

Thermoelectric Generator

Final Report

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Table of Contents

Requirements Specification	3
Project Overview.....	5
Introduction	6
Budget Analysis.....	7
Block Diagram	8
Functional Description of Blocks.....	9
Sub System Details	11
Thermosyphon	12
Thermoelectric Generator	13
Cooling System.....	14
User Interface and Inverter.....	15
Encasement.....	20
Testing Results	21
Recommendations	22
Appendices.....	23
Appendix A: Thermosyphon Parts	24
Appendix B: Thermoelectric Generator Parts.....	25
Appendix C: Cooling System Parts	26
Appendix D: User Interface and Inverter Parts.....	28
Appendix E: Encasement Parts	30

Requirements Specification

Background: There is a large interest in today's market for sustainable energy. Consumers are looking for devices that can provide electricity to their home, not only when power is unavailable but also in addition to their normal usage. The trouble with most products is that they are complex, bulky and expensive. Additionally, energy sources for these generators are not always available (wind/solar/fossil fuels).

What is needed is a low cost, storable, easy to use device that provides supplemental energy to the home or emergency electricity if the power is out. We believe that a generator using an already built fireplace as the energy source is the natural choice for this request. The major benefit of this generator is that the combustion chamber is already available and safe, users know how to use it and fuel is readily available.

The Deliverables: There are five deliverables as listed below:

1. Working Prototype
2. System Specifications
 - a. Design Concept
 - b. Block Diagram
 - c. CAD Drawing and Analysis
3. Circuit Schematics and Simulation Results
4. User's Manual
5. Bill of Materials

Principles of Operation: The user will begin by installing the generator to their existing fireplace. The device will not be permanent, but instead will be installed only when used. The actual generator will sit on the hearth outside of the fireplace. A device will extend into the fireplace to collect heat and transport it to the generator. Once a fire is built and the chamber reaches a sufficient temperature the generator will begin to produce electricity and notify the user that they can plug in a device. The user will then be able to plug in any electrical device which uses less than 150W of power to a standard NEMA Type B outlet.

Special Restrictions: The generator must be considered safe with no parts exposed that could cut or burn the user. Additionally, the electrical aspects should present no risk of fire or shock. The NEMA Type B outlet should be properly grounded.

Input: The input of the device is a wood burning fire in an open hearth fireplace. The heat from the fire will serve as the energy source for the electric generator. Closed stoves and gas burning fireplaces will not be supported.

Output: The generator's output connector will consist of a NEMA Type B electrical outlet. The outlet will provide 125 VAC \pm 15% and at least 1.5 A \pm 10% at 60 Hz \pm 0.5%. For comparison, most normal household electrical outlets in the United States provide approximately 125 volts and 15 amps at 60 Hz when connected to the power grid.

Technical Requirements: The following requirements must be met.

1. Size – The device should be small and light enough to be carried by a single person. The generator should be no greater than 0.6 x 0.6 x 0.46 meters (2 x 2 x 1.5 feet). This does not include the device for collecting and transporting heat from the fire to the generator.
2. Weight – The device should not weigh more than 22.7 kg (50 lbs).
3. Installation – The generator will sit on the hearth and a device will be extended into the fire for heat collection. There will be no permanent attachments such as bolts or screws to be affixed prior to use.
4. Harmful Gases – The device should not compromise the existing effectiveness of the fireplace to route harmful gases (carbon dioxide, carbon monoxide, nitrogen oxides and aldehydes) out from the house. Due to the large variety of sensors needed along with the associated costs, this will be judged by visually observing if there is a change to the amount of smoke in the room when the device is in use compared to when it is not in use.
5. Nature of Fuel – The device will work with a fire built with wood logs (not wood chippings or sawdust). The user will not be required to cut the logs to certain dimensions, provided the logs will fit in the fireplace.
6. User Intervention – The user will be responsible for maintaining the fire. An indicator on the device will notify the user if the fire is not hot enough (sufficient power is not being produced; see Indicators and Controls). The device should not require the user to burn more than 25 pounds of wood per hour.
7. Indicators and Controls – The device will indicate visually (e.g. LED) to the user when enough electricity is being generated to run a device. Additionally, the user will be able to cut off power to the outlet by shutting off the device with a switch.
8. Electrical Safety – The electrical system must be grounded by a connection to an existing wall outlet's ground. All internal wires should be able to handle the maximum amount of current in order to prevent electrical fires. Wire that is at least an AWG gage 10 nonmetallic insulated wire will provide this safety.
9. General Safety – Any exposed (outside of the fireplace) surface of the device should not exceed 43 degrees Celsius (110 °F) in order to prevent burning the user.

Project Overview

Introduction

The team set out to design a low cost, storable, easy to use device that provides supplemental energy to the home or emergency electricity if the power is out. The device that the team designed sits on an existing fireplace hearth and uses the heat from the fireplace as an energy source. The wood burning generator answers the call for a sustainable, small, simple home energy source.

The design of the wood burning generator went through three main stages. Each stage was defined by breakthroughs or changes in the method of heat transport. In the first stage (shown in Figure 1), a heat pipe was to be used to transport heat from the fireplace to the device. This approach was simple and required little effort of the part of the user. However, the design proved above the skill level of the team. The second stage (shown in Figure 2) was ushered in when serious design began. A thermosyphon was chosen as the best

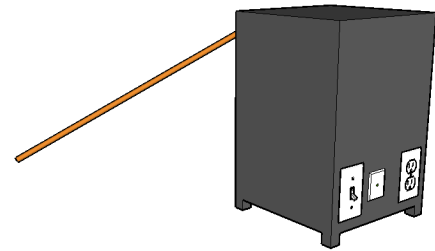


Figure 2: Stage 1 Design

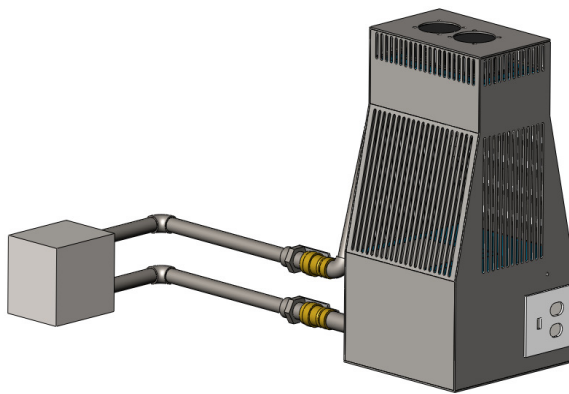


Figure 1: Stage 2 and 3 Design

way to transport the heat and the design was changed accordingly. Rather than one pipe entering the fireplace two were needed; one for steam and one for water returning to the boiler. The third and final stage began when the desired pressure of the thermosyphon boiler was reduced from 180 psi to 1 psi. This change greatly increased the safety of the project while allowing the theory to still be tested.

