Smart Grid and Renewable Energy, 2025, 16(12), 219-234
https://www.scirp.org/journal/sgre
ISSN Online: 2151-4844
ISSN Print: 2151-481X

Design, Construction, and Testing of a Fresnel Reflector Solar Cooker

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How to cite this paper: Mogmenga, L., Soré, S., Ky, T.S.M., Soubeiga, W.S.F., Ouedraogo, E., Dianda, B., Nana, G.G., Hartiti, B., Thevenin, P., Kam, S. and Bathiebo, D.J. (2025) Design, Construction, and Testing of a Fresnel Reflector Solar Cooker. *Smart Grid and Renewable Energy*, **16**, 219-234.
https://doi.org/10.4236/sgre.2025.1612013

Received: October 2, 2025
Accepted: November 5, 2025
Published: December 31, 2025

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Abstract

A linear system with Fresnel reflectors as a concentrator was designed, built, and tested for solar cooking. It consists of 17 reflectors (blades) made of 1 mm thick aluminum sheet metal, mounted on a metal support to ensure their alignment. The system has a geometric concentration of 17. The system is difficult to operate because the blades must be individually and manually oriented according to the sun. A series of tests was conducted from May to June in Ouagadougou, Burkina Faso, at a latitude angle of 12.21˚. Experiments involving 1.5 liters of oil and water in pots were conducted with and without glazing around the pots. On May 15, 2025, we obtained a maximum temperature of 118˚C at 12:26 p.m. for the oil and 83.2˚C at 11:41 a.m. for the water. The experiments with glazing reached maximum temperatures of 112.5˚C at 2:11 p.m. for the oil and 104.6˚C at 1:36 p.m. for the water on May 30, 2025. Spaghetti, rice, soy skewers, and fish dishes were cooked in a reasonable amount of time and ready for lunch.

Keywords

Cooker, Fresnel, Efficiency, Solar, Concentration

1. Introduction

Solar energy is converted into thermal energy in several applications, such as solar dryers for drying fruits and vegetables [1] [2], solar heaters for heating homes [3]

[4], solar distillers for evaporating water [5] [6], and solar cookers for cooking food [7]-[9]. Solar cookers are a sustainable and economical solution for cooking food, particularly in regions with high levels of sunshine and limited access to energy. In Burkina Faso, the annual solar flux is 1024 $kWh \cdot m^{-2}$ [10]. In sub-Saharan Africa, more than 900 million people do not have access to clean cooking appliances [11] [12].

Solar cookers are classified into two (2) groups: with or without storage [11]. In addition to this classification, three technologies generally compete to meet solar cooking needs: 1) Concentrating solar cooking systems such as parabolic cookers, cylindro-parabolic cookers [13], spherical cookers [14], the RAC (Ring Array Concentrator) cooking system [15] [16], the Scheffler-type cooking system [17] [18], and cooking systems using Fresnel reflectors [9]. Their operating process consists of deflecting the sun's rays hitting the reflector toward the receiver, which is the pot containing the food to be cooked, located at the focal point. The deflection occurs according to the profile of the reflector. These systems generally need to be oriented toward the sun. Some require precise alignment to function, necessitating an automatic motor to control the tracking process [19]. 2) Indirect solar cooking systems [20]-[25] that function like dryers, in which the collector is separate from the receiver. It is very often fixed or barely mobile, with a network of tubes containing a fluid that collects heat and transfers it to the cooking chamber. 3) Box-type solar cooking systems [26]-[31]. In this type of system, the box is designed to be as immobile as possible, less complicated to orient, and sufficiently reflective. The cover is usually glazed to create a greenhouse effect. The concentration ratio of these systems is considered high if it is between 10 and 15 [32].

Fresnel linear reflector technology has many applications. Small-scale Fresnel linear reflectors are used in the construction industry, unlike large-scale Fresnel linear reflectors, which are used in energy production and industrial operations [33]-[36]. The angle of incidence of solar radiation on the receiver tube will be determined in two projection planes [37]: the transverse angle of incidence and the longitudinal angle of incidence, taking into account a linear Fresnel reflector oriented in a north-south direction [38] [39].

