ASEI-ISEC REPORT

ASEI

ABSTRACT

Intensive development patterns have historically relied on inexpensive and energy-dense fossil fuels, which also happen to be the primary source of greenhouse gas emissions with the principal greenhouse gas contributor CO2's concentration in the atmosphere increasing from 2.57 parts per million (ppm) to 4.14 ppm in December 2020 (UNEP, 2021). However, new, clean technologies such as the ISECs can reorient development along a more sustainable trajectory without relying on energy-dense fossil fuels to source energy for cooking purposes.

Solar power is arguably the cleanest, most reliable form of renewable energy available. In Uganda the sun's rays are almost directly overhead due to its location along the equator, Uganda is endowed with an average of 5-6 kWh/m^2 radiation and 7kWh/m^2 per day on flat surfaces. The insolation is highest at the Equator.

An ISEC (insulated solar electric cooker) is a solar electric cooker uses electricity generated by solar panels to generate heat through resistive heating that is used for heating and cooking. ISECs can accelerate the transition to an affordable, reliable and sustainable energy system in cooking and set a trend for other technologies in the cooking sector to completely switch to clean renewable energy / fuel sources such as solar hence ensuring access to affordable, reliable, sustainable and modern energy for all.

Having successfully constructed and tested the ISECs cooking ability of different local foods in Fort Portal with 99% of the materials sourced locally in Uganda with the survey showing that 100% of the users expressed interest in purchasing the ISEC and 75% agreed that using the ISEC to cook is better than other cooking options such as using charcoal and mud stove while 100% agreed it is better than using a 3 stone stove. Reasons generally were due to the ISEC being clean compared to using biomass sources (firewood, charcoal) with no gas emissions, relatively good cooking time and less monitoring needed during the cooking. 100% of the users generally preferred cooking rice with the ISEC followed by matooke at 75% and groundnuts at 75%.

ASEI looks at scaling up production with a target of disseminating ISECs to the vast majority of the Rwenzori region and other parts of the country.

This document elaborates the findings from using the ISEC including cooking ability of the product (ISEC) and various foods that where cooked.

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LIST OF ACRONYMS

ISEC	Insulated solar electric cooker
CO^2	Carbon dioxide
GDP	Gross domestic product
LPG	Liquified Petroleum Gas
KWhm^2	kilo watt hour per square meter
°C	Degrees Celsius
°F	Degrees Fahrenheit
W/m K	Watt per meter Kelvin

1.0 INTRODUCTION

According to research majority of households in sub-Saharan Africa (90% of the population) (Njenga et al., 2019) still rely on traditional biomass (firewood and charcoal) for cooking and dependency continues to rise in most parts of Africa. Efforts to bring modern energy access to all – electricity and clean fuels – are far outpaced by population growth.

Burning either fossil fuels or biomass releases carbon dioxide (CO^2), a greenhouse gas that contributes to global warming and climate change. Other negative impacts are most notably on health with 600,000 lives lost each year in sub-Saharan Africa due to exposure to biomass smoke (Lambe et al., 2015).

The economic costs of high reliance of biomass for cooking are also substantial at about 36.9 billion USD per year, or 2.8% of GDP, including 29.6 billion USD from productive time lost gathering fuel and cooking. The impacts are particularly severe for women and girls, who are typically responsible for these chores (Lambe et al., 2015).

The need to achieve a shift to cleaner and safer cooking methods continues to grow with numerous interventions such as improved cookstoves across sub-Saharan Africa beginning to reach scale, with benefits to household health, livelihoods, environment and economies.

However, there is an urgent need to ramp up these initiatives, tailoring them to the specific conditions in each country. The prize is market transformation to cleaner cooking methods with clean and abundant fuels. Not only would such a transformation produce huge health improvements, but it would also create multiple business opportunities and jobs.

Most sub-Saharan countries including Uganda have a large abundance of solar energy with huge cooking potential if harnessed. The benefits of using this abundant and renewable energy source is that it does not produce any greenhouse gas emissions compared to traditional biomass sources plus other health benefits of no inhalation of gas emissions.

1.2 Cooking fuels and devices;

A study conducted on household levels across all the regions covering Uganda's major rural regions showed that the largest population (53.3%) of rural Ugandans still use the 3 stone stove fire for cooking, 27.3% use a charcoal stove, improved cooking stove usage at 16.9%, Electric cookers at 1.2%, LPG at 0.7% and biogas at 0.5% for the preparation of their various types of cooked foods while forest firewood is the commonly used biomass fuel for cooking with a percentage of 66.8% compared to charcoal, briquettes, saw dust and others with percentages of 27.1%, 0.7%, 0.7%, 1.1% respectively (Nsamba et al., 2021).

1.3 Solar energy potential;

The Sun is the primary source of sustenance for all living and nonliving things on this planet. Solar energy is the solitary renewable energy source with immense potential of yearly global insolation at 5600 ZJ, as compared to other sources such as biomass and wind.

Uganda is among countries with high solar energy resource potential, on average, estimated to be approximately 5.2 kWh per square meter per day (Aarakit et al., 2021).

Existing solar data clearly indicates that the solar energy resource in Uganda is high throughout the year with a yearly variation (max month/min month) of only about maximum 20% (from 4.5 to 5.5 W/m^2) which is due to the location near the equator. This high level of solar insolation, coupled with average daily sunshine of about 8h throughout the year, provides an excellent potential for solar energy use and development of solar energy conversion systems in the country (Aarakit et al., 2021).

So far, the household sub-sector is possibly one of the biggest markets for solar PV systems in Uganda (World Bank, 2018).

1.4 Solar cooking;

Current solar cooking technologies rely on direct solar energy to heat, cook or pasteurize drink and other food materials.

Solar cooking is one of the applications of solar thermal technology which was initiated by a German scientist Tschirnhausen during the year 1651–1708. It works on the principle of utilizing heat energy from the Sun for cooking purposes. Lens and reflectors are used to focus and reflect the solar radiation on to the system. The whole system is insulated to avoid heat loss to the surroundings (Sakthivadivel et al., 2021).

Depending on the structure, solar cookers are categorized into box type, concentrating type and panel type. Based on the cooking method, solar cookers are categorized into direct and indirect types. In direct-type cookers, heat from the Sun is used directly to heat the cooking vessel whereas indirect types use a steam medium through which the heat is transferred to the cooking vessel.

Vacuum tube and olive oil are used as a heat transfer medium in indirect type solar cookers. Among the various classifications, box-type cookers are quite famous and common. The time required for solar cooking is higher as compared to modern technology and hence solar cooking is not widely implemented in household cooking.

1.4.1 Principle of operation;

The solar cookers work on a principle of concentrating sunlight by a mirrored surface with high specular reflection into a small cooking area producing temperatures of 65 °C (150 °F) (baking temperatures) to 400 °C (750 °F) (grilling/searing temperatures) on a sunny day (Sakthivadivel et al., 2021).

The sunlight is concentrated onto a receiver such as a cooking pan which converts light to heat by conduction or onto a steam medium through which the heat is transferred to the cooking vessel. Conversion is maximized by using materials that conduct and retain heat.

The heat energy is then trapped by isolating the air inside the cooker from the air outside the cooker using a glass lid on the pot which enhances light absorption from the top of the pan and provides a greenhouse effect that improves heat retention and minimizes convection loss.

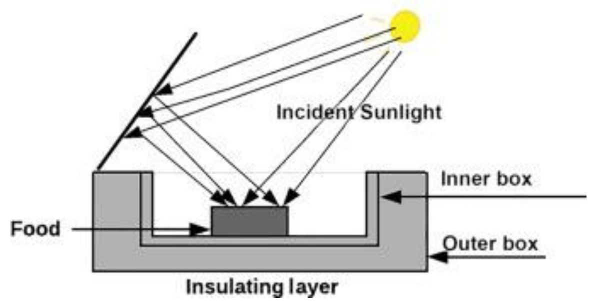


Figure 1 Schematic of solar cooker *(Sakthivadivel et al., 2021)*

The cooking time depends primarily on the equipment being used, the amount of sunlight at the time, and the quantity of food that needs to be cooked. Air temperature, wind, and latitude also affect performance.

However solar cookers have limitations which include;

- Solar cookers are less useful in cloudy weather and near the poles, where the sun is low in the sky, so an alternative cooking source is still required in these conditions.
- Some solar cookers, especially solar ovens, take longer to cook food than a conventional stove or oven.
- Some solar cooker designs are affected by strong winds, which can slow the cooking process, cool the food due to convective losses, and disturb the reflector.

1.5 Solar technologies;

Solar radiation is light – also known as electromagnetic radiation – that is emitted by the sun.

Solar technologies convert sunlight into electrical energy either through photovoltaic (PV) panels or through mirrors that concentrate solar radiation. This energy can be used to generate electricity or be stored in batteries or thermal storage.

Photovoltaic (PV) panels are used to produce electricity directly from sunlight. PV panels consist of a number of individual cells connected together to produce electricity of a desired voltage. Photovoltaic panels are inherently DC devices. To produce AC, they must be used together with an inverter.

Most PV cells are made from crystalline silicon. PV cells produce current in proportion to the solar radiation level (up to a certain voltage).

1.6 ISEC for cooking;

1.6.1 What is an ISEC?

An ISEC (insulated solar electric cooker) is a solar electric cooker uses electricity generated by solar panels to generate heat through resistive heating that retained and used for heating and cooking.

1.6.2 How does it work?

An ISEC consists of solar panels that harness power from the sun and produce electricity (current and voltage), the panels are then connected to a heating element.

A heating element converts electrical energy into heat through the process of resistive (otherwise known as Joule heating). The electric current passing through the element encounters resistance, which produces heat. The heating element is then responsible for heating and cooking the contents (food, water etc.) in the ISEC.

Typically, heating elements are made from a coil, ribbon or strip of wire that provides heat (like a lamp filament). Heating elements contain an electric current, which flows through the coil or ribbon or wire and becomes very hot. The element converts the electrical energy passing through it into heat, which spawns outward in every direction hence producing heat.

The heating element is attached to a pot or sauce pan that is responsible for heating the cooking pot and its contents. To reduce heat loss and improve cooking time, insulation is provided around, below and above the cooking pot.

The ISEC addresses most of the solar cooker limitations which include use during cloudy conditions by connection to a battery power source.