Construction began during the spring semester. Unfortunately, some design changes were made during this time resulting in increases to research and development costs. Many of these

changes simplified the final result and brought down the actual manufacturing cost as well as making a better product. Construction was completed with some time to spare. Initial testing of the system yielded electrical problems which were fixed before the prototype was ready for unveiling.

The system as a whole worked as designed. The thermosyphon successfully transported heat from the fireplace to the thermoelectric generators, and the cooling system effectively cooled the other side of the thermoelectric generators. Unfortunately, the thermoelectric generators were not able to produce enough power to charge the battery and power the fans due to the steam temperature of the thermosyphon being lowered. By using an external power source for the fans, the circuit was successfully used to charge the battery with the thermoelectric generators.

The wood burning generator project was an excellent test for the mechanical and electrical engineering skills of the team members. Despite challenges and setbacks encountered during both design and construction the team delivered a prototype which satisfied seven out of nine technical requirements and came very close to satisfying the other two (size and weight).

Budget Analysis

The team's total budget for producing a working prototype of the wood burning generator was set at \$850. The team ended the year having spent a total of \$841.01 leaving \$8.99 left over in the contingency fund. The actual cost for producing the device was found to be \$695.16. Mass producing the device could bring this cost even lower.

The research and development cost of the wood burning generator is broken down by subcomponent in Table 1. The actual production cost is shown in Table 2.

Table 1: Research and Development Cost by Sub Function

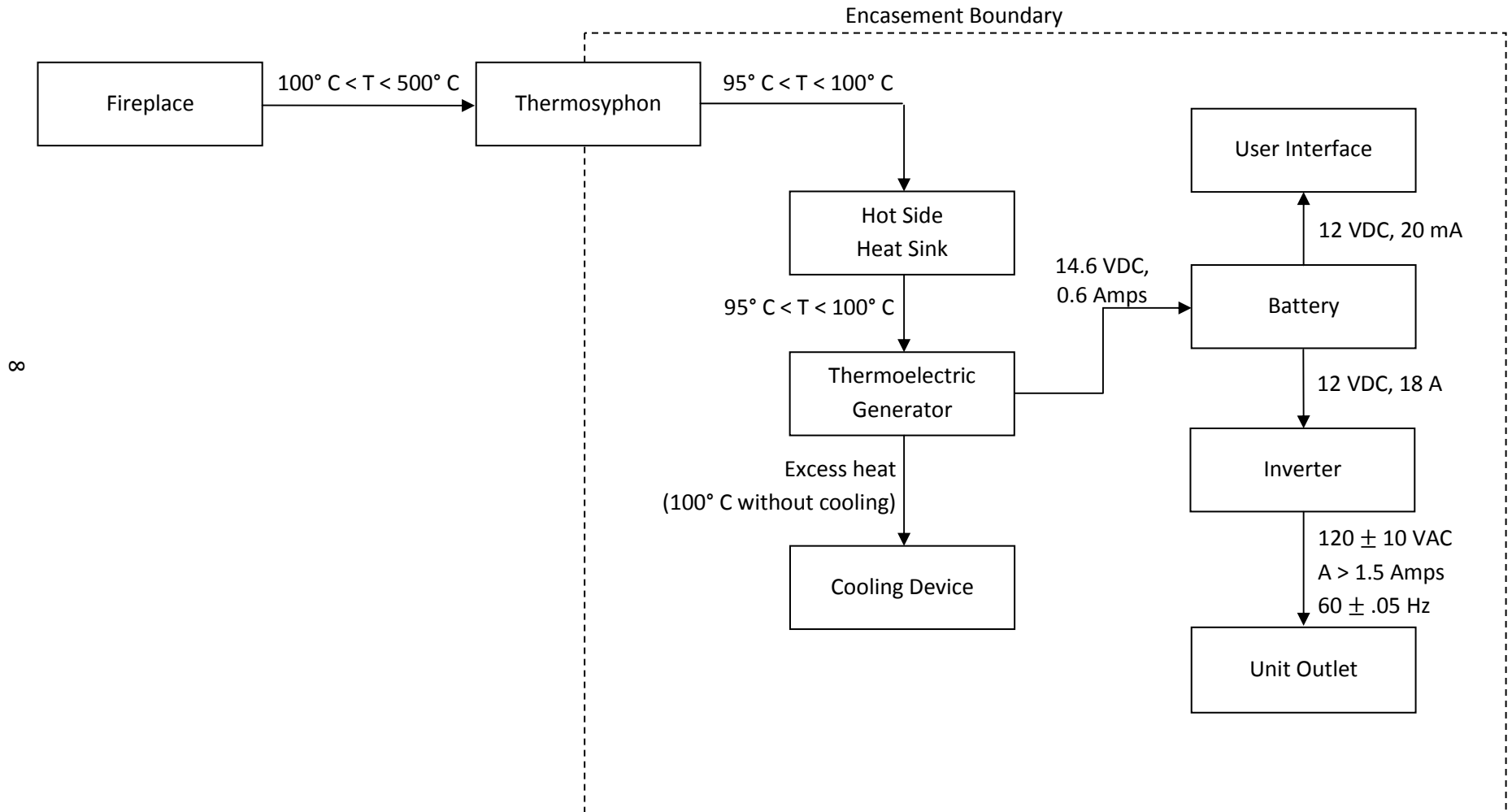
Sub Function	Original	Current
Thermosyphon	\$55.00	\$324.35
Thermoelectric Generator	\$215.00	\$205.36
User Interface	\$65.00	\$113.65
Inverter	\$60.00	\$47.22
Cooling System	\$70.00	\$113.20
Encasement	\$35.00	\$37.23
Contingency	\$350.00	\$8.99
Total	\$850.00	\$850.00

Table 2: Production Cost by Sub Function

Sub Function	Original	Current
Thermosyphon	\$55.00	\$194.85
Thermoelectric Generator	\$215.00	\$205.36
User Interface	\$65.00	\$104.61
Inverter	\$60.00	\$47.22
Cooling System	\$70.00	\$113.20
Encasement	\$35.00	\$29.92
Contingency	\$350.00	\$154.84
Total	\$850.00	\$850.00

The team came close to going over budget, but through judicious spending and careful choice of parts and vendors the total cost was \$841.01 with \$8.99 left over.

