	0.1210	0.0011	0.0001	0.4033	0.0004

14.00	**35.60**	**35.80**	**36.50**	**14.50**	**0.80**	**0.0790**	**0.0014**	**0.0001**	**0.0988**	**0.0001**
15.00	**36.10**	**36.30**	**36.80**	**14.50**	**0.60**	**0.0270**	**0.0018**	**0.0000**	**0.0450**	**0.0001**
16.00	**36.90**	**37.20**	**37.80**	**14.50**	**0.75**	**0.0230**	**0.0015**	**0.0000**	**0.0307**	**0.0000**
17.00	**37.30**	**37.70**	**38.10**	**14.30**	**0.60**	**0.0300**	**0.0016**	**0.0000**	**0.0500**	**0.0001**
18.00	**38.20**	**38.60**	**39.50**	**14.80**	**1.10**	**0.0260**	**0.0017**	**0.0000**	**0.0236**	**0.0000**
19.00	**38.90**	**39.10**	**40.10**	**14.60**	**1.10**	**0.0600**	**0.0031**	**0.0002**	**0.0545**	**0.0002**
20.00	**39.70**	**39.90**	**41.00**	**14.50**	**1.20**	**0.0680**	**0.0032**	**0.0002**	**0.0567**	**0.0002**
21.00	**40.30**	**40.50**	**41.60**	**14.50**	**1.20**	**0.0530**	**0.0044**	**0.0002**	**0.0442**	**0.0002**
22.00	**41.00**	**41.00**	**42.20**	**14.90**	**1.20**	**0.1080**	**0.0030**	**0.0003**	**0.0900**	**0.0003**
23.00	**41.80**	**41.10**	**42.80**	**14.50**	**1.35**	**0.1220**	**0.0031**	**0.0004**	**0.0904**	**0.0003**
24.00	**42.40**	**42.20**	**43.50**	**14.80**	**1.20**	**0.1450**	**0.0024**	**0.0003**	**0.1208**	**0.0003**
25.00	**43.10**	**43.00**	**44.10**	**14.70**	**1.05**	**0.1730**	**0.0019**	**0.0003**	**0.1648**	**0.0003**
26.00	**43.90**	**43.60**	**45.00**	**14.80**	**1.25**	**0.0780**	**0.0058**	**0.0005**	**0.0624**	**0.0004**
27.00	**44.70**	**44.20**	**46.00**	**14.80**	**1.55**	**0.0610**	**0.0072**	**0.0004**	**0.0394**	**0.0003**
28.00	**45.10**	**45.10**	**46.70**	**15.20**	**1.60**	**0.1220**	**0.0056**	**0.0007**	**0.0762**	**0.0004**
29.00	**45.60**	**45.30**	**46.90**	**14.60**	**1.45**	**0.1800**	**0.0036**	**0.0006**	**0.1241**	**0.0004**

30.00	46.60	46.20	48.30	14.70	1.90	0.2530	0.0016	0.0004	0.1332	0.0002
31.00	47.10	46.70	48.10	14.70	1.20	0.2030	0.0035	0.0007	0.1692	0.0006
32.00	48.00	48.00	48.90	15.00	0.90	0.1670	0.0054	0.0009	0.1856	0.0010
33.00	48.70	48.60	49.90	14.90	1.25	0.2760	0.0023	0.0006	0.2208	0.0005
34.00	49.20	48.70	50.20	15.00	1.25	0.1860	0.0058	0.0011	0.1488	0.0009
35.00	50.00	49.70	51.50	14.90	1.65	0.3330	0.0000	0.0000	0.2018	0.0000
36.00	50.50	49.60	52.00	14.90	1.95	0.3270	0.0000	0.0000	0.1677	0.0000
37.00	51.60	50.70	52.50	14.80	1.35	0.0550	0.0120	0.0007	0.0407	0.0005
38.00	52.10	51.30	53.50	14.60	1.80	0.0560	0.0123	0.0007	0.0311	0.0004
39.00	52.70	51.80	53.90	14.70	1.65	0.0610	0.0134	0.0008	0.0370	0.0005
40.00	53.50	52.70	55.00	15.00	1.90	0.0610	0.0130	0.0008	0.0321	0.0004
41.00	54.00	53.40	55.10	15.20	1.40	0.0620	0.0129	0.0008	0.0443	0.0006
42.00	54.90	54.10	56.10	14.70	1.60	0.0680	0.0136	0.0009	0.0425	0.0006
43.00	55.50	54.30	56.40	14.70	1.50	0.0690	0.0137	0.0009	0.0460	0.0006
44.00	52.20	49.20	51.70	15.10	1.00	0.0630	0.0120	0.0008	0.0630	0.0008
45.00	51.10	49.30	51.70	15.20	1.50	0.0570	0.0120	0.0007	0.0380	0.0005

