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Renewable Energy Burning Cookstove and Surface Environment

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Renewable Energy Burning Cookstove and Surface Environment

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Abstract

The purpose of this major qualifying project is to design and implement an electrical control system into a wood burning stove to increase its safety and efficiency. Measures implemented to increase safety include extra thermal insulation in key areas to prevent contact burns, and an embedded system designed to monitor the stove and its surroundings. The embedded system utilizes gas and temperature sensors that can notify its user of hazardous conditions via alarms and flashing lights. It is within the scope of this project to design an electro-mechanical system capable of automatically regulating the burner's heat energy output. The design calls for a processor that is programmed to control the combustion box's air intake through a series of feedback loop of temperature sensors, mechanical linkages, and DC motors. Overall efficiency of the stove is improved through the implementation of non-catalytic combustors to reduce emissions and increase fuel efficiency by inducing a more complete combustion cycle. Other features include an automated emergency shut-off mechanism to reduce the risk of kitchen fires and dangerous levels of toxic fumes. Mechanical features include a modular design allowing for interchangeability between various types of heating elements, including electric coils and oil burners. Adaptability is quantified by the stove's ability to combust various fuels including wood, coal, biomass, and kerosene while providing the additional option of utilizing electricity from a grid. Furthermore, the batteries that power the embedded system are designed with an automatic recharging circuit. Voltage can be generated from the combustion process by creating temperature differences across the plates of a Peltier junction. Proper implementation of the features from these designs will increase functionality while dramatically improving on the safety and efficiency of antique cooking stoves. The versatility and modularity of these concepts can influence the future of cookstove design and design considerations.

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Chapter 1: Development of a Renewable Energy Cookstove

1. Introduction

Throughout the world, approximately two million annual deaths are attributed to smoke inhalation due to poorly ventilated or unventilated combustion used for cooking. These deaths are most heavily concentrated in third world nations as well as impoverished regions. However, they are all completely avoidable and preventable. Cooking conditions for these areas usually involves dwellings completely filled with smoke from an open fire. These unhealthy conditions endanger the family still inside. Current cookstove technology ranges from three stones placed around an open fire to hold a pot, to homemade wood stoves, which are usually unsafe due to poor ventilation and thermal insulation. The inefficiency of these systems along with improper fuel selection results in incomplete combustion, which generates millions of tons of carbon emissions each year. Carbon emissions produced by people cooking with solid fuels is still a large contributor to the increasing amounts of greenhouse gasses in our atmosphere. Overall, a large portion of the world still does not have the safe, clean, and energy efficient standards of cooking as more developed nations are accustomed to. This brings about a negative impact on general health, as well as the environment.

The goal of this project was to develop an affordable cook-stove that is safe, reliable, energy efficient, and adaptable to various renewable and conventional fuel sources. The end user of this product could only afford to pay a few hundred dollars on a commercial wood burning cookstove; therefore the product was to be designed for a cost of under $500. The product needed to be resilient and maintainable, utilizing intuitive design and standard components; because the end user could not afford to buy a new stove should the cook-stove fail. The product needed to monitor levels of harmful emissions in the dwelling and alert the user of hazardous conditions. The cook-stove was also properly thermally insulated, with the exception of the heating element, so the user or a child would not be severely burned upon making contact with the outer surfaces of the stove. The cookstove needed to be well ventilated to prevent harmful emissions from entering the dwelling. The product needed to induce more complete combustion than current stoves to reduce harmful emissions and increase efficiency. Because electricity is an energy source limited to developed nations, and consumer batteries are an expensive and inefficient, the cook-stove needed to be capable of powering its system without a readily available electrical source. Oils and natural gas are expensive fuel sources with limited availability to the targeted end user. Therefore, the cook-stove needed to be capable of combusting the various fuel sources available to a region, including bio-mass, wood, wood pellets, and fire logs. Overall, this product will save the end user money by reducing fuel usage and increasing energy efficiency. Affordability was achieved by proper selection of materials and components, as well as developing methods for reducing operating costs for the user. Safety was be achieved by reducing fire and injury hazards, monitoring harmful gas levels, and implementing an effective ventilation design. Fire and injury hazards were reduced by proper insulation of the cook-stove. Hazardous emissions will be monitored through an embedded computer system. Effective ventilation was achieved by proper design of the cook-stove flue. Energy efficiency was achieved by increasing complete combustion in the firebox, which will also reduce harmful emissions. Reliability was achieved with a sturdy structural design that included resilient materials, and reliable electrical components.

In chapter 2, we discuss current cook-stove designs, emissions data of various fuel sources, as well as the electrical components of the embedded safety and control system. In chapter 3, we discuss the final design, implementation strategy, design analysis, and results of various components of the cook-stove. Finally, chapter 4 discusses our conclusions, along with our recommendations for improvement and future work.

Chapter 2: Evolution of Cookstove Design and Environmental Effects

2.1 Introduction

The main requirements for our stove are that it is a wood or oil burning stove, that it is safe, affordable, environmentally friendly, and comparable in efficiency to modern stoves. The most innovative feature of this stove will be that people will not be exposed to an open flame at all. This will drastically cut down on the number of house fires and the deaths related to those fires. A few possible designs can be seen in this chapter.

Figure 1: Modern Wood Stove [18]

This modern word stove in Figure 1 is similar to the configuration and size of the stove that the MQP group intends to build. The main advantage of a side-by-side combustion chamber and oven like the one in Figure 1 is that it heats the oven fully, while not taking up too much vertical space in the kitchen. It also heats one side of the stovetop to a very high temperature while the far side will be a lower temperature for controlled cooking without the use of electric controls. There is also a heat exhaust vent on the front of the stove that can be used to heat the house.

Figure 2: Older Design [2]

The Bake's Oven Stove from Antiquestoves.com shown in Figure 2 is an older version of a cook stove. The combustion chamber is between the cook top and the oven. This stove has an alternative location for the burn box that saves horizontal space. Key features are firebricks that increase thermal mass to stabilize the temperature and protect the firebox and an ash lip that prevents hot coals from dropping on to the floor. Important dimensions of the Baker's Oven Stove from Antiquestoves.com are of the firebox and oven 13"w x 11"d x 14"h and 14"w x 13"d x 11"h respectively [2]. The Baker's Oven Stove puts out 30,000 BTUs and can proved heat for 700-900 sq. ft. of living space.

Figure 3: Safe Stove [3]

This stove seen in Figure 3 is from Sideros S.p.a and has safety features that can be implemented in the design for this project. One feature is a cover that goes over the hot cooking surface of the stove. This protects the user from accidentally burning themselves on the hot surface. There is also a tray at the bottom of the stove that allows the user to easily remove the ash and debris that did not burn [3].

2.2 Evolution of Stoves

The evolution of stoves goes over the increasing complexity and sophistication of stoves and cooking environments of stoves in developing nations. The purpose of learning this is to explore the different types of cooking methods used around the world. This relates to the purpose of the MQP because part of the project is to learn about the cooking conditions in developing nations. Knowing the cooking conditions in these countries will also give a good background to know why indoor air pollution and global warming are a growing problem due to cooking.

2.2.1 Three Stone Fire

The three-stone-fire is the most primitive version of a cooking fire that still resembles a stove seen in Figure 4.

Figure 4: Three Stone Fire [13]

The concept behind the stove in Figure 4 is that three stones of equal height can be used to balance a pot or pan over a fire. This method is dangerous because people using these cooking fires are directly exposed to open flames. Another dangerous aspect of this method of cooking is that the stones used as support for the pot aren't always stable resulting in the pot falling off the stones potentially injuring people. Air toxicity can be very dangerous when people use these stoves inside. This method also has potential to start house fires because of the open nature of the cooking flame [13].

Aspects of the three-stone-fire that make it inferior to most other methods that are not related to safety are that it wastes a lot of fuel and it generally cannot cook for a lot of people. The fuel is wasted due to incomplete combustion of open flames. Most of the energy is lost to the surroundings. A diagram depicting the energy output of a three stone fire can be seen in Figure 5

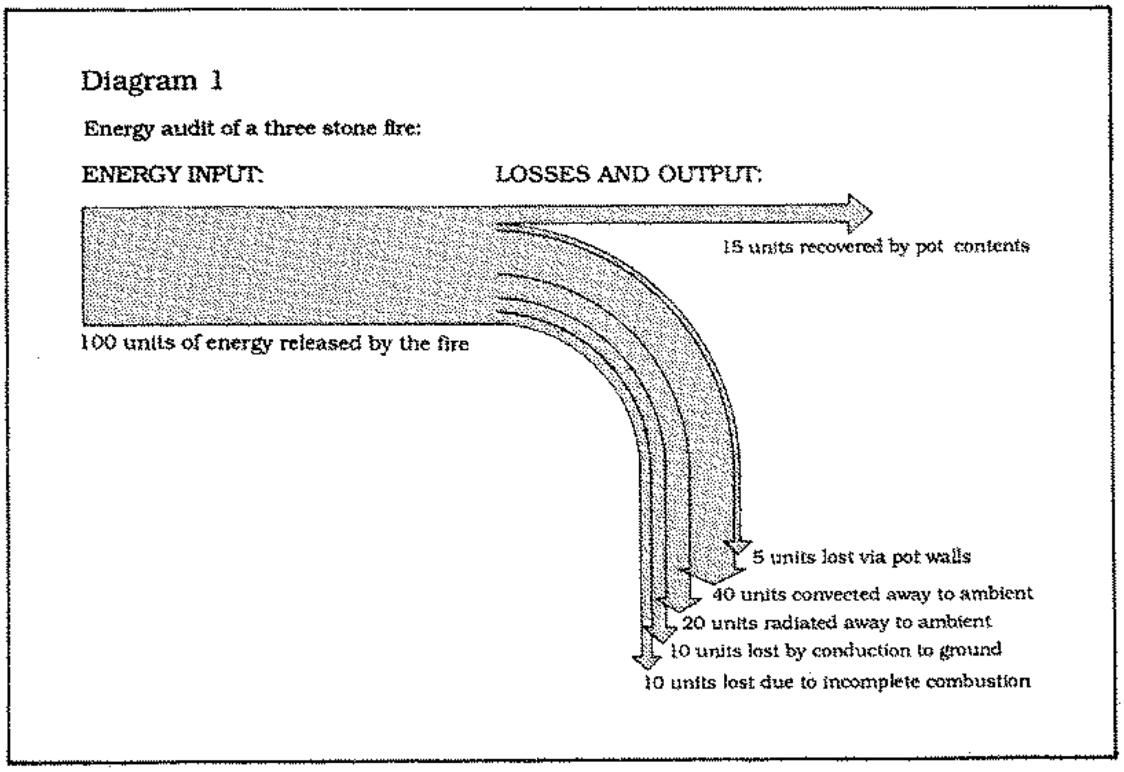


Figure 5: Energy Output of Three-Stone-Fire [13]

When a fire is open like it is in a three-stone-fire the fuel isn't under enough pressure to completely combust. Wasting fuel makes using this method more costly and wastes the time of the person using the fire. The reason why a three-stone-fire is ineffective for large groups of people is inherent in its design. The setup is intended to cook one pot over a fire. Unless the pot is extremely large, this method makes it a lot more time consuming to cook for a large family [13].

2.2.2 Lorena Adobe Stove

The next development to improve stoves is the Lorena adobe stove that is widely used in Central America. It is a stove made of mud and sand packed together to create the stove seen in Figure 6.

Figure 6: Lorena Adobe Stove [5]

Improvements over the three-stone-fire technique are that this stove has a chimney, which prevents most of the indoor air pollution. This stove design also contains the heat of the fire much better than the previously described stoves because it isn't a completely open fire design.

Although there are improvements in safety, the Lorena adobe stove is less efficient than the three-stone-fire. This is because the amount of material that is used for insulation acts as a heat absorber sometimes called thermal mass. The stove uses more fuel than the three-stone-fire in order to cook the same amount of food. Even though this stove is less efficient, it is still safer than having an open flame [15]. Figure 6 is of a well-designed and built Lorena cook stove.

The stove in Figure 6 has metal burners and a metal chimney. Figure 6 also shows the stove's smooth sides and clean cut edges. Many lower cost versions of this stove are very crude, and the material is composed of any dirt and sand that can be found in the area. Also, the burners are sometimes made to fit exactly one pot, or be covered by a single pan that is always used on that burner.

2.2.3 Rocket Stove

The rocket stove is a much cleaner stove than both the Lorena adobe stove method and the three-stone-fire. The rocket stove has higher ventilation and more insulation than both the previous methods. The wood in the fire burns hotter, which causes the smoke leaving the chimney to be cleaner with fewer unburned particles. A study of a program in Southern Africa that sold rocket stoves to residents of the Malawi had great results. The conclusion was the most encouraging part of the program, “Given that wood savings are measured at 70% per stove there is no doubt of the financial benefit to the users. Nor is there any doubt that immediate pollution is reduced” [12]. Figure 7 shows the components and operation of a rocket stove.

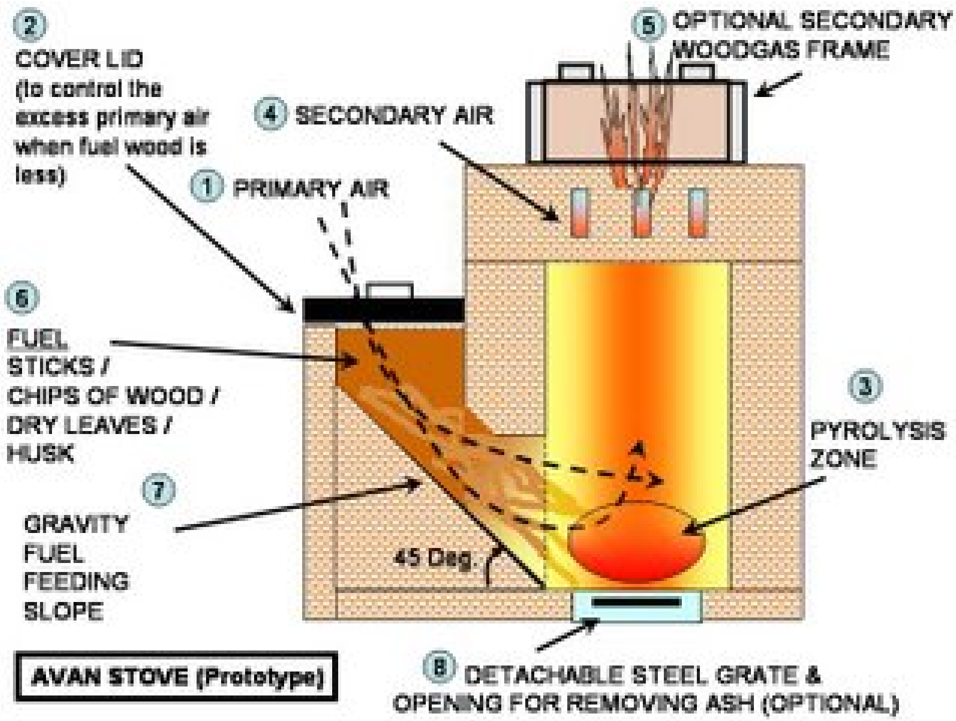


Figure 7: How a Rocket Stove Works [8]

The air is vented in through the opening that allows wood to be loaded. Fuel options are generally any biomass that is available in the area, but preferable dry sticks or wood chips. After being loaded, the wood will either slowly move down a chute, or need to be manually pushed into the combustion chamber. Once in the combustion chamber the wood is fanned by the primary vent. The smoke then rises up the chimney and new air is introduced into the system creating a secondary combustion point. This secondary combustion decreases the amount of pollutants in the exhaust [15].

Figure 8 is a stand-alone rocket stove called “Darius”.

Figure 8: Standalone Rocket Stove [15]

An interesting feature of the rocket stove is that it can be used in conjunction with the Lorena adobe stove. This improves the efficiency of the stove. When the Lorena adobe stove is designed with a rocket stove combustion chamber it can become a lot more efficient, and have much cleaner emissions, while still having the extra safety effects. Currently, a modified Lorena stove seems to be the best solution for people living in developing nations.

2.3: Safety of the Stove

Safety is a major concern when it comes to wood burning stoves. Fire, health, and environmental risks all have to be taken into consideration when designing a stove. This section will discuss the risks and hazards of operating a wood-burning stove.

2.3.1: Wood Stove Fire Risks

Wood is a highly flammable material. When burned, there is always the opportunity for accidental fires to happen. These fires can result in loss of property, injury, or life. Preventing accidental fires is a matter of safety oriented design and user responsibility. Figure 9 shows the results of a fire caused by a wood burning stove.

Figure 9: A fire caused by a wood stove [23]

Approximately 36% of structure fires reported in the US originate in the kitchen. According to the National Fire Protection Association, from 2004 to 2008 there were on average 154,700 fires a year involving cooking equipment. These fires are responsible for property damage, injury, and even death. Common causes of kitchen fires include unattended cooking equipment, misuse of cooking appliances, combustible material placed close to heating appliances, and the ignition of food products used in cooking. The number of reported structure fires caused by cooking from 1980-2009 is shown below in Figure 10 [1].

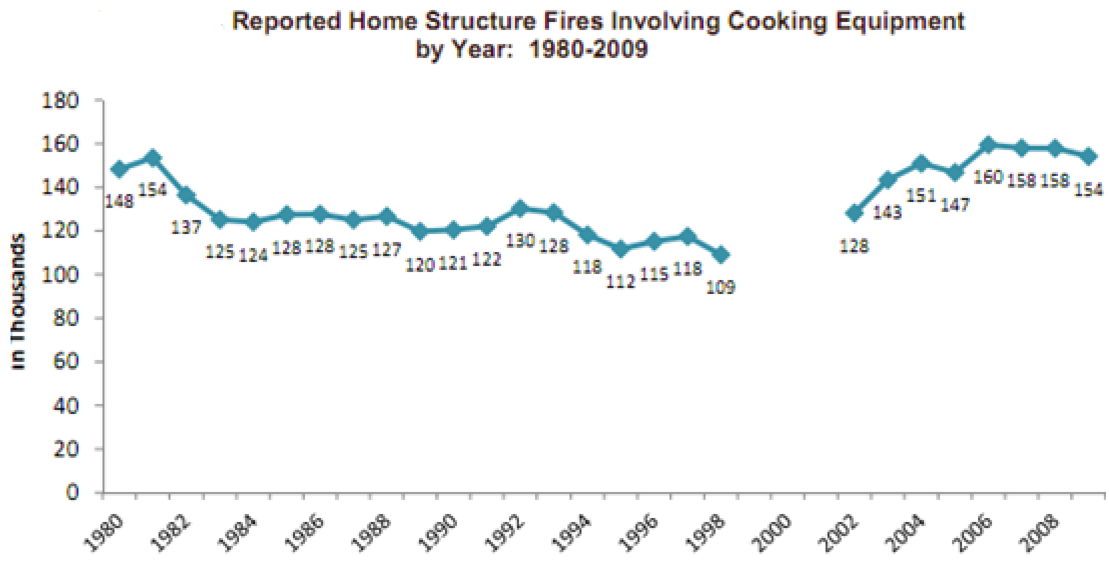


Figure 10: Fires caused by cooking over past 30 years [1]

From the data in Figure 10 it can be seen that over the last thirty years structure fires have remained consistently over 100,000 a year and in some years up 160,000. This is an amazing statistic to look at when people assume that homes have been getting safer over the years. Looking at this chart this assumption is clearly not true and home structure fires from cooking equipment are still problem.

2.3.2 Causes of Cooking Fires

Ignition of grease, oil, and fat are a common cause of cooking fires. These materials have a natural tendency to ignite when exposed to high heat for an extended period of time. The most common heating element involved in cooking fires is the range or cooktop. This is mainly due to use of open flame burners and the lack of containment mechanism if a fire were to ignite. Fires originating from a cooktop are responsible for 58% of all cooking fires. These fires are also statistically the most dangerous. 77% of injuries and 84% of deaths resulting from kitchen fires originated on a cooktop. The second most common origin of cooking fires is the oven. Oven fires cause 16% of all cooking fires, but are only responsible for 4% of deaths [1]. Ignition sources for kitchen fires in shown in Figure 11.

