DESIGN OF A THERMOELECTRIC EDU-KITCHEN SYSTEM

A Thesis
Presented to
The Academic Faculty

by

Akshaya Srivastava

In Partial Fulfillment
of the Requirements for the Degree
Bachelor of Science in the
Daniel Guggenheim School of Aerospace Engineering

Georgia Institute of Technology
May 2013

DESIGN OF A THERMOELECTRIC EDU-KITCHEN SYSTEM

Approved by:

Professor Narayanan Komerath, Advisor
Daniel Guggenheim School of Aerospace Engineering
Georgia Institute of Technology

Professor Lakshmi Sankar
Daniel Guggenheim School of Aerospace Engineering
Georgia Institute of Technology

Date Approved: April 30, 2013

This is Dedicated to my Family and my Professor

For all of their Support and Guidance

PREFACE

The project was undertaken help families who lack access to electric power. Many use open wood-fuelled fires surrounded by 3 stones to cook. The smoky kitchen fire is often the only light for children to study - at the risk of lung and eye disease. Fuel efficiency can mean less need to go out and collect firewood, a risky undertaking in war-torn regions.

ACKNOWLEDGEMENTS

It would not have been possible to write this thesis without the help and support of the kind people around me, to only some of whom it is possible to give particular mention here.

My parents and sister have given me their unequivocal support throughout, as always, for which my mere expression of thanks likewise does not suffice.

This thesis would not have been possible without the help, support and patience of my principal supervisor, Prof. Narayanan Komerath, not to mention his advice and unsurpassed sense of purpose, which always helped me figure out how to proceed.

For any errors or inadequacies that may remain in this work, of course, the responsibility is entirely my own.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

This thesis describes an integrated system to lower air pollution from fires, provide LED flood lighting, and UV water purification. The need for such systems is strong where families lack access to electric power. The system is conceived as an add-on rather than replacement to existing kitchen burners, in order to minimize cost and intrusion into established practices. The system is based on the aerospace technology of thermoelectric converters, used for long-term missions in deep space. As implemented in design, a thermoelectric module is integrated with thermal protection, and an air-cooled heat sink. Fresh air is induced into the heat sink, which is a chip cooler and direct current electric fan taken from a discarded personal computer. The exhaust air is driven into the wood fire to increase combustion efficiency, reducing pollutant formation and use of fuel. The thermoelectric module generates electric power, which is used through a bank of DC-DC voltage boosters to charge a battery. A lamp powered by light emitting diodes provides steady lighting. In a future implementation, another light emitting diode operating in the 254-264 nanometer range will eliminate bacteria from drinking water. In this thesis the aim is to show that the design of such a system will close, given the power budgets for each of the devices. This is pursued through conceptual analysis, analysis and component testing. It is shown that the design will close with currently available thermoelectric modules. The resulting testbed provides ongoing research opportunities.

CHAPTER I

INTRODUCTION

Many families around the world must do their cooking using rudimentary wood-burning stoves made of three stones or bricks, burning whatever wood scraps they can gather (commonly known as a 3-stone fire). These stoves are inefficient and with no more than natural convection for exhaust removal, generate high levels of pollution, leading to a high incidence of health problems. With mothers having to attend to cooking, their children must do their homework sitting in the same kitchen, with poor lighting and air quality. A high possibility of bacterial infection from drinking water is also a reality. The Edukitchen system described in this thesis uses a thermoelectric module from spacecraft technology as the centerpiece of a low-cost electric power generation to bring ventilation, pollution control, fuel efficiency, clean water and lighting to kitchens. This design defines the requirements for the system, and presents an initial version of a solution, as a testbed for research and development towards a mass-producible system.

1.1 Known Health Complications

Indoor air pollution is a major public health issue on a global scale. It is estimated that around 50% of the world population rely on combustable mass (generally biofuels) for light and heat; this method exposes the populace to indoor pollution, which has been observed to increase the risk of chronic pulmonary diseases[20]. This figure translates to roughly 3 billion people[101]. The combustion of these biofuels can create harmful substances such as polycyclic hydrocarbons [32]. Exposure to this pollution has also been strongly correlated with chronic bronchitis[18]. Wood fuels in particular have become a common replacement to the conventional gas stove, but the obvious renewability of this fuel is offset by the amount of pollution produced[71]. Demand for these fuels also places considerable pressures on the forest and other sources of these fuels, which can be linked to deforestation as well as other adverse environmental effects[116].

For example, in India, the principal biomass fuels are wood, crop residues and dung cakes, which are used in poorly ventilated households, increasing the air pollution and the effects of the pollution on the household[80]. It has also been suggested that the effects of fuels that produces more relative pollution tend to increase the risk of tuberculosis in Indian households[81].

1.2 Purpose

Besides the health issues that may arise from burning biofuel for warmth and light and cooking, water sanitation and efficient lighting are also issues that poor homes face. Most of these homes don't have enough money to afford new infrastructure. This integrated system tackles all three of these problems in an efficient manner. By adding on to the 3-stone fire, there isn't any new infrastructure that needs to be implemented. Instead, by taking advantage of existing infrastructure, This device is more readily accessible by the largest subset of homes.

CHAPTER II

THERMOELECTRIC POWER GENERATION

2.1 Theory

The thermoelectric effect occurs when one side of a material is heated and the opposite side is cooled. This creates a voltage difference due to the diffusion of charged carriers in the material. Conversely, should a voltage be applied to the material, a temperature gradient is created in the material. This phenomenon is also known as the Seebeck Effect due to its discoverer, Thomas Johann Seebeck. Seebeck realized that the voltage could be derived from the equation expressed here as Eq. 1. S_A and S_B are known as Seebeck coefficients, and are usually a nonlinear function of temperature. If they can be assumed constant over a range of temperatures, however, then Eq. 1 simplifies to Eq. 2. This effect is the driving principle for the thermoelectric modules and in simple circuits allows them to be treated like batteries .

$$V = \int_{T_1}^{T_2} (S_B(T) - S_A(T))dT \tag{1}$$

$$V = (S_B - S_A) \cdot (T_2 - T_1) \tag{2}$$

Other considerations include pressure exerted on the thermoelectric module. Pressure is needed to increase the thermal conductivity between the hot side of the panel and the aluminum plate that serves as thermal protection.This effect is due to the minimization of air between the hot side of the panel and the plate. Thus, less heat is lost to convection and radiation and heat transfer is purely a function of conduction[117].

Given the structural components needed to clamp the module under pressure, insulation is also required to minimize heat transfer through this structure to the cold side of the module and the heat sink. The outside of the device also requires insulation to make sure that it survives the temperatures that are reached in the fire.

2.1.1 Load Matching

In order to maximize the external power from a source, the resistance of the load must match the internal resistance of the source as seen from the output terminals [97]. Figure 1 shows the electric al schematic for a simple circuit.

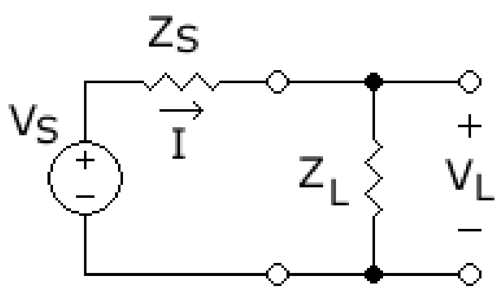

Figure 1: Schematic of Simple Resistive Circuit

By Ohm's Law, the current in Figure 1 must be:

$$I = \frac{V_s}{Z_s + Z_l} \tag{3}$$

The power dissipated in the load would then be:

$$P_l = I^2 Z_l$$

$$P_l = Z_l(\frac{V_s}{Z_s + Z_l})^2$$

$$P_l = \frac{V^2}{\frac{Z_s^2}{Z_l} + 2Z_s + Z_l} \tag{4}$$

We can now differentiate Equation 4 to maximize the power.

$$\frac{\partial P_l}{\partial Z_l} = \frac{V^2(Z_s - Z_l)}{(Z_s + Z_l)^3} \tag{5}$$

To get the possible maxima and minima, we set Equation 5 equal to 0 and solve.

$$\frac{V^2(Z_s - Z_l)}{(Z_s + Z_l)^3} = 0$$

$$Z_s - Z_l = 0 \tag{6}$$

Equation 6 implies that when the resistance of the source equals the resistance of the load, the power is either maximized or minimized. To figure out which one, we take the second derivative of Equation 4.

$$\frac{\partial^2 P_l}{\partial Z_l^2} = \frac{2V^2(Z_l - 2Z_s)}{(Z_s + Z_l)^4} \tag{7}$$

Realizing that any real resistance must be positive, if $Z_l = Z_s$, then the term on the left hand side of Equation 7 will be negative, proving that the power is maximized when $Z_l = Z_s$. This is known as Jacobi's Law [97].

CHAPTER III

PREVIOUS WORK

Thermoelectric modules are currently used mainly to create a temperature difference. By applying a voltage difference to the leads of the module, one can use it to create a temperature gradient through the module and therefore, pump heat out of a system. This is a valid and popular method of refrigeration for portable coolers. [54] as augmentors for power generation using a temperature gradient. Modules have been integrated into stove, designed for 100 Watts of power as a minimum for domestic use [85]. On the other hand, thermoelectric modules can be optimized and fabricated to produce as little as 60 μW of power.Theoretically, the thermoelectric module can go as low as 20 μW of power, which allows it to be used in a range of micro-systems [119]. Designing the modules can be assisted by ever-improving design tools and computational models. Models are sophisticated enough now to be able to calculate performance and power from boundary conditions and thermoelectric material parameters. [102]

Many novel ideas have been used to create other eco-friendly stoves for troubled regions such as Nicaragua, El Salvador, and Guatemala [118]. While some of these stoves can indeed lower fuel pollution and increase fuel efficiency [61], due to the basic design, the stoves create infrastructure instead of using existing infrastructure. Though they may be manufactured using small components, they are systems in and of themselves, and do not try to augment the canonical 3-stone fire. Given the life realities of the intended users, it is usually not feasible for them to buy these stoves. If they are provided with these stoves, they may often feel compelled to sell and replace them with three stones.