And the design enables indoor usage through placing or fixing solar panels outside on the roof and connecting wires to cooking point (ISEC) inside.

1.7 ASEI-ISEC collaboration;

Set out to inspire innovation in Africa through STEM, African STEM Education Initiative (ASEI) also strives through innovative projects to provide an opportunity through space, equipment, human capital, access to research and academia to the community, industry, public sector and development partners to innovate new or adopt existing technologies/models that respond to key issues in the agricultural value chain, renewable energy, tourism, water and environment which are key sectors in socioeconomic and environmental transformation of Uganda and the entirety of Africa.

ASEI's approach provides a clear linkage in Uganda between diverse background communities, industry, academia and researchers and as such cultivating a wealth of knowledge and skills and exposure that inspire job creation and a global workforce.

1.7.1 ASEI Sectors;

ASEI operations cut across different sectors in the ecosystem including;

- Energy sector;

ASEI aims to promote usage of alternative affordable energy sources especially solar and bioenergy which are extendable to marginalized communities and hence contribute to the achievement of SDG7 (Access to clean, reliable, sustainable and affordable energy for all).

- Environment;

ASEI aims to promote conservation of environmental resources through innovations and programs that are focused towards reducing pollution and over utilization of natural resources.

It is therefore from the above information that ASEI sought out to design, assemble and distribute the ISECS with a goal of disseminating them in the vast majority of the Rwenzori region (Western Uganda-Africa) and other parts of Uganda.

1.8 Food culture and dietary patterns in Uganda

Uganda grows several food crops, of which 16 are major according to the (UBOS, 2020). These include Maize, Millet, Sorghum, Rice, Cassava, Sweet potatoes, Irish potatoes, Beans, Cow peas, Field peas, Pigeon peas, Groundnuts, Soya beans, Simsim, Plantains and Coffee.

Diet in Uganda is primarily based around plant-based foods, and most of the energy in people's daily meals comes from plantains and starchy roots or tubers such as cassava and sweet potatoes and cereals including rice, maize, millet and sorghum.

According to a report by (CREEC, 2020) pulses and nuts intake is relatively high, while intake of meat, fish and poultry is limited but conventional.

Households in Central and Western Uganda heavily rely on matooke and sweet potatoes as their staple food while a wide variety of dry beans are produced predominantly in the Western and Northern regions and are cooked and served as a compliment ("sauce") to other staples.

Cooking practices and types of foods regularly consumed vary from one region to another depending on factors like climate and land cover as well as by ecological zone and ethnic group.

With more than 30 ethnic groups, Uganda does not have a single national dish that is universally eaten by all. However, matooke, a mashed green banana or plantain meal is popular among many households, especially in the central and southern part of the country. It is either boiled or steamed and then mashed and cooked in or served with a sauce of peanuts, beans, fresh fish or meat. Katogo is another dish like matooke, but the bananas are left whole and un-mashed.

A sauce is commonly made with groundnut flour, onions and tomatoes, leafy green vegetables, beans, and meat or fish. Beans or peas stew is also a common source of protein.

1.9 Food culture and dietary patterns in western region

Results from the UCA 2008/09 showed that the western region led in the production of all types of Bananas (2,883,648 tonnes) and Beans (411,945 tonnes).

	Plantain bananas	Finger millet	Maize	Sorghum	Rice	Sweet potatoes	Irish Potatoes	Cassava
Area Planted(hectares)								
Central	326,082	5,832	189,135	2,261	2,637	98,054	4,798	127,788
Eastern	69,504	86,911	388,762	101,645	36,033	159,948	1,271	342,387
Northern	9,195	105,656	247,780	249,330	25,912	60,573	594	269,886
Western	511,096	51,588	188,583	46,016	10,504	121,681	26,096	131,328
Production('tonnes)								
Central	1,039,837	13,734	449,859	2,678	2,173	312,402	13,290	409,812
Eastern	342,234	106,838	1,108,554	133,313	128,195	847,140	4,624	1,061,186
Northern	31,626	78,572	305,798	177,088	43,719	292,932	1,311	983,124
Western	2,883,648	77,784	497,745	62,716	16,649	366,295	135,210	440,189

Source: UBOS and MAAIF (Uganda Census of Agriculture)

Figure 2 Crop Area and Production by region, UCA (Uganda Census Agriculture)

Matooke is central to the western region diet and is abundant from mid-January until the end of June. Rice is not a traditional staple food in Uganda; however, it is becoming increasingly popular.
Green leafy dishes (dodo, cabbage, spinach) are generally considered affordable and accessible.

1.10 Cooking Ugandan popular dishes: techniques and processes

Most common and popular meals in Uganda are prepared by boiling and steaming, with steaming having a high cultural value attached to it.4

Steaming;

Steaming is a moist-heat method of cooking that works by boiling water which vaporizes into steam; it is the steam that carries heat to the food, cooking it. Unlike boiling food submerged in water, with steaming the food is kept separate from the boiling water but comes into direct contact with the hot steam. This involves wrapping foods in banana leaves, banana stalks are placed in a pan with water to a minimum level. The banana leaves with the food are then placed on top of the stalks. Dishes prepared with such methods include matooke, cassava, sweet potato, posho and luwombo.

Boiling;

Boiling is also a popular method of cooking. This mainly involves a cooking technique where water is added to food and cooked to boiling point. Some of the dishes that require boiling are matooke, potato, rice, cassava, and beans. Beans or peas and meat or fish stew are part of Ugandan's daily dish.

Stewing;

Stewing is a cooking method where every food is cooked together at the same time in one pot. The ingredients are placed in at different times as the sauce cooks and finally thickens. Hence, the process involves a mixture of techniques. For instance, preparing beans stew involves boiling of the beans, sautéing of basic ingredients (onions, tomato and green papers), and simmering of all ingredients including the boiled beans. No special utensils are required to prepare most of Ugandan dishes.

2.0 Methodology

2.1 Construction;

2.1.1 Determination of heating element;

A heating element is a material or device that directly converts electrical energy into heat or thermal energy through a principle known as Joule heating.

Joule heating is the phenomenon where a conductor generates heat due to the flow of electric current. As the electric current flows through the material, electrons or other charge carriers collide with the ions or atoms of the conductor creating friction at an atomic scale. This friction then manifests as heat. Joule‘s first law (Joule-Lenz law) is used to describe the amount of heat produced from the flow of electricity in a conductor. This is expressed as,

$$P = IV \text{ or } P = I^2R$$

From these equations, the amount of heat generated depends upon the current and the voltage or the conductor resistance. In the design of heating elements, the resistance is the more important factor.

Resistivity: To produce heat, the heating element must have enough electrical resistance. However, the resistance must not be so high that it becomes an insulator. Electrical resistance is equal to the resistivity multiplied by the length of the conductor divided by the conductor cross-section. For a given cross-section, to have a shorter conductor, a material with a high resistivity is used.

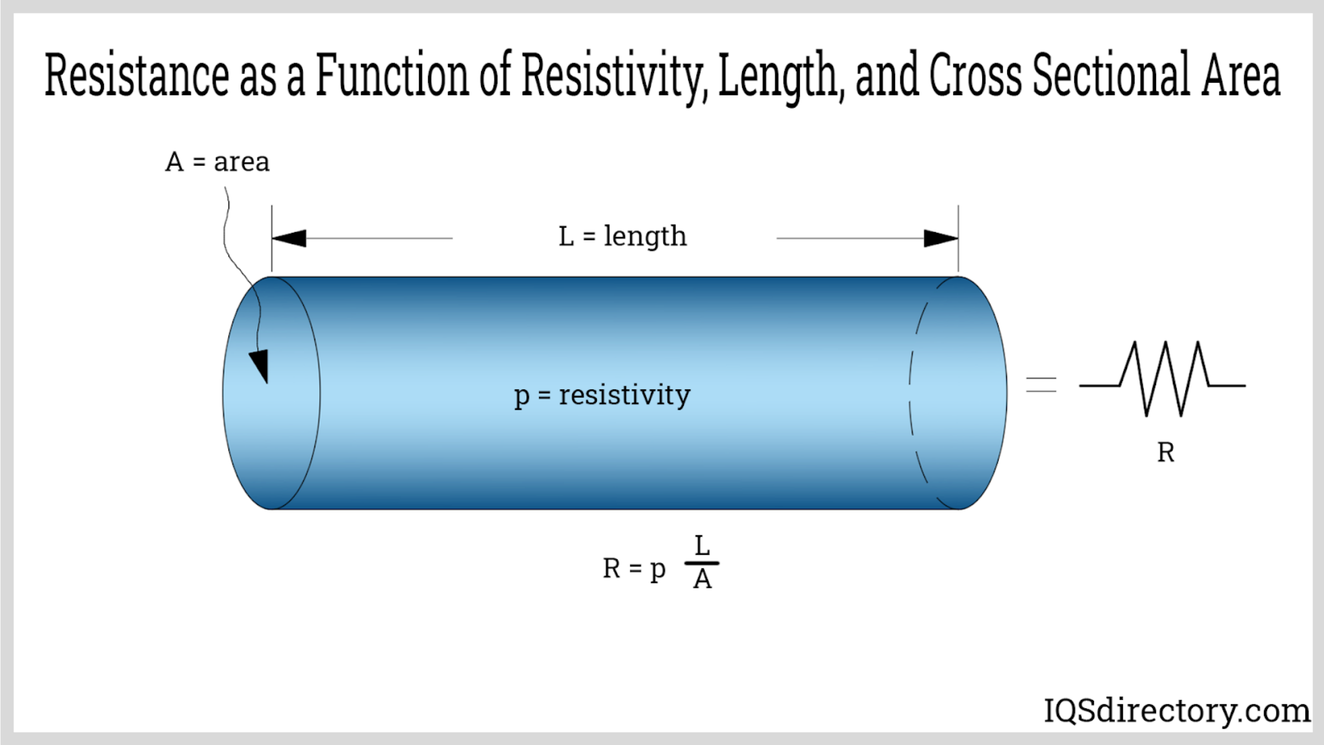


Figure 3 Resistivity calculation formula (IQSdirectory.com)

R = V/I, where R is resistance (in Ohms), V is voltage (in Volts), and I is current (in Amps).

2.1.2 Tubular Heaters;

Tubular heaters have lead terminals on the opposite ends of the tube. The whole tubular construction can be bent into different forms to suit the heat distribution required by the space or surface to be heated. Also, these heaters can feature fins that are mechanically bonded onto the sheath surface to aid in an effective heat transfer.

