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An Investigation for the Best-Performing Design of Box-Type Solar Cooker for Commercialisation: A Comprehensive Review

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A B S T R A C T

Solar energy is the cleanest way of cooking food using a solar cooker. But it is inefficient, takes a long time to cook, relies on the weather, doesn't transmit heat well, has a restricted temperature range, is bulky, degrades with time, needs maintenance, and is not very popular with users. Numerous researchers devised new ways to make box-shaped solar cookers to overcome these difficulties and tested them. Henceforth, it is hard to find the latest, most energy-efficient design of a box-shaped solar cooker so that it can be improved further to bring it to the commercial level. This work presents a state-of-the-art review of box-type solar cookers to find the most energy-efficient design. Based on this review, a box-type solar cooker with energy storage is investigated as the best-performing design with figures of merit F_1=0.23 and F_2=0.27. The size of the absorber plate is the most crucial factor in figuring out how much a solar cooker will cost. To deal with this difficulty, a regression equation has been estimated to be *"Absorber area (sq. m) = -1.134 + 0.00227 Max temperature (°C) + 0.0313 Cooking mass (kg) + 0.001541 Solar Irradiation (W per sq. m)."*

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1. Introduction

1.1 Brief history of cooking

Food preparation with fire is an essential human activity. Cooking fires have been discovered in archaeology for at least 300,000 years [1]. Due to agriculture, commerce, trade, and interstate transportation, civilisations have expanded [2]. Many new ingredients were introduced to cooks according to the cultures of various regions. Cooking techniques are developed through new inventions and technologies, such as the development of pottery for storing and boiling water [3].

The re-analysis of well-cooked bone fragments and plant ashes from South Africa's *Wonderwerk Cave* revealed evidence that humans controlled fire almost 1 million years ago. In the inspiring book *"Catching Fire: How Cooking Made Us Human"*, by Richard Wrangham proposes that bipedalism[1] and due to extensive cranial[2] development, allowed early Homo erectus to prepare meals [4]. However, archaeological evidence showed fire regulation began around 400,000 BCE, long after Homo erectus. Throughout Europe and the Middle East, archaeological evidence dating back 300,000 years has been discovered in ancient hearths, earth ovens, charred animal bones, and flint [5]. Anthropologists believe cooking fires first appeared around 250,000 years ago. The oldest houses were discovered recently by anthropologists who thought cooking fires were responsible for their extinction [6]. Jean-François Millet's painting (1854) on historical cooking illustrated cooking history by allowing communication between the old and new Worlds.

Potatoes, tomatoes, maize, beans, bell pepper, chilli pepper, vanilla, pumpkin, cassava, avocado, peanut, pecan, cashew, pineapple, blueberry, sunflower, cocoa, gourds, and squash are examples of New World foods. They were introduced across the Atlantic, significantly impacting Old World cooking [7]. From the nutritional point of view, cattle, sheep, pigs, wheat, oats, barley, rice, apples, pears, peas, chickpeas, green beans, mustard, and carrots were prevalent. Even now, these foods are popular and included in most people's regular diets.

During the seventeenth and eighteenth centuries, there was a notable scarcity of food. In the nineteenth century, known as the "Age of Nationalism," culinary practices emerged as a crucial emblem of national identity. The Industrial Revolution led to the emergence of mass production, marketing, and the standardisation of food. As factories initiated the processing, preserving, firing, and packaging of cereals, a type of grass utilised for grain production, it rapidly gained popularity in a range of foods, particularly as a breakfast staple. For food preservation, freezing processes were popular, and consequently, cafeterias and fast-food restaurants appeared in the 1920s [8–10].

The next section of the article introduces difficulties faced by humanity due to conventional methods of cooking (that use fossil fuels and biomass) and also presents the renewable method of cooking, i.e. solar cooking.

1.2 Difficulties with conventional cooking and solar cooking

Worldwide, almost 3 billion people cook over wood, animal dung, or charcoal fires [11]. Every day, they breathe in smoke and soot for hours. And they are more reliant on costly, unsustainable fossil fuels [12–14]. Electricity for cooking is not viable in many places since it is expensive, unavailable, or intermittent. Hence, some sustainable alternatives for cooking must be developed and disseminated in society [15–17]

It is well known that the sun is the primary energy source for all living beings [18]. Every square meter of Earth receives around 342 W of solar energy annually [19]. This energy is more than sufficient for small-scale cooking applications [20]. Scientists have been anxiously hunting for creative solar cooking solutions ever since. One hundred years after the end of the Industrial Revolution, in 1976, Barbara Kerr and Sherry Cole developed the simple cardboard solar box cooker, which was ultimately the first milestone in creating solar cookers internationally [21,22]

Solar cooking is the most basic, safest, and easiest method to prepare meals without fuel or heating the kitchen [23]. Solar cooking offers a clean, cost-effective alternative for hundreds of millions worldwide who cook over wood or dung fires, travel long distances to obtain firewood, and spend much of their small income on fuel [24–26].

Like solar cooking, solar water pasteurisation is a life-saving skill for millions who lack access to safe drinking water and become ill or die from preventable waterborne illnesses yearly [27,28]. According to the World Health Organisation, 10% of fatalities in 23 countries were due to unsafe water, inadequate sanitation and hygiene, and home air pollution caused by solid fuel used for cooking [29–33]. The next section of the article discusses the classification of solar cookers.

1.2.1 Classification of solar cookers

[1] Bipedalism is a kind of terrestrial walking in which a tetrapod travels using its two rear limbs or legs.

[2] The head skeleton of a human or animal.

A solar cooker is a device that uses direct sunlight to heat, cook, or pasteurise beverages and other food materials. Solar cookers are broadly classified as (a) box-type, (b) concentrating type, and (c) indirect type [34,35]. The detailed classification of solar cookers is given in Fig. 1 [36]:

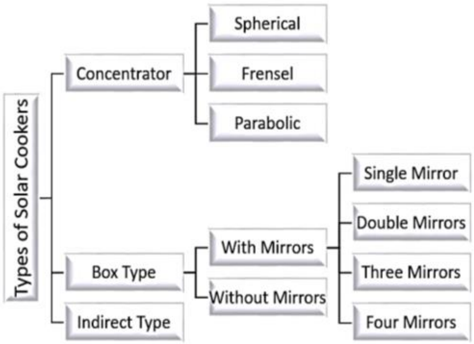

Fig. 1 Classification of the solar cooker [36]

1.2.2 Box cooker

A box-type solar cooker is shown in Fig. 2. It consists of an insulated box, metallic cooking pots inside, a double glass lid on the cooking tray, and a reflecting mirror. The sides and bottom of the cooking tray are insulated. The incoming solar radiation strikes the cooking pots and the dull black tray through the double glass lid. To facilitate cooking, the blackened surface absorbs heat and transfers it to the food in the pots. The mirror reflector is positioned to direct solar radiation toward the cooker box. The box is filled with black vessels. The commodity to be cooked is kept in the vessel. Cooking vegetables, rice, dals, cakes, and other foods takes 1.5 to 2 hours. The cooking time depends on the food type, depth, and solar irradiation.

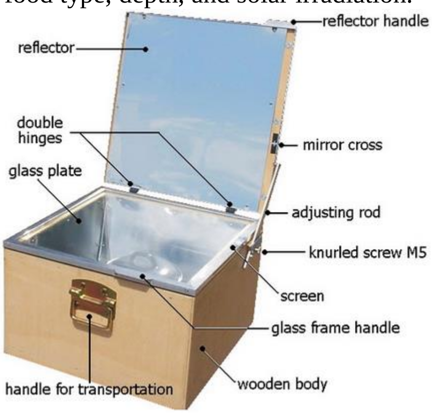

Fig. 2 Basic design of box-type solar cooker [37]

1.2.3 Panel cooker

The designs for solar panel cookers integrate elements of both box and parabolic cookers, as illustrated in Fig. 3. A substantial reflector area is often present, and the cooking pot typically features an enclosure designed to retain heat. Panel cookers are capable of achieving temperatures as high as 1400°C. Parabolic reflectors positioned above a box-type oven generally exhibit reduced size and weight. During the cooking process, the cooking pot is enclosed in a plastic bag, serving as an effective heat trap. A solar panel cooker promotes efficient cooking by utilising multiple reflecting panels to distribute sunlight radiation effectively. A limitation of a panel cooker is that wind affects the cooking temperature more significantly than a box cooker, as the cooking vessel is directly exposed to the surrounding air.

Fig. 3 Panel cooker [38]

1.2.4 Parabolic cooker

A parabolic solar cooker directs sunlight to a small area to generate heat for cooking via a parabolic-shaped reflector (Fig. 4). The solar cooker's orientation should be changed in response to the sun's movement. Compared to other solar cookers, a parabolic dish cooker can attain temperatures ranging from 350°C to 400°C [39].