CHAPTER IV

DEVICE DESIGN

4.1 Conceptual Design

Instead of a stand-alone stove, we set out to design add-on devices that could be conveniently integrated into the present kitchens of the intended users, and improve their lives.The system consists of a thermoelectric module enclosed in a flattened conical insert suitable to placing among firewood pieces in a stone burner. A separate thermocouple sensor monitors the temperature, while the thermoelectric power is used to charge a battery. The output from the battery, and the temperature signal, go through a micro-controller, which controls power to a small computer fan that drives air through the conical insert, optimizing the stoichiometry of the combustion, and powering the exhaust out of the kitchen. A separate power stream from the battery goes to an LED lighting system, providing steady, efficient lighting for a child to read by. Another power stream goes to a small ultraviolet LED mounted in the lid of a drinking water container. Figure 2 shows the concept graphically. The 254 nm UV wavelength is optimized to destroy bacteria, following guidance from the UV Waterworks system developed by Drs. Ashok Gadgil and Vikas Garud at Lawrence Livermore national labs.

The conceptual study shows that the advent of LEDs has made it feasible to obtain enough power for these functions using a thermoelectric module from such a burner. At this writing, we anticipate that results from the testbed and a prototype of the EduKitchen system will be presented at a conference. An extension of the testbed is also described, where a pyro photovoltaic generator from space technology is adapted to generate power from a larger household incinerator sized for a middle-class home

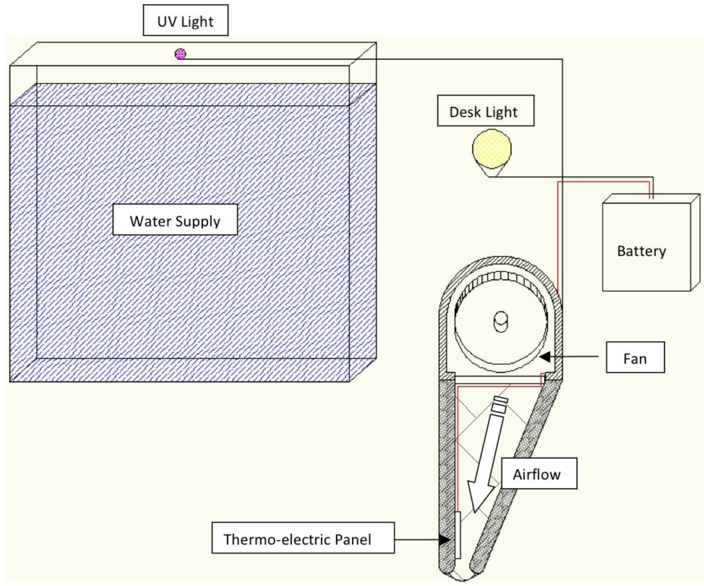

Figure 2: Concept Map

in developing nations.

4.1.1 Parts

A list of parts needed and costs is shown in Table 1. Per unit prices in mass production are expected to be 1 to 2 orders of magnitude below those given in the table; however we cannot project those at present, and must quote from what we can find in retail price lists, or estimate those. We do not project that people who must do their cooking and children's education by a kitchen wood fire will be able to afford even the mass production price. Instead, the argument for governments and non-governmental organizations to help people acquire these must be based on the long-term payoff in reduced eye disease, lung disease, and in the enhanced opportunities for education provided to a whole new generation of citizens.

The parts themselves are shown in Appendix A. The thermoelectric module (Figure 17) can produce up to theoretical 19.1 watts (Figure 3). However, based on the likely temperatures of the fire and cooling, the temperature difference will not be sufficient to produce 20 watts. The goal of the device is to be self sufficient with 8 watts. It could then charge a rechargeable 30-volt battery, which would be able to run all the various devices attached to it, namely: the fan, water purification system, and lighting apparatus.

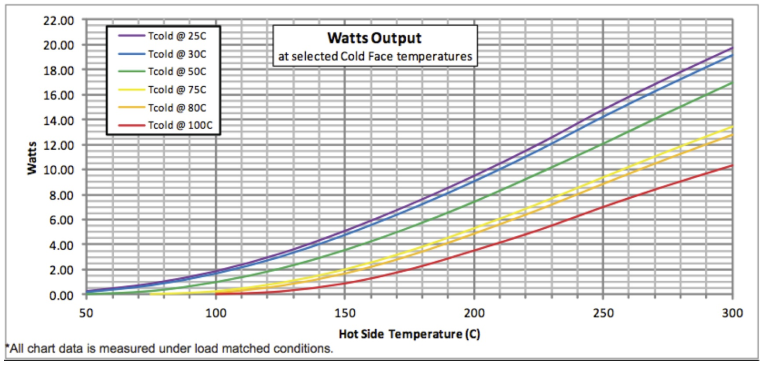

Figure 3: Wattage Output at Selected Cold Temperatures. Data and plot kindly provided by Custom Thermelectric Incorporated.[56]

Component	Price	Expected Mass Production Price
Thermoelectric Module	$80	$ 25-$50
Computer Fan	$8	$2-$10
LED Light	$25	$10-$20
270nm LED, single unit	$200	$2-$10

Table 1: Price per Part

4.1.2 Setting Up The ThermoElectric Module

Within the documentation, there is an ideal set up for the thermoelectric module beyond the load matching requirements. The setup is shown as Fig. 4. Based on the documentation, a more detailed setup configuration was formulated, shown here as Fig. 5. Fig. 6 shows the connections to the thermoelectric module to attain load matched configurations. Fig. 7 shows the set up with a halogen lamp at the ready to heat up the module's hot side. Figure 8 shows the lamp placement onto the set up to maximize the heat transfer.

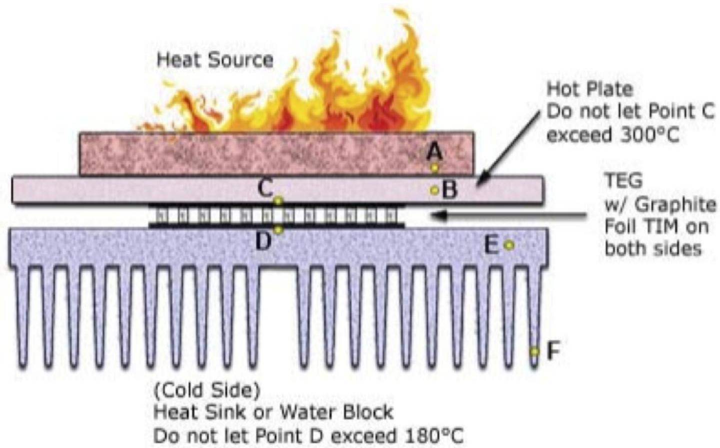

Figure 4: Ideal ThermoElectric Module Setup. Provided courtesy of Custom Thermoelectric Inc. [56]

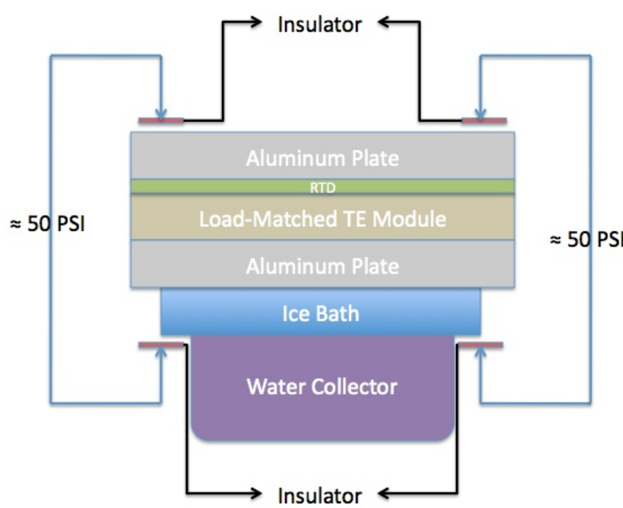

Figure 5: Modified ThermoElectric Module Setup

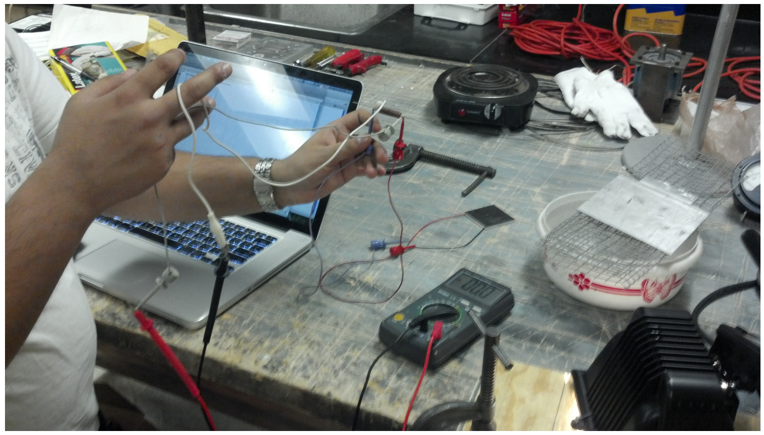

Figure 6: Connections to Load-Match the Thermoelectric Module

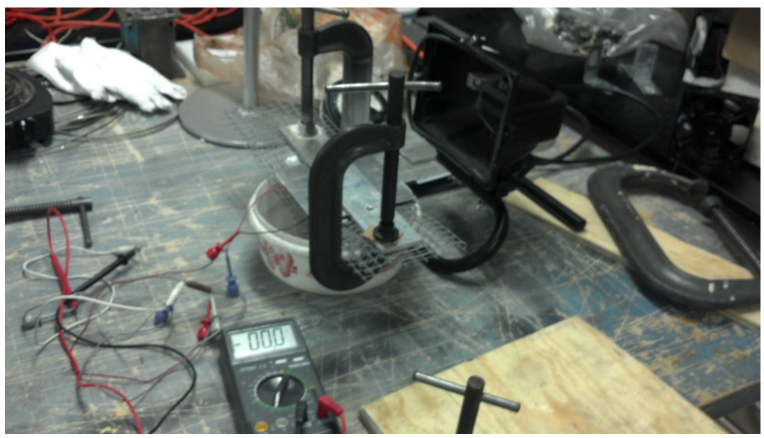

Figure 7: ThermoElectric Module Experiment Setup

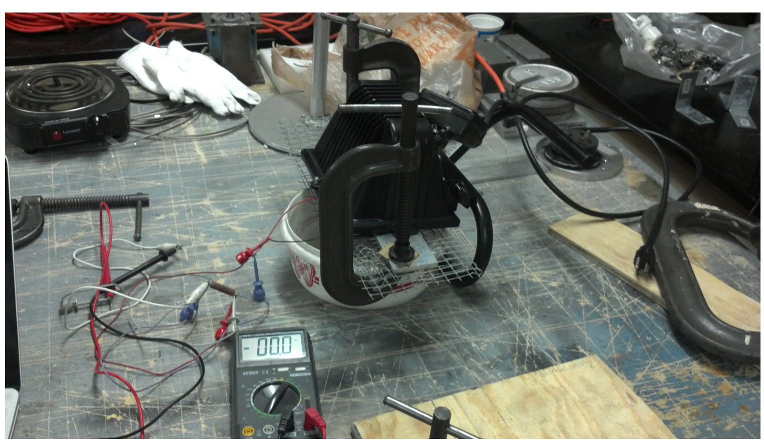

Figure 8: ThermoElectric Module Experiment Running

4.1.2.1 Pressure Considerations

It has been observed that when using the thermoelectric modules, an applied compression load is necessary for adequate power generation. However, simply bolting a plate to the hot and cold surfaces of the module is inadequate, as the plate may end up warping and creating space between the surface of the plate and the surface of module, as shown in Fig. 9.