Block Diagram



Functional Description of Blocks

Fireplace – The user's fireplace acted as the combustion chamber and contained the wood burning fire. The fire provided temperatures between 100° C and 500° C. The fireplace performed as expected and successfully supplied heat to the thermosyphon.

Input: Wood

Output: Temperatures between 100° C and 500° C

Thermosyphon – The thermosyphon collected heat from the fire in a boiler changing liquid water to water vapor which then exited the fireplace and delivered temperatures ranging from 95° C to 100° C. The vapor condensed in copper coils, was stored in the holding tank and then returned to the boiler. The thermosyphon went through many changes throughout construction (see Thermosyphon section for more information), but performed as anticipated. Improvements could be made by increasing the pressure of the boiler and therefore the temperature of the steam which would increase the energy production of the thermal electric generators.

Input: Temperatures between 100° C and 500° C

Output: Temperatures between 95° C and 100° C

Hot Side Heat Sink – The hot side heat sink transferred the heat from the thermosyphon to the hot side of 10 thermoelectric generators (40mm x 40mm each). It was maintained at temperatures between 95° C to 100° C.

Input: Temperatures between 95° C and 100° C

Output: Temperatures between 95° C and 100° C

Thermoelectric Generator – The thermoelectric generator used the temperature differential that existed between the hot side heat sink and the cold side heat sink to produce approximately 14.6 volts and 0.6 Amps DC or 8.76 Watts (ten individual thermoelectric generators providing approximately 1.5 Volts and 0.60 Amps each assuming a temperature differential of 50° C, all ten placed in series). The thermal electric generators did not produce the amount of power initially expected of them. However, this was due to changes in the thermosyphon. Additional thermoelectric generators or an increase in thermosyphon temperature could potentially increase power output.

Input: Temperature between 95° C and 100° C

Output: 14.6 Volts and 0.60 Amps DC (8.76 watts)

Excess heat (100° C without cooling)

Cooling Device - The cooling device removed approximately 2149 W or more of heat from the thermoelectric generators. This was achieved through forced convection by two fans over ten finned heat sinks. The cooling device successfully cooled one side of the thermoelectric generators. The system might be improved with larger heat sinks or heat sinks made of material with great heat conductance (e.g. copper)

Input: Excess heat (100° C without cooling)

Output: > 2149W heat removed.

Battery – The battery was charged by excess DC voltage produced by the thermoelectric generator. It served as a regulator as the output of the thermoelectric generator fluctuated.

Input: 14 V and 23 A DC (322 W)

Output: 12.7 V and 18 A DC (228.6 W)

Inverter – The inverter converted the DC power from the thermoelectric generator or battery into AC power and stepped up the voltage.

Input: 12 V and 18 A DC (216 W)

Output: 120 \pm 10 VAC, greater than 1.5 Amps, 60 \pm 0.05 Hz

User Interface – This circuitry controlled the flow of power to the outlet as well as indicated to the user when sufficient power was being supplied to the outlet. When the user switch was in the on position, power was available and the user could plug in a device using 200 watts or less. When it was in the off position, no power was supplied to the outlet. Additionally, a single indicator LED would light up when at least 12 volts was being supplied by the battery. The user interface worked as expected except for the low power output of the thermoelectric generators. If the power output from the thermoelectric generators could be increased, then the battery could be charged while operating the fans. The inverter needed to be run from the battery alone. However, the thermoelectric generators simultaneously charged the battery.

Input: 12.7 V DC and 1.5 A, 60 \pm 0.05 Hz

User controlled switch

Output: LED indicator

Unit Outlet – The unit outlet was a standard household outlet (NEMA type B) that the user plugged their device into. Originally, the neutral pin was to be connected to the metal frame of the device. However, during construction the encasement material was changed to wood and it was determined that the outlet was safe without this extra precaution.

Input: 110 VAC – 125 VAC, greater than 1.5 Amps, 60 \pm 0.05 Hz

Output: 110 VAC – 125 VAC, greater than 1.5 Amps, 60 \pm 0.05 Hz

Sub System Details

Thermosyphon

The purpose of the thermosyphon is to transfer heat from the fireplace to the thermal electric generators. This is done by boiling water in a boiler located inside of the fireplace. The steam produced then travels to a heat exchanger where the energy is transferred to the thermal electric generators. Any remaining steam is then condensed in copper tubes and eventually recycled back into the boiler.

The design of the thermosyphon consists of three main parts. The boiler is located in the fireplace and facilitates liquid water being turned in to water vapor. The thermal electric condensing chamber and the condensing tubes extract energy from the steam and return it to the liquid phase. The holding tank stores this water and allows the user to refill the boiler starting the process over again. A boiler gage allows the user to know the temperature and pressure of the boiler.

Many of the design changes throughout the spring semester were driven by safety concerns. There are many standards that affect boiler design and boiler safety that were unknown during initial design. Due to this, the operating pressure of the boiler was reduced from a gage pressure of 150 psi (1034 kPa) to 1 psi (6.9 kPa). This significantly increased the safety of the device, but drastically lowered the temperature of the hot side of the thermal electric generators (from 180° C to 100° C). To accommodate this change, an available 1 psi check valve replaced the 150 psi pressure relief valve. To further increase safety, a boiler gage reading both temperature and pressure was added to the front of the device.

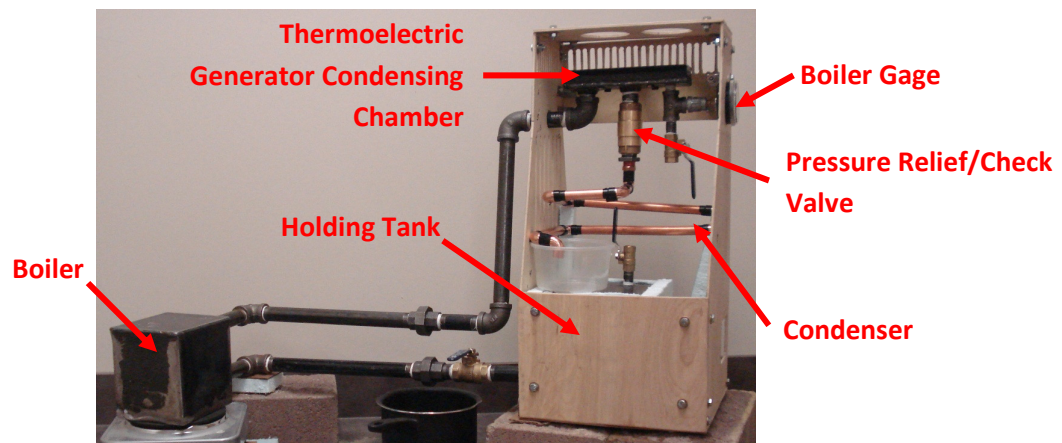


Figure 3: Thermosyphon

The thermosyphon was tested successfully independently and as a component within the larger system. The water in the boiler successfully boiled from this input and was able to pressurize the boiler to 1 psi (6.9 kPa). The temperature of the copper pad on which the thermal electric generators sit was measured at approximately 95 - 99°C. The piping between the thermal electric condensing chamber and the boiler also measures a similar temperature. The condensing tubes were tested to ensure that they were long enough and that only liquid water would exit at the end.