Fig. 4 Parabolic cooker [40]

1.2.5 Demand for solar cookers

Solar cooking improves individuals' quality of life and enables adaptation to an evolving environment. Individuals, including women and children, could experience improved air quality, contribute to the preservation of trees and soil, allocate more funds for nutrition and education, and prevent misuse. Consequently, the demand for solar cookers is rising steadily each day. The global market for solar cookers was valued at approximately USD 1,845.0 million in 2019 and is projected to attain around USD 3,209.3 million by the conclusion of 2026, reflecting a compound annual growth rate (CAGR) of 8.7% from 2020 to 2026 [41].

1.3 The motivation behind the work

According to the literature, numerous studies have explored different solar cooker designs aimed at enhancing energy efficiency and establishing a viable commercial market. Nonetheless, inquiries emerge regarding the optimal design that maximises energy efficiency and cost-effectiveness, aiming to refine it for commercial viability for the general public. As a result, individuals from both rural and urban areas can be encouraged to adopt solar cookers for their culinary needs. There is a possibility that it could be utilised at least during weekends and holidays, representing a small advancement in the effort to conserve electricity, biomass, LPG, or other fossil fuels. This initiative will contribute to lowering carbon emissions and represent a meaningful step towards achieving the UN Sustainable Development Goals for 2030. With this thought in mind, many review articles published on box-type solar cookers were rigorously studied to find the best design [42–62]. However, no evidence has been found in the literature investigating the most energy-efficient solar cooker. Hence, this review work has been undertaken.

1.4 Objectives of the present review work

The present review is limited to box-type solar cookers since they are cost-effective for the general population. It is compact and easy to handle for women and older adults. The other solar cookers, such as concentrating cookers, are voluminous and approximately five times costlier than a box-type solar cooker.

What are the different types of the box-type cooker? What are its essential components? What are its different types? Is there any demand for solar cookers in the national and international markets? How have the investigators used the various innovations to improve cookers' cooking power and energy efficiency? Which one is the most energy-efficient box-type solar cooker? What is the price range of solar box cookers in the market? This article deals with such questions. The specific objectives of this study are as follows:

a) To investigate and compare different box-type solar cooker designs.
b) To identify the most effective and energy-efficient solar cooker that can be commercialised for widespread use by people in rural, remote, and urban areas.

1.5 Novelty of the present review work

This review presents a cutting-edge design for a box-type solar cooker that showcases the latest advancements in performance. The analysed design has potential for further optimisation to achieve commercial viability. As a result, there is potential to decrease the cooking fuel load to a certain degree. This represents a small advancement in the pursuit of Sustainable Development Goal-7 (SDG-7), which aims to provide clean and affordable energy for everyone.

2. Bibliometric analysis and methodology of review work

2.1 Bibliometric analysis

Bibliometric analysis is a well-known initiation step of any literature review. The statistical analysis of books, journals, or other publications is known as bibliometrics. Bibliometric analysis monitors the production and influence of an author or researcher. Data from bibliometrics may also be displayed to better understand publishing linkages. To understand the quantum and impact of several publications published on box-type solar cookers, the Scopus database was analysed using VOSviewer open-source software. Ninety-six research papers from 2000 to 2023 were identified from the Scopus database for bibliometric analysis (excluding review articles). The following section illustrates the statistical analysis of the 96 research papers.

Citations keep the reader informed of whose thoughts or words are used at any given moment in each phrase and paragraph. Citations are critical since ideas are the currency of academics. Hence, citation versus published articles is essential to identify the most impactful papers in the field of research. For the present review work, the condition of one citation was set as the cutoff. Then, 82 articles met the threshold value out of 96 identified articles.

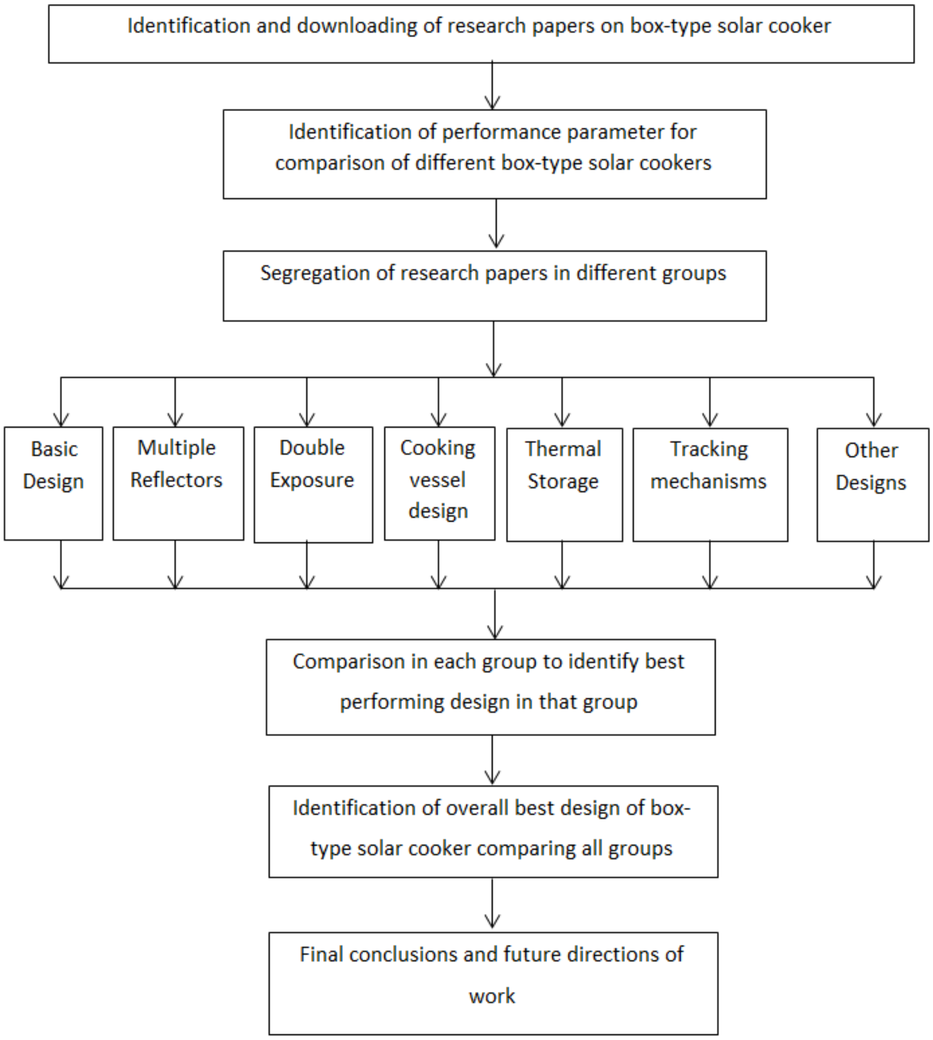

Fig. 5 Steps used to carry out the review work

The present article begins with an introduction that includes basic information about solar cookers, the motivation for the study, the goals of the current review work, mathematical modelling and a review of various box-type solar cookers. A comparison is made at the end of each section, and the best-performing cooker is investigated in that particular group. Finally, end comparisons were conducted to determine the overall best-performing box-type solar cooker across all sections. The article ends with a conclusion and a scope of future work. Fig. 6 depicts the year-wise number of research papers examined for this review work.

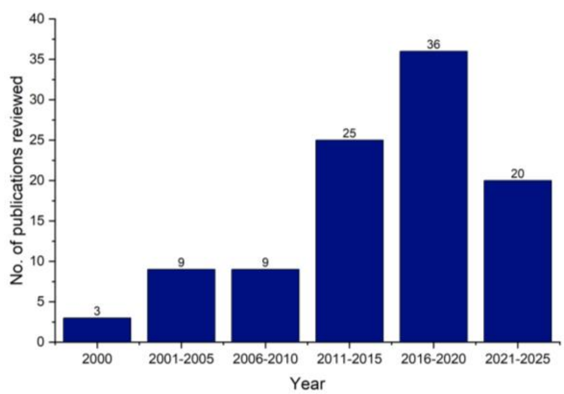

Fig. 6 Year-wise publications reviewed during the review work

3. Mathematical modelling and performance estimation equations

This section describes various mathematical equations used to investigate the thermal performance of box solar cookers and the standard testing procedure.

