

Study and Realization of a Light Version of the Aaron Stove

Stefano Bechis ^{1,*}  and Paolo Giglio ²¹ Interuniversity Department of Regional and Urban Studies and Planning, Viale Mattioli 39, 10125 Torino, Italy² Terresolidali NGO, Niamey P.O. Box 10388, Niger; paolo@paologiglio.net

* Correspondence: stefano.bechis@unito.it; Tel.: +39-0110907427

Abstract

One of the main causes of deforestation in Sub-Saharan Africa is the massive use of wood as a fuel for cooking. To address this problem, a pellet gasifier was designed and built. To eliminate wood consumption, the pellets used are produced from agricultural residues. To make the gasifier more economical, a redesign was carried out to produce the unit with less material. Starting from the original stove, certain parts were reduced and the gasification results were verified. The final result is a stove produced with 45% less material, with efficiency only dropping by 3%. Future developments of the project include the regulation of primary and secondary air access and the study of a biomass chip-fueled gasifier.

Keywords: biomass cooking; gasification stove; pellet making; household pollution; agricultural residues; deforestation

1. Introduction

The number of people relying on biomass for cooking in Africa has increased during recent decades [1–6]. The widespread use of biomass in the form of firewood and charcoal, mainly burned in three-stone fires or in simple cookstoves, contributes to the degradation of forests [7,8]. In some areas of sub-Saharan Africa, heavy deforestation also leads to objective difficulties in obtaining wood and charcoal for cooking, with fuel costs on the rise [9,10]. In addition, the burning of wood and charcoal produces a large amount of pollutants [11,12]. These pollutants cause very serious health problems for users, with the unfortunately well-known loss of human life in the millions each year [13–15].

In the years 2012–2015, a cooperation project in Niger, “Energies Durables dans les Régions d’Agadez et Tillabéri”, financed by the EU Energy Facility 2 program, tried to give answers to these problems. The strategy adopted was to develop and propose a cooking system that uses a different fuel than wood and charcoal [16]. The project leader was Terresolidali NGO, and the University of Turin was one of the partners.

This cooperation project focused on the design and production of an innovative gasification stove and the installation of a pellet production facility, working with agricultural residues and pruning.

The gasification process offers advantages over direct biomass combustion, such as greater efficiency and reduced smoke and pollutant production. Significant progress in terms of combustion efficiency and a reduction in smoke production has been achieved in the last fifteen years [17]. Pellet production plants are being introduced in African countries [18], focusing agricultural residues. Pellet burning has been found to be cleaner than burning raw biomass, benefitting the health of users [19,20].

Regarding the production of agricultural residues for pelletisation, potential synergy with agroforestry is envisioned. The latter represents an important opportunity to improve



Academic Editors: Fabrizio Scala and Maurizio Volpe

Received: 14 May 2026

Revised: 17 July 2026

Accepted: 29 July 2026

Published: 5 August 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and

conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

the current environmental situation and ensure the continuation of agricultural production even in disadvantaged areas thanks to its beneficial effects on soil and water conservation, biodiversity, and income diversification for farmers [21,22]. The emergence of a market for agricultural residues and pruning is a positive factor in increasing the potential for agroforestry to thrive. The two techniques effectively support each other: agroforestry simultaneously produces agricultural residues and pruning for use in pellet production, while pellet gasification creates a market for these agroforestry byproducts. From this perspective, the adoption of residues and pruning as fuel can help to overcome some of the barriers that slow down the adoption of agroforestry on a wider scale.

After the development of the abovementioned stove, research continued with the objective of producing a lighter unit to reduce the amount of metal required and manufacturing costs. Based on the design of the first stove, after applying a series of modifications, a new stove has been developed, reducing the quantity of iron sheet required to 54.8%. The process involved the production and testing of a series of prototypes.

2. Materials and Methods

2.1. The First Stove Realized

The first stove developed in the framework of the cooperation project, named Aaron, was designed by modifying the P-1 stove (Figure 1) previously built by the Brace Research Institute of Montreal (Montreal, QC, Canada) [23].

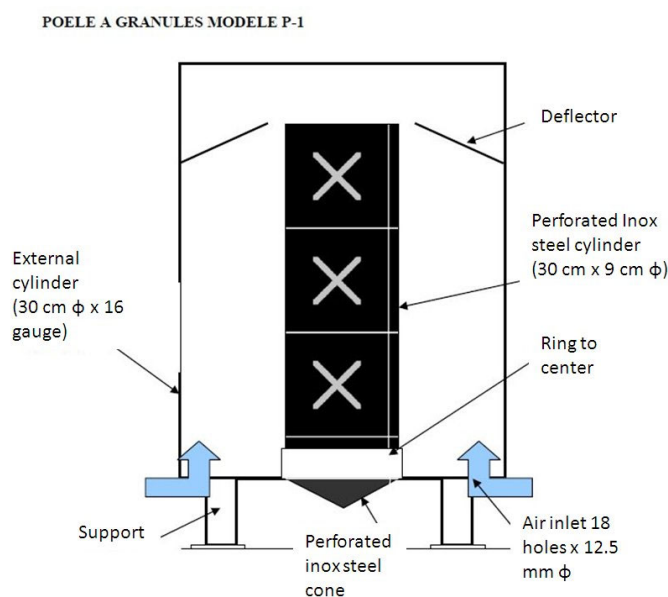


Figure 1. The P-1 stove designed by the Brace Research Institute.

The P-1 gasifier consists of two concentric cylinders, a deflector and a base disc. The internal cylinder is closed at the bottom by a perforated cone and contains the pellet to be gasified. Inside this internal cylinder is where the gasification reaction happens. The external cylinder together with the deflector has the function of conveying secondary air towards the area where the gas flames form.

The Aaron stove adopts this scheme, with the addition of a third cylinder.

These three cylinders are arranged one inside the other, in a concentric manner [24]. A technical drawing of the stove is represented in Figure 2. The thickness of the iron sheet is 0.6 mm.

