

Research Paper

COMPARATIVE STUDY OF ENERGY PERFORMANCE OF KEROSENE, ELECTRIC, WOOD AND CHARCOAL STOVES

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The “Comparative Analysis of Energy Performance of wood, kerosene, charcoal and electric stoves” was carried out. Water boiling test (WBT), controlled cooking test (CCT) and questionnaire methods were used. Thermal efficiency results showed 9.55%, 36.3%, 5.7%, 51% for wood, kerosene, charcoal and electric stoves respectively during the high power cold start phase and 14.6%, 38%, 14%, 58.3% for wood, kerosene, charcoal and electric stoves respectively during the high power hot start phase. The specific time results showed 56mins/kg, 55mins/kg, 82.5mins/kg, 80mins/kg, for wood, kerosene, charcoal and electric stoves respectively. The result for energy consumed showed 20.458 MJ, 2.155 MJ, 17.7 MJ, 1.924 MJ for the four stoves. The analysis of variance (ANOVA) at 5 % significant level showed that there was significant difference among the stoves in terms of temperature variation with time at cold and hot, starts. The results 197 questionnaire distributed reviewed that kerosene stove was mostly used with 40.70 %, most durable (49.75 %), most user friendly and with best fuel economy..

Keywords: Thermal efficiencies, Fire power, Specific consumption, Stove

INTRODUCTION

Energy is the capacity to do work such as powering automobiles and accomplishing many other tasks that are essential to human civilization. It occurs either as a result of the motion of the system (kinetic energy), the configuration of mass or changes in the system (potential energy) or the present of photons in the system (radiant energy).

Energy, like mass, is a scalar physical quantity. In the International System of Units (SI), energy is measured in joules, but in many fields other units, such as kilowatt-hours and kilocalories, are

customary. All of these units translate to units of work, which is always defined in terms of forces and the distances that the forces act through (Wikipedia, 2011).

Energy today, means the power or force derived or derivable from wood, coal, fuel oil, natural gas, electricity, hydro power, biomass, wind, ocean waves and the sun.

The vast majority of rural and even urban populace in Nigeria depends largely on fuel wood to meet most of their energy needs for cooking and heating. Trees are being indiscriminately cut down to meet the fuel wood demand with no

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systematic replenishment, until recently when serious desertification, desert encroachment and soil erosion were experienced in some parts of the country. With the rising demand for fuels and reduced supplies due to a number of limiting factors, there has to be more efficient use of available fuels, better management of natural resources, widespread substitution of alternative fuels (Stephen and Timothy, 1997).

Previous approaches done on stoves and afforestation include; Ballard - Tremeer and Jawurek, 1996), Studied the comparison of five rural wood - burning cooking devices. The cooking devices he compared were: an open fire built on the ground, an improved open fire built on a raised grate, a one - pot metal pot stove, a two - pot ceramic stove and a two metal stove. The study reviewed that average efficiencies were 14% for the open fire, 21% for the improved open fire, and (with no statistically significant difference) 20 to 24% for the stoves.

Victor *et al.*, (2007), undertook a study on energy performance of wood - burning cook stoves in Michoacán, Mexico. The work present an integrated energy evaluation of the patsari cook stove, an efficient wood - burning cook stove developed in Mexico that has recently obtained international recognition. The evaluation used standard protocols: The Water Boiling Test (WBT), The Controlled Cooking Test (CCT) and The Kitchen Performance Test (KPT). The results showed that WBT gave little indication of the overall performance of the stove. The patsari stove also showed reasonable CCT and KPT.

Erick *et al.*, (2000), also carried out a study on the fuel efficiency of a popular wood - burning stove, in comparison with the traditional open fire. The results indicate that the improved wood - burning stove consumed more fuel and take longer time than the open fire. Comparative studies on the performance of three solar cookers

under tropical conditions were also carried out by Bande in 2008.

Other approaches by energy researchers to bring about appreciable improvement in the performance of stoves (wood stoves) was the development of an iron framed wood burning stove in Zimbabwe in 1981. It cooked faster than the traditional fire place but consumed more fuel wood (Gill, 1983). Other undesirable features of the stove include; High heat loss through the iron frame, scattered smoke from the kitchen and danger of burn from hot iron frame surface.

The literature reviewed so far indicated that no work has been done by comparing the energy performance of kerosene, wood, electric charcoal and electric stoves, hence this research work presents a comparative analysis of energy performance of kerosene, charcoal, wood and electric stoves.

