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Design and Performance Assessment of an Energy-Efficient, Self-Contained Electric Fireplace for Sustainable Home Heating

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Authors' contributions

This work was carried out in collaboration among all authors. Author DFGA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors DMGFC managed the analyses of the study and reviewed the first draft. Author CGT managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The present work aims to design, build, and analyze the performance of an electrically self-sufficient improved fireplace. After the computer-aided design, and modeling based on the design and simulation, the physical design of the system was carried out, starting with the clay structure conforming to the proportions of water, clay, and grog normally used for Sè pottery in the Mono department of Benin, right through to the metal casing and the various associated compartments. Based on the sizing of both the loads to be supplied and the system's internal control loads, without disregarding the thermoelectric power generation system and the storage battery, a thermal efficiency of 24.64% and maximum electrical efficiency of 64.75% were obtained. It's worth noting that this system considerably improves the user's lifestyle, offering a wide range of functions, including cooking with complete peace of mind, whatever the weather or space, and electricity for lighting and recharging a cell phone without any external power supply.

Keywords: Agro-residues; improved; stoves; sizing; performance.

1. INTRODUCTION

Worldwide, around 2.8 billion people rely on various forms of solid fuels (firewood, charcoal, dung, residues, etc.) and kerosene to meet their energy needs [Stoner et al. 2021]. The proportion of the population using biomass for cooking is highest in sub-Saharan Africa. According to Boafo-Mensah et al. [2020], over 80% of Africa's population still relies on firewood as a primary source of cooking energy. The majority of consumers utilize traditional or three-stone stoves that have been constructed in a rudimentary or primitive manner. However, the energy, thermal, and emission performances of these stoves are found to be suboptimal. Only 5 to 10% of potential biomass energy is used for cooking [Ferriz Bosque et al. 2022], [Kailasnath et al. 2015]. This is mainly due to a lack of access to cleaner cooking appliances or an inability to afford to cook with a clean stove [Yunusa et al. 2023]. This use of biomass has undoubtedly contributed to the deforestation and climate crisis currently affecting the region [Rathore et al. 2022]. FAO [2010] reports that 3.4 million hectares of forest are lost annually in Africa due to the traditional use of biomass, resulting in a loss of approximately 500 million tons of wood [USAID 2018]. Burning biomass in traditional stoves or open fires produces air pollutants, like fine particles ($PM_{2.5}$), carbon monoxide (CO), and nitrogen dioxide (NO_2) [Barbour et al. 2021]. This has also led to major health problems, mainly in women. These include breathing problems [Barpatragohain et al. 2021], blood pressure problems, and cardiovascular problems [Ye et al. 2022], [Islam et al. 2024]. In 2020, 3.2 million people died early [WHO 2022]. The Africa Clean Cooking Energy Solution Initiative [Africa Clean Cooking Energy Solution Initiative ACCES 2014] says that nearly 600,000 people die every year in Africa, and millions suffer from chronic diseases.

According to Onyekuru et al. [Onyekuru et al. 2021], giving people better stoves could help to reduce these problems. Many different types of stoves have been made over time. Different stoves can be grouped according to their construction materials, number of pots, fuel type, etc. Fig. 1 shows the classification of biomass stoves [Mehetre et al. 2017]. According to Manaye et al. [2020], most improved stove designs are primarily aimed at optimizing fuel consumption, heat, and emissions performance. Various researchers have reported reductions in fuel consumption of 30-79% with improved stoves [Dresen et al. 2014, Rasoulkhani et al. 2018, Bantu et al. 2018]. Ürge-Vorsatz et al. [Ürge-Vorsatz et al. 2012], reported that switching from traditional stoves to improved stoves can reduce global emissions by about 0.6 to 2.4 Gt CO_2 per year. On the other hand, well-performing gasification stoves offer a 90% reduction in particulate emissions. On average, forced-air stoves with small fans reduce fuel consumption by 40% and emissions (CO and PM) by 90%. In another study, improved biomass stoves reduced black carbon emissions by 50-90% [Mehetre et al. 2017].

Like other countries in sub-Saharan Africa, Benin is facing this situation. For several decades, the country has been confronted with significant deforestation to supply fuelwood to the rural population. The domestic sector occupies a relatively large share of final energy consumption due to the predominance of wood fuel, which accounts for 59.4% of the national energy balance (firewood and charcoal) [DGRE 2022].

Due to population growth and the expansion of income-generating activities in the informal sector, the demand for wood fuel is increasing, leading to overexploitation of forest resources and increased deforestation in the country.

To optimize the use of firewood in households, several projects to design and popularize improved fireplaces are constantly emerging in the country [Akouehou et al. 2012]. Some of these improved stoves are shown in Fig. 2.

Despite ongoing advancements in fireplace technology, from the traditional three-stone fireplace to the Atigan fireplace and the Guev Cooker, their performance remains inadequate in addressing the challenges of today's market. On the one hand, this is due to a failure to consider design materials. On the other hand, the fuels used are limited to wood or charcoal. The continued use of wood or charcoal as fuel represents an obstacle to reducing deforestation, as highlighted by the FAO [2014]. There is a clear need for alternative biofuels, such as palm nut shells, biochar, and corn cob, to be considered as substitutes.