To avoid this, many methods were attempted. The first method was prestressing the plate so that the plate is not flush with the module surface before being bolted down as shown in Fig. 10. This method however, was unreliable, since too much torque on the bolts would then again start creating that space between the two surfaces.

The current design uses the heat sink to bolt directly to the aluminum case of the nozzle, with lips to hold the module in place and apply pressure to the hot side. This method has yielded the best results so far.

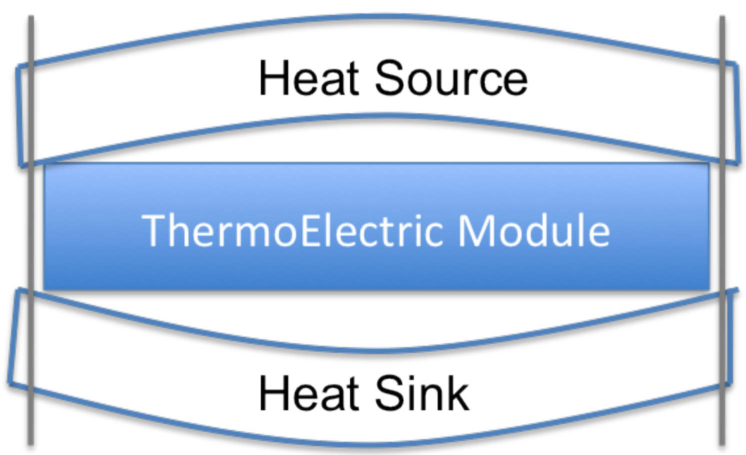

Figure 9: ThermoElectric Module Flush Clamp Effect

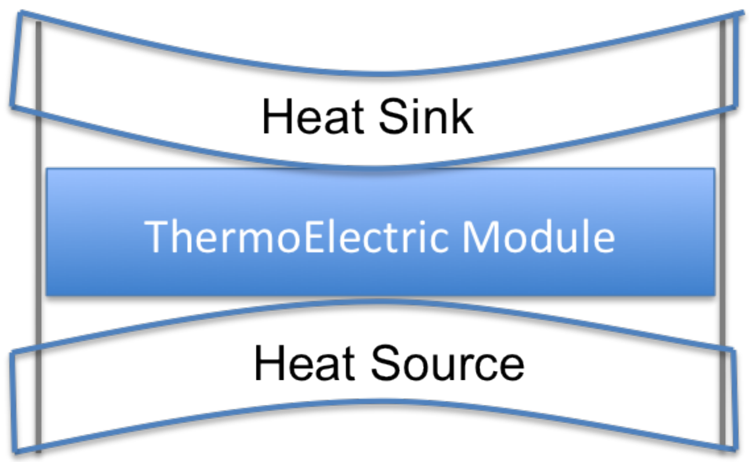

Figure 10: ThermoElectric Module PreBent Clamp Effect

4.2 Voltage Boost and Charging

In order to store the electricity generated by the thermoelectric module, a series of DC-DC converters can be used to boost the voltage. Current experiments have used the ELC-W0422-LED UnipolarBoost Converter Circuit by Custom Thermoelectric to power an LED with a constant voltage source of 2.5 Volts. In order to charge a 12-volt battery, five or six DC-DC converters can be placed in parallel with the Thermoelectric module and in series with each other to achieve the desired voltage needed to charge the battery. This schematic is shown in Figure 11. At this writing, delivery of these components is awaited.

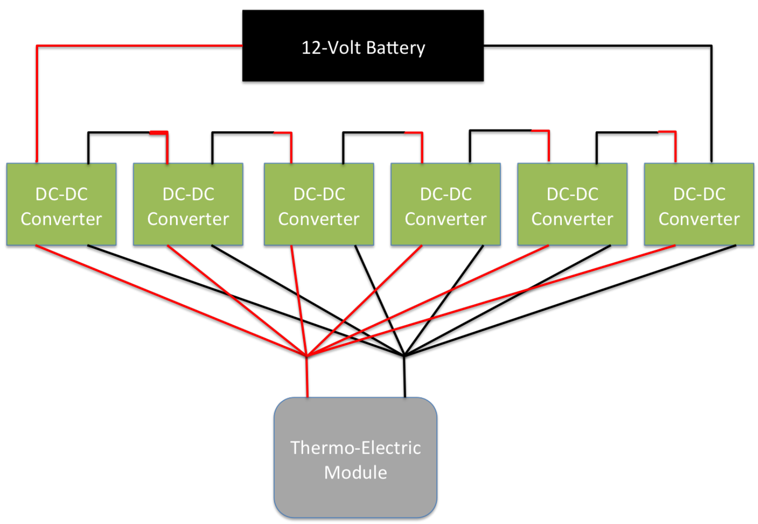

Figure 11: Battery Charging Schematic

4.3 Sample Wood Fuel Calculations for Thermochemical Equilibrium

In order to be able to control the combustion of a wood-fueled fire, the type of wood must be known. Using the ideal chemical combustion equation (Equation 8), it becomes possible to estimate the amount of air needed to achieve perfect combustion. At this point, there are little to no wood particulates that are left to form soot or smoke; the air is less polluted and vision is no longer obscured. Different wood species and the equivalent air needed to achieve perfect combustion are detailed. The wood species detailed here are used simply due to the availability of composition and heating values for the species. Other common species have less complete records. [111]

$$\eta_{Wood(HydroCarbon)} + \delta_{Oxygen} \rightarrow \nu_{CarbonDioxide} + \zeta_{Water} + \omega_{OtherProducts} \tag{8}$$

4.3.1 Calculations with Black Spruce

Black Spruce wood, while not a common fuel found in rural areas, was chosen due to the availability of information on the chemical makeup and properties of the wood. The calculations shown below demonstrate the procedure used to find the amount of air needed to figure out how much air needs to be sent to a fire burning the wood to completely burn the wood. The assumptions are also stated.

Black Spruce contains 27.3% lignin, 45.8% cellulose, and 12.5% pentosan.[104] One cord (85 cubic feet) of black spruce wood with approximately 20% moisture content produces 15.9 million BTU's of usable heat.[2] Assuming a perfect combustion reaction (Eq. 9) and accounting for air, all the reactants will only create H_2O, CO_2, and SO_2 and N_2. Eq. 14 shows the final equation, while Eqs. 10 to 13 show the atom balances.

$$\begin{aligned}&[\frac{\alpha}{100}\ C_{10}H_{12}O_3 + \frac{\beta}{100}\ C_6H_{10}O_5 + \frac{\gamma}{100}\ C_{14}H_{26}O_{21}S_4] \quad + \quad \mathbf{A}\ (O_2 + \frac{79}{21}\ N_2) \\ &\qquad \rightarrow \mathbf{B}\ CO_2 + \mathbf{C}\ H_2O + \mathbf{D}\ SO_2 \quad + \quad \mathbf{A}\ \frac{79}{21}\ N_2\end{aligned} \tag{9}$$

$$\begin{aligned} D &= \frac{4\gamma}{100} \\ D &= 0.5 \end{aligned} \tag{10}$$

$$\begin{aligned} B &= \frac{10\alpha}{100} + \frac{6\beta}{100} + \frac{14\gamma}{100} \\ B &= 7.228 \end{aligned} \tag{11}$$

$$
\begin{aligned}
2C &= \frac{12\alpha}{100} + \frac{10\beta}{100} + \frac{26\gamma}{100} \\
C &= 5.553 \qquad (12)
\end{aligned}
$$

$$
\begin{aligned}
2B + C + D4 &= \frac{3\alpha}{100} + \frac{5\beta}{100} + \frac{21\gamma}{100} + A \\
A &= 16.275 \qquad (13)
\end{aligned}
$$

$$
\begin{aligned}
[.273\ C_{10}H_{12}O_3 + .458\ C_6H_{10}O_5 + .125\ C_{14}H_{26}O_{21}S_4] \quad &+ \quad 16.275\ (O_2 + \frac{79}{21}\ N_2) \\
\rightarrow 7.228\ CO_2 + 5.553\ H_2O + 0.5\ SO_2 \quad &+ \quad 16.275\ \frac{79}{21}\ N_2 \qquad (14)
\end{aligned}
$$

Using this stoichiometric equation (Eq. 14), and realizing that a cord of wood actually occupies 124 ft^3, it can be shown (as in Eqs. 15 through 18) that one kilogram of black spruce can actually produce 9894.83 kiloJoules of energy.

