Energy Sustainable Materials and Design

Boundary Temperature Difference Energy Harvesting

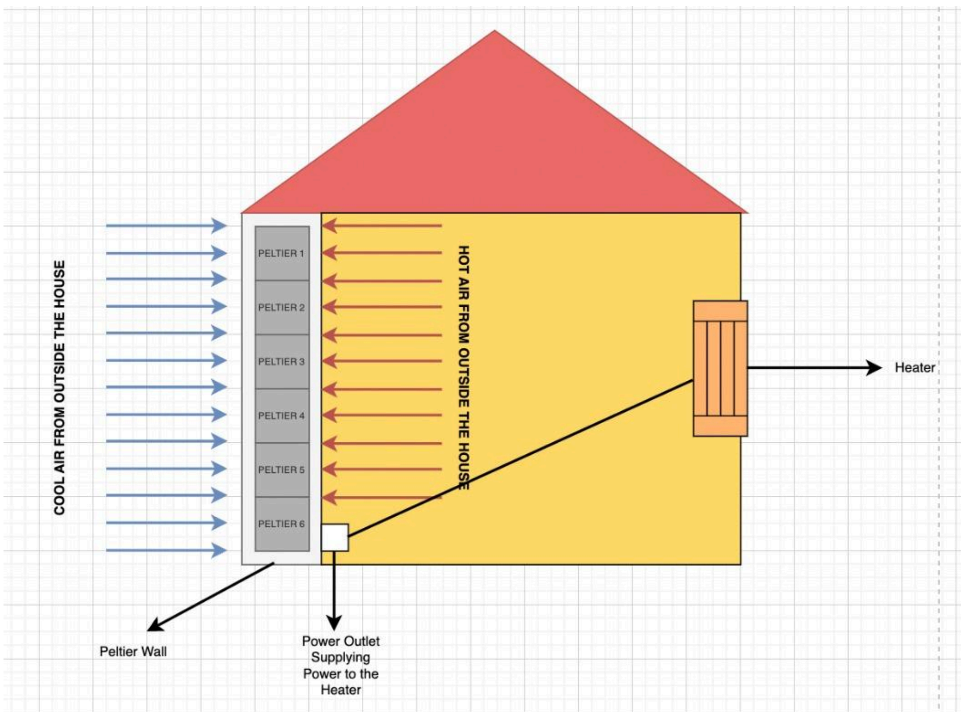


TABLE OF CONTENTS

Introduction

Project Synopsis

Today there is a need for sustainable alternatives to energy generation given the unprecedented rise in electrical consumption. Given the low grid connectivity of Indian villages, and fluctuating electric supply, cost, and energy-effective alternatives are needed. I has developed a sustainable alternative- a Peltier system arrangement in brick walls.

I analysed the feasibility of the proposed installation of Peltier systems in homes in regions with large temperature gradients, where the internal temperature of the home and external temperature have a great difference like in the North and South Pole where temperature difference is large and energy resources are lacking. Other applications include townships with large external-internal temperature differences.

To verify my proposed thermoelectric wall-generator using Peltiers, I performed data collection using several different Peltier arrangements and checked for trends in voltage versus temperature difference. I began prototyping and data collecting began with trend observation for a single-Peltier, using ice and candles to create a temperature gradient, and evolved into a six-Peltier series arrangement.

My data yielded results such that 6 Peltiers generated 3V of current with a 15-degree temperature difference with a 0.2A output current and thus 0.6W of power. When measured for Peltier installation in a home, the number of Peltiers was calculated to be 144000 and the output power was calculated as 14.4kW. On the basis of these results, and my theoretical calculation of heat loss across the brick wall, we find the proposal for Peltier installation in homes feasible for electric power generation.

Reasons for Pursuing the Topic

With electrical consumption reaching an unsustainable pace and our ever-increasing dependence on fossil fuels, finding sustainable alternatives has taken prime importance to address both the energy crisis and prevent the widespread pollution caused by conventional energy sources.

Today only 30% of the world's energy is generated through sustainable and renewable sources of energy, and 70% is produced through non-renewable and polluting energy sources. This low adoption rate of renewable energy sources is caused because of space consumption, high cost, low efficiency, and inconvenience posited by renewable energy source installation.

M project proposes a new form of renewable energy production through the use of thermoelectric generators in the form of Peltier systems. Where most natural forms of energy are being harnessed today, the electric capacity of temperature gradients is not being utilized for electric generation.

I propose the use of Peltier systems and their installation in homes where the temperature gradients across their walls are high enough to generate sufficient current to be fed into the electrical grid. This method addresses several problems:

- It is sustainable and non-polluting

- The installation in the walls of homes makes it space efficient and convenient for installation
- The lower cost of Peltiers makes the use of this form of energy economically viable
- The absence of any mechanical parts removes the cost of maintenance

Hence, through my project, I aim to analyze the electrical and power viability of installing Peltier systems in home walls by analyzing Peltier properties and determining the efficiency of installation in a brick wall or directly across the temperature gradient.

Primary Objectives of the Project

Analyzing the effectiveness of the proposal for Peltier installation in homes, I designed a report with the following objectives:

- Suggest a new form of sustainable, cost-effective, space-efficient, and convenient form of non-polluting renewable energy
- Analyze the voltage, current, and power characteristics of a single Peltier system to determine its effectiveness
- Determine the ideal method of Peltier installation- in the brick walls of the home, or directly across the temperature gradient
- Suggesting potential Peltier arrangement and installation- determining series or parallel arrangement, potential output power, and number of Peltiers required

Abstract

Due to the significant temperature difference between its two walls, Peltier systems, also known as thermoelectric devices, generate an electric current and potential difference. The purpose of this study was to examine prospective Peltier system installations in residences in colder or warmer climates where there is a large temperature difference between the interior room temperature and the outside air temperature. Peltier systems can be installed in various configurations to take advantage of this temperature differential and produce electricity for use in residences. In order to generate renewable energy with little use of space, my investigation examines Peltier systems that have been put directly across cold and warm surfaces as well as through brick insulation.

Background Information

The Peltier module, sometimes referred to as a thermoelectric cooler (TEC) or thermoelectric module (TEM), is a solid-state, mechanically inert device that, when powered on, conducts heat over a large temperature range. The Peltier effect, which was discovered in 1834 by French physicist Jean Peltier, serves as its theoretical foundation.

The Peltier module is architecturally made up of two ceramic electrically isolated yet thermally conducting plates and positive and negative doped semiconductor pellets. Each ceramic plate has an inner surface that is coated with a conductive metal pattern, to which the semiconductor pellets are soldered. All semiconductor pellets can be physically and electrically connected in series using this module design.

While the mechanical parallel connection enables heat to be absorbed by one ceramic plate (cold side) and released by the other ceramic plate, the electrical connection in series produces the required thermal effect (hot side).

Using the Peltier effect, a Peltier element can move heat. When a current is flowing inside the Peltier element, the Peltier effect causes a temperature difference between two sides.