MATERIALS AND METHODS

Water Boiling Test (Cold Start and Hot Start)

In the cold start phase the test began with the stove at room temperature using a pre-weighed fuel (kerosene, charcoal, bundle of wood) to boil 2.5kg water. The mass of water was determined by placing a known mass of a pot on a measuring scale and adding water until the total mass of the pot plus water were 2.5kg greater than the known mass of the pot used.

The thermometer was then, placed in the pot containing water using a wooden fixture. A small hole was bored in the centre of the wooden fixture such that the thermometer fitted into it tightly leaving no space for water vapour to escape. Slots were also cut from the fixture to accommodate pot rim. The initial temperature of water was measured and recorded.

Then, fire was ignited in a reproducible manner according to local practices, and the timer reset

as soon as combustion started. The temperature of the water in the pot was recorded at regular intervals of 1 minute until the water was brought to a brisk boil, and the time in which the water in the pot reaches its predetermined local boiling point was measured and recorded. The unburned woods from the stove were removed and loosed charcoal were knocked from the end of the woods and kept aside for weighing.

The Hot start phase test was conducted at a duly measured recorded condition of ambient temperature and relative humidity. The procedure for high power cold start was repeated using a timer to record the temperature of the water in the pot at regular intervals of 1 minute until the water was brought to a brisk boil. Then the time at which the water in the pot reached its pre-determined local boiling point together with the temperature were measured and recorded.

Finally, the hot water was discarded and thermal efficiency, fire power and specific consumption were calculated using equations (Ballard-Tremeer and G Jawurek, 1996); (Erick B *et al.*, 2000); and (Gill J, 1983) respectively for kerosene and charcoal stoves; equations (1)–(7) (Komolafe C A and Awogbemi O, 2010); (Erick B *et al.*, 2000) and (Gill J, 1983) respectively for wood stove and equations (Micuta W, 1985); (Siyanbola W O, 2004) and (Thomas B J and Laurie L, 1993).

$$H = \frac{4.186W_w (T_f - T_i) + 2260W_v}{F_d \times LHV} \quad \dots(1)$$

Where:

W_w = the mass of water in the pot, the specific heat of water (4.186j/g°C).

$T_f - T_i$ = The change in water temperature.

W_v = the product of the amount of water evaporated from the pot.

F_d = the dry - wood equivalent consumed during each phase of the test.

LHV = the lower heating value (Victor *et al.*, 2007).

$$P = \frac{F_d \times LHV}{60(t_f - t_i)} \quad \dots(2)$$

Where:

$(t_f - t_i)$ = the duration of the specific test phase.

$$Sc = \frac{F_d}{W_{wf}} \quad \dots(3)$$

Where:

W_{wf} = the mass of water boiled.

$$P = \frac{c_p m \Delta T + h_{fg} M_{fg}}{M_f h_f - M_c h_c} \quad \dots(4)$$

Where:

C_p = the specific thermal capacity of water (Kj/KgK).

m = the average mass of water in the pot during the heating - up phase (Kg).

ΔT = the rise in water temperature for heating - up phase (K).

h_{fg} = the enthalpy of vaporization of water (Kj/Kg).

M_{fg} = the mass of water evaporated (kg).

M_f = the mass of fuel (wood) used during the test (kg).

h_f = the enthalpy of combustion (lower calorific value) of the fuel (kj/kg).

M_c = the mass of charcoal remaining at the end of the test (kg).

h_c = the enthalpy of combustion of the charcoal (kj/kg).

$$Q_c = P_r \times t \quad \dots(5)$$

Where:

P_r = Power rating of the stove,

t = Time spent in heating (sec).

$$= \frac{\text{sum of } Q_u \text{ for all pots}}{Q_a} \quad \dots(6)$$

$$Q_a = W \times C$$

Where:

Q_a = the heat generated by the wood (dry weight)

W = weight of the wood burnt during the trial

C = the calorific content of the wood estimated as 17.39kj/g

$$Q_u = (W_i - W_f) \times C_v + (T_f - T_i) \times W_f \times C_e \quad \dots(7)$$

Where:

Q_u = heat utilized (kJ)

W_i = initial weight of water (g)

W_f = final weight of water (g)

C_v = water vaporization heat (2.253kj/g)

T_f = final water temperature (degree Celsius)

T_i = initial water temperature (degree Celsius)

C_e = water specific heat (0.00418kj/g/degree Celsius)

Controlled Cooking Test

0.4kg of rice was measured and placed in a small standard pot. Sufficient quantity of water about 1.1kg was weighed and added to the rice in the pot. The mass of the pot plus its lid together with the rice and water was measured to be about 1.9kg. This was the same for wood, kerosene, charcoal and electric stoves.

