# Performance Analysis and Thermal Efficiency Evaluation of a Standing Solar Box Cooker for Sustainable Cooking in Nigeria: A Case Study of Kwara State

Olaore Kayode Olatunde




Department of Physics, Institute of Applied Sciences, Kwara State Polytechnic, Ilorin, Nigeria

Correspondence to: Olaore Kayode Olatunde, mckayolaore@gmail.com

Additional material is published online only. To view please visit the journal online.

Cite this as: Olaore KO. Performance Analysis and Thermal Efficiency Evaluation of a Standing Solar Box Cooker for Sustainable Cooking in Nigeria: A Case Study of Kwara State. Premier Journal of Engineering 2025;3:100008

DOI: https://doi.org/10.70389/PJE.100008

Received: 17 February 2025
Revised: 7 April 2025
Accepted: 4 May 2025
Published: 17 May 2025

Ethical approval: N/a
Consent: N/a
Funding: No industry funding
Conflicts of interest: N/a
Author contribution: Olaore Kayode Olatunde – Conceptualization, Writing – original draft, review and editing
Guarantor: Olaore Kayode Olatunde
Provenance and peer-review: Unsolicited and externally peer-reviewed
Data availability statement: N/a

## ABSTRACT

This investigation examines the thermal efficiency and operational characteristics of a standing solar box cooker under Nigerian climatic conditions. The research conducts an experimental analysis of cooking various food items, including noodles, rice, and yams, utilizing solar thermal energy in Kwara State. A methodical evaluation revealed that the cooker achieved maximum absorber temperatures between 84.7°C and 93.6°C, with an overall thermal efficiency of 39%. The device demonstrated notable cooking capabilities, requiring approximately 60 minutes for noodles, 105 minutes for rice, and 125 minutes for yam preparation under average solar radiation levels ranging from 2651.2 W/m$^2$ to 6114 W/m$^2$. Statistical analysis revealed direct correlational relationships between solar radiation intensity and cooking chamber temperatures. The standardized cooking power calculation yielded 1222 W at 700 W/m$^2$ insolation. These findings established the viability of standing solar box cookers as sustainable cooking alternatives in Nigeria's North Central region, particularly beneficial for rural communities. This study provided empirical evidence supporting the adoption of solar cooking technology to reduce dependence on traditional biomass fuels while mitigating associated environmental impacts.

**Keywords:** Solar box cooker, Thermal efficiency, Sustainable cooking, Renewable energy, Kwara state

## Nomenclature

$P$ = Interval cooking power
$M_W$ = Mass of water
$C_W$ = Specific heat capacity
$T_f$ = Final water temperature
$T_i$ = Initial water temperature
$t$ = Time
$P_s$ = Standardizing cooking power
$I_s$ = Average solar insolation
$\eta$ = Overall thermal efficiency
$\Delta T$ = Temperature difference
$I_{av}$ = Average isolation
$A_c$ = Aperture area of the cooker
$\Delta t$ = Time required to achieve the maximum temperature
$T_{AG}$ = Air gap temperature
$T_{AP}$ = Absorber plate temperature
$T_{AS}$ = Absorber side temperature
$T_{PC}$ = Pot cover temperature
$T_F$ = Fluid temperature
$T_{AMB}$ = Ambient temperature
$SR$ = Solar radiation

## Introduction

Energy is the fundamental driving force behind all human activities, and its absence would render modern civilization unviable. Historically, the importance of energy sources has frequently been underestimated, particularly due to the untapped potential of solar energy. However, as societal demands have evolved, accelerated by population growth and technological advancements, the quest for sustainable energy solutions has intensified.[1] Cooking and heating are essential to our daily lives, as they meet our vital nutritional needs. In many rural areas, reliance on traditional energy sources, such as firewood, agricultural residues, and dung, persists. Unfortunately, these practices generate harmful emissions, intensifying urgent environmental issues, such as global warming. Therefore, it is essential to promote alternative renewable energy solutions that are suitable for rural communities.[2]

The sun provides an abundant and readily available energy source, demonstrating optimal efficiency for low-temperature heating applications, such as space heating and hot water production.[3] Furthermore, it can be harnessed to generate high-temperature heat through solar concentrators. In regions near the equator, solar radiation can exceed 1000 W/m$^2$ under optimal weather conditions, providing sufficient energy to power devices such as kettles.

Situated in the tropics, Nigeria enjoys abundant sunshine throughout the year, with the southern region averaging 8 hours of daily sunlight during the dry season and around 4 hours during the rainy season. Conversely, northern regions experience approximately 10 hours of sunlight in the dry season and 6 hours during the rainy season.[4] The annual horizontal radiation in Nigeria varies from 5000 MJ/m$^2$ to 940 MJ/m$^2$, with monthly values fluctuating between 416.7 MJ/m$^2$ and 783.3 MJ/m$^2$. Specifically in Kwara State, near Ilorin (coordinates: 8° 26'N and 4° 29'E), solar intensity fluctuates from 550 W/m$^2$ to 1075 W/m$^2$.[5]

Solar cookers are primarily classified into two categories: direct and indirect. Direct solar cookers encompass a variety of designs, including box-type, panel, and parabolic cookers. Numerous studies have evaluated the performance of these devices based on various parameters, primarily for daytime household use. A notable drawback is their inability to function at night, as well as their sensitivity to cloud cover.[6] Indirect solar cookers are further subdivided into flat-plate collectors, evacuated tube collectors, and concentrating collectors, which facilitate cooking at locations separate from the solar collector itself.