Without altering the connectors or mechanical setup, Peltier elements can be used to cool and heat depending on the direction of the DC current flow. The ability to realise compact designs and the absence of moving parts are additional benefits. A TEC controller regulates the current delivered to the Peltier element.

Under mechanical stress, the Peltier module's solder joints and semiconductor pellets may crack. arcTECTM-structured Peltier modules have been created by CUI Devices. Their distinct construction makes them resistant to thermal fatigue, enhancing the performance, dependability, and cycle life of the module.

First off, CUI Devices Peltier modules with arcTECTM structures include conductive resin in place of solder joints on the cold side of the modules. This resin, which is mechanically more flexible than solder, permits thermal expansion and contraction during repeated thermal cycles of the Peltier modules and aids in reducing stress and fracture in conventional Peltier module structures, leading to improved thermal connection, superior mechanical bonding, and performance that does not noticeably degrade over time.

In place of the more typical low-temperature bismuth solder (BiSn, 138°C), the remaining solder joints in the arcTEC structure are formed of high-temperature antimony solder (SbSn, 235°C). The Peltier module's reliability is increased by the superior thermal fatigue resistance and shear strength of antimony solder, which is more resistant to mechanical stress than bismuth solder. Additionally, a silicon rubber moisture-proof layer for mechanical compliance is included with the CUI Devices Peltier module. On request, additional moisture-proof coatings such epoxy resin are made available.

The reliability and service life of the Peltier module are significantly impacted by the combined action of the thermally conductive resin and SbSn solder connection in the arcTEC structure. The Peltier life expectancy is directly correlated with the

The higher thermal performance of the Peltier module with arcTEC structure is in addition to its superior dependability and module life. The integrated P/N components in the Peltier module are 2.7 times bigger than the elements found in other thermoelectric modules currently on the market because they are produced from high-quality silicon ingots. The thermal performance may be greatly affected by the larger elements' faster and more even cooling. The unit built by the arcTEC structure has a homogeneous temperature distribution over its ceramic substrate surface, according to an infrared inspection.

Conventional units, on the other hand, show various temperature changes, which raises the possibility of reduced cooling performance and shortened service life. The P/N element's poor quality, the element's small size, or the solder's poor quality may be the source of these temperature differences. Field tests show that the modules with arcTEC structure have improved cooling time by more than 50% compared to competing modules. This significant difference can be attributed to the size and quality of the P/N elements and the higher reliability of the arcTEC structure. An increase in the number of thermal cycles and resistance change in conventional modules will widen the gap.

The most recent data on the thermoelectric properties of cooling materials suitable for use near room temperature have been reviewed. The materials discussed include Bi2Te3 and its pseudo-binary Bi_2Te_3-Sb_2Te_3 and Bi_2Te_3-Bi_2Se_3 alloys, with the major emphasis on the pseudo-ternary alloys in the system Bi_2Te_3-Sb_2Te_3-Sb_2Te_3. The data presented include (1) the Seebeck coefficient, thermal conductivity, and figure of merit as a function of electrical resistivity; (2) the variations in the lattice thermal conductivity with alloying; (3) the temperature dependence of thermoelectric properties of the pseudo-ternary alloys. Presented also are the results of a recent study of growth variables on the thermoelectric properties of these alloys.

A thermocouple is a sensor that measures temperature. It is made up of two different metals that are attached at one end. A voltage is produced that is related to temperature when the junction of the two metals is heated or cooled. The thermoelectric circuit has a steady current when two wires made of different metals are linked at both ends and one of the ends is heated.

The net open circuit voltage (also known as the Seebeck voltage) depends on the junction temperature and the make-up of the two metals if this circuit is broken at the center. This indicates that a voltage is generated that is related to temperature when the junction of the two metals is heated or cooled.

Similar applications of the Seebeck effect include uses in thermoelectric generators. A temperature difference and heat flow are transformed into a useful DC power source by thermoelectric generators (TEG), which are solid-state semiconductor devices. The Seebeck effect is used by semiconductor thermoelectric generators to produce voltage. The voltage that is generated drives electrical current, which in turn creates usable power at a load.

The operation of a thermoelectric cooler is the opposite of that of a thermoelectric generator. The thermoelectric cooler generates an electrical current when a voltage is applied. The Peltier effect is produced by this current. Heat is transferred from the cold side to the hot side as a result. A solid-state semiconductor device also includes a thermoelectric cooler. The parts are the same as those in a thermoelectric generator, however most of the time their designs are different.

Thermoelectric coolers (Peltier coolers), as opposed to thermoelectric generators, are used to add or remove heat. Thermoelectric cooling has numerous uses in thermal management, temperature control, heating, and cooling.

Working Principle

A phenomenon known as the Seebeck effect occurs when a temperature difference between two semiconductors or electrical conductors that are not the same results in a voltage difference.

The heated electrons flow toward the cooler conductor or semiconductor when heat is applied to one of the two semiconductors or conductors. Direct current (DC) travels through an electrical circuit if the pair is connected.

In 1821, German physicist Thomas Seebeck discovered that a voltage develops in a circuit when two wires made of different metals are joined at two ends to form a loop and kept at different temperatures. As a result, the phenomenon has been given his name.

That metal heats up when heat is applied to one of the two semiconductors or conductors. As a result, this metal's valence electrons move toward the cooler metal. Electrons move to areas where there is less heat and energy, in this case. Direct current flows through the electrical circuit in which the metals are connected.

This voltage, on the other hand, is only a few microvolts per kelvin temperature difference. Temperature equilibrium is eventually reached as thermal energy is continuously transferred from the warmer metal to the cooler metal.

The Seebeck effect and the thermoelectric effect it produces can be reversed. Valence electrons will flow in the opposite direction and the DC current's direction will also change if the hot and cold junctions are switched.

Some applications of the seebeck effect include:

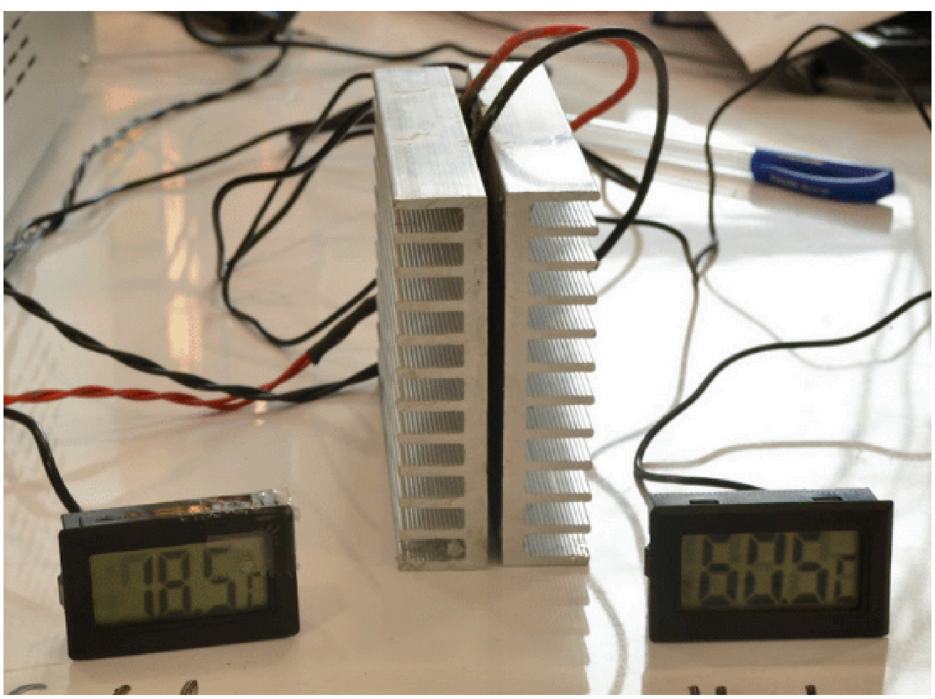
- in thermopiles (that is, in a setting where a number of thermocouples are connected in series);
- in thermoelectric generators that function as heat engines;
- in power plants to convert waste heat into (extra) power;
- in automobiles as automotive thermoelectric generators, to increase fuel efficiency;
- in high-frequency electrical power sensors;
- to verify material degradation and radiation level, and to perform strength testing of radioactive materials (which vary with temperature over a given time period); and
- to actuate security alarms or switches.