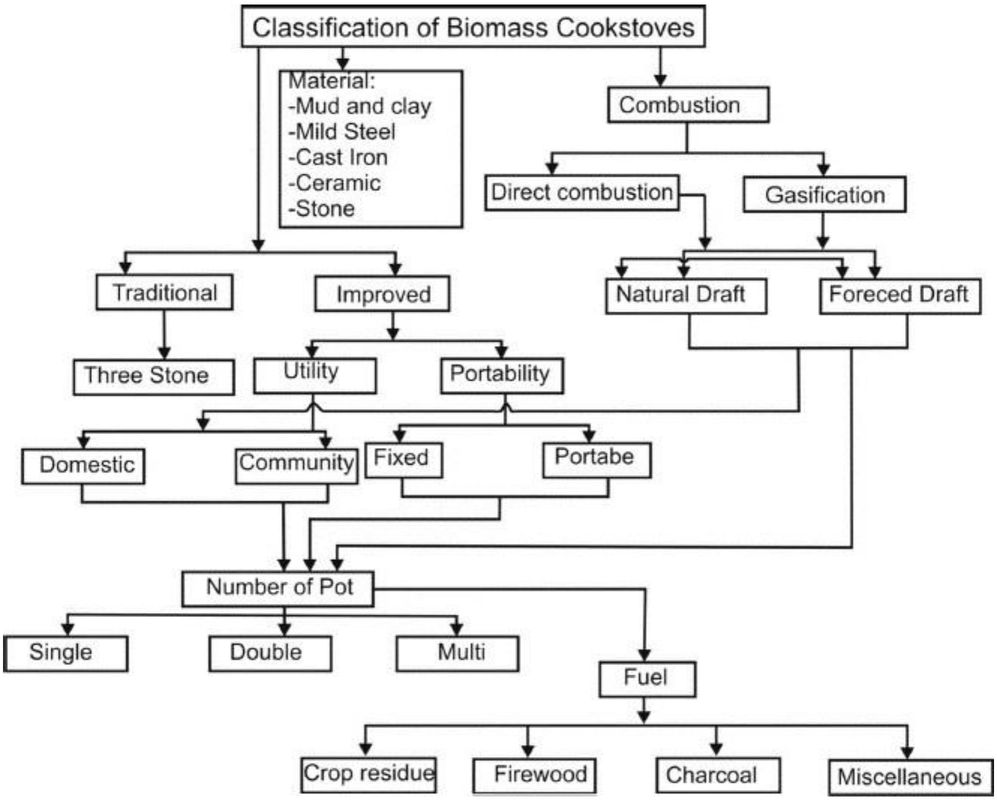


Fig. 1. Classification of biomass cookstoves [Mehetre et al. 2017]

Nansu ceramic fired **Gas flash** **Fixed rocket in banco** **Atingan** **Guev Cooker**

Fig. 2. Some improved biomass stoves developed in Benin

This study aims to design an improved furnace that efficiently produces heat and electricity from agricultural and agri-food residues.

2. MATERIALS AND METHODS

The methodology is structured into three main phases: fireplace design, implementation, and performance evaluation.

2.1 Fireplace Design

Definition of Service Functions: The Functional Need Analysis approach has been implemented by Standard NF X 50-150. It is a benchmark in the field of Industrial Engineering. Once a need has been identified, the relationships between the product and its environment are determined, along with the main function expected of the home and the constrained functions. The latter represents the requirements or obligations linked to the use of the fireplace in its environment. There are various constraints, whether functional, economic, safety, aesthetic, ergonomic, or ecological. The need to be met by the home is formulated as follows: "Produce heat and electricity from agricultural and agri-food residues efficiently ".

Choosing Fireplace Components: The FAST (Functional Analysis System Technic) method, one of the standard methods for internal functional analysis according to NF EN 1325-1, was used. First, service functions were broken down into technical functions that were easier to understand. These successive decompositions then led to the selection of the components that could be used to realize the technical functions required to build the fireplace.

Hearth Sizing: The fireplace to be designed consists mainly of the combustion chamber, to which is added the electrical system made up of various electrical and electronic components.

- Fuel characteristics

The model fuel used in the present study concerns palm nut shells. The main thermo-physical characteristics considered are presented in Table 1. The power Pc is evaluated for a half-hour combustion.

- Sizing the combustion chamber and ash outlets

The chamber volume is estimated using the equation 1:

$$v = H * \frac{\pi}{3}(R^2 + r^2 + Rr) \qquad (2.1)$$

In this study, we set the height H of the combustion chamber at 19 cm, the upper radius R at 6.25 cm, and the lower radius r of the combustion chamber at 5 cm.

The diameter D_{oc} of the ash outlet is set at 5 mm, which is smaller than the average grain size of the model solid fuel.

- Electrical system size

The system is sized according to the user's precise requirements to avoid using more power than can be produced. The external equipment to be powered consists of telephones and lamps, whose characteristics and conditions of use are presented in Table 2.

Table 1. Some thermo-physical characteristics of fuel

Parameters	Value
Diameter Dc (m)	0.04
Height Hc(m)	0.045
PCIc (MJ/kg)	30.61
Mass mc (kg)	0.06
Volume Vc (m)^3	0.00005652
Energy Ec (kWh)	0.51
Thermal power Pc (W)	1020.33

Table 2. External electrical requirements to be supplied

Equipment	Power (W)	Quantity	Time of use (h)	Daily Energy
Phone	15	1	2	30
Lamp	2	3	5	30
Total	**21**			**60**

Concerning the internal electrical loads to be supplied, the charge controller is at the heart of the synchronous operation of the system's various electrical and electronic components. It consists of several elements powered by the energy generated by the system. Their consumption is evaluated for six (6) hours of use per day. Table 3 shows the internal requirements and their power consumption.

The sensor used in the present work is the Peltier module TEP1-142T300. It generates DC electricity as long as there is a temperature difference between the two modules. The greater the temperature difference, the greater the power generated. The power profile generated by this type of module as a function of the temperature difference on either side of the module is illustrated in Fig. 3.