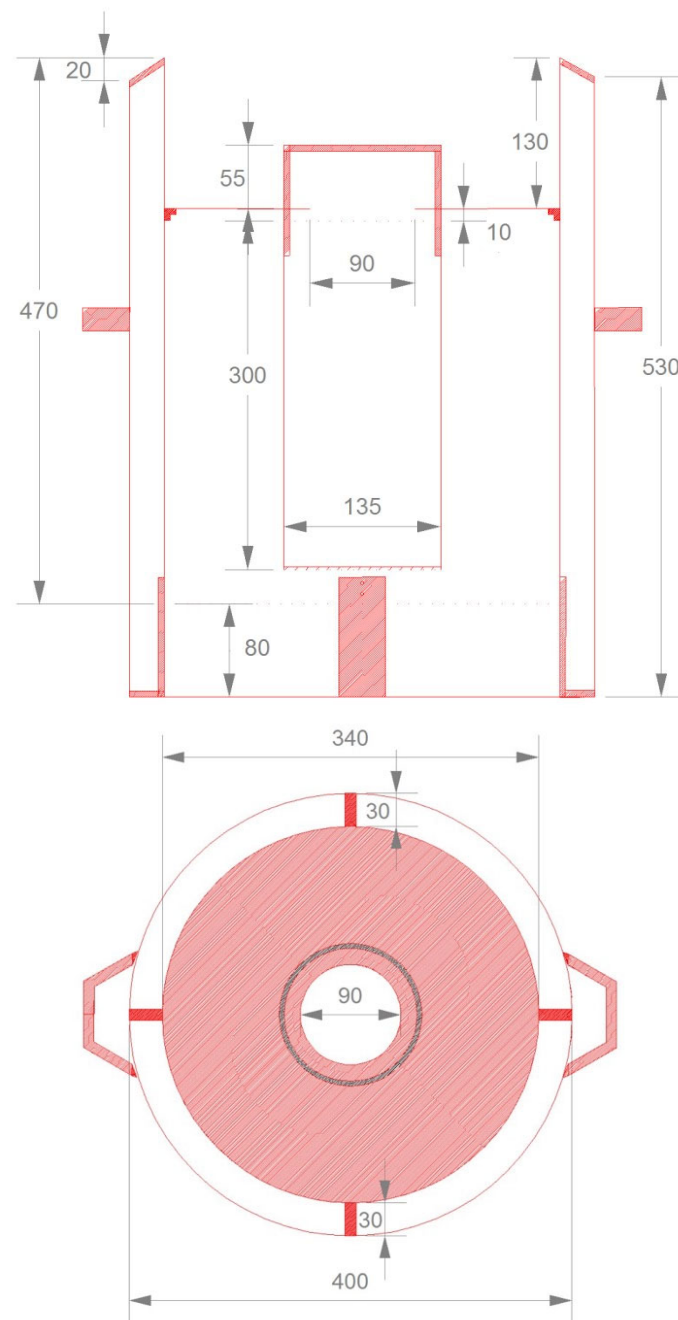


Figure 2. Technical drawing with measures of Aaron stove.

The innermost cylinder, the smaller of the three, has a diameter of 135 mm and contains the pellet to be gasified. It works as a reactor. Around the first cylinder, the second has a 340 mm diameter, and is intended to serve as a shelter from the wind for the flame area. The third and largest cylinder has a 400 mm diameter and is closed at the bottom by a metal disc. The two smaller cylinders are placed inside this last cylinder. The external cylinder has two functions: for safety, preventing users from touching the second cylinder, which gets very hot during operation, and for efficiency, recovering part of the heat that naturally flows outside the two inner cylinders thanks to the air that is forced to pass through the space between the third and the second cylinder to reach the inside of the stove.

The Aaron stove is loaded with 1.2 to 1.4 kg of biomass pellets. With this charge, the reactor is filled to two-thirds of its height, leaving 100 mm of empty space in the upper part. The mass is lit with a small amount of oil and a match (Figure 3). Simple combustion

begins with the pellets inside the reactor. A flame is formed in the reactor at the upper surface above the pellets. This first phase lasts about 3 min. As the reaction expands, a larger volume of pellets are drawn under combustion; the quantity of air filtering from below through the column of pellets is no longer sufficient to sustain complete oxidation, and, as a result, gasification begins. Partially oxidated gas moves upwards. At the upper end of the reactor, this gas meets the secondary air that comes from the space between the reactor and the medium cylinder. The gas and the oxygen in the secondary air ignite upon contact, forming the gas flame used for cooking.

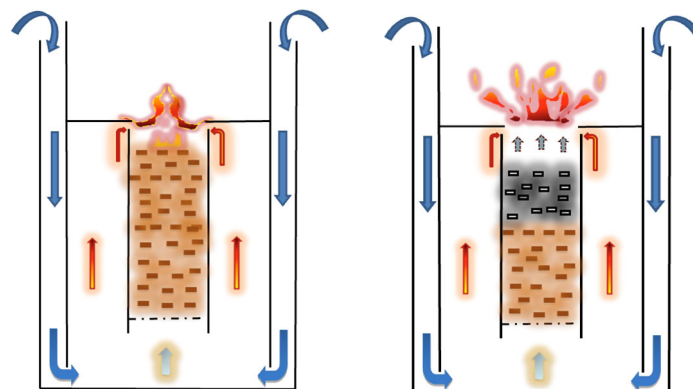


Figure 3. A section of the Aaron stove with air flow during the ignition phase (left) and during full gasification (right).

During operation, the heat developed inside the reactor causes the hot air to move upwards inside the two inner cylinders, specifically inside the reactor and in the space between the reactor and the second cylinder. The air that enters the reactor, the primary air, mixes and reacts with the gases developed by the gasification process. The air that flows upward in the space between the reactor and the second cylinder, the secondary air, flows out of this space through a circular slit where it meets the gases produced in the reactor. At this level, a gas flame develops. As the third cylinder is closed at the bottom, the external air is forced inside the stove from the upper part of the stove itself through the space between the second and third cylinder. Flowing downwards through this space, it is pre-heated.

The reaction progresses downwards, affecting a relatively thin horizontal layer of pellets; the mass above this layer is already gasified and the mass below this layer must undergo gasification (see Figure 3). When the reaction reaches the bottom of the reactor, the entire mass inside is transformed into biochar. If this biochar is extinguished with water at the end of cooking, it can still be used to for cooking in other stoves. If not, it remains in the gasifier, and a low-intensity combustion reaction continues at a temperature of approximately 120 degrees °C until it becomes ash. In this mode, it can keep freshly cooked food warm for 5 or 6 h. Biochar can also be applied to soils as an amendment, supporting carbon sequestration and water retention [25].

The manufacturing of one Aaron stove requires 1.511 square meters of iron sheet. In Sub-Saharan Africa, where the Aaron stove is intended to be used, a common raw iron sheet measures 2000 × 1000 mm. One sheet of iron is therefore required to manufacture one stove, leaving 0.489 square meters that can be used for further works or for a part of another stove.

2.2. Aim of Study

The aim of this study was to develop a smaller stove, manufactured with only one square meter of iron sheet, so that with a 2000×1000 commercial sheet, two stoves instead of one could be built, reducing material requirements and manufacturing costs.