These are some applications of my research. Other extensions can be found in the extensions section.

Evolution of Engineering

In order to analyze the Peltier systems, I first created a basic prototype in order to verify and test the working of Peltier systems. Hence, this prototype can be considered a prelimnary trial of method. The data for the single Peltier system was found using the following prototype arrangement.

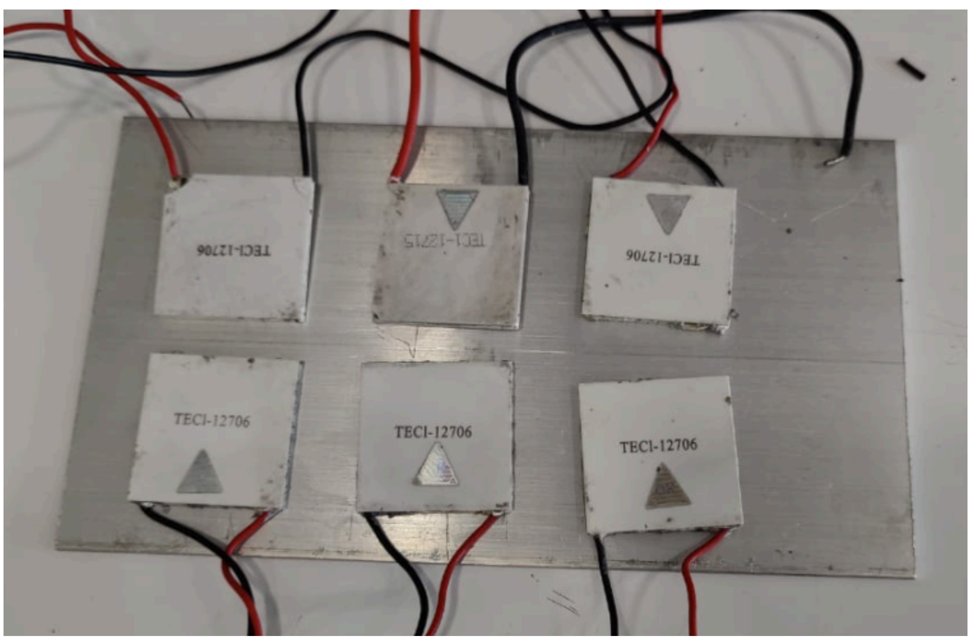
A single Peltier was attached to two conducting plates, using a thermal conducting plate. The sides of the Peltier were cooled and heated respectively using several reagents, including ice, dry ice, and heating filaments to simulate the real life application of the Pelties, and a current and voltage were generated from the temperature difference.



Prototype 1: Preliminary Trial of Method

After I successfully executed the preliminary trial of method, and got substantial readings, I tried several different methods of optimizing my output current and voltage. I then developed a second prototype, to test the effect of increasing the number of Peltiers, and their arrangement in series and parallel, to analyze power output trends.

My second prototype consisted of a series arrangement of 6 Peltiers placed between two conducting sheets with a thermal paste. Again, different heating and cooling reagents were tried, and the temperature differences noted.



Prototype 2: 6 Peltier testing prototype

Finally, for out Seebeck calculations, and final data collection, I created a more advanced prototype with better heating and cooling facilities, and more structural integrity. I used an eight Peltier system connected in series in order to optimize output. A heating element extracted from a regular household iron, and enhanced with coils and cutoff controllers, was used to heat the warm side. For the cold side, a compartment for the storage of icepacks was created. Hence, a large enough temperature difference of upto 20 degrees celsius was created. Because this is an experimental, lab controlled method, I had to use heating coils and cooling packs, but in real life applications, these temperature differences are pre-exisiting, thus no external cooling and heating will be required. Cooling and heating was done only for purposes of simulation.

Methodology

Theoretical Analysis

Where in the following calculations V is the output voltage, S is the Seeback coefficient, DT is change in temperature, n is the number of Peltiers in the arrangement, Th is the hot temperature in K, Tc is the cold temperature in K, and R is the resistance in the circuit.

$$V = S \times DT \times R$$

$$S = n\int_{Tc}^{Th} (S_p - S_n)dT$$

$$S = n\int_{Tc}^{Th} (-4.5312 \times 10^{-6} \times T^3 + 0.0012T^2 + 0.8712T - 27.09 - (-1.6797 \times 10^{-5} \times T^3 + 0.02219 \times T^2 - 9.356T + 1054.78))dT$$

$$S = n\left(\frac{61329Th^4}{20000000000} - \frac{2099Th^3}{300000} + \frac{3196Th^2}{625} - \frac{108187Th}{100} - \frac{61329Tc^4}{20000000000} + \frac{2099Tc^3}{300000} - \frac{3196Tc^2}{625} + \frac{108187Tc}{100}\right)$$

Given the statistics that average temperature in temperate regions in winter months is 7.5ºC which is 280.5K, and the room temperature is maintained at 25ºC. Similarly, average summer temperature in the torrid zone is recorded at 40ºC. Hence, using this relation: direct temperature gradient obtained is in a one Peltier arrangement is, and assuming resistance is 10Ω:

$$V = n\left(\frac{61329Th^4}{20000000000} - \frac{2099Th^3}{300000} + \frac{3196Th^2}{625} - \frac{108187Th}{100} - \frac{61329Tc^4}{20000000000} + \frac{2099Tc^3}{300000} - \frac{3196Tc^2}{625} + \frac{108187Tc}{100}\right) \times 10 \times DT$$

Single Peltier Voltage Output in Cold Regions:

$$V = \left(\frac{61329(298)^4}{2000000000} - \frac{2099(298)^3}{30000} + \frac{3196(298)^2}{62.5} - \frac{108187(298)}{10} - \frac{61329(280.5)^4}{2000000000} + \frac{2099(280.5)^3}{30000} - \frac{3196(280.5)^2}{62.5} + \frac{108187(280.5)}{10}\right) \times 17.5$$

$V = 1276385.66665957\ \mu V \approx 1.3V$

Single Peltier Voltage Output in Warm Regions:

$$V = \left(\frac{61329(313)^4}{2000000000} - \frac{2099(313)^3}{30000} + \frac{3196(313)^2}{62.5} - \frac{108187(313)}{10} - \frac{61329(298)^4}{2000000000} + \frac{2099(298)^3}{30000} - \frac{3196(298)^2}{62.5} + \frac{108187(298)}{10}\right) \times 15$$

$V = 974434.8605272\ \mu V \approx 1V$

Similarly, for the 6 Peltier arrangement, the theoretical calculation yields the following result.