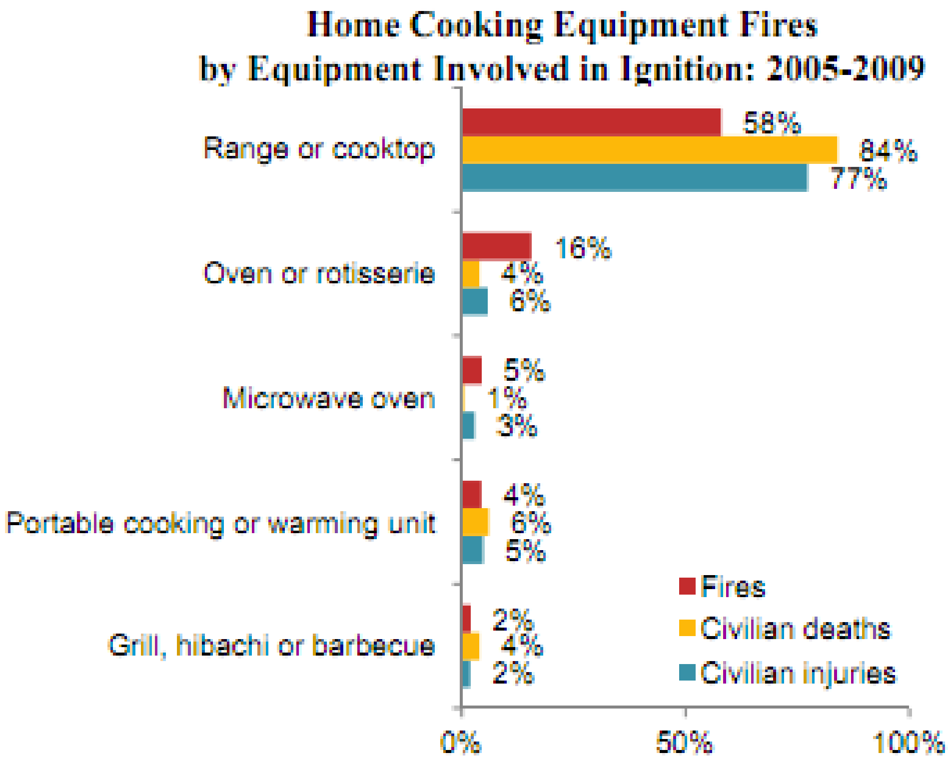


Figure 11: Source of fire ignition [1]

2.3.3 Costs of Cooking Fires

Fires caused by cooking are usually small and confined to the kitchen. Therefore they generally do not cause as much damage to a home or business when compared to fires that originated in other locations. Kitchen fires cause on average $4,736 in property damage. This can be compared to the average cost off all structure fires, which is about $14,252. One reason for this is that almost all kitchen fires are confined to the room of origin [1].

Injuries associated with cooking fires occur at about the same rate as all structure fires. Cooking fires result in approximately 32 injuries per 1,000 fires. Death occurs in approximately half as many cooking fires when compared with all structure fires. The rate of death caused by cooking fires is 2 per 1,000 fires. Structure fires in general result in a fatality in 5.1 per 1,000 cases [1].

2.3.4 Cooking Fire Prevention

In a commercial setting such as a restaurant, fire suppression systems are required to preventing the spread of fires caused by cooking. However, these systems are very expensive and not commonly found in residential kitchens. The following are patents for devices designed for fire prevention in residential cooking appliances.

Fire safety device for stove-top burner

Stovetop burners are responsible for almost 60% of fires caused by cooking equipment [1]. Many of these fires were caused by leaving the stove unattended. A patent was filed in 1997 that aimed to prevent these fires from starting. It is called “Fire Safety Device For Stove-Top Burner. The device relies on electronic sensors to determine if power should be cut off to stove for safety reasons. One of the main features of the device is its ability to determine the temperature of the cooking surface. If the device detects a temperature at an unsafe level, the burners on the stove are automatically shut off. This only happens if the user is not present. A motion detector deactivates the sensor if when a person is interacting with the stove. The flowchart in Figure 12 displays the devices logic system.

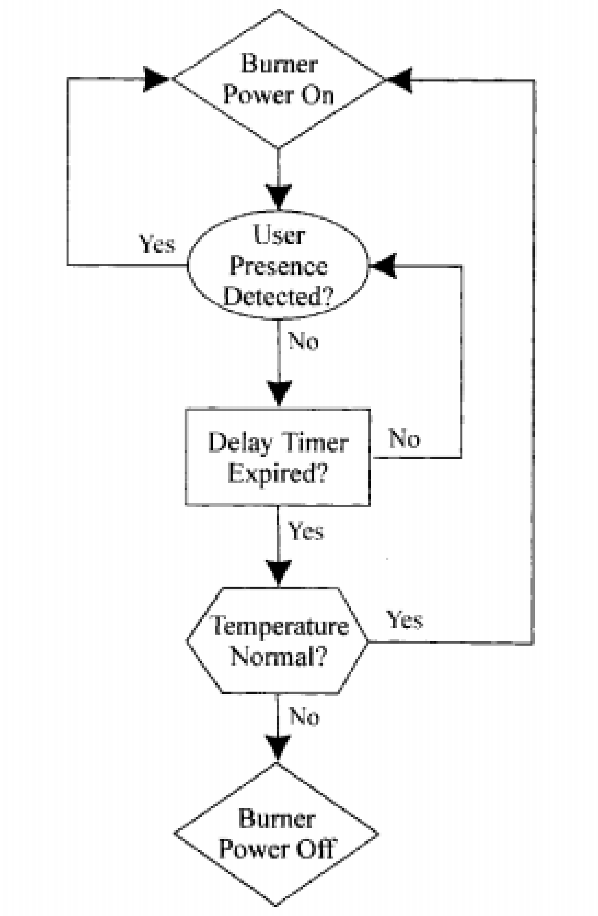


Figure 12: Flowchart of Device Logic System [6]

Ash Storage Safety

A common cause of house fires due to wood stoves is improper ash removal and storage. Approximately 9,070 fires are caused each year by improperly discarded ashes. Coals can stay hot for up to four days after use. Simply emptying hot coals into a plastic bag is a common way to start am accidental fire. Hot ash must be kept in a secure metal container away from flammable materials in order to be safe.

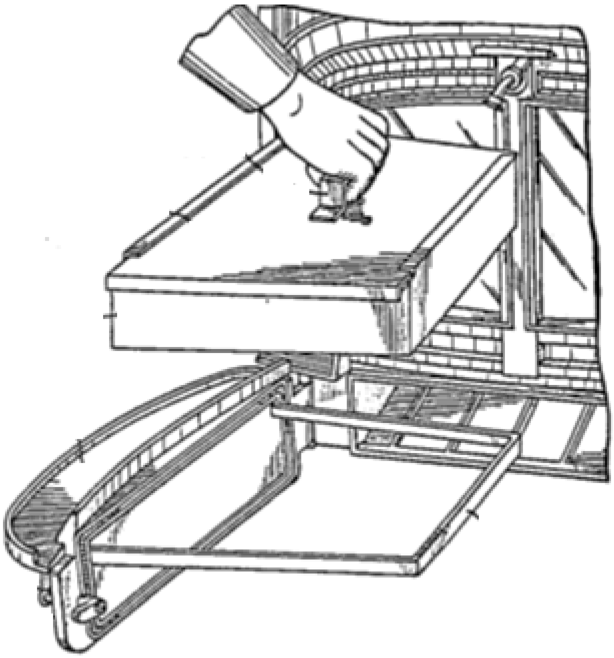


Figure 13: Ash Pan Assembly [11]

The invention shown in Figure 13 allows the user to safely remove hot ash from a wood stove without having to directly handle the hot ash. The ash is securely confined within a portable container that can be removed from the stove. This container can be stored in a safe place until the ash has cooled. The ash is then safely removed. This invention both prevents injury from handling hot ash and accidental fires started by improper storage of hot ash [11].

2.4: Global Warming

Global warming is sometimes called the “greenhouse effect” because pollutant gases that trap heat in the atmosphere. These gases that are the biggest contributors to the “greenhouse effect” are carbon dioxide, water vapor, methane, nitrous oxide, chlorofluorocarbons. Excluding Chlorofluorocarbons, these gases occur naturally and are necessary for Earth to stay warm, but they need to be kept within a certain range in order to support life. If these gas levels dropped, the earth would be too cold, and if they get too high too much heat will stay trapped.

The way that greenhouse gases trap heat is through reflecting heat from the sun. Of the light coming to earth, about 26% is reflected back to space by the atmosphere, 19% is absorbed in atmospheric gases, 4% is reflected from earth's surface, and about 51% of the energy from the sun makes it all the way to the surface of the earth. Once heated, the earth's surface radiates energy by heating air. Some of this radiation makes it to space, but with an increase of greenhouse gases, a lot of it to get reflected back to the surface. A chart of the major greenhouse gases and their increase over the years is shown below in Table 1[17].

Table 1: Major Greenhouse Gases [17]

Greenhouse Gas	Concentration-1700	Concentration-2005	Percent Change	Natural and Anthropogenic Sources
Carbon dioxide	278 PPM	379 PPM	36%	Organic decay; Forest fires; Volcanoes; Burning fossil fuels; Deforestation; Land-use change
Methane	715 PPB	1774 PPB	152%	Wetlands; Organic decay; Termites; Natural gas & oil extraction; Biomass burning; Rice cultivation; Cattle; Refuse landfills
Nitrous oxide	270 PPB	319 PPB	18 %	Forests; Grasslands; Oceans; Soils; Soil cultivation; Fertilizers; Biomass burning; Burning of fossil fuels
Chlorofluorocarbons (CFCs)	0	868 PPT	Not Applicable	Refrigerators; Aerosol spray propellants; Cleaning solvents
Ozone	Unknown	Varies with latitude and altitude in the atmosphere	Global levels have generally decreased in the stratosphere and increased near the Earth's surface	Created naturally by the action of sunlight on molecular oxygen and artificially through photochemical smog production

Climate models suggest that between the years 2030 and 2060 greenhouse gas levels will have doubled pre-industrial levels. The same models also suggest that if current annual emission levels remain constant the greenhouse gas levels will double pre-industrial levels by 2100. The result of the greenhouse gas levels rising will increase the temperature of the planet anywhere from 2-5° Celsius in the next fifty years and 3-10° Celsius. This type of temperature change can be compared to the difference in temperature between the last ice age and today [18].

When temperatures are higher, plant absorbs less carbon dioxide. When regions have longer warm seasons, permafrost can melt, and in some cases release methane pockets. The result of these types of reactions to global warming could increase the global temperature by an additional 1-2° Celsius [17].

One result of the impending massive climate changes is a redistribution of global heat that will change regional weather patterns and climates. Another result will be that the water cycle will intensify. This means that regions that have droughts will have worse droughts, and regions experiencing drought conditions will increase between 1 and 30 % [18].

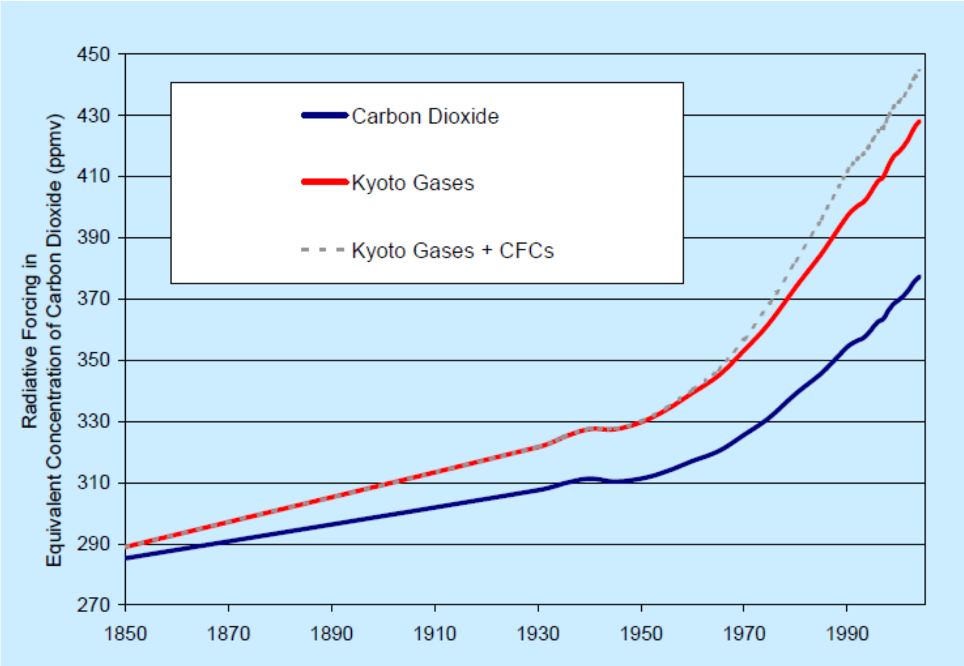


Figure 14: Change in Gases Levels over Time [18]

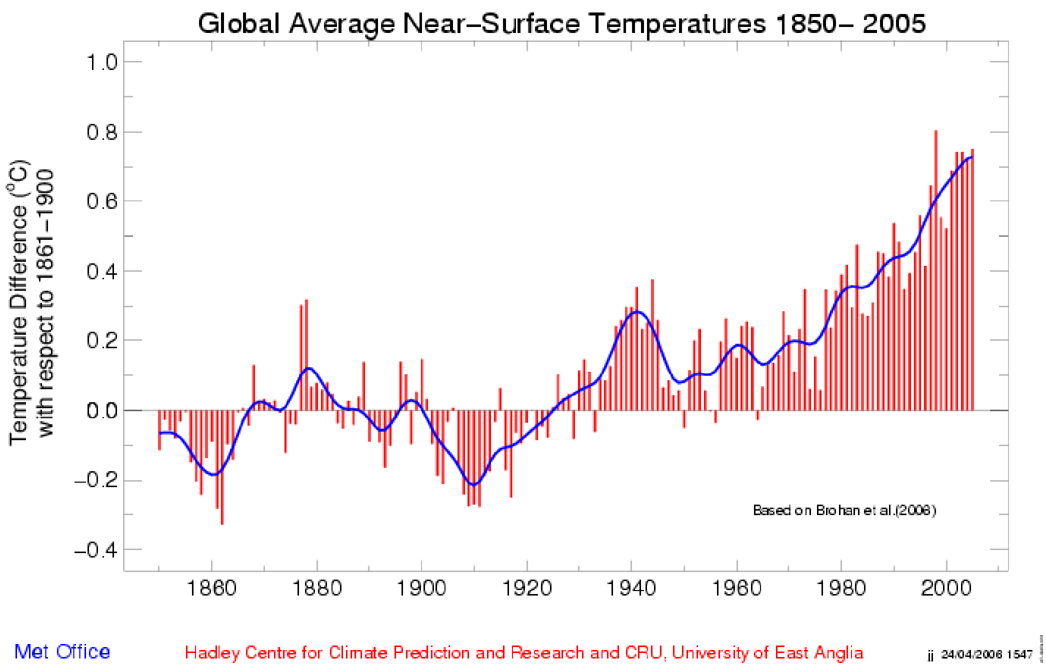


Figure 15: Change in Average Global Temperature [18]

Figure 14 and Figure 15 show the correlation between greenhouse gases and the global average near-surface temperature. The two figures follow a very similar curve trending upward. This trend seems to prove that there is a direct relationship to the concentration of greenhouse gases and the average global temperature. If this data is accurate there is a serious need to reduce emissions, or the world may be permanently affected by humans.

2.4.1 Wood Stove Environmental Risks

Wood stoves release a considerable amount of pollutants into the environment. Pollutants released by wood stoves include fine particulates, nitrogen oxides, sulfur oxides, carbon monoxide, volatile organic compounds, dioxins, and furans. Compared to stoves that use other types of fuel sources, wood stoves release a lot more pollution. The figure below shows this. Emissions of fine particles are measured in lbs./MMBtus of heat output [20]. Figure 16 shows that EPA certified woodstoves release about three times fewer emissions than uncertified woodstoves. Pellet stoves release even less emissions than EPA certified stoves (0.49 vs. 1.4). However, all of these options are not nearly as clean burning as oil or gas. Oil only releases 0.013 lbs./MMBtus of fine particles. Gas is the cleanest burning fuel shown at 0.0083 lbs./MMBtus.

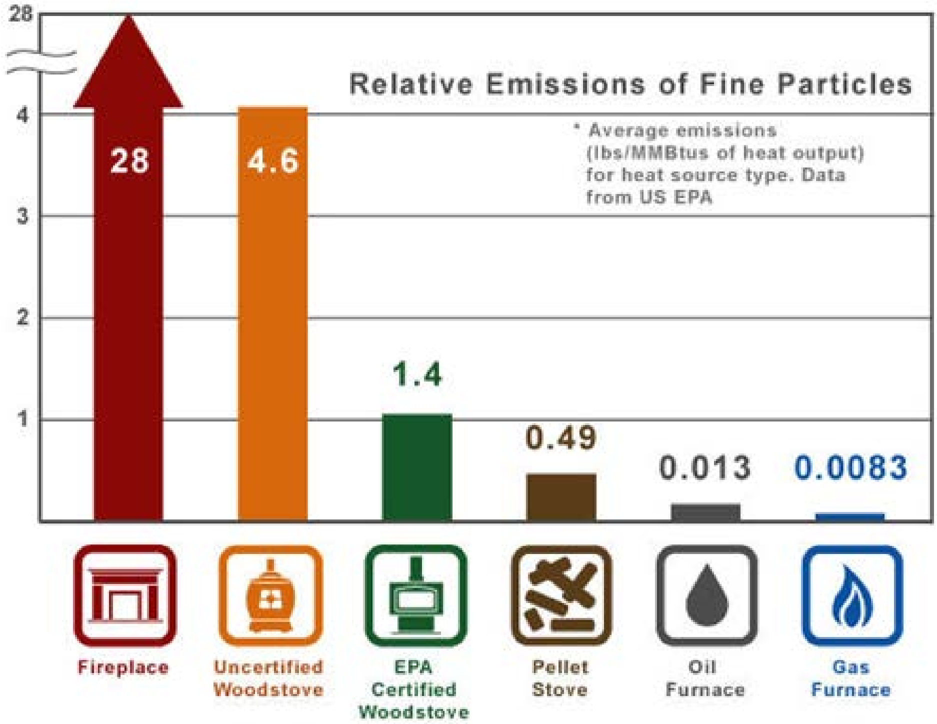


Figure 16: Relative Emissions of Fine Particles [21]

2.4.2 Catalytic Converters and Non-Catalytic Combustors

A catalytic converter is a standard future on all modern automobiles. Catalytic converters are a major factor in reducing toxic exhaust emissions. Catalytic converters are also commonly found on generator sets, forklifts, mining equipment, trucks, buses, trains, airplanes and other engine-equipped machines. Widespread use of converters first started in 1975 automobiles. The most modern catalytic converter is a three way converter [20]. A catalytic converter is shown below in Figure 17. Figure 18 shows a side-by-side comparison of wood stoves, one with a catalytic converter (left) and one with a non-catalytic combustor (right).

Figure 17: A Common Catalytic Converter [20]

A comparison of catalytic and non-catalytic combustors is shown in Table 2 below.

Table 2: Catalytic Converters vs. Non-Catalytic Combustors

Catalytic Combustor	Non-Catalytic Combustor
Higher efficiency than non-catalytic	Lower cost
Catalytic converter must be replaced as often as every 2 years	No catalytic converter to replace
Longer burn times	Add to firebox insulation
Enables the use of features such as top-loading	Requires less maintenance than catalytic stoves

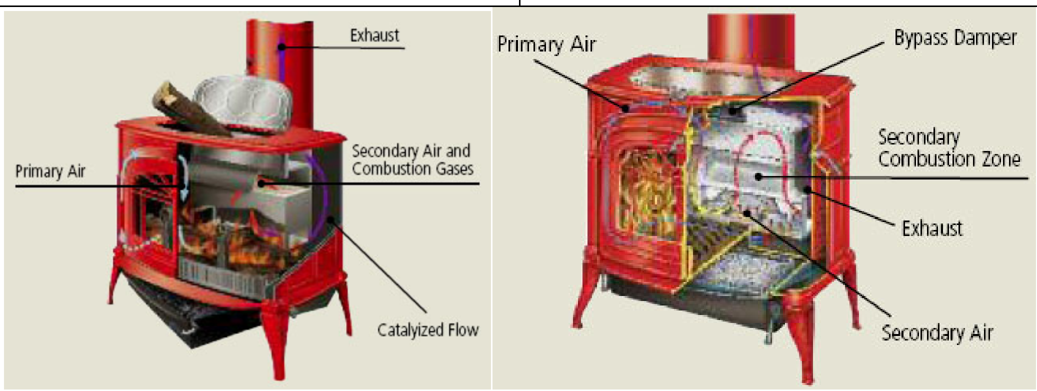


Figure 18: Non-Catalytic Wood stove (right), Catalytic Wood Stove (left) [20]

2.5 Wood Stove Health Risks

People with chronic lung diseases are at increased risk of negative health effects from wood burning stoves. This includes conditions such as COPD, emphysema, or asthma. Particulate matter, small particles released from the burning wood, can be inhaled into the lungs and cause problems. Particulate matter, when inhaled, can lead the development of health problems such as cancer. Some studies show that inhale smoke from as wood stove is just as bad as smoking cigarettes [24].