3.6kg of fuel wood was measured and charged into the wood stove and the fire was lit using a little quantity of kerosene. The pot containing the rice plus the water was then placed on the stove and the timer was started. Similarly, the initial mass of kerosene stove plus kerosene was weighed to be 1.75kg. The fire was lit and the pot containing the rice plus water was placed on the stove and the timer started. A measured quantity of charcoal was also charged into the stove and the mass of stove plus fuel was measured and recorded as 4.1kg. The fire was

lit with a small quantity of kerosene. The pot containing water plus rice was placed on and the timer was started.

The timer was stopped when the rice was completely cooked and the time it took each stove to cook the rice was recorded. The cooked rice was confirmed by other cooks who knew how to cook and eat rice. The fires from the wood, charcoal and kerosene stoves were extinguished and the unburned fuels were measured while the power of the electric stove was just turned off. The final masses of pot plus cooked food were measured to calculate the mass of cooked food for kerosene, wood, charcoal and electric stoves. Finally, the specific consumption, specific time, energy consumed and cost of thermal energy were calculated respectively using equations (Stephen K and Timothy R, 1997); (Thomas, B J, Laurie L, 1993); (Victor M B et al., 2007) and (11) for kerosene, wood and charcoal stoves. Similarly, specific time was calculated using equation (11), energy consumed was calculated using equation (Micuta W, 1985) and cost of thermal energy was calculated using equation (11) for electric stove.

$$SC = \frac{Fd - [C_n \left[\frac{H_{ofw}}{H_{och}} \right]]}{1 \text{ kg (foodcooked)}} \quad \dots(8)$$

Where:

C_n = the amount of residual charcoal resulting from the combustion of fuel wood;

H_{ofw} = the enthalpy of fuel wood (20MJ/Kg); and

H_{och} = the enthalpy of charcoal (28MJ/Kg).

$$T_s = \frac{tc}{m_{uf}} \quad \dots(9)$$

Where:

t_c = cook time

m_{uf} = mass of uncooked food

$$E = F_d \times \text{LHV} \quad \dots(10)$$

Cost of thermal energy

$$C_t = \frac{P_f}{E} \quad \dots(11)$$

Where:

P_f = price of fuel

E = Energy consumed

The four stoves used for the comparative analysis are shown in Figures 1, 2, 3 and 4.

Plate 1: Kerosene Stove



Plate 2: Three Stone Stove



Plate 3: The Charcoal Stove



Plate 4: Electric Stove



Questionnaire Approach

About 197 questionnaires were distributed to some parts of Makurdi town. This was done in order to see the views of the general public on these stoves. The questionnaire covered other aspects of our analysis which were not captured in the water boiling test and controlled cooking test. These aspects include comparisons according to; durability of stoves, user friendliness of the stove, cost effectiveness of the stove. Other aspects of this questionnaire include comparisons according to; fuel economy, rate of cooking/heating, efficiency. The questionnaires were distributed to 4 major parts of the town namely; North Bank, High Level, Ankpa Quarters and Judges Quarters to three major categories of persons; business people, students and civil servants. The questionnaire was geared towards “hearing from the horse’s mouth” to know which stove(s) people use, their reason(s) for using it/them, challenges they face while using it/them, their reasons for not using the ones they do not use.

RESULTS AND DISCUSSION

Thermal Efficiency

The thermal efficiency results from Table 1 show that in the high power phase, the electric hot plate demonstrated the highest thermal efficiencies both in the cold and hot starts of 51% and 58.3% respectively, the kerosene stove showed the second highest efficiency with 36.3% and 38%

in cold and warm starts respectively, the wood stove showed the third highest efficiency with 9.55% and 14.6% in cold and warm starts respectively while charcoal showed the least efficiency in cold and hot starts respectively with 5.7% and 14%.

Though the charcoal stove demonstrated the least efficiency in the high power phase, it is the only stove that showed an increase in thermal efficiency in the simmer phase with 16.9% while kerosene stove showed a decrease to 26% and wood stove showed a decrease to 4.54%.

Although there was no WBT in the simmer phase for the hot plate because there was no provision to control the power but it is clear that electric stoves show the highest thermal efficiency among the four stoves.