For cold systems:

V= 7.8V

For warm systems:

V= 6V

This calculation assumes the installation of the Peltier system directly across the temperature gradient.

Heat loss through a brick wall can be calculated using the literature values of a temperature drop of 5.7% per unit area.

Hence, the temperature of 313K externally becomes 295K. Similarly, the following data is obtained using the relation:

Ambient Temperature	Peltier Temperature Through Wall
313K	295K
298K	281K
280.5K	264.5K

Table 1: Ambient temperature and temperature through brick calculations

Hence, using above calculations for a 6 Peltier home installation system, the following data will be obtained for theoretical Peltier installation in brick walls.

For hot systems:

V= 4885141.14608304 V

For cold systems:

V= 6447922.65759288 V

However, this yields significant results for a 6 Peltier system, and can be further increased by increasing the number of Peltier systems installed in the brick wall. The data can be reconfirmed with an experimental analysis and data collection.

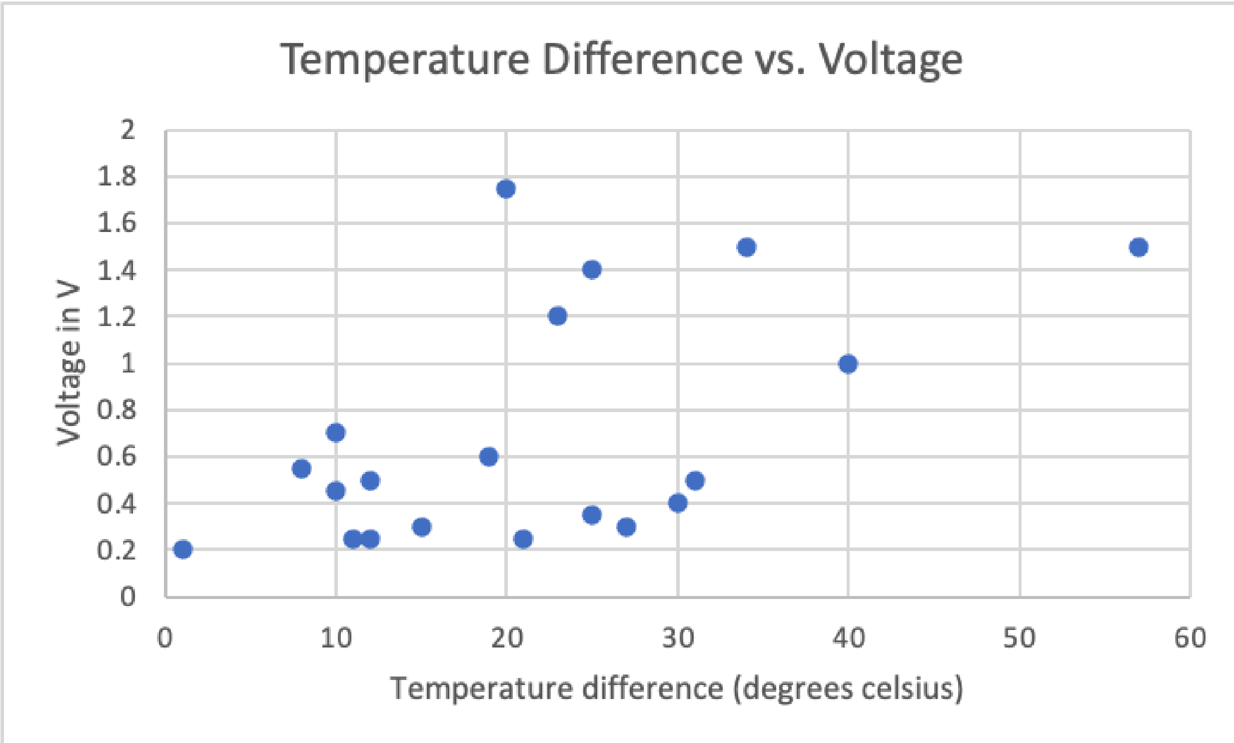
Experimental Analysis

To verify the theoretical data and perform analysis of a Peltier device for better understanding, I worked on a single Peltier system and obtained the following data.

Bottom Temp	Top Temp	Temp Difference	Voltage
39	38	1	0.2
25	17	8	0.55
60	50	10	0.7
17	7	10	0.45
31	20	11	0.25
53	41	12	0.5
24	12	12	0.25
10	-5	15	0.3

30	11	19	0.6
9	-11	20	1.75
24	3	21	0.25
30	7	23	1.2
40	15	25	1.4
30	5	25	0.35
39	12	27	0.3
29	-1	30	0.4
30	-1	31	0.5
25	-9	34	1.5
30	-10	40	1
45	-12	57	1.5

Table 2: Temperature difference and voltage data of a single Peltier system



Graph 1: Scatterplot of temperature difference and voltage obtained through experimental data

From the graph I can conclude a weak correlation between temperature difference and voltage, but a generally increasing trendline. Additionally, tis suggests that at temperature differences between 15 degrees and 20 degrees celsius (as measured by the theoretical model), the voltage is around 0.5 V, suggesting a loss in energy in real life testing.

For further testing, to analyze the voltage output from a 6V Peltier system, I created a prototype for testing purposes.

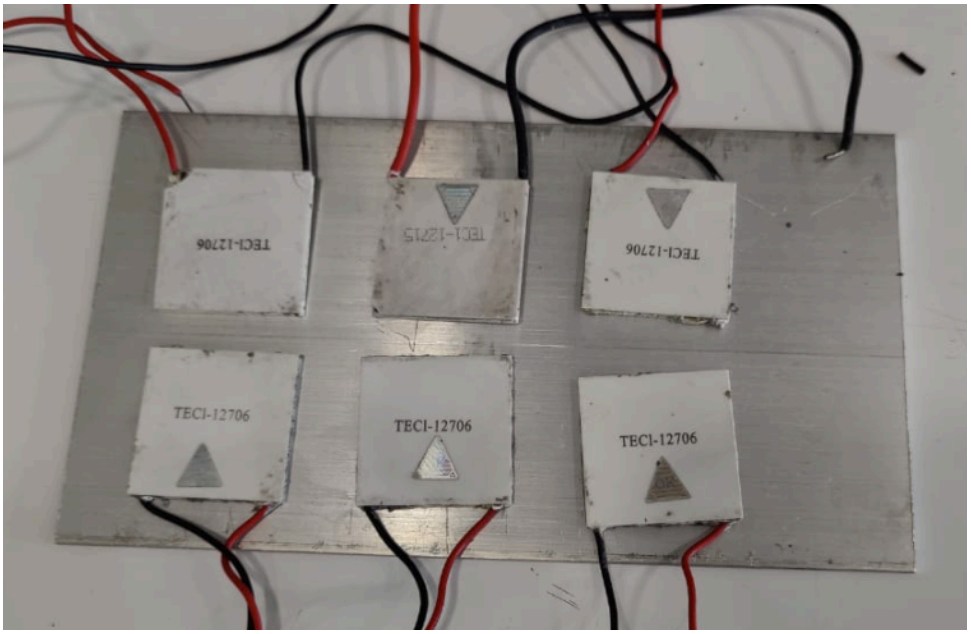


Image 1: Internal section of the Peltier prototype consisting of a 6 Peltier module