2.3. Test Methodology

The process of developing the new stove involved the production and testing of a series of prototypes with the same general layout as that of the original stove, reducing the dimensions of certain parts. Only the reactor was left almost untouched as its dimensions are fundamental for the development of the gasification process. The reactor (inner cylinder) was also the smallest part of the stove, so no big material savings could be expected from modifications of this part. Efforts to reduce the dimensions of certain parts were concentrated on the second and third cylinder and the base disc. The process was as follows: building a prototype and testing it, making modifications and testing it until a new prototype incorporating all the necessary modifications was developed. Seven different prototypes have been built following this work scheme. The behaviour of each prototype of the “light” stove has been tested after every modification and based on the result the specific modification was either accepted or rejected. This process was repeated 82 times, following the 4.2.3 version of the Water Boiling Test methodology [26]. The test results, also obtained by other researchers [27], have been compared with those obtained for similar types of stoves [28–31].

To simulate the operating conditions for this stove as closely as possible, a typical aluminum pot with a convex bottom produced in Niger was used for the tests. These pots are widely used in the Sahel countryside, in peri-urban and urban areas. They come in different sizes; for the tests, a very common size known as “number 5” was used, with a total capacity of 12.0 dm^3 (Figure 4). The Water Boiling Test methodology involves filling the pot two-thirds full; so, in every test, the pot was filled with 8000 g of water.



Figure 4. A traditional aluminum round pot, number 5, on a stone fire (left) and during testing on the Aaron stove (right).

To reduce the quantity of iron sheet, modifications have been made under the condition of obtaining at least 90 min of continuous flame and 45% efficiency.

For all tests, the following measures have been recorded:

- Ambient temperature;
- The amount of water used;
- The temperature of water;
- The temperature inside the reactor;
- The number of pellets;

- The mass of biochar at the end of the process;
- The amount of water in the pot at the end of the process;
- The duration of the process.

Water and pellets were weighed using an electric scale, mod. Sartorius 1507 B MP 8-1, with two decimals. Measures were approximate to the gram.

Temperatures were measured using two T thermocouples inside the pot for water and a T thermocouple for ambient temperature; data sampling was performed every second and the average was recorded every minute using three Onset Hobo U12-014 dataloggers.

The temperature inside the reactor was monitored in one test using a K thermocouple directly placed into the pellets and connected to an Onset U12-014 Hobo datalogger.

From these measures the following parameters were calculated:

- Water temperature rise;
- The amount of water evaporated;
- Heat developed during gasification and burning;
- Heat absorbed by the water in the pot;
- The efficiency of the process.

Commercial wood pellet was used for the tests, as the pellet-making facility in Niamey was developed after the design and testing of the stove. The following values were used for the energy content of pellet and residue:

Energy content of pellet: calorific value (4.128 kcal/kg) $\times$ mass (kg);

Residue energy content of char: calorific value (6.689 kcal/kg) $\times$ mass (kg).

The energy developed by the stove during the process was calculated as the energy contained into the wood pellets charged into the reactor minus the energy still contained in the biochar in the reactor when the flame turns off.

$$\text{Energy developed} = \text{energy content in pellet} - \text{energy content in residue (char)}$$

The energy absorbed by the water was calculated as the sum of the heat used for the rise in temperature up to boiling point and the heat absorbed by the vaporization of water.

$$\text{Energy absorbed by the water} = \text{Heat to rise temperature} + \text{Heat for vaporization}$$

The amount of heat used for the rise in temperature is defined as $(Q) = mc \Delta T$ where:

Q = heat (kcal);

m = mass of water;

c = specific heat (1 cal/g °C)

ΔT = rise in temperature from the beginning of the test to the boiling temperature.

The amount of heat used for vaporization is defined as $(q) = m \times L_{vap}$

where:

q = heat (kcal);

m = mass of water vaporized;

L_{vap} = latent vaporization heat.

Efficiency is calculated as follows:

$$\text{Efficiency} = \frac{\text{energy absorbed by the water}}{\text{energy developed}}$$

The first Aaron stove, charged with 1400 g of pellets, recorded an efficiency of 51% and cooking times of 1 h and 50 min [29]. During practical tests with pellet produced in

Niger from agricultural residues, the thermal energy developed by a 1400 g charge has proven largely sufficient to cook a meal for the average family.

The temperature in the reactor reached 550 °C during the gasification phase.

A year after the Aaron gasifier was developed, the cooperative project was able to make pellets produced from agricultural residues in Niger thanks to the new pellet-making facility in the city of Niamey. These pellets were used in real-life cooking tests, carried out by the local people involved in the research.

Pellet made from millet stalks at the facility in Niamey has been analyzed by the Department of Chemistry of the University of Turin, measuring a density equal to 1.17 g/cm³. The calorific value has been measured equal to 2494 kcal/kg, determined with a bomb calorimeter.

3. Results

The two external cylinders have been reduced in diameter and height, and the base disc has been eliminated in order to limit the use of iron sheet to 0.857 square meters. The net surface of the elements comprising the stove is actually 0.829 square meters but to close the cylinders, some superposition between the two opposite ends was necessary. It was therefore necessary to make the sheets 32 mm longer for the medium cylinder and 62 mm longer for the external cylinder. These measures can vary depending upon the technique used to produce the cylinders from the plain iron sheet. The study, design and test routine continued until the achievement of a working time of one hour fifty minutes and 48% efficiency.

Tests were carried out from the month of June to February with different ambient temperatures. The effect of this difference is shown in Figure 5, where the maximum temperature achieved by the water in the pot declines after the first 50 tests as the last 32 tests were conducted in declining temperature conditions. The water evaporation curve shows an increase on the right part of the graph as a result of better optimization of the prototype. After test n. 73 the changes made to the prototype did not produce improvements. The characteristics of the stove have been fixed according to the test prototype that achieved the best efficiency.