$$\frac{Wood\ Volume}{Total\ Cord\ Volume} = \frac{85\ ft^3}{128\ ft^3} = 0.66\ Cord \qquad (15)$$

$$(\frac{0.66\ Cord}{1})(\frac{15.9 \times 10^6\ BTU}{1\ Cord})(\frac{1055.06\ J}{1\ BTU})(\frac{1\ kJ}{1000\ J}) = 11139949.92\ kJ \qquad (16)$$

$$(\frac{85\ ft^3}{1})(\frac{29.2\ lb}{1\ ft^3})(\frac{0.4536\ kg}{1\ lb}) = 1125.84\ kg \qquad (17)$$

$$\frac{11139949.92\ kJ}{1125.84\ kg} = 9894.83\ \frac{kJ}{kg} \qquad (18)$$

4.3.2 Calculations with Hybrid Poplar

Hybrid Poplar encompasses many species of Poplar woods. Abundant throughout the United States and Canada, this wood is considered a woody crop with a short rotation. It is composed of 48.45% Carbon, 5.85% Hydrogen, 43.69% Oxygen, and negligible amounts of Nitrogen and Sulfur [105]. Equation 26 shows the unbalanced equation, while the following equations are the atom balances required for an ideal combustion reaction as shown in Equation 8.

$$\begin{aligned} [\frac{\alpha}{100}\, C + \frac{\beta}{100}\, H + \lambda\, O] \quad &+ \quad \gamma\, (O_2 + \frac{79}{21}\, N_2) \\ \rightarrow \mathbf{A}\, CO_2 + \mathbf{B}\, H_2O \quad &+ \quad \gamma\, \frac{79}{21}\, N_2 \end{aligned} \tag{19}$$

$$\begin{aligned} A &= \frac{\alpha}{100} \\ A &= 0.4845 \end{aligned} \tag{20}$$

$$\begin{aligned} 2B &= \frac{\beta}{100} \\ B &= 0.02925 \end{aligned} \tag{21}$$

$$\begin{aligned} \alpha &= 48.45 \\ \beta &= 5.85 \\ \lambda &= 0.4369 \end{aligned} \tag{22}$$

$$\begin{aligned} \gamma &= \frac{(2A + B - \lambda)}{2} \\ \gamma &= 0.1646 \end{aligned} \tag{23}$$

$$\begin{aligned}[0.4845\ C + 0.0585\ H + .4369\ O] \quad &+ \quad 0.1646\ (O_2 + \frac{79}{21}\ N_2) \\ \rightarrow 0.4845\ CO_2 + 0.02925\ H_2O \quad &+ \quad 0.1646\ \frac{79}{21}\ N_2 \end{aligned} \tag{24}$$

Using a known heating value, the heat released under an ideal combustion reaction would be $\approx$ 235 BTUs of heat. The calculation is shown in Equation 25 [105].

$$(0.0128kg)(19.38\frac{MJ}{kg})(947.817120313\frac{BTU}{MJ}) = 235.9324BTU \tag{25}$$

4.3.3 Calculation with Ponderosa Pine

Ponderosa Pine wood is plentiful in the Northwest regions of the United States and the western regions of Canada. It contains 49.25% Carbon, 6% Hydrogen, 44.36% Oxygen, and negligible amounts of Nitrogen and Sulfur [105]. Equation 26 shows the unbalanced equation, while the following equations are the atom balances required for an ideal combustion reaction as shown in Equation 8.

$$\begin{aligned}[\frac{\alpha}{100}\ C + \frac{\beta}{100}\ H + \lambda\ O] \quad &+ \quad \gamma\ (O_2 + \frac{79}{21}\ N_2) \\ \rightarrow \mathbf{A}\ CO_2 + \mathbf{B}\ H_2O \quad &+ \quad \gamma\ \frac{79}{21}\ N_2 \end{aligned} \tag{26}$$

$$\begin{aligned} A &= \frac{\alpha}{100} \\ A &= 0.4925 \end{aligned} \tag{27}$$

$$\begin{aligned} 2B &= \frac{\beta}{100} \\ B &= 0.02995 \end{aligned} \tag{28}$$

$$\begin{aligned}
\alpha &= 49.25 \\
\beta &= 5.99 \\
\lambda &= 0.4436
\end{aligned} \tag{29}$$

$$\begin{aligned}
\gamma &= \frac{(2A + B - \lambda)}{2} \\
\gamma &= 0.3306
\end{aligned} \tag{30}$$

$$\begin{aligned}
[0.4925\ C + 0.0599\ H + .4436\ O] &+ 0.3306\ (O_2 + \frac{79}{21}\ N_2) \\
\rightarrow 0.4925\ CO_2 + 0.02995\ H_2O &+ 0.3306\ \frac{79}{21}\ N_2
\end{aligned} \tag{31}$$

Using a known heating value, the heat released under an ideal combustion reaction would be $\approx$ 250 BTUs of heat. The calculation is shown in Equation 32 [105].

$$(0.0131kg)(20.02\frac{MJ}{kg})(947.817120313\frac{BTU}{MJ}) = 248.0637BTU \tag{32}$$

4.3.4 Summary

By calculating the amount of heat produced by a perfect combustion, we can see how efficient an actual fire is. We can also gauge how much of a difference the type of wood makes on the heat realized by the fire. This knowledge is crucial to understanding the efficiency of the device and is summed up here as Table 2. It is realized that slum dwellers in most parts of the world will not have access to wood chips from the Ponderosa Pine, Poplar or Black Spruce. Similar methods must be used to empirically obtain the properties of typical mixtures of scrap wood that people would be able to collect. This illustrates one of the many difficulties in this field: obtaining the data for such applications is much more difficult than obtaining thermochemical data for rocket engines or weapons.

Table 2: Summary of Different of Types of Wood Fuels

Type of Wood	Stoichiometric Moles of Air	Heat Released BTU
Black Spruce	16.275	9377
Hybrid Poplar	0.1646	236
Ponderosa Pine	0.3306	248

4.4 Feedback Loop

While the prototype will contain only a dial to turn the airflow up and down, the ultimate goal for the device is to be self-powered and self-monitored. A feedback loop should be able to sense the ideal temperature and adjust the airflow accordingly to achieve ideal combustion. The key to the loop will be coding chemical equations into MATLAB or other similar languages in such a way that reduce the inputs required from the user. An ideal device would need only to be plugged in, and sensors should be able to ascertain the wood type and ideal combustion conditions. The two main measurements needed are measurements of temperature and of airflow, as these two measurements at any given point in time give you the state of the device. A preliminary feedback loop is shown here as Figure 12.

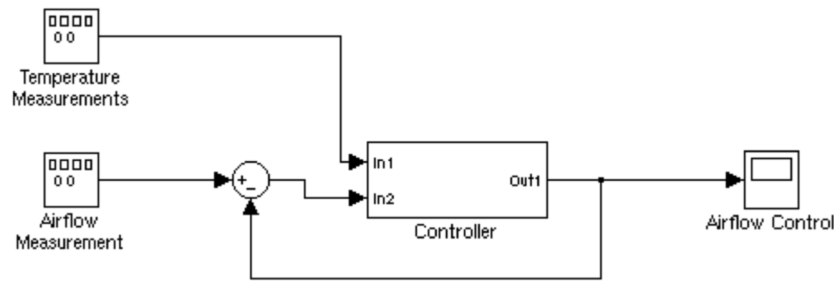

Figure 12: Preliminary Feedback Control

4.4.1 Sensor Considerations

In order for the device to contain a feedback loop, sensors are needed to take airspeed and temperature measurements, as well as a small, programmable microprocessor to handle any changes as needed. Ideally, there would also be a method to input what the fuel type is. While this may add complexity and cost to the device, the feedback loop will also enable the device to be completely self sufficient. It will also drive up the power requirements that needs to be produced by the device to charge the battery.

4.4.1.1 Temperature Sensors

The best way to measure these temperatures would be to use a surface resistance temperature detectors (RTDs). These sensors are small and use more circuitry; however they offer the most accurate and stable measurement of temperature over time. [9] This accuracy would offer the most control over the device through the feedback loop, though other options such as thermocouples and thermistors exist.

4.4.1.2 Airflow Sensors

For this device, a TSI VelociCalc velocimeter was used to measure airspeed at the exit of the nozzle. This method is described more in detail in Section . Another common alternative is hot film anemometers, but these may be too brittle to use in a device that needs to be robust. There are other methods and sensors that have been patented and may be of more use for this device. The one that seems to be the most promising was created by Shaun L. McCarthy[77]. Future tests will try to incorporate this sensor into the device and experiments.

4.5 Flow Rate Measurement

A setup, shown in Fig. 13 was used to measure the flow rate. The flow is measured at 5 points at the exit: the center, the left side, the right side, the top, and the bottom. Fig 14 shows the variation of speed with respect to voltage for the different positions.