The input parameters required for sizing the entire electrical system are shown in Table 4.

- Storage system sizing

The storage system is sized according to the user's needs, the daily cooking time, and the energy that can be stored.

Table 3. System's internal power requirements

Equipment	Power (W)	Total power	Energy (Wh)	Number
Ventilo1	1.44	1.44	8.64	1
Ventilo2	2.16	2.16	12.96	1
Relay	0.475	2.685	16.11	6
LED Green	0.027	0.027	0.162	1
Red LED	0.024	0.048	0.288	2
LED Yellow	0.024	0.024	0.144	1
LED Blue	0.026	0.026	0.156	1
Diode 1N4007	1.1	3.3	19.8	3
ATMEGA 328	4.8	4.8	28.8	1
7805 controller	1.9	7.6	45.6	4
Capacitor22pF	7.64E-12	5.34722E-11	3.21E-10	7
220Ω resistor	0.65	7.85	47.12	12
Capacitor470uF	1.63E-04	0.000163194	0.000979	1
0.1nF capacitor	3.47E-11	3.47222E-11	2.08E-10	1
1kΩ resistor	0.144	0.432	2.592	3
Quartz	0.001	0.001	0.006	1
ACS712 sensor	0.024	0.024	0.144	1
Transistor2N2222	0.5	3	18	6
Zener diode	1	1	6	1
Total	**14.27220865**	**34.42170865**	**206.5303**	

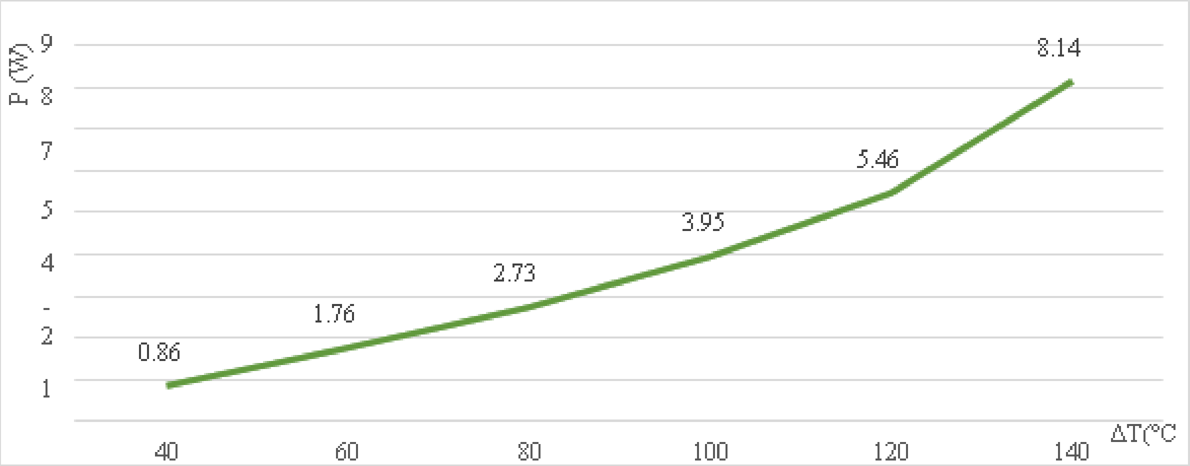


Fig. 3. Representative curve of power generated as a function of temperature difference

Table 4. Dimensioning constants

Parameters	Value
Maximum collector power (W)	8.14
Maximum sensor voltage (V)	8.4
Autonomy (J)	2
Battery capacity (Ah)	18
Battery voltage (V)	12
Deep discharge	0,8
Cooking time (h/d)	6
Number of Peltier modules	12
Battery efficiency	0.8
System voltage	33.6

Setting the Fireplace Configuration: The fireplace structure was determined through a comparative analysis of the shapes of various existing fireplaces. This was followed by a computer-aided design using FreeCad software to create a mock-up.

2.2 Building the Fireplace

The main stages of the project are described below:

- Making the fireplace mold: The chamotte-water proportions recommended for making pottery in the village of Sè in the Mono department of Benin were used as shown in Table 5. The volume of clay was measured using a 4.25.10-2 m^3 basket, and that of a grog using an 8.48.10-3 m^3 box.
- Construction of the hearth frame by clay molding. The ash outlet is arranged on a circle of radius r = 7 cm, with 4 holes of 5 mm spaced 5 mm apart.
- Mounting electronic components on the fireplace
- Lining the clay hearth with metallic materials

2.3 Charge Controller Design

Being at the heart of the synchronous operation of the various electrical and electronic components of the system, the charge controller is equipped with several functions, such as:

- Check module production and synchronous fan operation.
- Protect the battery against deep discharge and overcharging.
- Distribute energy to the various electrical loads connected.
- Protect against increased electrical loads.

