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### RESEARCH ARTICLE

#### EXPERIMENTAL STUDY OF THE ENERGY PERFORMANCE OF NANSU STOVE WITH A MODIFIED GRID BY THE CONTROLLED COOKING TEST

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#### Abstract

The present work concerns the modification of the grid of the Nansu stove, used in many households in Africa and in particular in Benin. The performance of the stove obtained (modified Nansu) was estimated and compared on the one hand with that of the corresponding reference stove and on the other hand with that of the ordinary Nansu stove. To do this, the Controlled Cooking Test (CCT) was used to determine the specific fuel consumption and cooking time for three dishes, namely rice, beans and voandzou. The results of these tests show that the modified Nansu fireplace is significantly more economical, in terms of fuel consumption and cooking time, compared to the ordinary Nansu fireplace. The savings made by the modified Nansu stove compared to the ordinary Nansu stove are 34.57% to 64.31% in specific consumption and 9.42% to 37.81% in cooking time depending on the type of dish.

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#### Introduction:-

Energy and environmental problems have been of great concern to leaders around the world since the 1980. This is how development programs and projects have been designed in this direction. One of the areas that influence this duo (Energy and Environment) is that of cooking. Some 2.5 billion inhabitants of the planet use traditional biomass, mainly firewood, to cook their food. The global charcoal consumption scenario reveals a significant increase in charcoal in all regions up to 2025. For Africa, levels and trends in charcoal consumption are highest in the tropical sub-regions: eastern Sahelian, humid western, southern tropical and Central African [1]. The use of wood or charcoal stoves is widely transmitted in these countries. Indeed, the majority of the population, with a modest monthly income, uses even more firewood, charcoal and agricultural residues to satisfy their energy needs for cooking fuel. Wood energy is mainly used for cooking food in households where any alternative energy is inaccessible so expensive.

This high consumption of wood energy leads to the gradual degradation of forest resources. The pursuit, at the current rate, of the destruction of the vegetal covered of tropical forests by agriculture, the search for firewood and charcoal in the countries of sub-Saharan Africa, with a speed calculated at 0.7 % (of the deforestation rate), can lead to a dead end situation [2]. The exposure to fumes from combustion in wood or charcoal stoves constituting a danger to the health of users. Faced to these situations, reforestation and energy crops, the popularization of high energy performance stoves are among other solutions proposed to slow down deforestation and reduce the scale of environmental problems. Unfortunately, in most of these countries, wood or charcoal fireplaces are manufactured by

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craftsmen whose qualifications cannot take into account energy efficiency constraints and their consequences on the environment.

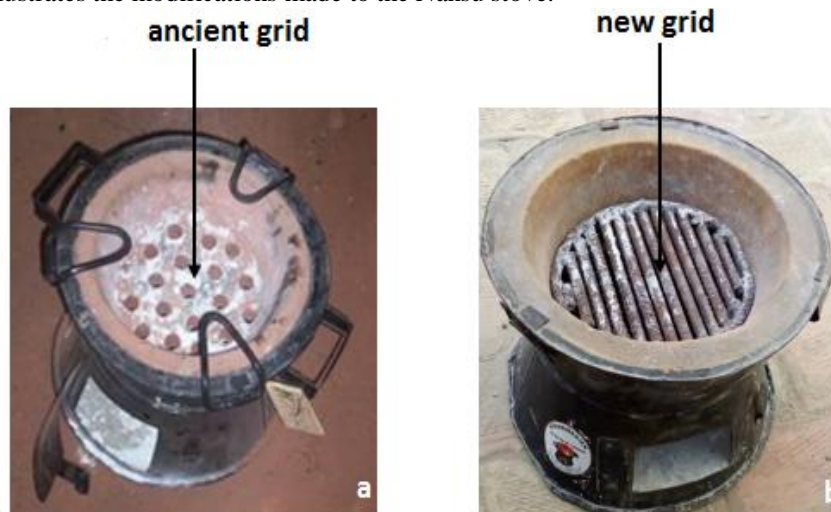
According to global estimates, between 2001 and 2018, Benin lost 0.55 million ha (or 70 million tonnes of CO<sub>2</sub>-eq emissions), a sign of alarming deforestation [3]. The forest area per inhabitant also fell from 1.63 ha in 1980 to 0.87 ha in 1995 and is expected to decline further to 0.29 ha in 2025 if current deforestation trends are maintained. The loss of forests between 2007 and 2017 occurred mainly in forests of the protected domain [4].