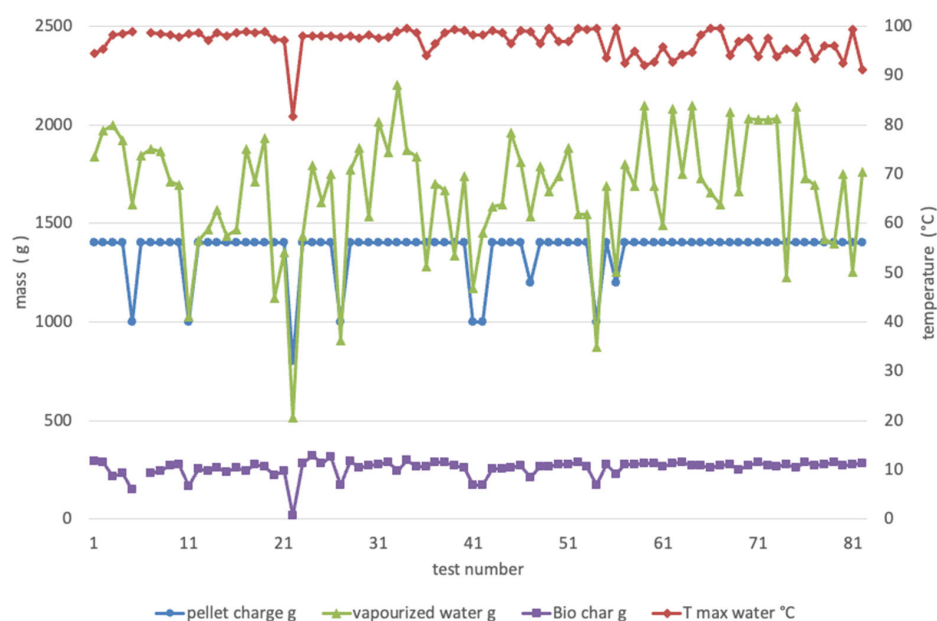


Figure 5. Some of the parameters recorded during the tests. On the x-axis, the test number is shown; on the left y-axis, the mass of pellet charge, vaporized water and remaining biochar are shown; on the right y-axis, the maximum temperature reached by the water is shown.

The energy involved in the process is reported in Figure 6, together with the calculated efficiency. The best results were achieved in tests n. 70, 71, 72 and 73, with efficiencies, respectively, of 48%, 49%, 48% and 47%.

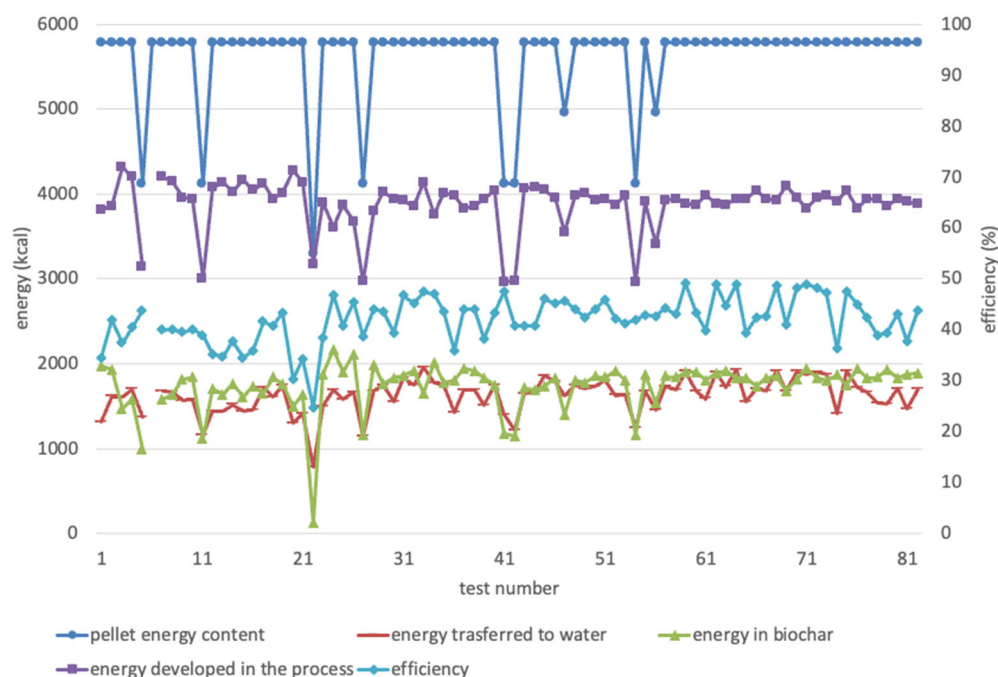


Figure 6. Energy involved in the gasification process during the tests and the resulting efficiency.

The goal of building two new stoves with a commercial 2000×1000 iron sheet has been achieved. Starting from the first Aaron stove, the dimensions of the second and third cylinder have been reduced significantly. The iron disc at the base of the stove has been eliminated.

The internal cylinder that carries the pellet (reactor) is the core of the stove and had to be preserved to assure the conventional development of the gasification reaction. Its diameter was reduced by only 5 mm, not to reduce material requirements but to slow down the gasification reaction, which had been somehow accelerated by the new air path defined by the new architecture of the stove.

The second cylinder has been reduced significantly both in diameter and height. The lower part of the second cylinder does not cover the inner cylinder (reactor), as in the previous version, but spans approximately half of the reactor's length.

The third (external) cylinder has been reduced by 50 mm in diameter and 30 mm in height. The external cylinder of the Aaron light stove encompasses the stove, protects the flame from the wind, and keeps the heat close to the pot. These functions were performed by the second cylinder in the first stove. The third cylinder still serves to protect users from accidental contact with the hot internal parts. The differences in the dimensions of the different parts comprising the two stoves are detailed in Table 1.

The external dimensions of the Aaron light stove are reduced when compared to the original Aaron stove (Figure 7). The weight of the Aaron stove reaches 8 kg, whereas the weight of the Aaron light stove remains under 5 kg, with both stoves made with 0.6 mm thick iron sheet.

Table 1. Measures, in square meters, of the different elements of the Aaron stove and the Aaron light stove.

Element	Aaron Stove	Aaron Light Stove
external cylinder diameter	0.400	0.350
external cylinder height	0.530	0.500
external cylinder area	0.666	0.550
middle cylinder diameter	0.340	0.200
middle cylinder height	0.470	0.200
middle cylinder area	0.502	0.126
internal cylinder diameter	0.135	0.130
internal cylinder height	0.300	0.300
internal cylinder area	0.127	0.122
bottom disc area	0.126	-
upper disc area	0.091	0.031
TOTAL AREA	1.511	0.829



Figure 7. A lateral view of the original Aaron stove (left) and the Aaron light stove (right).

However, looking at the two stoves from above (Figure 8), the important reduction in size of the second (medium) cylinder is clearly visible. The absence of a bottom iron sheet in the Aaron light stove is also easily seen.



Figure 8. The view from above of the original Aaron stove (left) and the Aaron light stove (right). To better sustain the pot, an iron ring can be welded to the three supports, like in the center of the original stove on the left.

The disposition of the elements in the original Aaron stove and in the Aaron light stove is reported in Figure 9. While the internal and external cylinder have had minor

adjustments, the second cylinder has undergone major changes. In the light version, the base disc (part n. 4 in Figure 9) has been eliminated.