Not all solar rays are reflected by the mirrors in the longitudinal plane and reach the absorber tube [40]-[43]. Final losses are the result of this phenomenon [44]. However, some of the solar rays are reflected by the mirrors and do not reach the absorber tube. The latitude of the site, the time of evaluation, and the geometry of the mirror field all affect the final losses of the absorber tube [45]. The rows of mirrors and the absorber tube in large-scale linear Fresnel reflectors have an angle of 0˚ with the horizontal plane. Furthermore, the absorber tube and rows of mirrors cannot move longitudinally due to their size. In this case, the rows of mirrors can be rotated around a north-south axis in order to follow the daily movement of the sun (transverse movement). In this case, the final efficiency is approximately 97% due to the size of the absorber tube and the height of the receiver in Almeria (Spain) [46], and the loss of reflected light is not generally taken into account in the mathematical expression commonly used to calculate the power absorbed by the absorber tube [44] [47] [48]. Fresnel power plants typically use direct steam generation to improve efficiency and reduce costs. They are known to be less space-intensive than traditional parabolic trough plants, requiring approximately 1.3 ha/MW. One of the largest plants in operation is the Augustin Fresnel 1 plant in France, which has a production capacity of 250 MW. This plant uses water as a heat transfer fluid, which leaves the heat collection field at 300˚C. The operating pressure of the turbine is 100 bar. The plant began generating electricity for the grid in 2012 [49].

Given Burkina Faso's high levels of sunshine, solar ovens should be a common means of cooking. However, charcoal, wood, and agricultural waste are regularly used for cooking, despite the country's geographical disadvantage of being close to the Sahara Desert [7] [8]. Cooking with these solar systems does not take place in Burkina Faso, probably due to the considerable inconveniences of rigorous sun tracking; alignment with the sun for most systems must be very precise for these systems to work. Ideally, the process of tracking the sun is best when automated, which means that electricity is required, thus limiting access in rural areas where the electrical grid often does not exist. Another aspect to consider is the frequency of operation of the tracking system. Indeed, a new solar technology that requires users to radically change their habits compared to the traditional method does not convince them. However, the fact that users must prepare all the ingredients in advance or that they can peel, cut, or wash the ingredients while using the sun tracking device at the same time will increase their enthusiasm for using the technology.

The advantages and disadvantages of concentration systems are listed in **Table 1** below [48].

Among the various solar concentration technologies, the use of a reflector based on Fresnel mirrors offers major advantages: simplicity of construction, low cost, ease of maintenance, and less wind resistance than large cylindro-parabolic mirror collectors. Depending on the location, the reflectors (lenses, blades, etc.) used, and the type of sun tracking system and therefore mirror alignment, Fresnel-type cookers producing steam at 100/164˚C (0 to 6 bar), manually operated, intended for food cooking and small food processing facilities, such as dairies, slaughterhouses, pre-cooking facilities, semolina mills, beer and soap manufacturing, and essential oil extraction, may be of interest. Although the thermal efficiency of the current LFR system is slightly lower than that of the parabolic trough collector [50], its manufacturing, operating, and maintenance costs are considerably lower, which justifies its application in solar concentration technologies.

This article presents a scientific summary of the design, construction, and experimental testing of a solar cooker using Fresnel reflectors as concentrators. We chose this technology for the following reasons:

- The need to test the technology in order to compare it with other types of reflectors such as cylindrical-parabolic, parabolic, and spherical reflectors.

- Flat mirrors are simpler to manufacture and cheaper than parabolic and parabolic trough mirrors.

- There is less wind resistance and the infrastructure is less extensive than a parabolic trough power plant.

2. Description of the System Studied

The system we studied was designed and built at the Renewable Thermal Energies Laboratory (L. E. T. RE.) at Joseph KI-ZERBO University in Ouagadougou, Burkina Faso. It is a solar cooking system whose concentrator consists of Fresnel reflectors, as shown in **Figure 1** below.

The reflectors, which are rectangular sheets of aluminum foil 1 mm thick, are each 102 cm long and 7 cm wide. The system presented here comprises 17 linear reflectors that collect the sun's rays and redirect them toward the receiver, which is a pot. The assembly forms a concentrator with a surface area of 1.2138 m^2, measuring 1.36 m long and 1.08 m wide. The iron absorber consists of two cylindrical pots, each 7 cm in diameter and 30 cm long. It is placed in the center of the concentrator at a height (focal distance) of 1 m, held in place by a triangular support with adjacent sides measuring 1.65 cm, opposite sides measuring 1.60 cm, and a hypotenuse measuring 2.15 cm.