The thermal efficiency determined by Thomas and Laurie (1993) for hot plate was 70%. This is not too far from the value obtained from this project work. Difference in the value could be as a result; different power rating of the stove, the voltage supplied to the stove and the amount of water use for the test.

Thermal efficiency for kerosene stove by Thomas and Laurie (1993) was 40%, thermal efficiency of kerosene stove by (Siyanbola *et al.*, 2004) was about 37%. This compares well with the value found in this analysis of about 36.3%, 38% for cold start and hot start respectively for kerosene stove. Thermal efficiency for charcoal stove by (Komolafe and Awogbemi, 2010) was about 11%. Thermal efficiency of three stone fire stove by (Victor *et al.*, 2007) was between (9.3%-16.7%) for cold start, (4.8% -23.2%) for hot start and (12.2%-25.8%) for simmer phase. (Ballard and Jawurek, 1996), also determined the efficiency of open fire stove to be about 14%.

The differences in values for charcoal, kerosene, wood stove could be as a result of differences in calorific values used, because the calorific values of fuels fall within a range, differences in

simmer time (30 or 40mins), difference in quantity of water that was used, difference in ambient conditions of wind, temperature, relative humidity, etc. another factor that can affect the difference in values for wood stove is the percentage moisture content used and amount of charcoal recovered. For example, (Victor *et al.*, 2007) assumed zero percent moisture content while an assumed moisture content of about 6.5% was used in this analysis.

Fire Power

The fire power results from Table 1 indicate that charcoal produced the highest fire power than wood and kerosene stoves in all 3 phase with 9.46kw, 9.83kw and 4.92kw for cold start, hot start and simmer phases respectively. Wood stove produced the second highest fire power with 7.97kw, 5.9kw and 4.86 for cold start, hot start and simmer phases respectively. Electric stove has an inbuilt fire power of 1kw. The results for fire power as determined by (Victor *et al.*, 2007) was between (8.6kw- 9.8kw), (5.6kw- 8.6kw), (3.1kw- 4.7kw) for cold start, hot start and simmer phases respectively for three stone fire stove. The results as obtained from the hot start and simmer phases fall within the range determined by (Victor *et al.*, 2007) while that from the cold start phase falls below the range. This implies that the value from the cold start of about 7.97kw is better than that determined by (Victor *et al.*, 2007) because the smaller the value of fire power, the better the stove. However, there were no fire power results for kerosene, charcoal and electric stoves.

Specific Time

The results for specific time from Table 2 for CCT indicate that kerosene stove cooks fastest with a specific time of 55mins/kg followed by wood stove has the third highest specific time of about 80mins/kg while charcoal stove showed the least specific time of about 82.5mins/kg. Specific time as determined by (Komolafe and Awogbemi,

Table 1: Water Boiling Test Results of Kerosene, Wood, Electric and Charcoal Stoves

	Thermal efficiency %	specific fuel consumption (Kg/Kg)	fire power (KW)
High power phase cold start			
Kerosene	36.3	0.02	2.245
Wood	9.55	0.178	7.97
Charcoal	5.7	0.204	9.46
Electric	51	-	1
High power phase warm start			
Kerosene	38	0.02	2.76
Wood	14.6	0.109	5.94
Charcoal	14	0.082	9.83
Electric	58.3	-	1

2010), for cooking rice using charcoal stove was about 260mins/kg. This shows that the value of 82.5mins/kg obtained is better than that of (Komolafe and Awogbemi, 2010), because the lesser the specific time, the better the stove. The differences in result could be as result of ambient conditions of wind, temperature, relative humidity, etc. Other factors that can affect the difference in result include; the type of charcoal stove used, the amount of rice cooked and the cook's ability to cook rice and know when it is fully cooked. There was however no known specific time results from previous research on wood, kerosene and electric stoves.

Energy Consumed

The energy consumed by the four stoves from the controlled cooking test result as shown in Table 2 show that about 20.458MJ, 2.155MJ, 17.7MJ and 1.924MJ of energy were consumed by wood, kerosene, charcoal and electric stoves respectively. The results for energy consumed imply that wood stove consumed the highest energy of about 20.458MJ while electric stove consumed the least energy of about 1.924MJ.

The energy consumed by (three stone fire) stove as determined by (Victor *et al.*, 2007) was

between (21.78MJ- 37.94MJ). The value obtained of about 20.458MJ for wood stove is close to Victor *et al.*'s value of 21.78MJ and is better because the lower the energy consumed, the better the stove. There was however no concrete results for energy consumed determined for kerosene, charcoal and electric stoves.