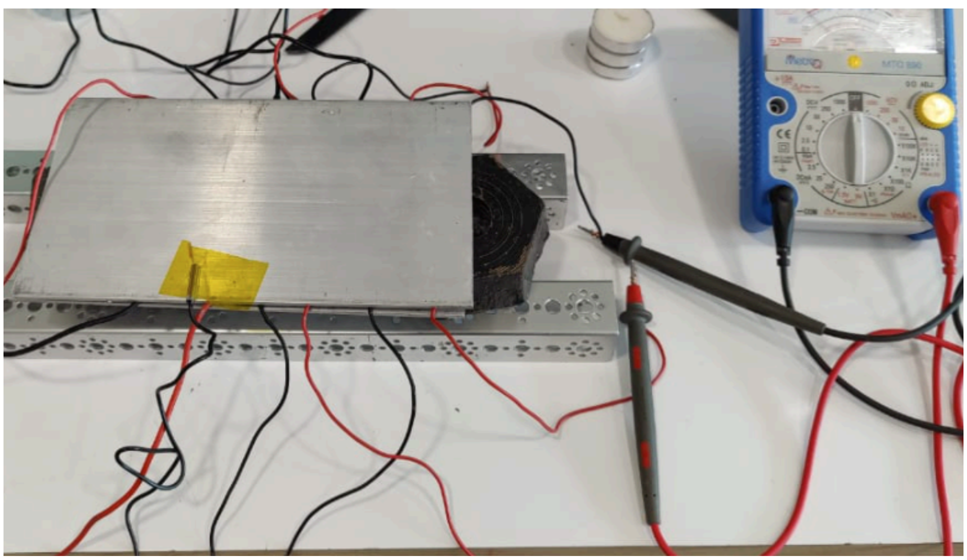


Image 2: Image of final Peltier prototype, and experimental arrangement

I also tested the 6 Peltier data set and got consistent data with a substantial trend line.

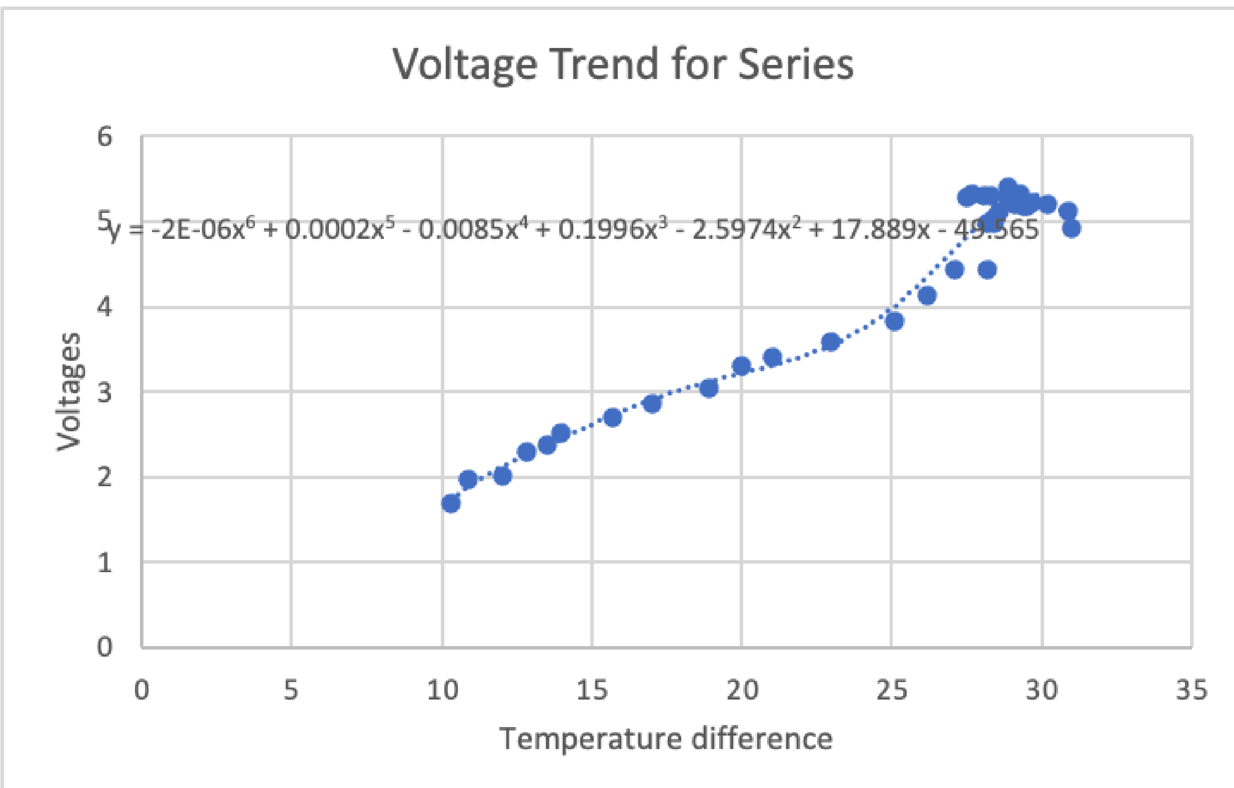
Following is my experimental data:

Warm side temperature	Cold side temperature	Voltage obtained	Temperature difference
29.80	19.50	1.70	10.30
30.90	20.00	1.98	10.90
32.60	20.60	2.01	12.00
33.90	21.10	2.30	12.80
35.00	21.50	2.38	13.50
36.00	22.00	2.53	14.00
38.20	22.50	2.71	15.70
40.10	23.10	2.86	17.00
42.50	23.60	3.04	18.90
43.00	23.00	3.30	20.00
45.00	24.00	3.40	21.00
47.00	24.00	3.60	23.00
49.60	24.50	3.84	25.10