Today there are several types of improved stoves on the market. But actual measurements show that many of these stoves have low savings compared to benchmark households. To improve the performance of these improved stoves and make even more efficient stoves with a remarkable economy compared to reference stoves, it is necessary to carry out research work to support the producers of the stoves. In Kenya and Senegal, since 2020, a technical assistance and investment project has started to accelerate the production of Improved Stoves, guaranteeing product quality, supporting marketing activities, and developing knowledge of these products, in order to establish an autonomous and sustainable market for Improved Stoves, and increase the adoption of Improved Stoves by households, with the aim of reducing greenhouse gas (GHG) emissions from home cooking [5]. This is an important asset in terms of improving indoor air quality, reducing greenhouse gas emissions, reducing the daily workload of women and reducing spending devoted to cooking energy.

The objective of this work is to improve the energy performance of Nansu stoves, which is one of the improved stoves with notable performance compared to reference stove. To do this, two essential elements have been modified on the stove:

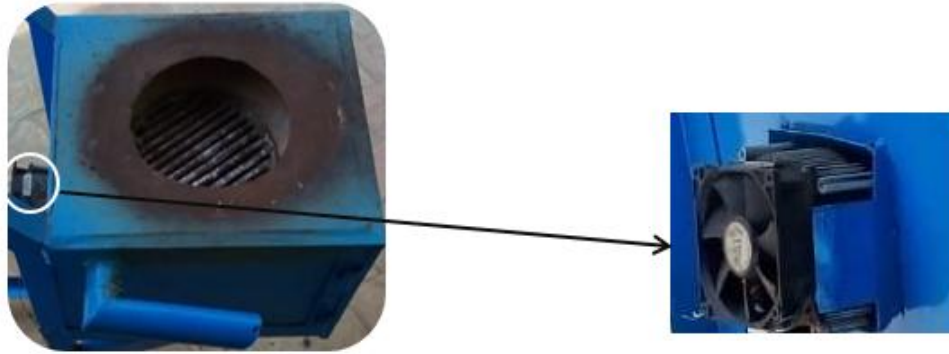
- The primary air circuit which was natural is made forced
- The heart grid is modified. The new grid has a higher porosity and the pore sizes are small than the old grid. This makes it possible to make the Nansu dual-fuel stoves (charcoal and coconut shell). The pot supports are also removed to allow the stove to be positioned in another frame that can support the fan, the air duct and channel the fire below the pot.

The figure below illustrates the modifications made to the Nansu stove.



**Figure 1:-** Ordinary Nansu (a) and Modified Nansu (b).

The modified Nansu placed in its frame is shown in figure 2 below. This frame carries the ventilator, the exhaust duct for any smoke and the air duct connecting the ventilator and the bottom of the grille.



**Figure 2:-** Modified NANSU placed in its frame.

The primary air circuit in forced circulation is composed of a small fan with a power of 2.28 W (voltage 12 V and intensity 0.19 A), and an air duct which brings in the blown air by the fan under the stove grate.

The experimental study consists of using the controlled cooking tests to determine the energy parameters at the level of the two households, namely the Nansu stove currently used in households and the modified Nansu stove.