Table 5. Proportion of Clay-Chamotte-Water mixture

Container	Clay	Chamotte	Water
Proportion	1 basket	5 boxes	1.5 liters

Fig. 4. Basket and box used to measure clay and grog

2.4 Performance Evaluation

Experimental Tests: Several tests have been carried out to assess the oven's cooking performance. The parameters calculated are:

- Boiling time (TE): the time required to reach boiling point.
- Specific boiling time (SBT): the time required to bring 1 liter of water from 0 to 100 °C.
- Percentage of heat used 1st phase (PCU1): ratio of the energy recovered by the contents of the kettle to the energy produced by combustion during the first phase.
- Specific consumption 1st phase (CS1): quantity of carbon required to bring 1 liter of water from 0 to 100 °C
- Power 1st phase (P1): the amount of energy produced during the 1st phase per unit time.
- Specific consumption 2nd phase (CS2): quantity of carbon required to evaporate 1 liter of water for 2nd phase
- Power 2nd phase (P2): the amount of energy produced during the 2nd phase per unit time.
- Percentage of Total Heat Utilized (PCUT): ratio of the energy recovered by the contents of the kettle to the energy produced by combustion during the entire test.
- Total coal consumption during test (CT)
- Flexibility (F): ratio of power 1st phase to power 2nd phase
- Mass of water evaporated over the entire test (MEV)

The experimental protocol is as follows:

- Note the weather conditions
- Weigh the empty pot (lid + thermometer). Note MV
- Weigh the pot of water to 2/3 of its capacity. Replace the lid and thermometer
- Weigh the full pot and note M0;
- Note water temperature T0
- Clean the hearth thoroughly, weigh empty and note FV
- Weigh out a certain quantity of charcoal. This will depend on the size of the pot.

Introduce it into the firebox

- Light the fire with twigs or kerosene without putting the pot down.
- Five minutes after ignition, weigh the full hearth and note F0
- Place the pot on the stove and start the timer.
- If there is a door closing flap, it must remain open.
- Check water temperature every 5 minutes
- When the water starts to boil, note the time TE
- Weigh the complete pot and note M1
- Weigh the full hearth and note F1
- Rest the pot on the hearth and close the burglar flap, if present, for 30 minutes.
- Ensure that the water temperature does not fall below 95 °C. If it does, the test is no longer valid.
- After 30 minutes, weigh the complete pot and note M2
- Weigh the full focus and note F2

Heat Transfer Simulation: The data collected was used to simulate heat transfer within the structure using COMSOL software. The temperature profile on the walls and heat propagation within the structure were studied.

To facilitate heat transfer simulation in the hearth, the clay's thermophysical characteristics (density, effective thermal conductivity, and heat capacity) were determined. The average density of 5 clay samples is used (Table 6). It is evaluated at ρ_m = 1647.39 kg/m^3. The samples were weighed using a digital balance.

The thermal conductivity and heat capacity of terracotta were estimated based on the literature [Pompeo and Gueret 2020]. In total, the thermo-physical characteristics selected are shown in Table 7.

Simulation data were used to determine the furnace's thermal and electrical efficiency.

Table 6. Average characteristics of clay samples

Sample	1	2	3	4	5	Average
Average weight me (kg)	0.0927	0.0406	0.0632	0.0344	0.0264	-
Average volume Ve (m)^3	$1.46.10^{-4}$	$5.024.10^{-5}$	$2.94.10^{-5}$	$1.575.10^{-5}$	$1.575.10^{-5}$	-
Average density ρe (kg/m)^3	635.55	808.529	2151.04	2188.92	2452.92	1647.39

Table 7. Approximate characteristics of Clay

Density ρ (kg/m)^3	Effective thermal conductivity λ (W/m.K)	Heat capacity Cp (J/kg.K)
1647.39	0.64	1000

Thermal Efficiency Calculation: This efficiency takes into account the loss of heat recovered in the furnace from the heat generated within it. In this case, the heat is evaluated according to the characteristics of the fuel used in the simulation.

The energy recovered will be evaluated on the side where the collectors are placed and above the hearth, precisely where the food to be cooked will be placed. Thermal efficiency is evaluated (2.1 – 2.4).

$$\eta_{th} = \frac{P_{rg} + P_{dv}}{P_c} \tag{2.2}$$

$$P_{rg} = \frac{S_{tc} * \Delta T_{va}}{R_{th}} \tag{2.3}$$

$$P_{dv} = \frac{S_{sc} * \Delta T_v}{R_{ai}} \tag{2.4}$$

With P_{rg} thermal power recovered at the left wall where the thermoelectric collectors are located, P_{dv} the thermal energy that would have been recovered at the bottom of a pot placed on the hearth, and P_c the thermal energy generated by the fuel used in the simulation; S_{tc} total module area (0.0192 m^2); ΔT_{pg} temperature difference between inside and outside of the left wall (K); R_{th} thermal resistance of the internal structure (0.103 m^2 K/W); S_{sc} surface area of the upper base of the combustion chamber (0.012 m^2), ΔT_v temperature difference in a vertical direction from the base of the combustion chamber to the level of the kettle (K) and R_{ai} = minimum air resistance within the combustion chamber (0.05 m^2 K/W).

Calculating Electrical Efficiency: This efficiency includes the electrical power consumed by the system's internal components and the electrical power generated by all the modules. It is subdivided into two parts: Theoretical Electrical Efficiency and Practical Electrical Efficiency.

- Theoretical Electrical Efficiency

This efficiency is the ratio of the electrical power of the modules specified by the manufacturer to the total power required by the system's internal components (2.5).

$$\eta_{et} = \frac{E_a - E_{bi}}{E_g} \tag{2.5}$$

With E_g total theoretical energy generated (586.05 Wh) and E_{bi} the system's total internal electrical requirement (206.53 Wh).

- Practical Electrical Efficiency

This efficiency is the ratio of the electrical power of the measured modules to the total power required by the system's internal components (2.6).

$$\eta_{ep} = \frac{E_{pg} - E_{bi}}{E_{pg}} \tag{2.6}$$

E_{pg} total practical energy generated (261.37 Wh) and E_{bi} the system's total internal electrical requirement (206.53 Wh).