50.90	24.70	4.14	26.20
51.80	24.70	4.44	27.10
52.50	25.00	5.28	27.50
52.80	25.10	5.33	27.70
53.50	25.40	5.31	28.10
53.60	25.40	4.98	28.20
53.60	25.40	4.43	28.20
53.70	25.40	5.31	28.30
52.80	24.40	5.04	28.40
53.60	25.20	4.99	28.40
53.50	24.90	5.12	28.60
52.40	23.50	5.40	28.90
52.10	23.20	5.29	28.90
52.80	23.70	5.21	29.10
52.60	23.30	5.32	29.30
51.70	22.30	5.18	29.40
52.80	23.30	5.18	29.50

51.00	21.30	5.23	29.70
50.40	20.20	5.21	30.20
49.60	18.70	5.13	30.90
48.00	17.00	4.93	31.00

Table 3: Temperature difference vs. Voltage trend line for 6 Peltiers connected in Series



Graph 2: Voltage vs. temperature difference graph for 6 Peltiers

Hence, for a temperature difference of between 15 and 20 degrees celsius, a voltage of 3V is obtained. This depicts the a trend in voltage observations where:

$$Voltage\ of\ n\ Peltier\ system = 0.5 \times n$$

Where 0.5 is chosen because 0.5 is the voltage of a single Peltier testing. The current of 2A was constantly supplied which was checked in the experimental tests.

On average 9600 bricks are required for a 1200 sq. foot home, and the dimensions of each brick are 225mm x 112.5mm x 75mm, where the vertical cross section is 225mm x 112.5mm. Hence, number of Peltiers of dimensions 40mm x 40mm per brick is:

$$Number\ of\ Peltiers = \frac{225 \times 112.5}{40 \times 40} = 15\ Peltiers$$

Hence total number of Peltiers is:

$$Peltiers\ in\ a\ home = 15 \times 9600 = 144000$$

And voltage output is:

$$Voltage\ output\ from\ 144000\ Peltiers = 0.5 \times 144000 = 72000V$$

Power output:

$$Power = voltage \times current$$

$$Power = 72000 \times 0.2 = 144000W = 14.4kW$$

Although these results may vary significantly because of external conditions, variations in trends with higher concentrations of Peltier attachments and extrinsic errors, a result of this magnitude favors the installation of Peltier systems in homes. Following is a block diagram of the installation of Peltiers in home and their connection to the home grid system for a cold region with internal heating:

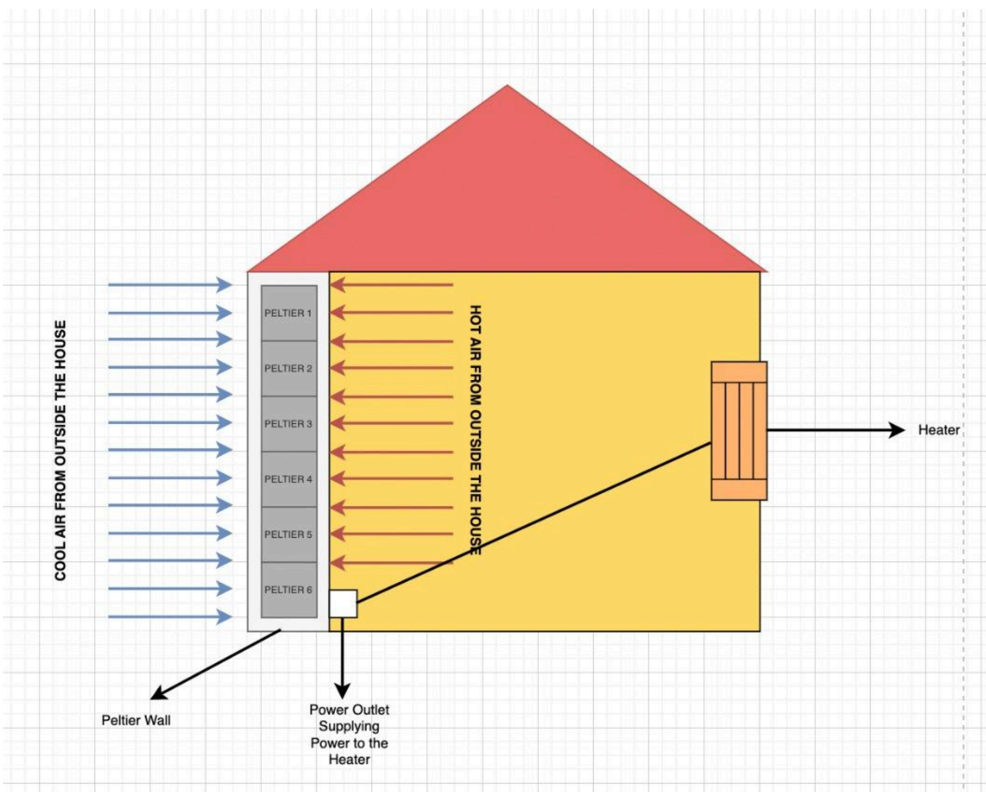


Image 3: Blok diagram of Peltier arrangement in homes as proposed by my models

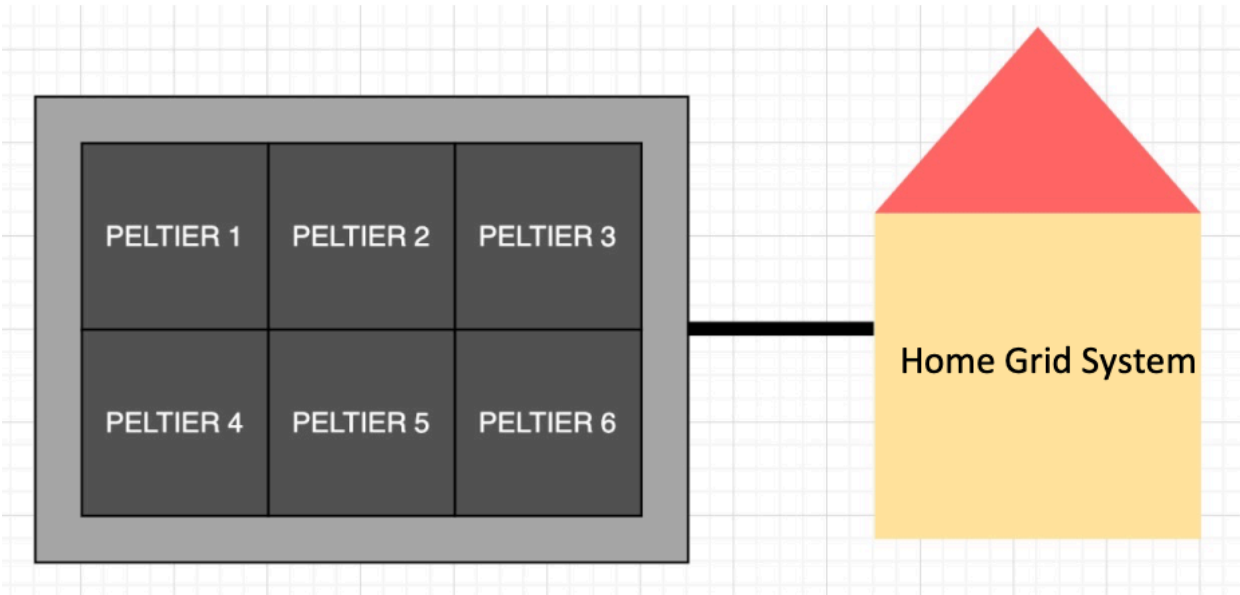


Image 4: Peltier connection to the home grid system

Similar to this, my 8 Peltier system also yielded some significant results that align with the already pre-analyzed trends. Following is the data for the 8 Peltier system.

