ASHESI UNIVERSITY

IMPROVED THERMOELECTRIC BIOMASS COOKSTOVE

CAPSTONE PROJECT

B.Sc Electrical & Electronic Engineering

Hellen Wairimu Kagunyi

2020

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CAPSTONE PROJECT

Capstone project submitted to the Department of Engineering, Ashesi University in partial fulfilment of the requirements for the award of Bachelor of Science degree in Electrical & Electronic Engineering.

Hellen Kagunyi

2020

DECLARATION

I hereby declare that this capstone is the result of my on original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidates Signature:

Candidates Name: Kagunyi Hellen Wairimu

Date: 5/30/2020

I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University.

Supervisor's Signature:

Supervisor's Name:

Date:

Acknowledgement

To my supervisor Dr. Heather Beem whose encouragement and academic advice helped me undertake this project. To the Ashesi Engineering faculty members, Lab and workshop assistants whose insights helped me reach a successful completion of the project.

ABSTRACT

This paper documents the development of an improved, thermoelectric biomass cookstove, a product aimed at making the cooking process among off-grid communities more environment-friendly and safer for use. A biomass cookstove is embedded with a thermoelectric generator that uses the Seebeck effect to convert waste heat into electricity. Produced electricity is in return, used to blow air into the combustion chamber hence, increasing the air-to-fuel ration.

In addition, this paper reports the building and testing of additional functionalities aimed at increasing efficiency of the stove. These are; automatic fuel-level indicator and fan-speed control. Results are recorded and analyzed, providing possible measures for optimization for the future.

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CHAPTER ONE

1.1 INTRODUCTION

It is indisputable that tropical deforestation is a serious environmental problem which has become a global issue due to its adverse effects on climate. In Ghana, wood fuel accounts for over 50% of the country's final total energy consumption. In addition, it is reported that 2010 national population census, over 73% and 16% of rural households depend on firewood and charcoal for cooking, with the demand for charcoal quickly overtaking that of firewood. [1]. This statistic shows that continuous reliance on wood fuel is a definite contributor to the decreasing forest cover in Ghana. This calls for a better alternative that would provide fuel other than the cutting down of trees. Several reports by researches and Ghana media have reported the increase in lung cancer among non-smoking mothers and respiratory diseases among young children due to smoky kitchens. [2]. This further pushes for health friendly fuels that will have clean burn without affecting the health of the users.

During the research on the potential of biomass energy for electricity production in Sub-Saharan Africa in 20111, it was reported that access to electricity is 26% which falls to 1 % in rural areas. [3]. This simply gives further evidence that the cleanest source of energy cannot be relied upon by a larger part of the population across Africa. However, there is a record of huge quantity of residue from agricultural and forest produce processing. Efforts have been made to develop biomass fuel from coconut husks, rice husks and sawdust. This fuel can be made feasible and useful in small scale production of electricity by the use of a well-designed cookstoves equipped with thermoelectric generators. The biomass stove is designed to consume the possible minimum fuel at a time compared to the conventional old stoves.

1.2 PROBLEM STATEMENT

Off-grid and low-income communities have over the years had challenges in acquiring an economic, environmentally friendly and health-friendly cooking energy. Despite the use of biomass cookstoves which reduces cutting of trees, the present design of stove consumes a lot of fuel. In addition, a lot of heat energy is wasted as it is not built for the user to regulate the rate of combustion. The heat energy produced could also be put to another good use aside cooking if the product was well designed and equipped with thermoelectric generator.

1.3 MOTIVATION

In summer 2018, I visited the people of *Ketekrache,* one of the remote island communities in Lake Volta, Ghana. For many years, these people have depended on the sun, the moon and fire for lighting. Due to lack of electricity and the high cost of liquid fuels such as kerosene, these communities live in the dark. For their cooking, they cut down trees for charcoal and firewood. In the recent past, innovators have introduced to them biomass fuel and energy saving cookstoves. However, cooking in a stove does not provide lighting in the night. They still put up the firewood fires when darkness comes in. Although these solutions are aimed at reducing the cutting down of trees, they are not feasible enough.

Children in these islands are limited from studying in the evening. In addition, some of them have to travel very far distances just to get their phones charged. I imagined how inconvenient this would be in a night of an emergency.

This got me thinking about the astounding change an improved thermoelectric biomass cookstove would have on such communities economic and environmental sectors. A thermoelectric cookstove would make cooking efficient as well as charge their lamps for lighting concurrently.

In addition, I believe that such a product would have a good market not only from off-grid communities but also among campers, sea travelers and any other middle-class household that may find the available electricity being more expensive compared to this product.

1.4 PROJECT SCOPE

The objective of this project is to create a thermoelectric generator that can be embedded onto a cookstove. The generator should be able to create enough power for facilitating clean combustion by reducing the emissions. The product should be more efficient and user friendly. This way, it can have a wider market. Summary of the scope is given in three subsystems.

1) Power Generation
2) Automatic Power Regulation
3) Fuel Level Indicator

1) Power Generation:

Involves the building of the thermoelectric generator and embedding in a cookstove. In the case where power produced is too small to efficiently reduce emissions and require manual fanning, a dc-dc voltage converter will be created to boost the power produced before powering the load.

2) Automatic Power Regulation

The stove is able to control its rate of combustion by regulating the rate at which air is supplied into the combustion chamber. The user is also given the power to set a certain preferred temperature based on the type of dish they are cooking and cooking time available. Other than giving the user more control over the rate of combustion, this system will ensure that the fan is not over-worked when the required temperature difference has already been achieved. It will also help slow down the consumption of biomass fuel when not needed, hence reducing wastage.