The thermosyphon was a major component of the wood burning generator. During construction a lot of extra time was devoted to ensuring that it would work successfully and safely. Despite many setbacks, a working system for heat transport was developed and implemented.

Thermoelectric Generator

Thermal electric generators (TEGs) were used to convert the temperature differential provided by the thermosyphon and the cooling system into electricity. This is done by utilizing the Seebeck effect which consists of a current loop being created by two metals joined in two places with a temperature differential between the junctions. This current loop is then used to provide electrical power.

Preliminary testing of the first thermal electric generator suggested that each generator could produce approximately 7 V and 4.6 A from a 130°C differential. To have an output of approximately 14 V and 23 A the thermal electric generators were designed in the configuration shown in Figure 4.

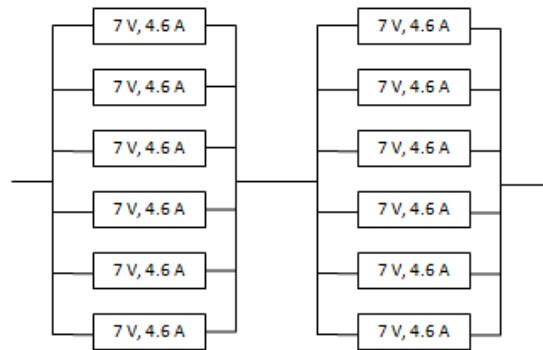


Figure 4: Original Thermal Electric Generator Configuration

After the thermosyphon pressure was reduced the team knew that the original configuration would not produce the needed voltage. After further testing was completed the thermal electric generators were connected in the configuration shown in Figure 5. This configuration produces 14.6 V and 0.6 A using a temperature differential of approximately 50°C.

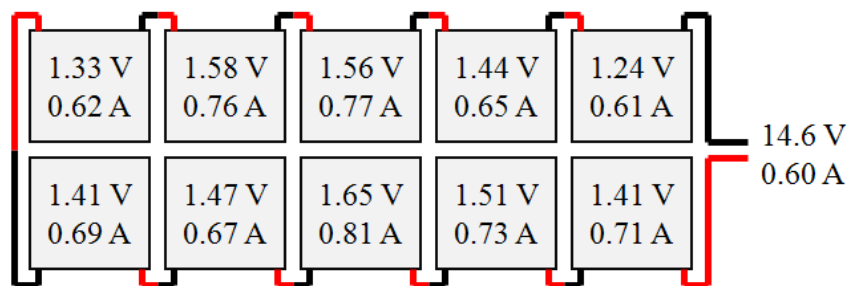


Figure 5: Final Thermal Electric Generator Configuration

The thermal electric generators did not provide the total power output that was originally desired by the team, but the voltage needed was achieved. Additionally, the output of 14.6 V was very steady and only fluctuated within ± 0.05 V during steady operating conditions. The thermal electric generators were successfully used to power the circuit and charge the battery. Unfortunately, this was only possible when the fans were being powered by an external power source and the inverter was turned off.

Cooling System

The cooling system removes heat from the top of the thermoelectric generator. It consists of 10 finned heat sinks and two fans. One $0.60\text{ }^{\circ}\text{C/W}$ thermal resistance heat is attached to the top of each TEG and secured by a worm clamp system and thermal paste. Above the heat sinks are two 80mm diameter fans mounted to the bottom side of the top panel of the encasement. The fans provide an essential temperature difference to the TEGs. During testing, the average output of the TEGs was 11.6 V higher after the fans were turned on.

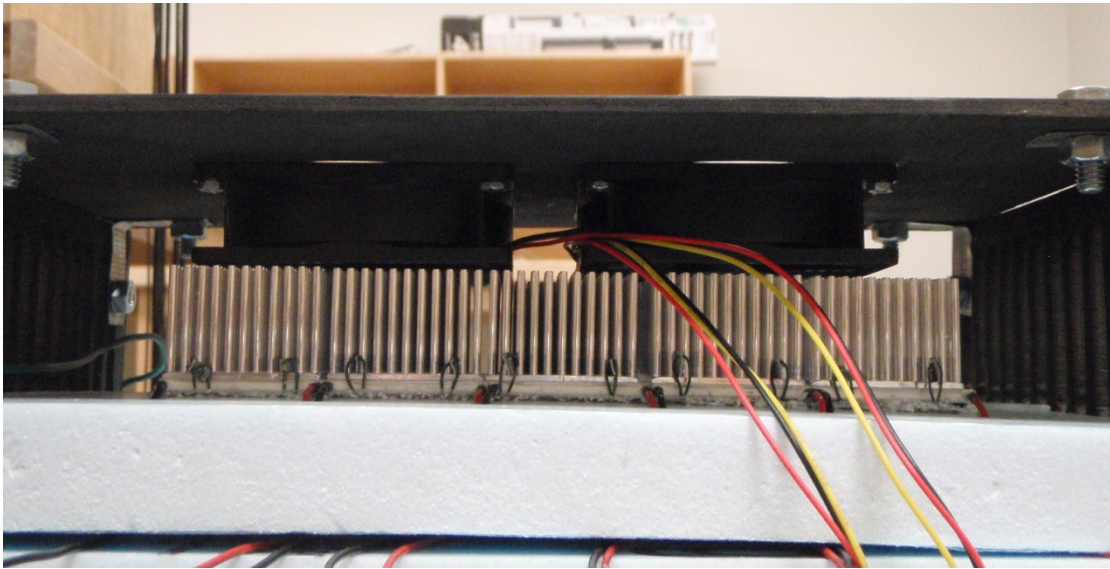


Figure 6: Cooling System

Using an equation determined during the design process, the expected resultant thermoelectric generator output for the final design was 25.7 W. This is 14.1 V higher than the actual results. The equation's main purpose was to determine the number of fans. It served that purpose well. Nevertheless, this equation was not good for estimating the actual output of the thermoelectric generators. This is due to the different configuration of the thermoelectric generators and an 83°C temperature drop in the hot side thermoelectric generator temperature.