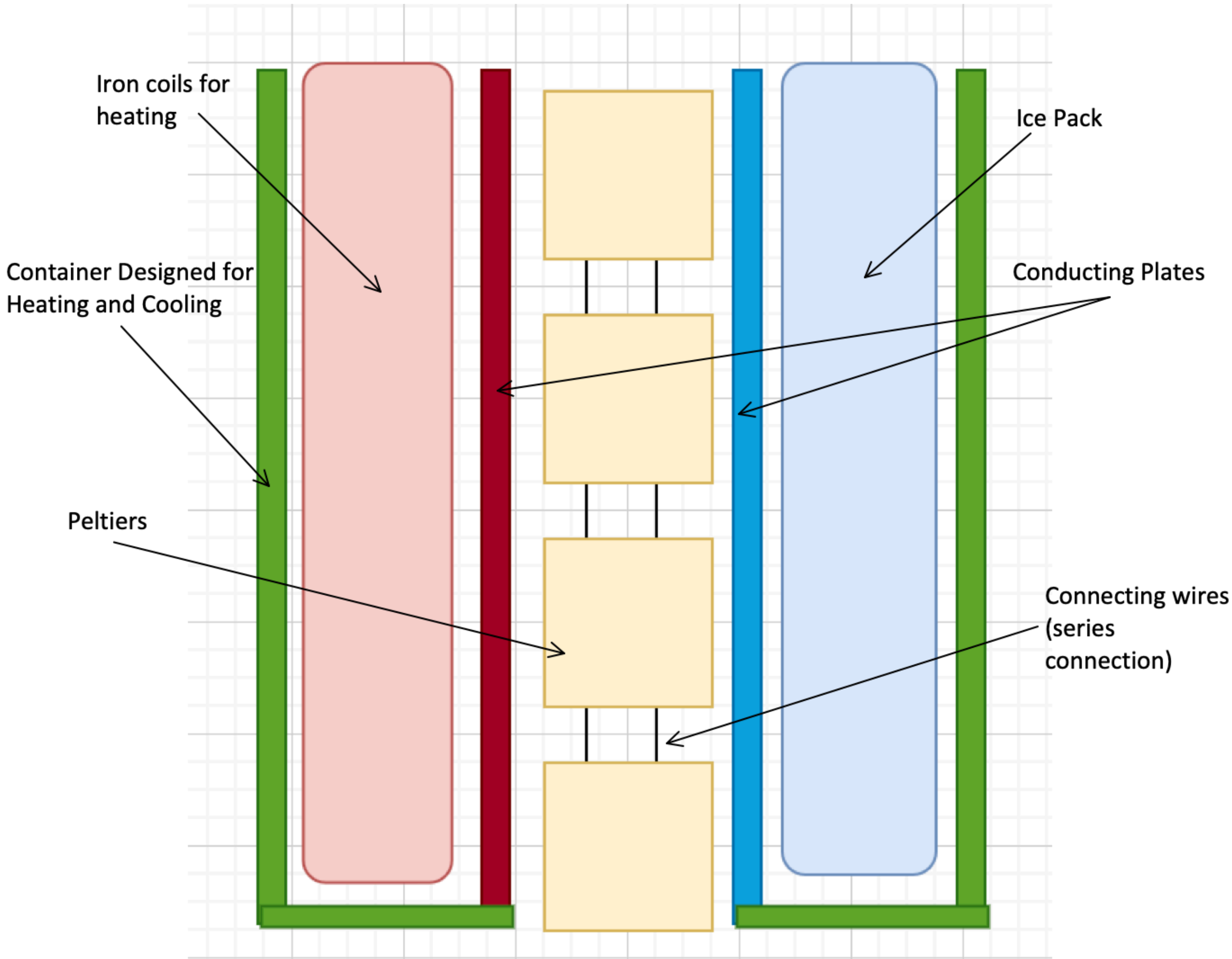


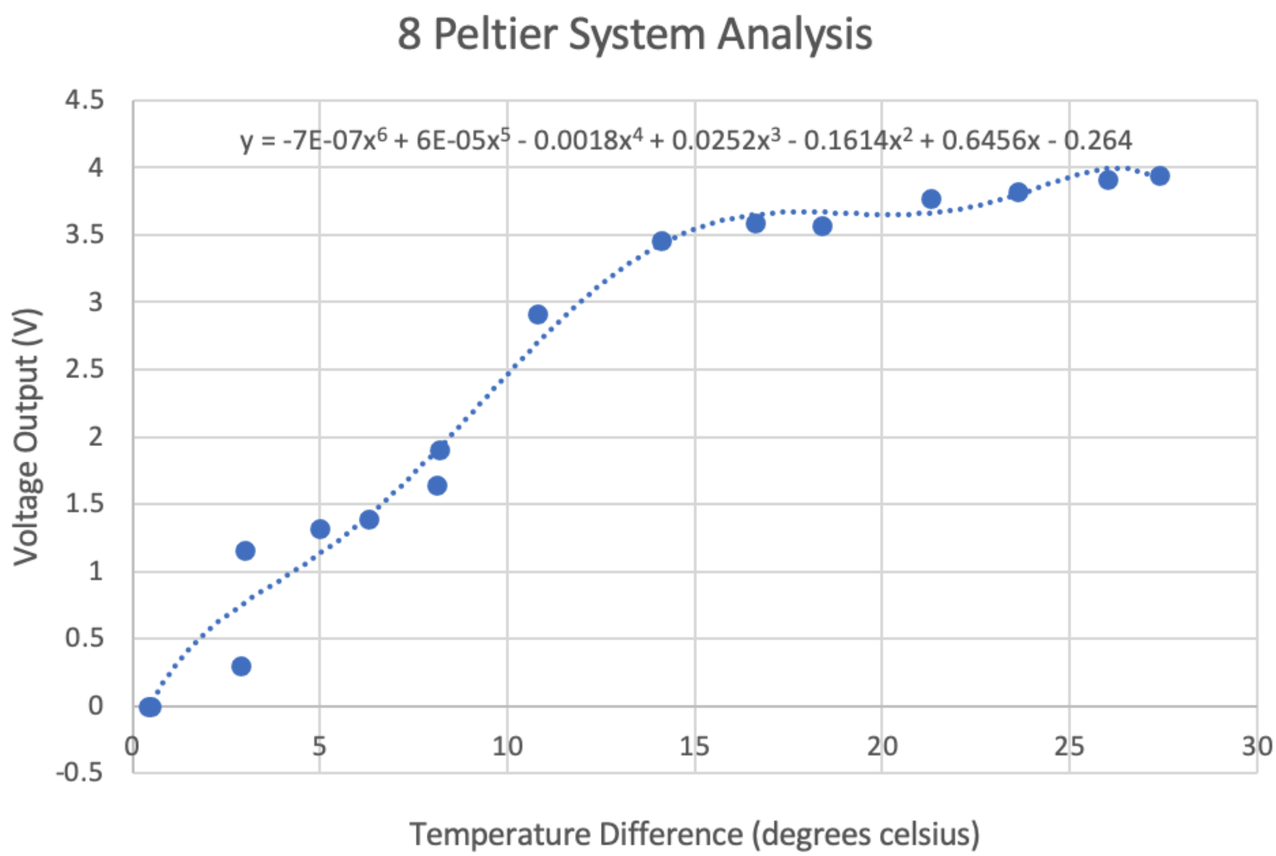
Image 5: Experimental Set Up (diagrammatic representation)