3) Fuel Level Indicator

With this functionality, the user is able to identify when the biomass fuel in the combustion chamber has been exhausted to half. This system is able to alert the user about the level, both visually and audio in the case where the stove is out of close sight to the user. As a result, the stove will cook consistently without over-working the fan.

1.5 MILESTONES

The first milestone will be to carry out an extensive research on past related works that would inform major design decisions of the end-product. Secondly, a prototype for testing concepts and workability, for instance, continuous flow of current, adequate cooling and attainment of required temperatures.

Material selection using Cambridge Engineering Selector followed by drawing and simulating systems using SolidWorks. Finally, building and assembling systems into a safe, portable and working product.

CHAPTER TWO

2. LITERATURE REVIEW: THERMOELECTRIC BIOMASS COOKSTOVE

2.1 SEEBECK EFFECT

[1] Thermoelectric conversion is the direct conversion of heat energy into electricity. Thomas Seebeck discovered the concept of Seebeck Effect which explains that difference in temperatures results in a voltage. A potential difference builds up across a semiconductor resulting from diffusion of charge carriers along a temperature difference. This temperature gradient is due to the fact that one side of the semiconductor is hot while the other is kept cold. Below is an image of a thermoelectric module [5].

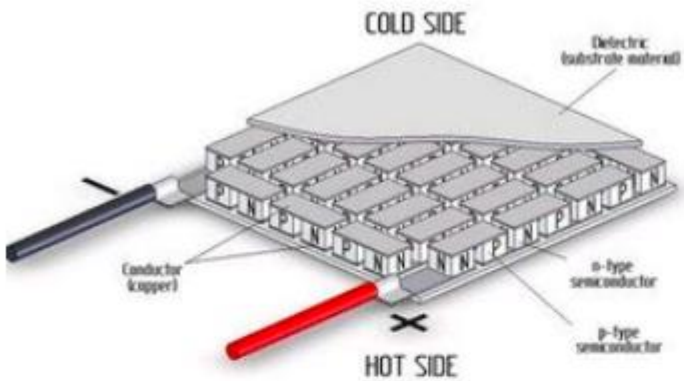

Figure 1. TE Module (Peltier tile)

2.3 INTEGRATED THERMOELECTRIC COOKSTOVE

Even though thermoelectric cookstoves are not common, other researches have built and tested the workability of a cookstove equipped with thermoelectric generator. In this model, the cookstove's excess heat, which is not being used to heat the pot, is converted into electric energy that runs a fan. The fan forces air into the combustion chamber, enabling a clean burn.

From a study carried out by C. Lertsatitthanokorn [2], it was observed that with a temperature difference of 150 degrees Celsius, an output of 2.4W is achieved. This is approximately a conversion rate of 3.2%. This power was enough to run a small radio and light bulb concurrently. These results indicate that TEG can be relied upon as a source of power from a biomass cookstove.

2.4 OTHER WORK IN IMPROVED COOKSTOVES

BioLite Home Stove

Produced a wood-burning cookstove whose thermoelectric power generator charges devices hooked up to USB port. The product reduces carbon emissions. It is however, still under testing and thus not released for commercial purposes. Below is an image of the biolite stove [3].

Figure 2. BioLite improved stove

Mega Ecofon

This stove is produced by Prolena in Nicaragua. It does not have thermoelectric generator. It has a metal body and pumice stone insulation. It has a higher cooking capacity. Below is an image of the Mega Ecofon stove [3].

Figure 3. Mega Efocon Improved stove

ONIL Plancha stove

Mainly produced in Guatemala. It has a concrete body and pumice stone insulation. It claims to have reduced 60% wood consumption. Below is an image of the ONIL Plancha stove [3].

Figure 4. ONIL improved stove

Berkely Darfur stove

Produced for use mainly in Sudan. Aimed at reducing emissions and wood consumption. It claims the ability to reduce expenses by US$ 160 per household per year. The image below is an example of a Berkely Darfur stove [3].

Figure 5. Darfur Improved stove

Harish M. & Damodara D. [3] In their research in waste heat to energy conversion concluded that power output depends on the temperature difference. They are directly proportional in that, for there to be a higher power generated, there has to be a higher temperature difference. This indicates that it is vital to ensure that the cold side is maintained at very low temperatures by using a better performing cold sink.

In addition, power produced is very small. Hence, the need to connect the output to a dc-dc converter to boost it before powering the load. Extra power can be used to charge small devices such as mobile phones or camp lamps.

[4] Rajendra P. & Risha M explain that by using the right dc-dc step up converter, a steady output voltage of 5 volts is attained from as low as 800 millivolts. With the converter added, the system is able to run a 12v dc 1.4W Sunon fan. From their study, they conclude that there is need for a battery to store the energy that will be used during the initial period. This helps attain a higher efficiency in reducing emissions.

CHAPTER THREE

3. DESIGN SPECIFICATIONS & DESIGN MODELLING

i. Requirements

- Must be able to maintain a 150 degrees Celsius gradient and above
- Components must be heat resistant
- Must provide adequate air for clean, non-smoky burn. This will be determined by the production of a blue flame and little or no smoke
- Must keep temperatures at set value
- Must indicate when fuel is exhausted

ii. User requirements

- Set the value of temperature they require
- Add fuel when alerted that combustion chamber is running out
- Start the fire

iii. Block Diagram of the systems.