46.00	**50.90**	**49.00**	**51.50**	**15.20**	**1.55**	**0.0550**	**0.0120**	**0.0007**	**0.0355**	**0.0004**
47.00	**50.50**	**49.00**	**51.30**	**15.20**	**1.55**	**0.0590**	**0.0115**	**0.0007**	**0.0381**	**0.0004**
48.00	**50.50**	**48.80**	**51.20**	**15.10**	**1.55**	**0.0570**	**0.0113**	**0.0006**	**0.0368**	**0.0004**
49.00	**50.10**	**48.90**	**50.90**	**15.10**	**1.40**	**0.0840**	**0.0111**	**0.0009**	**0.0600**	**0.0007**
50.00	**49.80**	**48.20**	**50.70**	**15.40**	**1.70**	**0.1200**	**0.0085**	**0.0010**	**0.0706**	**0.0006**
51.00	**49.70**	**48.00**	**50.30**	**15.40**	**1.45**	**0.0960**	**0.0095**	**0.0009**	**0.0662**	**0.0006**
52.00	**49.20**	**47.80**	**50.20**	**15.10**	**1.70**	**0.1580**	**0.0063**	**0.0010**	**0.0929**	**0.0006**
53.00	**49.10**	**47.70**	**50.20**	**15.10**	**1.80**	**0.1400**	**0.0075**	**0.0011**	**0.0778**	**0.0006**
54.00	**49.10**	**47.30**	**49.90**	**15.50**	**1.70**	**0.2530**	**0.0020**	**0.0005**	**0.1488**	**0.0003**
55.00	**48.80**	**47.50**	**49.90**	**15.30**	**1.75**	**0.2160**	**0.0037**	**0.0008**	**0.1234**	**0.0005**
56.00	**48.50**	**46.90**	**49.60**	**15.40**	**1.90**	**0.2700**	**0.0001**	**0.0000**	**0.1421**	**0.0000**

Data for 3 Modules in Parallel

T1 Front of TEG 1	T2 Front of TEG 3	T3 Tank	T4	Delta T	V	A	W	$V/\Delta T$	$W/\Delta T$
19.1	19.4	20.1	14.0	0.9	0.0050000	0.0015000	0.0000075	0.005882	0.000009
19.3	19.6	20.4	14.0	0.9	0.0070000	0.0020000	0.0000140	0.007368	0.000015
19.6	19.9	20.9	14.0	1.2	0.0080000	0.0024000	0.0000192	0.006957	0.000017
19.7	20.2	21.3	14.1	1.4	0.0080000	0.0025000	0.0000200	0.005926	0.000015
20.1	20.6	21.5	14.0	1.2	0.0080000	0.0023000	0.0000184	0.006957	0.000016
20.6	20.9	22.0	14.4	1.3	0.0090000	0.0026000	0.0000234	0.007200	0.000019
20.6	21.1	22.6	14.4	1.8	0.0100000	0.0031000	0.0000310	0.005714	0.000018
21.0	21.5	22.6	14.7	1.4	0.0090000	0.0026000	0.0000234	0.006667	0.000017
21.6	21.9	22.9	14.8	1.1	0.0080000	0.0024000	0.0000192	0.007048	0.000017
21.6	22.2	23.6	14.8	1.7	0.0100000	0.0029000	0.0000290	0.005882	0.000017
21.9	22.5	24.3	14.6	2.1	0.0120000	0.0035000	0.0000420	0.005714	0.000020
22.3	23.0	24.3	14.7	1.7	0.0090000	0.0026000	0.0000234	0.005455	0.000014
22.7	23.2	24.6	14.7	1.7	0.0100000	0.0029000	0.0000290	0.006061	0.000018