To address the limitation of nighttime cooking with solar cookers, integrating heat storage systems offers a viable solution. These systems can be categorized into two main types: sensible heat storage and latent heat storage. Sensible heat storage depends on the specific heat capacity of the material used to store and retrieve thermal energy, whereas latent heat storage relies on the latent heat of fusion during phase changes of the material. Phase change materials (PCMs) exhibit unique thermal, physical, and chemical properties that enhance their efficacy in energy storage applications.[7] Prioritizing the development of effective heat storage systems is crucial for enhancing the efficiency and usability of solar cookers, thereby enabling cooking at any time, regardless of sunlight availability. A solar cooker that integrates a latent heat storage system presents a promising solution; however, careful design is necessary for optimal efficiency and adaptability.

The innovative standing solar box cooker is designed to facilitate cooking, heating, drying, and pasteurizing food and beverages without the need for fuel, resulting in significantly reduced operational costs. Compared to conventional cooking methods, this device significantly reduces fuel expenses and lowers air pollution. The design focuses on concentrating solar energy onto a compact cooking area through a reflector, converting solar radiation into heat. The cooking surface effectively retains heat, allowing for adjustments according to latitude and weather conditions.[8] Meals can be prepared from sunrise to late in the afternoon. Unlike traditional cooking appliances, the standing solar box cooker operates without generating smoke, which can be harmful to public health and the environment, contributing to health issues and ecological damage.[9]

This study aims to evaluate the performance of a freestanding solar box cooker in preparing pasta, rice, and yams under the climatic conditions of Kwara State, while systematically measuring various temperature parameters (Table 1).

## Literature Review

The exploration of solar box cookers as sustainable energy solutions has garnered significant attention in recent years, illuminating their potential to reduce dependence on fossil fuels. Anthony et al.[10] investigated a solar box cooker designed to utilize solar energy while producing no harmful emissions. This research, conducted from January 2018 to January 2019 at Landmark University in Omu-Aran, Nigeria, utilized the ASHRAE empirical model to assess solar irradiance levels. Anthony's findings indicated average cooking temperatures of 32°C, with an energy efficiency of 28°C; however, the study indicated a reduction in efficiency attributed to the degradation of the aluminum foil reflector, which adversely affected the reflection of sunlight into the cooker's absorber. Moreover, the influence of overcast weather conditions further diminished overall performance.

In a related study, Gregory et al.[11] developed a solar box cooker capable of boiling approximately 1.8 liters of water at an ambient air temperature of 110°C in 45 minutes. Their testing involved exposing the cooker to direct sunlight for three consecutive days while systematically recording temperature variations throughout the day with thermometers calibrated from 0°C to 360°C. The results highlighted optimal cooking times occurring between 11:00 AM and 4:00 PM (Nigerian time) on days with clear sunlight. The study further emphasized that the integration of heavy materials, such as stones, into the design can significantly enhance heat retention, effectively extending cooking utility until 5:00 PM.

Viral et al.[12] concentrated on assessing the performance of box-type solar cookers under the challenging mid-summer climate conditions prevalent in Gujarat. Their research compared two distinct designs: a cooker featuring a black-painted base and another utilizing a coal-enhanced black base. Experiments were conducted in both fixed and sun-tracking operational modes. Results indicated that the fixed-position cooker achieved thermal efficiencies ranging from 25.2% to a peak of 53.8% at maximum solar intensity, around 12:13 PM, with an average of 32.3%.

Conversely, the coal-painted cooker that employed a sun-tracking mechanism consistently outperformed the fixed design, attaining thermal efficiencies from 28% to 62.1%, with an overall average efficiency of approximately 43.8%. These findings highlight the

**Table 1 | Comparative description of different solar cookers[6]**

| S/N | Type of Cooker | Maximum Attainable Temperature for Cooking after a Certain Time, in °C | Preferred for Household (Small Scale)/ Community Cooking | Availability | Limitation |
|---|---|---|---|---|---|
| 1 | Box cooker | 95–100°C | Small scale | Sunshine hours | Takes more time |
| 2 | Solar panel cooker | 100–122°C | Small scale | Sunshine hours | Not useful in cloudy conditions |
| 3 | Parabolic cooker | 120–170°C | Small scale | Sunshine hours | Need a large aperture area of the collector |
| 4 | Evacuated tube cooker | 250–300°C | Small scale/ Community | Sunshine hours | Too costly |
| 5 | Fresnel lens cooker | 250–300°C | Community | Sunshine hours | Costlier and needs a skilled operator |
| 6 | Scheffler cooker | 150–180°C | Community | Daytime and sometimes after it | Need a large area that is suitable for community cooking only |
| 7 | Solar cooker with heat storage | 120°C | Small scale | Daytime as well as evening | Need a separate design for storage as well as for the transfer system |

 DOI: https://doi.org/10.70389/PJE.100008 | Premier Journal of Engineering 2025;3:100008

significant advantages of sun-tracking systems in maintaining higher thermal efficiencies throughout daylight hours.