3. RESULTS AND DISCUSSION

3.1 Description of the Improved Fireplace

Fig. 5 shows the designed firebox. It is suitable for simple cooking or grilling using any solid fuel except wood.

It consists of 2 fans, a battery, 3 LEDs (green, orange, and red), a Peltier module, a buzzer, and electrical loads.

At start-up, activation energy is supplied to the fuels. When the embers become live, the fan switch is switched on, runs for 20 seconds, then switches off and on periodically at 15-second intervals. Fan 2 switches on when the voltage across the module's field reaches a threshold voltage preset by the controller electronics.

Table 8 presents the details of the functioning of the control system.

Some electrical loads are powered at 12V, others at 5V. When cumulative loads exceed 21W, the load supply circuit opens and the buzzer beeps.

Once cooking is complete, the combustion chamber is closed to extinguish the fuel and benefit from the heat it releases.

Table 8. Details of the functioning of the control system

Task to be carried out by the control system	Sequence of the task	Purpose
Monitor module production	When the modules are generating energy, a blue indicator LED lights up	See how the modules work (production of electrical energy)
Controls synchronous fan operation	On start-up, fan 1 switches on for 20 seconds, then switches off and on again periodically at 15 second intervals.	Reduce the energy required to operate the fan used to oxygenate the combustion chamber
	Fan 2 switches on when the voltage at the module field terminal is 0.3 volts (below the saturation voltage of the transistor connected in series with the field).	Maintain the temperature difference on either side of the modules
Battery protection against deep discharge and overcharging	When the battery voltage falls below 11.5 volts, the red LED lights up, the battery's power supply circuit opens, leaving the battery charging circuit closed and the battery starts to charge (this means that the battery is below deep discharge).	Protect the battery against repeated deep discharges
	When this voltage is between 11.5 volts and 11.75 volts, the red LED remains lit and the circuit closes (this means that the battery is discharged but above deep discharge).	Alert the user to reduce external loads and allow the battery to charge
	When the voltage is between 11.75volts and 12.6volts, the orange LED lights up and the load supply circuit always remains closed (battery charging).	Alert the user that charging is proceeding normally
	When the voltage is between 12.70volts and 13volts, the green LED lights up and the circuit always remains closed (battery charged).	
	When the voltage exceeds 13 volts, the green LED remains lit and the battery charging circuit opens and the electrical load supply circuit closes in order to discharge the battery and prevent overcharging.	Protect the battery against repeated deep overcharging
Distribution of energy to the various electrical loads connected	Some electrical loads are powered at 12V, others at 5V.	Protect connected electrical loads from being supplied with inappropriate voltage
Protection against increased electrical loads	When the cumulative loads exceed 21W, the load supply circuit opens and the buzzer beeps.	To warn the user that the power of the connected electrical loads exceeds the threshold so as not to damage the battery and the module