2.1.3 Pot material;

Thermal conductivity k - is the quantity of heat transmitted due to a unit temperature gradient, in unit time under steady conditions in a direction normal to a surface of the unit area.

Thermal conductivity indicates ability of a metal to conduct heat.

Material	Thermal Conductivity k (W/m K)
Aluminum	237
Steel - Stainless, Type 304	14.4
Steel - Stainless, Type 347	14.3

Table 1 Thermal conductivity of materials

The pot diameter and size to be used is determined basing on the family size which informs the quantity of food to be cooked.

2.1.4 Solar Panel Sizing;

Solar panel sizing is determined by amount of power (Wattage) required to heat the resistive heater element for effective cooking.

Various solar panel power sizes range from as low as 10W to as high as 400W and more.

P (power required)

$P = IV$ or $P = I^2R$

2.1.5 Wires;

The wire should have low resistivity to allow current flow to the resistive heater element. And ability to conduct current produced by the solar panels.

The required current usually determines the gauge required.

AWG	Dia mm	SWG	Dia mm	Max Amps	Ohms / 100 m
11	2.30	13	2.34	12	0.53
12	2.05	14	2.03	9.3	0.67
13	1.83	15	1.83	7.4	0.85
14	1.63	16	1.63	5.9	1.07
15	1.45	17	1.42	4.7	1.35
16	1.29	18	1.219	3.7	1.70
18	1.024	19	1.016	2.3	2.7
19	0.912	20	0.914	1.8	3.4
20	0.812	21	0.813	1.5	4.3
21	0.723	22	0.711	1.2	5.4
22	0.644	23	0.610	0.92	6.9
23	0.573	24	0.559	0.729	8.6
24	0.511	25	0.508	0.577	10.9
25	0.455	26	0.457	0.457	13.7
26	0.405	27	0.417	0.361	17.4
27	0.361	28	0.376	0.288	21.8
28	0.321	30	0.315	0.226	27.6
29	0.286	32	0.274	0.182	34.4
30	0.255	33	0.254	0.142	43.9
31	0.226	34	0.234	0.113	55.4
32	0.203	36	0.193	0.091	68.5
33	0.180	37	0.173	0.072	87.0
34	0.160	38	0.152	0.056	110.5
35	0.142	39	0.132	0.044	139.8

Figure 4 Copper wire gauge chart

2.1.6 Wire Insulation;

High heat temperatures of close to 400degrees celsius could burn the wires hence insulation should be able to with stand high temperatures without burning.

2.1.7 Insulation;

Insulation required is calculated basing on expected heating coil temperature and ability to resist fire below the temperature. Tubular heating elements can heat up to 800degrees celsius.

2.2 Foods;

The foods were determined using the information described in the introduction.

2.3 Research methodology

2.3.1 Data type and Source

The study used a primary source of data which data was collected using questionnaires that were administered by the researcher to the respondents.

2.3.2 Area of study

The study was carried out in four villages Booma, Kitumba, Njara, Mukubo in the west, central, west and southern divisions of Fort Portal city respectively in the Rwenzori region.

Fort Portal city is located approximately 296 kilometers (184 miles) by road, west of Kampala, Uganda's capital and largest city. The city lies between 0°39'16.0"N, 30°16'28.0"E (Latitude:0.654444; Longitude:30.274444) and is situated at an average elevation of 1,523 meters (4,997 ft) above sea level with an estimated population of 60,800 people (2020 UBOS).

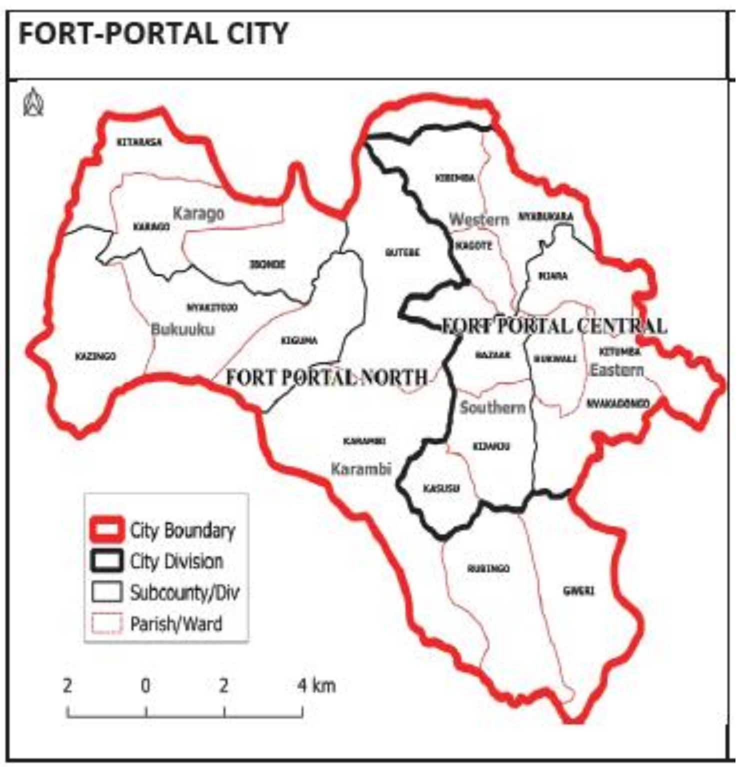


Figure 5 Map of Fort Portal city

2.3.3 Study Population

The main target group of the study was households. These households served as core primary targets because the study aimed at disseminating ISECs in homes and collecting feedback hence a sample was purposively selected.

2.3.4 Tools for measurement of variables

2.3.4.1 Measurement of cooking patterns

Cooking patterns were measured by interview of daily cooking frequency and mainly cooked foods.

2.3.4.2 Measurement of the energy usage

Data was collected using a questionnaire, a structured interview that provides detailed information on the amount and kind of foods cooked using the ISEC.

Data was collected using a questionnaire, a structured interview that provides information on the energy usage demand through grouping of cooking fuel sources in three categories of firewood, charcoal, gas and electricity plus asking most used fuel source.

2.3.4.3 Measurement of ISEC usage patterns

ISEC usage patterns were measured using a structured interview basing on weekly ISEC cooking usage and regular ISEC start cooking times. Further foods majorly cooked using the ISEC were selected according to the major Ugandan grown food crops which according to the (UBOS, 2020) include maize, millet, sorghum, rice, cassava, sweet potatoes, irish potatoes, beans, cow peas, field peas, pigeon peas, groundnuts, soya beans, simsim, plantains and coffee.

2.3.4.3 Data Analysis

Data from questionnaires was edited, collated, coded into themes and analyzed. Computer packages of SPSS (Statistical Package for Social Scientists) v.26 and Microsoft Excel v.2020 were used for data analysis.

3.0 RESULTS AND DISCUSSION

3.1 Results;

3.1.1 ISECs constructed;

The ISEC was constructed and unit material cost was 551,600Ugshs per ISEC which includes two 100W panels.

Figure 6 Completed ISEC units

3.1.2 Socio-demographics;

All the respondents that were purposively sampled were willing to participate in the study and that made a response rate of 100%.

The mean age group of respondents was between 30-39. From the total of 4 respondents, 50% were males and 50% were females of which 50% were single, 25% married and 25% widowed. All respondents resided in Fort portal city with 25% in the central (Kitumba), 25% in the southern (Mukubo),25% in the west (Booma), 25% in the west (Njara) divisions as shown in **Table 2.**

Table 2 Socio-demographic characteristics of respondents and household heads (n=4) in Fort Portal city

Socio-demographic Characteristics		**Frequency**	**Percentage (%)**
Gender of respondents			
	Male	2	50
	Female	2	50
Age of respondents			
	20-29	1	25
	30-39	2	50
	40-49	1	25
Marital Status			
	Single	2	50
	Married	1	25
	Widowed	1	25
Level of Education			
	Secondary	2	50
	Tertiary	2	50
Occupation of respondent			
	Administrative assistant	1	25
	Farmer	2	50
	Academic	1	25
Household Head			
	Yes	4	100
	No	0	0
District of respondent			
	Fort portal	4	100
Municipality of residence			
	Central Division	1	25
	Southern Division	1	25
	West Division	1	25

	West Division	1	25
Village of residence			
	Booma	1	25.0
	Kitumba	1	25.0
	Mukubo	1	25.0
	Njara	1	25.0
People in household			
	Mean (3.5)		
Transport means			
	Bicycle	3	75
	Car	1	25
Water source			
	National Water	2	25
	Tank Water	1	12.5
	Rain Water	3	37.5
	Borehole Water	2	25
Equipment owned			
	Smart Phone	4	50
	Television	2	25
	Radio	2	25

All the respondents were the heads of the household. A large proportion of household heads had at least secondary and others tertiary level of education at 50% and 50% respectively, those who had tertiary education were at least between 30-39 years of age.

Among the respondents 50% were engaged in farming while 25% (1 out 4) was an administrative assistant and the remaining 25% was in the academic (teaching field).

The average number of people living in the households was 3.5 per household.

75% of the household heads (3 out of 4) own a bicycle while only 25% (1 out of 4 respondents) own and use a car as their means of transport. 75% of the respondents use rain water, while 50% and 50% use borehole and national piped water respectively, only 25% store water in tanks for use. All respondents own smart phones while only half also reported to owning a television (50%) and radio (50%) as shown in table 2.

3.1.3 Dietary and cooking trend

3.1.3.1 Cooking frequency;

Figure 6 shows that 75% of the respondents cook more than 3 times daily while 25% cook only 2 times daily.