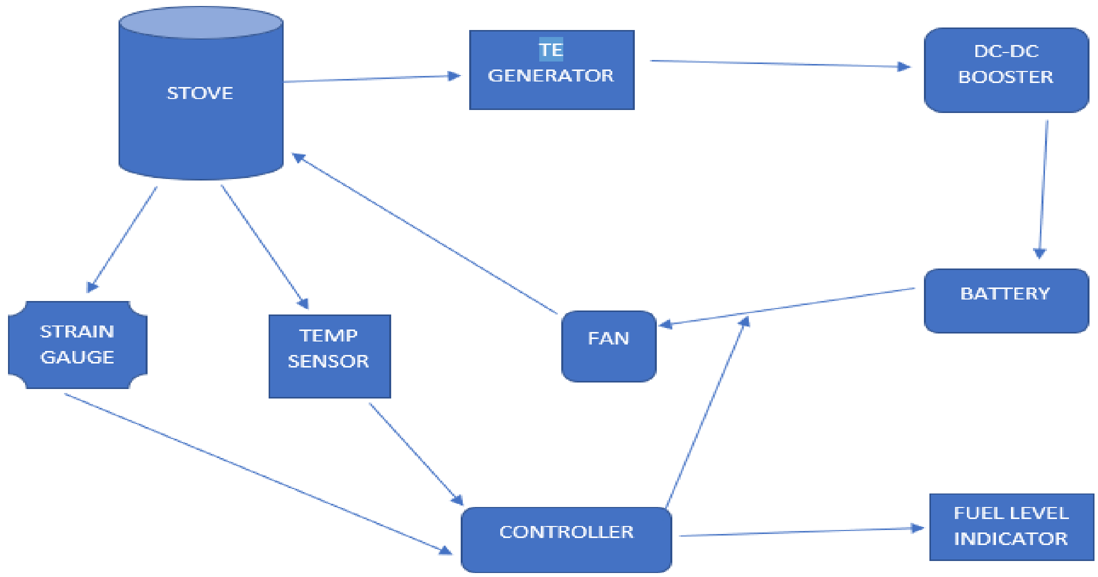

Figure 6. Block diagram of the systems

iv. Stove proposed design

Choice of design

(a) Stability on ground: The battery is stored at the base to lower center of gravity and keep the stove stable.

(b) Perforated combustion chamber: The combustion chamber, which is the charcoal holder is perforated. This is to allow the air to pass through and provide oxygen for cleaner combustion.

(c) TE compartment: mounted on the side of the stove for better cooling which wouldn't be possible if placed underneath. It is positioned at the middle for better conduction of heat from the combustion chamber.

(d) Aluminum is the preferred material: Aluminum can stand the high temperatures. Although copper has a higher resistance to heat than aluminum, it is quite expensive and heavy hence lesser portability.

(e) Embedded sensors: a temperature sensor and weight gauge are added to the stove to read the temperatures and mass of the fuel.