The challenge is to come up with a design that meets the need and to discuss its capabilities, because Fresnel reflectors (blades) must be manually aligned individually and perfectly for optimal performance. **Figure 1** shows the system.

Figure 1. Solar cooker.

3. Optical Analysis of the System

The Fresnel reflector (or linear concentrator) consists of parallel blades that can be tilted on an axis so as to reflect and concentrate the light rays toward a line where the receiver (which is the black-painted pot) is located. Concentration occurs on a linear receiver with a geometric concentration C_g that can be evaluated using the following Equation (1):

$$c_g = \frac{S_{ref}}{S_{rec}} \tag{1}$$

S_{ref} (m^2) the concentrator (reflective sheet) surface area and S_{rec} (m^2) is the absorber surface area

4. Financial Study

The materials used to design the solar cooking system are listed in **Table 1** below.

The total cost of the system is $524.18.10. For comparison, the system built with a parabolic mirror and a radiant tube is currently on sale at a reduced price of $769. Also the cooker solar cooker built with a spherical reflector had cost $420.10. [51].

Table 1. Cost evaluation of the system.

Material	Nber	Unit cost (in USD)	Total cost (in USD)
Steel sheet of 10/10e	1	53.3	53.3
Tube of 40 per 27 (length = 6 m)	1	15.83	15.83
Tube of 40/60 (length = 60 m)	3	24.17	72.5
Flat steel of 40 (length = 6 m)	1	13.33	13.33
Flat steel of 20 (length = 6 m)	1	12.5	12.5
Round steel of 8 (length = 6 m)	1	10	10
Casters	4	11.67	46.67
Paint and thinner	1	23.33	23.33
Aluminum reflective sheet	1	58.33	58.33
Various expenses…	1	60	60
Cylindrical cooking utensils	2	16.67	33.34
Workforce	1	125	125
			524.18

5. Experimental Study of the System

A series of tests was conducted to compare the device under study with certain common cooking appliances, and several food cooking experiments were also carried out.

5.1. Measuring Equipment

- ✓ A Graphtec GL220 Midi Logger with three type K thermocouples for measuring oil or water temperature. Their measuring range is between $-100^\circ C \leq T\ emp. \leq 1370^\circ C$. and their accuracy when used with the data logger is: ± (0.1% of reading + 0.3˚C).
- ✓ A Hukseflux SR03 pyranometer for measuring global radiation. Its sensitivity is 7.64 µV ($W \cdot m^{-2}$). Its accuracy (or uncertainty) is considered as follows: Sec-

ond-class equipment used in summer in mid-latitudes = 8.4%. ˚C).

5.2. Method: Thermal Analysis of the System

The thermal efficiency of the receiver and that of the collector can be evaluated using the following Equations (2) and (3) [51]:

$$\eta_{th} = 0,557 - 0,967 \times \frac{T_{oil} - T_{amb}}{I} \tag{2}$$

$$\eta_{th} = \left(1 - \frac{\sigma T_{oil}^4}{I \times C_g}\right)\left(1 - \frac{T_{amb}}{T_{oil}}\right) \tag{3}$$

T_{amb} is the ambient temperature, σ Stefan-Boltzmann constant = 5.667 × 10^{-8} W·m^{-2} K^{-4}, T_{oil} oil temperature, I the incident solar irradiance in W/m^2

6. Results and Discussion

Figure 2 and **Figure 3** show the curves representing the variation in sunlight and temperatures recorded during the tests on May 15 and 30, 2025.

During these days, there is a gradual increase in sunshine from the morning, reaching successive maximums of 906W/m^2 around 11:46 a.m. and 896 W/m^2 around 11:08 a.m., followed by a gradual decrease to minimums of 10 W/m^2 at 5:30 p.m. and 15.7 W/m^2 at 6:31 p.m. The bell-shaped curves of the sunshine duration therefore indicate the availability of radiation during these days. The peaks recorded on May 30 can certainly be explained by cloudy spells.