Soe[13] emphasized the necessity for alternative, renewable energy sources, highlighting that many households still predominantly depend on traditional fuels or grid electricity for heating and drying applications. To address this challenge, he designed a homemade solar box heater using locally sourced materials and technologies. The performance of this solar cooker was evaluated based on various configurations of reflectors (one, two, and three) while consistently using 500 grams of water as the test liquid. Soe used descriptive statistical methods, such as mean, range, and regression analysis, to determine that the quantity of reflectors significantly influenced temperature measurements from the heat absorber plate, the heating chamber, and the test liquid. Notably, his results showed that the highest temperature achieved was 95.7°C in the configuration with three reflectors, while the one-reflector model recorded a minimum of 92.87°C. A coefficient of determination of 99.6% highlighted a strong correlation between water temperature variations within the solar heaters and the number of reflectors, indicating that increasing the number of reflectors substantially enhances heat absorption efficiency.

This literature highlights the innovative developments and practical applications of solar box cookers as a viable alternative to conventional energy sources, underscoring their potential benefits for sustainable energy practices.

## Materials and Methods

### Materials Used

Plywood was selected for constructing the box due to its affordability and local availability. Being an opaque material, plywood effectively prevents light penetration. This material is derived from cellulose molecules, which lend it strength and rigidity.[14] Moreover, plywood exhibits greater resilience in tension than in compression. It maintains strength in two dimensions but is more susceptible to warping than solid wood, which has grain oriented in a single direction.[15] The box sides were constructed from 2.40 cm-thick wood, while the base was made from 2.00 cm-thick wood to ensure that the overall weight of the cooker remains manageable.

For insulation, the inner side of the box was lined with polystyrene foam, reducing heat loss through convection. This insulation minimizes heat loss from the sides and bottom of the trapezoidal-shaped iron plate oven, resulting in a consistent heat flow along the length of the metal plate oven.

The dimensions of the wooden box are 112 cm × 85 cm × 60 cm. The inner absorber metal plate, shaped as a trapezoid, measures 100 cm × 75 cm × 60 cm × 22 cm, with a thickness of 3 mm. The inner absorber plate was painted black to enhance heat absorption, as black surfaces are known to be excellent emitters and absorbers of radiation, absorbing all incident radiation while reflecting and transmitting none.[16]

To maximize cooking effectiveness, a dark, shallow, lightweight pot made of thin aluminum was used, ensuring a tight fit to retain heat and moisture. The selected pot diameter is slightly larger than that of the food being cooked.

The standing solar box cooker features two hinged cover panels. The outer panel is fitted with a 5 mm thick mirror, measuring 108 cm × 81 cm, which functions as a reflector. This panel is affixed in a manner that allows it to tilt at an angle upon placement in its grooves, facilitating the 'greenhouse effect,' the operating principle of the solar device. Beneath this, the inner panel consists of double-paned glass, with the inner glass being 10 mm thick. The outer glass is 5 mm thick, measuring 108 cm × 81 cm. Glass was preferred over plastic due to its approximately 10% better performance, especially in windy conditions, as it maintains stability and does not dissipate heat.[17]

The standing solar box cooker was strategically positioned on open ground adjacent to the Physics Laboratory of Kwara State Polytechnic to maximize sunlight exposure without obstruction. A thermometer was used to monitor the temperatures of the absorber plate within the cooker and the ambient air at various intervals (Figures 1 and 2).

Fig 1 | Inside the solar box cooker

Fig 2 | Standing solar box cooker noodles

## Methods

### Cooking Procedure

Three distinct experiments were conducted over three consecutive days utilizing a standing solar box cooker. The focus of these experiments was the cooking of noodles, rice, and yams.

### Cooking of Noodles

The first experiment took place on April 17, 2024, using an aluminum pot with a black-painted exterior, chosen for its superior heat absorption properties. At 11:00 AM, the solar box cooker, equipped with an aluminum pot, was oriented towards the east to maximize solar exposure, aligning with the sunrise. The solar box cooker successfully captured heat radiation for 10 minutes. At precisely 11:10 AM, 250 grams of water, initially at a temperature of 32.5°C, was added to the pot. The water was then boiled for 20 minutes, during which various parameters were systematically recorded. The ambient temperature was noted at 28.2°C, and the solar radiation intensity was measured at 585.2 W/m$^2$.

At 11:30 AM, 75 grams of noodles were introduced to the boiling water, with the noodle weight verified using a digital scale. Temperature measurements and other relevant data were meticulously recorded every 15 minutes, capturing the following parameters: room temperature, air gap temperature, absorber temperature, pot temperature, side absorber temperature, pot lid temperature, food temperature, and sunlight intensity (Figures 3 and 4).

Fig 3 | Cooking noodles in the solar box cooker

Fig 4 | Cooked noodles

### Cooking of Rice

On April 18, 2024, at 11:00 AM, we initiated the solar cooking experiment using a cooker featuring an aluminum pot that had been painted black to enhance heat absorption. The cooker was strategically positioned to face east, aligning with the sun's trajectory for optimal thermal exposure. After allowing the cooker to absorb solar radiation for 10 minutes, we added 350 cm³ of water, initially measured at 30.5°C, to the pot at 11:10 AM.

The water was brought to a boil over the next 15 minutes, during which we recorded solar radiation and ambient temperature at 608 W/m$^2$ and 30.5°C, respectively. At 11:25 AM, we added 110 grams of rice, precisely measured using a digital scale, into the boiling water. Throughout the cooking process, we systematically documented the solar radiation, ambient temperature, air-gap temperature, and the temperatures of the pot's sides, pot cover, absorber, and the food itself at 15-minute intervals (Figures 5 and 6).