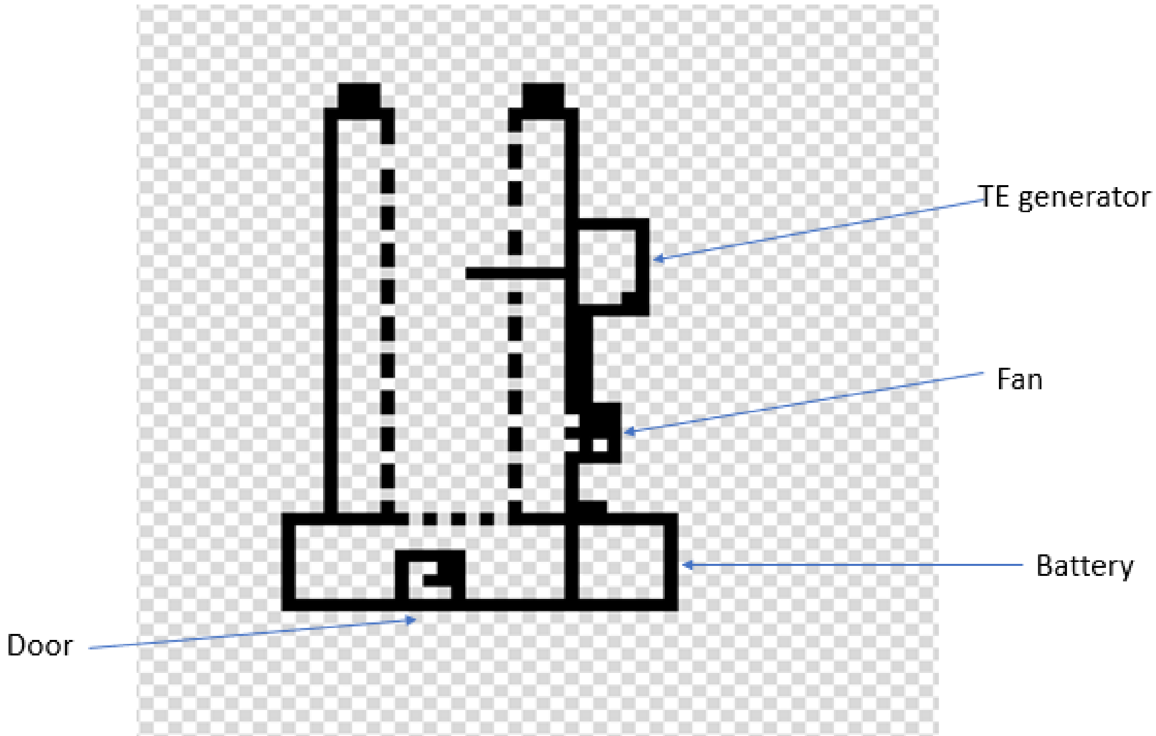

Figure 7. Thermoelectric stove pixel diagram

v. Electrical circuits

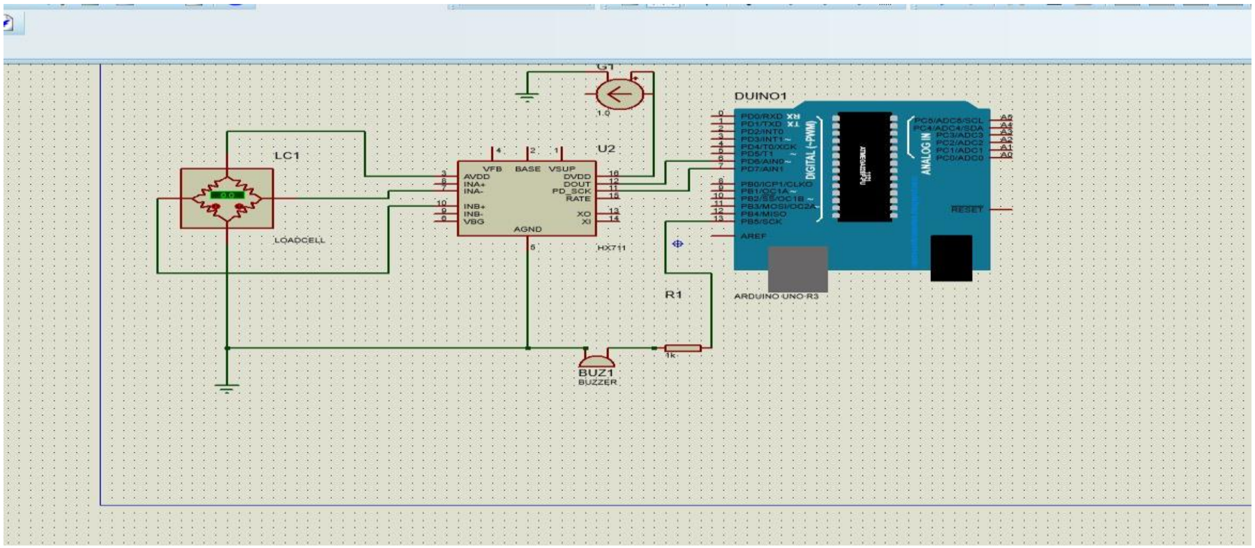

Figure 8 Fuel-level indicator circuit

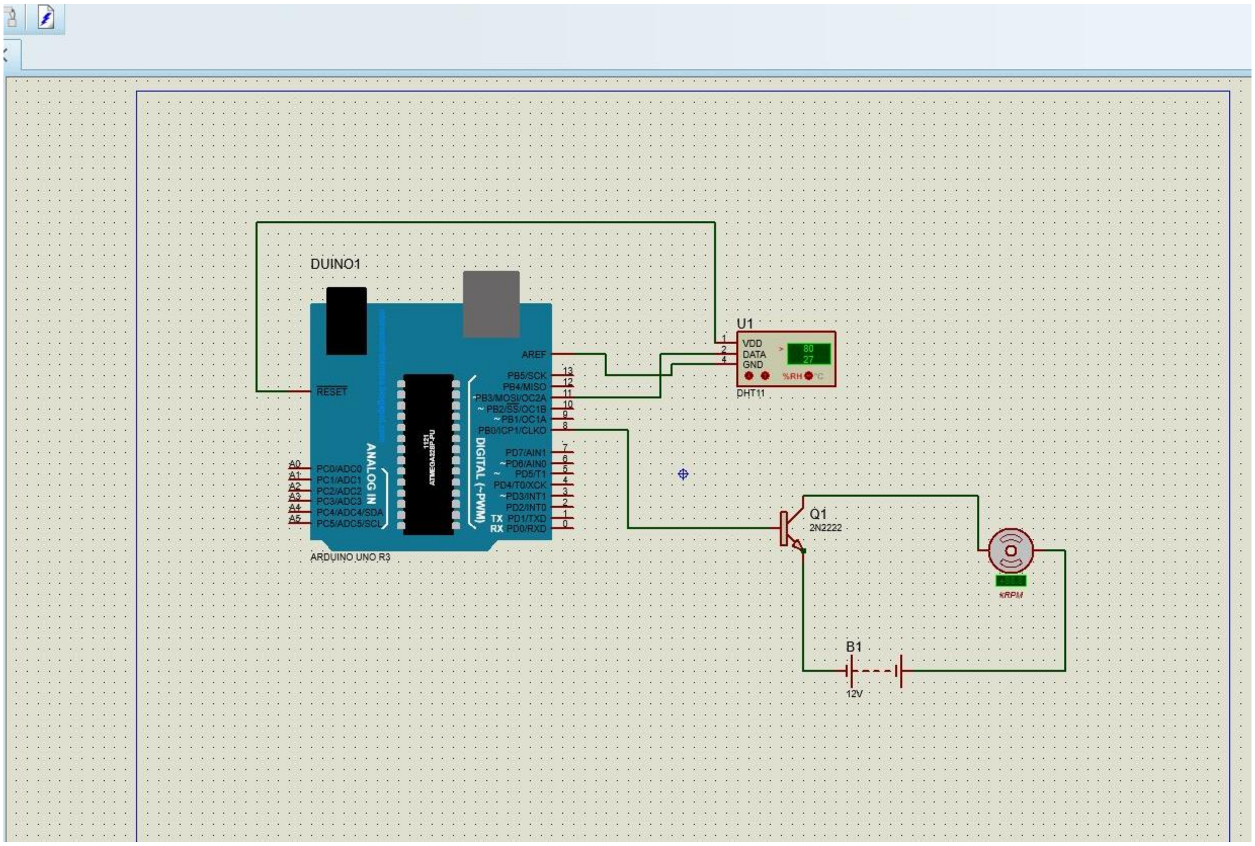

Figure 9 Fan Speed control circuit

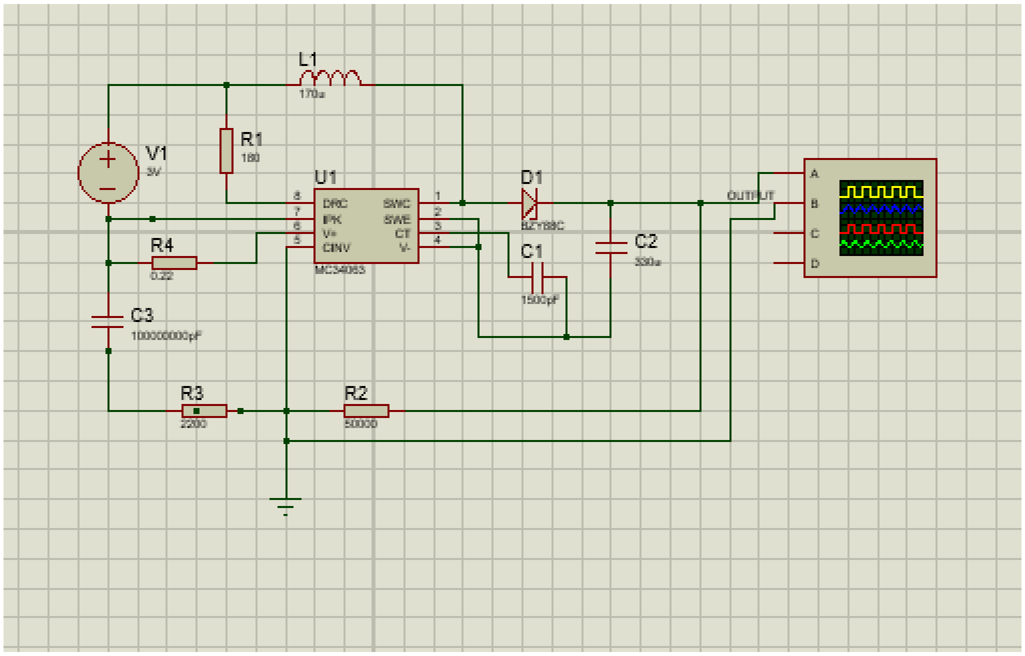

Figure 10. Simulated DC-DC booster circuit using IC MC34063

CHAPTER FOUR

4. METHODOLOGY

In the creation of the thermoelectric cookstove, the process is divided into subsystems whose efficiency can be tested independently before the assembly. The following steps are followed.

4.1 DC-DC Booster

4.1.1 Specifications and Component functions

The Dc-Dc booster takes an input of 5Volts from the thermoelectric module and gives an output of 15Volts. Inductor stores the charge. When the switch is closed, the current flows through the inductor, charging it up. When the switch is opened, the charge stored in the inductor delivers current to the output terminals. The Capacitor and diode act as rectifiers. The diode will be custom- made based on the calculations. Based on the ratings of the load and the estimated circuit efficiency of 95%, the current to through the load will be 0.4-0.5A.

4.1.2 Component Size Calculations

To provide an output of 10Volts from an input of 5volts, the following capacitance, and inductance is required.

$Vin = 5volts$, Input voltage from the TE generator

$Vout = 15volts,$ Expected output voltage

$Io = 0.4\ A$