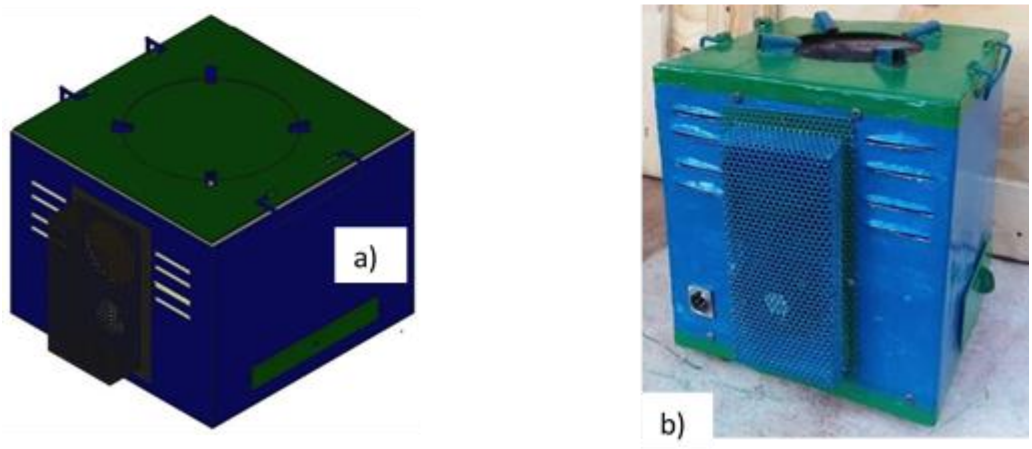


Fig. 5. a) Improved fireplace model, b) Real fireplace

3.2 Analysis of Heat Transfer within the Structure

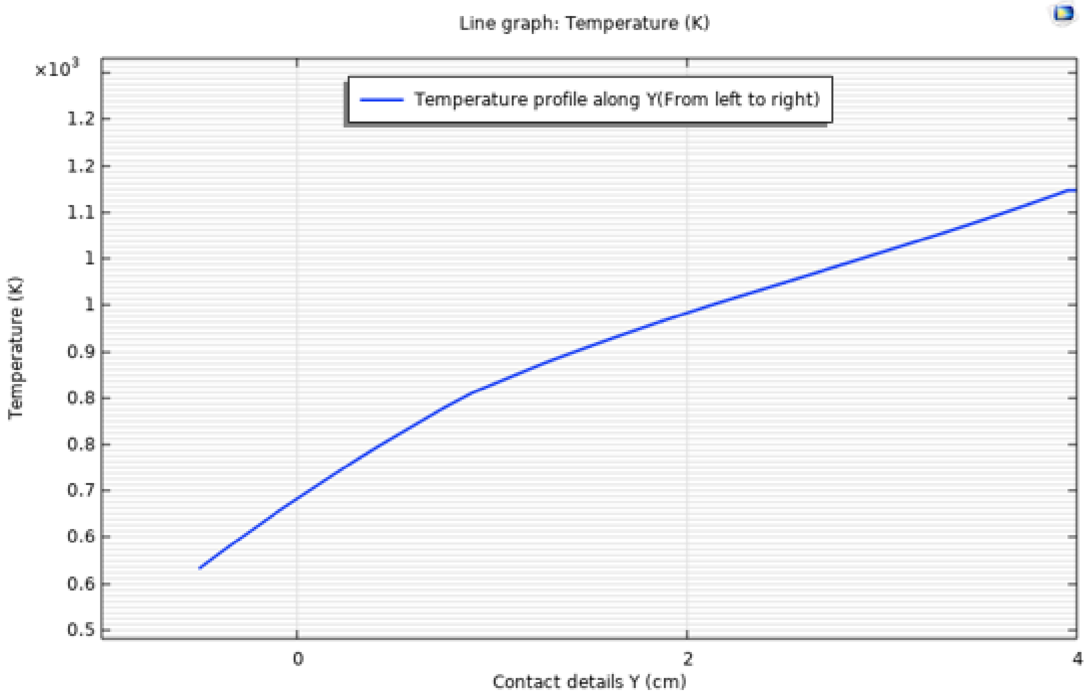
Fig. 6 shows the temperature profiles at the left wall where the sensors are located (in °C) and inside the combustion chamber (in K).

The temperature difference between the outside and inside of the left wall of the firebox is estimated at 525 °K. The temperature difference between the vertical at the base of the combustion chamber and the vertical at the level of the kettle is estimated at 640°K.

Figs. 7, 8, and 9 show the physical propagation of temperature in the clay structure of the hearth. The combustion chamber's *ra* are fixed to the side walls and propagate vertically.

3.3 Voltage and Current Measured at TEP1-142T300 Module Terminals

Table 9 shows the voltage and current measured across the TEP1-142T300 modules in the system. These are obtained by linear interpolation from the characteristic curve of the modules. This produces the Fig. 10.



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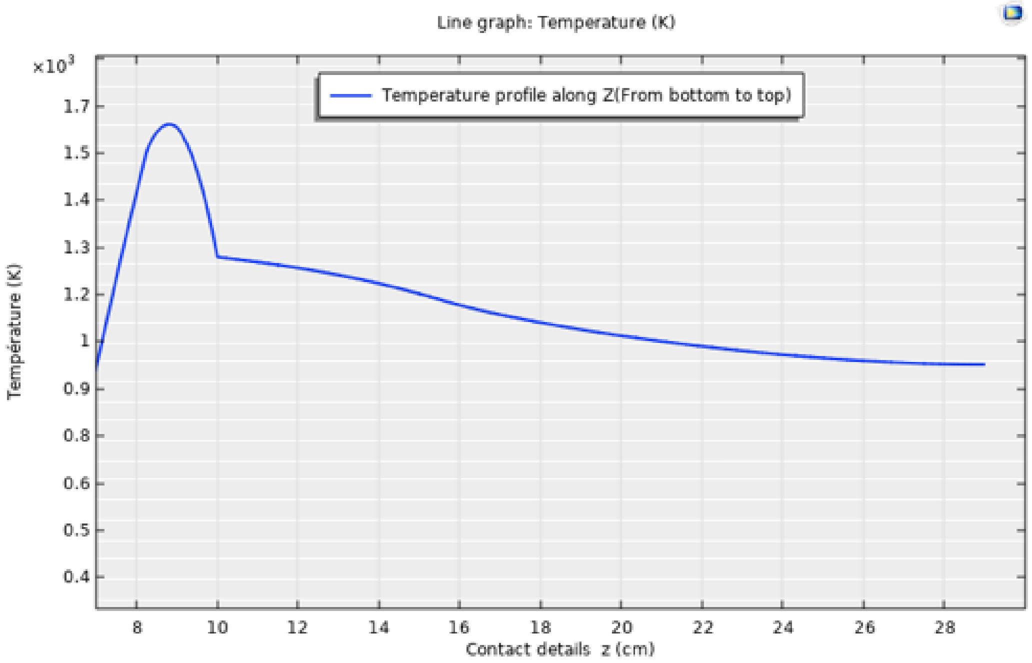

b)

Fig. 6. a) Temperature profile at the left wall of the furnace and b) Temperature profile inside the combustion chamber