#### **The Controlled Cooking Test (CCT):-**

Three (03) tests are known to date to assess the performance of stove: the Water Boiling Test (TEE), the Controlled Cooking Test (CCT) and the Cooking Performance Test (CPT). In the context of this consultation, only the Controlled Cooking Test (CCT) was carried out. The TCC is designed to assess the performance of improved stoves compared to traditional stoves that the improved model is expected to replace. The households are compared by performing a standard cooking task in the laboratory which approximates the culinary practices of the populations. However, the tests are designed to minimize the influence of uncontrollable factors and to allow the test conditions to be reproducible.

#### **Material And Method:-**

The controlled cooking test was carried out on three hearths, namely the Nansu (NA), the modified Nansu (NA<sub>m</sub>) and the square Colporte (SC) hearth which serves as a control (figure 3).



**Figure 3:-** Ordinary Nansu (a), modified Nansu (b), and square Colporte (c).

The experimental set-up is simple and includes the hotplates to be tested, the pots and the measuring instruments. The parameters observed during the tests are:

- a. Wind speed (m / s);
- b. Ambient air temperature (°C) and humidity (%) measured by a "HUMICOR" type H1100 thermo-hygrometer;
- c. Local boiling point of water (° C);
- d. Fuel moisture content (%);
- e. Mass of empty pot (g);
- f. Mass of the ember container (g);
- g. Initial mass of fuel (g);

- h. Final mass of fuel (g);
- i. Mass of coal (embers) remaining with the container (g);
- j. Mass of the pot with the cooked food (g);
- k. Cooking start and end time (min).

The masses are measured by a digital scale (VidaXL) with rechargeable battery, 5 g for precision, the speed is measured with a thermo anemometer, the temperature (°C) and humidity of the ambient air (%) measured by a probethermo-hygrometer with "HUMICOR" type H1100 and the humidity of the Fuel is determined using an electronic oven.

To carry out this study, version 2.0 of the Controlled Cooking Test (CCT) adapted to cookstoves using charcoal was used. The test procedure, based on the CCT 2.0 protocol, is as follows:

- a) Ensure the cleanliness of the site of the test, the fireplace, the pot;
- b) Record the atmospheric conditions (ambient temperature);
- c) Weigh the empty pot and record the weight;
- d) Weigh the ember shovels and note the mass;
- e) Take a mass of 1 kg of food (after sorting);
- f) Weigh the necessary amount of water to cook the food, add it, then weigh the pot with the water and the food;
- g) Weigh a quantity of fuel deemed largely sufficient for the duration of the test;
- h) Load the stove. Light the fire as is normally done in households or in the region;
- i) Start the stopwatch while placing the pot on the hearth and note the start time;
- j) During the test, note the observations and comments that the tester makes (eg difficulties encountered, excessive heat, smoke, instability of the hearth or pot, etc.);
- k) When the meal is ready to cook, take the time;
- l) Remove the pot from the fireplace and weigh it with the cooked food. Note the mass;
- m) Remove the embers and weigh it with its container. Note the mass;
- n) This is the end of the test. Each household is tested three (03) times.
- o) number of parameters are used to measure the performance of stoves. These are specific fuel consumption, fuel saving cooking time, cooking time saving and average power.

The controlled cooking test was carried out on each household. To better appreciate the performance of the hotplates, three dishes with different cooking times were cooked:

1. Thailand rice of short cooking time;
2. Northern beans of medium cooking time;
3. Northern voandzou of long-cooking time.

Before these various tests, preliminary experiments were carried out in order to determine the quantity of water necessary for cooking each dish according to the size of the pot.

For the present tests, the following method was adopted: the three dishes are directly fired with water at room temperature. Each hearth is in triplicate and each dish is prepared three times on each copy of the hearth. The average per dish and per item is calculated and the average per dish and per type of stove is then calculated.