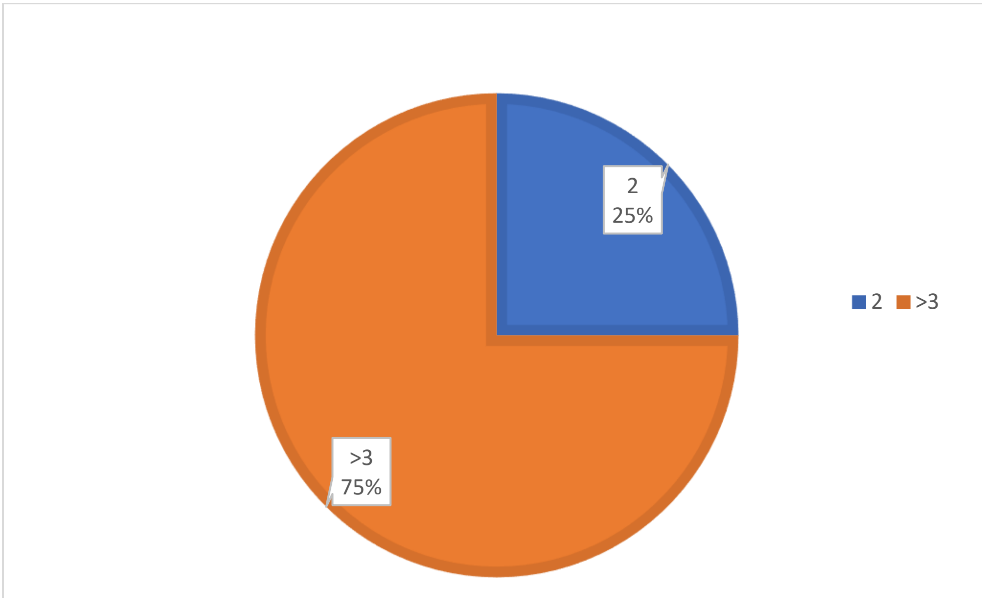


Figure 7 Daily cooking frequency in households

3.1.3.2 Foods mainly cooked in households

Figure 8 represents the patterns of food consumption in the different households. The data revealed that food with the highest levels of consumption according to percentage response preceding the survey was matooke (100%), Groundnuts (100%), Rice (75%), Vegetables (75%), Milk, Eggs, Sweet potatoes, Millet, Beans were 50%.

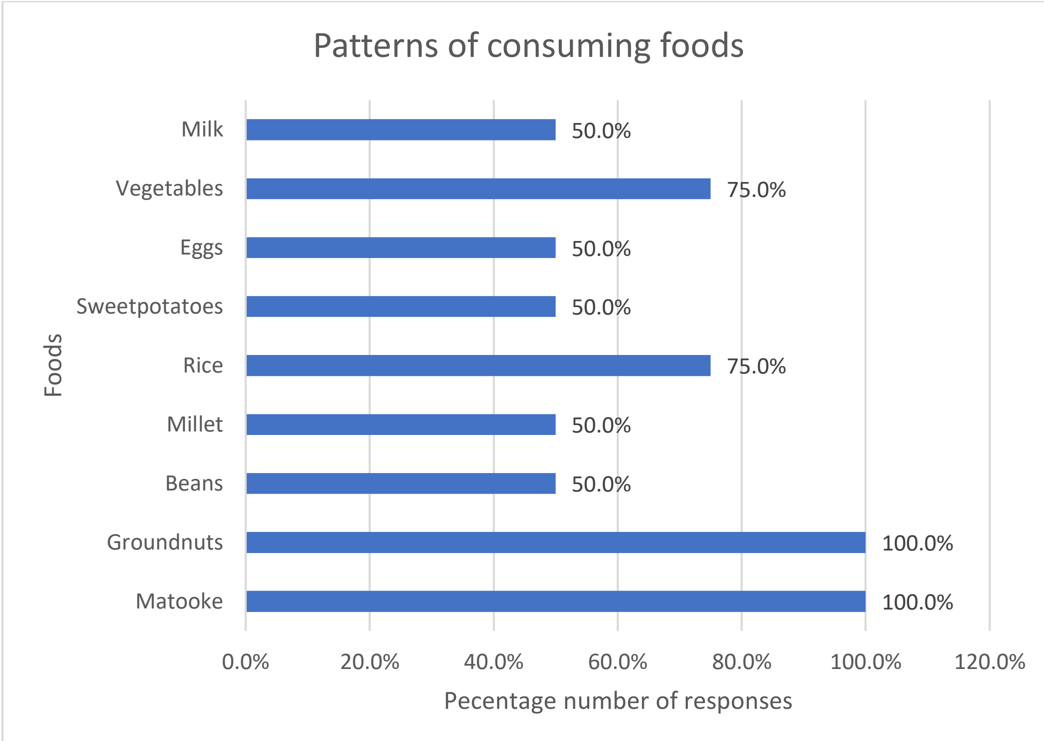


Figure 8 Patterns of consuming foods according to percentage responses

Figure 9 represents the percentage of foods according to preference with Matooke at 17%, Groundnuts at 17%, Vegetables at 13% and Rice at 13%.

The percentage preference of foods ranks Milk, Eggs, Sweet potatoes, Millet, Beans all at 8% as the lowest cooked foods in surveyed households.

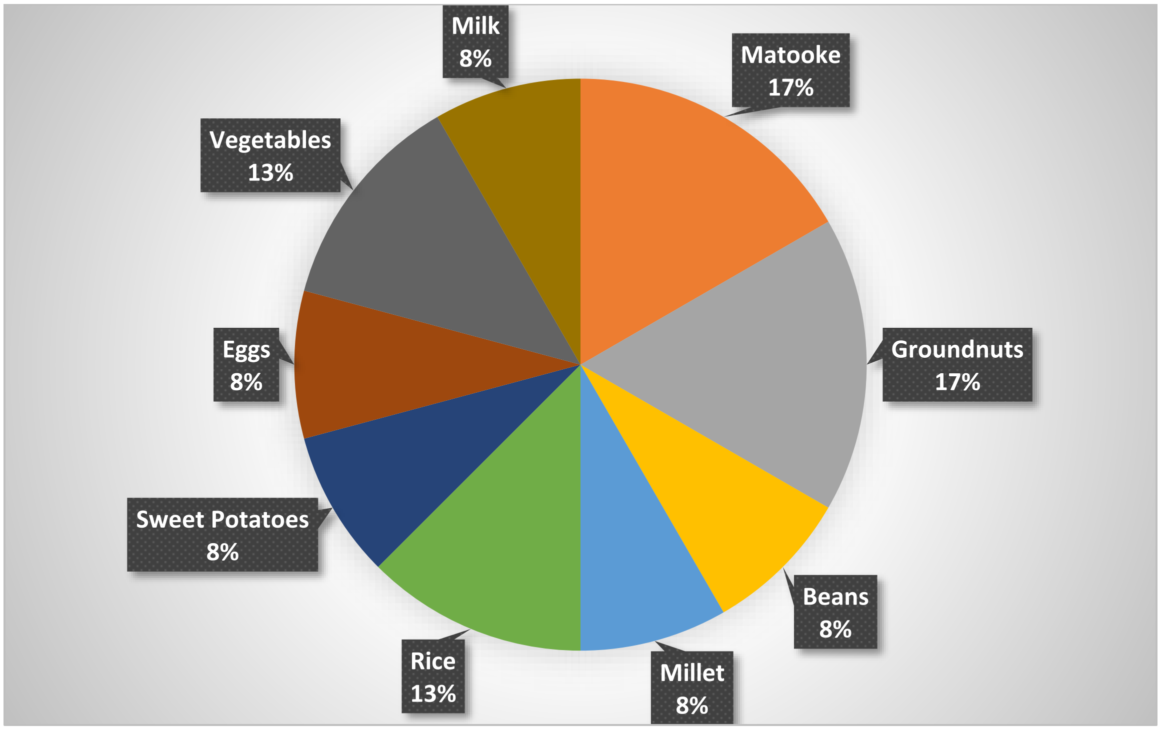


Figure 9 Percentage of foods according to preference

3.1.4 Energy demand

Figure 10 represents the fuel source used for cooking foods with charcoal being the most used and consumed at 57% to prepare food while firewood and charcoal are at 29% and 14% respectively. Charcoal is the most heavily used fuel source for cooking with 28%,48% more usage compared to firewood and gas respectively.

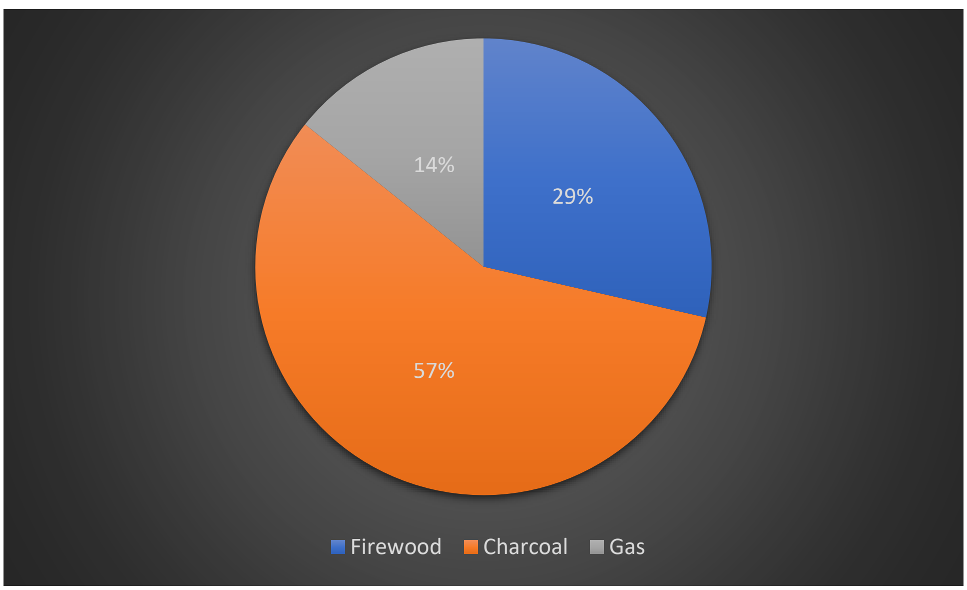


Figure 10 Cooking fuel source used in households

3.1.4.1 Most preferred fuel source

Most preferred fuel source is charcoal (50%) and firewood (50%).