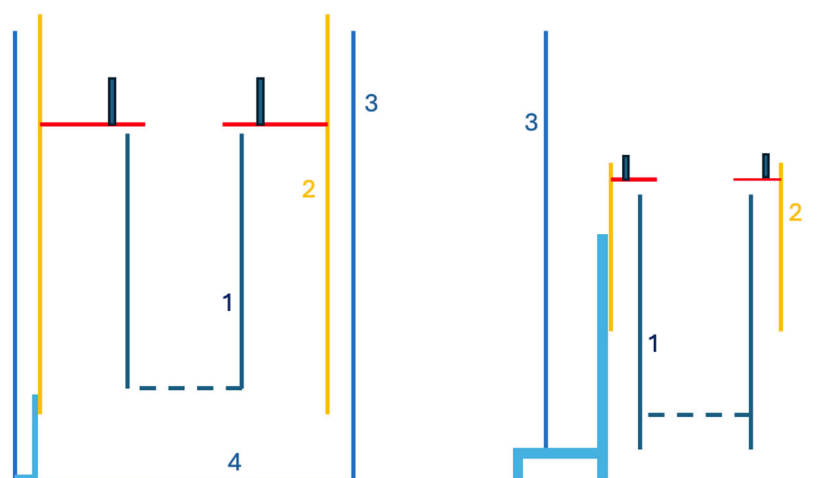


Figure 9. A section of the Aaron stove (**left**) and the Aaron light stove (**right**). 1—internal cylinder (reactor), 2—second cylinder, 3—external cylinder, and 4—base disc.

The change in disposition of the elements involved a change in the air path. In the original Aaron stove, external air is forced to enter the stove from above as the base of the stove is closed by the base disc (Figure 3). The air then flows inside the space between the second (medium) and third (external) cylinder. This movement of air is sustained by the draw of hot air in the flame area. In the Aaron light stove, there is a gap between the lower part of the external cylinder and the ground. The external air enters the stove from this gap (Figure 10). It is then heated by the reactor and the second cylinder and flows naturally upwards.

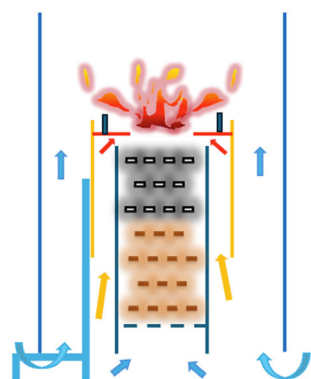


Figure 10. Air movement inside the Aaron light stove. The supports on the right of the stove are not reported in this drawing to visualise the gap between the external cylinder and the ground.

The proportions of the three cylinders of the Aaron light stove can be seen in Figure 11, where the external cylinder has been removed.

A technical drawing of the Aaron light stove is reported in Figure 12.

Flat development of the elements comprising the stove and the scheme for cutting a 2000 × 1000 mm iron sheet into the required parts for manufacturing two stoves are reported in Figure 13.



Figure 11. The Aaron light stove with the external cylinder removed. On the left is the external cylinder, on the right is the second (medium) cylinder, and inside it is the inner cylinder and the reactor, with its lower part visible.

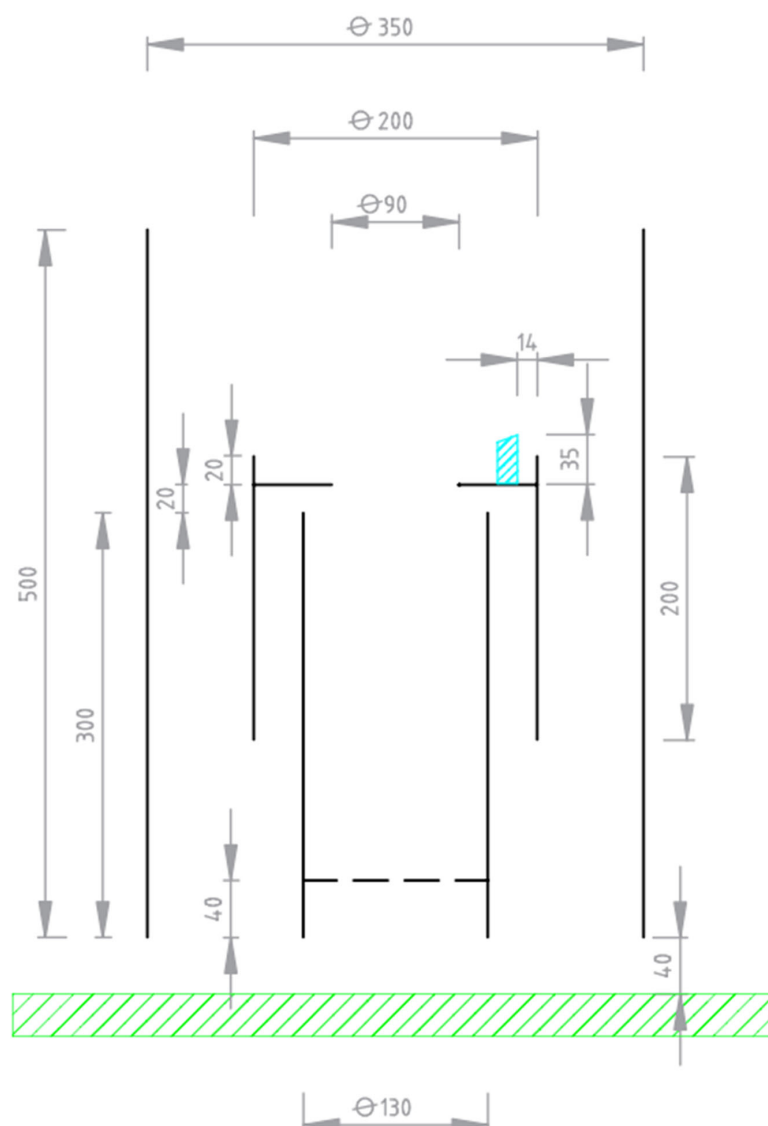


Figure 12. Technical drawing of Aaron light stove with measurements (mm).