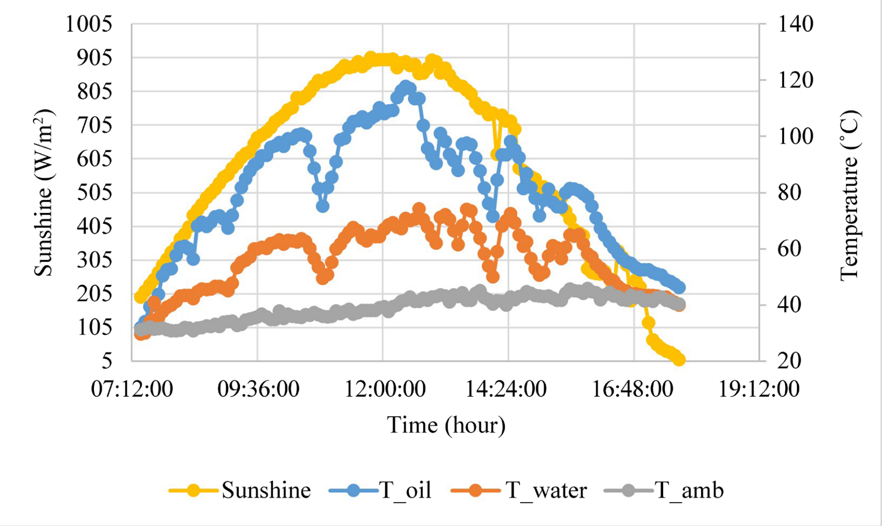

Figure 2. Variation in sunshine, oil temperature (T_oil), water temperature (T_water), and ambient temperature (T_amb) on May 15, 2025.

The temperature curves are similar to those for sunlight, showing a dependence on climatic conditions. They rise gradually from the morning onwards, then fall to reach their minimum values in the evening. There is a noticeable increase in the temperature of the water and oil in the pot. On May 15, 2025, we recorded a maximum temperature of 118˚C at 12:26 p.m. for the oil and 83.2˚C at 11:41 a.m. for the water. Experiments with glazing allowed us to reach maximum temperatures of 112.5˚C at 2:11 p.m. for the oil and 104.6˚C at 1:36 p.m. for the water on May 30, 2025.

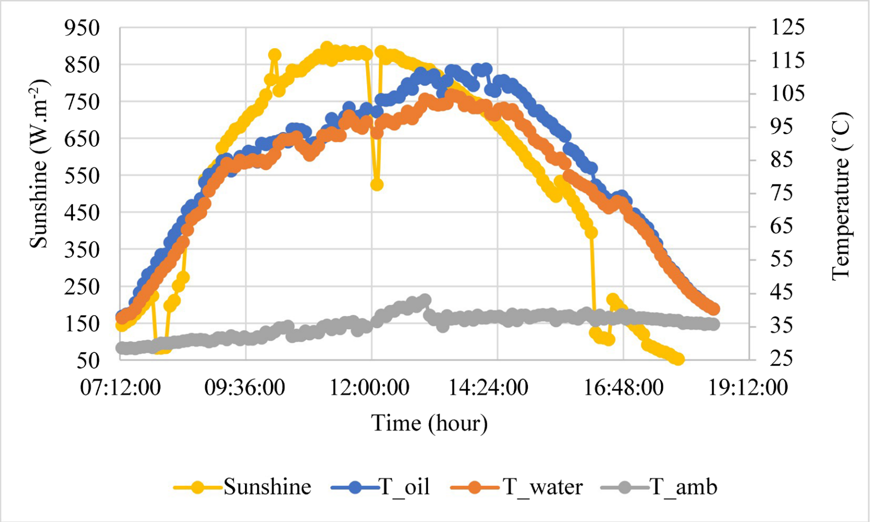

Figure 3. Variation in sunlight, oil temperature (T_oil), water temperature (T_water), and ambient temperature (T_amb) on May 30, 2025.