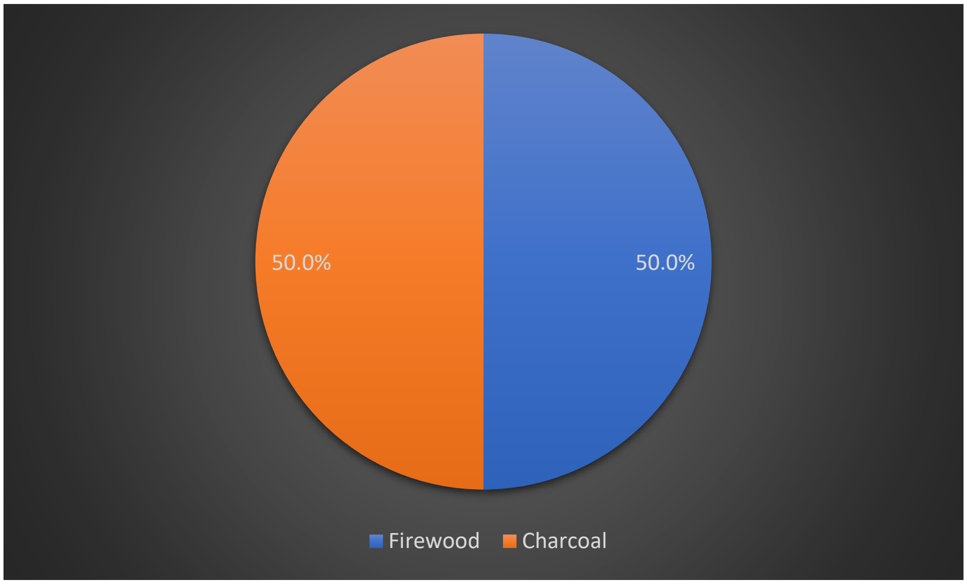


Figure 11 Fuel source according to preference

3.1.4.2 Solar energy;

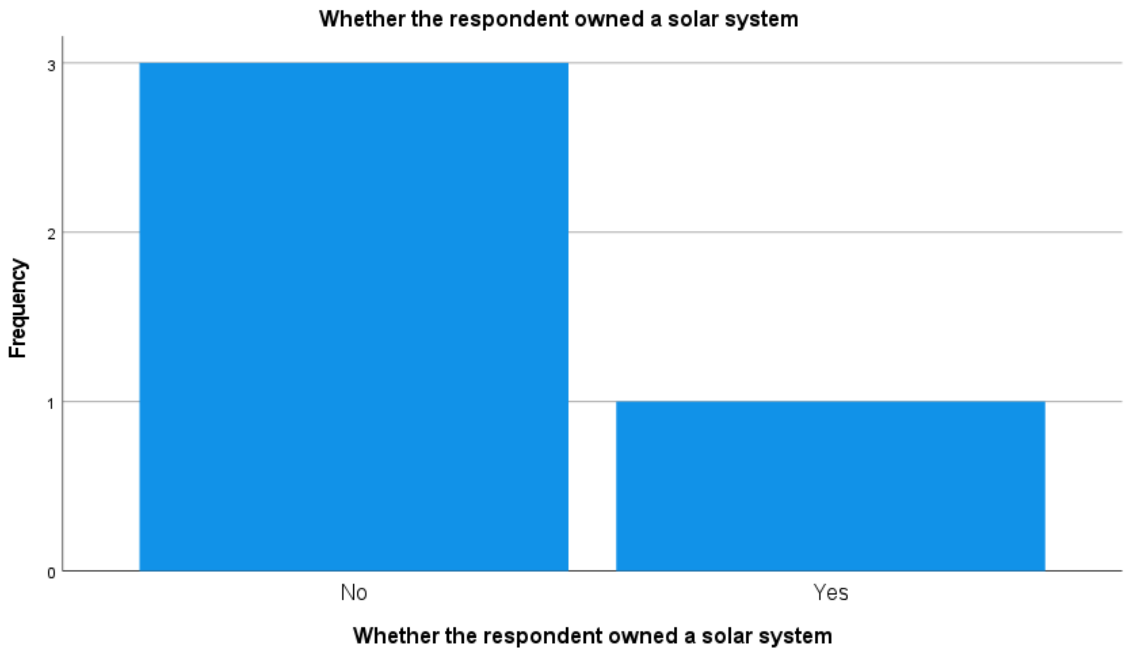


Figure 12 Solar System owned responses

Solar panel owned: 100W

3.1.4 ISEC USAGE

3.1.4.1 ISEC cooking patterns

Figure 13 shows that 50% of the users used the ISEC 3 times in a week, while 25% used it 4 times and 5times respectively.

The average ISEC cooking times was 3.75 times per week with a standard deviation at 0.95743

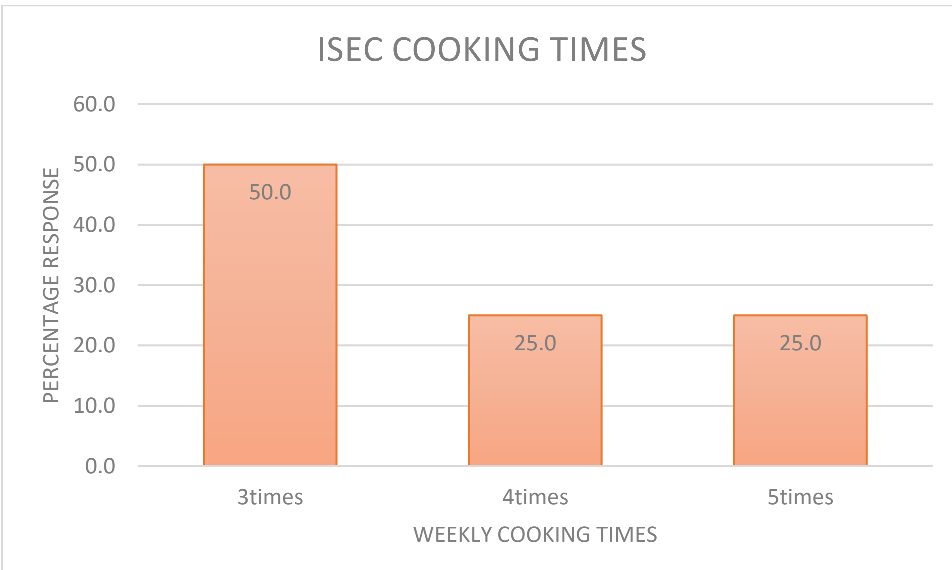


Figure 13 Times in a week cooking with the ISEC

3.1.4.2 ISEC cooking times

Fig 14 shows the time the households mostly begun using the ISECs with only 50% of the respondents using the ISEC between 12-1PM while 25% reported to use the ISEC between 8-9AM and 10-11AM (25%).

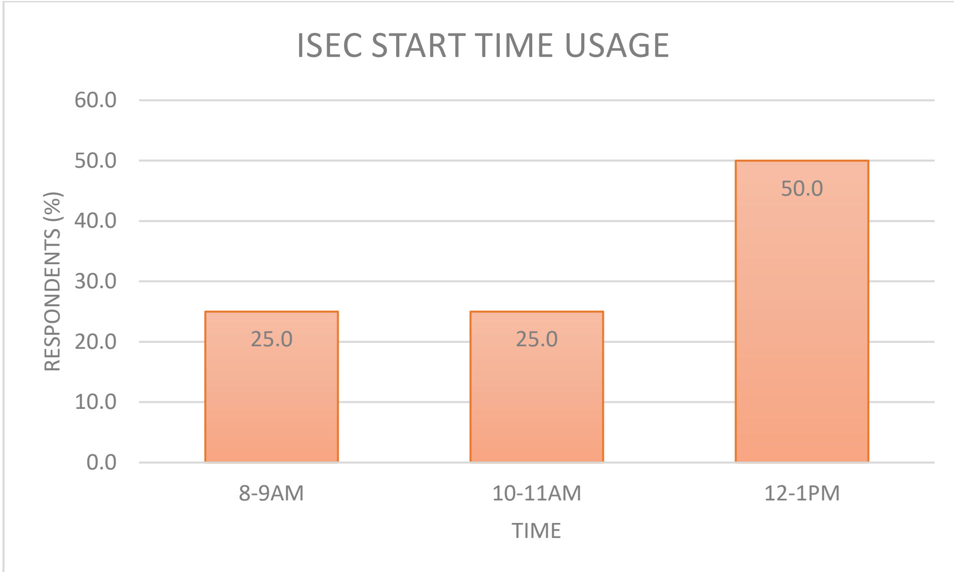


Figure 14 ISEC usage start times by households surveyed

3.1.4.3 Foods cooked with ISEC

A variety of foods were cooked using the ISEC ranging from cereals such as rice (100% of respondents), legumes and nuts such as beans (50% of respondents) and groundnuts (50%), vegetables (75%) such as dodo, eggs (50%), sweet potatoes (75%), matooke (100%) as shown in figure 15.

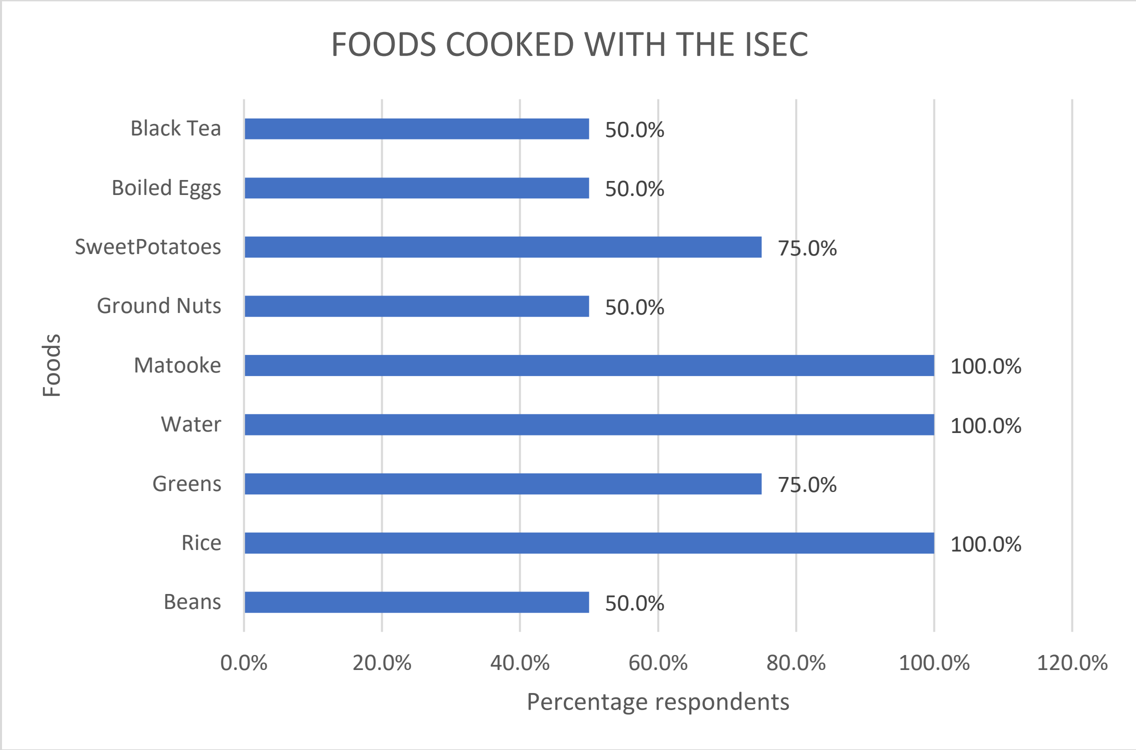


Figure 15 Different foods cooked using the ISEC and percentage of respondents who cooked the foods

3.1.4.4 FOODS PREFERED USING ISEC

The users mostly preferred cooking foods such as rice (100%), matooke (75%), sweet potatoes (75%) while 50% of the respondents also preferred cooking beans, boiled eggs, water, greens and only 25% indicated preferring groundnuts.