### Specific fuel consumption

This is the main indicator of a household's performance for CCT. It gives the amount of fuel needed to cook a given amount of food in accordance with "standard cooking tasks". It is calculated as a simple ratio of the mass of fuel and food [6-8]:

$$CS = \frac{\left[ (M_{fi} - M_{ff}) \times (1 - \phi_f) - 1.5M_{ce} \right]}{M_{pc} - M_{pe}} \quad (1)$$

Specific consumption is expressed in grams of fuel per kilogram of cooked food (gc/kg).

**Cooking time**

It is also an important indicator of household performance in CCT. Household users may appreciate this indicator more or less than the Specific Consumption indicator depending on local conditions or individual preferences. It is calculated as a simple difference:

$$t = t_f - t_i \quad (2)$$

**Fuel economy**

This criterion measures the fuel reduction induced by the use of the modified Nansu stove compared to the ordinary Nansu stove. It is given by the relation:

$$E_f = \frac{CS_{or} - CS_{mo}}{CS_{or}} \times 100 \quad (3)$$

CS<sub>stemoin</sub> and CS, the specific consumptions of the control household and of the tested household.

**Cooking time economy**

It measures the time reduction induced by using the modified Nansu stove compared to the regular Nansu stove. It expresses in % and is given by the relation:

$$E_t = \frac{t_{or} - t_{mo}}{t_{or}} \times 100 \quad (4)$$

**The average power consumed by the household**

It expresses the average power of the household and is expressed in kW by [9]:

$$\bar{P} = \frac{PCI \times \left[ (M_{fi} - M_{ff}) \times (1 - \phi_f) - 1.5M_{ce} \right]}{60 \times t} \quad (5)$$