$fs = 50Hz,$ frequency of the IC (switch)

a. Calculate Duty Cycle D;

$$D = 1 - \frac{Vin}{Vout}$$

$Hence, D = 0.667$

b. Calculate total Load resistance

$Total\ Resistance\ of\ Load = \frac{Vout}{Io} = \frac{15}{0.4} = 37.5\ ohms$

c. Calculate capacitance

$$Capacitance = \frac{Io \times D}{fs \times Vr}, where\ Vr\ is\ ripple\ voltage\ (2.622 \times 10^{-3})$$

$C = 2.044 \times 10^{-3} F$

New Vr is $Vr = \frac{Io \times D}{C \times fs} = 2.597 \times 10^{-3}$

d. Calculate Inductance

$$L = \frac{Vrnew \times D}{\Delta Io \times fs}, where\ \Delta Io\ is\ taken\ as\ 10\%\ of\ Io.$$

$$L = 860ų$$

Having developed the values of the required components, the inductor is made using insulated copper wire.

4.1.3 Building the Inductor.

Given that the required inductance is 860 microfarads, the length of the coil is 3cm long and the diameter is 1cm, the number of turns is calculated as follows;

$$turns(n)^2 = \frac{L(Henry)}{\left(\frac{D}{2}\right)\left[\ln\left(\frac{8D}{d}\right) - 2\right] \times Ʊo}\ , where\ Ʊo\ is\ 1.26 \times 10^{-6}$$

$where\ D\ is\ diameter\ of\ coil\ and\ d\ is\ diameter\ of\ wire\ while\ L\ is\ inductance\ and\ Ʊo\ is\ permiability$

$n = 79 turns$

4.1.4 Testing the Booster

Connect the input terminals of the booster circuit to the 5volts terminals of the power supply. Connect the outputs to a multimeter which will measure the output voltage of the booster. With the output voltage, the efficiency of the dc-dc converter is found.