Cost of Thermal Energy

The results show the following cost of thermal energies from Table 2:

- 1.08/MJ for wood stove
- 2.32/MJ for kerosene stove
- 1.06/MJ for charcoal stove and
- 4.16/MJ for electric stove. This implies that charcoal stove has the cheapest cost of thermal energy while electric stove has the most expensive cost of thermal energy. This also shows that about 74.04%, 44.23%, 74.52% savings were made from wood, kerosene and charcoal stoves respectively when to electric stove which has the highest cost of thermal energy of about 4.16/MJ.

Specific Consumption

The results for specific consumption from Table 2 for CCT show that wood stove has the highest specific consumption of about 0.573kg/kg followed by charcoal stove with about 0.5kg/kg and kerosene having the least specific consumption of about 0.042kg/kg. The value obtained by (Victor *et al.*, 2007) for three stone fire stove was within the range of about (1.09kg/kg- 1.89kg/kg). This implies that the value of 0.573kg/kg for three stone fire stove in this analysis is better because the lower the specific consumption, the better the stove. The values obtained by (Thomas and Laurie, 1993) were 1kg/kg, 2.3kg/kg, 0.55kg/kg for kerosene, charcoal and electric hot plate stoves respectively. This also implies that the values obtained from this analysis are better because the lower the specific

consumption, the better the stove.

The specific consumption results from WBT as shown in Table 1 also confirms that wood had the highest specific consumption 0.178kg/kg, 0.109kg/kg and 0.327kg/kg for cold start, hot start and simmer phases respectively while kerosene have the least specific consumption of 0.02kg/kg, 0.02kg/kg and 0.05kg/kg respectively for cold start, hot start and simmer phase. Though charcoal stove showed a higher specific consumption in the cold start than wood stove with a value of about 0.204kg/kg but lesser values of 0.082kg/kg and 0.31kg/kg in the hot start and simmer phase respectively. The results for specific consumption for three stone fire stove as determined by (Victor *et al.*, 2007) were 0.19kg/kg, 0.13kg/kg, and 0.29kg/kg. This means the values obtained in this analysis are very close to the values and therefore compare well to those obtained by (Victor *et al.*, 2007).

Stoves	Specific Consumption (Kg/Kg)	Specific Time (Mins/Kg)	Energy Consumed (MJ)	Cost of Thermal Energy (/MJ)
Kerosene	0.042	55	2.155	2.32
Wood	0.573	56	20.458	1.08
Charcoal	0.5	82.5	17.7	1.06
Electric	-	80	1.924	4.16

Variation of Temperature with Time

The graph of cold start variation of Temperature with time from Figure 1 shows that kerosene is the fastest stove for boiling water of 2.5kg within an interval of 16minutes; wood stove is the second fastest boiler of water with 17minutes. Charcoal is the third faster stove with about 26minutes while electric stove boils with the slowest time of about 27minutes. This implies that kerosene stove is most suitable to boil water when the stoves are still cold while electric stove is not suitable for this condition. The summary of the

analysis of variance for the temperature with time in Table 3 showed a significant difference in terms of temperature variation with time at 5% significant level for four stoves at cold start.

The graph of hot start variation of Temperature with time from Figure 2 shows that charcoal stove is the fastest stove for boiling water with about 10minutes for 2.5kg of water, kerosene stove is the second fastest boiler of water with about 13minutes, wood stove is the third fastest boiler of water with about 14minutes while electric stove again boils with the slowest time of about 23minutes. Also, the summary of the analysis of variance for the temperature with time in Table 4 showed a significant difference in terms of temperature variation with time at 5% significant level for four stoves at hot start.

This implies that when the stoves are warm, charcoal stove is most suitable to boil water while electric stove is still not suitable.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	7151.838	3	2383.946	8.102834	0.000118	2.748191
Within Groups	18829.53	64	294.2114			
Total	25981.37	67				
Ho: F ≤ Fcrit					á = 0.05	
Ho: F > Fcrit						

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4940.305	3	1646.768	3.566381	0.018829	2.748191
Within Groups	29551.85	64	461.7477			
Total	34492.16	67				
Ho: F ≤ Fcrit					á = 0.05	
Ho: F > Fcrit						

Questionnaire

The questionnaire results from Table 5 show that 46.70%, 43.52%, 10.15%, 8.63% out of 197 questionnaires distributed across 4 parts of Makurdi, use kerosene, wood, charcoal and electric stoves respectively.