Children are especially vulnerable to the toxic emissions of wood stoves. There is an increase in cases of ear infection in children who live in areas with wood stoves. Children also breathe in more air than adults in proportion to their weight. This causes air pollution from wood stoves to have a greater effect on them. The Figure 19 shows difference between a healthy lung and one that is inflamed [22].

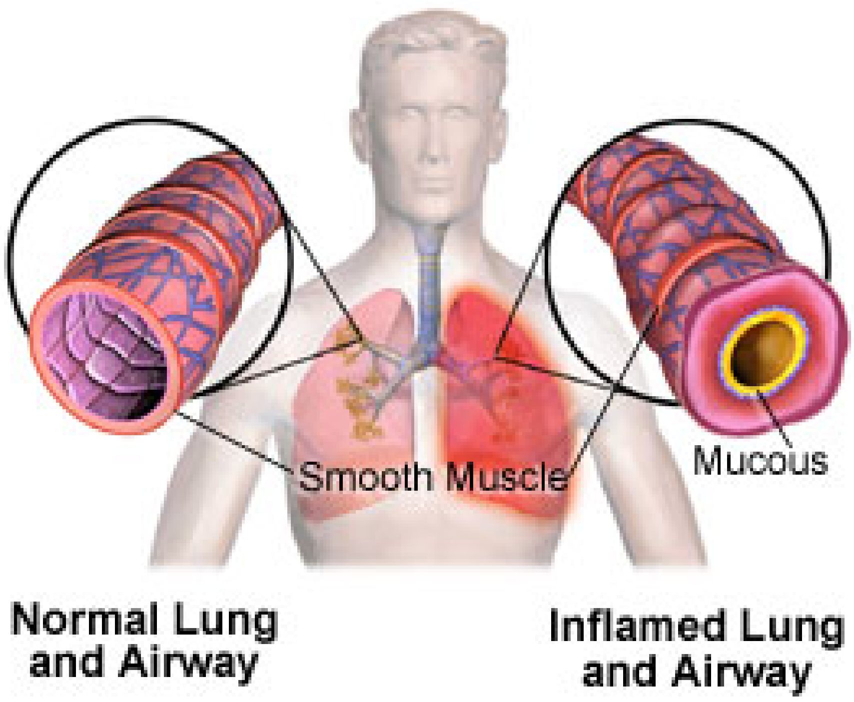


Figure 1917: Effect of Smoke on lungs [22]

Although children breathe in more air than adults the extent of exposure is a major factor. Women are exposed to the indoor air pollution for a much longer time than children because they are generally in charge of taking care of the household in developing nations. This extended exposure to indoor air pollution has a dramatic effect on women in developing nations.

2.6: Consumer Demographic

The consumer demographic of the cookstove is geared toward developing nations. Mexico has made long strides in improving the well-being of rural housewives and their children by investing into the development of Patsari stoves. Professors from the National Autonomous University of Mexico (UNAM) and University of California at Irvine (UC Irvine) created an energy evaluation of the Patsari stove using three different efficiency tests.

Mexico has made advances in cookstove technology for the improvement to the thermal efficiency of cooking and the respiratory health of the user and family. Professors from UNAM and UC Irvine have compared three different types of cookstoves: a traditional and simple three stone fire, a clay U-type cookstove, and the Patsari cookstove. The Patsari cookstove is an efficient wood-burning stove developed by the Interdisciplinary Group on Appropriate Rural Technology and the Center for Ecosystems Research in UNAM. The name of the Patsari stove comes from the Purhepecha language meaning “the one that keeps” for its intent to tend to the salutary, environmental, and economic future of the users. A sample size consisting of rural households in the state of Michoacán, Mexico was selected to replace traditional stoves with a Patsari cookstove. The three different tests performed to evaluate the efficiency of the cookstoves are the water boiling test (WBT), controlled cooking test (CCT), and the kitchen performance test (KPT). Below are pictures of the Patsari cookstove inside of a rural household and a cross-sectional view of the cookstove.

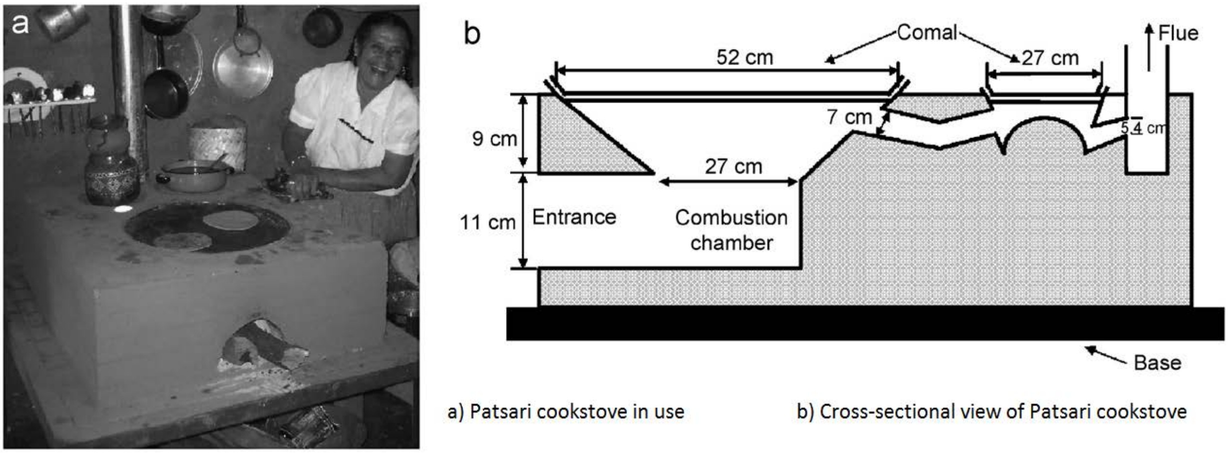


Figure20: The Patsari Cookstove

The water-boiling test is a three part evaluation to determine the time and fuel needed to boil three liters of water. The first evaluation of the WBT is the high-power boiling test with a set amount of fuel and the starting conditions at room temperature. The second evaluation is a similar process, but the starting conditions occur right after the cold start test when the stove is still warm. The third evaluation is a low-power simmering phase performed after the high-power tests to heat water to 3°C under the boiling point for 45 minutes. The WBT determines thermal efficiency (H), firepower (P), and specific fuel consumption (SC) mathematically derived from three equations derived below.

$$H = \frac{C \times W_w(T_f - T_i) + \Delta H_{vap} \times W_{vap}}{f_d \times LHV}$$

$$P = \frac{f_d \times LHV}{60(t_f - t_i)}$$

$$SC = \frac{f_d}{W_{wf}}$$

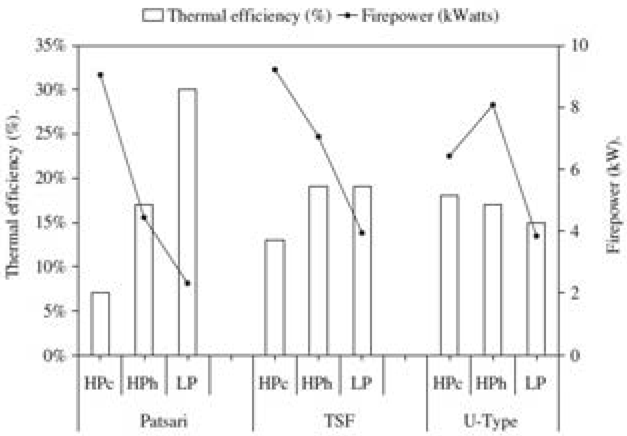
In the thermal efficiency (H) equation; C is the specific heat of water, W_w is the mass of the water in the pot, $(T_f - T_i)$ is the change in water temperature, ΔH_{vap} is the latent heat of vaporization of water, W_{vap} is the amount of evaporated water, f_d is set amount of fuelwood and

LHV is the lower heating value. Regarding the firepower (P) equation, $(t_f - t_i)$ is the time elapsed for the duration of the water boiling test. W_{wf} is the mass of the boiled water in the specific fuel consumption (SC) equation. Table 3 displayed below, correlates the results from the WBT of three different cookstoves in three separate starting conditions.

Table 3: Water boiling test results of improved wood cookstove (Patsari) and open-fires

	Thermal efficiency (%)	Specific fuel consumption (kg wood/kg water)	Firepower (kW)
High-power phase cold start			
Patsari	7±0.6	0.49±0.8	9.1±1.2
TSF	13±3.7	0.19±0.2	9.2±0.6
U-type	18±0.9	0.13±0.1	6.4±1.2
High-power phase warm start			
Patsari	17±3.9	0.18±0.4	4.4±0.5
TSF	19±4.2	0.13±0.3	7.1±1.5
U-type	17±0.7	0.14±0.1	8.1±0.4
Low-power phase simmer			
Patsari	30±11.7	0.19±0.1	2.3±1.1
TSF	19±6.8	0.29±0.5	3.9±0.8
U-type	15±1.3	0.28±0.4	3.8±0.6

Note: In all tests $n = 3$.



The controlled cooking test is a stove performance evaluation of cooking handmade corn tortillas. Measured factors of the CCT include the moisture levels of the fuel wood, ambient temperature, elapsed cooking time and the time required to light the firewood. The CCT equation for the specific fuel consumption (SC) is different from the WBT equation and derived below.

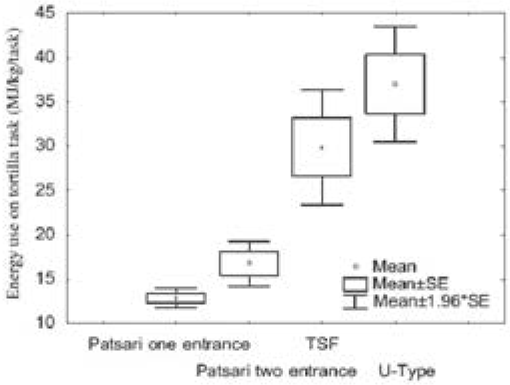
$$SC = \frac{f_d - \left[C_h\left(\frac{H_{o_{fw}}}{H_{o_{ch}}}\right)\right]}{1\ kg\ of\ tortillas}$$

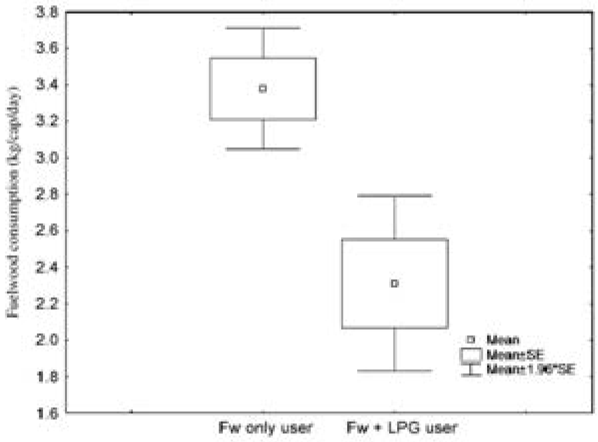
In the CCT, specific fuel consumption equation; C_h is the amount of remaining charcoal, Ho_{fw} is the enthalpy of the fuel wood and Ho_{ch} is the enthalpy of the charcoal. Table 4 compare the energy and mass of fuel wood required to cook tortillas.

Table 4: Fuel wood and energy consumed for a standard cooking task

Device	*n*	Fuelwood for tortilla task (kg/kg)	Energy consumed (MJ/kg)	Savings compared to U-type (%)	Savings compared to TSF (%)
Patsari, metal comal	6	0.64 ± 0.07	12.89 ± 1.32	65	57
Patsari, clay comal	6	0.84 ± 0.16	16.72 ± 3.18	55	44
TSF	6	1.49 ± 0.40	29.86 ± 8.08	19	–
U-type	6	1.85 ± 0.41	36.98 ± 8.13	–	–

Note: We use 20 MJ/kg (oven-dry) and 28 MJ/kg as the heating value of wood and charcoal respectively (adapted from Masera et al., 2005).





The third evaluation performed is called the kitchen performance test (KPT) designed to test the stove's performance under the conditions of the local communities. During the KPT study, 600 Michoacán households were selected for the assessment of the Patsari stove's effect on respiratory health. The KPT was a field test spanning over a year of observations throughout three-phase test cycle. Phase 1 consisted of evaluating a base of 43 households using just fuel wood (23 households) or a mix of fuel wood and liquid propane gas (20 households) in a traditional U-type stove. Phase 2 consisted of evaluating 32 households (21 households using just fuel wood and 11 using a mix of fuels) with a Patsari stove installed six months after phase 1. Phase 3, occurring a year after the beginning of phase 2, evaluates 14 households (8 households using just fuel wood and 6 using the mixed fuels) on the average fuel and energy consumed between the different types of stoves. Table 4 above displays the KPT data before and after the implementation of the Patsari stove into Michoacán households. Table 5 is a kitchen performance test evaluating the difference of fuel wood consumption between households just using fuel wood and households that use a mix of fuel wood and LPG.

Table 5: Kitchen Performance Tests

Kitchen performance test

Type of users	n	Traditional cookstove (before)		n	Patsari (after)		Savings	
		kg_{fw}/cap/day	MJ/cap/day		kg_{fw}/cap/day	MJ/cap/day	Fw (%)	LPG
Exclusive	23	3.4 ± 0.8	54.1 ± 13.0	21	1.4 ± 0.6	23.1 ± 9.7	57	n.a.
Mixed	20	2.3 ± 1.1	41.8 ± 17.5	11	1.2 ± 0.8	22.5 ± 10.6	48	30%

Average daily fuel and energy consumed per standard adult in homes with traditional stoves and in homes after 6 months of Patsari usage (±SD).

Kitchen performance test

Type of users	n	Traditional cookstove (before)		n	Patsari (after)		Savings	
		kg_{fw}/cap/day	MJ/cap/day		kg_{fw}/cap/day	MJ/cap/day	Fw (%)	LPG
Exclusive	23	3.4 ± 0.8	54.1 ± 13.0	8	1.1 ± 0.4	17.9 ± 6.7	67	n.a.
Mixed	20	2.3 ± 1.1	41.8 ± 17.5	6	0.8 ± 0.3	14.1 ± 3.3	66	64%

Average daily fuel and energy consumed per standard adult in homes with traditional stoves and in homes after 1 year of Patsari usage (±SD).

The kitchen performance test compares the energy consumption between using only fuel wood and using a mix of fuel wood and liquid propane gas. The traditional U-shaped stove requires more fuel wood and consumes more energy to perform the same cooking task as the energy-efficient Patsari cook stove. Users of the Patsari cook stove, adopting a mix of fuel wood and liquid propane gas, required less weight in fuel wood and reduced the overall energy consumed compared to a Patsari stove solely burning fuel wood. The U-shaped, open fire stoves were proven to be detrimental to respiratory health and required the per capita energy consumption of over 67% more than the energy used by the Patsari cook stove. The per capita energy consumption of the hybrid Patsari stove decreased to almost 74% in households that had a supplementary used of liquid propane gas.

2.7 Examples of Stoves

The examples of stoves in this section is intended to represent the different ways a stove can be modified in order to make it safer and burn cleaner. It will also help to visualize the variety of stoves that are available and how they can be specialized for particular functions. The stoves are also similar to the type of stove that is being designed to this project because the safety features and dimensions.

2.7.1 Antique Stoves

Figure 21: The Big Bear Sheepherder

The Big Bear Sheepherder ® household cook stove by Transocean Ltd, seen in Figure 21, is an example of a simply designed stove that is incredibly functional. The oven is large enough to cook a meal large enough for an average family without the use of any electricity. The fire box can burn both coal and wood and can heat a space 1850- 2100 square feet. The stovetop is made of 5/16 inch plate steel and the walls are ¼ inch plate steel. The glass for the doors is made of pyroceram glass. There is a 4.2 gallon water reservoir on the side so that hot water is always available. The total weight for this stove is 370 lbs. which is rather heavy, but is expected when using plate steel for the construction of the whole stove. The dimensions of the Big Bear Sheepherder ® are in Table 6.

Table 6: The Big Bear Sheepherder Dimensions

Parameter	Depth (Inches)	Width (Inches)	Height (Inches)	Diameter (Inches)
Cooking Surface	34	34		
Fire Box	12	12	18	
Oven Size	18	14	14	
Wall Thickness	0.25			
Top Thickness	0.3125			
Vent				6

Figure 22: The Sheepherder

Table 7: The Sheepherder Dimensions

Parameter	Depth (Inches)	Width (Inches)	Height (Inches)	Diameter (Inches)
Total	25	16	19	
Cooking Surface	28	20		
Fire Box	14	12	13	
Oven Size	16	12	9	
Wall Thickness	0.25			
Top Thickness	0.3125			
Vent				6

Another oven by Transocean Ltd. is the Sheepherder®, seen in Figure 22. This oven is essentially the original version of the Big Bear Sheepherder ®. The oven will heat over 800 square feet and is a size that is manageable enough to just be used as a heating oven on a regular basis and only used for cooking in the event of extend power outages. The dimensions for The Sheepherder stove can be seen in Table 7. The fuel that can be used in this oven is generally wood or coal. The size of this oven is more similar to the size of the oven that is being designed in this project and will be a good comparison during the design process.

2.7.2 Hybrid Stoves

Hybrid stoves are stoves that can cook food through the use of multiple energy sources. These can include any combination of wood, gas, electric, coal, bio-fuel, etc… Hybrid stoves have many advantages over single energy source stove. For example, a wood/electric stove would still be operational if electrical power was lost. The ability to have a wood back up option is very useful in areas subject to frequent power disruptions.

The stove shown in the Figure 23 can burn coal and wood. It can also run on electricity.

Figure 23: Combination wood, coal, electric stove

The stove in Figure 23 is the most similar to the stove used in the tests for this project because it is a woodstove electric stove. This is an intermediate development in stoves when electricity wasn't the most reliable source of energy. The ability for people to decide whether or not to use electricity made this stove a popular choice in the 50's.

2.8: Electrical Controls

The electrical portion of this project will ultimately function as a monitoring, warning, and control system. This portion of the project is necessary to improve the fuel efficiency as well as the safety of the cook-stove. The system will achieve its goal of regulating burning temperatures by monitoring temperatures of the inside and outside of the stove. By keeping track of the temperatures the system will be able to regulate them by controlling a flue vent with a stepper motor. The system will also be able to run off an outlet and use electric heating coils for stovetop and oven cooking. The system will have LEDs as well as a buzzer to provide the user with warnings about unsafe levels of harmful gasses around the stove. The system will also have an LED to indicate there is combustion happening in the stove. The user will be able to adjust the temperature of the stove with up and down arrow buttons. Finally the electrical system will have an LCD screen to provide the user with some basic information such as temperature of the cooktop, cooking timer and burning and igniter fuel indicators. Overall all of these features will be necessary in order to make the stove as easy to operate as pushing a button and will ultimately make the stove much safer and fuel-efficient.

The stove will be capable of working off of both burning materials as well as electricity. If the consumer has access to electricity they can use the stove with the electrical coils for cooking instead of burning materials. This will not only increase the output of more harmful gasses but also decrease the time it takes to cook a meal since electrical coils are a lot faster than having to wait for the heat of the burning chamber to heat the entire stove. These electrical coils will be removable from the top of the stove and have metal heating plates underneath them that will be heated by the burning of materials in the combustion chamber. By having electrical coils as well as a combustion chamber increases the market for the stove to anybody who wants one since it allows them to have the option to burn to heat the stove when electricity goes out. Overall having a stove capable of working with both electricity and burning materials is a big part of what will make a market for it.

The electrical system will have to be capable of running off a small amount of electricity generated either by a small solar panel or the heat of the stove. The heat of the stove can be converted into electricity in many different ways however; two ways have proven to be the most feasible for this project. The first of the ways of converting the heat of the stove into electricity is to use a Sterling engine that would push a magnetic piston through coils of wire in a linear motion. This idea came from the hand-powered flashlights that you shake to power. The second way of converting the heat to electricity is to use an electrical device called a TEG (Thermoelectric Generator) module, which is done by a process called the Seebeck effect that converts temperature differences between two thermal plates directly into electricity. Solar panels are also a considerable power option however solar energy is inconsistent and would therefore require some battery storage that increases the overall price of the project. Finally we considered wind power however this is both inconsistent and considerably more expensive than the other options considered due to the high precision and tolerances in the manufacturing of the moving parts. Overall The TEG module or solar panel would be preferable since they are solid-state devices. Using a Sterling engine requires moving parts, which can mean breakdown of the stove and this is not acceptable.