### Cooking of Yams

On April 19, 2024, the third-day experiment was conducted, commencing at 11:00 AM. The standing solar box cooker was strategically positioned to face east, maximizing its exposure to sunlight. After a 10-minute preheating period, at 11:10 AM, 400 cm³ of water, initially measured at a temperature of 28.1°C, was poured

Fig 5 | Cooking rice in the solar box cooker

Fig 6 | Cooked rice


DOI: https://doi.org/10.70389/PJE.100008 | Premier Journal of Engineering 2025;3:100008

Fig 7 | Cooked yams

into the pot. This water was allowed to boil vigorously for the next 15 minutes. During this phase, the solar radiation was recorded at 640 W/m$^2$, while the ambient temperature was noted at 31.5°C. Following the boiling period, the water temperature rose to 56.8°C. At 11:25 AM, 110 grams of sliced yams were added to the boiling water. Throughout the experiment, data were systematically collected every 15 minutes, encompassing ambient temperature, air gap measurements, absorber temperature, pot temperature, temperatures from the absorber side, pot cover, food substance, and solar radiation levels (Figure 7).

### Determination of Cooking Power Estimation Interval Cooking Power

Mullick and Kandal[18] adopted an interval cooking power to calculate the usable energy available during cooking durations. This value is derived by multiplying the temperature change of the water within each compartment by the mass and specific heat capacity of the water in the cooking vessel. To determine the cooking power in watts, this product is then divided by the time over the specified intervals.

$$P = \frac{M_W C_W (T_f - T_i)}{t} \quad (1)$$

Where

$P$ = Interval cooking power ($W$)
$T_i$ = Initial water temperature
$T_f$ = Final water temperature
$M_w$ = Mass of water (kg)
$C_w$ = Specific heat capacity (4186 j/kg °C).

$$P = \frac{2.5 \times 4186\,(81.5 - 32.5)}{900}$$

$$P = \frac{10465\,(49)}{900}$$

$$P = 569.8 \text{ W}$$

### Determination of the Standardized Cooking Power

To calculate the standard cooking power ($P_s$), the cooking power ($P$) for each interval is adjusted to reflect standard insolation, following the methodology established by Abdulhamid.[19]

$$P_s = \frac{P \times 700}{I_s}$$

Where

$P_s$ = The standard cooking power in Watt
$P$ = Interval cooking power
$I_s$ = Interval average solar insolation W/m$^2$

$$P_s = \frac{569.8 \times 700}{326.3}$$

$$P_s = \frac{398790}{326.3}$$

$$P_s = 1222 \text{ W}$$

### Overall Thermal Efficiency

The Overall thermal efficiency of the standing solar box cooker is mathematically defined according to the work of Aidan.[20]

$$\eta = \frac{M_w C_w \Delta T}{I_{av} A_c \Delta t}$$

Where

$M_w$ (kg) = Mass of water
$C_w$ = The specific heat Water (j/kg °C),
$\Delta T$ = Temperature difference between the maximum temperature of the cooking fluid and the ambient air temperature,
$A_c$ = The Aperture area of the Cooker (m$^2$),
$\Delta t$ = The time required to achieve the maximum temperature of the cooking fluid and
$I_{av}$ = The average isolation (W/m$^2$) during the time interval.

$$\eta = \frac{0.40 \times 4186 \times 55}{2651 \times 0.132 \times 900} \times 100$$

$$\eta = \frac{92092}{314938.8} \times 100$$

$$\eta = 30\%$$

### Economic Analysis

Table 2 presents a breakdown of the cost of producing a unit of the standing solar box cooker, with a total cost of US$104. The economic analysis aims to determine the payback time of acquiring the Standing Solar Box Cooker.

In the rural regions of Kwara State, Nigeria, charcoal and firewood are the primary sources of cooking fuel. A supply of firewood costing approximately US$2 can facilitate the preparation of 12 yam meals for a family of five. Yam was specifically chosen due to its longer cooking duration in this study compared to the other foods. Given that most families in these rural areas typically have two meals a day, a US$2 investment in firewood can meet their cooking energy needs for up to 6 days. Considering the operational hours of the standing solar box cooker, which range from 10:00 AM to 5:00 PM, families will be able to prepare two meals daily. Consequently, the energy payback time for the standing solar box cooker can be determined using the methodology proposed by Negi and Purobit.[21]

$$\ell = \frac{(n \times \mathcal{R} \times \mathcal{E})}{\mathcal{P}}$$

Where

$\ell$ = the energy payback time
$n$ = the number of cooking days for US$1 cost of firewood
$\mathcal{R}$ = the standing solar box cooker acquisition cost,
$\mathcal{P}$ = the firewood cost,
$\mathcal{E}$ = the standing solar box cooker cooking days factor = 1.5.

**Table 2 | Bill and evaluation table**

| Component | Cost (US$) |
|---|---|
| Plywood | 32.00 |
| Wood plank | 5.00 |
| 5 mm glass | 7.00 |
| 10 mm glass | 15.00 |
| Polystyrene | 9.00 |
| Iron plate | 27.00 |
| Aluminum pot | 2.00 |
| Glass mirror | 6.00 |
| Hinges | 1.00 |
| Paint and brush | 3.00 |
| Total US$ | US$104.00 |

## Results and Discussion

The significance of solar cooking technologies continues to gain attention, and the analysis presented here offers compelling evidence through meticulously recorded data on solar radiation and temperature variations captured over 15-minute intervals across three distinct clear-sky days: April 17, 2024, April 18, 2024, and April 19, 2024. Tables 3–5 illustrate the detailed observations.