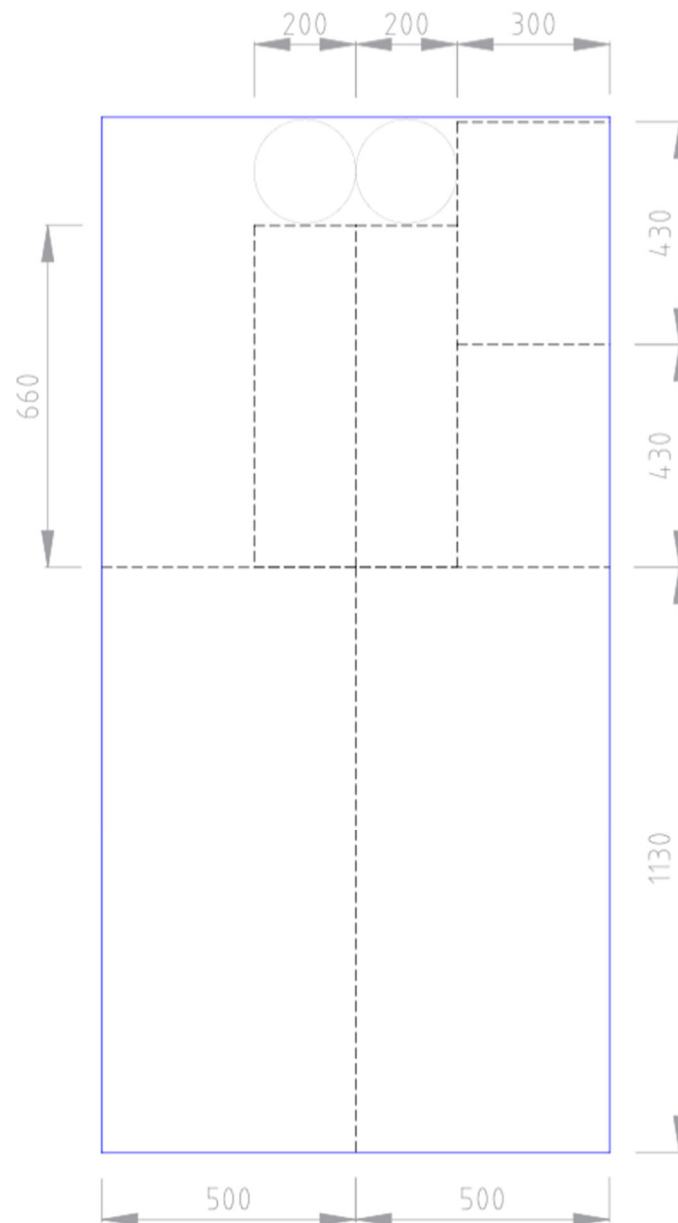


Figure 13. A scheme of the metal cut into a 2000×1000 mm iron sheet for the manufacturing of two Aaron light stoves (measurements in mm).

In parallel with the WBT that prescribes the use of the pot without a lid, several tests with the lid on the pot were carried out to assess the time needed to reach boiling temperature and its duration. These tests are important to allow us to assess the effective suitability of the stove to meet the needs of the preparation of the most popular dishes, like *riz sauce*. Monitoring the temperature rise and the time required, it was possible to calculate the power transferred instantly to the water inside the pot (Figure 14).

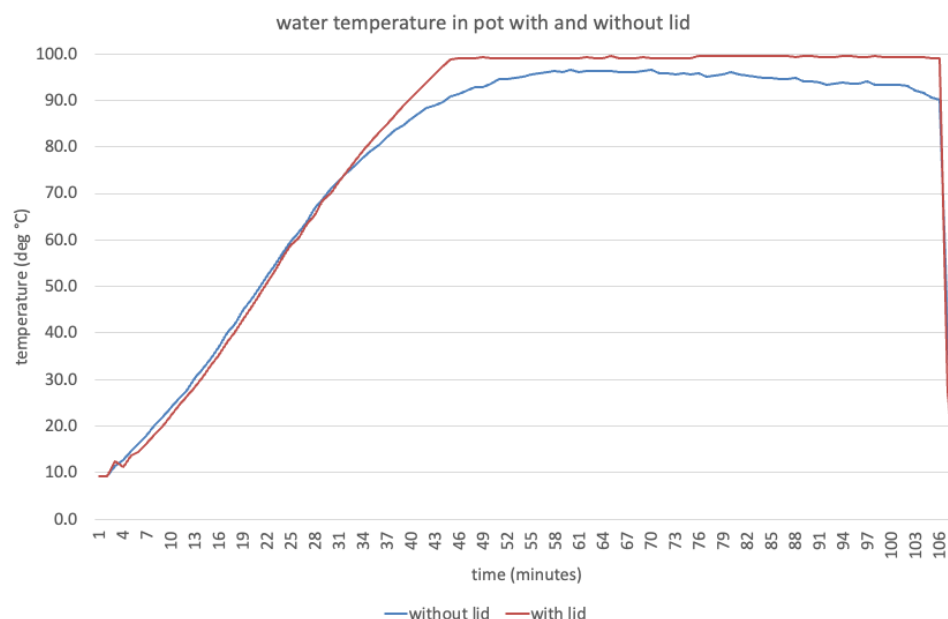


Figure 14. Two tests carried out on the same day with the same configuration. Reactor diameter: 130 mm, length 310 mm; intermediate cylinder: diameter 220 mm, length 345 mm. Test number L55: without lid, final efficiency 44%; test number L56: with lid, final efficiency 42.5%.

Considering test number L56 (red line in Figure 14), analysing the most regular and steep part of the temperature curve, from minute 13 to minute 25, a rise in temperature of 29.7 degrees for 8000 g of water is equal to the transfer of 237.76 kcal. As this happens in 12 min, the heat transfer on an hourly basis is equal to 1188.8 kcal/h, or 1.38 kW.

As can be seen in Figure 14, the heating phase of the water inside the pot with the lid on lasts about 45 min, and the following simmering phase lasts about one hour before the flame goes out. The tests were carried out in a location 413 m above sea level, where the boiling point of water is 98.6 °C in standard atmospheric pressure conditions. The curve of the water in the pot without a lid tends to reach the maximum temperature after 45 min because of intense evaporation and heat loss towards the air above the pot. The maximum temperature reached without the lid was 96.4 °C.

The total duration of combustion in the Aaron light stove is 1 h and 50 min, with a charge of 1400 g of pellets. It equals the performance of the original Aaron stove and satisfies the time needed for cooking.

Average recorded efficiency values are around 48%, with the best value reaching 49.2% in one test. In comparison with the original Aaron stove, efficiency reduction is around 3%, which is a reasonable value, considering the reduction in manufacturing material of around 45%.

As for the Aaron stove, if the reactor is charged with a lower quantity of pellet, for example 1200 or 1000 g, the gasification reaction becomes faster, resulting in a stronger flame and shorter combustion times. This behaviour can be explained by the fact that the resistance at the air flow in the pellet mass becomes weaker when the reactor is only partially filled, as the path inside the pellet mass is shorter.

The Aaron light stove, like the original Aaron stove, has no air flow adjustment; to ensure a constant flame, a balance between the dimensions of the reactor and the length and width of the air paths is necessary. Some solutions to reduce the air flow have been tested, but none have been successful so far.

A 1400 g pellet charge is sufficient to enable cooking for the average Sahel family including six to seven members.