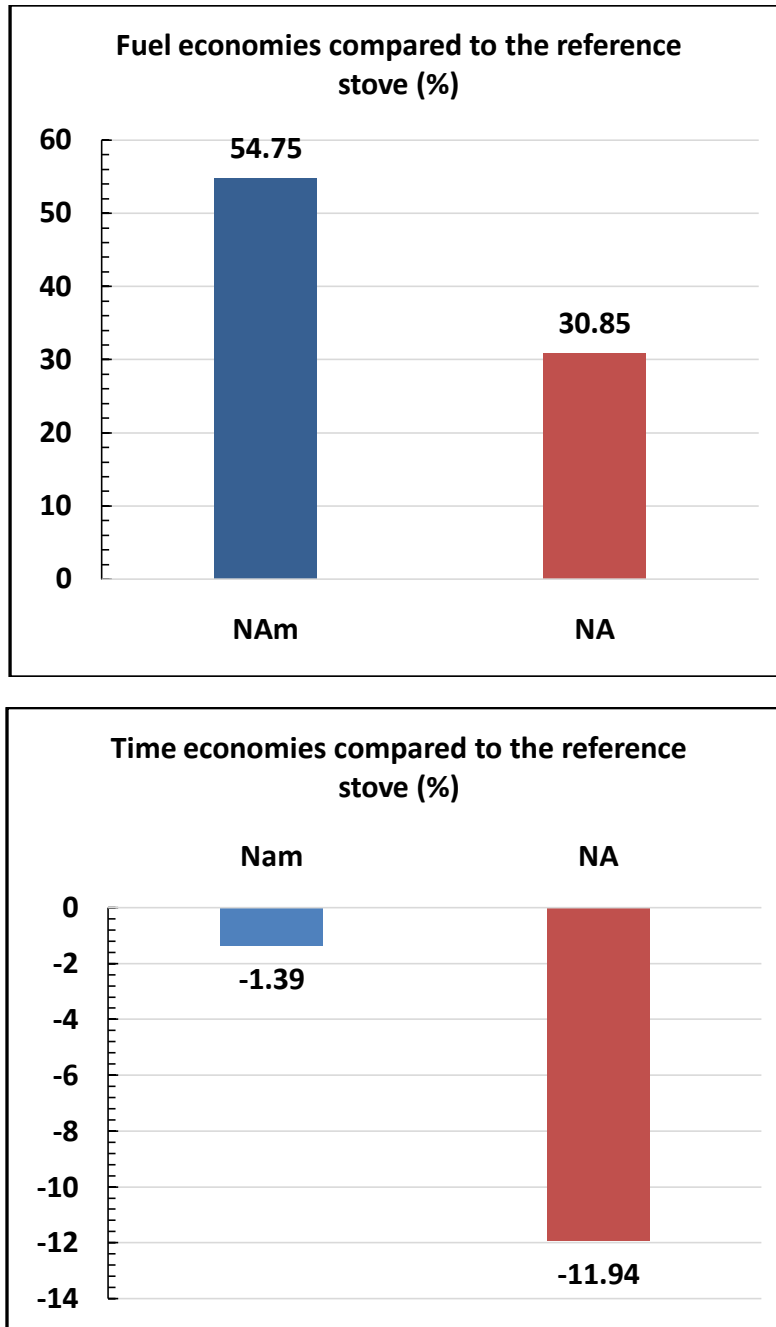
**Result And Interpretations:-**

The averages of the results of the cookstoves for the cooking tests are presented in Table 1 below:

**Table 1:-** Results of the cookstoves.

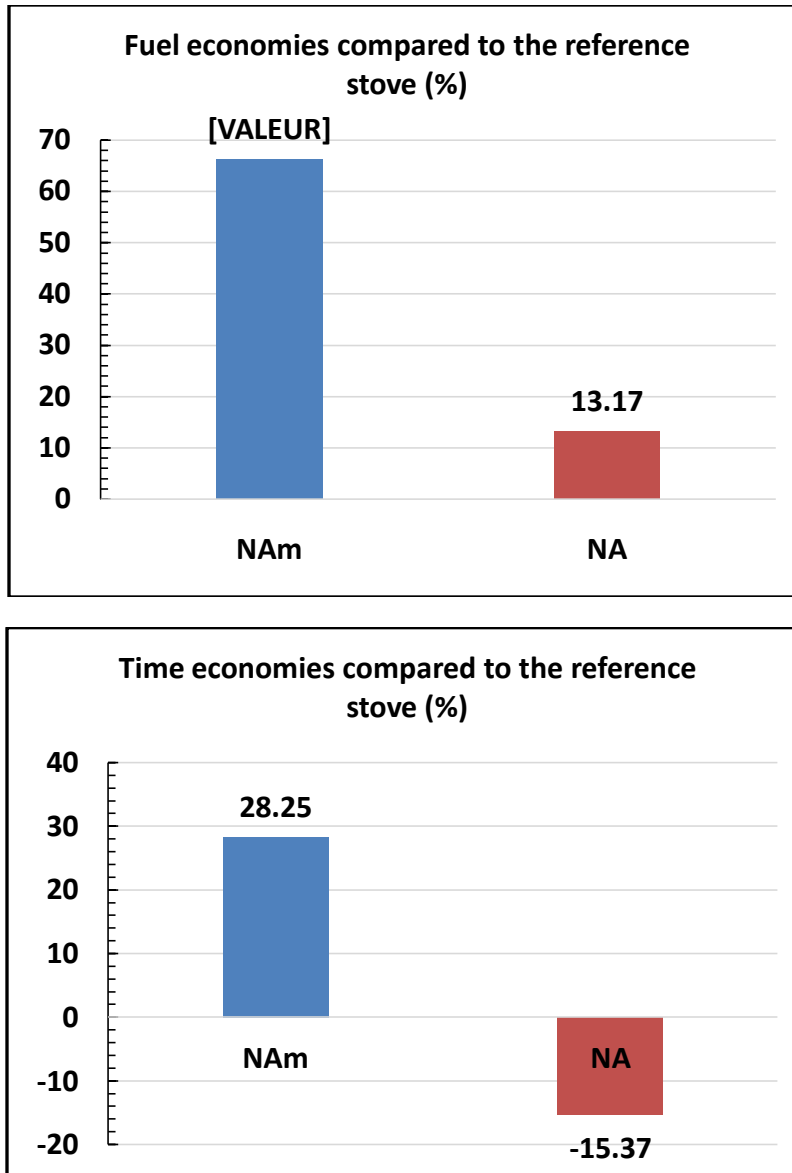
N°	Stove Code	Rice test				Bean test				Voandzou test			
		CS (g/kg)	T (mn)	P (kW)	Ee (Wh)	CS (g/kg)	T (mn)	P (kW)	Ee (Wh)	CS (g/kg)	T (mn)	P (kW)	Ee (Wh)
1	NA	57	32	2,87	1,216	96	70	2,50	2,66	210,00	175,00	1,31	6,536
2	NAm	87,12	35,33	3,78	0	246,13	112,56	3,78	0	588,36	227	2,99	0
3	SC	125,98	31,56	6,16	0	283,45	97,56	4,56	0	645,56	202,67	3,80	0