3.1 First Figure of Merit

The thermal performance of box-type solar cookers is evaluated by two figures of merit, F_1 and F_2. The optical efficiency to overall heat loss coefficient ratio is the first figure of merit, F_1. The higher the F1 value, the better the performance of the cooker [63].

$$F_1 = \frac{(T_{ps} - T_{as})}{G} \quad (1)$$

3.2 Second Figure of Merit

The second figure of merit, F_2, controls the sensible heating load. The box-type solar cooker's second figure of merit, $F_{2,}$ is evaluated under full-load conditions. It is the sum of the heat exchange and the optical efficiency factor [64].

$$F_2 = \frac{F_1 (MC)_w}{A_p \Delta t} \ln\left[\frac{1 - \frac{1}{F_1}\left(\frac{T_{W1} - T_a}{G}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2} - T_a}{G}\right)}\right] \quad (2)$$

3.3 Cooking Power

The rate of useful energy available during heating per unit of time is called cooking power. It can be calculated as a function of the change in water temperature for each interval and the mass and specific heat capacity of the water contained in the cooking utensil [65].

$$P = (MC)_w \frac{(T_{w2} - T_{w1})}{T_a} \quad (3)$$

3.4 Thermal Efficiency

The thermal efficiency of a solar cooker is the ratio of energy used for cooking the food to the total energy collected by the solar cooker. Thermal efficiency indicates the ability of a solar cooker to use incident solar energy for heating and cooking food [66].

$$\eta = \frac{(m_p c_p + m_w c_w)(T_w - T_a)}{A \times G \times t} \quad (4)$$

3.5 Energy analysis

The solar box cooker's components are subjected to energy balance equations. The following are the energy balance equations for the glass cover, internal air, absorber plate, cooking vessel, and liquid [67,68].

$$T_{gc}(t+1) = T_{gc}(t) + \frac{A_{gc}}{m_{gc} c_{gc}} dt[G\alpha_{gc} - h_{gc} - amb(T_{gc}(t) - T_{amb}) - h_{gc} - sky(T_{gc}(t) - T_{sky}) + h_{air} - gc(T_{air}(t) - T_{gc}(t)) + h_{cv} -_{gc} (T_{cv}(t) - T_{gc}(t)) + h_{ap-gc}(T_{ap}(t) - T_{gc}(t))] \quad (5)$$

$$T_{air}(t+1) = T_{air}(t) + \frac{dt}{m_{air} c_{air}}[h_{ap} -_{air} (A_{ap} - A_{cv})(T_{ap}(t) - T_{air}(t) - h_{air} -_{gc} A_{gc}(T_{air}(t) - T_{gc}(t) - h_{air} -_{cv} A_{cv}(T_{air}(t) - T_{cv}(t)] \quad (6)$$

$$T_{ap}(t+1) = T_{ap}(t) + \frac{dt}{m_{ap} c_{ap}}[G\alpha_{ap}\tau_{gc}A_{ap} - \frac{k_{cv}A_{cvb}(T_{ap}(t) - T_{cv}(t))}{w_{cvb}} - h_{ap} -_{air} A_{ap}(T_{ap}(t) - T_{air}(t)) - h_{ap} - gcA_{gc}(T_{ap}(t) - T_{gc}(t))] \quad (7)$$

$$T_{cv}(t+1) = T_{cv}(t) + \frac{A_{cv}}{m_{cv} c_{cv}} dt[G\alpha_{cv}\tau_{gc}A_{cv} + h_{ap-cv}(T_{ap}(t) - T_{cv}(t) + h_{air-cv}(T_{air}(t) - T_{cv}(t)) - h_{cv-gc}(T_{cv}(t) - T_{gc}(t)) - h_{cv-liq}(T_{cv}(t) - T_{liq}(t)) \quad (8)$$

$$T_{liq}(t+1) = T_{liq}(t) + \frac{dt}{m_{liq} c_{liq}}[G\tau^2{}_{gc}A_{cv1} + A_{cv}h_{cv-liq}(T_{cv}(t) - T_{liq}(t))] \quad (9)$$

3.6 Exergy analysis

Exergy is the maximum work a system can perform (till the system reaches equilibrium with the environment). Solar box cookers' exergy input and exergy output can determine the energy balance equation [67].

$$E_{in} = GA\Delta t[1 + \frac{1}{3}(\frac{T_{amb}}{T_{sun}})^4 - \frac{4}{3}\frac{T_{amb}}{T_{sun}}] \quad (10)$$

$$Ex_{out} = m_w C_{pw} \int (1 - \frac{T_{amb}}{T_w}) dT_w \quad (11)$$

The following equation can be rewritten:

$$Ex_{out} = m_w c_{pw} (T_{wf} - T_{wi}) - m_w c_{pw} T_{amb} \ln \frac{T_{wf}}{T_{wi}} \quad (12)$$

$$Ex_{out} = E_{out} - m_w c_{pw} T_{amb} \ln \frac{T_{wf}}{T_{wi}} \quad (13)$$

3.7 Exergy Efficiency

Exergy efficiency calculates a system's effectiveness in terms of its performance under reversible conditions [67].

$$\eta_{ex} = \frac{Ex_{out}}{Ex_{in}} = \frac{E_{out} - m_w c_{pw} T_{amb} \ln \frac{T_{wf}}{T_{wi}}}{GA\Delta t[1 + \frac{1}{3}(\frac{T_{amb}}{T_{sun}})^4 - \frac{4}{3}\frac{T_{amb}}{T_{sun}}]} \quad (14)$$

4. Review of several box-type solar cookers

After introductory information on solar box-type cookers and defining several mathematical equations for the investigation of thermodynamic and thermoeconomic performance, from this section onwards, the article introduces and compares the performance of different solar box cookers investigated by several investigators in various groups, as explained in the methodology section.

4.1 Basic design

Let's review the primary types of solar cookers, i.e., a simple box-type solar cookers with reflector(s), as shown in Fig. 7.

Chaudhari *et al.*, [69] fabricated a box-type solar cooker (Fig. 7) with a cooking capacity of 4-5 persons. The outer dimension of the cooker was 700 X 600 mm, and the inner dimension was 640 X 540 mm. Glass wool insulation with a 25 mm thickness was used to reduce heat loss. The aperture size of the collector was 0.382 m^2. The transparent glass cover was 5 mm thick, and the mirror was a reflector. The authors reported that the figures of merit, F_1 was 0.11 and F_2, were 0.41, respectively. The cooker's thermal efficiency and cooking power were estimated at 28.93% and 84.18 W, respectively. The water reached a temperature of 95 °C with solar irradiation of 700 W/m^2.

Fig. 7 Solar box cooker [69]

Aremu *et al.*, [70] studied solar cooker performance in the tropical climate of Ibadan. They used plywood for the outer periphery of the solar cooker. The coconut coir was used as an insulator, and aluminium foil was used as a reflector. The cooker had an aperture area of 0.25 m^2. The authors said this cooker could cook food for 4 to 5 people. They also found that with 700 W/m^2, the stagnation temperature reached 126 ˚C. The figure of merit values ranged from F_1=0.11-0.13 and F_2=0.24-0.30. The maximum cooking power was calculated as 92.4 W.

Nahar [71] fabricated a solar cooking hot box (Fig. 8). The external box was constructed of steel sheets 22 SWG. The internal compartment was made from 22 SWG aluminium sheets. The measurements of the external box were 610 X 610 X 200 mm^3, and the dimensions of the inward box were 450 X 450 mm^2 at the very top and 415 X 415 mm^2 at the bottom, with an 80 mm height. The distance between the outer plate, the inner plate and the external box was lined and separated by glass fleece and a wooden casing. The internal plate was darkly painted. Two 4-mm-thick transparent glass sheets with an openable wooden edge had been fixed over the inward plate. The inner and outer box gaps contained 5 kg of used motor oil. An elastic between the plate and the detachable casing was a gasket to seal it. Over it, a 4-mm mirror reflector was fixed. Depending on the season, the glass slant can range from 0 (closed lid) to 120 degrees from the flat plane. Four cooking vessels separated by 20 mm were kept inside the cooker to cook four dishes simultaneously. The dimensions of the cookers were 610 X 610 X 275 mm. The author discovered that the cooker's efficiency was 27.5 %.

Fig. 8 Solar box cooker with four cooking vessels [71]

Mahavar *et al.*, [72] fabricated a single-family box-type solar cooker, as shown in Fig. 9. They used an outer casing with a rigid board thickness of 2.5 mm and a 58 X 46.5 X 15.5 cm^3 dimension. They used a black matt-painted rectangular aluminium plate with a thickness of 0.35 mm and a size of 47 X 35.5 X 8.5 cm^3. They used two glazes of polymethyl methacrylate (PMMA) material with 13 mm space between them and a thickness of 2.75 mm. They used one reflector with a dimension of 54.6 X 40.5 cm^2 of 4 mm thickness with silicate glass material. The insulation of materials was corrugated cardboard, expanded polystyrene, and newspaper. On the side, they used insulation of 5 cm, and at the bottom, it was 3.5 cm thick. They also used two pots of aluminium black matt painted in a cylindrical shape with a diameter of 20 cm and a height of 6 cm. The author revealed that with 2 kg of water and solar radiation of 830 W/m^2, the highest temperature achieved was 94.5 $^{\circ}$C. The values of F1 and F2 were 0.116 and 0.466, respectively, with a cooking power of 103.5 W.