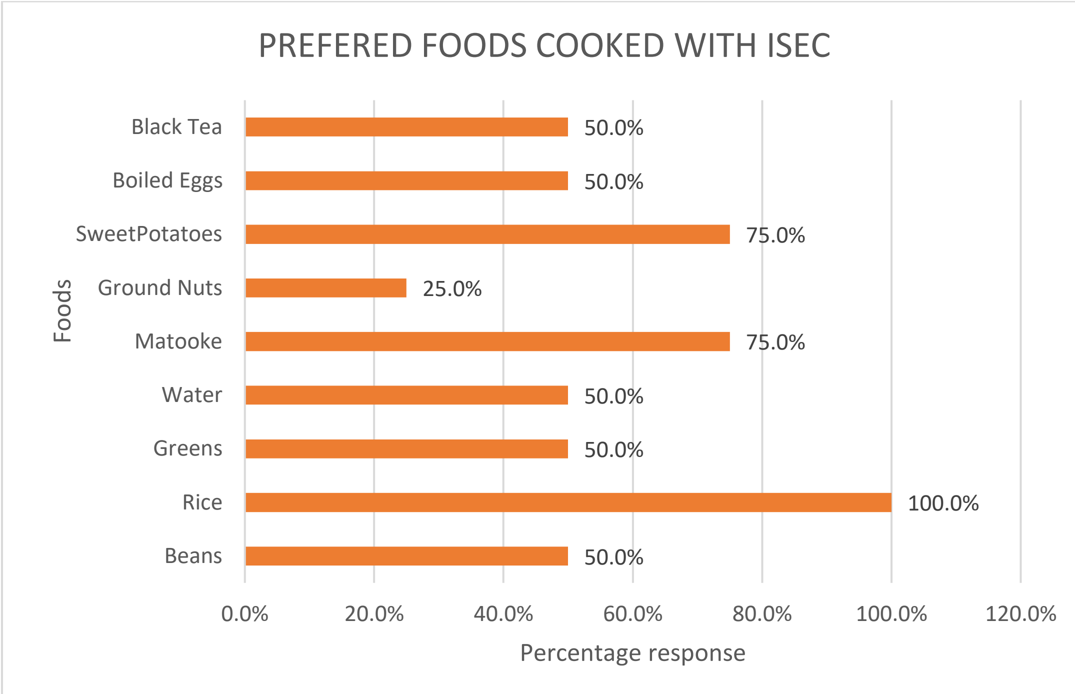


Figure 16 Percentage preference of cooking foods using the ISEC

3.1.4.5 Why did you prefer?

Table 3 Reasons for food cooking preference using ISEC

Reason	Responses (%)
Less Monitoring Needed	33.3%
Foods can be cooked with the available sun hours	22.2%
Its convenient to cook the foods with the ISEC	33.3%
Foods are high fuel consuming, rather use an ISEC that relies on free solar	11.1%
Total	100.0%

When asked why the respondents preferred cooking these foods using the ISEC, majority (75%) said it is because the ISEC required less monitoring during cooking and because of the convenience to cook the above foods with the ISEC while 50% mentioned foods are able to get ready within the available sun hours. 25% said it was also because the foods are high fuel consuming and they would rather use an ISEC that uses a free energy source.

3.1.4.6 Food Cooking times using the ISEC

Table 4 Food cooking times using the ISEC

	Rice	Beans	Greens	Water	Matooke	Groundnuts	Sweet potatoes	Eggs
N	**3**	**3**	**4**	**4**	**4**	**1**	**2**	**2**
Mean	**2.333**	**2.500**	**1.250**	**1.875**	**2.250**	**2.000**	**3.000**	**2.000**
Std. Deviation	**0.2887**	**1.8028**	**0.5000**	**0.6292**	**0.2887**		**0.0000**	

On average foods that took the longest time to cook include sweet potatoes which took the longest cooking time with a mean cook time of 3 hours using the ISEC, beans took 2.5 hours which was 30minutes less than sweet potatoes. Matooke took 2.25hours on average (SD ±0.2887), rice 2.333hours (SD ±0.2887), eggs 2hours, groundnuts 2hours. Foods that took the lowest time to cook include greens with an average cook time of 1.25hours (SD ±0.5), water 1.875hours (SD ±0.6292).

3.1.5 ISEC improvement required

All the respondents reported the ISEC needed possible improvements with most users 75% suggesting incorporation of a battery and adding a switch, 50% also suggested improving the outer appearance and addition of cooking pot handles to the cook pot.