The result show that wood fuel is the cheapest, next to wood fuel is kerosene fuel and then charcoal fuel and electricity is the most expensive. The result in terms of efficiency shows that kerosene is the most efficient. Next to kerosene is wood fuel while charcoal and electric to have the least efficiencies.

The result show that kerosene stove cooks and boils faster than all the other stoves, next to kerosene is electric stove, followed by wood and charcoal stove respectively.

The results prove that kerosene has the greatest fuel economy with wood fuel having the second highest fuel economy and charcoal having the least fuel economy.

Kerosene stove is the most durable, with wood stove as the second most durable, charcoal stove is the third most durable stove and electric stove is the least durable of all the stoves, the most user friendly stove is kerosene followed by charcoal, wood and electric stove respectively.

Figure 1: Graph of Cold Start Variation of Temperature with Time

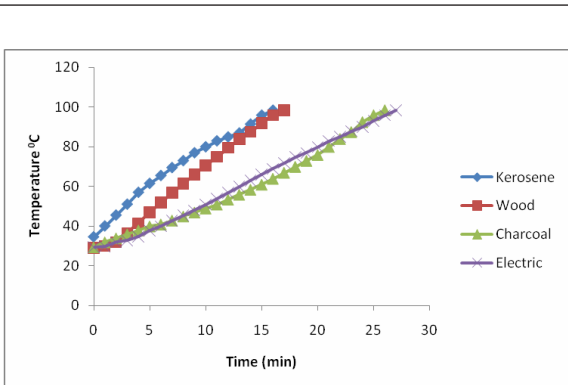


Figure 2: Graph of Hot Start Variation of Temperature with Time

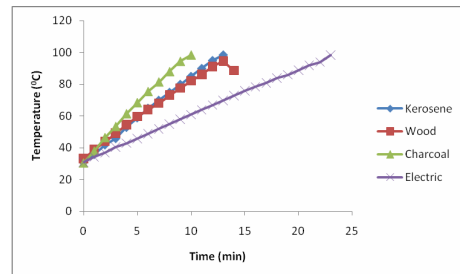


Table 5: Questionnaire Results Obtained from 72 Students

	Kerosene (%)	Wood (%)	Charcoal (%)	Electric (%)
Mostly used	66.67	16.67	9.72	6.94
Cost of effectiveness	33.33	11.11	9.72	5.56
Efficiency	43.06	1.39	-	-
Faster cooking/heating	13.89	4.17	1.39	5.56
Fuel economy	36.11	19.44	27.78	15.28
Stove durability	59.72	11.11	15.28	12.50
User friendliness	44.44	12.50	25.00	15.28
Using all-	16.67%			

CONCLUSION

From the results of the study, the following conclusion can be drawn.

- i. The results of the thermal efficiency from Water boiling test indicates that electric stove is the most efficient of all the stoves while wood stove showed the least average efficiency. The results also showed that charcoal stove performs more efficiently when hot.
- ii. The fire power results from Water boiling test showed that charcoal stove produced the highest fire power while electric stove produced the least fire power.
- iii. The specific consumption results for both Water boiling test and Controlled cooking test showed that kerosene consumes the least

fuel when compared to charcoal and wood stoves while wood consumes the most fuel.

- iv. The results for specific time for Controlled cooking test show that kerosene stove cooks fastest as compared to charcoal, electric and wood stove, while charcoal stove cooks slowest.
- v. The graph of variation of temperature with time for hot start shows that charcoal stove boils fastest when hot while the graph of variation of temperature with time for cold start shows that kerosene boils fastest when the stoves are cold. The graphs also show that electric stove is not suitable for boiling because it is too slow.
- vi. The cost of thermal energy results from Controlled cooking test showed that charcoal has the cheapest cost of thermal energy with savings of up to 74.52% when compared to electric stove which has the most expensive cost of thermal energy of about 4.16/MJ.
- vii. The Controlled cooking test results also showed that wood stove consumes the highest energy of about 20.458MJ while electric stove consumes the least energy of about 1.924MJ.
- viii. The results from the questionnaire imply that kerosene stove is mostly used. This is because it is the most efficient of all four stoves; it has the fastest cooking/heating rate, has the best fuel economy, is the most durable and is the most user friendly and least hazardous of all the stoves.
- ix. The questionnaire results also imply that wood stove is the second mostly used stove mainly because it is cheap.

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