Figure 8 illustrates the temperature and solar radiation fluctuations on April 17, 2024, from 11:28 AM to 12:28 PM, during the preparation of noodles under conditions of average solar radiation of 2651.2 W/m². Notably, the absorber temperature reached a maximum of 84.7°C when the sun was directly overhead. The corresponding maximum temperatures were 78.2°C for the air gap, 70.0°C for the side absorber, 69.1°C for the pot cover, and 81.5°C for the fluid. These temperatures are sufficiently high for effective pasta cooking, suggesting that the standing solar cooker exhibits commendable efficiency throughout this process. This finding is consistent with the reported result,[19] where a peak absorber temperature of 82°C was observed under similar conditions.

The data illustrated in Figure 8 further indicates a clear correlation between solar radiation and ambient temperature variations throughout the experiment, suggesting a direct proportionality between changes in ambient temperature and those of the other recorded parameters. The ambient temperature experienced a steady increase during the observation period, reaching its peak at 12:28 PM. The lowest temperatures were recorded at 11:28 AM, with the ambient temperature at 28.2°C,

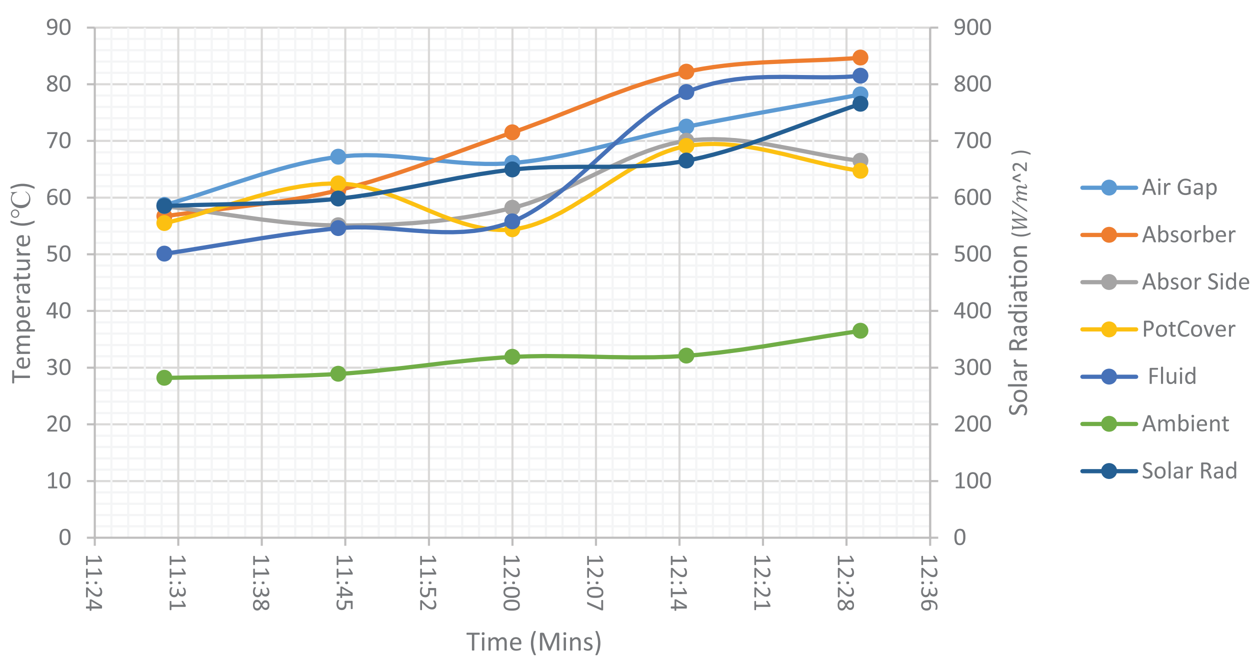


Fig 8 | The effect of solar radiation and temperature against time for the cooking of noodles

 DOI: https://doi.org/10.70389/PJE.100008 | Premier Journal of Engineering 2025;3:100008

absorber temperature at 56.7°C, fluid temperature at 50.1°C, air gap temperature at 58.7°C, side absorber temperature at 58.8°C, and pot cover temperature at 55.5°C. The average cooking duration for the noodles was 1 hour.

Figure 9 presents data from April 18, 2024, illustrating temperature and solar radiation from 11:25 AM to 1:10 PM during rice cooking under an average solar radiation of 5013.8 W/m². The graph shows that the absorber temperature peaked at 89.0°C when the sun was directly overhead, followed by the cooking liquid, affirming the process's efficiency. Specific temperatures recorded include 83.6°C for the air gap, 76.8°C for the side absorber, 80.0°C for the pot cover, and 84.2°C for the fluid temperature, all of which are adequate for rice preparation. This outcome is consistent with the reported results,[21] where, despite lower thermal radiation in Owerri (southeastern Nigeria), rice was successfully cooked, albeit at lower temperature measurements. The overall cooking duration for rice was 1 hour and 45 minutes, which, although exceeding traditional methods, underscores the economic and ecological advantages of solar cooking.