Table 1 shows the specific consumption, the cooking time, the power of the hearth and the electrical energy consumed for cooking with the stoves Nansu, the modified Nansu and the square colporte stove (the reference). These results show that in all cases (dishes with short cooking time, medium cooking time and long cooking time), the improved Nansu stove and the modified Nansu have low specific fuel consumption compared to the reference stove. In any case, the modified Nansu stove consumes less fuel than the Nansu. For cooking times, the square Colporte reference stove is faster than the Nansu stove but slower than the modified Nansu stove except in the case of rice (short cooking time) where the modified Nansu stove is slightly less faster than the reference stove. The figures 4, 5 And 6 show the fuel and time economies compared to the reference stove. For rice cooking (short cooking time), the modified Nansu and Nansu stoves show respectively 54.75% and 30.85% fuel economies and respectively 1.39% and 11.94% loss of time relative to the reference stove.



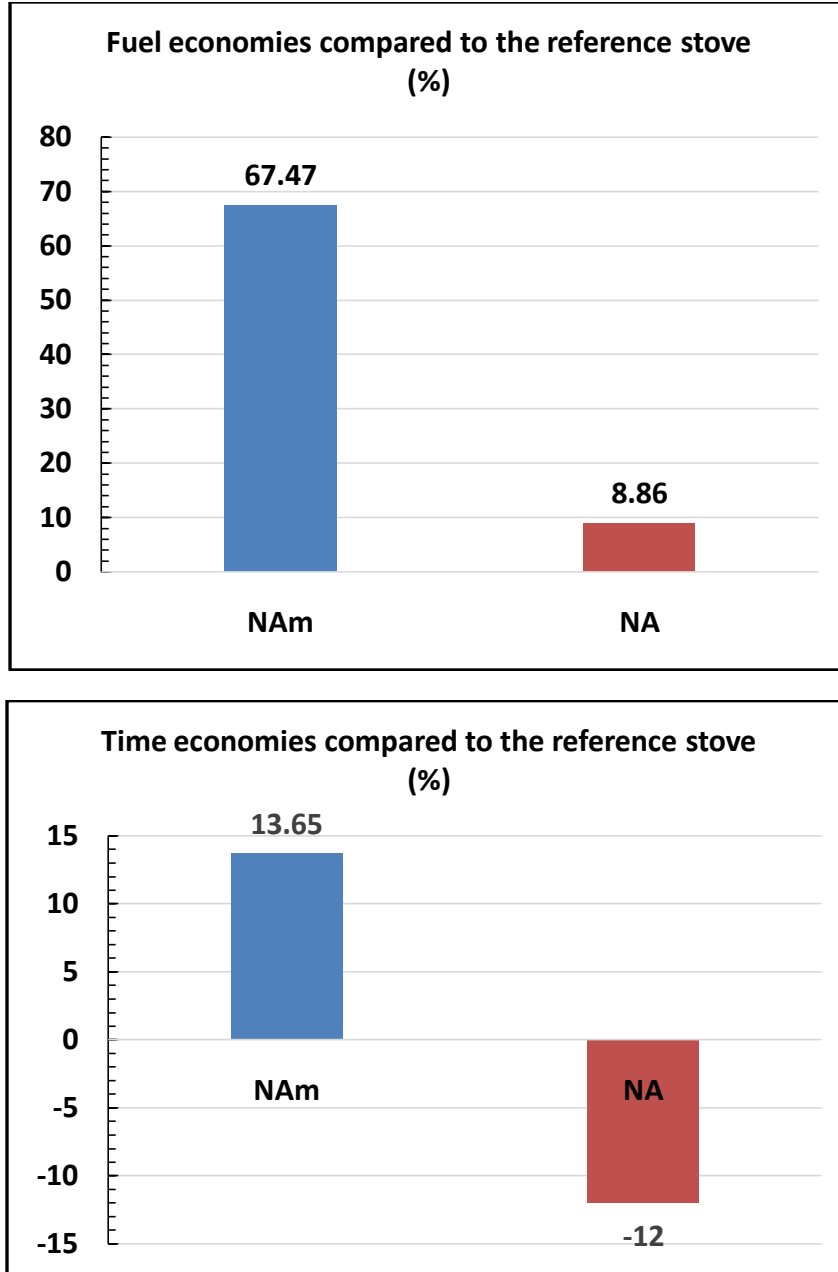
**Figure 4:-** Fuel economies (above) and time economies (at the bottom) compared to the reference stove for cooking rice.