22.9	**23.4**	**24.9**	**14.7**	**1.8**	**0.0100000**	**0.0031000**	**0.0000310**	**0.005714**	**0.000018**
23.0	**23.6**	**25.2**	**14.5**	**1.9**	**0.0110000**	**0.0033000**	**0.0000363**	**0.005789**	**0.000019**
23.5	**24.0**	**25.7**	**14.5**	**2.0**	**0.0110000**	**0.0034000**	**0.0000374**	**0.005641**	**0.000019**
23.6	**24.3**	**26.0**	**14.4**	**2.1**	**0.0130000**	**0.0039000**	**0.0000507**	**0.006341**	**0.000025**
24.1	**24.6**	**26.3**	**14.4**	**2.0**	**0.0120000**	**0.0035000**	**0.0000420**	**0.006154**	**0.000022**
24.4	**24.9**	**26.7**	**14.4**	**2.1**	**0.0120000**	**0.0035000**	**0.0000420**	**0.005854**	**0.000020**
24.7	**25.0**	**27.2**	**14.4**	**2.4**	**0.0140000**	**0.0042000**	**0.0000588**	**0.005957**	**0.000025**
25.0	**25.4**	**27.5**	**14.4**	**2.3**	**0.0130000**	**0.0038000**	**0.0000494**	**0.005652**	**0.000021**
25.2	**25.8**	**28.0**	**14.3**	**2.5**	**0.0150000**	**0.0044000**	**0.0000660**	**0.006000**	**0.000026**
25.5	**26.0**	**28.3**	**14.2**	**2.6**	**0.0140000**	**0.0042000**	**0.0000588**	**0.005490**	**0.000023**
25.9	**26.4**	**28.9**	**14.4**	**2.8**	**0.0160000**	**0.0046000**	**0.0000736**	**0.005818**	**0.000027**
26.1	**26.6**	**28.9**	**14.5**	**2.6**	**0.0150000**	**0.0044000**	**0.0000660**	**0.005882**	**0.000026**
26.4	**27.0**	**29.3**	**14.2**	**2.6**	**0.0150000**	**0.0043000**	**0.0000645**	**0.005769**	**0.000025**
26.7	**27.3**	**29.8**	**14.3**	**2.8**	**0.0160000**	**0.0049000**	**0.0000784**	**0.005714**	**0.000028**
27.0	**27.6**	**30.1**	**14.3**	**2.8**	**0.0160000**	**0.0047000**	**0.0000752**	**0.005714**	**0.000027**
27.2	**27.8**	**30.5**	**14.4**	**3.0**	**0.0180000**	**0.0052000**	**0.0000936**	**0.006000**	**0.000031**

27.6	27.9	30.8	14.3	3.1	0.0190000	0.0055000	0.0001045	0.006230	0.000034
27.9	28.4	31.1	14.2	3.0	0.0170000	0.0050000	0.0000850	0.005763	0.000029
27.9	28.7	31.6	14.5	3.3	0.0180000	0.0053000	0.0000954	0.005455	0.000029
28.5	28.9	32.2	14.5	3.5	0.0190000	0.0057000	0.0001083	0.005429	0.000031
28.7	29.0	32.1	14.2	3.3	0.0180000	0.0055000	0.0000990	0.005538	0.000030
28.9	29.3	32.5	14.2	3.4	0.0210000	0.0063000	0.0001323	0.006176	0.000039
29.5	29.6	33.0	14.4	3.5	0.0200000	0.0061000	0.0001220	0.005797	0.000035
29.4	30.0	33.5	14.4	3.8	0.0210000	0.0064000	0.0001344	0.005526	0.000035
29.7	30.3	33.6	14.0	3.6	0.0210000	0.0062000	0.0001302	0.005833	0.000036
30.0	30.5	34.0	14.2	3.8	0.0210000	0.0062000	0.0001302	0.005600	0.000035
30.3	30.7	34.3	14.2	3.8	0.0210000	0.0064000	0.0001344	0.005526	0.000035
30.6	31.1	34.6	14.3	3.8	0.0210000	0.0064000	0.0001344	0.005600	0.000036
30.8	31.3	35.1	14.1	4.1	0.0230000	0.0069000	0.0001587	0.005679	0.000039
31.3	31.7	35.7	14.1	4.2	0.0220000	0.0064000	0.0001408	0.005238	0.000034
31.6	32.0	35.7	14.3	3.9	0.0230000	0.0068000	0.0001564	0.005897	0.000040
32.0	32.5	36.6	14.0	4.4	0.0240000	0.0072000	0.0001728	0.005517	0.000040