The system will use feedback loops in order to regulate temperatures inside the stove better and better over time. This temperature control will be achieved by monitoring the differences between the desired and actual temperatures as well as movement of the flue vent. As the system runs for more uses and even as humidity changes it will be able to adapt by constant monitoring and adjusting. The ventilation fan will also play a role in this by being adjustable in speed and thus increasing the amount of air flowing out from the stove’s burning chamber.

In order to achieve all of the functionality described the system will need a microprocessor both low power enough to be feasible for use with the small amounts of electricity that will be generated by the stove. It will also have to be fast enough to achieve all the monitoring, controlling and reporting in a timely fashion. Finally the microprocessor must be an affordable model as the overall stove design cannot cost much more than $100 USD to the consumer. For design purposes the an Atmel processor from the AT91 series will be used for building and testing and can be switched out with a cheaper more energy efficient microprocessor when in a manufacturing stage.

A few TEG modules have been looked into for powering the electrical system. The first of the modules is the TEP1-1264-1.5. This module generates $8.6V_{OC}$ (Volts Open Circuit) with a hot side temperature of 230°C and cold side temperature of 50°C. This output voltage and an output wattage of about 5.4W this should be plenty of power for the electrical system. The second module that was looked into was the TEP1-12656-0.8 and the 0.6. These two modules produce open circuit voltages of 8.7V and output wattages of 10.5 and 14.7 respectively. Overall the TEP1-

1264-1.5 is the most cost effective for the application and thus should be the one that will be used. This module costs around $60 for 1-10 units and around $14 for 1000+ units. This means that for 2 of these modules per stove, if needed, would be around $28 at production cost and translates to about a $2.60 cost/watt minus the cost of burning fuel.

During the research into designing the electrical control and safety system turned up one project that is similar and could be considered competition for our cook-stove design. The stove found in researching was designed by a team of engineers in Nepal and is called the Batho Chulho [2], which means smart cook-stove in Napalese. This stove uses a microcontroller control system to control a flue vent in order to regulate airflow and control the burning temperature. The Batho Chulho also has an LCD display with indicators to the cooking mode that consists of multiple temperature ranges for the stove to be operating at and a knob to increase or decrease the heat of the stove. The LCD panel also gives indications to cooking timer controlled by a cooking time knob, igniter and burning fuels, as well as battery power level. Finally the system includes a power LED that tells the user there is combustion inside the stove. The Batho Chulho stove is estimated to cost around $37.50 and has an operating cost of around $0.15 per briquette which is estimated to last for two cooking sessions for a family of 5 people plus another $1.50 and $1.00 every 2 months for a battery, and igniter fuel and lighter respectively [2].

Although the Batho Chulho is much less expensive than we are aiming to make our stove for it does not include all of the added functionality and safety measures that our cook-stove will have. The Batho Chulho lacks a harmful gas monitoring and reporting system, which is a very important part of this project since one of the biggest concerns is to keep the user safe while they are using the stove. The Batho Chulho also lacks exhaust the smoke from the stove any faster than air wants to flow through it, whereas the stove that is being designed in this project will have a small inline vent fan that will allow for quick exhausting of potentially harmful gasses when needed. Also the Batho Chulho does not have an auto burning fuel feeder, which the project group’s prototype will have, hopefully further increase the burning efficiency of the stove. Finally the Batho Chulho is a much smaller stove than the prototype and is only a single burner with no oven and can really only cook for a few people at a time. Overall, the prototype should have an advantage over the Batho Chulho since it has some added safety features, more ways of increasing the burning efficiency, and can cook for a large family whereas the Batho Chulho cannot.

Chapter 3: Renewable Energy Cookstove Design

3.1 Design Specifications

The following are design specifications that we intend to accomplish in this MQP.

1. The usable power output must be greater than 1.86 KW.
2. The device must cost under $500.
3. The device must be intuitive to operate.
4. The device must release fewer toxic emissions than comparable cookstoves used in third-world countries.
5. There must be no surfaces on the exterior of the stove that our capable of burning the user with the exception of the cook top.
6. The device must alert the user of toxic conditions in the operating environment.
7. The device must have a system for monitoring toxic emissions.
8. A ventilation system that will prevent harmful gases from entering the living quarter of the user must be developed.
9. The device must induce a more complete combustion than current similar cookstoves.
10. The device must run on multiple fuel sources including wood, gas, oil, coal, wood pellets, and bio-fuel.
11. The device must be more energy efficient than current similar cookstoves.
12. The device must weigh less than 600lbs
13. The device must be capable of being transported by 3 or fewer adults using standard moving equipment.
14. The user must not be exposed to any source of open flame.
15. The internal components of the device must only be assessable to a qualified technician.
16. The device must feature an intuitive control system.
17. The device must be able to be operated by an untrained adult.

18. The device must have a method for controlling oven temperature.

19. The burn box should be inaccessible to the user.

In the next section we will describe a test conducted by the group that is used to define design specification #1.

3.2 Hybrid Stove Test

The usable power output of a stove is the amount of thermal energy that is able to be applied towards heating or cooking over time. This attribute can be correlated to the idealized verses actual energy output of a thermodynamic system. There are many factors that affect the energy efficiency of a stove. This includes fuel selection, material selection in the stove as well as the cookware, condition of the stove in terms of maintenance, overall design.

In the field of thermodynamics and heat transfer, a British Temperature Unit (BTU), is the amount of energy required to raise 1 pound of water 1 degree Fahrenheit. A US pint is the volume of water that has a mass of approximately 1 pound at room temperature. The following procedure and materials were utilized to obtain baseline measurements for the actual usable power outputs from an 8 inch (nominal) electric coil burner on a consumer electric range top into an aluminum cooking pot.

Materials:

- 1 Aluminum cooking pot with glass lid
- Measuring Cup
- Scale
- Tap Water
- Cooking Thermometer
- Electric Range Top
- Clock

Procedure:

1.) Measure 4 US Pints (8 US Cups) of room temperature tap water to equate to 4 pounds and pour them into the cooking pot, weigh and record mass of water.

2.) Turn on the electric range top to desired setting (Low, Medium, Med-Hi, or High)

3.) Allow for the electric coil burner to properly heat up.

4.) Place the thermometer into the water so its probe does not directly contact the bottom surface of the pot, while allowing the gage to stick out of the pot. Place the lid on top of the pot to hold the thermometer in place as seen in Figure 24.

5.) Record the Temperature reading on the thermometer as $\mathbf{T_{initial}}$.

6.) Immediately after recording $\mathbf{T_{initial}}$, Carefully place the pot onto the electric coil burner and Record Time as $\mathbf{t_{initial}}$.

7.) Observe the temperature change of the water over time.

8.) When the water boils its temperature will reach approximately 212° Fahrenheit, record the final time in minutes and seconds as $\mathbf{t_{final}}$.

- If the temperature of the water ceases to rise before boiling, record the final temperature as $\mathbf{T_{final}}$ and the final time as $\mathbf{t_{final}}$.

9.) Turn off burner and allow pot to cool before removing.

10.) Repeat steps 1-9 for other available settings (Low, Medium, Med-Hi, or High)

11.) Analyze Results.

Figure 24: Thermometer, pot, and lid arrangement for experiment on range top

The difference between recorded temperatures in a predetermined mass of water can be utilized to calculate the usable energy output of the heating element from the electric range top into the aluminum cooking pot. In the case of this experiment, 4 US pounds was determined to be an appropriate mass. In the equation below m is specific heat, ΔT is the change in temperature of the water, and E is energy.

$$m * \Delta T = \mathrm{E}$$

The difference between recorded temperatures in a predetermined mass of water over time can be utilized to calculate the usable power output of the heating element from the electric range top into the aluminum pot. The reasoning behind using a mass of 4 lbs. of water was to reduce the magnitude of error that could be potentially induced into our analysis and calculations by imprecise recording of times throughout the experiment. The new variables in the equation below are Δt the change in time and P which is power.

$$\frac{m * \Delta T}{\Delta t} = \frac{\mathrm{E}}{\Delta t} = \mathrm{P}$$

Throughout the experiment, the water mass is assumed to be constant and the system pressure is assumed to be atmospheric. These assumptions are included due to the gaps between the pot and lid where the thermometer is inserted as well as the small vent hole in the glass lid to the left of the lid's handle, as shown in Figure 24. Although water vapor will escape the system through both of these gaps, the mass of the water that is lost due to vaporization is assumed to be minimal; due to the small area of the gaps coupled with the short timeframe where significant amounts of water vapor are produced throughout each trial. Conversely, the area of the vent hole alone is significant enough to prevent the system of heating water from building up any notable pressure.

At the start of the first trial, the 4 lbs. of tap water was measured to have a temperature of 60 °F. Utilizing the "High" setting on the burner, the water was brought to a constant full boil, 212 °F, in 6:00 minutes. Remembering that 1 BTU is approximately the amount of energy to raise one pound of water 1 °F:

$T_{initial} = 60\ \text{°F}$

$\text{V} = 8\ US\ Cups = 0.0668402778\ \text{ft}^3$

$v_{f,\text{water 60 °F}} = 0.01604\ \frac{\text{ft}^3}{lbm}$

$m = \text{V} * v_{f,\text{water 60 °F}} = 4.16709961\ lbm$

$m = 4.167\ lbm$

$T_{final} = 212\ \text{°F}$

$\Delta T = T_{final} - T_{initial} = (212\ \text{°F}) - (60\ \text{°F})$

$\Delta T = 152\ \text{°F}$

$\text{E} = m * \Delta T$

$$\text{E} = (4.17\ lbm) * (152\ \text{°F}) = 633.399141\ \text{BTU}$$

$\mathbf{E = 633.3991\ \boldsymbol{BTU}}$

The electric coil was able to create a 152 degree F change in temperature in 4 lbs. of water in 6 minutes. By dividing the energy output by the time, we can calculate the power output and convert it to several different sets of units.

$$\mathrm{E} = 633.3991\, BTU$$

$$\Delta t = 6\, minutes : 0\, seconds = 360\, seconds$$

$$\mathrm{P} = \frac{\mathrm{E}}{\Delta t} = \frac{m * \Delta T}{\Delta t}$$

$$\mathrm{P} = \frac{633.3991\, BTU}{360\, s} = 1.759442059\, \frac{BTU}{\mathrm{s}}$$

$$1 \frac{BTU}{\cancel{second}}\ \mathrm{X}\ \frac{3600\, \cancel{seconds}}{1\, hour} = \frac{BTU}{\mathrm{hr}}$$

$$\mathrm{P} = 6333.991412469\, \frac{BTU}{\mathrm{hr}}$$

$$\mathbf{P = 6334\ \frac{\boldsymbol{BTU}}{hr}}$$

$$1 \frac{\cancel{BTU}}{second}\ \mathrm{X}\ \frac{1\ \mathrm{kJ}}{0.94781712\, \cancel{BTU}} = \frac{\mathrm{kJ}}{\mathrm{s}} = \mathrm{kW}$$

$$\mathrm{P} = 1.856309642\ \mathrm{kW}$$

$$\mathbf{P = 1.856\ kW}$$

3.3 Stove Design

Figure 25 seen below is the 3-D top view of the hybrid stove. Descriptions of parts A1to A5 are below the figure.

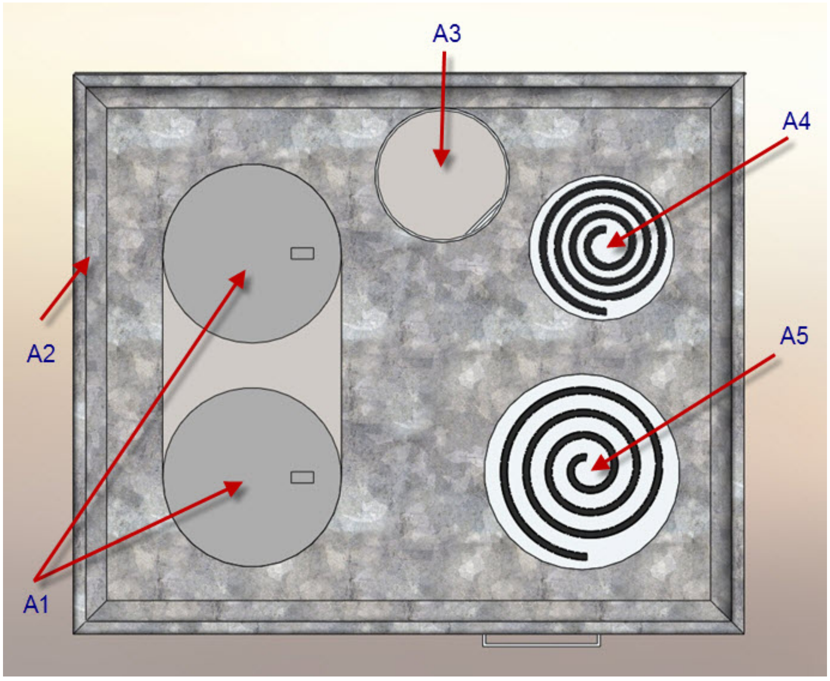


Figure25: Hybrid Stove Design Top View

A1 – Conduction plates for combustion heated range top. Both plates are 8” in diameter, and made from ¼” plate steel. Both also feature a square notch that a hook can be placed into to pull out the burner plate when hot.

A2 – This is a ¾ “lip on the top surface of the cook stove that covers the entire perimeter of the range top. The lip can catch and contain a large volume of spilled liquids on range top, creating a buffer between the user and a cascade of boiling liquid in event that a pot of hot liquid is accidently knocked over.

A3 – The exhaust flue for was positioned on the rear of the range top to allow the cookstove body to fit into a standard sized countertop opening for an oven, the average dimensions being 30” W x 26” D, without overtly protruding beyond the front plane of standard sized kitchen countertops.

By placing the duct on top of the oven and properly insulating the back panel of the cookstove, the oven can be flush-mounted to the wall if it is accordance with the guidelines, laws, codes, and standards of the NFPA and AHJ.

A4 – 6” (Nominal) Nichrome coil electrical heating element. This burner assembly v=can be interchanged with a kerosene burner.

A5 – 8” (Nominal) Nichrome coil electrical heating element. This burner assembly can be interchanged with a kerosene burner.

Figure 27 is a much more detailed 3-D assembly view of the stove where the interior is visible. The description of each component can be seen below the figure.

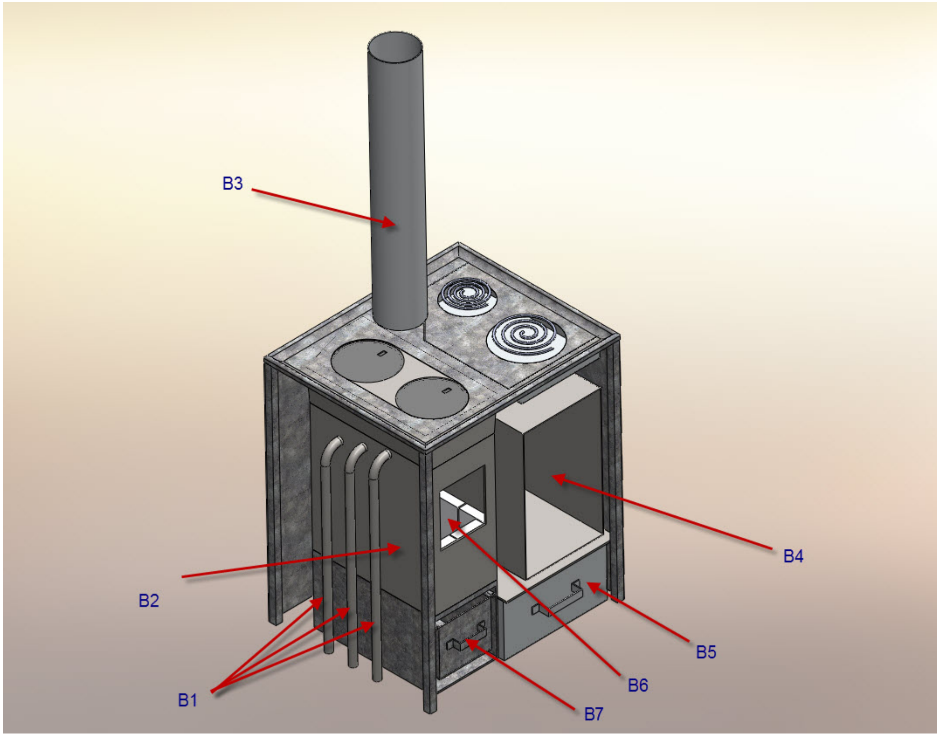


Figure 26: Isometric View of Hybrid Cookstove Design with Front and Side Panels Removed

B1 – Air intake for Non-catalytic combustors.

B2 – Sidewall of burn box.

B3 – Exhaust ducting, comprised of 4-layered thin gauge sheet steel.

B4 – Oven compartment, made of thin gauge stainless steel.

B5 – Storage drawer for pots pans and trays.

B6 – Ceramic brick insulation used to line interior wall of burn box

B7 – Ash pan

Figure 27 is a detailed view of the non-catalytic converter.

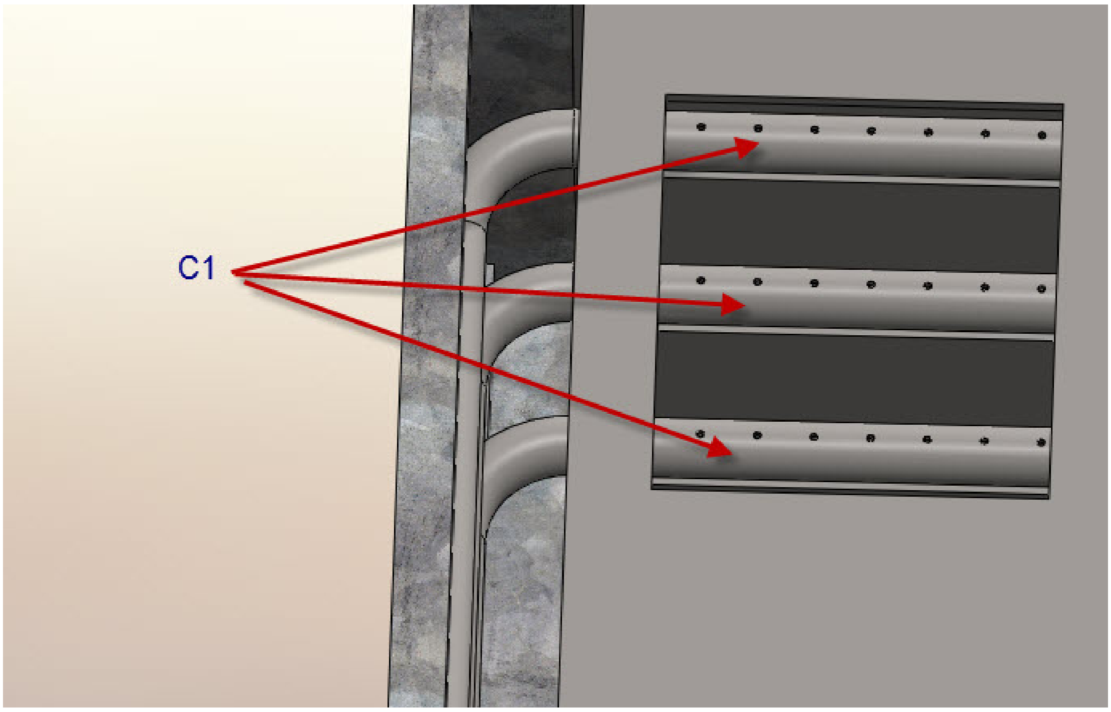


Figure 27: View of Non - Catalytic Combustor Tubing in the Top of the Burn Box

C1 – Non-catalytic combustor, made from 3/4 " stainless steel tubing with holes drilled along the length allowing airflow into the burn box. As the hot exhaust gases from combustion rises from the burn box, remnants of the fuel that did not combust leave with it. This means that the fuel did not undergo complete combustion, resulted in less fuel efficiency, less usable energy output, and an increase in emissions. Adding a secondary air intake, more oxygen is allowed to react with the non-combusted fuel particulate in the exhaust gases, creating a secondary phase of combustion. This increases the stove's fuel efficiency, increases the usable energy output, and decreases emissions.

Figure 28 is a 3-D model showing the drawers working.