User Interface and Inverter

The circuit layout shown below (Fig. 7) is a representation of the professional circuit board originally designed last semester. The circuit was designed to charge the battery as well as provide power to an inverter. The program used is called PCB Artist and was designed by Advanced Circuits to allow customers to design and order simply. The red trace and blue trace indicate a two layer board which benefits our project in the way of size. They are flexible with their dimensions and allow for a max of a 0.038709 m². board for the cost of \$33.00. This rate is based on a student discount which allows for us to spend more inexpensively and receive a quality product. Turnaround time is fairly quick, being only approximately five days.

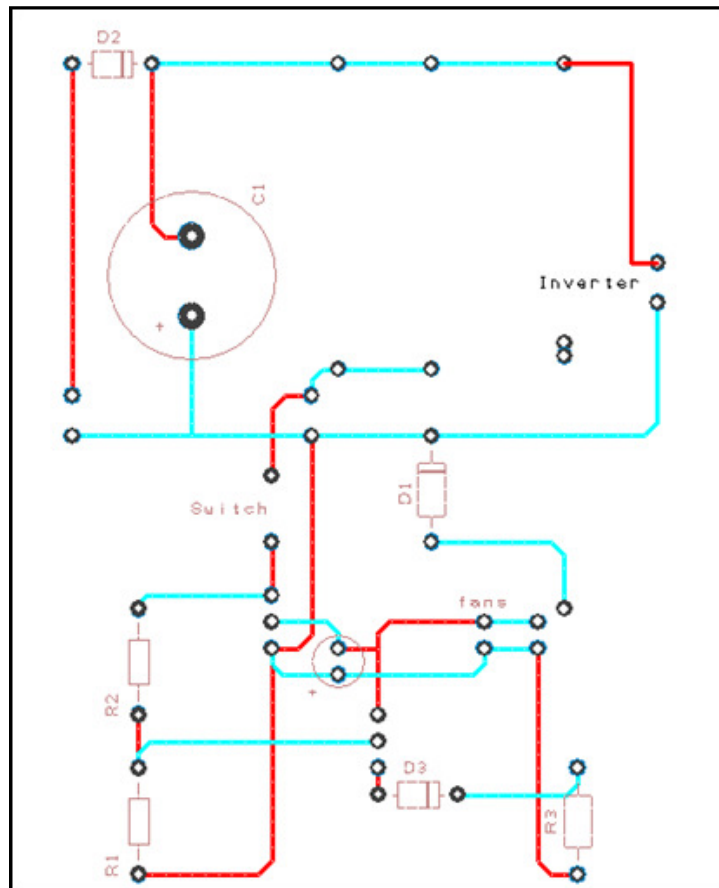


Figure 7: Professional Circuit Board Layout

Fig. 8 on page 16 is a design of a switching circuitry that will allow the battery to be charged separately from using the inverter. The TEGs, in series configuration, do not provide enough power output to run the fans and also charge the battery. This design will work best with more TEGs supplying more current to the battery charging circuit. An extra power supply is needed for our design to charge the battery. However, our tests indicate that it is possible to charge the battery and power the fans with enough TEG power. The idea is to switch the power from the TEGs and power to the fans ON while keeping the other switch to the inverter OFF. Then when the battery is at a charged state (approx. 12 – 13V) switch the power from the TEGs and to the fans off and turn the switch to the inverter ON.

This is a design of the professionally fabricated board that has been finalized and ordered. The reason behind the consideration of this modification is because we were getting close to 90 mA into the battery with the circuit in Figure 7, but we were having trouble providing enough power to the inverter. If you refer to Tables 4 and 5, on page 19, you will see the difference in the circuit output with the circuit working independently as opposed to working in tandem with a separate power supply. If this modification does not work, then we will work with what we are given from the circuit in Figure 7 above.

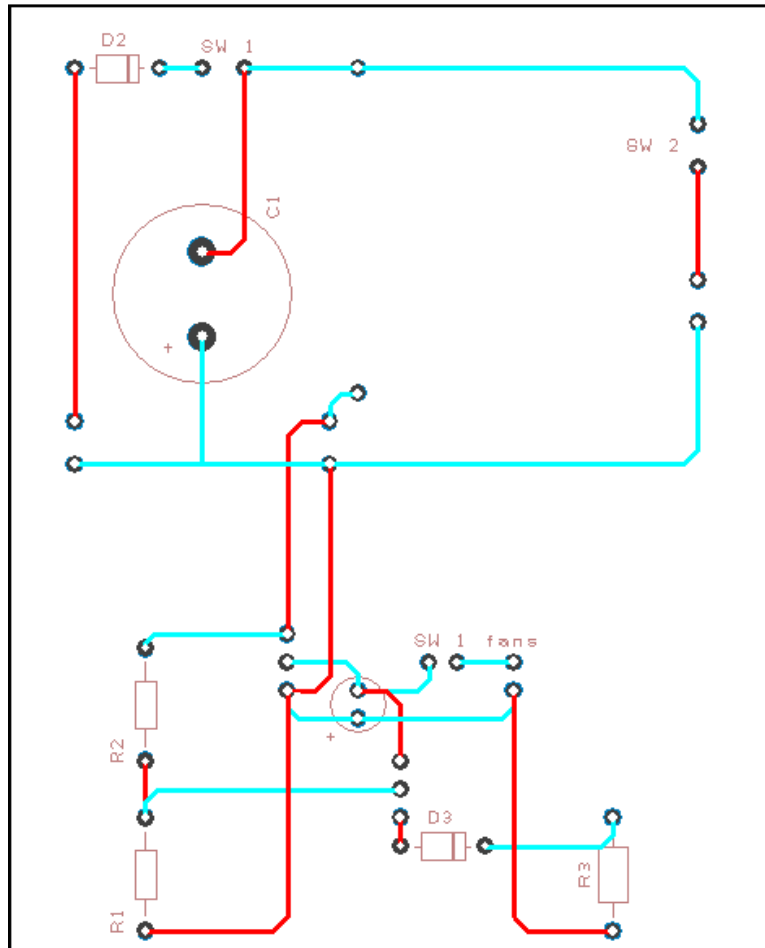


Figure 8: Professional Circuit Board Schematic

The LED circuitry is important to our project in a sense of allowing the user to know when the battery is at a sufficient voltage (approx. 12 V minimum). With the circuit shown in Figure 7, the LED lights properly and does the job that it was intended to do from the beginning.

The designs above, Figure 7 and Figure 8, are based on the circuit diagram on page 17, Fig. 9. We are using a 3300 μF capacitor before the battery to smooth the output from the TEGs. The 18 Ah sealed lead acid battery we are using is at maximum when charged to approximately 12.8 – 12.9 volts. The battery in the diagram is represented by a piecewise voltage source for testing purposes only. The voltage regulator steps down the voltage from the SLA battery so that the fans will run properly. Also, the fans draw about 160 mA at 12 V each. The diode (D2) is used to keep current from flowing back into the TEGs and keep the battery from trying to run them in reverse as Peltier coolers.