32.1	32.7	36.7	13.9	4.3	0.0240000	0.0071000	0.0001704	0.005581	0.000040
32.5	32.9	37.4	14.1	4.7	0.0250000	0.0074000	0.0001850	0.005319	0.000039
32.9	33.3	37.6	14.2	4.5	0.0240000	0.0072000	0.0001728	0.005333	0.000038
33.0	33.5	38.2	14.4	5.0	0.0250000	0.0075000	0.0001875	0.005051	0.000038
33.6	33.8	38.7	15.1	5.0	0.0270000	0.0080000	0.0002160	0.005400	0.000043
33.8	34.3	38.9	15.1	4.9	0.0270000	0.0080000	0.0002160	0.005567	0.000045
34.2	34.4	39.1	15.0	4.8	0.0260000	0.0078000	0.0002028	0.005417	0.000042
34.5	34.7	39.4	14.9	4.8	0.0270000	0.0080000	0.0002160	0.005625	0.000045
34.7	35.0	39.6	15.0	4.8	0.0270000	0.0081000	0.0002187	0.005684	0.000046
34.9	35.3	40.3	14.7	5.2	0.0290000	0.0085000	0.0002465	0.005577	0.000047
35.4	35.5	40.6	15.0	5.2	0.0290000	0.0087000	0.0002523	0.005631	0.000049
35.6	35.6	40.9	14.4	5.3	0.0290000	0.0086000	0.0002494	0.005472	0.000047
35.9	35.9	41.0	14.6	5.1	0.0300000	0.0088000	0.0002640	0.005882	0.000052
36.1	36.3	41.7	14.5	5.5	0.0320000	0.0095000	0.0003040	0.005818	0.000055
36.5	36.5	41.9	14.6	5.4	0.0300000	0.0091000	0.0002730	0.005556	0.000051
36.7	36.8	42.3	14.6	5.6	0.0310000	0.0092000	0.0002852	0.005586	0.000051

36.9	**37.1**	**42.6**	**14.5**	**5.6**	**0.0330000**	**0.0098000**	**0.0003234**	**0.005893**	**0.000058**
37.5	**37.3**	**43.3**	**14.4**	**5.9**	**0.0340000**	**0.0101000**	**0.0003434**	**0.005763**	**0.000058**
37.7	**37.6**	**43.1**	**14.4**	**5.5**	**0.0330000**	**0.0097000**	**0.0003201**	**0.006055**	**0.000059**
37.8	**37.9**	**43.7**	**14.6**	**5.9**	**0.0330000**	**0.0099000**	**0.0003267**	**0.005641**	**0.000056**
38.2	**38.0**	**43.9**	**14.4**	**5.8**	**0.0340000**	**0.0102000**	**0.0003468**	**0.005862**	**0.000060**
38.7	**38.4**	**44.1**	**14.4**	**5.6**	**0.0350000**	**0.0104000**	**0.0003640**	**0.006306**	**0.000066**
38.4	**38.6**	**44.9**	**14.2**	**6.4**	**0.0370000**	**0.0109000**	**0.0004033**	**0.005781**	**0.000063**
39.1	**38.9**	**45.2**	**14.3**	**6.2**	**0.0370000**	**0.0109000**	**0.0004033**	**0.005968**	**0.000065**
39.2	**39.3**	**45.5**	**14.1**	**6.3**	**0.0360000**	**0.0106000**	**0.0003816**	**0.005760**	**0.000061**
39.3	**39.4**	**46.0**	**14.5**	**6.7**	**0.0360000**	**0.0108000**	**0.0003888**	**0.005414**	**0.000058**
39.8	**39.9**	**46.2**	**14.5**	**6.4**	**0.0360000**	**0.0107000**	**0.0003852**	**0.005669**	**0.000061**
39.9	**40.0**	**46.2**	**14.4**	**6.3**	**0.0360000**	**0.0108000**	**0.0003888**	**0.005760**	**0.000062**
40.1	**40.3**	**46.7**	**14.5**	**6.5**	**0.0380000**	**0.0112000**	**0.0004256**	**0.005846**	**0.000065**
40.6	**40.6**	**47.2**	**14.7**	**6.6**	**0.0380000**	**0.0114000**	**0.0004332**	**0.005758**	**0.000066**
41.0	**40.7**	**47.3**	**14.5**	**6.5**	**0.0380000**	**0.0115000**	**0.0004370**	**0.005891**	**0.000068**
41.2	**40.9**	**47.8**	**14.3**	**6.8**	**0.0390000**	**0.0116000**	**0.0004524**	**0.005778**	**0.000067**