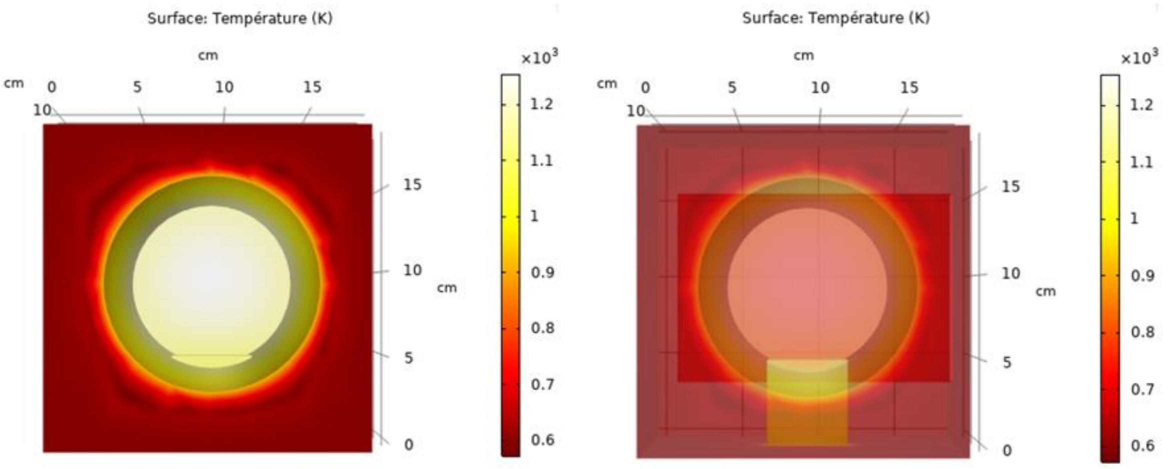

Fig. 7. Heat propagation along the X-Y surface

Table 9. Measured characteristics

Temperature difference (°C)		Voltage (V)	Current (A)	Power (W)
∆T	32.72	1.8	0.319	0.57
	38.18	2.1	0.37	0.78
	47.14	2.7	0.42	1.15
	54.28	3.2	0.46	1.47
	58.57	3.5	0.48	1.68
	86.66	5.2	0.60	3.13
	95	5.7	0.64	3.63

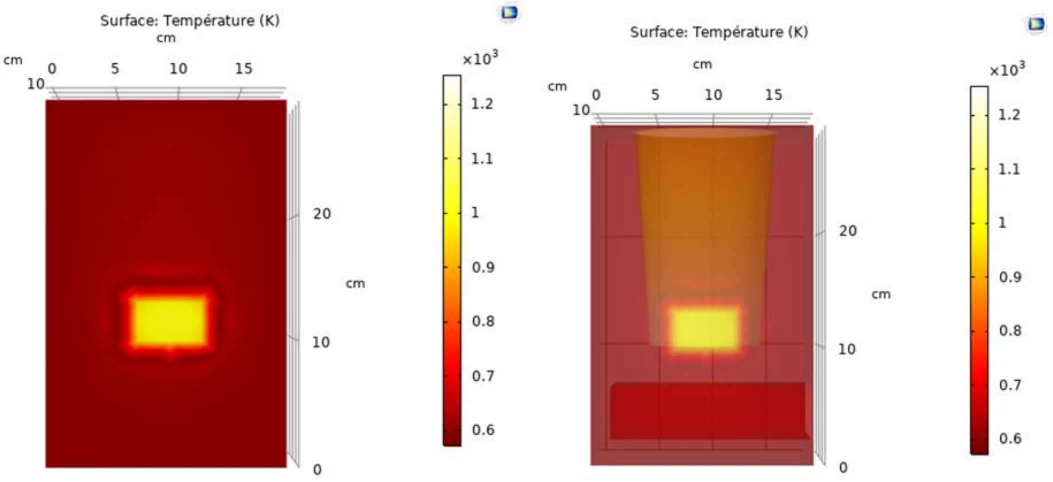

Fig. 8. Heat propagation along the Z-Y surface

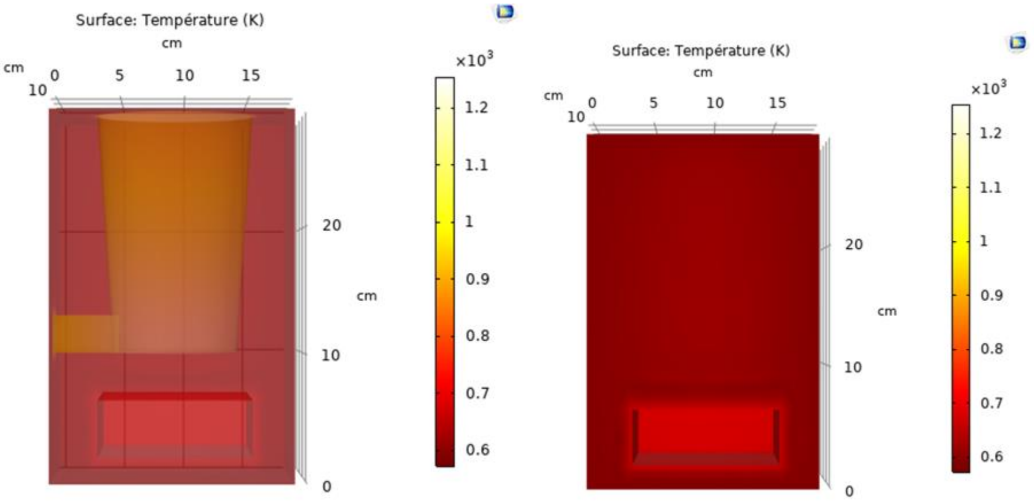

Fig. 9. Heat propagation along the Z-X surface

The practical efficiency is estimated at ηep = 20,98%. Based on this output, it takes 17 h of cooking, or 6h a day, for the modules to fully charge a 7Ah, 12V battery. The electrical power generated by the collectors is used to power the external loads listed in the Table 10.

3.4 Thermal and Thermoelectric Simulation of the System

Table 11 shows the electrical sizing parameters for the fireplace.

The fireplace is electrically self-sufficient and has a maximum theoretical electrical power of 97 W. It has 2 days of electrical autonomy. The storage system is powered by an 18Ah, 12V battery.

The thermal and electrical efficiencies obtained are shown in Table 12. A thermal efficiency of 24.64% and a practical electrical efficiency of 20.98%.

Table 13 provides a comparison with thermal efficiencies found in the literature.