The cooperation project introduced the first pellet-making machines in Niger. An unexpected development was the interest it sparked among farmers. Tests were carried out to make pellets with the softest part of sorghum stalks and millet. The resulting pellet was easier to store and transport than the raw material, and animals consumed it without any problems. Tests were carried out with the hardest part of the stalks. After passing into the mill and the pelletizer, even plant parts not normally consumed by animals were found to be palatable. Laboratory analyses were carried out in Italy by Neolac laboratory on samples collected in Niger:

- Millet straw.
- Millet straw with leaves.
- Straw from grass.
- Niebé leaves (cowpea, *Vigna unguiculata* L.).
- Niebé flour.

All the samples were found to be suitable for animal consumption.

The first stoves were manufactured in 2014. They still work after 12 years. Maintenance is reduced to the cleaning of parts and the net at the bottom of the reactor. If the reactor develops cracks due to alternating temperatures, it can be opened and replaced. This requires cutting the reactor at the support level and welding in a new reactor. Operators must be careful not to cause thermal shock to the reactor. For example, the use of water to extinguish the flame or to cool down the biochar can cause damage.

The new light stoves are built with the same material and undergo the same use. It can be assumed that they have the same duration as the old stoves.

Beyond the 82 tests performed to develop the new stove design, 8 extra combustion and gasification tests have been carried out with wood chips. These tests will form the basis of further development of the Aaron project. Chip production is simpler than pellet production, requiring only one machine instead of two and a lower specific quantity of energy for the transformation process.

4. Discussion

A light version of the Aaron stove has been successfully designed, built and tested. It satisfies all the goals that were set out for its development: with one sheet of metal measuring 2000×1000 mm, it is possible to build two stoves; its efficiency is only 3% lower than that of the original Aaron stove; and its combustion time is sufficient for the preparation of a meal for the average Sahel family when charged with 1400 g of pellet.

The availability of pellets is fundamental for the adoption of the Aaron light stove by families. Small pellet-making machines should be considered to set up “light” pellet-making facilities, enabling small-scale production in rural or peri-urban areas. To make pellet production possible, a balance must exist among the agricultural residues available in the area, pellet-making facility production, and the number of stoves. In an ideal situation, the stoves should be able to use all the pellet produced daily by the facility.

The main limitations of the new stove are that it is not possible to add pellet during combustion, and there is a lack of regulation of primary and secondary air flow. The next prototype will focus on these issues, along with the possibility of gasifying biomass organized in the form of chips. Technically, adding pellets to the reactor during the reaction would be feasible, but this would complicate the stove’s structure, which would contradict the underlying design requirement of a simple and low-cost stove. Primary and secondary air flow regulation is the basis to further improve stove performance [32–34]. To regulate primary and secondary air flow, a relatively simple solution would be to close the existing air inlets and use vented inlets instead. However, this would also contradict the requirements of simple construction and low cost. Therefore, future research will focus on

finding a solution that regulates air flow based on the natural draft generated by the heat developed in the reactor.

Measurement of the quantity and composition of gases released from the combustor has not been the object of this study [35]. This still has to be carried out in the future.

Dealing with the use of chips instead of pellets will involve a new design for a new gasifier stove, considering the differences in terms of the density of the material to be gasified, the dimensions of the chips and the resistance to air flow into the mass.

Author Contributions: Conceptualization, S.B. and P.G., methodology, S.B., investigation S.B. and P.G., writing-original draft preparation S.B. and P.G., writing-review and editing S.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: This research has been carried out testing prototypes and recording their working parameters. Therefore the recorded data are stored in the archives of the authors and can be received upon request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Bonjour, S.; Adair-Rohani, H.; Wolf, J.; Bruce, N.G.; Mehta, S.; Prüss-Ustün, A.; Lahiff, M.; Rehfuess, E.A.; Mishra, V.; Smith, K.R. Solid fuel use for household cooking: Country and regional estimates for 1980–2010. *Environ. Health Perspect.* **2013**, *121*, 784–790. [PubMed]
2. Ayoub, J. *Energy Requirements for Cooking in the Developing Areas of the World*; Report no. F-38; Brace Research Institute: Montreal, QC, Canada, 1986.
3. Roth, C.; Andreson, P.; McLaughlin, H.; Homlinson, T.; Wilson, K. Micro-Gasification: Cooking with Gas from Dry Biomass 2nd Revised Edition. GIZ HERA. 2014. Available online: https://energypedia.info/images/0/05/Micro_Gasification_2.0_Cooking_with_gas_from_dry_biomass.pdf (accessed on 15 April 2025).
4. Stoner, O.; Lewis, J.; Martínez, I.L.; Gumy, S.; Economou, T.; Adair-Rohani, H. Household cooking fuel estimates at global and country level for 1990 to 2030. *Nat. Commun.* **2021**, *12*, 5793. [CrossRef] [PubMed]
5. IEA. Africa Energy Outlook. 2022. Available online: <https://www.iea.org/reports/africa-energy-outlook-2022> (accessed on 15 April 2025).
6. IEA. *World Energy Outlook 2025*; IEA: Paris, France, 2025.
7. Department of Economic and Social Affairs. The Global Forest Goals Report 2026. United Nations. 2026. Available online: <https://forests.desa.un.org/> (accessed on 17 June 2026).
8. FAO. *Sustainability by Numbers—Forest Production at FAO*; FAO: Rome, Italy, 2023. [CrossRef]
9. Zulu, L.C.; Richardson, R.B. Charcoal, livelihoods, and poverty reduction: Evidence from sub-Saharan Africa. *Energy for Sustainable Development.* **2013**, *17*, 127–137.
10. Makungwa, S.D.; Epulani, F.; Woodhouse, I.H. Fuelwood supply: A missed essential component in a food security equation. *J. Food Secur.* **2013**, *1*, 49–51.
11. Ravindra, K.; Singh, T.; Mor, S. Emissions of air pollutants from primary crop residue burning in India and their mitigation strategies for cleaner emissions. *J. Clean. Prod.* **2019**, *208*, 261–273.
12. Mitchell, E.J.S.; Ting, Y.; Allan, J.; Lea-Langton, A.R.; Spracklen, D.V.; McFiggans, G.; Coe, H.; Routledge, M.N.; Williams, A. Pollutant emissions from improved cookstoves of the type used in Sub-Saharan Africa. *Combust. Sci. Technol.* **2019**, *192*, 1582–1602.
13. Mabonga, F.; Beattie, T.K.; Luwe, K.; Morse, T.; Hope, C.; Beverland, I.J. Exposure to air pollution in rural Malawi: Impact of cooking methods on blood pressure and peak expiratory flow. *Int. J. Environ. Res. Public Health* **2021**, *18*, 7680. [PubMed]
14. Kim, K.-H.; Jahan, S.A.; Kabir, E. A review of diseases associated with household air pollution due to the use of biomass fuels. *J. Hazard. Mater.* **2011**, *192*, 425–431. [PubMed]
15. Mortimer, K.; Lesosky, M.; Semple, S.; Malava, J.; Katundu, C.; Crampin, A.; Wang, D.; Weston, W.; Pope, D.; Havens, D.; et al. Pneumonia and exposure to household air pollution in children under the age of 5 years in rural Malawi. *Chest* **2020**, *158*, 501–511. [CrossRef] [PubMed]
16. Bechis, S. Possible impact of pelletised crop residues use as a fuel for cooking in Niger. In *Renewing Local Planning to Face Climate Change in the Tropics*; Bridging Modern and Traditional Knowledge; Tiepolo, M., Pezzoli, A., Tarchiani, V., Eds.; Springer Nature: Berlin/Heidelberg, Germany, 2017. Available online: <https://link.springer.com/book/10.1007%2F978-3-319-59096-7> (accessed on 19 September 2024).