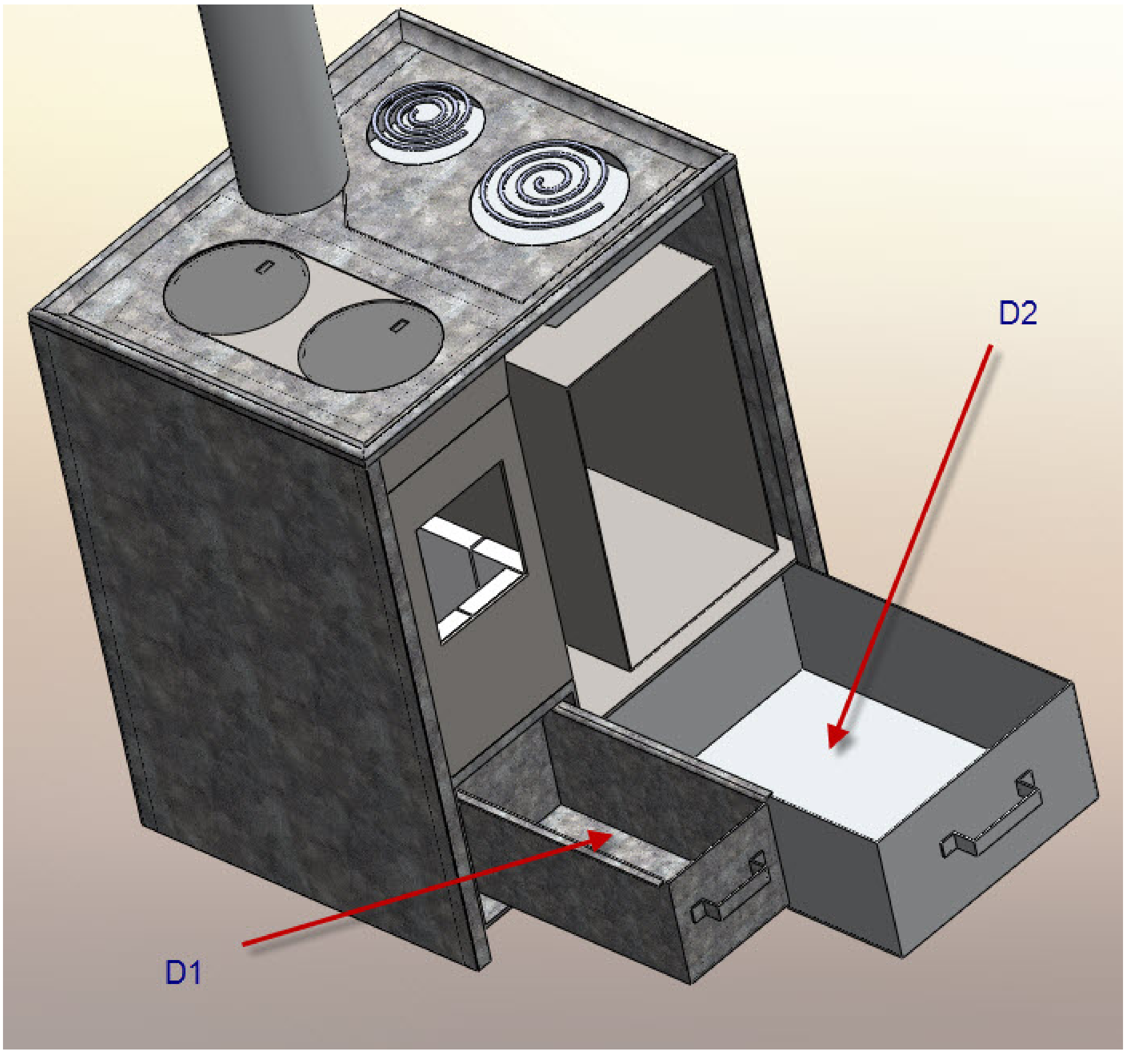


Figure 28: Isometric view of stove with drawers pulled out

D1 – Ash pan slides out so the ashes can be safely emptied and disposed of after the embers have been properly extinguished and cooled.

D2 – The sliding storage drawer is protected from exhaust gases by insulation and plate steel Nominal) Nichrome coil electrical heating element. This burner assembly v=can be interchanged with a kerosene burner.

3.4 Final Design Drawings

The drawing seen in Figure 29 is the completely assembled drawing with dimensions of the height width and depth. This drawing gives a good idea of how large the whole stove is and how it will fit into a kitchen.

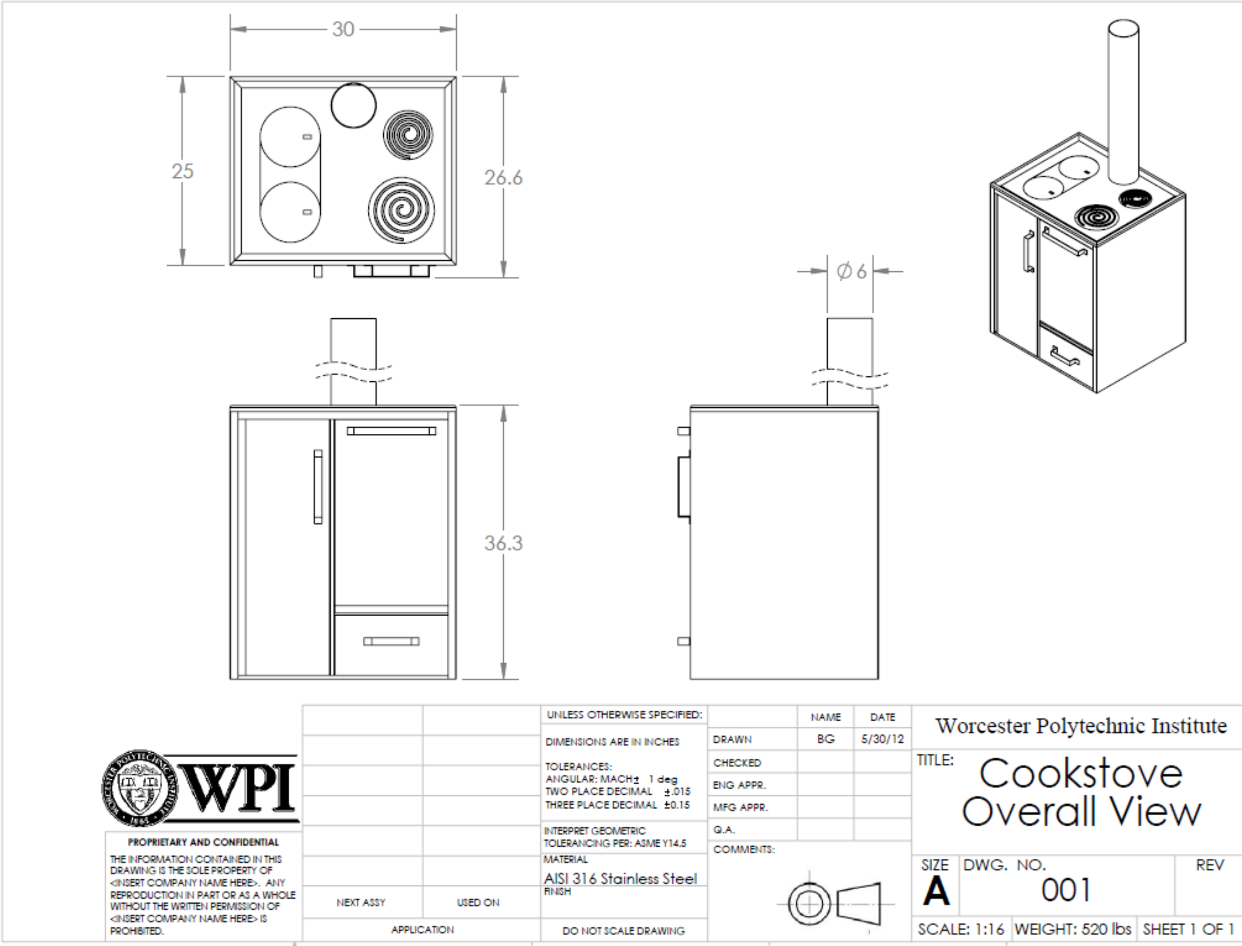


Figure 29: Final Design Drawing

Figure 30 is an exploded view drawing of the overall view of the cookstove final design. Each part is labeled as an item number that can be referenced in Table 8.

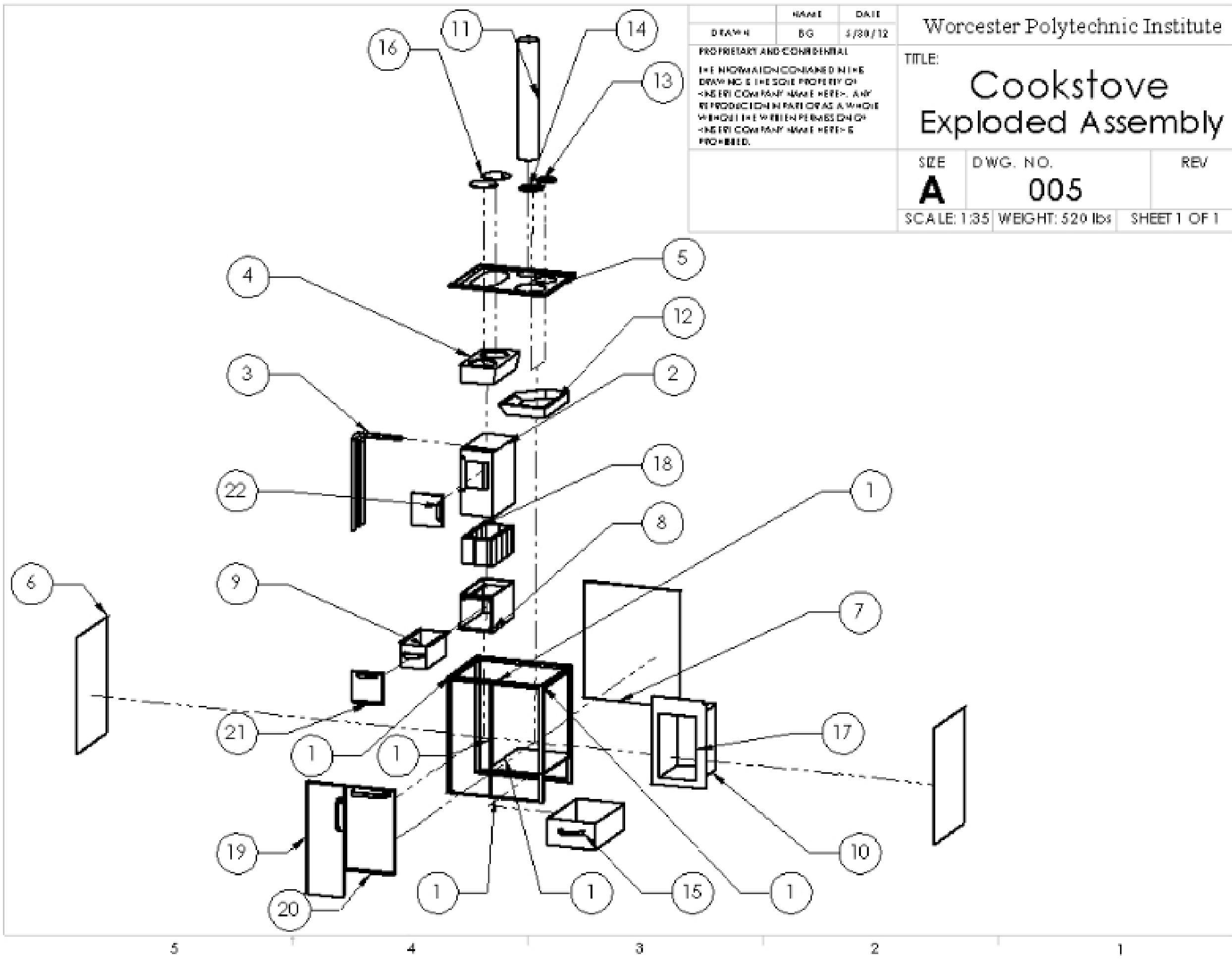


Figure 30: Exploded View of Final Design

This list of materials that corresponds to the numbers in Figure 30 can be seen below.

Table8: Part Numbers of Design Components

ITEM NO.	PART NUMBER	QTY.
1	Frame	1
2	Burn Box	1
3	Non-Catalytic Combustor	1
4	Burn Box Loft	1
5	Range Top	1
6	Exterior Side Wall	2
7	Exterior Back Wall	1
8	Ash Box Holster	1
9	Ash Box	1
10	Oven Compartment	1

11	Exhaust	1
12	Burner Drip Pan	1
13	6in Nichrome Coil	1
14	8in Nichrome Coil	1
15	Storage Drawer	1
16	Burner Contact Plate	2
17	Oven Front Skirt	1
18	Brick Insulation	1
19	Left Door	1
20	Right Door	1
21	Ash Box Door	1
22	Burn Box Door	1

In the next section we will describe the electrical components of our cookstove. The integration and implementation of these components will be discussed as well.

3.5 Electrical Design Overview

The design of this system has been mapped out into an easy to understand block diagram, which can be seen in Figure 32. You can see in the diagram that the center of the system is the microprocessor. To the left of the microprocessor is the power system including wall power and the TEG modules along with the battery charging circuit. To the top of the microprocessor are all of the various sensor inputs including gas sensors, thermal resistive sensors, and potentiometers. Finally all of the outputs of the system are shown below the microprocessor and they include the LCD screen, LEDs, DC motors, and a buzzer. All of these pieces of the system are described in more detail in the implementation section below.

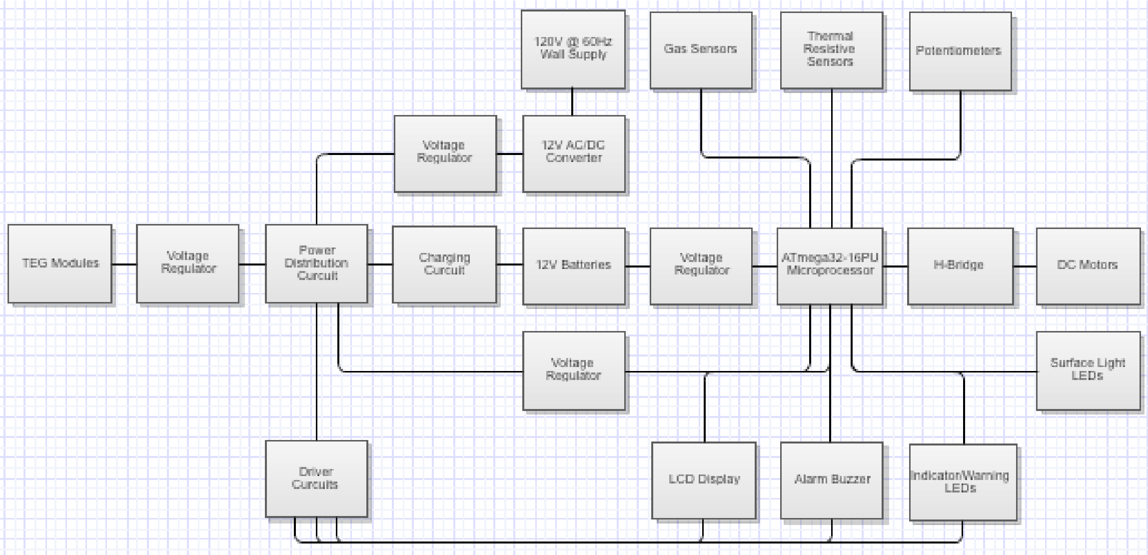


Figure 181: Circuit Design Block Diagram

3.6 Implementation

3.6.1Processor

The processor that is being used to implement this design is the ATmega32-16PU. This is an 8-bit AVR processor manufactured by Atmel. The processor is set onto an Olimex development board that has voltage regulation onboard. The development board also has an LED, a single button, RS232 port, and JTAG connector. The JTAG connector is connected through USB via a programmer that goes from USB-JTAG. The code involved with this project will involve interfacing with various I/O devices as well as feedback loops between the temperature sensors and the vent controller motors. For programming software we are using IAR kickstart for AVR processors as well as another freeware program called AVRstudio 5.0. IAR kickstart can program the board directly while AVRstudio 5.0 needs a secondary program to download the compiled code called WinAVR. Both programs work for programming the ATmega32 AVR processor, however IAR kickstart does not come with the library of header files for the processor. Both programming software are capable of programming the AVR processor through the USB programmer. The development board and USB programmer can be seen in the Figure 33.

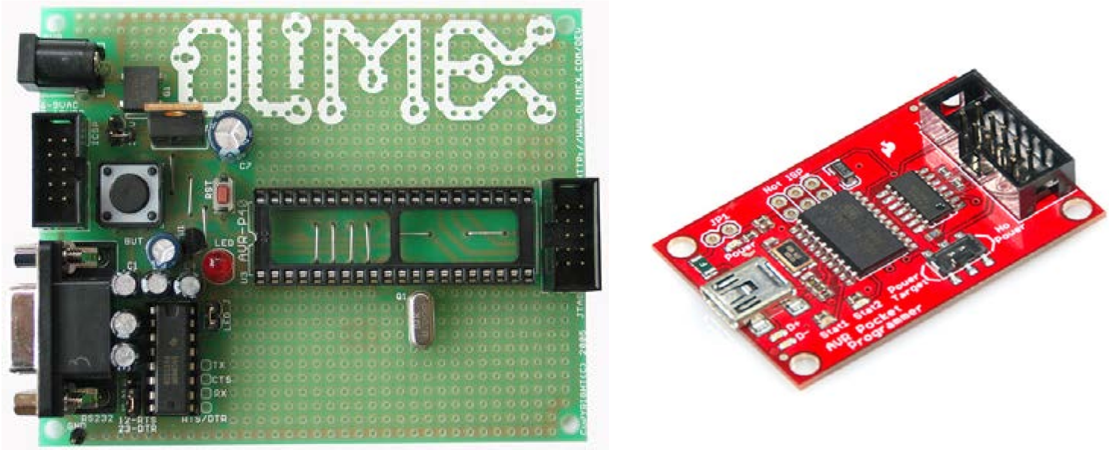


Figure 192: Olimex 40 Pin Development Board and USB Pocket Programmer

For design purposes and due to some time constraints an MSP430 was used to design and test the functionality of the electrical control system. These processors are designed for very low power consumption and are readily available for use in the ECE labs. The code for these tests can be seen in the appendix. The functionality of the code is to read a potentiometer and thermistor value. It also controls a DC motor accordingly to represent the opening and closing of an air intake valve in the stove.

3.6.2 Power System

The power system will be comprised of several components. These components include AC/DC converter for DC power from a wall outlet, AC and DC voltage regulators, Thermo-Electric Generator Modules, and Battery Storage.

Wall Power

In order to utilize 120V, 60Hz wall power an AC/DC converter circuit will be designed to regulate the wall power down to 9VDC. This AC/DC converter circuit will not be implemented in this MQP, however if needed an AC/DC converter by ROHM part number BP503405 will be used to convert the wall power down to 5VDC. The 5VDC is enough voltage to power the processor and all of the I/O devices, however for the final design implementation a circuit will need to be designed as this converter only provides 100mAmax and this is not enough to run all the I/O devices at the same time.

Thermo-Electric Generation

In researching renewable energy sources devices called TEG modules were discovered. These modules utilize a process called the “Seebeck Effect”, a process which turns a temperature differential across two ceramic plates into electricity through NPN junctions. The modules were tested on top of an electric range sandwiched between two heat sinks. The two modules tested were wired in series and produced a maximum of about 4.2VDC. The setup of this experiment can be seen in the image below. The heat differential across the two plates of both modules has yet to be measured as a thermometer capable of reading temperatures over 600°F. Five of these modules will be placed on a wall of the stoves burn chamber and will have heat sinks on the other side to keep the temperature differential as high as possible. With the five modules purchased for this project there should be plenty of output to power the processor along with all of the I/O devices. Because the voltage output of these modules can vary and is not always producing current we need both battery storage as well as voltage regulation to charge the battery storage cells at a constant voltage. In some cases a battery charging circuit will also be required but can easily be purchased as an IC along with some battery cells.

Voltage Regulation

As mentioned above the output voltage of the TEG modules is not always consistent as it is a function of the temperature differential between the two ceramic plates. In order to regulate this voltage to a constant supply to charge a battery or provide voltage to a charging circuit a DC voltage regulator will be utilized in a regulator circuit. This will most likely be done with a small voltage regulator IC.

Battery Storage

When wall power is not available battery backup that is charged by both the TEG modules as well as the wall power. This will allow the circuit to be functional even when wall or heat power is not available, until the stove heats up again. In order to allow the batteries to charge and be used as supply for the circuit charging will have to switch between two battery backup cells.