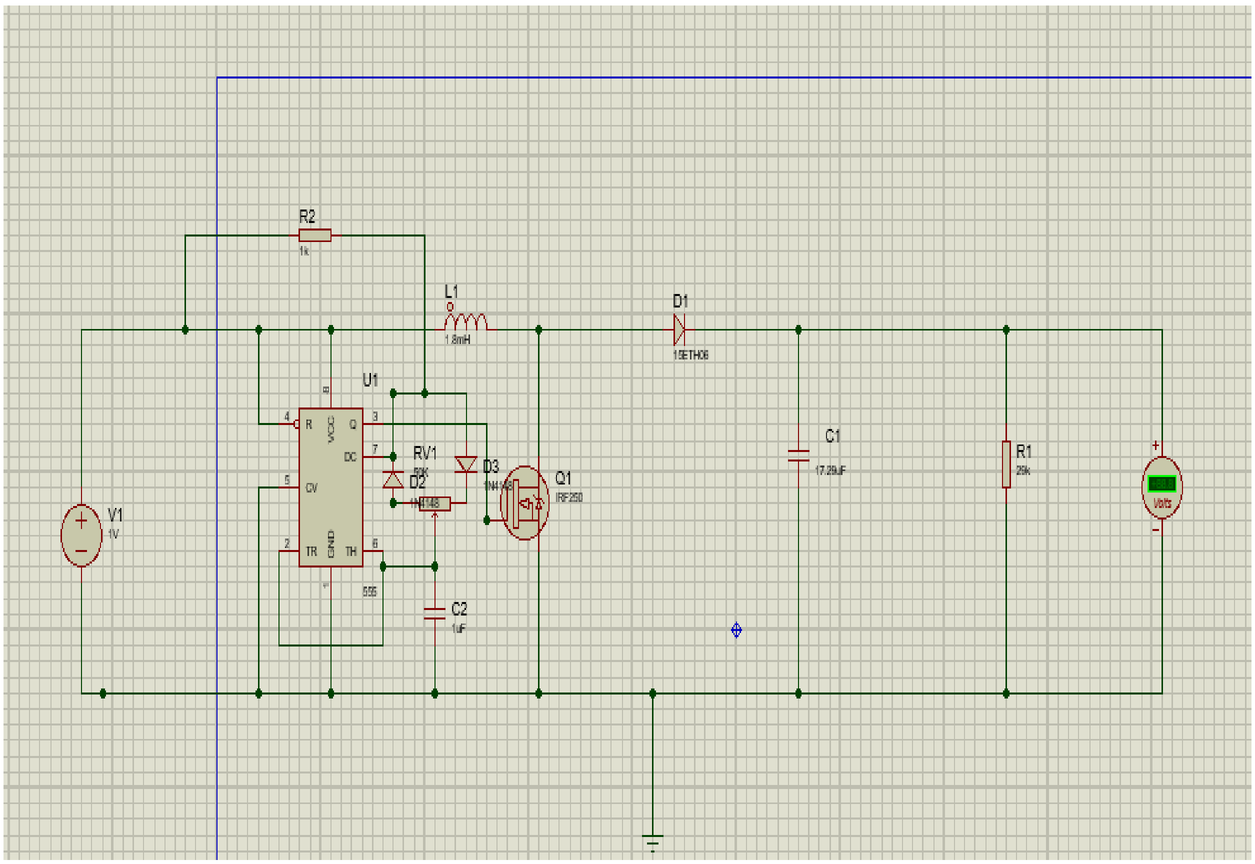

Figure 11. Updated Circuit for voltage booster

4.2 Fuel Level Indicator

The fuel level indicator involves a weight sensor which is connect to the base of the biomass holding barrel/charcoal chamber. The charcoal cylinder is freely fitted into the stove structure to allow the measurement of strain due to the additional mass of biomass.

4.2.1 Coding the mass control system

A load cell is a suitable weight sensor. The loadcell's output is connected to the development board. Using the Arduino board, a program is written to read voltage values from the sensor which are changing with the addition and reduction of biomass fuel in the combustion cylinder.

Code used in this functionality is available in appendix 3.

4.2.2 Amplification

The loadcell available is a 5-10kg sensor. This is not the most suitable sensor since the mass of biomass being measured registers very small changes in mass with each addition or reduction of biomass fuel into the combustion chamber. Therefore, the too small for the sensor to give a visibly varying output. This calls for amplification. Here, the HX711 amplifier is used to amplifier the output signal.

4.2.3Set up the user interface

A comparator code is written to compare the incoming signal from the weight sensor to a set value which represents the mass of the fuel cylinder when half-filled. If the values fall below the set value, then the use gets an audio and visual alert to go and add fuel into the cylinder.

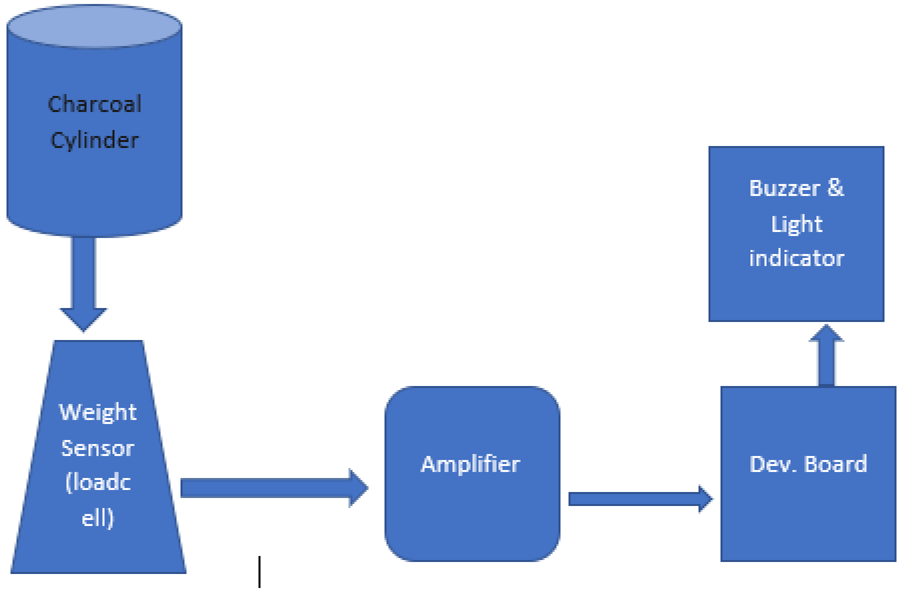

Figure 12. Flow diagram of the fuel-level indicator system

4.3Power Generation

4.3.1 Thermoelectric Generator

The thermoelectric generator has a Peltier tile, heat sink, heat probe and case fans. The heat probe and the heat sink are attached to either sides of the Peltier tile to provide the temperature difference, that is, cold and hot sides. The heat probe is inserted into the stove from which it conducts the heat.