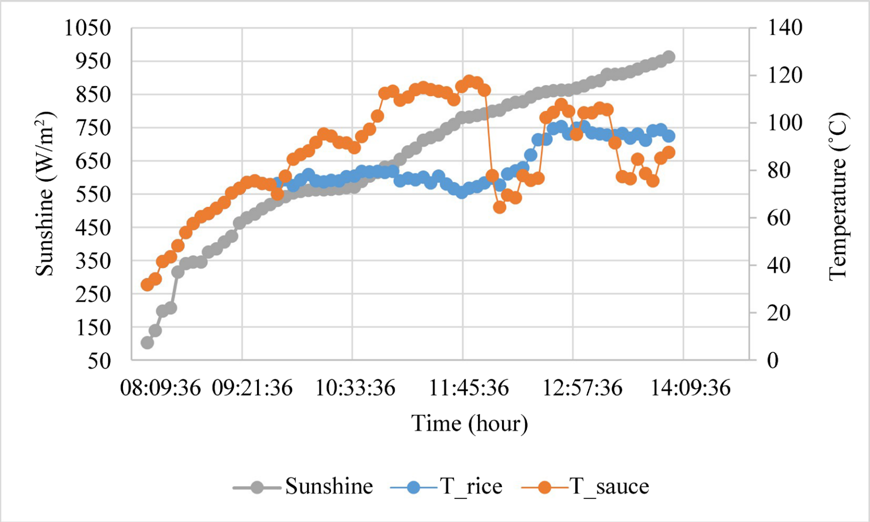

Figure 4. Evolution of radiation and temperature during rice cooking on June 7, 2025.

These graphs illustrate the direct relationship between sunlight and the temperature of the fluid in a solar heating system. The irregularities observed on the temperature curve can be explained by the adjustments made to the reflectors to direct as much sunlight as possible onto the receiver. A maximum water temperature of 91.7˚C was reached at 10:45 a.m. by Kossi *et al.* [52] using a hemispherical cooker. This temperature was reached in 30 minutes by Gianluca Coccia *et al.* (2016) [31] using a low-cost solar oven equipped with a high-performance Fresnel lens.

Figure 4 shows the evolution of radiation and temperature during rice cooking on June 7, 2025.

Figure 4 shows a maximum oil temperature of 117˚C between 10:59 a.m. and 11:49 a.m. and 107˚C reached by the sauce between 12:39 p.m. and 1:19 p.m.; and 87.1˚C for the rice between 12:59 p.m. and 1:39 p.m. On that day, the maximum sunlight was 950 W/m^2 at 1:54 p.m. and the maximum ambient air temperature was 40.1˚C.

The pasta preparation tests were conducted on June 9, 2025. **Figure 5** shows the evolution of radiation and temperature during the cooking of spaghetti on June 9, 2025.

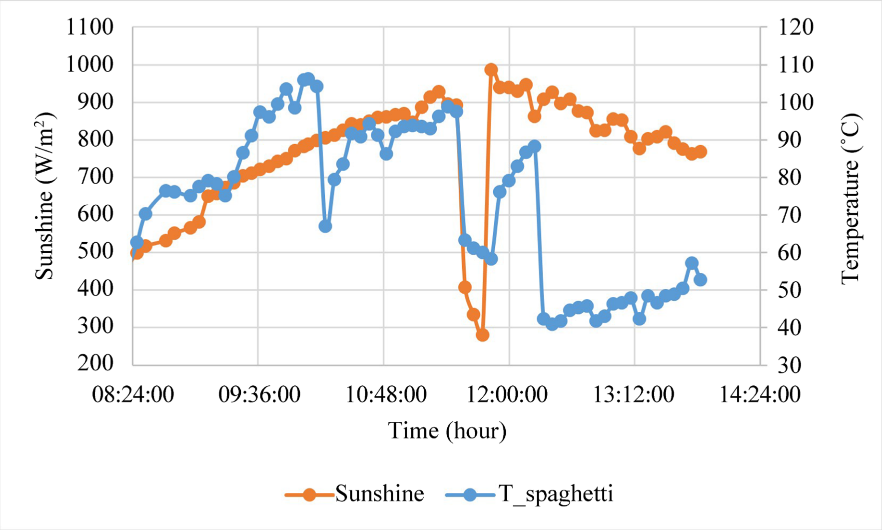

Figure 5. Curve showing changes in radiation and temperature during the cooking of spaghetti on June 9, 2025.

Figure 5 shows a maximum oil temperature of 103˚C between 10 a.m. and 98.8˚C reached by the spaghetti at 11:24 a.m. Maximum sunlight was 986 W/m^2 at 11:49 a.m. and the maximum ambient air temperature was 39.1˚C.