3.6.3 Sensor Inputs

The system will include multiple sensor inputs that will be described further below. The sensors that will be used in this system include various gas sensors, thermal resistive sensors, and potentiometers.

Gas Sensors

This project will include various gas sensors including carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), nitric oxide (NO), and nitrogen oxide (NO_2). All of these gas sensors will be connected to and monitored by the ADC of the microprocessor. There will be interrupts which will trigger if any of the levels on any of the sensors reach a certain threshold. This threshold will be determined from researching the dangerous levels of each of the various gasses. All the gas sensors will be places around where the user will be cooking, as that is the area we want to ensure has good air quality. If all the sensors are in the safe levels then the area is safe for cooking. Upon reaching any unsafe levels the microprocessor will sound a loud buzzer alerting the user to evacuate the area and ventilate. The microprocessor will also shut off airflow to the stove causing the fire inside the burn box to extinguish. Overall the gas sensors will ensure the user is not breathing any harmful gasses while cooking.

Thermal Resistive Sensors

This design is going to include various temperature sensors that will be read by the microprocessors ADC as well. These values, once calibrated will allow the microprocessor to determine how much to open or close the air intake and flue vent valve in order to reach the right temperatures on the stovetop and inside the oven. These sensors are going to be placed at various points around the stove as determined by the ME group designing the actual stove and will also be shielded with some type of metal in order to ensure they do not directly contact any open flame.

Potentiometers

The system will include various potentiometers, ultimately two to control the stovetop heating coils, and one for the oven temperature control. These controls will work by being calibrated with the ADC of the microprocessor and the lowest and highest settings of each potentiometer will correspond to completely off all the way up to full heat.

3.6.4 Outputs

The system will include various outputs in order to communicate certain things to the user. These outputs will be explained further below and will include and LCD screen, Feedback LEDs, DC motors, and a buzzer.

LCD

The LCD screen in this project will be used to display the oven temp as well as time and cooking timers. The LCD screen being used for this project is a small black and white 8-bit LCD screen. The LCD screen has internal memory to store 8-bits of the display at a time. The screen is communicated to by 8 parallel bus lines, which will be cycled with a sequence of 8-bit pages. The LCD screen then prints page by page to the 127x32 pixel screen starting in the top left and moving to the right and down just like we read a book. The LCD screen also includes a backlight so it can be seen at night and will be kept on while the stove is off in order to display a clock at night.

LEDs

This system will include multiple LEDs for various functions. First there will be bright white LEDs mounted above the cooking surface in order to allow for nighttime cooking. There will also be a red LED indicating that the stove is hot and warns the user not to touch it. Finally there will be a couple LEDs in order to notify the user if the gas sensors go off as to which one exceeded its safety threshold.

DC Motors

DC motors will be included in this project in order to demonstrate a way of opening and closing an air intake or flue valve. The DC motors will have a gear ration such that the spinning of the arm will have a good amount of torque and slow RPMs to ensure accurate amounts of opening or closing of the valves. The motors are hooked into an H-Bridge in order to allow switching of voltage across the DC motor reversing the polarity and allowing the motor to spin one way or the other.

Buzzer

As mentioned above in the gas sensor section, a buzzer will be implemented in order to notify the user of any unsafe conditions that may arise with the stove indicating to the user that they should evacuate the area around the stove. In order to ensure that the buzzer is loud and piercing enough to notify the user properly a buzzer was chosen with a dB rating of over 80dB @ 1m and a frequency of over 2,000Hz. The buzzer chosen has an internal crystal oscillator and therefore just needs to be provided with a DC voltage to be operated. In order to make the buzzer even more noticeable the buzzer will beep rather than just staying on constantly and will go off when the gas levels are back within a safe range. In the next section we will discuss the results of our project by analyzing our results vs. the original design specifications.

3.7 Design Analysis

The following section analyzes to what level we have reached our design goals set forth in chapter 3.1.

1. The usable power output must be greater than 1.86 KW.

   This goal will be accomplished in the future if the cookstove is constructed and tested.

2. The device must cost under $500.

   Component costs for the developed design are under $500. This does not include manufacturing cost.

3. The device must be intuitive to operate.

   The operation concept in the design is similar to that of a regular consumer household stove.

4. The device must release fewer toxic emissions than comparable cookstoves used in third-world countries.

   A non-catalytic combustor was implemented in the design to reduce emissions.

5. There must be no surfaces on the exterior of the stove that our capable of burning the user with the exception of the cook top.

   The amount of insulation used in the design is sufficient to reduce the temperature off exterior surfaces to not burn the user.

6. The device must alert the user of toxic conditions in the operating environment.

   A control system was developed to alert the user of toxic conditions

7. The device must have a system for monitoring toxic emissions.

   An electronic system was developed to monitor toxic emissions.

8. A ventilation system that will prevent harmful gases from entering the living quarter of the user must be developed.

   The final design includes a ventilation system that releases all emissions outside of the living quarters.

9. The device must induce a more complete combustion than current similar cookstoves.

   The design features a non-catalytic converter that allows for more complete combustion.

10. The device must run on multiple fuel sources including wood, gas, oil, coal, wood pellets, and bio-fuel.

    The prototype design is capable of running on primarily wood, and can be modified to run off of other fuels.

11. The device must be more energy efficient than current similar cookstoves.

    There are many features including a non-catalytic combustor that increase the energy efficiency of the designed cookstove.

12. The device must weigh less than 600lbs

    The designed cookstove weighs less than 600lbs.

13. The device must be capable of being transported by 3 or fewer adults using standard moving equipment.

    This design specification has not been tested.

14. The user must not be exposed to any source of open flame.

    The design of the cookstove prevents the user from coming into contact with any sources of open flames.

15. The internal components of the device must only be assessable to a qualified technician.

    This feature will be implemented in future revisions of the design.

16. The device must feature an intuitive control system.

The device features a comparable control system to that found in modern consumer stoves.

17. The device must be able to be operated by an untrained adult.

    The device can be operated by anyone capable of operating a modern stove.

18. The device must have a method for controlling oven temperature.

    The device features a control system for monitoring and controlling oven temperature.

19. The burn box should be inaccessible to the user.

    Future revisions of the design will feature a mechanism for preventing access to the burn box.

Chapter 4: Concluding Remarks

4.1 Mechanical Design

The design outlines in Chapter 3 of this report is a design of a stove geared towards safety and efficiency. Even though we feel that this stove was design to the best of our understanding of the problem statement and our objects we also feel like there are alternative solution to our problem that do not involve the design of a prefabricated stove made of steel or cast iron. The initial problem presented for this project was to design a stove that is efficient, clean and inexpensive. The purpose of this was to provide a way for developing nations to cook safely and save money on fuel. Through research it was determined that there are many programs already in place to help people with this problem. As seen in the appendix there is a lot of information available on how to build an efficient stove on the internet and being spread person to person in developing nations. The idea that is being spread worldwide is the idea of the combination of a rocket stove and a Lorena Adobe stove. The appendix shows a complete guide on how to build one of these fuel efficient and significantly safer stoves.

Moving on from the original problem that was presented in this project, we began designing a stove that could be using in America and in developing nations. The aspect that allowed it to be used in both extremely different demographics was that it was a hybrid stove. The stove was designed to be both a biomass burning stove, and also run off of electricity or gas. This idea is very good because it will allow people in developing nations to use it when they can only use biomass fuels. On top of this, the electrical implements allow the stove to be incredibly safe even when they are not connected to the grid. The major setback was the price of the stove. The stove would be too expensive for anyone in a developing nation to buy with their yearly income. In America the stove could still sell well because it applies to a niche group of people who would like to have a wood burning stove. However, for the general public a wood burning stove cooks too slow or causes too much of a hassle compared to other conventional methods as confirmed by the water boiling test described in the previous chapter.

The solution to the problem of the general public not wanting to use a wood burning stove and the stove being too expensive to people in developing nations is simple. People who want to buy the stove for themselves in America can still buy the stove for themselves. The stove will be marketed to wealthier people who would like to donate the stove to people in developing nations. This will advertise the stove promoting more people to buy the stove because it supports a good cause and give the stove to people who need it. This marketing strategy will be effective if we can find a philanthropist willing to buy a lot of the stoves for the less fortunate and this is well publicized. After this it will be easy to continue selling the stoves we designed. Through this method the project will have successfully accomplished the goal it set to design a safe and efficient stove for people in developing nations.

4.2 Electrical System Design

For this project, all of the functionality described in the design and implementation sections above were not completely achieved due to time constraint; however, the project could be continued and the full functionality of the design could be achieved. The continuation of the project will include working with the processor to achieve a small proof of concept circuit. This circuit will include interfacing with the DC motors; also the potentiometers will be monitored in order to decide how to control the motors. Also the relationship between the values of the potentiometer and the value of the thermal resistive sensors will designate how long and in which directions to move the DC motors. The diagram below shows which parts of the system will be implemented for this MQP, which parts might be implemented shall time allow, and which components will not be implemented for this MQP. In the block diagram shown in Figure 34 each square is color coded. The green squares are the components that will be implemented for this MQP, the orange squares are the ones that may be implemented if time permits, and the red squares are the components are that will not be implemented for this MQP. The block diagram in Figure 34 is the same as the one in the previous section except that it has color coded squares to indicate what the goals of this MQP are.

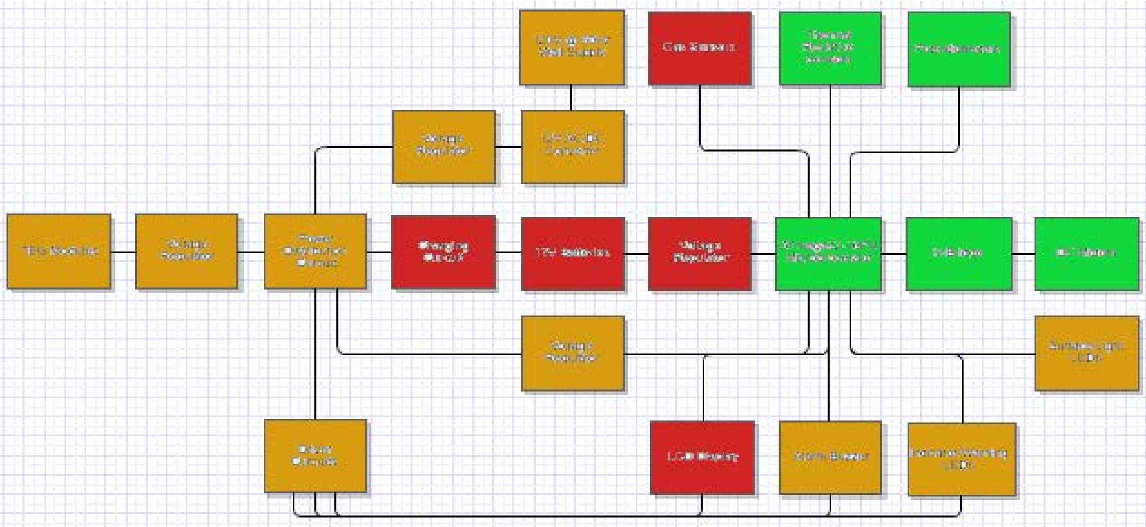


Figure 203: MQP Goal Block Diagram

An overall parts list for all the components used for this MQP can be seen in the excel spreadsheet below. The cost of all the parts is just around $150.00 and is under $100.00 at the bulk prices.

Part Description	Price	Bulk Price (100+)	Part Number	Quantity
Processing				
ATMEGA8515-16PU-ND	$3.87	$2.16	96K6517	1
Inputs				
Resistance Temperature Detector	$13.82	$1.53	615-1045-ND	3
Methane Gas Sensor	$3.90	$2.90		1
Carbon Monoxide Sensor	$8.90	$6.90		2
Air Quality Control Sensor	$6.90	$4.90		1
Outputs				
Red LEDs	$0.07	$0.07	L53HD-ND	10
Green LEDs	$0.18	$0.08	754-1262-ND	10
Bright White LEDs	$1.69	$1.45	365-1507-1-ND	3
LCD display	$11.00	$7.92	NHD-C12832A1Z-F	1
Buzzer	$3.55	$1.68	668-1204-ND	1
DC Motors	$3.25	$2.27	P14354-ND	4
Power				
TEG Module (G2-30-0313)	$1.00	$1.00		1
Battery	$13.64	$10.59	5169-UBP001	2
Battery Charging IC	$7.25	$3.63	296-9356-5-ND	1
AC/DC Converter (120 VAC - 5 VDC)	$6.25	$3.13	BP5034D5-ND	1
Totals				
Total Green	$121.23	$59.22		
Total Red	$29.60	$22.60		
Sub Total	$150.83	$81.82		