4.3.2 Building Stove Structure

Mold the outer cylinder (diameter of 30cm, height of 50cm) and the inner cylinder which is the biomass holder (diameter of 25cm, height of 40cm). The inner cylinder is perforated to allow air into the combustion chamber. The 10cm space between the base of the combustion cylinder and the outer cylinder is filled with glass wool for insulation. This is to protect the weight sensor mounted inside to measure the mass of the fuel.

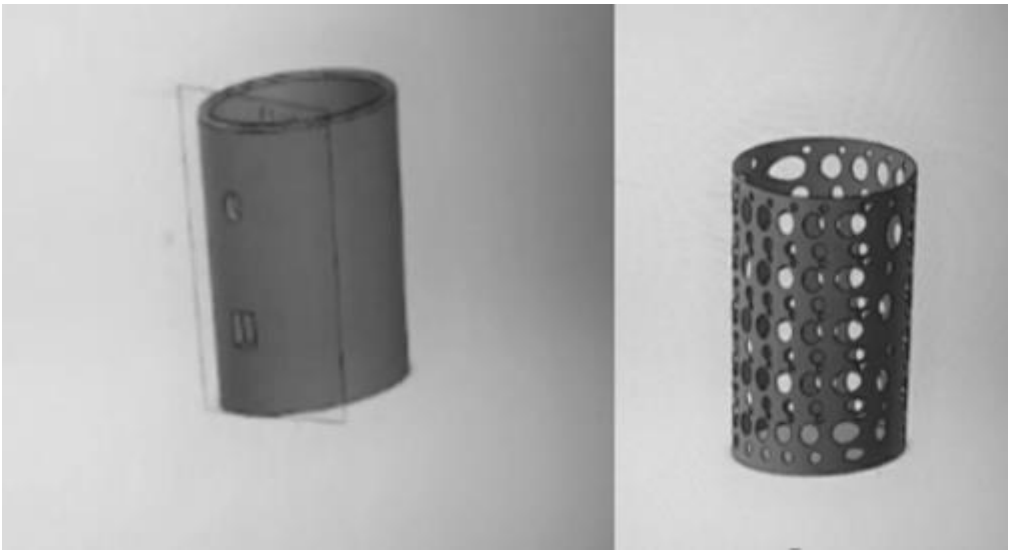

Figure 13 Design of the stove's outer casing and the perforated fuel-holder

CHAPTER FIVE

5. RESULTS

5.1 Observations

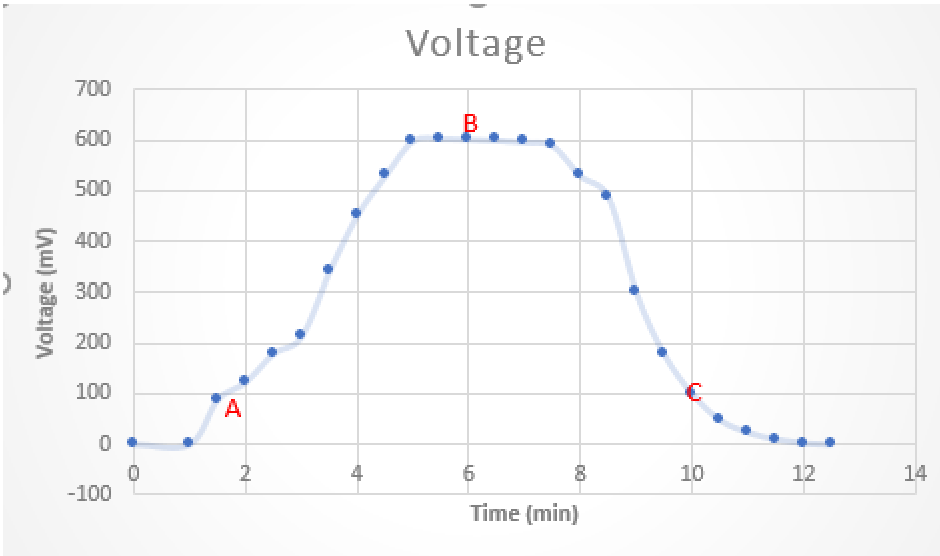

Figure 14 Graph showing voltage generated with time

The thermoelectric generator system was placed on fire in a cookstove. The output is connected to a voltmeter to measure the voltage produced. The generated voltage is recorded with time. It is observed that for the first 2-3 minutes, very small but slowly increasing voltage is recorded. It ranges between 0-300 millivolts. For the next five minutes, the voltage rapidly increases and remains constant at 600 millivolts, recording a maximum of 610 volts. For the 9^{th} to 12^{th} minute, the voltage decreases to zero.

The brushless 12v DC case fan is unable to run with the produced voltage. Therefore, air is not blown into the stove as expected. When the output is connected to a DC-DC booster circuit, a the 0.6 volts is amplified to 3V. The booster's output is connected to a 2.5V dc case fan motor which runs, blowing air into the stove. A maximum temperature difference of 150-160 degrees is achieved during the 5^{th} to 8^{th} minute. This exponentially decreases after the 8^{th} minute.

5.2Analysis

The region marked **A** in the graph showing generated voltage, indicate small voltage as the heat probe, which is a hollow, 9cm long Aluminum rod, get heated up to create the hot side of the thermoelectric module. The graph section labeled **B** shows the output when the highest temperature difference is obtained. Here, the heat probe is hot enough and the heat sink is dissipating the heat into the environment, thus establishing the cold side.