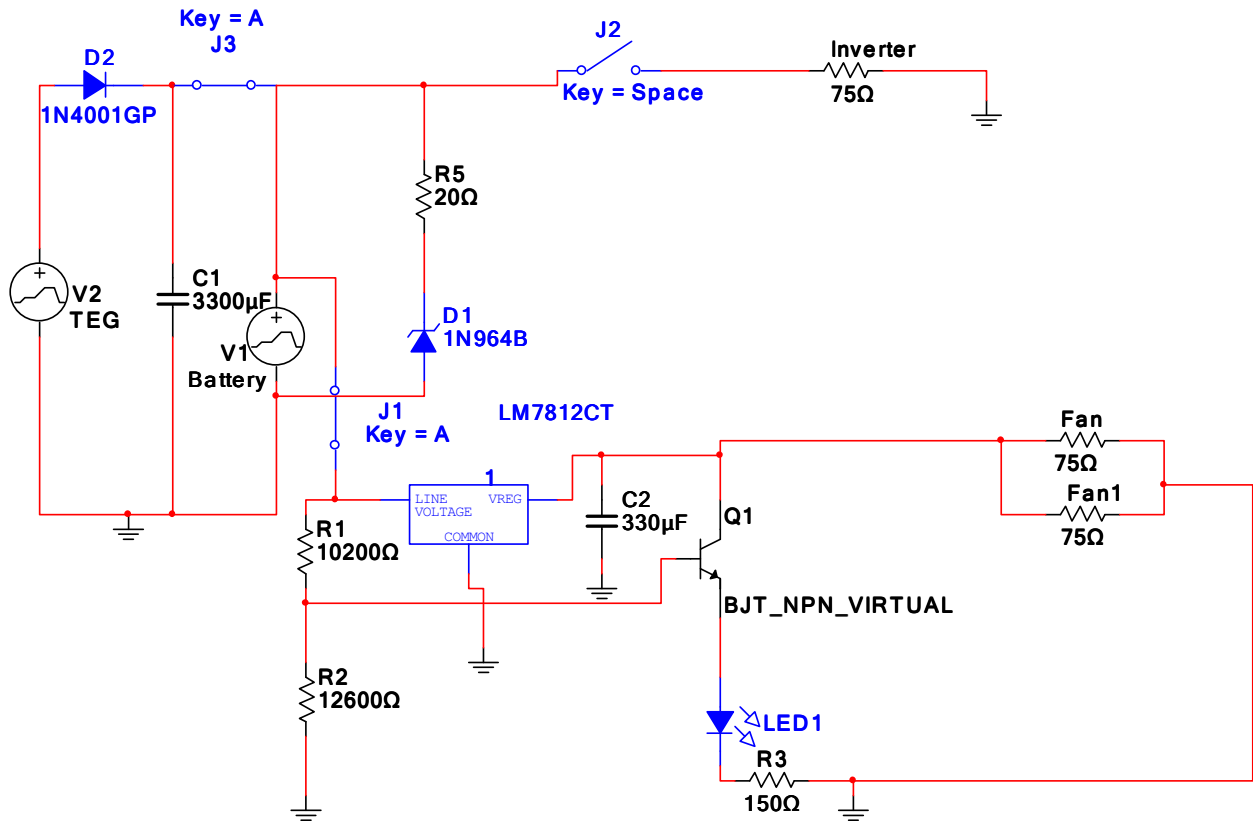


Figure 9: Circuit Diagram

You can see in the bottom of picture below the blue LED is lit and the battery voltage was at 12.5 V. The extra wires are just for testing purposes to tell us exactly what was happening in the circuit.

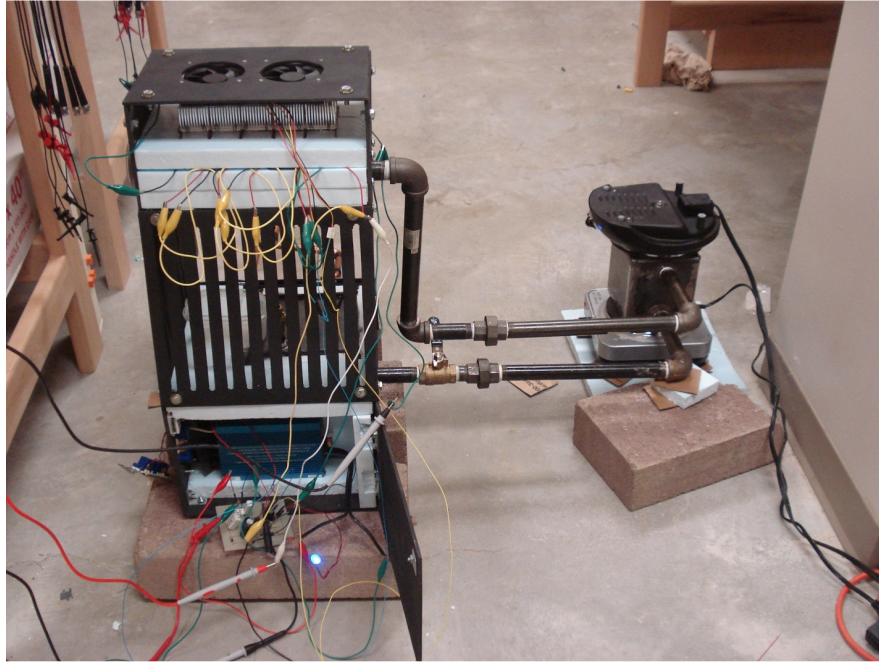


Figure 10: Electrical Sub System Testing

Table 3: Individual TEG voltages

TEG #	TEG output voltage	TEG output current
1	1.33	0.62
2	1.58	0.76
3	1.56	0.77
4	1.44	0.65
5	1.24	0.61
6	1.41	0.69
7	1.47	0.67
8	1.65	0.81
9	1.51	0.73
10	1.41	0.71

Table 3 shows the voltage and current outputs of the individual TEGs. With the TEGs all placed in series the output overall is 14.6 V with 0.60 A.