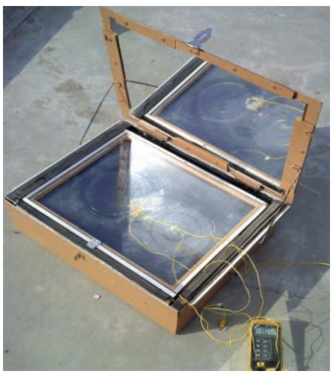

Fig. 9 Single-family solar cooker [72]

Mahavar *et al.*, [73] constructed an optimum load range solar box cooker with a 1.2-1.6 kg capacity, as shown in Fig. 10. The size of the cooker's aperture was 0.167 m^2. The author found that the maximum temperature reached was 94.5 $^{\circ}$C with solar radiation of 830 W/m^2. The figures of merit were F_1=0.116 and F_2=0.466, respectively.

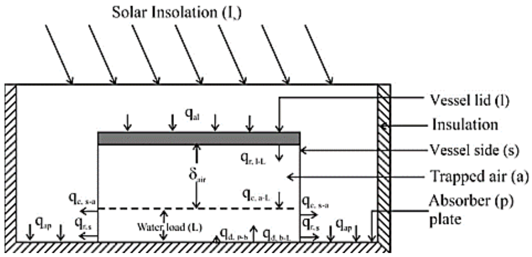

Fig. 10 Solar box cooker for optimum load range [73].

Okonkwo *et al.*, [74] tested the sun-based box cooker (Fig. 11) made of 3/4-inch thick pressed wood (1.9 cm). The square structure had a 53.81 cm outer side length. The bottom of the cooker was made of Chinese plane wood with a 1/4 in thickness (0.6 cm). The aluminium foil was used on internal surfaces to reflect solar radiation towards the interior surfaces of the wooden box. The sun-protective shield was made of aluminium 0.54 mm thick. It was built as a pyramidal square frustum. The internal reflector component was made of a 1 mm sheet of aluminium. The dark-painted matte 1 mm thickness is used as an absorber plate. The author stated that with 1 kg of water and 1366.7 W/m^2 of solar irradiation, the maximum temperature of 100 $^{\circ}$C was attained inside the solar cooker. The calculated merit of the figure was F_1 = 0.129, F_2 = 0.285.

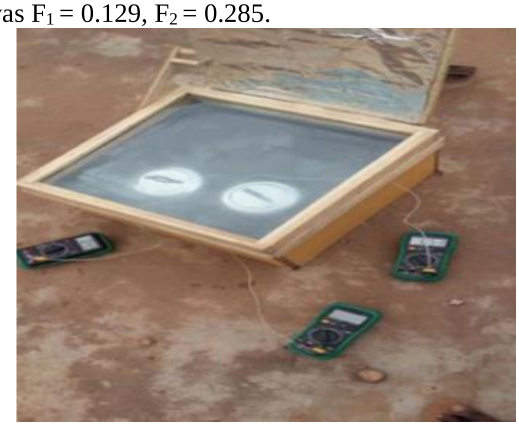

Fig. 11 Square type of solar cooker [74]

Chatelain *et al.*, [75] fabricated a solar cooker using a wooden structure filled with 5 cm of sheep wool, as shown in Fig. 12. The inner partitions were wrapped in aluminium foil. The surface area of the cooker was 0.4 square meters. The two-layer coating comprised two clear glasses, 3 mm thick, with a 24 mm inside air layer. The layers of glass were embedded in the wooden edge. The cooker's foundation had a dimension of 66.5 cm x 61 cm. The most excellent height with the reflector was 45 cm, and the most significant height with the reflector open was 95 cm. A cooking load of 9 kg was given for its performance investigation. This cooker has two settings: one for winter low-light positions and another for sunlight-based beams coming from high overhead. According to the authors, the maximum temperature reached 116 ˚C with solar radiation of 660 W/m^2. Figures of merit were estimated as F_1=0.15 and F_2=0.315, and the calculated cooking power was estimated at 30.9 W.

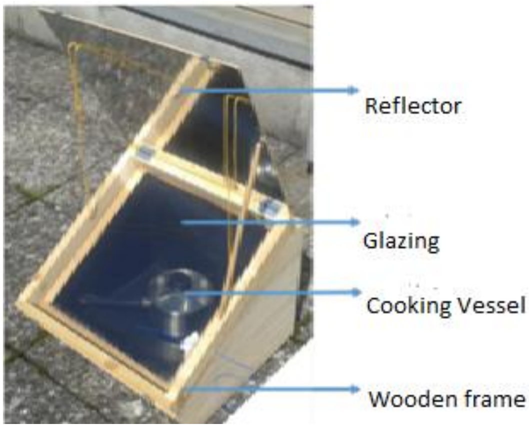

Fig. 12 Solar box cooker [75]

Ali [76] used outside and interior reflectors to improve the cooker's thermal performance (Fig. 13). The inside reflectors were two pieces of mirror placed at 45° to the sides of the cooker. The cooker was outfitted with an outer wall made of a rectangular mirror (90 x 40 cm), pivoting to the vertical back of the cooker and adjustable through a bar and bolt mechanism. The inner reflectors were set at 70^0. The external box (100 x 50 cm) is constructed from long wooden pieces. The aluminium absorber was darkly painted with black mat paint. The overall shape of the plate was a trapezoid, with the forward portion being a square shape with an area of 0.267 m^2. The cooker's entryway was a 30 cm x 25 cm opening in the back's centre. A piece of mirror was placed on the inside surface. The top of the cooker was covered with a two-fold sheet of standard window glass separated by 1 cm, outlined with wood bits of rectangular cross-section 8 x 2.4 cm and always dashed to the cooker. The author reported that for 2 kg of water, the merit figures were computed as F1=0.11 and F_2=0.37, with a thermal efficiency of 21.4 %, and the maximum temperature reached 140.3°C with 1000 W/m^2 of solar radiation. The cooking power was estimated to be 9.7 W.

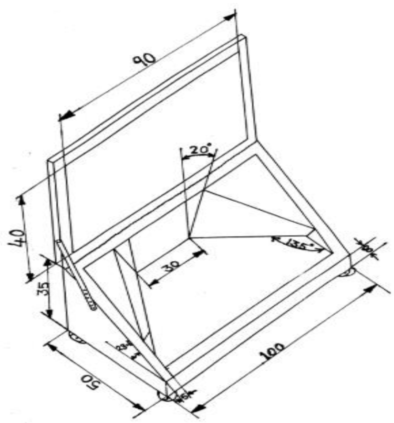

Fig. 13 Solar box Cooker [76]

4.2 Comparison of simple box-type solar cooker

Table 1 compares the essential performance parameters of simple box-type solar cookers with reflectors discussed in section 4.1. It shows that a wood cooker with sheep wool insulation is the best-performing cooker in this section since it has the highest value of F_1.

Table 1. Comparison of experimental results of a simple box-type solar cooker

Sn	Author (s)	Material	Insulation	Area (m^2)	Energy efficiency (%)	Cooking power (W)	Maximum temperature	F_1	F_2
1	Chaudhari *et al.,* [77]	Plywood	Glass wool	0.275	37.7	58.4	95.8°C	0.10	0.31
2	Nahar [71]	Wood	Glass wool		27.5				
3	Mahavar *et al.,* [72]	Wood	Polystyrene expanded			103.5	94.5°C	0.11	0.46

4	Ugochukwu *et al.*, [74]	Plywood	Aluminium foil	0.22			100°C	0.12	0.28
5	Chatelain *et al.*, [75]	Wood	Sheep wool	0.4		30.9	116°C	0.15	0.31
6	Ali [78]	Plywood	Polystyrene	0.16	21.4	650	81.6°C	0.11	0.37

4.3 Multiple Reflectors

In multifaceted reflectors, numerous reflections are obtained from several planar mirrors arranged in a row. These use the principle of total external reflectance, which occurs for angles of incidence beyond a critical angle (often near 10° grazing-incidence) when the reflective index is less than unity, and the material has zero absorption. This occurs for angles of incidence beyond a critical angle when light strikes a surface at an angle more significant than the acute angle. This section of the article describes the thermal performance of a box-type solar cooker with multiple reflectors.

Olumuyiwa *et al.*, [79] examined multiple reflectors in the solar cooker to find the best exergy efficiency, as shown in Fig. 14. They used 1R, 2R, 3R and 4R as reflectors for the experiment. They used reflectors on small sides 1 and 3 with a reflector area of 0.15 m2 and large sides 2 and 4 with a reflector area of 0.09 m^2. They also used plywood for the outer box, 0.84 m2, and the inner box, 0.70 m^2. A black-painted absorber plate of 380 mm x 230 mm with a glazing mirror of dimension 510 mm x 290 mm, 4 mm mirror thickness was also used. The black-painted cooking pot, which was 15 cm in diameter and 12 cm in height, was used to place 1 kg of water. The size of the cooker's aperture was 0.064 m^2. Glass wool was used as an insulator. The author got the best results for 4R with 31.47% exergy efficiency. The highest temperature reached 100^0C for the solar intensity of 953.5 W/m^2.