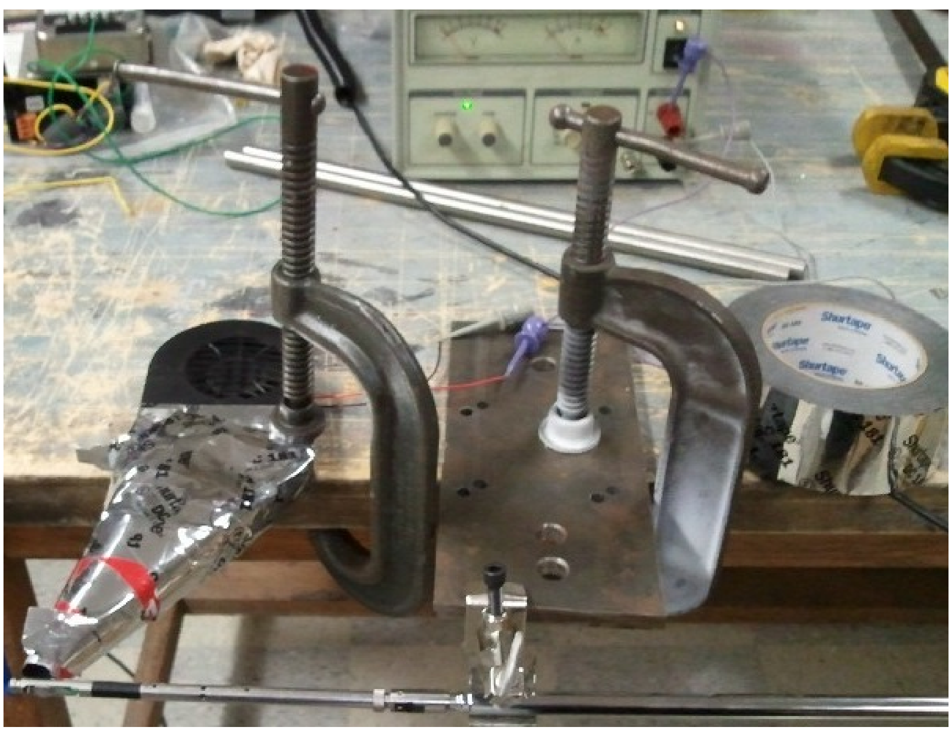

Figure 13: Setup to Measure Airflow

Based on these measurements, we can take an average of the flow to find the

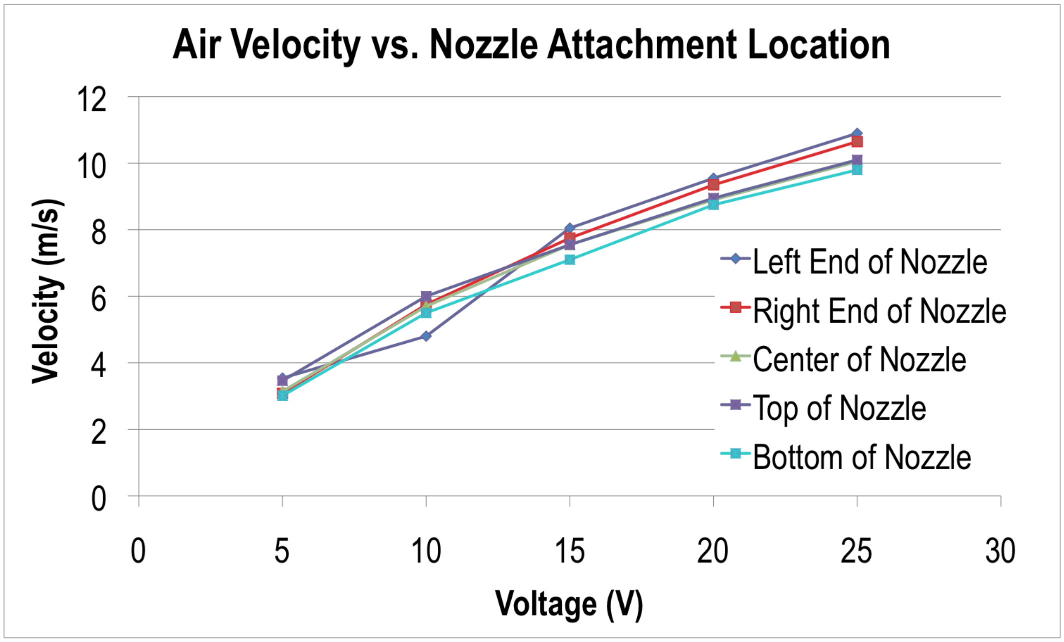

Figure 14: Results of Airflow Measurements

average flow rate needed to achieve a certain power setting (shown in Fig. 15). Comparing these values with the values of power we expect to supply to the fan via the thermoelectric module, we can see that complete combustion is within the realm of the fan's capabilities; in essence, we have complete control of the airflow to the fire. With the same data, how much voltage is needed by the fan to achieve a specific airflow is show here as Fig. 16.

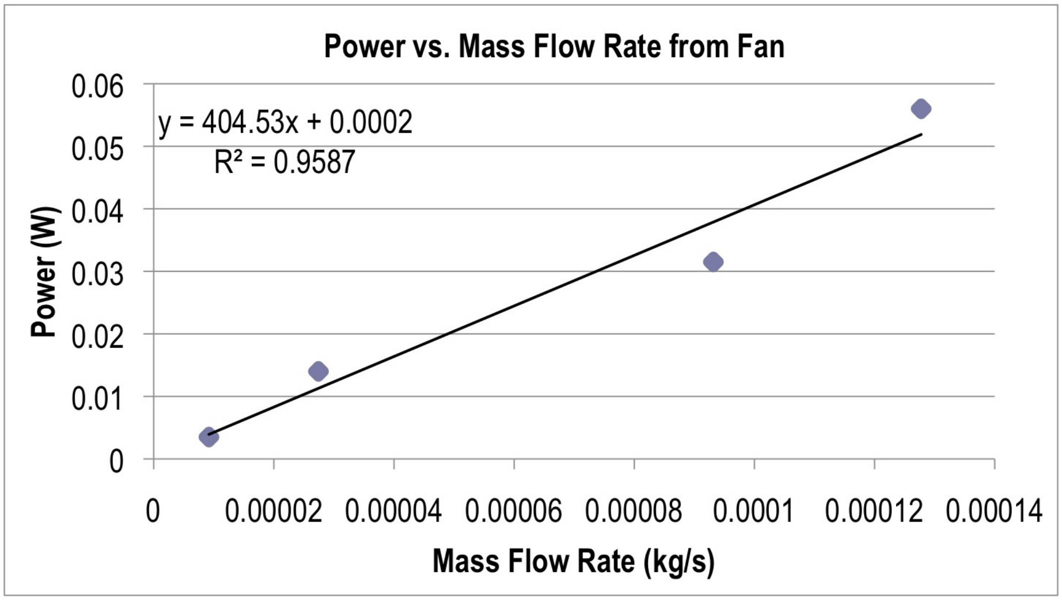

Figure 15: Power to Mass Flow Rate of the Fan

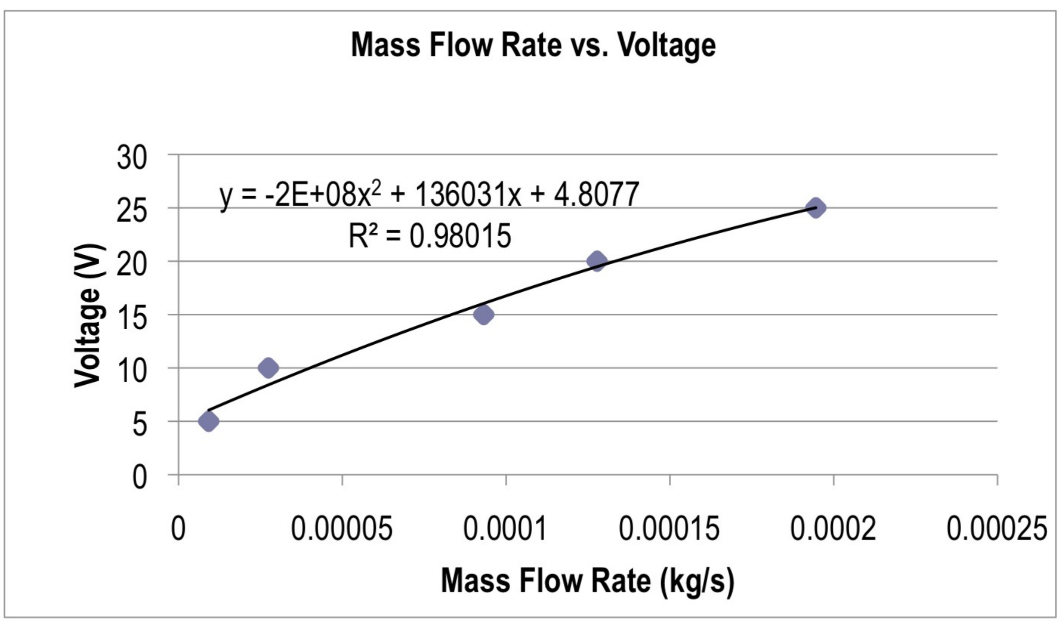

Figure 16: Voltage to Mass Flow Rate of the Fan

4.5.1 Lighting

LED lighting consumes very minimum wattage per LED. While different LED lights have different power consumption, they generally need only 2.5 volts to run with nominal brightness. Thus, with a constant voltage source, placing multiple LED's in parallel with the battery or the thermoelectric module can power an array of LED's for flood lighting.

4.6 Water Filtration

Many people purify water by boiling it. While this is an effective way to disinfect water, if done over a traditional 3-stone fire or other biomass cookstove, pollutants are released into the atmosphere, and much of the heat is lost to external effects (heating air and the like) [46]. A portable water filtration device will be used to filter water by irradiating the water with a low energy ultraviolet (UV) light [45], [47].

The first demonstrated use of ultraviolet light to disinfect water (also known as ultraviolet germicidal irradiation or UVGI) was seen in 1877 [103]. Since then, UV radiation has been used to treat smallpox, lupus, and other diseases [84]. UVGI attacks vegetative bacteria first and then moves on to mycobacteria, bacterial spores, and then finally fungal spores. Attacking these classifications of bacteria and spores can give a purification of about 99.999% [76].

4.6.1 Power Requirements

While UV lighting can seem to be intuitively power intensive, this is not the case. UV light can be produced via LED's and as such, the power considerations shown in Section 4.5.1 apply. Thus, only 2.5 volts are nominally needed to run a water-depth purification system.

CHAPTER V

CONCLUSIONS

Thermoelectric power generation can be used in conjunction with DC-DC voltage converters to theoretically create a self-charging, self-sustaining system. This system would consist of a thermoelectric module to create electric power that would then go to be stored in a battery. The battery would then be used to power a small computer fan with a nozzle, which will blow air into a fire. The airflow would serve a dual purpose: to cool the cold side of the thermoelectric module and to add oxygen to the flame, thereby increasing combustion and reducing smoke and other harmful particulates. With any extra power generated by the thermoelectric module, an array of LED lights can be lit to provide indoor lighting. Another use of the extra power is for a UV water purification system to obtain clean water. It has been demonstrated that within operating limits, this device can maintain sufficient temperature difference to be used in conjunction with DC-DC converters. The power budget for this system will only close with the use of DC-DC converters at the time of writing, as sufficient power cannot be generated by one thermoelectric module alone. Care must also be taken to protect all the components from damage. Suitable test loads are also being investigated. However, surmounting these hurdles will potentially provide lighting, clean water and clean air for lower-income families whose livelihood and cooking methods rely on conventional 3-stone fires.

5.1 Suggestions for Future Work

1. **Light Bulb Tests**: Testing should be done to confirm the power requirements and operability of DC-DC converters with a flashlight bulb. They should also be put in series to power a normal energy saver bulb, to confirm the use of DC-DC converters in series.

2. **Close System with Battery-in-the-Loop**: The system should be created such that the fan is no longer operating on an external power supply and instead is powered by the batter that is being charged by the DC-DC converter array.