Table 4: Results of system testing with extra power source

TEG voltage	Battery Voltage	Current Out of Battery
13.3 V	12.6 V	200 mA

Table 5: Results of system testing without extra power source

TEG Voltage	Battery Voltage	Current Into Battery
13.5 V	12.63+ V	85 mA

These results (Tables 4 and 5) show that the battery can be charged, but with our current configuration (all TEGs in series), we are not able to power the fans as well. We connected two TEGs in parallel and connected those in series with the remaining eight and the results of that test were less than from Table 5. The current into the battery was approximately 30 mA and 13.1 volts. These results were taken with the extra power supply working in tandem with the circuitry. We believe that the reason behind this is because the voltage of the two TEGs is not equal to the voltage of the other eight. Most of the time you would connect two sources of equal voltage potential to double the current output. However, with this configuration the output voltage from the two TEGs and the other eight would be approximately 2.8 V at 0.6 A and 11.8 V at 0.6 A.

Encasement

By size alone, the encasement is the largest section of the Wood Burning Generator. Because the generator is required to be easily moved and stored, 5.0mm utility plywood was chosen to be the encasement material to keep the generator light yet sturdy. The encasement is pictured in the figure below.



Figure 11: Encasement

The encasement holds all of the other subsystems of the generator with the exception of the boiler section of the thermosyphon that is placed inside the fireplace itself. The dimensions of the encasement are as follows: 31.1cm wide, 29.2cm long, and 61.9cm high. Two sections of the encasement have doors held shut by magnets. The first section is for the user to interact with the system and add water to the holding tank. The second section is for easy access to the electrical components and would be left out of a production model of this generator. The encasement was spray painted black for aesthetics.

Testing Results

To ensure that the subsystem integration went smoothly and then to ultimately test the device given the requirements specification the wood burning generator went through three levels of testing: sub component testing, integration testing and finally requirements specification testing.

Each sub component had its own tests to pass before it was considered complete. The thermosyphon had to transport heat from the fireplace to the thermal electric condensing chamber. This test was passed when the temperature of the thermal electric generator pad reached a temperature above 95°C. The thermosyphon was also checked to make sure the boiler could be successfully refilled. The cooling system fans were connected to a 12 volt power supply and tested to ensure that they worked. The electrical systems were tested by modeling the thermal electric generators as a power supply and the output was verified to meet requirements. The encasement was tested to ensure that it was sturdy enough to support the weight of the other components. Initially, the encasement failed this test, but by replacing the brackets the encasement passed the test.

Further tests were performed while integrating the sub components with one another. The thermosyphon was tested with the encasement to ensure that the pipes had holes to go through as well as the tanks having enough space inside the generator. The thermal electric generator pad was tested to make sure there was enough space between it and the top of the encasement for the thermoelectric generators, the heat sinks and the fans to fit. Initially, this test failed, but by changing the length of one pipe on the thermosyphon the test was passed. The cooling system, thermal electric generators and the thermosyphon were integrated and tested for electrical output. Initially, one of the cooling system fans failed and the output was much less, but in a second test both fans worked and the output was found to be 14.6 V and 0.6 A. The last major integration test involved connecting the circuit to the thermal electric generators. This test was initially failed, but modifications were made and the circuit performed as expected. However, the thermal electric generators could not produce enough current to both power the fans and charge the battery.

The last set of tests involves satisfying the requirements specification. The size of the device was measured and found to be 1.92 x 2.08 x 1.08 feet (0.59 x 0.63 x 0.33) which is only approximately 1 inch over the size limit of 2 x 2 x 1.5 feet (0.61 x 0.61 x 0.46 m) in the middle dimension (height). The weight was measured at 55 lbs (24.9 kg) which was slightly over the weight limit of 50 lbs (22.7 kg). The generator was taken to a home with a fireplace and tested. Nothing was permanently installed satisfying that specification. Whether the usage of the generator increased the dangerous gases in the room was judged visually, and the amount of smoke in the room did not change significantly. The fire built to test the device was built with wood and therefore passes that specification. Once power generation began an LED light indicated to the user when something could be plugged in. The user could also shut the power off by the use of a switch. The external temperature of the device was measured using an infrared thermometer. All of the readings were below 43°C and therefore this specification was satisfied.

The wood burning generator went through many tests before it could be considered finished and operational. Ultimately, the device fulfilled seven out of nine specified technical requirements while coming very close to satisfying the remaining two (size and weight).

Recommendations

During the construction of the first prototype the team came up with design variations of the wood burning generator that could not be implemented due to either cost restrictions or time restrictions. These modifications could possibly be implemented in a second prototype.

The thermosyphon went through many changes during design and construction. Some of which left a few parts obsolete. In a second prototype, the holding tank could be much smaller if not eliminated all together. It could be replaced with a simple port allowing the user to refill the boiler. The distance between the boiler and the generator should be increased to facilitate larger fireplaces. This length could possibly be made adjustable so that the user could personalize the device. Lastly, the boiler and piping could be built according to ASTM boiler standards to allow higher pressures, and therefore higher temperatures, to be used. This would increase the power output of the thermal electric generators.

The thermal electric generator design was very successful and worked well with the device as a whole. If the thermosyphon could be designed to provide higher temperatures, it might be possible to incorporate a microprocessor that would adjust the configuration of the generators to allow maximum power output. For example, at lower temperatures the thermal electric generators could all be put in series to provide the necessary voltage. At higher temperatures, the configuration could be modified by putting a few thermal electric generators in parallel therefore increasing the current while keeping the voltage close to 14 volts.

The current cooling system worked well with the thermal electric generator, but a few upgrades are possible. The current design uses aluminum heat sinks, but it may be possible to use copper heat sinks which have a lower thermal resistivity and would cool the thermal electric generators more efficiently. Additionally, analysis shows that the use of more fans or fans in different configurations increase the cooling capacity of the cooling system. This would particularly be effective if the thermosyphon temperature was increased.

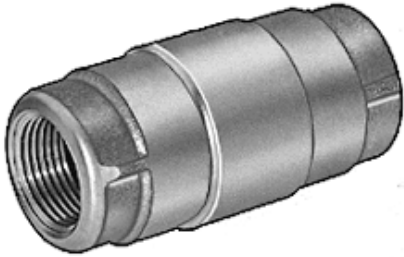
The electrical system could also be improved in a second prototype. Since the voltage from the thermoelectric generators does fluctuate, this could be made even steadier by the use of a capacitor. A larger capacity battery could be used to increase the life of the generator before it needs to be recharged. However, this would add a lot of weight to the device as a whole.

The encasement material was changed from steel to wood during construction because of weight and cost concerns. A second prototype might be made from aluminum, which would be more durable than the wood and weigh less than the originally proposed steel. The current generator is difficult to move because it is heavy and there are no clear lifting points besides the bottom. Handles could be affixed to the device in locations that are reinforced to support the weight. Lastly, to allow the generator to be used with more types of fireplaces adjustable legs could be added to the bottom.