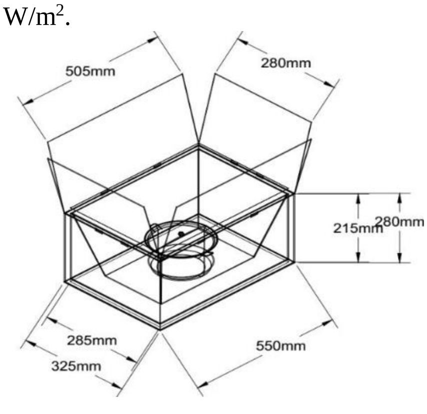

Fig. 14 Box-type solar cooker with reflector [79]

Aremu *et al.*, [80] tested a box-integrated building-type cooker (Fig. 15). They used 20 mm thick teak wood of dimensions 100 mm x 20 mm x 550 mm, and for the inner part of the outer section, 3 mm thick plywood of sizes 170 mm x 130 mm x 450 mm was used. The corn husk was used as an insulator. The 3-plane aluminium foil as reflectors were placed at an inclined angle of 35^0 on the plywood of dimensions 540 mm x 550 mm x 15 mm. A matte black painted steel sheet, sized 280 mm x 300 mm x 355 mm, was used as an absorber. An aluminium cooking pot with a diameter of 210 mm and a height of 90 mm was used. A trapezoidal indoor shape was made with a thickness of 20 mm and a dimension of 282 mm X 355 mm. A double-glazing 3 mm tempered float glass of 50 mm x 550 mm x 550 mm was used. The author found that for 1 kg of water, the maximum temperature reached 98.2^0C with solar radiation of 1032 W/m^2. The first and second figures of merit were calculated to be 0.12 and 0.25.

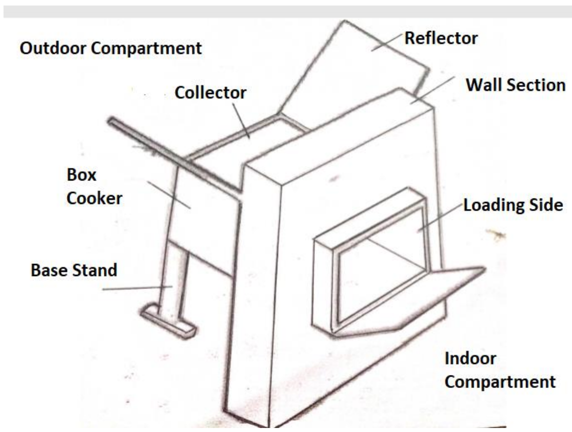

Fig. 15 A building-integrated Box-type solar cooker [80]

Adewole *et al.*, [81] made a 5 mm two-wall cardboard box-type solar cooker (Fig. 16). The inward boxes were constructed from aluminium sheets. The external and inner box spaces were filled with 50 mm-thick packed sawdust. Four reflectors are mounted on the container. The reflector's inner pieces were made of a 1 mm aluminium sheet and are covered on the outside with layered cardboard of 5 mm thickness.

The slant of the reflectors was set at 72.5 degrees. The bottom and top cooker surface areas were 0.0625 m^2 and 0.0719 m^2, respectively. The proportion of cooker focus was 1.667. The cooker's dimensions were 255 mm x 255 mm x 465.3 mm, weighing 1.16 kg. The absorber plate was made of polished aluminium in black. The absorber plate's external piece was made of 5mm thick cardboard. One black aluminium pot with a 170 mm diameter and a 100 mm height was used to cook the food. According to the author, the maximum temperature for 1 kg of water reached 67^0C with solar radiation of 520 W/m^2. F_1=0.08 and F_2=0.54 were the merit figures.

Fig. 16 Solar box cooker with four reflectors [81]

Farooqui [82] tested a solar cooker box with a mirror booster located at an optimum angle on the opposite side of the same size (Fig. 17). This cooker was tested with three different aspect ratios. The cooker's aperture size was 0.43 m^2. The cooker was 120 cm x 45 cm x 33 cm. The figures of merit were calculated as F_1=0.12 and F_2=0.33. The cooking power was calculated as 89.6W. The maximum temperature reached 90°C with solar radiation of 961.33 W/m^2. The author concluded the best results for the 2.66 length-to-width ratios.

Fig. 17 Solar box cooker with three different aspect ratios with two booster mirrors [61]

Ali [78] made a sun-powered cooker with compressed wood that measures 40 cm X 40 cm X 40 cm, as shown in Fig. 18. The 40 cm X 40 cm gap window was made of glass (6 mm thick) and was supported by the cooker's side construction. The glass cover was used to close the cooking box and help catch and trap the sun's heat. A dull black-painted absorber plate exposed to solar radiation was made of a thick aluminium plate of (3 mm) thickness. The four reflectors (trapezoidal shape) of a lower base of (40 cm), an upper base of (80 cm), and a height of (40 cm) were covered with mirrors that were adhered to the reflectors all around with a special paste. Mirrors were used to reflect the sunlight. A polystyrene leading body (50 mm) thickness was used to protect the cooker sides and base. A pot with an aluminium cover was used to warm (cook) food inside it. The pot was painted dark to absorb the sun's heat more deeply; it will warm up faster. According to the author, the highest temperature reached 81.6°C with 1.5 kg of water and 500 W/m^2 solar intensity. The cooking power was measured at approximately 650 W.

Fig. 18 Solar box cooker with four reflectors [57]

Ademe *et al.,* [83] fabricated a solar cooker comprising a 50 mm single-walled cardboard box, as shown in Fig. 19. The inward box was developed utilising an iron sheet 1.5 mm thick. The space between the outer and inner tubes was filled with 50 mm-thick sawdust as an insulator. Three adjustable reflectors were mounted to reflect the radiation onto the absorber plate's base and sides. The reflectors' inward pieces were fabricated from a 1.5 mm-thick iron sheet. The authors concluded that three reflectors with a double-glazing solar cooker with 1.43 kg of water reached 96.1°C with solar radiation of 1083 W/m^2. The merit figures were calculated as F_1=0.123 and F_2=0.827. The calculated cooking power was 51 W. The thermal efficiency was estimated to be 31.4 %.

Fig. 19 Box-type cooker with three reflectors [83]

4.4 Comparison

Table 2 compares the thermal performance of box-type solar cookers with multiple reflectors. Farooqui's solar cooker [82], with a mirror booster located at an optimum angle on the opposite side of the same size, is the best-performing solar cooker in this category, with the highest figure of merit (F_1) as 0.14.

Table 2. Comparison of experimental results of a simple box-type solar cooker with multiple reflectors

Sn	Author (s)	Material	Insulation	Area (m^2)	Efficiency (%)	Cooking power (W)	Maximum temperature	F_1	F_2
1.	Olumuywa *et al;* [79]	Plywood		0.06	68		100°C		
2.	Aremu *et al.,* [80]	Thick wood	Corn husk				129.3°C	0.12	0.25
3.	Aremu *et al.,* [70]	Plywood	Coconut coir	0.25		92.4	126°C	0.11-0.13	0.24 - 0.30
4.	Farooqui [82]						90°C	0.14	0.31
5.	Ali [78]	Plywood	Polystyrene	0.16		65	81.6°C		
6.	Ademe *et al.,* [83]	Cardboard	Saw dust	0.22	31.4	51	108.3°C	0.12	0.82

4.5 Double exposure

In a double-exposure solar cooker, the sun's rays that enter the cooker are redirected by a cover using a combination of concentrator and flat-plate collector principles. This section of the article compares the thermal performance of box-type solar cookers with double exposure.

Saravanan *et al.,* [84] developed a cooker using pressed wood. It was a double exposure box- with inside and outside dimensions of 0.52 m X 0.84 m X 30 m and 0.44 m X 0.75 m X 0.30 m (Fig. 20). Glass wool insulation was installed in the space (0.05 m) between the internal and external surfaces. The absorber plate was a black matt-painted copper plate with a thickness of 0.005 m and a size of 0.35 x 0.60

m. It was set at a distance of 15 cm from the box's top edge to increase its absorptivity. Tray-moulded reflectors with a slanted point of 30° were attached to the cooker's inside on different sides. The front glass thickness of 0.004 m was used at the base side of the cooker, which was 0.15 m from the absorber plate. The cooker's top had been made as an edge utilising the glass cover, using pressed wood with a component of 45.85 m and fixed at the top side of the cooker. Round and hollow moulded aluminium and copper base cooking vessels with widths and lengths of 0.15 m and 0.10 m were used to cook various foods. The author discovered that the figures of merit for the double exposure cooker were F_1=0.1504 and F_2=0.4422 for the copper vessel with 1 kg of water. The highest temperature reached was 102°C, with solar radiation of 1122 W/m^2.