For cooking beans (medium cooking time), the modified Nansu and Nansu stoves have respectively 66.13% and 12.17% fuel savings and respectively 28.25% and -15.37% (loss here) time saving compared to the reference stove.



**Figure 5:-** Fuel economies (above) and time economies (at the bottom) compared to the reference stove for cooking bean.

For cooking the voandzou (long cooking time), the modified Nansu and Nansu stoves have respectively 45.78% and 8.86% fuel savings and respectively 15.13% and -12.00% (loss here) time saving compared to the reference stove.



**Figure 6:-** Fuel economies (above) and time economies (at the bottom) compared to the reference stove for cooking voandzou.

A comparison between the Nansu stove and the modified Nansu stove reveals that the modified Nansu stove is more advantageous in terms of fuel consumed and time than the Nansu stove. Figures 6 and 7 show that the fuel savings achieved by using the modified NANSU stove instead of the Nansu stove are respectively 34.57%, 61.00% and 64.31% for cooking 1 kg of rice, 1 kg of beans and 1 kg of voandzou. At the same time, there are savings in cooking time of 9.43%, 37.81% and 22.91% respectively for cooking 1 kg of rice, 1 kg of beans and 1 kg of voandzou.

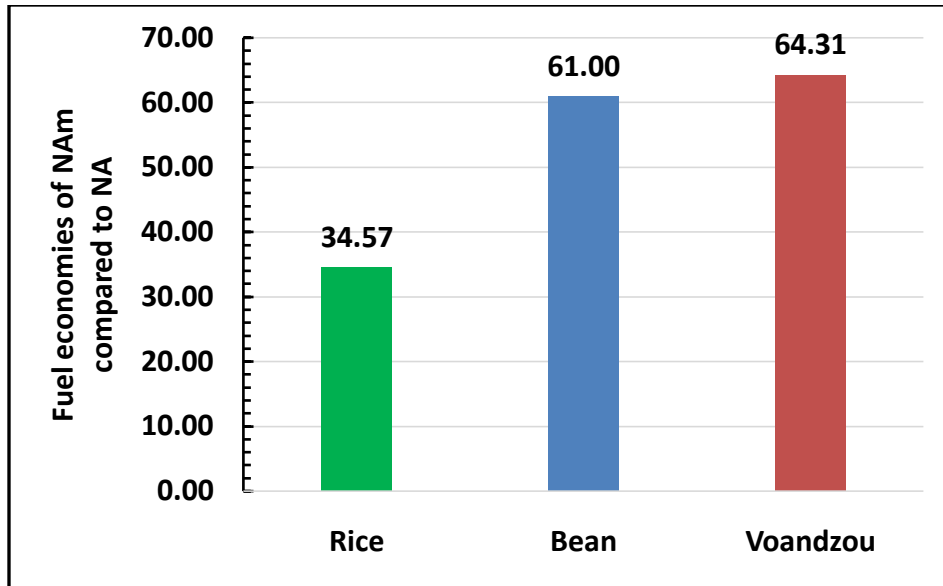


Figure 7:- Fuel economies of Nansu midified compared to ordinary Nansu.

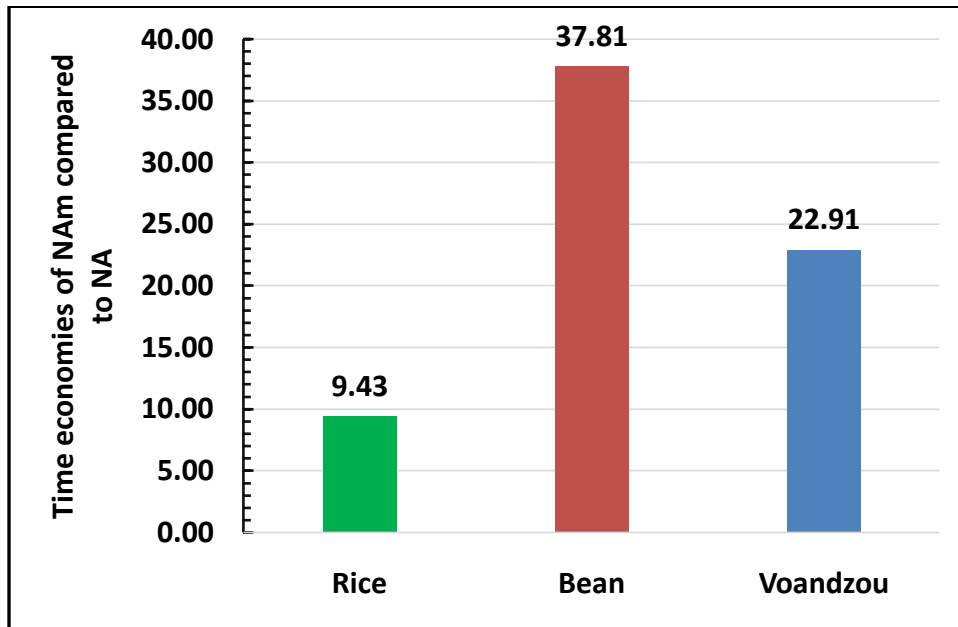


Figure 8:- Times economies of Nansu midified compared to ordinary Nansu.

These different results show that the use of the modified Nansu stove instead of the Nansu stove saves 30 g of charcoal for 1 kg of prepared rice, 150 g of charcoal for 1 kg of prepared bean and 378 g of charcoal for 1 kg of prepared voandzou. In terms of electrical energy consumption, the Nansu fireplace is more advantageous because it does not consume any electrical energy. However, it should be noted that this consumed energy is insignificant compared to the savings made on this fireplace.

**Conclusion:-**

By observing these results, we can easily see that the modified Nansu stove constitutes a more important asset in the preservation of our forests. Its use not only allows women to have time for other activities, but also allows the population to reduce expenses related to the purchase of fuel for cooking. However, the components of the modified

Nansu hearth make its manufacture a little more complex and generate an additional cost compared to the metallic Nansu hearth usually used. But this additional cost will quickly be amortized by the various savings linked to its use.

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