Upon conducting the experiment, I found the following data:

Cold Side Temperature	Hot Side Temperature	Voltage Generated
24.2	24.6	0
24.5	25	0
25.8	28.7	0.3

21	24	1.16
18	23	1.32
15	21.3	1.39
11.8	19.9	1.64
10.1	18.3	1.9
5.8	16.6	2.91
2.2	16.3	3.46
0.3	16.9	3.59
-0.2	18.2	3.57
-1.6	19.7	3.77
-1.5	22.1	3.82
-0.8	25.2	3.91
-0.1	27.3	3.94

Table 4: 8 Peltier System Analysis Graphs



Graph 4: 8 Peltier System Analysis

The graph can be seen approaching an asymptotic value of 4V, as was seen in the 6 Peltier graph. Although the trend line may be increasing exponentially, the values in reality in the given range of measurement approach a given asymptote, which in every measured case can be approximated with the forumla:

$$Voltage\ of\ n\ Peltier\ system = 0.5 \times n$$

Efficiency and Feasibility Analysis

The collected data was measured over a period of 5 minutes. Given the average consumption of an Indian household is 1.25 kWh every hour, I can understand the efficiency and Peltier requirements in an average home.

$$Peltier\ Power\ Output\ in\ 1\ hour = 14.4 \times 12 = 172.8kWh$$

$$Ratio\ of\ ideal\ output\ to\ required\ output = \frac{1.25}{172.8}$$

$$Number\ of\ Peltiers\ required = \frac{1.25}{172.8} \times 144000 = 1042$$

Hence 1042 Peltiers are required for the generation of the ideal energy required for a home. Considering the average cost of the Peltier to be 150 INR, I can consider the cost of home Peltier installations can be approximated to 1,56,300 making it cost-efficient.

Similarly, the 8 Peltier system will also lead with results similar to the above data, because power output is the same, because the voltage per Peltier is the same, and the current output is also maintained at approximately 0.2A

Conclusion and Discussion

Conclusion

My collected data analyzes the installation of Peltier devices in homes with large temperature gradients across their walls. I have created both a theoretical model that verifies the use of Peltier modules and presents the ideal case for installation in homes, measuring both the energy generation on direct installation and on installation through a brick wall. My experimental approach determines the real life applications of Peltiers and creates a trend that enables proposals for Peltiers on larger scale with greater availability of space in households. Both of my data sets show coherence with theoretical values with a deviation close to 50% indicating 50% error margin in the experimental use of Peltier contrasted with their theoretical analysis.

Discussion

Given the viability of my data, I conclude the output power to be very high in relation to power supply needed in households. Hence, through my data collection and calculations it becomes evident that Peltier systems can be used widely in households as thermoelectric energy generators and thus my proposal is supported by both theoretical calculations and empirical data. Additionally, in order to further test the viability of this project, I is working on improving the data collection method by inserting Peltier devices inside the cross section of a brick and measure the output current, voltage and power received in order to simulate real installation situations. However, given the data obtained through experimental analysis, my proposal for Peltier devices to generate heat from boundary temperature differences has great scope and can be implemented as a sustainable alternative.

Bibliography

Ismail, Yehea, and Ahmed Al-Askalany. "Thermoelectric Devices Cooling and Power Generation." Accessed November 14, 2022. https://arxiv.org/pdf/1403.3836.pdf.

Jaziri, Nesrine, Ayda Boughamoura, Jens Müller, Brahim Mezghani, Fares Tounsi, and Mohammed Ismail. "A Comprehensive Review of Thermoelectric Generators: Technologies and Common Applications." *Energy Reports*, December 24, 2019. https://doi.org/10.1016/j.egyr.2019.12.011.

Jouhara, Hussam, Navid Khordehgah, Sulaiman Almahmoud, Bertrand Delpech, Amisha Chauhan, and Savvas A. Tassou. "Waste Heat Recovery Technologies and Applications." *Thermal Science and Engineering Progress* 6 (June 2018): 268–89. https://doi.org/10.1016/j.tsep.2018.04.017.

Omega. "Thermocouple Hub." https://www.omega.com/en-us/, n.d. https://www.omega.com/en-us/resources/thermocouple-hub.

www.meerstetter.ch. "Peltier Element Applications," n.d. https://www.meerstetter.ch/customer-center/compendium/33-peltier-element-applications.

www.meerstetter.ch. “Peltier Elements,” n.d. https://www.meerstetter.ch/customer-center/compendium/70-peltier-elements.

KYOCERA GROUP GLOBAL SITE. “Peltier Module (Thermoelectric Module) - Energy Conversion Devices - KYOCERA,” n.d. https://global.kyocera.com/prdct/ecd/peltier/.

Tec2Med. “Peltier Module: Mechanism, Pros, Cons, Application, Specification, Etc,” December 5, 2020. https://www.tec2med.com/peltier-module/.

Arrow.com. “Peltier Modules Ideal for Cooling Applications.” Accessed January 17, 2023. https://www.arrow.com/en/research-and-events/articles/peltier-modules-ideal-for-cooling-applications.

Thermoelectric. “Power Generation,” n.d. https://thermal.ferrotec.com/technology/thermoelectric-reference-guide/thermalref13/.

Satyajeet Vispute. “Pros, Cons, and Applications of the Peltier Effect Explained.” ScienceStruck. ScienceStruck, 2017. https://sciencestruck.com/peltier-effect-explained.

www.sciencedirect.com. “Temperate Climate - an Overview | ScienceDirect Topics,” n.d. https://www.sciencedirect.com/topics/earth-and-planetary-sciences/temperate-climate#:~:text=Temperate%20climates%20of%20the%20Earth.

www.ykyb.cn. “Thermal Resistance/Thermocouple_Pressure and Temperature Instrument Series_Product-Dalian Yoke Instrument & Meter Co.,Ltd.” Accessed November 14, 2022. https://www.ykyb.cn/en/?product/178.html.

Yim, W.M., and F.D. Rosi. “Compound Tellurides and Their Alloys for Peltier Cooling—a Review.” *Solid-State Electronics* 15, no. 10 (October 1972): 1121–40. https://doi.org/10.1016/0038-1101(72)90172-4.