Fig. 20 Box-type solar cooker[84]

Amer [85] investigated a solar box cooker made of plywood with a thickness of 4 mm with dimensions 70 cm x 70 cm x 30 cm (Fig. 21). The matt black-painted absorber plate made of a 0.5 mm thick copper tray had an area of 60 cm x 60 cm, and the sides of the tray were tilted at an angle of 20^0. The door was provided to the outer box for in and out of the cooking pot of 2 kg, having a cylindrical shape of 18 cm diameter and 8 cm depth. The transparent cover was 5 mm thick glass. The distance between the glass cover and the absorber was 7 cm. A cooker also used two more 3 mm thick glass covers on top of the first cover. There was a 5 cm gap between these covers. With 1000 W/m^2 solar radiation on the absorber plate, it reached the temperature of 165°C.

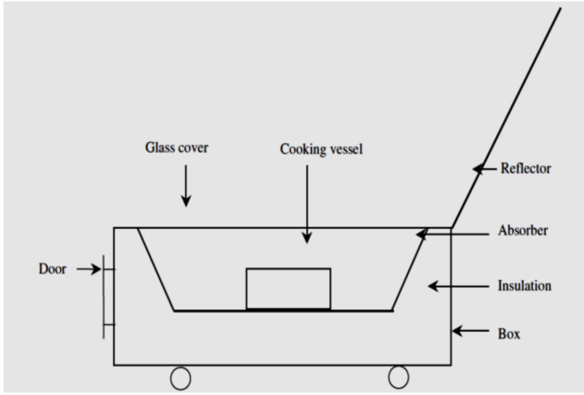

Fig. 21 Solar box cooker with double exposure [85]

Adetifa *et al.*, [86] built a solar box cooker with double exposure. The outer box was a 25 mm thick drum wood made of 670 mm x 670 mm x 195 mm, and the inner container was 3 mm thick plywood of dimensions 530 mm x 530 mm x 120.50 mm. The sawdust of 50 mm was used as an insulator. The 3 mm tempered float glass of 650 mm x 650 mm double glazing was used. Three-plane aluminium foil reflectors of 3 mm were used. The absorber plate of dimensions 520 mm x 520 mm x 116 mm was used. The aluminium cooking pot was 210 mm in diameter and 90 mm in height. The authors found the best results for benzoic acid; the figures of merit and cooking power were calculated as 1 kg of water, F_1=0.13, F_2=0.45, 19.1 W. The highest temperature reached 93°C with solar insolation of 764.8 W/m^2.

Satish *et al.*, [87] showed that adding a hybrid nano-enhanced phase change material (PCM) with 1% multi-walled carbon nanotubes (MWCNTs) and 1% silicon oxide (SiO_2) to a box-type solar cooker (Fig. 22) makes it work much better in terms of heat. The hybrid PCM reached a maximum temperature of 145.2°C, a cooking power of 47.6 W, and an average efficiency of 28.5%. It also cut the cooking time from 36.3 minutes to 18 minutes. Exergy efficiency climbed to 6.2%. Ultrasonication made sure that the nanoparticles were evenly spread out. The hybrid PCM worked better than the solo PCM and the single-nanoparticle versions. It was a cheap and energy-efficient way to cook using solar energy, even when the sun wasn't always shining.

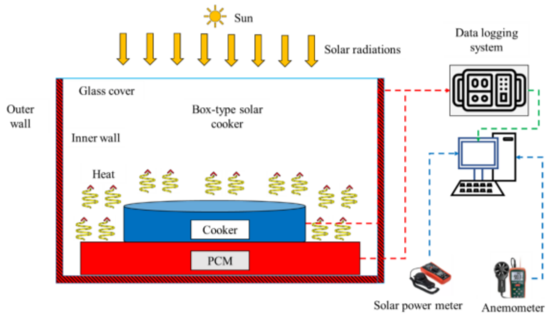

Fig. 22 Arrangement of the solar box cooker [87]

Soni *et al.*, [88] experimented with a conventional and modified double-glazing solar cooker (Fig. 23). The cooker was created with 18 mm and 12 mm thick wooden sheets for the side and lower surfaces, respectively. Its overall dimension was 615 mm x 615 mm x 220 mm with one opening. The absorber plate comprised an aluminium sheet of trapezoidal moulded having aspects 365 mm x 375 mm from the base, 525 mm x 520 mm from the top, and 70 mm depth. Glass fleece was used as insulation between the wooden pressed wood and the absorber plate. Blackboard paint was used to paint the cooker's absorber plate. The top of the cooker was covered with a double glazing of 5mm thickness with a hole of 10 mm between the mirrors, and this glass cover made an opening area of 0.26 m^2. The clear glass was utilised in the front of the box, which had a light transmission of 91%, density of 12.5 kg/m^3, and transmissivity of 0.9; it had been fixed in a wooden edge which can be opened and firmly shut the cooking zone. A single reflector of dimensions 535 mm x 535 mm x 4 mm was used. The author found that with 1 kg of water, the final temperature reached 96.5ºC with 675 W/m^2 of solar radiation. F_1=0.14 and F_2=0.34 were the calculated figures of merit.

Fig. 23 A white water glass in a double-glazing cover of a new box-type cooker [88]

Folaranmi [89] created a solar box cooker (Fig. 24) with an outer box of 700 mm x 700 mm x 400 mm and a sawdust thickness of 10 mm. The cooker's inner tray was made of a 600 mm x 600 mm x 300 mm aluminium sheet with a thickness of 1 mm. The silver glass mirror was a 700 mm x 700 mm reflector with a 2 mm thickness, and 50 mm fibreglass insulation was used. A 600 mm x 600 mm double-glazing glass sheet with a thickness of 4 mm was used. The sheets were separated by 40 mm. The cooking pot was a dull black-painted aluminium cylindrical pot with a 300 mm diameter and a 300 mm height. The cooker's aperture measures 0.36 m^2. According to the author, the final temperature of 2 kg of water reached 95ºC, with solar radiation of 711.7 W/m^2. On a typical day, cooking power was calculated as 23.9 W. F_1=0.11, and F_2=0.31 as the figures of merit.

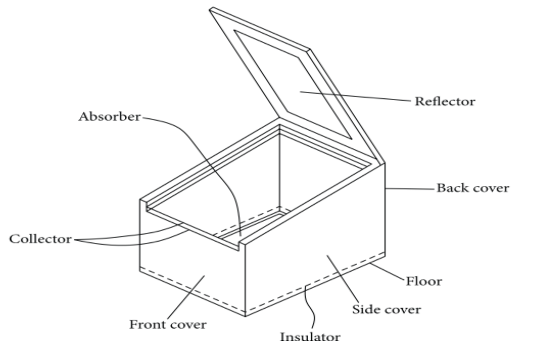

Fig. 24 Solar oven with double-glazed box windows and reflector [89]

Ekechukwu *et al.*, [90] tested a cooker comprising a 1 mm thick aluminium tray moulded as a retaining surface (Fig. 25). The cooking chamber was a square-based modified pyramid with matt dark paint on the inside walls. The tray base was 0.36 m^2, and the slant height was 0.12 m. The top comprises an aluminium-outlined, twofold-coated glass cover with a 0.49 m^2 transparent surface area. The tray was housed in a 0.8 m x 0.8 m x 0.23 m pressed wood container with a fibreglass insulator filling the gap between the plate and the wood. The plane reflector was made of a timber frame. When not in use, a plane mirror was sized to form a cover for the enclosure. The arrangement was designed for four cylinders for cooking with flat bases, each of which can hold up to 1 kg of water. The author found that, with 1 kg of water and a cooker's aperture area of 0.49m^2, the final temperature reached 95ºC with solar irradiation of 885.6 W/m^2. The figures of merits were found to be F_1= 0.11 and F_2 = 0.26.

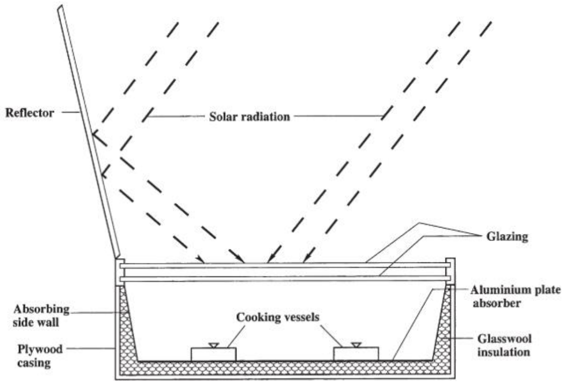

Fig. 25 Expanded plane reflector box-type solar cooker [90]

Kahsay *et al.,* [91] built two Internal and external reflector-type solar cookers (Fig. 26). The identical materials were used to make the cookers. The external box was made of 50 mm thick wood, the inner box of metal sheets, and the upper leather cover of a 1.5 mm thick two-layer coating. Overall, the cooker's width was 0.43 m; the length was 0.48 m, the front height was 0.15 m, and the back height was 0.35 m. The inside surfaces of the cooker's metal box were darkly painted. The width of the cooker was moulded at 60^0 slants. Both cookers had an aperture area of 0.142 m^2. The author discovered that the maximum reflector temperature achieved was 117.8°C for 0.5 kg of water with solar radiation of 719.3 W/m^2.