6.1. Stagnation Temperature

The stagnation temperature and optimal operating temperature must be determined. Under our study conditions, to find the optimal operating temperature (T$_{opt}$) of the system, the stagnation temperature of the oil, which is the maximum temperature it can reach when the receiver is exposed to specific solar radiation and reaches quasi-steady-state conditions [22], was calculated using the following Equations (4) and (5):

$$T_{stag} = \sqrt[4]{\frac{I \times C_g}{\sigma}} \tag{4}$$

$$T_{opt} = \sqrt{T_{stag} \times T_{amb}} \tag{5}$$

For a stagnation temperature of 371.40˚C, the optimal operating temperature given by relation (4) [53] is 120.35˚C.

6.2. Thermal Efficiency of the Fresnel Linear System

The thermal efficiency of the receiver

The thermal efficiency of the Fresnel linear system receiver was determined by obtaining instantaneous efficiency values for a wide range of incident solar radiation, ambient temperature, and overall oil temperature values. This required experimental measurement of the incident radiation on the concentrator and the rate of energy addition to the transfer fluid under quasi-steady-state conditions. Tests were conducted using oil taken at ambient temperature.

Figure 6 shows the thermal efficiency curves as a function of $\frac{(T_{av}-T_a)}{G_b}$ during testing. Using equation (2), it can be seen that the efficiency varies linearly with the corresponding values of $\frac{(T_{av}-T_a)}{G_b}$ and that the relationship between thermal efficiency and this ratio can be expressed as follows under conditions in Ouagadougou:

$$\eta_{th}=0,5561-0,9685\times\frac{T_{av}-T_a}{G_b}\quad \text{with } R^2 = 0.9949$$

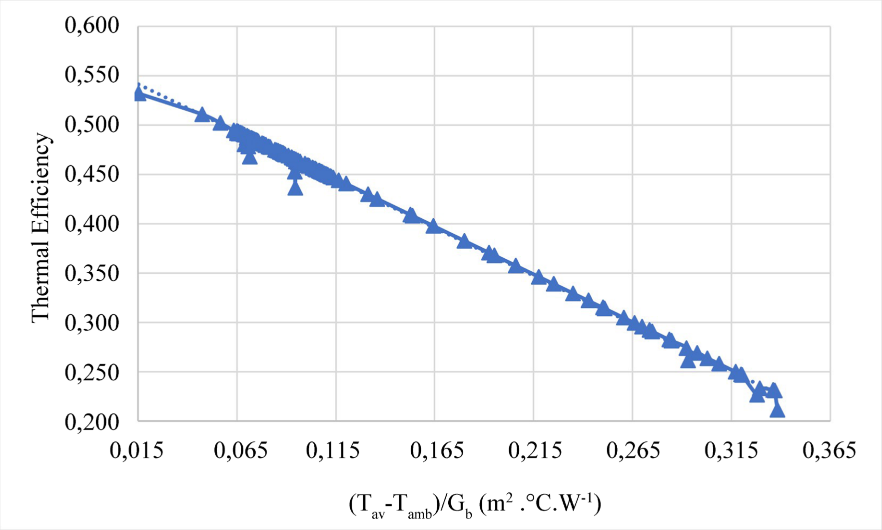

Figure 6. The thermal efficiency curves as a function of $\frac{(T_{av}-T_a)}{G_b}$.

For the test without glazing on the receiver, when the rate varies from 0.004 to 0.59, the thermal efficiency decreases from 55% to 23%, and for the test with glazing on the receiver, when the rate increases from 0.015 to 0.33, the thermal efficiency decreases from 53% to 21%, showing that the receiver temperature was high, which led to an increase in heat loss. It is therefore necessary to use other techniques to enhance receiver performance in order to improve optical efficiency. The results obtained are corroborated by Beltagy's study [9], which examined the influence of the glass cover on the receiver and the use of two absorber tubes on the optical performance of a linear Fresnel solar concentrator through modeling and numerical simulation. The results show that removing the glass increases annual optical efficiency by up to 5.6% and that using two absorber tubes leads to an estimated 15.5% increase in optical efficiency.