17. Hayyat, U.; Khan, M.U.; Farooq, M.; Sultan, M.; Amjed, M.A.; Liu, G.; Chunyu, X.; Riaz, F.; Alkhedher, M. Recent developments and challenges in biomass cookstove. *Energy Rep.* **2024**, *12*, 2193–2208. [\[CrossRef\]](#)
18. Apraku, S.E.; Shen, Y. Biomass pellet fuel production and utilization in Ghana: A review. *ACS Sustain. Resour. Manag.* **2024**, *1*, 586–603. [\[CrossRef\]](#)
19. Owusu, F.; Kuranchie, F.A.; Odonkor, S.; Frimpong, K.; Muri, M. Biomass stove for pelletized sawdust fuel in Ghana. *Combust. Sci. Technol.* **2019**, *192*, 1719–1730. [\[CrossRef\]](#)
20. Champion, W.M.; Grieshop, A.P. Pellet-fed gasifier stoves approach gas-stove like performance during in-home use in Rwanda. *Environ. Sci. Technol.* **2019**, *53*, 6570–6579. [\[CrossRef\]](#) [\[PubMed\]](#)
21. Mbow, C.; Van Noordwijk, M.; Luedeling, E.; Neufeldt, H.; Minang, P.A.; Kowero, G. Agroforestry solutions to address food security and climate change challenges in Africa. *Environ. Sustain.* **2014**, *6*, 61–67.
22. Bhandari, S.; Paudel, S.; Upadhaya, S. Socio-economic and environmental benefits of agroforestry and its multilevel barriers to adoption: A systematic review. *Sustainability* **2025**, *8*, 5.
23. Brace Research Institute. *Conception de Poêles Multifonction à Biomasse Densifiée en Granules Pour Usages Domestiques et Communautaires*; Report No. I-378-P-267; Faculty of Engineering, Brace Research Institute, McGill University: Montreal, QC, Canada, 1999.
24. Bechis, S.; Barigazzi, F.; Giglio, P.; Lawand, T.A. The Aaron stove, switching to agricultural residues to save firewood. In Proceedings of the 2014 ASABE/CSBE Annual International Meeting, Montreal, QC, Canada, 13–16 July 2014. Paper n. 1890993.
25. Sundberg, C.; Karlton, E.; Gitau, J.K.; Kätterer, T.; Kimutai, G.M.; Mahmoud, Y.; Njenga, M.; Nyberg, G.; de Nowina, K.R.; Roobroeck, D.; et al. Biochar from cookstoves reduces greenhouse gas emissions from smallholder farms in Africa. *Mitig. Adapt. Strateg. Glob. Change* **2020**, *25*, 953–967. [\[CrossRef\]](#)
26. Clean Cooking Alliance. The Water Boiling Test Version 4.2.3. 2014. Available online: <https://cleancooking.org/protocols/> (accessed on 10 February 2022).
27. Boubacar, S. *Resultats des Tests sur le Foyer Aaron*; CNES, Centre National d’Energie Solaire: Niamey, Niger, 2013.
28. Brunet, E.; Ayoub, J.; Alward, R. Performance of Improved Household and Community Fuelwood Cookstoves. In Proceedings of the Solar Energy Society Conference, Renewables ’94, Ottawa, ON, Canada, 14–18 February 1994.
29. Odesola, I.F.; Ige, E.O.; Yunus, I.O. Design and performance evaluation of energy efficient biomass gasifier cook stove using multi fuels. *J. Energy Res. Rev.* **2019**, *3*, 1–7. [\[CrossRef\]](#)
30. Kurmi, O.P.; Jain, S.; Tyagi, S.K. Performance assessment of an improved gasifier stove using biomass pellets: An experimental and numerical investigation. *Sustain. Energy Technol. Assess.* **2022**, *53*, 102432. [\[CrossRef\]](#)
31. Champion, W.M.; Shen, G.; Williams, C.; Virtaranta, L.; Barnes, M.; Christianson, C.; Hays, M.D.; Jetter, J.J. Evaluating the laboratory performance of pellet-fueled semigasifier cookstoves. *Environ. Sci. Technol.* **2025**, *59*, 2006–2017. [\[CrossRef\]](#) [\[PubMed\]](#)
32. Kirch, T.; Birzer, C.H.; van Eyk, P.J.; Medwell, P.R. Influence of primary and secondary air supply on gaseous emissions from a small scale staged solid biomass fuel combustor. *Energy Fuels* **2018**, *32*, 4212–4220. [\[CrossRef\]](#)
33. Caubel, J.J.; Rapp, V.H.; Chen, S.S.; Gadgil, A.J. Practical design considerations for secondary air injection in wood-burning cookstoves: An experimental study. *Dev. Eng.* **2020**, *5*, 100049. [\[CrossRef\]](#)
34. Himanshu; Parameswaran, S.P.; Kurmi, O.P.; Tyagi, S.K. Development of a forced draft gasifier stove with optimized insulation and airflow rates: An experimental study. *Clean Technol. Environ. Policy* **2024**, *27*, 3807–3823. [\[CrossRef\]](#)
35. Jetter, J.; Zhao, Y.; Smith, K.R.; Khan, B.; Yelverton, T.; DeCarlo, P.; Hays, M.D. Pollutant emissions and energy efficiency under controlled conditions for household biomass cookstoves and implications for metrics useful in setting international test standards. *Environ. Sci. Technol.* **2012**, *46*, 10827–10834. [\[CrossRef\]](#) [\[PubMed\]](#)

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.