Table 10. External electrical requirements to be supplied

Equipment	Power (W)	Quantity	Time of use (hr)	Daily Energy
Phone	15	1	2	30
Lamp	2	3	5	30
Total	21			60

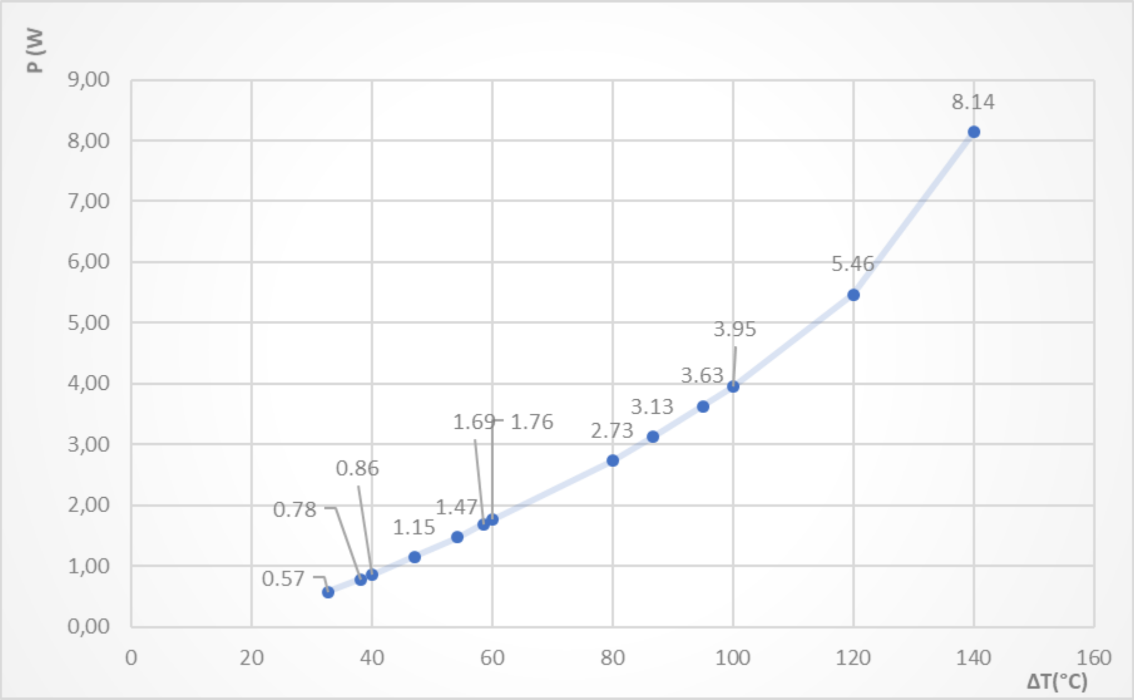

Fig. 10. Practical power generated as a function of temperature difference

Table 11. Electrical sizing results

Output	Theoretical	Practice
Power requirement P_{ne} (W)	55.42	55.42
Maximum power generated P_g (W)	97.67	43.56
Energy required E_{ne} (Wh)	266.53	266.53
Energy generated E_g (Wh)	586.05	261.37
Capacity required C_{ne} (Ah)	54.50	35.82
Number of batteries (N)	3.02	1.99

Table 12. Furnace thermal and electrical efficiencies

Thermal efficiency	Theoretical electrical Efficiency	Practical electrical efficiency
ηth = 24.64 %	ηet = 64.75%	ηep = 20.98%

Table 13. Thermal efficiencies of some fireplaces in the literature

Fireplace type	Composition	Thermal efficiency (%)	Reference
Fireplace with multi-marmite combustion chamber	Clay	22.05	[Segbefia et al. 2018]
Single-pot combustion chamber fireplace	Clay	20.15	
Malagasy home	Metal	18	
WANROU fireplace size 6		23.3	
WANROU fireplace size 8		23.5	[LBEB 2015]
WANROU fireplace size 10	Clay	23	
Charcoal fireplace	Clay	17.06	[Abasiryu et al. 2016]
Charcoal fireplace	Metal	20.02	
Orbagen		35	[Center for International Forestry Research 2021]
Butembo	Clay-metal	27	
Boyoma		24	
AFB		23	

Fireplace type	Composition	Thermal efficiency (%)	Reference
Foyer ASUTO or Toyola	Clay-metal	25	[Laboratoire sur l'Énergie Solaire, Université de Lomé 2010]
OUAGA	Metal	27	
Foyer Conique-UB	-	29	
FAN - C	-	25	
Ban ak Suuf	Clay and sand	24 - 35	[Louppe 2024]
Sakhanal	Metal	24 - 35	
3 Improved Stones (rustic fireplace)	Clay and sand	22 - 30	

The designed system meets the estimated thermal efficiency for its type. A comparative analysis of the data presented in the table reveals that the enhanced, self-contained fireplace exhibits superior performance when compared to traditional clay fireplaces, as well as some metal, clay-metal, and clay-sand fireplaces. However, its ability to recover thermal energy losses to produce electrical energy for lighting and telephone recharging makes it a high-value-added product compared with the various types of single-function fireplaces. Moreover, the fireplace is self-sufficient in terms of electrical energy, requiring no external supply.

4. CONCLUSION

This work focused on the development of an improved, electrically self-sufficient fireplace for the valorization of agricultural residues. The design incorporates a combustion chamber, constructed in clay, which is integrated with a range of electrical and electronic components. Simulations have shown that recovering the energy lost through wall dissipation and converting it into electrical energy is a key factor in optimizing energy efficiency, on the one hand, and ensuring the home's energy autonomy, on the other. The rest of the energy recovered is used to satisfy the user's external needs. This is what sets our system apart from other existing fireplaces.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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