3. **Integrate LED Floodlighting and UV Purification System**: Once the system design closes, the device is feasible and marketing plans can be developed for this device. By adding DC-DC converters to the array for more expedient charging, alternate small-power consumption devices such as an LED array for floodlighting and UV water purifications systems can be added.

4. **Controller Design**: The feedback controller must now be designed. Perhaps more importantly, feedback sensors must be selected and strategically placed for optimal performance and control.

APPENDIX A

PARTS

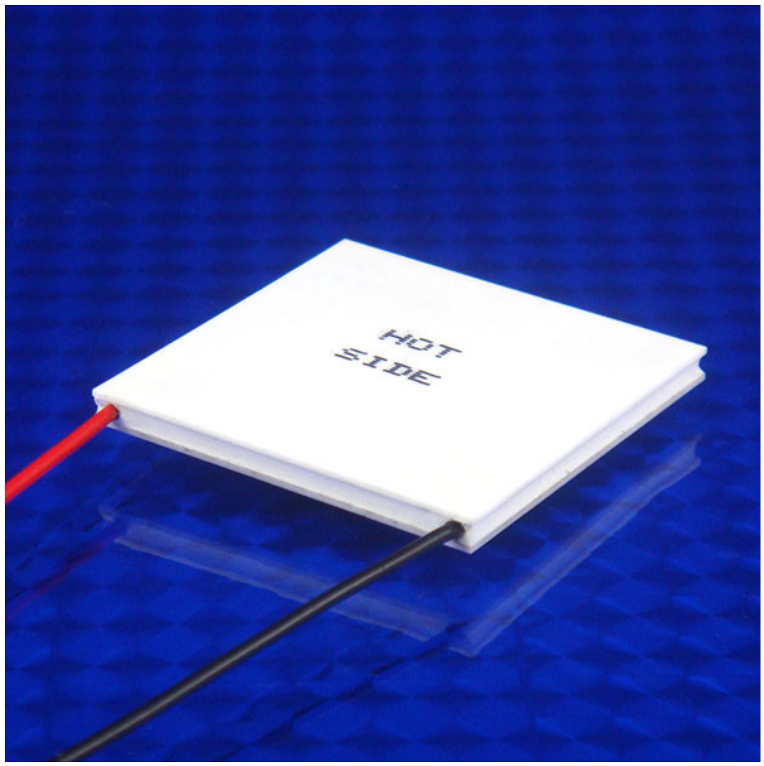

Figure 17: 1261G-7L31-10CX1 Power Generation Module from Custom Thermoelectric

Figure 18: Boxer Computer Fan

Figure 19: Rechargeable Battery

Figure 20: LED Floodlight

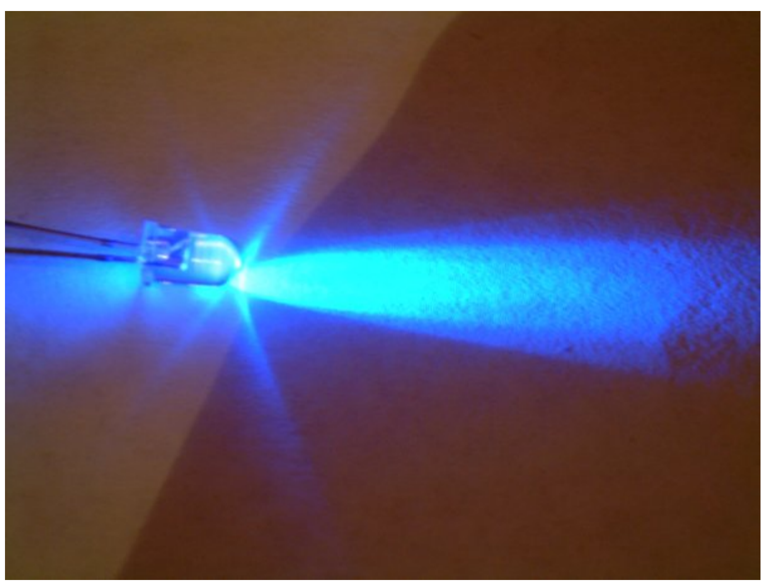

Figure 21: Purifying UV LED

REFERENCES

[1] "Jx crystals thermophotovoltaics," October 2011.

[2] Aderemi, A. and Otitoloju, A., "An assessment of landfill fires and their potential health effects-a case study of a municipal solid waste landfill in lagos, nigeria," *International Journal of Environmental Protection*, vol. 2, no. 2, 2012.

[3] Allen, D., Haugeto, R., Kajor, M., and Namazian, M., "Small thermoelectric generators," in *Thermoelectrics, 2002. Proceedings ICT'02. Twenty-First International Conference on*, pp. 424–426, IEEE, 2002.

[4] Amrose, S., "Development and testing of the berkeley darfur stove," 2008.

[5] Amrose, S., Kisch, G., Kirubi, C., Woo, J., and Gadgil, A., "Development and testing of the berkeley darfur stove," Report LBNL-116E, Lawrence Berkeley National Laboratories, Berkeley, CA, March 2008.

[6] Anon., "Wood and combustion heat values," 2011.

[7] Azorin, J., Furetta, C., and Scacco, A., "Preparation and properties of thermoluminescent materials," *physica status solidi (a)*, vol. 138, no. 1, pp. 9–46, 1993.

[8] Azorin, J., Furetta, C., and Scacco, A., "Preparation and properties of thermoluminescent materials," *Physics Stat. Solids (a)*, vol. 138, no. 9, 1993.

[9] Baker, B., "Precision temperature sensing with rtd circuits," *AN687, Microchip Technology Inc*, 1998.

[10] Barnett, A., Kirkpatrick, D., and Honsberg, C., "Very high efficiency solar cells," in *Proceedings of SPIE*, vol. 6338, p. 63380N, 2006.

[11] Barnett, A. e. a., "Very high efficiency solar cell modules," *Progress in Photovoltaics: Research and Applications*, vol. 17, pp. 75–83, October 2008.

[12] Bass, J., Elsner, N., and Leavitt, F., "Performance of the 1 kw thermoelectric generator for diesel engines," in *AIP Conference Proceedings*, pp. 295–295, IOP INSTITUTE OF PHYSICS PUBLISHING LTD, 1995.

[13] Bennett, G., Lombardo, J., and Rock, B., "Power performance of the general-purpose heat source radioisotope thermoelectric generator," *Space nuclear power systems 1986*, pp. 437–450, 1987.

[14] Bhada, P., "Capacity-to-act in indias solid waste management and waste-to-energy industries," 2005.

[15] Bitnar, B., "Silicon, germanium and silicon/germanium photocells for thermophotovoltaics applications," *Semiconductor science and technology*, vol. 18, p. S221, 2003.

[16] Bitnar, B., "Silicon, germanium and silicon/germanium photocells for thermophotovoltaics applications," *Semiconductor science and technology*, vol. 18, p. S221, 2003.

[17] Bitnar, B., Palfinger, G., Durisch, W., Mayor, J., Grützmacher, D., Sigg, H., and Gobrecht, J., "Simulation and demonstration model of a high efficiency thermophotovoltaic system," in *Proc. 14th Quantsol Workshop 2002*, pp. 69–70, 2002.

[18] Blanc, P., "The role of household expsoures in lung disease among women," *European Respiratory Monograph*, vol. 8, pp. 118–130, 2003.

[19] Bogner, J., Ahmed, M., Diaz, C., Faaij, A., Gao, Q., Hashimoto, S., Mareckova, K., Pipatti, R., and Zhang, T., "Waste management in climate change 2007: Mitigation. contribution of working group iii to the fourth assessment report of the intergovernmental panel on climate change," 2007.

[20] Bruce, N., Perez-Padilla, R., Albalak, R., and others, "Indoor air pollution in developing countries: a major environmental and public health challenge," *Bulletin of the World Health Organization*, vol. 78, no. 9, pp. 1078–1092, 2000.

[21] Bulls, K., "More-efficient thermoelectrics," 2010.

[22] Buse, K. and Ringhofer, K., "Pyroelectric drive for light-induced charge transport in the photorefractive process," *Applied Physics A: Materials Science & Processing*, vol. 57, no. 2, pp. 161–165, 1993.

[23] Carlson, R. and Fraas, L., "Adapting tpv for use in a standard home heating furnace," in *Thermophotovoltaic Generation of Electricity(AIP Conference Proceedings Volume 890)*, vol. 890, pp. 273–279, American Institute of Physics, 2 Huntington Quadrangle, Suite 1 NO 1, Melville, NY, 11747-4502, USA,, 2007.

[24] Chan, W., *Towards a high-efficiency micro-thermophotovoltaic generator*. PhD thesis, Massachusetts Institute of Technology, 2010.

[25] Chen, J., "Thermodynamic analysis of a solar-driven thermoelectric generator," *Journal of applied physics*, vol. 79, no. 5, pp. 2717–2721, 1996.

[26] Chen, K., "Man portable tpv generator system.," tech. rep., DTIC Document, 1997.

[27] Chen, K. and Goldstein, M., "Man portable tpv generator system.," tech. rep., DTIC Document, 1997.

[28] Colangelo, G., Risi, A., and Laforgia, D., "New approaches to the design of the combustion system for thermophotovoltaic applications," *Semiconductor science and technology*, vol. 18, p. S262, 2003.

[29] Costia, D., "Popescu,¡. o., popescu, cl, craciunescu, a.,photovoltaic solar cell like receiver for electromagnetic waves in vhf-uhf bands. paper 303," in *International Conference on Renewable Energies and Power Quality (ICREPQ10), Granada (Spain), 23rd to 25th March*, 2010.

[30] Coutts, T., "An overview of thermophotovoltaic generation of electricity," *Solar energy materials and solar cells*, vol. 66, no. 1-4, pp. 443–452, 2001.

[31] Damaschke, J., "Design of a low-input-voltage converter for thermoelectric generator," *Industry Applications, IEEE Transactions on*, vol. 33, no. 5, pp. 1203–1207, 1997.

[32] de Koning, H., Smith, K., and Last, J., "Biomass fuel combustion and health," *Bulletin of the World Health Organization*, vol. 63, no. 1, p. 11, 1985.