Legend
Order
Don't Order

Figure 34: Parts List for MQP parts

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Appendices

Appendix A: Code for the Stove Controls

```
/* MQP: REBCE
Advisor: Robert Labonte
Nick Knight
*/

#include <msp430x44x.h>
#include <stdlib.h>
#include <string.h>          // for some string functions

//********************************************* GLOBAL VARIABLES*******************************************************
char *LCD = LCDMEM;          // pointer to LCD Memory Segments. Pretty cool, got this idea from TI-website
unsigned int timer;
unsigned int timer_length;
char disable_interrupt;
char disabled; //not in ISR, but helpful for debug

//********************************************* LCD CONSTANTS *********************************************************
#define     a      (0x80)    // definitions for LCD seegments on the Olimex LCD. 4-Mux operation is assumed
#define     b      (0x40)    // For more details on 4-Mux operation, gather your LCD datasheet,
#define     c      (0x20)    // TI's MSP430F449 User Guide (look for LCD Controller, then 4-Mux),
#define     d      (0x01)    // and MSP-449STK-2 schematic. You will need ALL these 3 when defining
#define     e      (0x02)    // each number or character. Remember, the Olimex LCD doesn't use a LCD driver!
#define     f      (0x08)    // You tell the LCD what characters to display. It's very time consuming!!
#define     g      (0x04)
#define     h      (0x10)

// ***************************************** FUNCTION DECLARATIONS ****************************************************
//void shortDelay(unsigned int max_cnt);
void init_sys(void);
void disable_timer(void);
void enable_timer(void);
void runtimerb(void);
void stoptimerb(void);
void setupADC(void);
unsigned int pollADC0(void);
unsigned int pollADC1(void);
void setupMotor(void);
void motorOnCW(void);
void motorOnCCW(void);
void motorOff(void);
void clearLCD(void);
void initLCD(void);
void shortDelay(int dSpeed);
void writeLetter(int position,char letter);
void writeWord(const char *word, int repeat_times);
void writeNumber(int long number);
void writeSentence(const char *word, int scrollForever);
```

```
//--------------------------MAIN---------------------------//
int main(){
  init_sys();

  motorOnCW();
  motorOff();
  motorOnCCW();
  motorOff();

//  float voltage = 0;
//  float Vtherm = 0;
//  unsigned int i = pollADC0();
//  unsigned int j = pollADC1();
//  voltage = (0.000734*i)-0.005872;
//  Vtherm = (0.000235*j)-0.008214;
//
//  while((voltage > 0.00 && voltage < 1.2) == 1){    //for low temperature setting
//    unsigned int i = pollADC0();
//    unsigned int j = pollADC1();
//    voltage = (0.000734*i)-0.005872;
//    Vtherm = (0.000235*j)-0.008214;
//
//    Vtherm = 1.0;
//
//    if(Vtherm < 1.2 && Vtherm > 0.00)
//      writeSentence("LOW TEMPERATURE READY",0);
//    else if(Vtherm > 1.71)
//      motorOnCW();                          //turn motor on closing the flue if temperature is above low
//    else
//      motorOnCCW();                         //else turn motor in opposite direction opening the flue
//  }
//
//  while((voltage > 1.00 && voltage < 2.2) == 1){    //for medium temperature setting
//    unsigned int i = pollADC0();
//    unsigned int j = pollADC1();
//    voltage = (0.000734*i)-0.005872;
//    Vtherm = (0.000235*j)-0.008214;
//
//    Vtherm = 2.0;
//
//    if(Vtherm > 1.00 && Vtherm > 2.2)
//      writeSentence("MEDIUM TEMPERATURE READY",0);
//    else if(Vtherm > 1.78)
//      motorOnCW();                          //turn motor on closing the flue if temperature is above medium
//    else
//      motorOnCCW();                         //else turn motor in opposite direction opening the flue
//  }
```

```
//  while((voltage > 2.00 && voltage < 3.2) == 1){    //for high temperature setting
//    //unsigned int i = pollADC0();
//    unsigned int j = pollADC1();
//    voltage = (0.000734*i)-0.005872;
//    Vtherm = (0.000235*j)-0.008214;
//
//    Vtherm = 3.0;
//
//    if(Vtherm < 3.2 && Vtherm > 2.00)
//      writeSentence("HIGH TEMPERATURE READY",0);
//    else if(Vtherm > 1.85)
//      motorOnCW();                                //turn motor on closing the flue if temperature is above high
//    else
//      motorOnCCW();                               //else turn motor in opposite direction opening the flue
//  }


//    unsigned int i = 0;
//    P1DIR |= 0x08;              // Set P1.3 to output direction to run LED
//    for (i = 1; i<=2;i++) {  // repeats words two times
//    writeWord("SYSTEM ",1);  // show this word once
//    writeWord("READY. ",1);} // show this word once also
//    writeSentence("MSP430F449 REPORTING FOR DUTY!", 0);

}

/******************** initSys() *****************************/
void init_sys(void){
  //setup globals
  timer = 0;
  timer_length = 12000 - 1; //max legal value--will be set when timer is activated
  initLCD();                  // Setup LCD for work
  clearLCD();                 // Clear LCD display
  setupADC();                 // Setup ADC for use
  setupMotor();               // Setup motor for use
  WDTCTL = WDTPW + WDTHOLD;   // Stop watchdog timer
  _BIS_SR(GIE); // Global Interrupt enable
}

/****************Timer Functions**********************/

/* This function configures and starts Timer B */
void runtimerb(void)
{
  TBCTL = TBSSEL_1 + CNTL_0 + MC_1 + ID_0; // ACLK, 16 Bit, up mode, div=1
  TBCCR0 = 0x0147; // 327 ACLK tics = ~1/100 seconds
  TBCCTL0 = CCIE; // TBCCR0 interrupt enabled


}

/* This function stops Timer B */
void stoptimerb(void)//(int reset)
{
  TBCTL = MC_0; // stop timer
  TBCCTL0 &= ~CCIE; // TBCCR0 interrupt disabled
  /*
  if(reset)
  {
    timer=0;
    min=0;
    tsec=0;
  }
  */
}

/***************** setupADC() ***********************/
void setupADC(void){
  ADC12CTL0 &= ~ENC;
  ADC12CTL1 &= ~ENC;
  P6SEL = 0x03;                                    // Enable A/D channel A0 and A1
  ADC12CTL0 = SHT0_2 + REFON + ADC12ON + REF2_5V;  // Turn on ADC12, set sampling time, REFERENCE VOLTAGE (set to 2.5V)
  ADC12CTL1 = SHP;                                 // Use sampling timer
  __delay_cycles(128);
  ADC12CTL0 |= ENC;                                // Enable conversions
  ADC12CTL1 |= ENC;
}

/***************** pollADC0() ************************/
unsigned int pollADC0(void){
  ADC12CTL0 |= ADC12SC;                   // Start conversion
  while ((ADC12IFG & BIT0)==0)
    _NOP();                               // SET BREAKPOINT HERE
  return ADC12MEM0;
}

/***************** pollADC1() ************************/
unsigned int pollADC1(void){
  ADC12CTL1 |= ADC12SC;                   // Start conversion
  while ((ADC12IFG & BIT1)!=0)
    _NOP();                               // SET BREAKPOINT HERE
  return ADC12MEM1;
}

/*************************setupMotor************************/
void setupMotor(void){
```

```c
  P1DIR |= 0xC0;
  P2DIR |= 0x30;
  P2SEL = 0x00;
  P1SEL = 0x00;
  motorOff();
}

/*************************motorOnCW*************************/
void motorOnCW(void){
  P1OUT |= 0xC0;
}

/**********************motorOnCCW**************************/
void motorOnCCW(void){
  P2OUT |= 0x30;
}

/**********************motorOff()*************************/
void motorOff(void){
  P1OUT = 0x00;
  P2OUT = 0x00;
}

// ************************************************* numberScroll ******************************************************
void writeNumber(int long number)   // A cool function that moves number right to left
{
   unsigned int i;                    // dummy variable
   unsigned int digit;                // dummy digit
   char Letter;

   clearLCD();

   for (i=1; i<=9; i++)               // Extract each digit in number, put in an integer array, and count total length also
   {
      digit = number%10;              // digit = the least significant character obtained from number for display
      number = number/10;             // remove the least significant character from number

      switch(digit)                   // pass on the right char value to writeLetter function
      {
          case 0:  Letter = '0'; writeLetter(i,Letter); break;
          case 1:  Letter = '1'; writeLetter(i,Letter); break;
          case 2:  Letter = '2'; writeLetter(i,Letter); break;
          case 3:  Letter = '3'; writeLetter(i,Letter); break;
          case 4:  Letter = '4'; writeLetter(i,Letter); break;
          case 5:  Letter = '5'; writeLetter(i,Letter); break;
          case 6:  Letter = '6'; writeLetter(i,Letter); break;
          case 7:  Letter = '7'; writeLetter(i,Letter); break;
          case 8:  Letter = '8'; writeLetter(i,Letter); break;
          case 9:  Letter = '9'; writeLetter(i,Letter); break;
      }

      if (number == 0)                // when the number has finally been reduced to zero
          break;                      // break so that LCD doesn't diplay leading zeroes. E.g 234 instead of 0000234
   }
   shortDelay(2);                     // remove this delay if you update numbers regularly
}
// ************************************************* shortDelay ****************************************************
void shortDelay(int dSpeed)  // a very easy to code delay which keeps the processor busy for a small duration of time
{
     unsigned int iDelay = 0;
     unsigned int kDelay = 0;
     for (kDelay = 1;kDelay < dSpeed * 5 ;kDelay++)    // kDelay value can be changed from 10 - 50
     {
       iDelay = 8000;                     // Do not make iDelay more than 40000. Change kDelay instead
       do (iDelay--);
       while (iDelay != 0);
     }
}

// ************************************************* initLCD ******************************************************
void initLCD(void)   // initialize the various registers for LCD to work (code obtained from sample demos of MSP430F449)
{
    FLL_CTL0 = XCAP18PF;                 //set load capacitance for 32k xtal
    // Initialize LCD driver (4Mux mode)
    LCDCTL = LCDSG0_7 + LCD4MUX + LCDON; // 4mux LCD, segs16-23 = outputs
    BTCTL  = BT_fLCD_DIV128;             // set LCD frame freq = ACLK
    P5SEL  = 0xFC;                       // set Rxx and COM pins for LCD
}

// ************************************************* clearLCD ******************************************************
void clearLCD(void) // makes the LCD blank
{   // clear LCD memory to clear display
    unsigned int iLCD;
    for (iLCD =0; iLCD<20; iLCD++)   // clears all 20 LCD memory segments
    {
      LCD[iLCD] = 0;
    }
}

// **********************************************  writeLetter *******************************************************
void writeLetter(int position,char letter) // writes a single character on the LCD. User can specify position as well
{
    // DO NOT PLAY WITH THE CODE BELOW ----------------------------------------------------------------------------
    if (position == 1)  {  position = position + 6; } // this is position adjustment for compatibility.
```

```
    else if (position == 2 || position == 3 || position == 4 || position == 5 || position == 6 || position == 7)
    {  position = ((position * 2) - 1) + 6; }  // adjust position
    // ----------------------------------------------------------------------------------------------------------------

    switch(letter)
    {
      // letter  // LCDM7                          // LCDM8                            // End
      case 'A':  LCD[position-1] = a + b + c + e;     LCD[position] = b + c + g;        break;
      case 'B':  LCD[position-1] = c + h + e;         LCD[position] = b + c + g;        break;
      case 'C':  LCD[position-1] = a + h;             LCD[position] = b + c;            break;
      case 'D':  LCD[position-1] = b + c + h + e;     LCD[position] = c + g;            break;
      case 'E':  LCD[position-1] = a + h + e;         LCD[position] = b + c + g;        break;
      case 'F':  LCD[position-1] = a;                 LCD[position] = b + c + g;        break;
      case 'G':  LCD[position-1] = a + c + h + e;     LCD[position] = b + c;            break;
      case 'H':  LCD[position-1] = b + c + e;         LCD[position] = b + c + g;        break;
      case 'I':  LCD[position-1] = a + h + f;         LCD[position] = d;                break;
      case 'J':  LCD[position-1] = b + h + c;         LCD[position] = c;                break;
      case 'K':  LCD[position-1] = d + g;             LCD[position] = b + c + g;        break;
      case 'L':  LCD[position-1] = h;                 LCD[position] = b + c ;           break;
      case 'M':  LCD[position-1] = b + c + g;         LCD[position] = b + c + f;        break;
      case 'N':  LCD[position-1] = b + c + d;         LCD[position] = b + c + f;        break;
      case 'O':  LCD[position-1] = a + b + c + h;     LCD[position] = b + c;            break;
      case 'P':  LCD[position-1] = a + b + e;         LCD[position] = b + c + g;        break;
      case 'Q':  LCD[position-1] = a + b + c + h + d; LCD[position] = b + c;            break;
      case 'R':  LCD[position-1] = a + b + d + e;     LCD[position] = b + c + g;        break;
      case 'S':  LCD[position-1] = a + c + h + e;     LCD[position] = b + g;            break;
      case 'T':  LCD[position-1] = a + f + b;         LCD[position] = d + b;            break;
      case 'U':  LCD[position-1] = b + c + h;         LCD[position] = b + c;            break;
      case 'V':  LCD[position-1] = g;                 LCD[position] = b + c + e;        break;
      case 'W':  LCD[position-1] = b + c + d;         LCD[position] = b + c + e;        break;
      case 'X':  LCD[position-1] = d + g;             LCD[position] = e + f;            break;
      case 'Y':  LCD[position-1] = b + c + h + e;     LCD[position] = f;                break;
      case 'Z':  LCD[position-1] = a + h + g;         LCD[position] = e;                break;

      // number  // LCDM7                             // LCDM8                          // END
      case '0':  LCD[position-1] = a + b + c + h;     LCD[position] = b + c;            break;
      case '1':  LCD[position-1] = b + c;                                               break;
      case '2':  LCD[position-1] = a + b + e + h;     LCD[position] = c + g;            break;
      case '3':  LCD[position-1] = a + b + c + e + h; LCD[position] = g;                break;
      case '4':  LCD[position-1] = b + c + e;         LCD[position] = b + g;            break;
      case '5':  LCD[position-1] = a + c + h + e;     LCD[position] = b + g;            break;
      case '6':  LCD[position-1] = a + c + h + e;     LCD[position] = b + c + g;        break;
      case '7':  LCD[position-1] = a + b + c;                                           break;
      case '8':  LCD[position-1] = a + b + c + e + h; LCD[position] = b + c + g;        break;
      case '9':  LCD[position-1] =a + b + c + e ;     LCD[position] = b + g;            break;

      // others
```

```
      case '^':                                       LCDM2 = c;                        break;  // top arrow
      case '!':                                       LCDM2 = a;                        break;  // bottom arrow
      case '>':                                       LCDM2 = b;                        break;  // right arrow
      case '<':                                       LCDM2 = h;                        break;  // left arrow
      case '+':                                       LCDM20= a;                        break;  // plus sign
      case '-':                                       LCDM20= h;                        break;  // minus sign
      case '&':                                       LCDM2 = d;                        break;  // zero battery
      case '*':                                       LCDM2 = d + f;                    break;  // low battery
      case '(':                                       LCDM2 = d + f + g;                break;  // medium battery
      case ')':                                       LCDM2 = d + e + f + g;            break;  // full battery */
    }
}

// *********************************************  writeSentence*********************************************************

void writeSentence(const char *word, int scrollForever)  // writes out an entire sentence scrolling it right to left
                                                            // sentences must be in upper case
{
   unsigned int strLength = 0;           // variable to store length of the sentence
   unsigned int i;                       // dummy variable
   unsigned int j;                       // dummy variable
   unsigned int k;                       // dummy variable
   char letter_list[75];                // keeps track of characters. Sentence can have upto 74 characters. Do not make too large
   unsigned int position_list[75];      // keeps track of position of the characters
   unsigned int marker = 0;              // keeps track of index of the last being displayed character
   unsigned int dispCount = 0;           // keep count of how many characters are being displayed
   unsigned int flag = 1;                // a normal flag that defines if process should be stopped

   strLength = strlen(word);             // get the length of the sentence

   for (i = 1; i <= strLength; i++)      // put each character in string in a special array called letter_list
   {
      letter_list[strLength - i + 1] = word[i-1];
      position_list[i] = 0;              // also, place their relative position values in an array called position_list
   }

   marker = strLength;                   // marker takes the position of the last character
   position_list[marker] = 1;            // Set the marker of this position to 1
   dispCount++;                          // dispCount = 1; meaning we start display with 1 character

   do                                    // Digit Shifter with light + delay
   {
      shortDelay(2);                     // take a short break so that the user can see the changes
      clearLCD();                        // since we are gonna update LCD soon, clear the LCD first
      P1OUT ^= 0x08;                     // toggle the pin connected to LED to that we can see it blinking

      for (k = marker; k >= marker - dispCount + 1; k--)    // display the first frame
```

```
        {
            writeLetter(position_list[k],letter_list[k]);
        }

        if (dispCount < 7)                // update frame count (characters to be displayed during next frame)
          { dispCount++; }

        for (i = marker; i >= marker - dispCount + 1;i--) // shift the relative position values
        {
            position_list[i] = position_list[i] + 1;
            if (position_list[i] == 8)
            {   marker--;                               // shift the marker value

               if (marker - dispCount + 1 <= 0)
               {
                  marker = dispCount;                   // make sure marker never goes less than zero
               }

            }
        }

        if (position_list[1] == 2)                      // when marker has hit maximum index
           {
              if (scrollForever == 0)
              {  flag = 0; clearLCD();  }               // adjust flag value to repeat or not
              marker = strLength;                       // reset marker to original
              dispCount = 1;                            // display length of frame to 1
              for (j = 1; j <= 50; j++)                 // reset position_list to original
              {
                 if (marker != j)
                 { position_list[j] = 0; }
                 else if (marker == j)
                 { position_list[j] = 1; }              // set position list of marker character to 1
              }
           }
    } while (flag == 1);                                // function repeats forever if flag remains 1

}

// ***********************************************  writeSentence*********************************************************
void writeWord(const char *word, int repeat_times)  // displays a word (upto 7 characters) for specified number of times
                                                    // words must be in upper case
{
   unsigned int strLength = 0;   // variable to store length of word
   unsigned int i;               // dummy variable
   unsigned int k;               // dummy variable

   strLength = strlen(word);     // get the length of word now

   for (k = 1; k <= repeat_times; k++)  // repeat display
   {
       for (i = 1; i <= strLength; i++) // display word
       {
          writeLetter(strLength - i + 1,word[i-1]);  // displays each letter in the word
       }
       shortDelay(3);         // software delay
       clearLCD();            // clears the LCD
       shortDelay(3);         // software delay
   }

}

// ************************ short Tutorial on using LCD commands effectively *******************************************

/* //(a) To display battery life indicator (copy and paste the following):
        writeLetter(1,'&');   // zero battery life
        shortDelay(5);

        writeLetter(1,'*');  // low
        shortDelay(5);

        writeLetter(1,'(');  // medium
        shortDelay(5);

        writeLetter(1,')');  // full battery life
        shortDelay(5);                              */
    // -----------------------------------------------------------------


/*  //(b) To display + and - signs:
         writeLetter(1,'+');   // displays plus sign
         shortDelay(5);
         writeLetter(1,'-');   // displays negative sign  */
    // -----------------------------------------------------------------

/*  //(c) To display signed numbers with decimals:
         writeWord("+153.89",1);       */
    //  ----------------------------------------------------------------

/*  //(d) To display a number excluding decimals
         writeNumber(1234567);    */
    // -----------------------------------------------------------------

/*  //(e) To display a number including decimals

     // -----------------------------------------------------------------

/*    //(g)To display the arrows on LCD:
         writeLetter(1,'^');    // shows top arrow
         shortDelay(5);

         writeLetter(1,'!');    // shows bottom arrow
         shortDelay(5);

         writeLetter(1,'>');    // shows right arrow
         shortDelay(5);

         writeLetter(1,'<');    // shows left arrow
         shortDelay(5);       */
```

Appendix B: Burn Test #1 3lbs Dura Flame Log

	H2O	Front	Ashbox	Triangle	Burnbox	Sidewall	S1	S2	Mid L	Mid M	Mid R	Back A	Back B	Back C	Exhaust
4:14:00 AM	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62
4:55:00 AM	85	244	59	73.5	106	67.5			84		73	138	96.5	73.5	150
5:01:00 AM	95														
5:03:00 AM	99														
5:04:00 AM	100	230				70									
5:05:00 AM			57	74	113							131	98	76.5	
5:07:00 AM							188	185							
5:08:00 AM															130
5:10:00 AM									75		65				
5:11:00 AM	109														
5:14:00 AM	111	225				73			72		67				
5:16:00 AM							185	190							
5:17:00 AM												124	97	75	142
5:18:00 AM			61	71	114										
5:19:30 AM	114														
5:23:00 AM	115	228							78		68.5				
5:24:00 AM			57	77	117										
5:26:00 AM												120.5	92	73.5	
5:27:00 AM							186	175							
5:28:00 AM	119														139
5:36:00 AM	122	218													
5:37:00 AM							186	140	76		71				
5:40:00 AM												110	90.5	72.5	
5:42:00 AM															130
5:43:00 AM	72.5														
5:45:00 AM			57	76.5	115										
5:46:00 AM	125														
5:50:00 AM	125														
6:00:00 AM	126	172.5							79	200	70.5				
6:02:00 AM							140	156.5							
6:05:00 AM												100	81.5	61.5	
6:06:30 AM	125														
6:07:00 AM															106
6:09:00 AM			56	64	107.5										
6:10:45 AM	124														
6:18:00 AM	125														
6:23:00 AM	124														

Appendix C: Burn Test #2 9 lbs. Dry Logs

	H2O	Front	Ashbox	Triangle	Burnbox	Sidewall	S1	S2	Mid L	Mid M	Mid R	Back A	Back B	Back C	Exhaust
7:02:00 AM	55														
7:03:00 AM		369							110	552	83				
7:04:00 AM												345	240	140	
7:04:30 AM	65														
7:05:00 AM					70										
7:06:00 AM							620	530							
7:07:00 AM															690
7:08:00 AM	100														
7:09:00 AM	120														
7:09:30 AM		508													
7:10:00 AM									135	635	140				
7:12:00 AM							550	502							
7:13:00 AM						109									
7:13:30 AM												470	360	208	
7:14:00 AM	150														
7:14:45 AM															500
7:15:30 AM	180														
7:17:00 AM			81	135	199										
7:18:00 AM	172														
7:18:30 AM		535													
7:20:00 AM	181														
7:21:00 AM		502													
7:21:30 AM									175	545	130				
7:22:00 AM							4:50	385							
7:23:00 AM												318	270	180	
7:24:00 AM	195														
7:25:00 AM															340
7:26:00 AM	198														
7:27:00 AM		460				128									
7:28:00 AM	200	450													

Appendix D: How to Build the Improved Household Stove

THE REPUBLIC OF UGANDA

MINISTRY OF ENERGY AND MINERAL DEVELOPMENT

Energy Advisory Project

HOW TO BUILD THE IMPROVED HOUSEHOLD STOVES

A CONSTRUCTION MANUAL FOR THE ROCKET – LORENA AND SHIELDED FIRE STOVES

With the Support of the German Technical Cooperation

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Introduction

Uganda faces a biomass energy crisis marked by an increasing imbalance between the supply and the demand of the firewood by households, institutions and industries.

One of the most effective strategies to sustainably contribute towards the reduction of this problem is through an extensive dissemination of biomass energy efficient technologies.

The purpose of this manual is to provide to all interested parties a practical tool to use in the construction of improved firewood stoves i.e the rocket – lorena and the shielded fire.

The improved biomass energy efficient technologies have been developed to improve energy efficiency for household, institutional and industrial practices. They include the domestic and institutional firewood stoves and the firewood baking oven.

These improved household stoves have efficiencies of 30 % (average) compared to the traditional (open) 3-stone fire stove at 15.6 %, in a high power water-boiling test*.

The main objective in developing the improved firewood stoves is to achieve relatively efficient firewood combustion and maximising heat transfer to the food being cooked.

These improved stoves help the users to have firewood savings of 50 – 60 % when compared to the traditional (open) 3 stone stove. Yet another strength of these stoves is that they are built using local materials including clay, anthill soil and sand for the body whereas insulating materials include sawdust, pumice and vermiculite.

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* Data source: GTZ – EAP / MEMD records. “Firewood Cook stoves Development and Testing” by Leonard Mugerwa, September 2003.

THE IMPROVED FIREWOOD STOVES

The improved stoves are able to achieve maximum transfer of heat to the food because they heat at least 90 % of the saucepan's surface area and have insulation around the combustion chamber and the fire passages.

Advantages

1 Firewood Fuel Savings

The stoves have been tested and proven to be economical in firewood consumption, with an efficiency averaging 30% compared to the traditional (open) 3-stone fireplace at 15.6%. This means that by using the improved stove, you double the amount of energy is transferred from the wood to the food being cooked.

2 Almost Smokeless Operation

The stoves hardly produce smoke during their operation. A bit of smoke is produced only when lighting the fire.

3 Easy to Operate

Once lit, the stove fire does ***not*** stop unless firewood feed into the stove is stopped. There is ***no need*** of straining one's lungs to blow air into the stove to fan the flame as it is with the Traditional (open) 3-stone fire. This is done by the air chamber below the feeding shelf.

4 Affordable

The stoves are constructed using local materials including anthill soil and sand for the body whereas vermiculite, sawdust, pumice, etc are used for thermal insulation.

5 Safe to Use

The stoves are safe-to-use domestic appliances. Firewood is neither toxic nor highly inflammable. The shielded fire is screened (out of reach) and therefore less likely to cause burns to children and the user.

6 Environmentally Friendly

The stoves use less firewood leading to reduction of the deforestation rate. The stoves are less pollutant because of their nearly smokeless operation, attributed to the shelf-fitted rocket elbow combustion chamber, which improves the air : fuel ratio.

THINGS TO CONSIDER WHEN PREPARING TO BUILD THE IMPROVED STOVES

1.0 SHELTER

Ensure that there is a kitchen in place to house and protect the stove to be built from intrusion and unfavourable weather conditions e.g. rain.

2.0 TOOLS

The tools required when building the improved firewood stoves include:

	Tool	Purpose
1	Hoe	Digging foundation base and mixing ingredients
2	Shovel or Spade	Mixing ingredients
3	Jerry can	Fetching water
4	Sieve (4 mm)	Sifting ingredients
5	Trough *(karaayi)*	Measuring materials by volume and carrying mixtures
6	Trowel / blunt machete	Smoothing plaster / stove finish
7	Measuring Tape / ruler	Taking measurements
8	Bow saw	Cutting pumice blocks into insulation slabs
9	Spirit level (optional)	Inspecting horizontal level for laid bricks / stove finish
10	Plumb line (optional)	Inspecting vertical alignment for laid bricks / structure
11	Try Square (optional)	Inspecting right angled corners

Safety Gear[1]

	Device	Purpose
1	Nose Mask	Protection against inhaling dust during sifting
2	Overalls / work clothes	Protection of clothes during work
3	First Aid Kit[2]	Treatment for injuries

[1] Recommended for use where available.

[2] Professional workshop practice recommends that a First Aid kit should be in place.