The team learned a lot from the first prototype both in design and in construction. An even better product could be made by building a second prototype including some innovative upgrades that would make the device more efficient and easier to use.

Appendices

Appendix A: Thermosyphon Parts



Part Name: Brass Piston Check Valve Spring-Loaded, 1" NPT Female

Supplier: McMaster-Carr

Catalog Number: 7746K83

Datasheet: Unavailable

Specifications: Maximum Pressure is 200 psi @ 225° F

Cracking Pressure: 1 psi

Temperature Range: 33° to 225° F

Connections are 1" NPT Female



Part Name: Brass Ball Valve

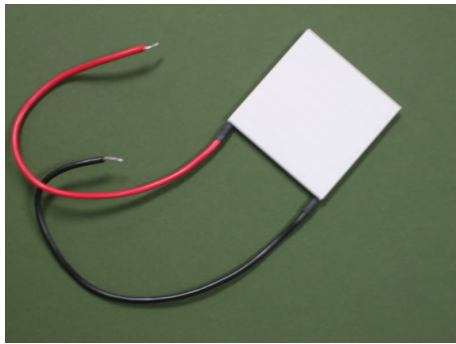
Supplier: Lowe's Home Improvement

Manufacturer: American Valve

Catalog Number: M100

Datasheet: Attached

Appendix B: Thermoelectric Generator Parts



Part Name: Thermoelectric Generator

Supplier: Thermal Enterprises

Manufacturer: Thermal Enterprises

Catalog Number: HT1-12710 TEG

Datasheet: Unavailable

Specifications: 40mm x 40mm x 3.3mm

Operates from 0-16 volts DC and 0-10.5 amps

Operates from -60 deg C to +225 deg C

Fitted with 6-inch Teflon insulated leads

Perimeter sealed for moisture protection



Part Name: Thermal Grease

Supplier: Newegg.com

Manufacturer: Arctic Silver

Model Number: Ceramique

Datasheet: Unavailable

Specifications: See Below

Model

Brand	Arctic Silver
Model	Ceramique

SPEC

Specifications	<p>Thermal Conductance: >200,000W/m².°C (0.001 inch layer)</p> <p>Thermal Resistance: <0.007°C-in²/Watt (0.001 inch layer)</p> <p>Average Particle Size: <0.38 microns</p> <p><0.000015 inch (67 particles lined up in a row equal 1/1000th of an inch.)</p> <p>Temperature Limits: Peak: -150°C to >180°C, Long-Term: -150°C to 125°C</p> <p>Coverage Area: At a layer 0.003" thick, one tube will cover approximately 20 square inches</p>
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Features

Features	2.5-gram(~0.8 cc.) tube
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Appendix C: Cooling System Parts



Part Name: Fan

Supplier: Newegg.com

Manufacturer: Link Depot

Model Number: 8025-B

Datasheet: Unavailable

Specifications: Size: 80x80x25mm

Current: 0.16A

Air Flow: 38.2CFM

Speed: 3000RPM

Power: 1.92W

Bearing: One ball bearing

Voltage: 12VDC

Noise: 32.1dBA



Name: Heat Sink

Supplier: Cool Innovations

Model Number: 3-151511U

Datasheet: Attached



Name: Aluminum Scrap Metal

Supplier: Harding University (Physical Resources)

Manufacturer: Unknown

Model Number: Unknown

Datasheet: Unavailable



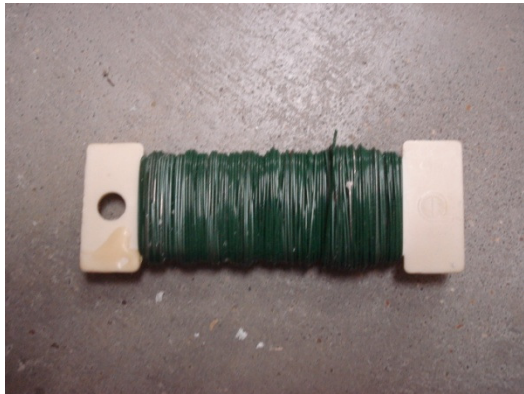
Part Name: Worm Clamp, 1/4"

Supplier: Lowe's Home Improvement

Manufacturer: King Seal Fastener Technology

Model Number: BCMM4SS09P10

Datasheet: Unavailable



Part Name: Picture Wire

Supplier: Unknown

Manufacturer: Unknown

Model Number: Unknown

Datasheet: Unavailable

Appendix D: User Interface and Inverter Parts



Part Name: Battery
Supplier: atbatt.com
Manufacturer: Amstron
Model Number: AP-12180NB
Datasheet: Unavailable
Specifications: See Below

Specifications

Chemistry	Lead Acid
Voltage	12
Capacity	18,000 mAh / 18 Ah
Rating	216 Whr
Connector	R Terminal
Length	7.13 inch / 18.11 cm
Width	3.03 inch / 7.70 cm
Height	6.57 inch / 16.69 cm
Color	Gray
Weight	11.02 lb / 4,998.56 g
Warranty	1 Year
UPC Code	880487220647



Part Name: Inverter

Supplier: Buy.com

Manufacturer: Tripp-Lite

Model Number: PV375

Datasheet: Unavailable

Specifications: See Below

General Specifications

Weight:	2.2 lbs
Device Type:	DC to AC power inverter - external
Miscellaneous	
Cables Included:	1 x power cable
Manufacturer Warranty	
Service & Support:	1 year warranty
Service & Support Details:	Limited warranty - 1 year
Power Device	
Input Connector(s):	1 x automobile cigarette lighter
Output connector(s):	2 x power NEMA 5-15
More Information	
Shipping Weight (in pounds):	2.25
Product in Inches (L x W x H):	6.0 x 3.0 x 4.0
Assembled in Country of Origin:	Imported
Origin of Components:	Imported

Appendix E: Encasement Parts



Part Name: Encasement Exterior (Utility Plywood)

Supplier: Lowe's

Datasheet: Unavailable

Specifications: Thickness: 5.2mm

Area: 4 x 8 Feet



Name: Insulation

Supplier: Lowe's

Manufacturer: Dow

Model Number: 263063

Datasheet: Unavailable

Specifications: See Below

Reduced energy loss- lower heating
& cooling bills
High R-value
Unsurpassed durability
Moisture resistant facers
Lightweight, easy to install

Insulation Type:	Polyisocyanurate
Thickness (Inches):	0.5
Length (Feet):	8.0
Width (Feet):	4.0
R-Value:	3.0
Installation Instructions included:	Yes
Weather Resistant Barrier:	Yes