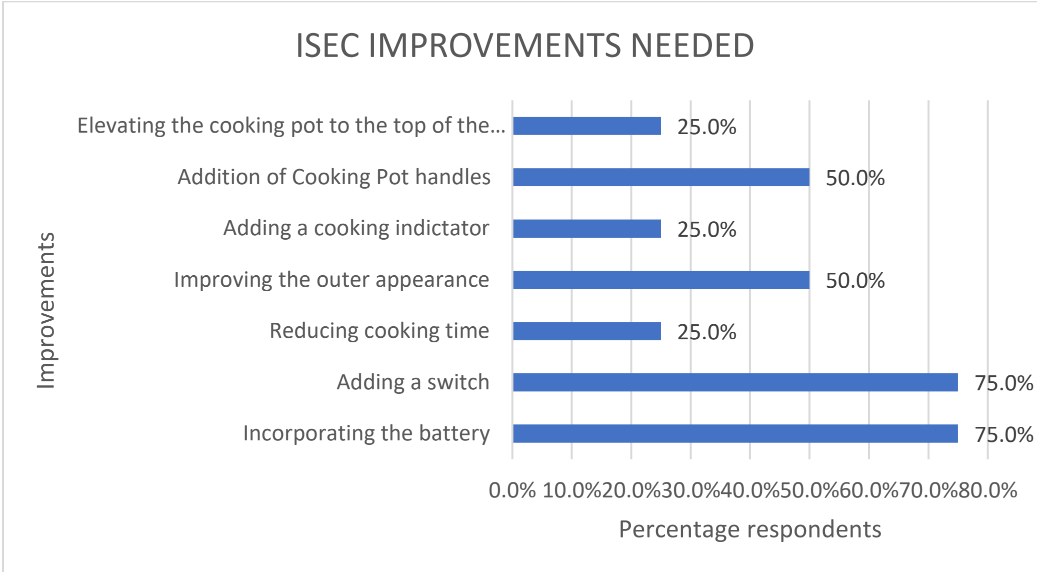


Figure 17 User ISEC suggested improvements needed

3.1.6 ISEC user perception

3.1.6.1 Usability

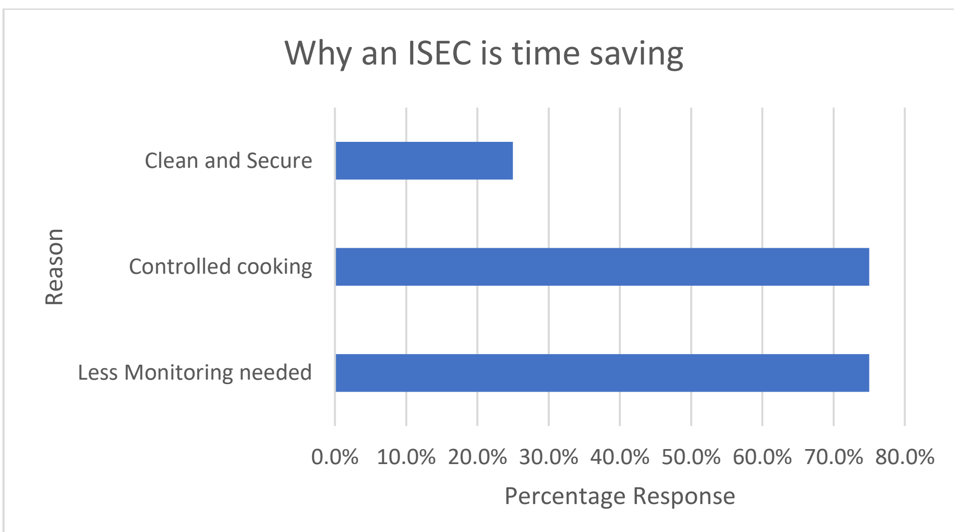


Figure 18 Responses to why an ISEC is considered time saving

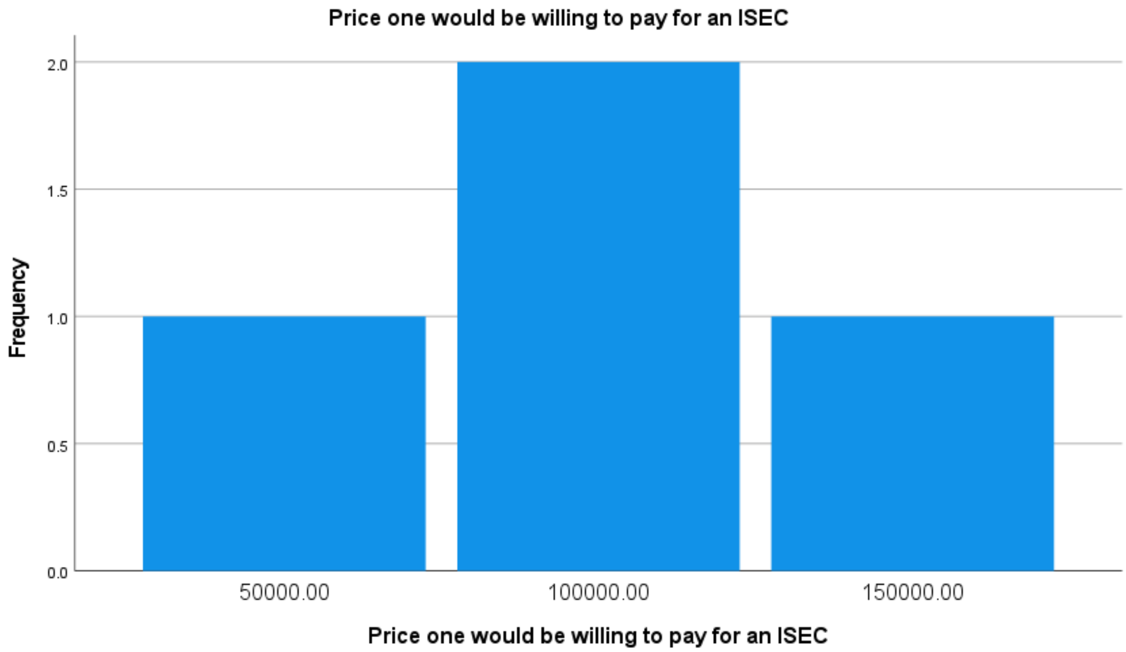
100% of the users agreed that an ISEC is easy to use by anyone in the household while 50% agreed that an ISEC is easy to clean after usage.

75% agree to rather use an ISEC for boiling than frying.

100%, 75%, 75% agreed that using an ISEC for cooking is being better than using a 3 stone stove, charcoal stove, mud stove respectively.

50%, 50% agree to using an ISEC for cooking being better than using gas and electricity respectively. While 100% agree to using an ISEC for cooking being cleaner than other biomass sources (firewood, charcoal etc.). 75% agree to using an ISEC for cooking as being cost saving.

3.1.6.2 Purchasing price



3.2 Discussion

3.2.1 Onsite ISEC and field ISEC comparison

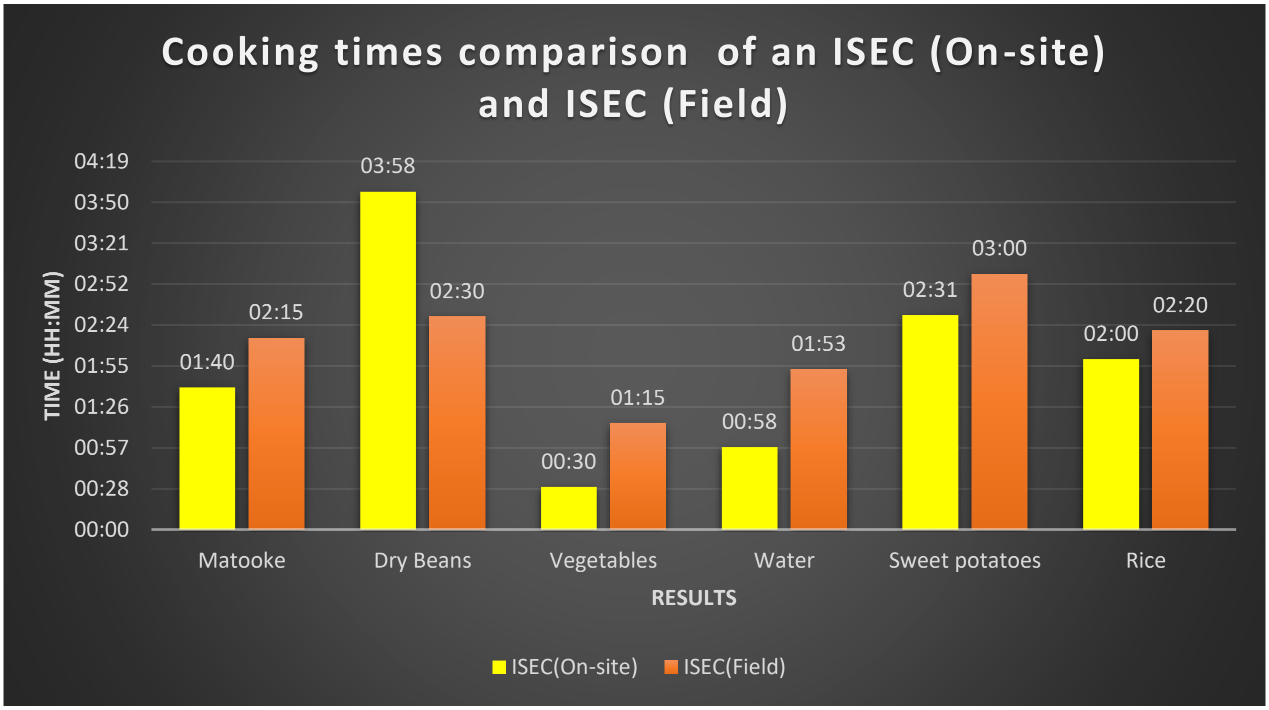


Figure 19 Cooking comparison of an On-site ISEC and an ISEC in the field

On-site ISEC tests were done at the ASEI premises under more controlled conditions with extra attention on proper usage practices such as covering during cooking and recording cooking times.

During both tests two 100W panels were used bringing the total wattage to 200W in a bid to optimize cooking time.

With these conditions the onsite ISEC cooking times for matooke was 35minutes less than the field ISEC times while vegetables took 45minutes less than the field ISEC to fry. Other food tests showed that cooking times of water, sweet potatoes, rice were 55, 29, 20 minutes less than the field ISEC cooking results.

One of the reasons for the on-site ISEC performing better than the field-ISEC can be attributed to extra attention paid to the usage instructions and good usage practices such as orienting the solar panels towards the sun and prevention of partial shading.

The field ISEC tests showed that beans took 1hour and 28minutes lesser time to cook compared to the onsite ISEC which was attributed to the fact that some of the ISEC users cooked using fresh beans while some cooked using presoaked beans and also added rock salt to improve cooking times, the on-site ISEC cooked dry beans and no addition of rock salt was used hence the great difference in cooking times.

3.2.2 ISEC cooking times

The onsite ISEC cooking times were used in comparison to a Controlled Cooking Test (CCT) by CREEC carried out to compare performance of different cooking fuels and devices. The CCT involved use of a local dish that was representative of domestic cooking practices.

3.2.2.1 Dish: Matooke

Matooke is a famous meal in the central and western regions of Uganda.

Cooking matooke using an ISEC took 1 hour and 40 minutes, this compared to a study done by (CREEC, 2020) is 3,15,13 minutes longer compared to using charcoal, LPG, hot plate respectively.

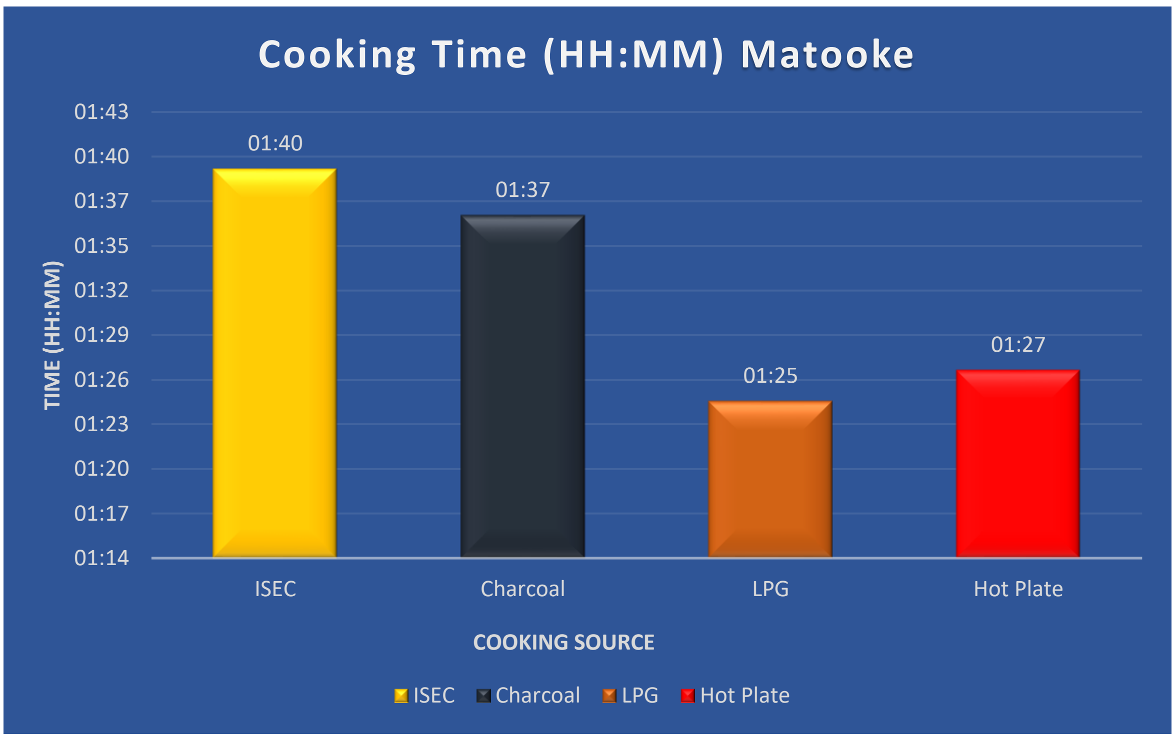


Figure 20 Cooking Time, Dish: Matooke

3.2.2.2 Dry Beans

With 200Watts, beans were cooked in 4hours which basing on (Andrea Meyers, 2020) is an average time for cooking beans.

However compared to a study by CREEC dry beans took 56minutes, 1hour 10minutes, 54 minutes longer to cook compared to using charcoal, LPG, Hot plate (CREEC, 2020).

NB: The beans cooked using the ISEC were not pre-soaked.