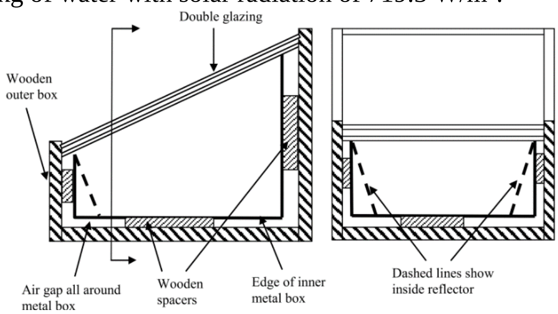

Fig. 26 Solar cooker with and without reflectors [91]

Guidara et al., [72] presented experimental work on solar box cooker thermal performance with an outer reflector. The author used a wooden box with two trapezoidal walls with an inner volume of 0.007 m^3, as shown in Fig. 27. Four removable reflectors made of polished stainless steel 32 mm in size were placed between the wooden walls. Rock wool insulation was used between wood walls and reflectors to fill the clearance and increase the solar energy capture rate. At the bottom of the wooden box, a black-painted aluminium plate was used as an absorber. Through double glazing fixed to the inclined aperture of the wood box, incident solar radiation was transmitted to the absorber plate, which acts as a black body. The authors concluded that the final temperature reached 96°C with 0.5 kg of water and solar radiation in the 827-831 W/m^2 range. The first figure of merit increased from 0.07 to 0.14, and the second figure of merit increased from 0.34 to 0.39.

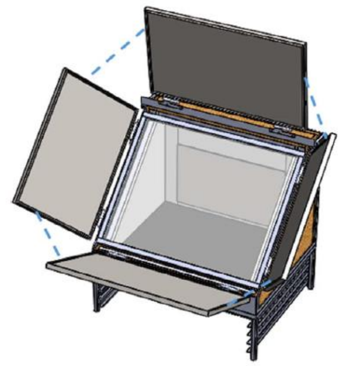

Fig. 27 Four outer reflectors on a solar box cooker [92]

Poonia *et al.,* [93] created a two-layered high-protection box-style solar cooker with a reflector (Fig. 28). The outside box was constructed of steel sheets (22 SWG), while the inside box was made of aluminium sheets (22 SWG). The external box dimensions were 610 mm x 610 mm x 200 mm, and the dimensions of the inward box were 355 mm x 355 mm with an 80 mm depth. Glass fleece was used to protect the area between the outside and inside boxes. The top surface of the plate was darkly painted with writing board paint. Two 4 mm-thick transparent window glasses were fixed over a similar wooden casing. The spacing between the two glass covers was 15 mm. An elastic gasket was placed between the wooden case to make the plate watertight. It was covered with a 4 mm-thick plain mirror reflector. The reflector fits over the cooker and rotates like a top. Depending on the season, the slant of the reflector can range from 60° to 120°. The angle was adjusted every two weeks. The cooker's aperture area was 0.126 m^2. It was used to prepare four dishes. An angle iron stand held the cooker. The resulting values for a high insulation box-style solar cooker outfitted with four cooking zones and utensils with 3 kg of cold water were as follows: F_1=0.121, F_2=0.424 and 45 W is the cooking power. Overall cooker efficiency was 26.5 per cent, and the highest hot water temperature was recorded as 101°C with 900 W/m^2 of solar radiation.

Fig. 28 A solar cooker with a double-glazed, high-insulation box and a reflector [93]

El-Sebaii *et al.,* [94] experimented on two solar box cookers with the exact dimensions of a cooking pot with a 0.13 m diameter and 0.14 m of depth welded to the absorber plate (Fig. 29). The author used 1 kg of water in one cooking pot. In model II, 4 kg of water is in four cooking pots. The outer box was wooden with one dimension opening 0.65 m x 0.85 m x 0.30 m. The upper surface of a matte-black painted copper flat plate measuring 0.49 x 0.56 m2 and with a thickness of 0.002 m was used as an absorber to absorb maximum solar radiation. The solar cooker's top aperture, with a thickness of 0.003 m, was covered by a double glass cover separated by 0.02 m. A 0.60 m X 0.54 m plane mirror was hinged at the top cover between the box's bottom, the absorber plate, and the sides of the box; glass-wool insulation was used to reduce heat loss from the cooker. The authors concluded that model II was best with a 1 m^2 aperture area with an efficiency of 26.7%. The highest temperature achieved was 95°C, with solar radiation of 902.5 W/m^2. The figures of merit calculated as F_1 were 0.13, and F_2 were 0.407.

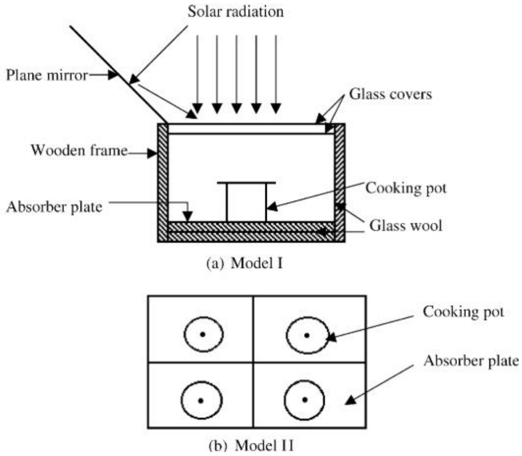

Fig. 29 Solar box cooker with a double glass cover and four cooking pots [94]

Purohit *et al.,* [95] tested different types of solar cookers (Fig. 30). The solar cooker's external box was mainly made of GI; conversely, aluminium and fibre plastic sheets were used for the internal box. The internal cooking plate, i.e., the absorber plate, was constructed from dull black aluminium sheets that absorbed solar radiation. The inward cooking box was a little smaller than the outer box. The top glazing, made up of two sheets of glass, was held together by an aluminium outline that separated them by 2 cm. This space was filled with air, which protected and kept heat from escaping within to prevent hotness spillage; an elastic strip was fastened around the casing's edges. The space between the external box and the inward plate, including the lower part of the plate, was loaded with protective material, such as glass fleece cushions, to reduce heat losses from the cooker. The reflector was installed on the inner side of the entire front of the container in a solar cooker to increase the radiation input on the engaging space.

Daylight reflects off the mirror and enters the cooker through the double glass top. The absorber plate was typically made of aluminium. These pots were also darkly painted outside, allowing them to absorb direct solar radiation. The author stated that the figures of merit were F_1=0.002-0.003 and F_2=0.015-0.033. The maximum temperature reached 90°C, with 600 W/m^2 of solar radiation.

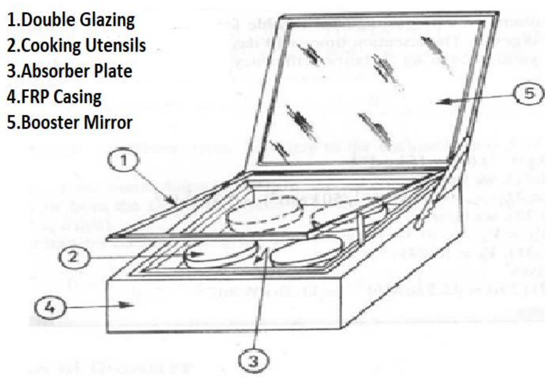

Fig. 30 Double-glazing solar box-cooker [95]

Subodh Kumar [45] trailed a dull black-painted aluminium trapezoidal-shaped tray with a 0.245 m^2 aperture inside the cooker (Fig. 31). To reduce thermal losses through conduction, glass wool insulation was used on the bottom and sides of the range. In outdoor experiments conducted during May, the same cooker (without the use of a boosting mirror) was used in the tray (0.38 m X 0.38 m at the bottom) to obtain sensible heating curves for varying loads of water, e.g., 1.0, 1.5, 2.0, 2.5, and 3.0 kg, by exposing the solar cooker on clear days. The weight was evenly distributed among four black-painted aluminium pots. The water temperature increased until it peaked close to the boiling point on a horizontal surface. The optimal efficiency was calculated to be 69%.