The thermal efficiency of the collector

Applying formula (3) gives an average thermal efficiency of the system equal to 10.5%. The results are weaker compared to those obtained with other types of concentrators. Indeed, Imbga *et al.*, who worked on a hemispherical cooker achieved a thermal efficiency of [52]. During vacuum tests with a volume of 1.5 liters of water, they obtained a maximum temperature of 91.5˚C. During cooking tests, they reached frying oil temperatures of 130˚C. Ky *et al.* [54] obtained better results during tests on the cooker. Over two days of testing, they obtained maximum oil temperatures of 184˚C and 221˚C.

Compared to similar cookers, using automated tracking system, the thermal efficiency of our system is low. Indeed, Masoud *et al.*, in their work on the development and performance evaluation of an indirect Fresnel lens solar oven with a thermal oil storage tank, achieved a thermal efficiency of 16.92%. Qusay *et al.*, who worked on the experimental and numerical study of a linear Fresnel solar collector equipped with a two-axis tracking system, obtained thermal efficiencies of the receiver ranging from 24.38% to 52.1% over four days of testing. Lin *et al.*, focusing on the experimental and theoretical analysis of a prototype linear Fresnel reflector solar collector with a V-shaped cavity receiver, showed that for a system stagnation temperature of approximately 260˚C, the optimal operating temperature is approximately 121˚C.

Our results can be explained in several ways:

- Losses due to the fact that the mirrors must be individually oriented and alignment issues,
- Convective and radiative losses from uninsulated receiver containers,
- Optical losses due to imperfect manual reflection,
- Losses caused by shading created by the operator, which can fall on the reflectors,
- Because we used a very large initial volume. In fact, the temperature would increase more if the volume of water or oil were smaller (1 liter or 0.5 liters, for example),
- For the same type of fluid in the container, we would obtain better results,
- The type of reflector used can also be a factor. Lenses would undoubtedly give better results given their high reflection coefficient,
- The beam concentration principle is achieved by superposition. The question that could be asked is: what would the results be if juxtaposition were used?

Several meals were prepared during the load tests with the device: these included rice with tomato sauce, pasta, grilled fish, and soy skewers. They were all ready for lunch. **Figure 7** and **Figure 8** show images of the prepared dishes.

Looking ahead, we plan to repeat the tests for each type of fluid using initial volumes of 1 liter and 0.5 liter, and redo the tests using lenses as reflectors.

Figure 7. Cooking rice with tomato sauce.

Figure 8. Grilled fish, soy skewer, and cooking spaghetti.

7. Conclusions

The system designed, built, and tested for outdoor solar cooking was subjected to a series of tests conducted in Ouagadougou, Burkina Faso, at a latitude of 12.21˚. A series of tests was conducted in May 2025. The sun tracking system was manual. The average ambient temperatures and average radiation were 39˚C and 591.43 W/m^2 for the day of May 15, 2025, and 35.24˚C and 513.34 W/m^2 for the day of May 30, 2025. We can conclude the following:

- Experiments conducted on oil and water placed in a pot positioned at the focal point allowed the oil to reach a maximum temperature of 118˚C at 12:26 p.m. on the first day and 112˚C at 2:11 p.m. on the second day. The water reached a maximum temperature of 83˚C at 11:41 a.m. on the first day and 104.6˚C at 1:36 p.m. on the second day. This is slightly below the theoretical target temperature (expected optimal theoretical temperature) of 121˚C using formula (5), for a number of reasons, but sufficient for the system to be used for cooking purposes.
- Spaghetti, rice, soy skewers, and fish dishes were cooked within a reasonable time frame and were ready for lunch, confirming the usefulness of the system.
- The system achieved an average thermal efficiency of 10.50%.
- For the test without glazing on the receiver, when the rate varies from 0.004 to 0.59, the thermal efficiency decreases from 55% to 23%, and for the test with glazing on the receiver, when the rate increases from 0.015 to 0.33, the thermal efficiency decreases from 53% to 21%, showing that the receiver temperature was high, thus leading to an increase in heat loss.
- A comparison of costs with other solar cooking systems currently being promoted in the country shows that the new system could be even more advantageous thanks to accessible technology.
- Issues such as finding a better way to locate the focal point and safety, particularly eye protection, need to be addressed for better use of the system.

Acknowledgements

The authors would like to express their sincere gratitude to the International Science Program (ISP) for its support of BUF01 in Burkina Faso.

They would also like to thank the Federation for World Peace and Unification (FFWPU-HQ, South Korea) for the resources made available to them to carry out this work.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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