3.0 STOVE CONSTRUCTION MATERIALS

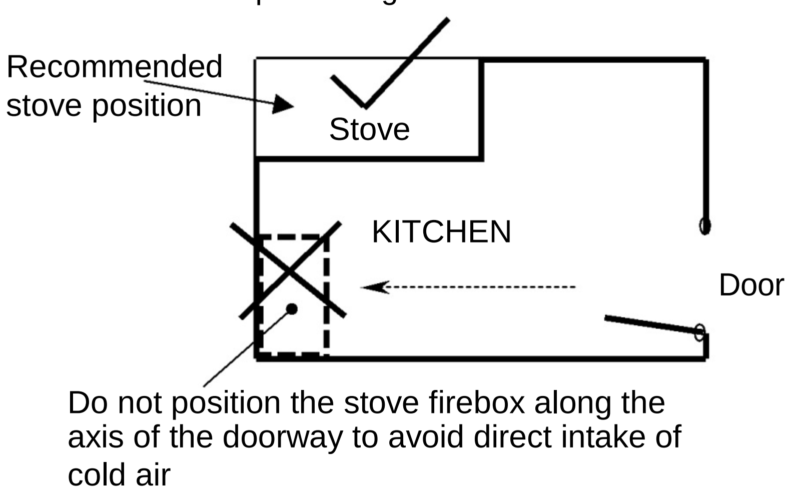
	Materials	Options	Quantity	
			Rocket - Lorena	Shielded Fire
1	Clay	Anthill soil	8 – 12 wheel barrows	4 – 6 wheel barrows
2	Sawdust	Dry chopped grass, dry chopped banana leaves, vermiculite or pumice	8 – 12 wheel barrows	4 – 6 wheel barrows
3	Mud bricks	-	60 – 80 bricks	10 bricks
4	Clay tile	-	1 pc (25 x 13 x 1 cm)	1 pc (25 x 13 x 1 cm)
5	Water	-	7 – 10 jerry cans (20 litres each)	4 jerry cans (20 litres each)
6	Sand	-	8 – 12 wheel barrows	4 – 6 wheel barrows

4.0 PURCHASE AND DELIVERY OF MATERIALS

Purchase the construction materials and deliver them outside the kitchen where the stove is to be built.

5.0 MAPPING OUT THE STOVE POSITION

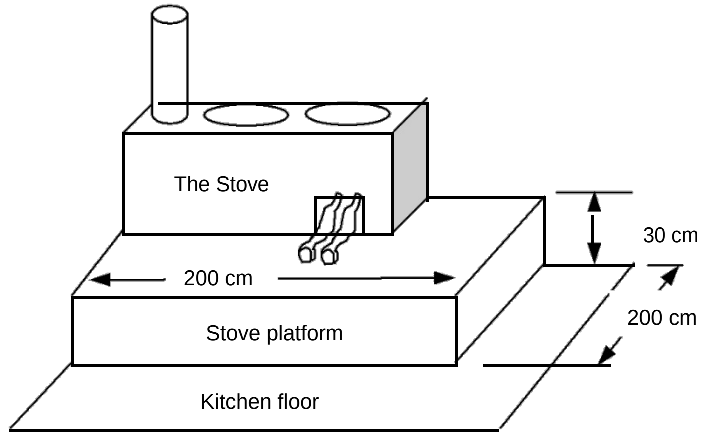
Choose a corner in the kitchen to be occupied by the stove. This will save it from accidental damage and it will also be useful in preventing the stove from direct intake of cold air.



Kitchen plan

NOTE:

It is advisable that one week prior to stove construction, a 200 X 200 X 30cm high platform be built in the kitchen corner that has been marked above. On this platform, the stove will be constructed. This will help to keep the stove out of reach for very young children.



6.0 MATERIALS PREPARATION

Prepare the construction materials, at least two days before the time for stove construction. The preparation procedure will depend on the materials combination chosen as described below:

6.1 Sawdust and clay (or anthill soil option)

6.1.1 Crash the clay (or anthill soil) into smaller granules, which can be sieved through the 4 mm sieve.

6.1.2 Using the sieve, sift the clay (or anthill soil) to obtain fine granules.

In the same way sift an equal amount of sawdust to obtain fine particles.

6.1.4 Slowly add water to the mixture to make it mouldable.

6.1.5 Blend the mixture using the feet similar to the way it is locally done when preparing mud for brick making.

In the event that sawdust is not available in your place, you may use any of the following stove construction materials combination depending on availability:

6.2 Grass and clay (or anthill soil option)

6.2.1 Use the machete *(panga)* to chop dry grass into small pieces of approximate length 1 cm.

6.2.2 Using the sieve, sift the clay (or anthill soil) to obtain fine ingredients.

6.2.3 Mix the chopped dry grass and clay (or anthill soil option) volumetric ratio 1:1.

6.2.4 Slowly add water to the mixture just to make it mouldable.

6.2.5 Blend the mixture using feet similar to the way it is locally done when preparing mud for brick making.

6.3 Dry banana leaves and clay (or anthill soil option)

6.3.1 Separate the stalk and mid-rib from the lamina. Use the dry lamina of the dry banana leaves.

6.3.2 Use the machete *(panga)* to chop the dry lamina into small pieces of approximate length 1 cm.

6.3.4 Using the sieve, sift the clay (or anthill soil) to obtain fine ingredients.

6.3.5 Mix the chopped lamina and clay (or anthill soil option) volumetric ratio 1:1.

6.3.6 Slowly add water to the mixture just to make it mouldable.

6.3.7 Blend the mixture using feet similar to the way it is locally done when preparing mud for brick making.

6.4 Pumice, anthill soil and sand.

6.4.1 Using the sieve, sift the sand and clay (or anthill soil) separately to obtain fine ingredients.

6.4.2 Mix the clay (or anthill soil) and sand (ratio 1:1).

6.4.3 Slowly add water to the mixture just to make it mouldable.

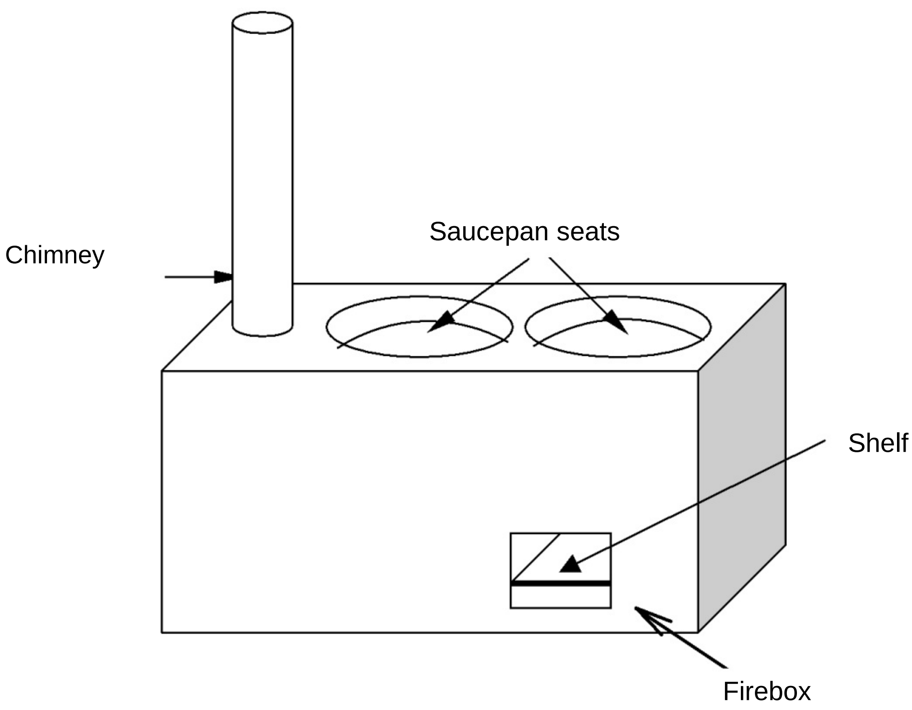
Blend the mixture using feet similar to the way it is locally done when preparing mud for brick making.

6.4.5 Cut / shape the pumice into slabs of 5cm thickness.

Note: The slabs will later be used in providing thermal insulation around the combustion chamber and the fire (hot flue gases) passage. They will be fastened together using the anthill soil – sand mixture.

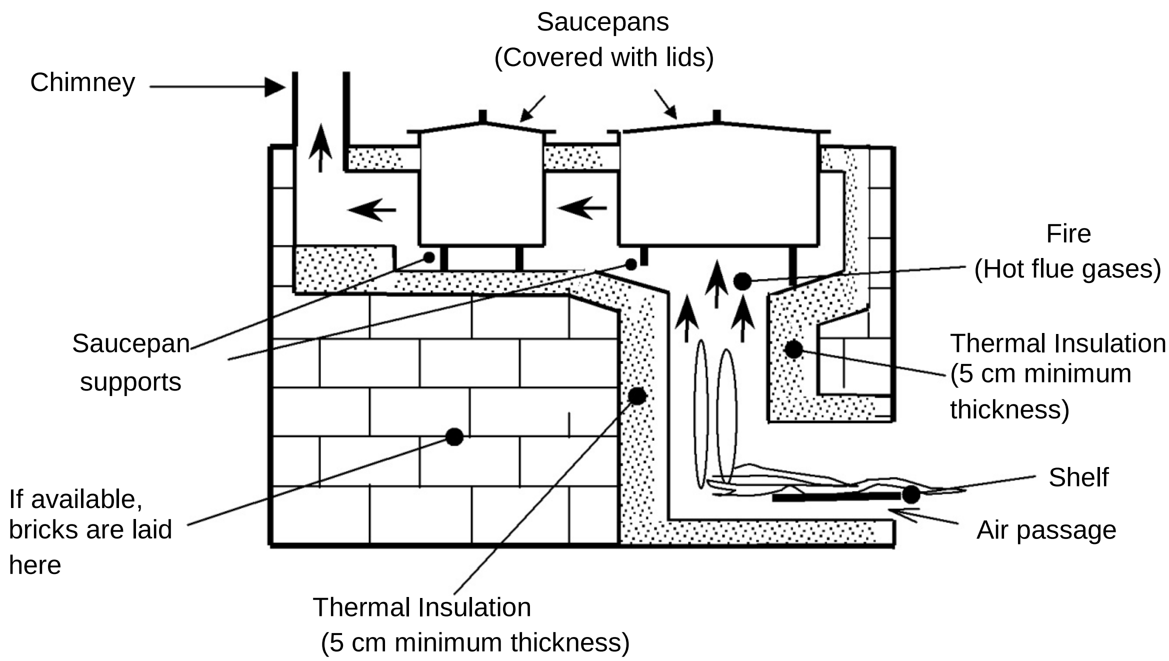
PART 1

HOW TO BUILD THE IMPROVED ROCKET - LORENA STOVE



HOW THE ROCKET LORENA STOVE WORKS

Below is the sectioned front view of the stove, showing how it is intended to function. Note that the saucepan seats are deep enough to have the saucepans submerged into the stove's hot gases' passage. This increases the surface area of the saucepan being exposed to the fire (hot flue gases), which results into increased heat transfer into the saucepan.



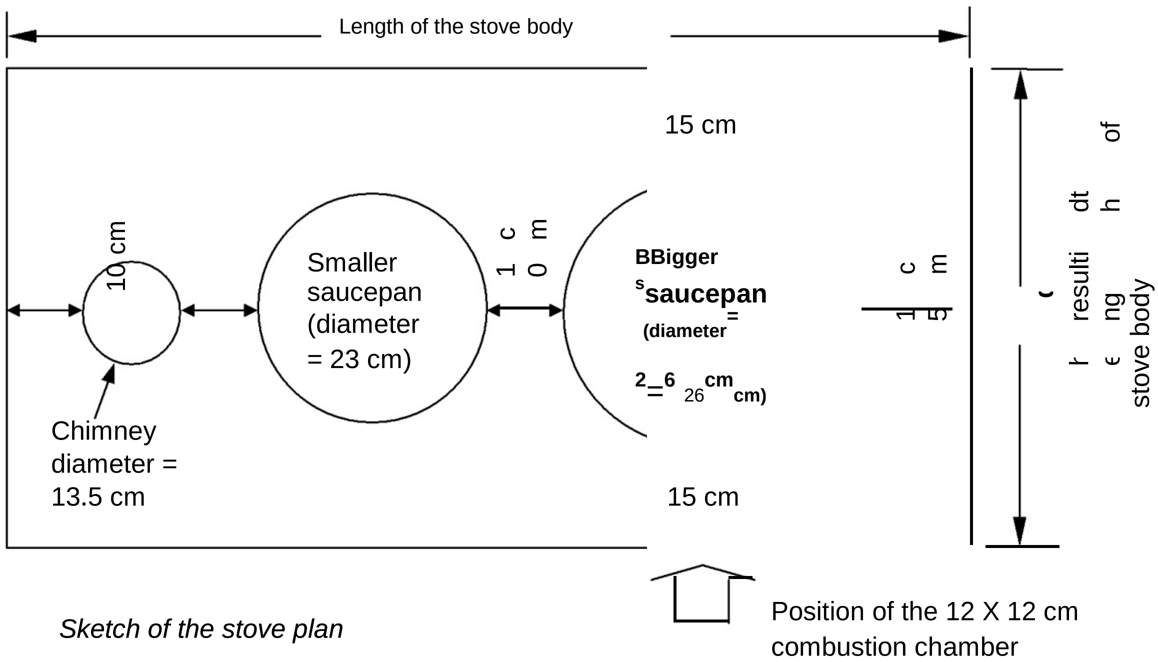
7.0 Building the Rocket - Lorena Stove

The size of the stove will depend on the size of the saucepans that will be used when cooking with it.

<u>Example:</u>

For a home that frequently uses two saucepans with diameter 26 cm and 23 cm, the bigger saucepan should be positioned directly above the combustion chamber while the smaller one takes the other position. The size of the combustion chamber will be 12 X 12 cm (or circular option diameter = 13.5 cm). This will be the inner diameter of the chimney.

The stove designed for 26 cm bigger diameter and 23 cm smaller diameter saucepans will have the resulting outer dimensions = 107 X 56 cm.



Sketch of the stove plan

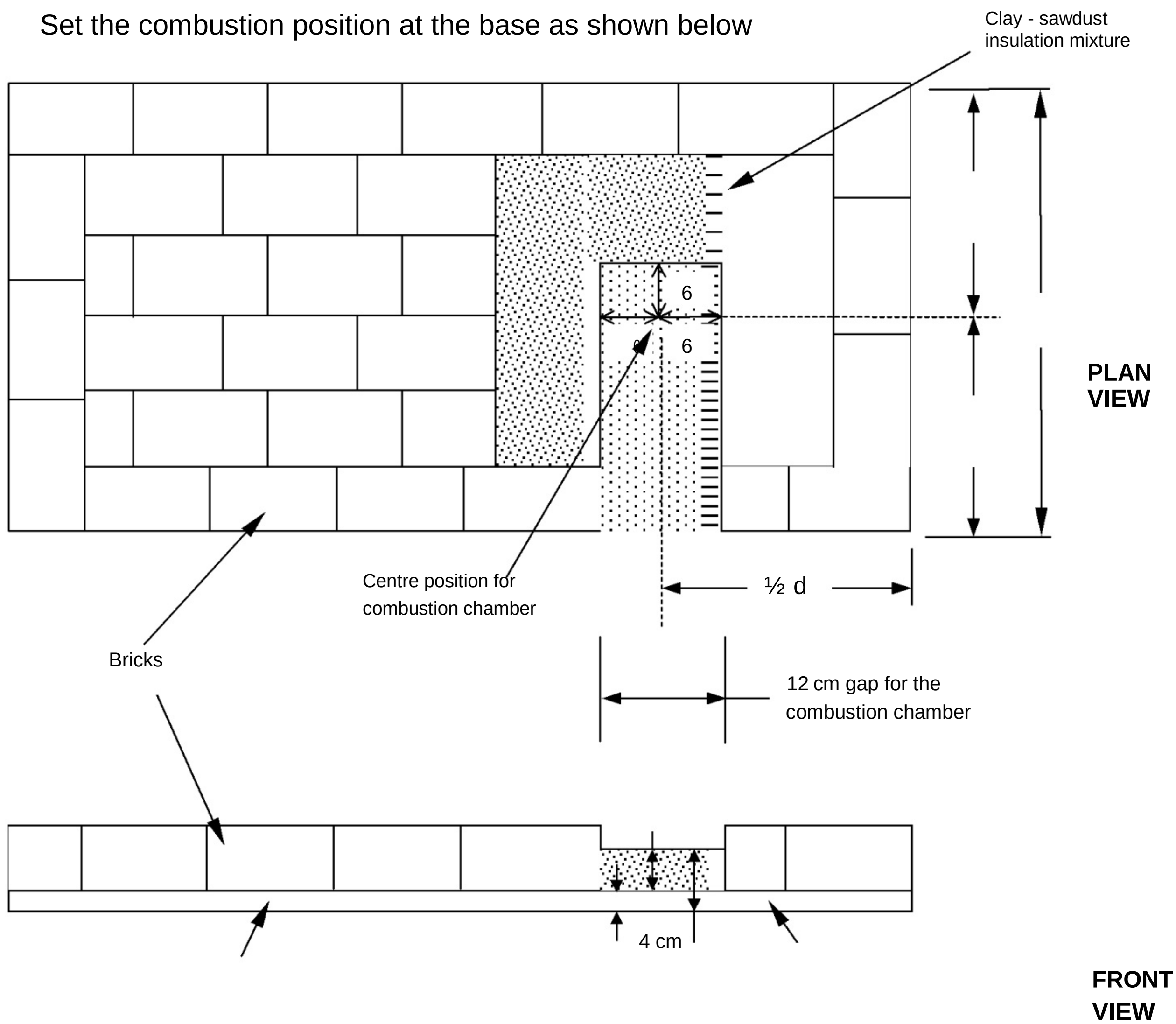
Draw the outline of the stove foundation on the platform as illustrated above. The bigger saucepan should be positioned directly above the combustion chamber while the smaller one takes the other position. In the event that a measuring tape is not available, use the palm width. The width of your palm approximates 10 cm. For the 15 cm measurement use 1½ palm widths.

7.1 Wet the position to be occupied by the stove. Using the mixture in 6.1.5 above, lay down a 2 cm high base for the stove, bordered by the marked out line.

7.2 Lay the foundation bricks on the 2 cm high mixture. If bricks are not available, use the sawdust-clay mixture.

7.3 While setting the foundation the combustion chamber base should be catered for as shown. For example if the bigger saucepan diameter is 26 cm, build a 12 cm wide combustion chamber (refer to the tables in appendix).

7.4 Set the combustion position at the base as shown below



2 cm high mixture for
the foundation base

2 cm 6 cm Clay - sawdust
insulation mixture

7.5 Building the combustion chamber

You will need some material to mould the combustion chamber shape during stove construction.

In order to build a square cross section combustion chamber of 12 X 12 cm for support use square cross section bricks of same size (12 X 12 cm) covered in polythene material.

For the option of a circular combustion chamber use diameter = 13.5 cm.
(For details of the calculation, refer to appendix 1)

Appendix E: Authorship

Chapter 1: Development of a Renewable Energy Cookstove

1. Introduction	Brian Grabowski

Chapter 2: Evolution of Cookstove Design and Environmental Effects

2.1 Introduction	Michael Jenkins
2.2 Evolution of Stoves	Michael Jenkins
2.2.1 Three Stone Fire	Michael Jenkins
2.2.2 Lorena Adobe Stove	Michael Jenkins
2.2.3 Rocket Stove	Michael Jenkins
2.3: Safety of the Stove	Justin Mathews
2.3.1: Wood Stove Fire Risks	Justin Mathews
2.3.2 Causes of Cooking Fires	Justin Mathews
2.3.3 Costs of Cooking Fires	Justin Mathews
2.3.4 Cooking Fire Prevention	Justin Mathews
2.4: Global Warming	Michael Jenkins
2.4.1 Wood Stove Environmental Risks	Justin Mathews
2.4.2 Catalytic Converters and Non-Catalytic Combustors	Justin Mathews
2.5 Wood Stove Health Risks	Justin Mathews
2.6: Consumer Demographic	Matthew Goon
2.7 Examples of Stoves	Michael Jenkins
2.7.1 Antique Stoves	Michael Jenkins
2.7.2 Hybrid Stoves	Michael Jenkins
2.8: Electrical Controls	Nicholas Knight

Chapter 3: Renewable Energy Cookstove Design

3.1 Design Specifications	Justin Mathews
3.2 Hybrid Stove Test	Brian Graboski
3.3 Stove Design	All
3.4 Final Design Drawings	All
3.5 Electrical Design Overview	Nicholas Knight
3.6 Implementation	Nicholas Knight
3.6.1Processor	Nicholas Knight
3.6.2 Power System	Nicholas Knight
3.6.3 Sensor Inputs	Nicholas Knight
3.6.4 Outputs	Nicholas Knight
3.7 Design Analysis	Justin Mathews

Chapter 4: Concluding Remarks

4.1 Mechanical Design	Michael Jenkins
4.2 Electrical System Design	Nicholas Knight
References	Michael Jenkins, Justin Mathews

Appendices

Appendix A: Code for the Stove Controls	Nicholas Knight
Appendix B: Burn Test #1 3lbs Dura Flame Log	Brian Grabowski
Appendix C: Burn Test #2 9 lbs. Dry Logs	Brian Grabowski
Appendix D: How to Build the Improved Household Stove	Michael Jenkins
Appendix E: Authorship	
Revised and Edited:	Justin Mathews, Michael Jenkins