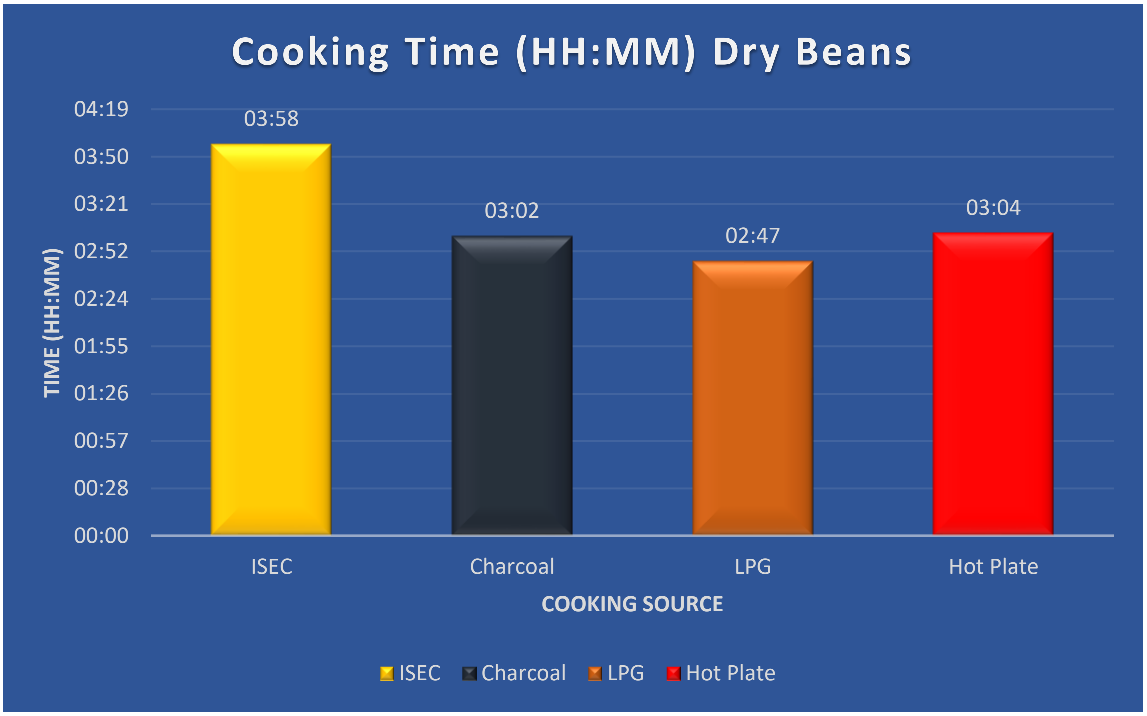


Figure 21 Cooking time, Food: Dry Beans

3.2.2.3 Vegetables

A comparison on leafy vegetables showed that the ISEC took 10,21,15 minutes longer to cook compared to using charcoal, LPG and a hot plate.

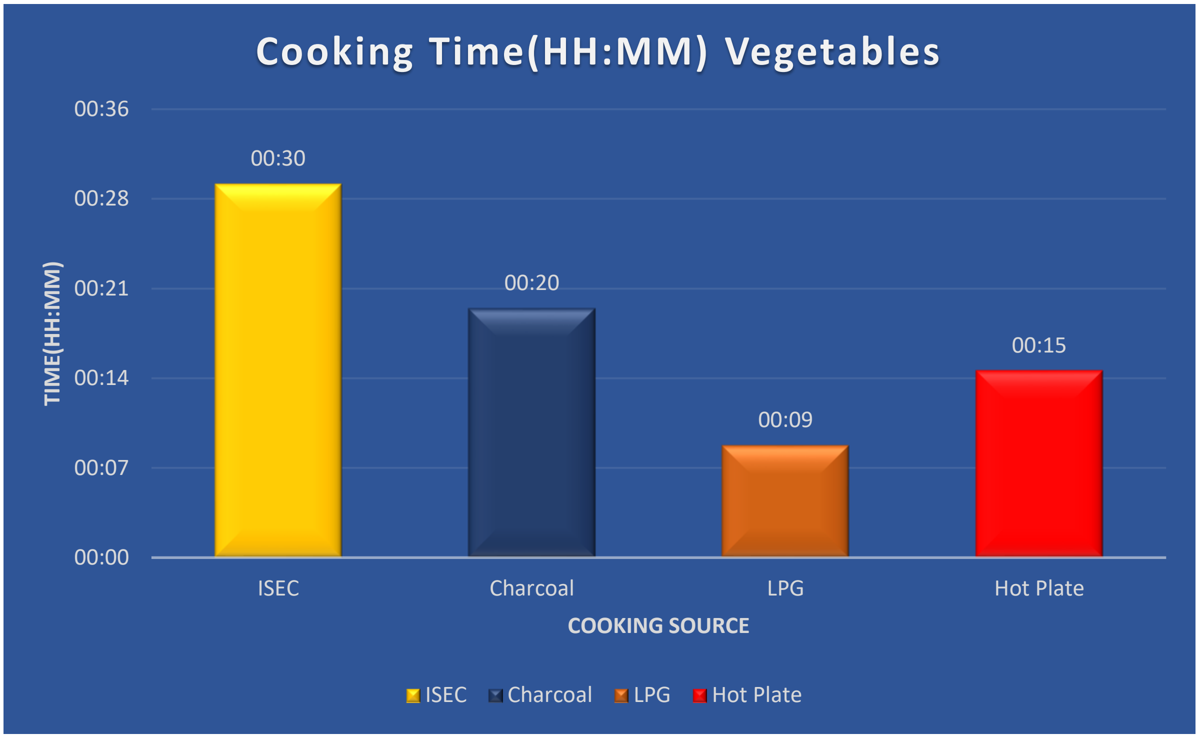


Figure 22 Cooking time, Food: Vegetables

The difference in cooking times of the ISEC compared to other cooking devices can be attributed to use of the direct cooking ISEC that does not use a battery source hence is affected by variations in insolation throughout the day which translates to power variations compared to constant power supply of other cooking devices.

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion;

A study done concluded that respondents expressed a high demand for Improved Cook Stoves (ICS) that could serve their needs and meet their preferences. Based on the data from this survey, most of the households are willing to adjust from the use of 3 stone fire stoves to ICS that can help in meeting the needs of the end user such as, good heat retention, minimal smoke production, ease of use as well as its ability to generate electricity alongside heat (Nsamba et al., 2021).

The solar electric cooker offers a better option given it fits all the above requirements in the study and despite the slightly longer cooking times compared to other methods of cooking, the ISEC uses a free energy source and as such offers more cost savings in the long run coupled with environmental benefits of no gas emissions. User feedback also shows good user acceptability with the survey showing that 100% of the users expressed interest in purchasing the ISEC.

4.2 Recommendations, progress and next steps;

Basing on the findings in the first stage of the ISEC implementation, the following recommendations will be considered in the next stages of the project including;

- Further prototyping and refining different ISEC designs to meet market satisfaction and meet all customer segments demands plus incorporating improvements from the customer findings.
- Further testing and experimentation of the ISECs to record findings and analyze possible areas of improvement which will play a big role in providing marketing data given evidence of product specifications and capabilities.
- Looking for price reduction models of the final ISEC price, this may include importation of materials or solar panels to bring the final cost down or low-cost material substitutions.

5.0 REFERENCES;

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APPENDIX

APPENDIX A; Foods cooked

Figure 23 Leafy Vegetable (Doodo)

Figure 24 Rice prepared by the ISEC

Figure 25 Beans being cooked by the ISEC

Figure 26 Beans cooked by the ISEC

Figure 27 Matooke prepared by the ISEC

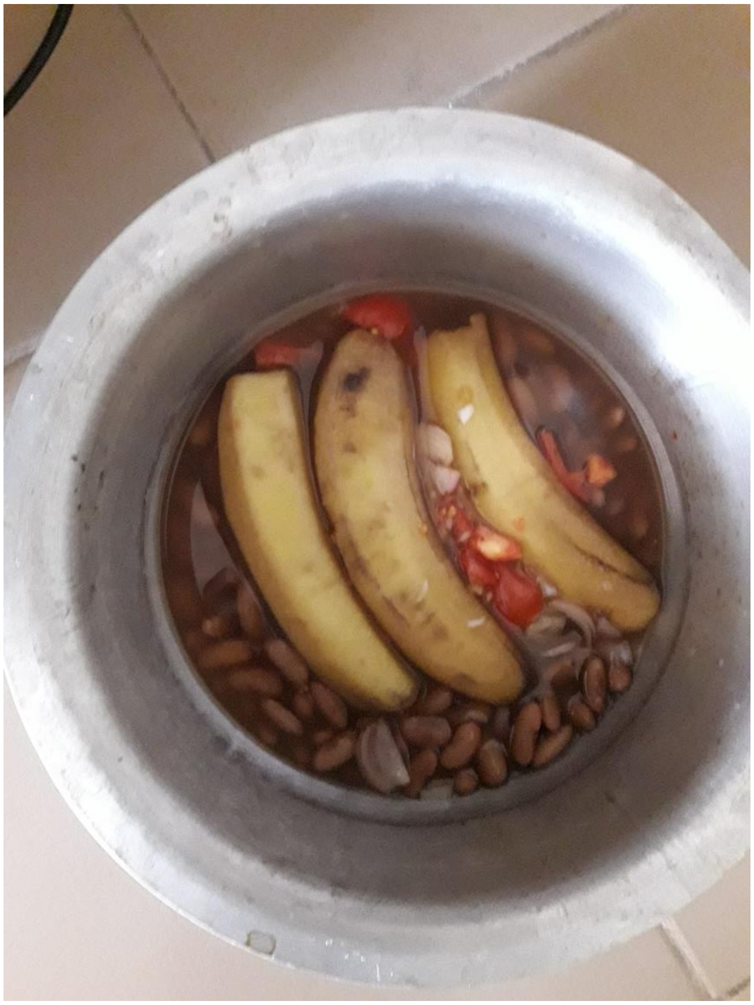

Figure 28 Local dish (katogo) prepared by the ISEC

Figure 29 Sweet potatoes prepared by the ISEC

APPENDIX B: Dissemination pictures

Figure 30 ISEC usage at one of the user's premises

Figure 31 Interested passer by examining the ISEC

Figure 32 Fresh beans meal preparation for cooking using the ISEC

Figure 33 Handover of ISEC to one of the household owners MR Paul (R)

Figure 34 Women in STEM, Head of Finance (L) handing over to MR Paul (R)

Figure 35 Demonstration of an ISEC to one of the households


Figure 36 Official handover of ISEC to one of the households


Figure 37 ISEC usage at one of the households