[33] Dudley-Flores, M. and Gangale, T., "The globalization of space–the astrosociological approach," in *AIAA Space 2007 Meeting Papers on Disc*, Citeseer, 2007.

[34] Dudley-Flores, M. and Gangale, T., "The globalization of space the astrosociological approach, aiaa space 2007 meeting papers on disc [cd-rom]," tech. rep., AIAA-2006-XXXX, Reston, Virginia, 2007.

[35] Dudley-Rowley, M. and Gangale, T., "Sustainability public policy challenges of long-duration space exploration," *Proceedings AIAA ARIC Spec. Mtg.*, 2006.

[36] Dudley-Rowley, M. and Gangale, T., "Sustainability public policy challenges of long-duration space exploration, aiaa space 2006 meeting papers on disc [cd-rom]," tech. rep., AIAA-2006-7489, Reston, Virginia, 2006.

[37] Durisch, W., Grob, B., Mayor, J., Panitz, J., and Rosselet, A., "Interfacing a small thermophotovoltaic generator to the grid," in *AIP Conference Proceedings*, vol. 460, p. 403, 1999.

[38] Emery, K. and (US), N. R. E. L., *Photovoltaic spectral responsivity measurements*. National Renewable Energy Laboratory, 1998.

[39] Ericzon, C., Pettersson, J., Andersson, M., and Olin, A., "Determination and speciation of selenium in end products from a garbage incinerator," *Environmental science & technology*, vol. 23, no. 12, pp. 1524–1528, 1989.

[40] Fatemi, N., "A solar thermophotovoltaic electrical generator for remote power applications.," tech. rep., DTIC Document, 1996.

[41] Fraas, L., Avery, J., Malfa, E., Wuenning, J., Kovacik, G., and Astle, C., "Thermophotovoltaics for combined heat and power using low nox gas fired radiant tube burners," in *AIP Conference Proceedings*, pp. 61–70, IOP INSTITUTE OF PHYSICS PUBLISHING LTD, 2003.

[42] Fraas, L., Avery, J., and Huang, H., "Thermophotovoltaics: Heat and electric power from low bandgap solar cells around gas fired radiant tube burners," in *Photovoltaic Specialists Conference, 2002. Conference Record of the Twenty-Ninth IEEE*, pp. 1553–1556, IEEE, 2002.

[43] Fthenakis, V., Wang, W., and Kim, H., "Life cycle inventory analysis of the production of metals used in photovoltaics," *Renewable and Sustainable Energy Reviews*, vol. 13, no. 3, pp. 493–517, 2009.

[44] Fthenakis, V., "End-of-life management and recycling of pv modules," *Energy Policy*, vol. 28, no. 14, pp. 1051–1058, 2000.

[45] Gadgil, A. and Garud, V., "Uv water disinfector," July 14 1998. US Patent 5,780,860.

[46] Gadgil, A., Greene, D., and Rosenfeld, A., "Energy-efficient drinking water disinfection for greenhouse gas mitigation," *Proc. 1998 Summer Study on Energy Efficiency in Buildings*, vol. 5, pp. 131–41, 1998.

[47] Gadgil, A., "Portable water treatment unit," Oct. 15 2002. US Patent 6,464,884.

[48] Gadgil, A., Greene, D., and Rosenfeld, A., "Energy-efficient drinking water disinfection for greenhouse gas mitigation," in *Proceedings of ACEEE Summer Study "Energy Efficiency in a Competitive Environment"* ., (at Asilomar in Pacific Grove, CA,), ACEEE, August 23-28 1998.

[49] Gordon, J., "Generalized power versus efficiency characteristics of heat engines: The thermoelectric generator as an instructive illustration," *American Journal of Physics*, vol. 59, p. 551, 1991.

[50] Green, M. and Baillie, A., "Forty three per cent composite split-spectrum concentrator solar cell efficiency," *Progress in Photovoltaics: Research and Applications*, vol. 18, pp. 42–47, 2010.

[51] Green, M. and Ho-Baillie, A., "Forty three per cent composite split-spectrum concentrator solar cell efficiency," *Progress in Photovoltaics: Research and Applications*, vol. 18, no. 1, pp. 42–47, 2010.

[52] Harrison, A., "Overcoming the image of little green men: Astrosociology and seti," *Astrosociology. com Virtual Library, URL: http://www. astrosociology. com/Library/PDF/Submissons/Overcoming*, vol. 20.

[53] Hirsch, H. and Mandal, A., "A cascade theory for the aerodynamic performance of darrieus wind turbines," *Wind Engineering*, vol. 11, no. 3, pp. 164–175, 1987.

[54] Huang, B., Chin, C., and Duang, C., "A design method of thermoelectric cooler," *International Journal of Refrigeration*, vol. 23, no. 3, pp. 208–218, 2000.

[55] Ikoma, K., Munekiyo, M., Furuya, K., Kobayashi, M., Izumi, T., and Shinohara, K., "Thermoelectric module and generator for gasoline engine vehicles," in *Thermoelectrics, 1998. Proceedings ICT 98. XVII International Conference on*, pp. 464–467, IEEE, 1998.

[56] Inc., C. T., "Teg specification sheet," *International Journal of Refrigeration*, pp. 3, year=, publisher=Custom Thermoelectric Inc.

[57] Ishikawa, T., Ueno, M., Endo, ., Nakaki, Y., Hata, H., Sone, T., and Kimata, M., "Low-cost 320x240 uncooled irfpa using conventional silicon 1? process," *Opto-Electronics Review*, vol. 7, no. 4, pp. 297–303, 1999.

[58] Islam, M., Ting, D., and Fartaj, A., "Aerodynamic models for darrieus-type straight-bladed vertical axis wind turbines," *Renewable and Sustainable Energy Reviews*, vol. 12, no. 4, pp. 1087–1109, 2008.

[59] Jacobson, S. and Epstein, A., "An informal survey of power mems," in *The international symposium on micro-mechanical engineering*, vol. 12, pp. 513–519, 2003.

[60] Jermann, F. and Buse, K., "Light-induced thermal gratings in linbo 3: Fe," *Applied Physics B: Lasers and Optics*, vol. 59, no. 4, pp. 437–443, 1994.

[61] Jetter, J. and Kariher, P., "Solid-fuel household cook stoves: characterization of performance and emissions," *Biomass and Bioenergy*, vol. 33, no. 2, pp. 294–305, 2009.

[62] Jungbluth, N. and Tuchschmid, M., "Photovoltaics," *Sachbilanzen von Energiesystemen: Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz. Ecoinvent report*, no. 6-XII, 2009.

[63] Khvostikov, V., Sorokina, S., Potapovich, N., Khvostikova, O., Malievskaya, A., Vlasov, A., Shvarts, M., Timoshina, N., and Andreev, V., "Thermophotovoltaic generators based on gallium antimonide," *Semiconductors*, vol. 44, no. 2, pp. 255–262, 2010.

[64] Khvostikov, V., Sorokina, S., Potapovich, N., Khvostikova, O., Malievskaya, A., Vlasov, A., Shvarts, M., Timoshina, N., and Andreev, V., "Thermophotovoltaic generators based on gallium antimonide," *Semiconductors*, vol. 44, no. 2, pp. 255–262, 2010.

[65] Kirke, B., *Evaluation of self-starting vertical axis wind turbines for standalone applications*. PhD thesis, Griffith University, 1998.

[66] Komerath, N., "Prediction and validation of a micro wind turbine for family use," in *Proceedings of the IMETI Conference*, (Orlando, FL), July 2011.

[67] Komerath, N., "Terrestrial micro renewable energy applications of space technology," *Physics Procedia*, vol. 20, pp. 255–269, February 2011.

[68] Komerath, N. and Komerath, P., "Terrestrial micro renewable energy applications of space technology," *Physics Procedia*, vol. 20, pp. 255–269, 2011.

[69] Korneev, N., Mayorga, D., Stepanov, S., Gerwens, A., Buse, K., and Krätzig, E., "Enhancement of the photorefractive effect by homogeneous pyroelectric fields," *Applied Physics B: Lasers and Optics*, vol. 66, no. 3, pp. 393–396, 1998.

[70] Kullmann, S., *Specific energy yield of low-power amorphous silicon and crystalline silicon photovoltaic modules in a simulated off-grid, battery-based system.* PhD thesis, Humboldt State University, 2009.

[71] Larson, T. and Koenig, J., "Wood smoke: emissions and noncancer respiratory effects," *Annual review of public health*, vol. 15, no. 1, pp. 133–156, 1994.

[72] LU, L., ZHU, L., and WU, Z., "Simulation of city garbage incinerators,"

[73] Luckiesh, M., *Applications of Germicidal, Erythemal and Infrared Energy.* New York, NY: D. Van Nostrand Co., Inc., 1946.

[74] Luckiesh, M. and Knowles, T., "Resistivity of escherichia coli to ultraviolet energy (=2537) as affected by irradiation of preceding cultures," *Journal of Bacteriology, American Society for Microbiology*, vol. 55, pp. 369–372, March 1948.

[75] Marsh, M., Rygalov, V., and Livingston, D., "Life support systems functional stability and human control limitations-an astrosociological approach," in *SPACE 2008 Conference and Exposition*, no. 2008-7814, AIAA, September 2008.

[76] Martin Jr, S. B., Dunn, C., Freihaut, J. D., Bahnfleth, W. P., Lau, J., and Nedeljkovic-Davidovic, A., "Ultraviolet germicidal irradiation,"

[77] McCarthy, S. L., "Mass airflow sensor," June 17 1986. US Patent 4,594,889.

[78] McHenry, R., "The design and construction of a high temperature photon emitter for a thermophotovoltaic generator.," tech. rep., DTIC Document, 1995.

[79] Mills, R. and Desmon, L., "Operating experience in the suspension burning of waste materials in cyclone incinerators," in *Proceedings of... National Incinerator Conference*, vol. 5, p. 195, American Society of Mechanical Engineers., 1972.

[80] Mishra, V., Retherford, R., and Smith, K., "Biomass cooking fuels and prevalence of blindness in india," *Journal of Environmental Medicine*, vol. 1, no. 4, pp. 189–199, 1999.