After a while, an average of eight minutes, the heat is transferred into the heat sink, which is conducting from the heat probe. Since the size of the heat sink cannot dissipate all the heat, the temperature difference starts to fall. This explains the fall in the voltage being generated as shown on section labeled **C** on the graph, as the heat sink gets heated up, making the cold side warmer.

CHAPTER SIX

CONCLUSION & FUTURE WORKS

Results from this project support the hypothesis that waste heat can be used to not only generate power, but the concept can also be applied in production of thermoelectric cookstoves. Off-grid communities can have their cooking made cleaner by the blowing of air into the combustion chamber which increases the air to fuel ratio. Other functionalities such as fuel measurement and temperature regulation can be incorporated to improve efficiency, which in return, will attract a wider market for the product. If this product is embraced by society, it has the potential of replacing the use of firewood and charcoal hence conserving the environment and user health.

From the recorded outputs, it is observed that the voltage generated highly depends on the maintenance of high temperature difference. Future work should focus on designing more efficient heatsinks designs of broader surface area or how cold-water system can be used to keep the fins cold for longer duration. In addition, employing a pre-charged storage battery would help in having an additional fan that blows air through the fins of the heat sink.

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APPENDIX

1. Testing the TE system on gas fire

Figure 14 The heat probe placed on gas stove to test the TE generator

2. Bill of Materials

Parts Requisition Form

Main parts	Material	Quantity/size	Process (welding, milling, etc)	Connected to	Link
Thermoelectric module	Semiconductor (Peltier tile)	Two (12V, 40mm)	TE generation	Heat probe and heat sink each on either sides.	https://www.jumia.com.gh/tec1-12715-thermoelectric-cooler-cooling-heatsink-peltier-plate-module-40mm-12v-generic-mpg289280.html
Case fan	Metallic	1, 5blade, 1.5-3W	Aeration (force)	Battery for power. Mounted on stove to provide air	https://www.jumia.com.gh/2pcs-12v-mini-cooling-computer-fan-small-40mm-x-10mm-dc-brushless-2-pin-generic-mpg403265.html
Heat sink	Aluminum	1 (16cm by 9cm by 5cm)	Cooling	Cold side of the module	https://www.jumia.com.gh/generic-aluminium-heatsink-amplifier-heat-sink-good-thermal-conductivity-heat-sink-cooling-fin-40-40-20mm-11-teeth-12144704.html

Battery	Li-ion	9v (rechargeable) 800mAh +	Store power	Booster	https://www.jumia.com.gh/generic-soshine-v4-smart-lcd-display-4-slot-lithium-ion-lifepo4-9v-rechargeable-battery-charger-eu-3877903.html
Heat Probe	Aluminum	1 (9cm by 5cm by 1cm)	Conduct heat to TE gen	Hot side of TE module	
Insulation	Mineral wool	1 (10cm by 10cm)	Insulation	Between Heat sink and probe	
Cables	Heat resistant	1.5 wire (1m long)	Connections	Overall connections	https://www.amazon.com/High-temperature-wire-AWG-roll/dp/B001ALK97C
Inductors	170, 100, 10 uH	1 each	DC-Dc booster circuit		
Capacitors	330,100,1.5,4,1 uH	1 each	Dc-dc booster circuit		
Diodes	1N5817	2	dc-dc booster circuit		
Zener Diodes		1	Converter (dc-dc)		
Resistor	1k,10k	6, 6,	Converter circuit		
IC	MC34063	1	Converter circuit		
IC	ADP1613	1	Converter circuit		
Temperature sensor	RTD (preferred) Thermocouple	1	Temp regulation	From the stove to the controller chip	
Strain gauge	High temperature	1	Fuel control	Fuel holder	
Aluminum sheet	Aluminum	1 (50cm by 50 cm)	Stove structure	Forms Body of the stove	
Paforated Al sheet	Aluminum	1 (30cm by 38cm)	Combustion chamber	Forms combustion chamber	
LED		5	Indicators	Control chip	
ARM cortex board		1	Systems control	Temp sensor, strain gauge	

3. Fuel Control Code

```
#include <HX711.h>

#define DOUT  3
#define CLK  2

HX711 scale;

float calibration_factor = -7050;

// LED setup declarations
int ledPin = 13;
int RedLed = 8;

int BuzzerPin = 12;

void setup() {
  Serial.begin(9600);
  Serial.println("HX711 calibration sketch");
  Serial.println("Remove all weight from scale");
  Serial.println("After readings begin, place known weight on scale");
  Serial.println("Press + or a to increase calibration factor");
  Serial.println("Press - or z to decrease calibration factor");

  scale.begin(DOUT, CLK);
  scale.set_scale();
  scale.tare(); //Reset the scale to 0

  long zero_factor = scale.read_average();
  Serial.print("Zero factor: ");
  Serial.println(zero_factor);

  pinMode(ledPin, OUTPUT);
  pinMode(RedLed, OUTPUT);
  pinMode(BuzzerPin, OUTPUT);
}

void loop() {

  scale.set_scale(calibration_factor); //Adjust to this calibration factor
  Serial.print("Reading: ");
  Serial.print(scale.get_units(), 1);
  Serial.print(" lbs"); //Change this to kg
  Serial.print(" calibration_factor: ");
  Serial.print(calibration_factor);
  Serial.println();


  if(scale.get_units() <= 5){
    digitalWrite(ledPin, HIGH);
    digitalWrite(BuzzerPin, HIGH);
    digitalWrite(RedLed, LOW);
    delay(1000);
  }
   else{
     digitalWrite(ledPin, LOW);
     digitalWrite(BuzzerPin, LOW);
     digitalWrite(RedLed, HIGH);
     delay(1000);
   }
}
```