Figure 10 illustrates the temperature and solar radiation variations during yam cooking on April 19,

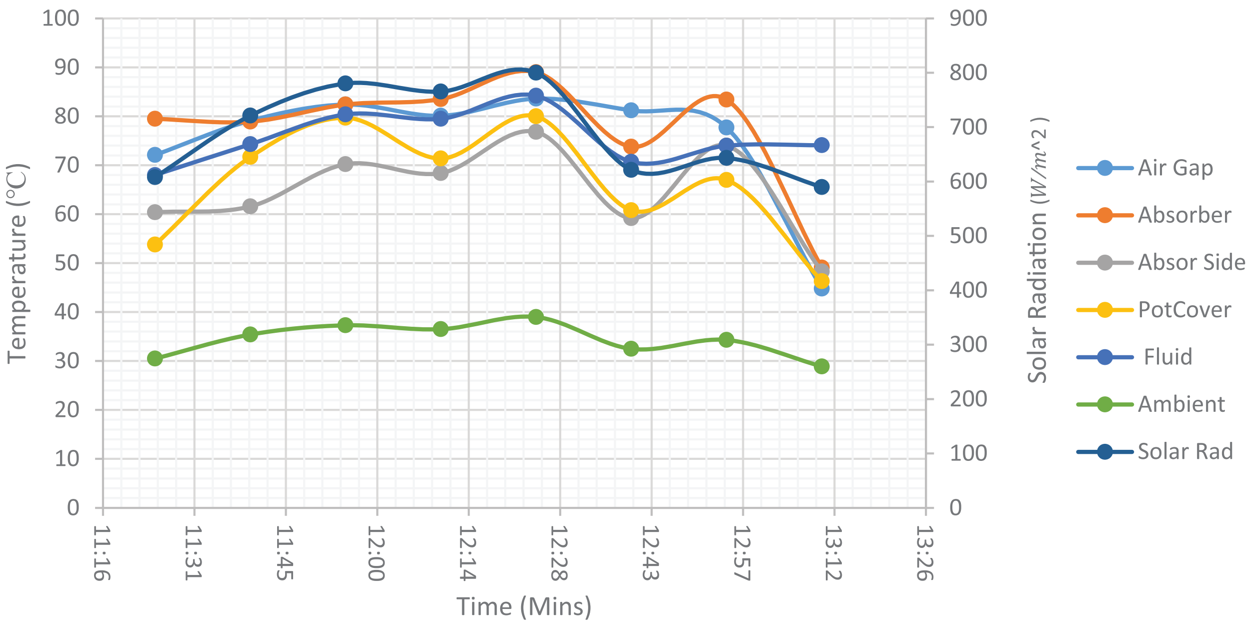


**Fig 9 | The effect of solar radiation and temperature against time for the cooking of rice**

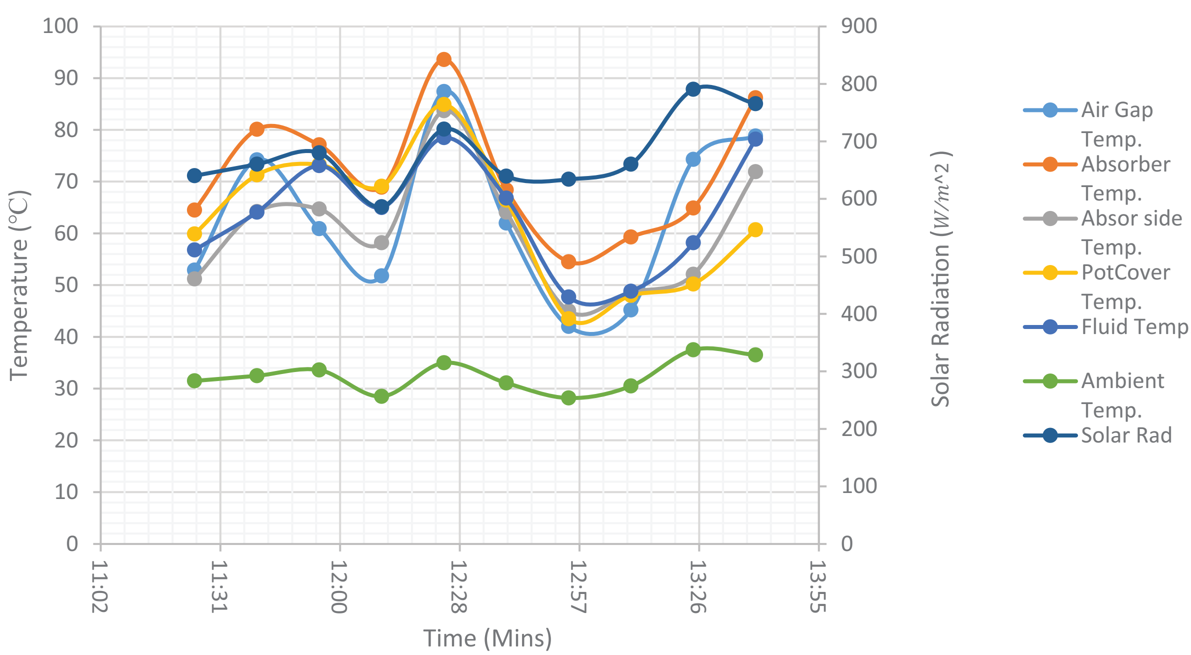


**Fig 10 | The effect of solar radiation and temperature against time for the cooking of yams**

**Table 3 | Solar radiation and temperature measurements of various parameters of the standing solar box cooker used in cooking noodles on 17th April, 2024**

| Time | $T_{AG}$°C | $T_{AP}$°C | $T_{AS}$°C | $T_{PC}$°C | $T_{F}$°C | $T_{AMB}$°C | *SR* |
|---|---|---|---|---|---|---|---|
| 11:30 | 58.7 | 56.7 | 58.5 | 55.5 | 50.1 | 28.2 | 585.2 |
| 11:45 | 67.2 | 61.3 | 55.1 | 62.5 | 54.6 | 28.9 | 598.2 |
| 12:00 | 66.1 | 71.5 | 58.2 | 54.4 | 55.8 | 31.9 | 649.5 |
| 12:15 | 72.5 | 82.2 | 70.01 | 69.1 | 78.6 | 32.1 | 665.2 |
| 12:30 | 78.2 | 84.7 | 66.5 | 64.7 | 81.5 | 36.5 | 765.3 |