[81] Mishra, V., Retherford, R., and Smith, K., "Biomass cooking fuels and prevalence of tuberculosis in india," *International Journal of Infectious Diseases*, vol. 3, no. 3, pp. 119–129, 1999.

[82] Mubaiwa, A. and Africa, P., "Community based waste management in urban areas," *SPONSORS*, p. 99, 2006.

[83] Niino, M., Ohshima, T., and Matsubara, K., "Research project on the effective use of untapped thermal energy from garbage incineration etc," in *Thermoelectrics, 1997. Proceedings ICT'97. XVI International Conference on*, pp. 539–546, IEEE.

[84] NobelPrize.org, "Niels ryberg finsen - biography," 22 Apr 2013.

[85] Nuwayhid, R., Rowe, D., and Min, G., “Low cost stove-top thermoelectric generator for regions with unreliable electricity supply,” *Renewable energy*, vol. 28, no. 2, pp. 205–222, 2003.

[86] Nuwayhid, R., Rowe, D., and Min, G., “Low cost stove-top thermoelectric generator for regions with unreliable electricity supply,” *Renewable energy*, vol. 28, no. 2, pp. 205–222, 2003.

[87] Nuwayhid, R., Shihadeh, A., and Ghaddar, N., “Development and testing of a domestic woodstove thermoelectric generator with natural convection cooling,” *Energy conversion and management*, vol. 46, no. 9, pp. 1631–1643, 2005.

[88] Paraschivoiu, I., “Aerodynamic loads and performance of the darrieus rotor,” *J. Energy;(United States)*, vol. 6, no. 6, 1982.

[89] Pass, J., “Invitation to astrosociology: Why the sociologist-space enthusiast should consider it1,”

[90] Pass, J., “Space: Sociology’s forsaken frontier1,”

[91] Pass, J., “The astrosociology of space colonies: Or the social construction of societies in space,” in *Space Technology and Applications International Forum-Staif 2006*, vol. 813, pp. 1153–1161, American Institute of Physics, 2 Huntington Quadrangle, Suite 1 NO 1, Melville, NY, 11747-4502, USA,, 2006.

[92] Pass, J., “Developing astrosociology for the space sciences,” *2006b), http://www. astrosociology. com/Library/PDF/Submissions/Developing% 20Astrosociology. pdf, accessed July*, vol. 15, 2006.

[93] Pass, J., “Enhancing space exploration by adding astrosociology to the stem model,” in *proceedings of AIAA SPACE*, 2007.

[94] Pass, J., "The potential of astrosociology in the twenty-first century: Developing an emerging field to help solve social problems," in *AIP Conference Proceedings*, vol. 1103, p. 674, 2009.

[95] Pass, J., Dudley-Rowley, M., and Gangale, T., "The cultural imperative to colonize space: An astrosociological perspective," 2006.

[96] Pettersen, R., "The chemical composition of wood," *The chemistry of solid wood*, vol. 20, 1984.

[97] Phillips, T. S., *Dynamo-Electric Machinery; a Manual for Students of Electrotechnics*. BiblioLife, 2009.

[98] Pilawa-Podgurski, R., Pallo, N., Chan, W., Perreault, D., and Celanovic, I., "Low-power maximum power point tracker with digital control for thermophotovoltaic generators," in *Applied Power Electronics Conference and Exposition (APEC), 2010 Twenty-Fifth Annual IEEE*, pp. 961–967, IEEE, 2010.

[99] Quanlu, L., "Integrated photoelectric device made of a piezoelectric ceramic exhibiting pyroelectricity and an internal photoeffect," *The Journal of the Acoustical Society of America*, vol. 108, p. 608, 2000.

[100] Ragauskas, A., "Chemical composition of wood."

[101] Riaz, A. and Sughis, M., "Biomass smoke-a silent killer," *theHealth*, vol. 2.

[102] Rodríguez, A., Vián, J., Astrain, D., and Martínez, A., "Study of thermoelectric systems applied to electric power generation," *Energy Conversion and Management*, vol. 50, no. 5, pp. 1236–1243, 2009.

[103] Roessler, P. F. and Severin, B. F., "Ultraviolet light disinfection of water and wastewater," *Modeling disease transmission and its prevention by disinfection. Cambridge University Press, Cambridge, United Kingdom*, pp. 313–368, 1996.

[104] Saka, S., "Chemical composition and distribution," *Wood and cellulose chemistry, Marcel Dekker, New York*, pp. 51–82, 2001.

[105] Sannigrahi, P., Ragauskas, A., and Tuskan, G., "Poplar as a feedstock for biofuels: A review of compositional characteristics," *Biofuels, Bioproducts and Biorefining*, vol. 4, no. 2, pp. 209–226, 2010.

[106] Saxton, P., Moran, A., Harper, M., and Lindler, K., "Thermophotovoltaic emitter material selection and design," in *Energy Conversion Engineering Conference, 1997. IECEC-97., Proceedings of the 32nd Intersociety*, pp. 1107–1112, IEEE, 1997.

[107] Saxton, P., Moran, A., Harper, M., and Lindler, K., "Thermophotovoltaic emitter material selection and design," in *Energy Conversion Engineering Conference, 1997. IECEC-97., Proceedings of the 32nd Intersociety*, pp. 1107–1112, IEEE, 1997.

[108] Schaevitz, S., *A MEMS thermoelectric generator*. PhD thesis, Massachusetts Institute of Technology, 2000.

[109] Schaevitz, S., Franz, A., Jensen, K., and Schmidt, M., "A combustion-based mems thermoelectric power generator," in *The 11th International Conference on Solid-State Sensors and Actuators*, pp. 30–33, 2001.

[110] Sheldahl, R. and Klimas, P., "Aerodynamic characteristics of seven symmetrical airfoil sections through 180-degree angle of attack for use in aerodynamic analysis of vertical axis wind turbines," tech. rep., Sandia National Labs., Albuquerque, NM (USA), 1981.

[111] Smale, M., Savoie, M., Shirwa, Z., and Axmed, M., "Wood fuels consumption and cooking practices in selected sites of lower shabeelle, banaadir and gedo regions of somalia," 1984.

[112] Snyder, G., "Application of the compatibility factor to the design of segmented and cascaded thermoelectric generators," *Applied physics letters*, vol. 84, no. 13, pp. 2436–2438, 2004.

[113] Snyder, G., "Application of the compatibility factor to the design of segmented and cascaded thermoelectric generators," *Applied physics letters*, vol. 84, no. 13, pp. 2436–2438, 2004.

[114] Snyder, G. and Ursell, T., "Thermoelectric efficiency and compatibility," *Physical review letters*, vol. 91, no. 14, p. 148301, 2003.

[115] Snyder, G. and Ursell, T., "Thermoelectric efficiency and compatibility," *Physical review letters*, vol. 91, no. 14, p. 148301, 2003.

[116] Staton, D. and Harding, M., "Health and environmental effects of cooking stove use in developing countries," 1998.

[117] Steinberg, D. S., *Cooling techniques for electronic equipment*. Wiley New York, 1991.

[118] Still, D. and Winiarski, L., "Increasing fuel efficiency and reducing harmful emissions in traditional cooking stoves," *Boiling Point*, vol. 47, pp. 36–39, 2001.

[119] Stordeur, M. and Stark, I., "Low power thermoelectric generator-self-sufficient energy supply for micro systems," in *Thermoelectrics, 1997. Proceedings ICT'97. XVI International Conference on*, pp. 575–577, IEEE, 1997.

[120] Stordeur, M. and Stark, I., "Low power thermoelectric generator-self-sufficient energy supply for micro systems," in *Thermoelectrics, 1997. Proceedings ICT'97. XVI International Conference on*, pp. 575–577, IEEE, 1997.

[121] Strickland, J. H., "The darrieus turbine: A performance prediction model using multiple streamtubes," Report SAND75-0H31, Sandia National Laboratories, October 1975.

[122] Templin, R., "Aerodynamic performance theory for the nrc vertical-axis wind turbine," *NASA STI/Recon Technical Report N*, vol. 76, p. 16618, 1974.

[123] Wenming, Y., Siawkiang, C., Chang, S., Hong, X., and Zhiwang, L., "Research on micro-thermophotovoltaic power generators with different emitting materials," *Journal of Micromechanics and Microengineering*, vol. 15, p. S239, 2005.

[124] Yang, W., Chou, S., Shu, C., Li, Z., and Xue, H., "Experimental study of micro-thermophotovoltaic systems with different combustor configurations," *Energy conversion and management*, vol. 48, no. 4, pp. 1238–1244, 2007.

[125] Yang, W., Chou, S., Shu, C., Xue, H., and Li, Z., "Development of a prototype micro-thermophotovoltaic power generator," *Journal of Physics D: Applied Physics*, vol. 37, p. 1017, 2004.

[126] Zerbock, O., "Urban solid waste management: Waste reduction in developing nations," *Written for the Requirements of CE*, vol. 5993, 2003.

Index

VITA

Akshaya is a Senior in the Guggenheim School of Aerospace Engineering. He got his private pilot's license at the age of 17, and when not flying, he does various research work, including research on the feasibility of fuel depots in space. During the summer of 2011, he worked at NASA LaRC integrating ADS-B technologies with UAVs. The following summer saw Akshaya working at NASA's Jet Propulsion Laboratory (JPL), helping understand the feasibility of robotic mission to Europa, one of Jupiter's many moons that may harbor life. After graduation, he plans to attend graduate school after working in the industry for some time. Other interests include video games, playing guitar, and martial arts.

Design of a Thermoelectric Edu-Kitchen System

Akshaya Srivastava

47 Pages

Directed by Professor Narayanan Komerath

The driving force behind this project is to aid the people who live in rural areas of the world and have difficulties in accessing basic electricity and kitchen efficiencies. The most basic kitchen is a pot over a fire. However, this setup will pollute the environment drastically. This project proposes to reduce the pollution by powering a fan to help regulate air intake and make the flames burn more efficiently. The question posed then is how to power the fan. The solution provided by this project is to use a thermoelectric panel, similar to those used in space missions, but of a lower cost and power. This thermoelectric component will utilize the Seebeck effect to charge a battery that will then serve to run the fan. The battery can also power an LED light to provide light while cooking. Additionally, the battery could also be connected to an ultraviolet LED, an integral part to a recently developed water purification system.