41.1	41.0	47.8	14.2	6.8	0.0390000	0.0115000	0.0004485	0.005778	0.000066
41.5	41.5	48.5	14.5	7.0	0.0410000	0.0121000	0.0004961	0.005857	0.000071
42.0	41.7	48.7	14.5	6.9	0.0400000	0.0113000	0.0004520	0.005839	0.000066
42.1	42.1	49.2	13.8	7.1	0.0410000	0.0121000	0.0004961	0.005775	0.000070
42.4	42.4	49.2	14.2	6.8	0.0400000	0.0119000	0.0004760	0.005882	0.000070
42.7	42.5	49.7	14.0	7.1	0.0420000	0.0125000	0.0005250	0.005915	0.000074
42.9	42.8	49.9	14.0	7.1	0.0410000	0.0123000	0.0005043	0.005816	0.000072
43.1	43.0	50.3	14.3	7.3	0.0410000	0.0123000	0.0005043	0.005655	0.000070
43.4	43.2	51.0	14.3	7.7	0.0440000	0.0129000	0.0005676	0.005714	0.000074
43.6	43.5	51.1	14.2	7.6	0.0430000	0.0128000	0.0005504	0.005695	0.000073
44.1	43.9	51.5	14.2	7.5	0.0440000	0.0130000	0.0005720	0.005867	0.000076
44.4	44.2	51.9	14.2	7.6	0.0440000	0.0131000	0.0005764	0.005789	0.000076
44.6	44.4	52.0	14.2	7.5	0.0430000	0.0128000	0.0005504	0.005733	0.000073
44.5	44.5	52.4	14.3	7.9	0.0440000	0.0131000	0.0005764	0.005570	0.000073
44.7	44.7	52.5	14.0	7.8	0.0450000	0.0133000	0.0005985	0.005769	0.000077
45.2	45.1	52.9	14.5	7.7	0.0450000	0.0134000	0.0006030	0.005806	0.000078

45.3	**45.4**	**53.4**	**14.2**	**8.1**	**0.0450000**	**0.0133000**	**0.0005985**	**0.005590**	**0.000074**
45.6	**45.7**	**53.8**	**14.2**	**8.1**	**0.0460000**	**0.0136000**	**0.0006256**	**0.005644**	**0.000077**
45.9	**45.9**	**54.0**	**14.0**	**8.1**	**0.0460000**	**0.0137000**	**0.0006302**	**0.005679**	**0.000078**
46.3	**46.0**	**54.3**	**14.6**	**8.2**	**0.0460000**	**0.0137000**	**0.0006302**	**0.005644**	**0.000077**
46.2	**46.1**	**54.5**	**14.4**	**8.3**	**0.0480000**	**0.0141000**	**0.0006768**	**0.005749**	**0.000081**
46.6	**46.5**	**55.0**	**14.1**	**8.5**	**0.0470000**	**0.0140000**	**0.0006580**	**0.005562**	**0.000078**