**Table 4 | Solar radiation and temperature measurements of various parameters of the standing solar box cooker used in cooking rice on 18th April, 2024**

| Time | $T_{AG}$°C | $T_{AP}$°C | $T_{AS}$°C | $T_{PC}$°C | $T_{F}$°C | $T_{AMB}$°C | *SR* |
|---|---|---|---|---|---|---|---|
| 11:25 | 72.1 | 79.5 | 60.4 | 53.8 | 68 | 30.5 | 608 |
| 11:40 | 79.1 | 78.9 | 61.6 | 71.7 | 74.3 | 35.4 | 721.4 |
| 11:55 | 82.4 | 82.4 | 70.2 | 79.7 | 80.4 | 37.3 | 780.3 |
| 12:10 | 80.1 | 83.5 | 68.4 | 71.4 | 79.5 | 36.5 | 765.5 |
| 12:25 | 83.6 | 89 | 76.8 | 80 | 84.2 | 39 | 800.1 |
| 12:40 | 81.2 | 73.8 | 59.2 | 60.8 | 70.7 | 32.5 | 621.5 |
| 12:55 | 77.7 | 83.4 | 74 | 67 | 74 | 34.3 | 643.3 |
| 13:10 | 44.8 | 49.1 | 48.3 | 46.3 | 71.8 | 28.9 | 589.9 |

**Table 5 | Solar radiation and temperature measurements of various parameters of the standing solar box cooker used in cooking yam on 19th April, 2024**

| Time | $T_{AG}$°C | $T_{AP}$°C | $T_{AS}$°C | $T_{PC}$°C | $T_{F}$°C | $T_{AMB}$°C | *SR* |
|---|---|---|---|---|---|---|---|
| 11:25 | 52.9 | 64.5 | 51.2 | 59.9 | 56.8 | 31.5 | 640.2 |
| 11:40 | 74.2 | 80.1 | 64.2 | 71.3 | 64.1 | 32.5 | 660.3 |
| 11:55 | 60.9 | 77.1 | 64.7 | 73.3 | 73.1 | 33.6 | 680.1 |
| 12:10 | 51.8 | 68.9 | 58.2 | 69.1 | 65 | 28.5 | 586.4 |
| 12:25 | 87.4 | 93.6 | 83.7 | 84.9 | 88.5 | 38 | 798.8 |
| 12:40 | 62 | 68.4 | 64.1 | 66.4 | 66.8 | 31.1 | 639.5 |
| 12:55 | 42 | 54.5 | 45 | 43.5 | 47.7 | 28.2 | 634.1 |
| 13:10 | 45.2 | 59.3 | 48.6 | 48 | 48.81 | 30.5 | 660.2 |
| 13:25 | 60.3 | 64.9 | 52.1 | 50.2 | 59.2 | 33.5 | 710.5 |
| 13:40 | 78.8 | 86.2 | 71.9 | 70.7 | 74.2 | 34.5 | 765.5 |

2024, from 11:25 AM to 1:30 PM, under conditions of average solar radiation of 6114 W/m$^2$. The results indicated that the absorber temperature peaked at 93.6°C, accompanied by recordings of 87.4°C for the air gap, 83.7°C for the side absorber, 84.9°C for the pot cover, and 88.5°C for the fluid. These values are ideal for cooking yams, suggesting a highly effective cooking process. A clear trend observed was that the temperatures of the solar box cooker and other measured parameters diminished simultaneously with decreasing solar radiation, underscoring the correlation between increased solar radiation and elevated cooking temperatures. Yams required a total cooking duration of 2 hours and 15 minutes, which, while exceeding traditional methods, highlights the economic and environmental benefits of solar cooking.

This study highlighted the significant contribution of the reflector in maximizing solar radiation entering the standing solar box cooker, finally achieving the maximum absorber plate temperature of 93.6°C. The use of reflectors concentrated sunlight more efficiently, resulting in higher temperatures on the absorber plate. Supporting this observation,[22] it was noted that reflector utilization enhances the amount of solar radiation captured within the enclosure, allowing the absorber plate to attain temperatures exceeding 90°C.

Finally, an analysis of Figures 8–10 indicates that the temperature differential between the absorber plate temperature and the air gap temperature is minimal, suggesting favorable emittance or selective surface characteristics of the absorber plate. This phenomenon is critical for maximizing thermal efficiency in solar cooking applications.

## Conclusion

This study highlights the transformative potential of the standing solar box cooker as a sustainable and environmentally friendly cooking alternative, particularly in regions with abundant solar radiation, such as Kwara State, Nigeria. The cooker offers notable thermal efficiency at 30% and can prepare various food items, including noodles, rice, and yams, within acceptable timeframes under ideal meteorological conditions.

The efficiency of the cooker is significantly influenced by factors such as solar radiation levels, ambient temperature, and key design elements, including the absorber plate, reflector, and insulation. Moreover, its ability to retain heat for extended periods enhances its practicality for rural applications where access to conventional energy sources may be limited.

Importantly, the standing solar box cooker addresses critical environmental and socio-economic issues associated with traditional cooking methods, including deforestation, greenhouse gas emissions, and health hazards from indoor air pollution. By harnessing free solar energy, this technology minimizes reliance on fossil fuels and promotes sustainable energy practices.

While the cooking time may be marginally longer compared to conventional methods, the associated economic and environmental benefits far outweigh this drawback. This study reinforces the viability of solar cooking technologies as a means to enhance energy access, mitigate environmental degradation, and improve living standards in rural communities.

Integrating solar cooking solutions, such as the standing solar box cooker, can significantly contribute to a more sustainable future and should be promoted as a viable energy alternative in regions where traditional energy sources are limited.

## References


1 Folaranmi J. The performance of a double glazed box-solar oven. Sci Technol Vision. 2013;2:136–43. ISSN: 1341-0231.
2 Agcaoili Shirley O. Evaluation of a home-made solar box heater for domestic heating. Int J Eng Sci Res Technol. 2018;3:436–42. ISSN: 2277-9655.
3 Olaore KO, Danshehu BG, Muhammad BA, Muazu M. Investigating the operational parameters of a centrifugal pump used in reverse mode as turbine for electricity generation. Glob J Sci Front Res A Phys Space Sci. 2021;21(6). Version 1.0, ISSN: 2249-4626.
4 Adewole BZ, Asere AA, Popoola OT. Thermal performance of a reflector based solar box cooker implemented in ile-ife, Nigeria. Int J Energy Eng. 2015;2:95–101. https://doi.org/10.5923/j.ijee.20150505.02
5 Onkwai AO, Okonkwo UC, Osueke CO, Olayanju TMA, Ezugwu CA, Diarah RS. Thermal analysis of solar box cooker in Omu-Aran metropolis. Int Conf J Eng Sustain World. 2019;3:1–20. ISSN: 1378s.
6 Danladi YB, Datau SG, Alhassan AM. Factors affecting the performance of solar still: a review. Int J Sci Res Technol. 2021;7(9): ISSN: 2623-7861 November, 2021 Editions.
7 Gawande TK, Ingole DS. Comparative study of solar cookers. IOSR J Eng. 2020 Jan;10(1). ISSN (e): 2250-3021, ISSN (p): 2278-8719 ||Series -V|| PP 34-43. https://www.iosrjen.org/
8 Mukaro R, Tinaiwo D. Performance evaluation of a hot-box reflector solar cooking using a microcontroller based measurement system. Int J Energy Res. 2008;1:1339–48. https://doi.org/10.1002/er.1441
9 Shawn S. Development of a comparative framework for evaluating the performance of solar cooking devices. In: Project on combining ergonomic, thermal and qualitative data into an understandable, reproducible and rigorous testing method. NY, USA; 2002. p. 1–53.
10 Anthony OO, Ugochukwu CO, Osueke CO, Chiebuka TC. Thermal analysis of solar box cooker in Omu-Aran. J Phys Conf Ser. 2019;1378:032065. https://doi.org/10.1088/1742-6596/1378/3/032065
11 Gregory AA, Mejeha IM, Ogungbenro O, Nwandikom GI, Akujor C. Design and construction of a solar box cooker as an alternative in Nigerian kitchen. Sci Technol Vis. 2010;6:57–62. ISSN: 2346-3215.
12 Viral KP, Shailesh NC, Bakul TP. Assessment of thermal performance of box type solar cookers under gujarat climate condition in mid-summer. Int J Eng Res Appl. 2010;1(4):1313–6. ISSN: 2248-9622. https://www.ijera.com/
13 Soe NN, Win AK, Min NKT. Design and construction of a solar box cooker system. Icon Res Eng J. 2019;3(1). ISSN: 2456-8880.
14 Chaudhari RH, Modi VM, Gora A, Desai NN, Chaudhary HS, Bhavsar S, et al. Performance evaluation and cost economics of developed box type solar cooker. Int J Curr Microbiol Appl Sci. 2018;7(12). ISSN: 2319-7706. https://doi.org/10.20546/ijcmas.2018.712.208
15 Kimambo CZM. Development and performance testing of solar cookers. J Energy South Afr. 2007;8:41–51. ISSN: 4321-3216.
16 Duffie J, Beskman, Williams A. Solar engineering of thermal processes. Vol. 4. USA: John Wiley & Sons; 2000. p. 667–82. ISBN: 9781118671603.
17 Funk PA. Evaluating international standard procedure for testing solar cookers and reporting performance. J Solar Energy. 2010;68:1–7. ISSN: 0038-092X.
18 Mullick S, Kandal T. Thermal test procedure for box-type solar cookers. J Power Solar Energy. 1987;39(4):353–60.
19 Abdulhamid A, Kulla DM, Kaisab MU, Omisanya NO, Shaaba MM. Simulation, construction and performance evaluation of a solar box cooker. J Sci Educ. 2020 Mar;1:318–27. ISSN: 2277-0011.
20 Aidan J. Performance evaluation of a solar box cooker at Mautech, Yola, Nigeria. Int J Innovat Res Dev. 2017;6:46–50. ISSN: 2278-0211.
21 Negi BS, Purohit I. Experimental investigation of a box type solar cooker employing a non-tracking system. J Adv Sci. 2004;2:1–28. ISSN: 2134-2352.
22 Iwuoha AU, Ogunedo BM. Performance evaluation and economic analysis of a domestic solar cooker. Open Acc Lib J. 2021;8:e7263. https://doi.org/10.4236/oalib.1107263