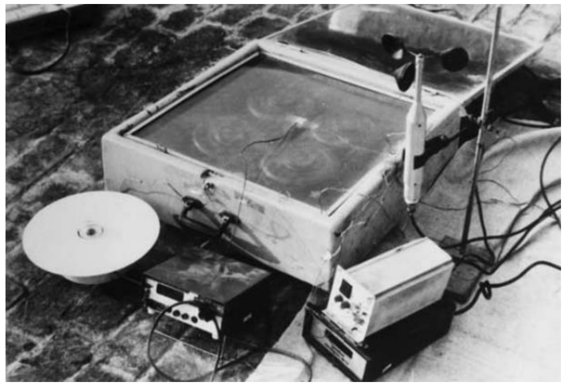

Fig. 31 Experimental set-up for outdoor solar cooking experiment [96]

4.6 Comparison

Table 3 shows that El-Sebaii's [74] has the highest value of F_1 and F_2 in this category. It has demonstrated good thermal efficiency and is the best-performing solar cooker in this category.

Table 3. Comparison of experimental results of the box-type solar cooker with double exposure

Sn	Author (s)	Material	Insulation	Area (m^2)	Efficiency (%)	Cooking power (W)	Maximum temperature	F1	F2
1.	Saravana *et al.*, [97]	Plywood	Glasswool		20.1	76.35	100°C		
2.	Amer [85]	Plywood	Glasswool				165°C		
3.	Adetifa *et al.*, [86]	Sawdust					93°C	0.13	0.4
4.	Soni *et al.*, [88]	Wooden ply	Glasswool	0.26			96.5°C	0.14	0.3
5.	Folaranmi [89]	Wood	Fibreglass	0.36		23.95	95°C	0.11	0.3
6.	Ekechukwu[90]	Plywood	glass wool	0.49			95°C	0.11	0.2
7.	Kahsay *et al.*,[91]	Wood		0.14			117.8°C		
8.	Guidara *et al.*,[92]	Wood	Rockwool				96°C	0.07-0.14	0.34-0.39

9.	Poonia *et al.*,[93]	Galvanised steel sheet	Glass wool	0.12	26.5	45	145°C	0.12	0.42
10.	Purohit *et al.*, [95]	Galvanized iron	Thermal insulation	1			90°C	0.002 - 0.003	0.015 - 0.033
11.	El-Sebaii [94]		Glass wool	1	26.7		95°C	0.15	0.19
12.	Kumar[96]	Fibreglass	Glasswool	0.24			141°C		

4.7 Innovative cooking vessel

Fins are areas that protrude from an item to increase the heat transmission rate to or from the surroundings by boosting circulation. The quantity of heat an item transfers is determined by its conduction, convection, or radiation [98]. Heat transmission increases by raising the temperature difference between the object and the surroundings, the convective heat transfer coefficient or the object's surface area. Changing the first two choices is not always possible or cost-effective. Adding fins to an item thus expands its surface area and can sometimes be a cost-effective answer to heat transmission issues. Extrusion, casting, skiving, or machining creates one-piece finned heat sinks. Thus, attaching fins to the cooking pot would help increase heat transfer to food, reducing cooking time [99]. This section of the article discusses the thermal performance of solar cookers with different cooking pot configurations.

Vengadesan *et al.*, [100] developed a finned cooking vessel (Fig. 32) to use in a container-type sunlight-based cooker with internal dimensions of 0.385 m x 0.385m x 0.07 m and external dimensions of 0.5 m x 0.5m x 0.135 m. Aluminium was chosen as a cooking vessel and fins material. Four round and hollow moulded aluminium cooking vessels were used, and barrel-shaped aluminium fins of three different lengths were connected at the three pots, as shown in Fig. 32 (c). A traditional round aluminium vessel without blades (configuration I) and a tube-shaped aluminium vessel with lengths of 25 mm (Configuration II), 35 mm (Configuration III), and 45 mm (Configuration IV) were available for testing. The cooking vessels were made of a 1 mm thick aluminium sheet, 160 mm long and 75 mm tall. Efficiency was found to be increased by using fins.

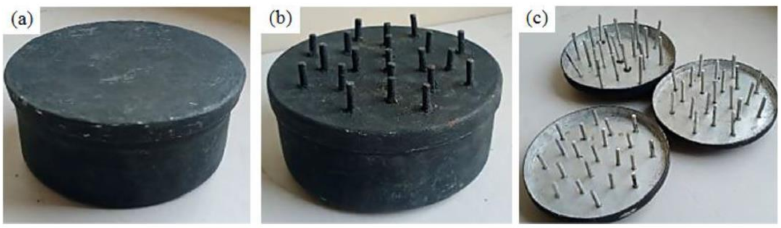

Fig. 32 Finned cooking pot [100]

Sethi *et al.*, [101] developed a parallelepiped cooking vessel compared to the horizontal and inclined cookers (Fig. 33 and 34). Two identical box-type solar cookers with 580 mm length, 580 mm width and 155 mm height were built from a 1 mm thick galvanised iron (GI) sheet. The traditional cooker was placed on a level plane on the ground surface, while the ideally slanted cooker was placed on a slanted casing at 45 degrees. One Booster mirror was installed on an even and slanted cooker with the arrangement of changing the position using the screwed handle. The inclined cooker yielded the best results for the author, with figures of merit of F_1=0.16 and F_2=0.54. On a typical day, cooking power was discovered to be 22.2 W. With solar radiation of 800 W/m^2, the maximum temperature reached 100°C.

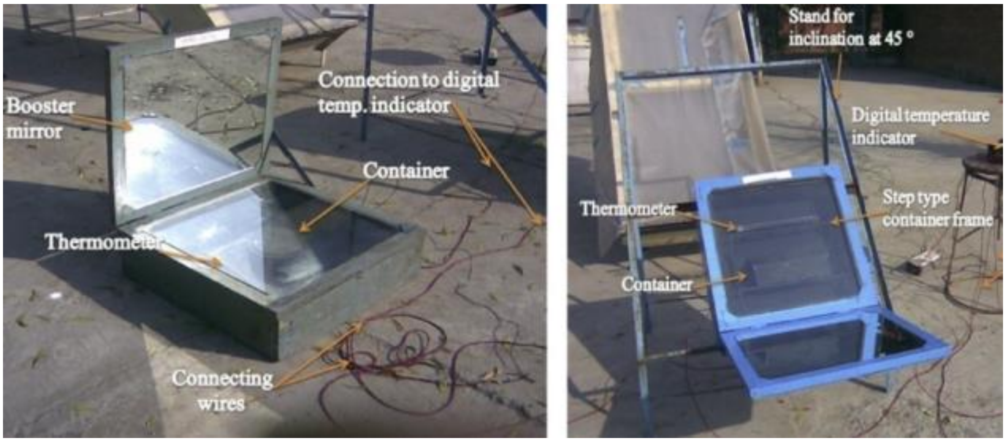

Fig. 33 Horizontal and inclined solar cooker [101]

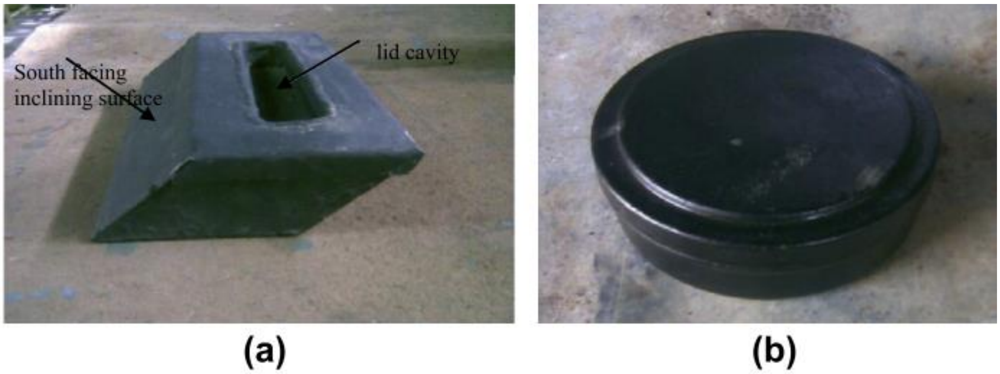

Fig. 34 Trapezoidal and conventional vessel [101]

4.8 Comparison

Table 4 compares the thermal performance of solar cookers with fins or extended surfaces mounted on the heat transfer area of solar cookers. Sethi's [101] solar cooking arrangement emerged as the best-performing design for solar cooking, with the highest F_1 and F_2 being 0.16 and 0.54, respectively, in this group.

Table 4. Comparison of experimental results of the box-type solar cooker with the modified cooking vessel

Sn	Author (s)	Material	Area (m^2)	Efficiency (%)	Cooking power (W)	Maximum temperature	F_1	F_2
1.	Vengadesan et al., [100]	Aluminium	0.160 x 0.075	56.03	73.69	102°C	0.12	0.58
2.	Sethi *et al.*, [101]	Galvanised iron			22.2		0.16	0.54

4.9 Solar cookers with thermal energy storage

Thermal energy storage devices are typically used in small-scale hot water, air heaters and other heating practices. It is also used in large-scale electrical energy production. During high power consumption, electricity is generated using the accumulated thermal energy.

Usually, there are two types of energy storage materials: (a) sensible heat storage materials and (b) latent heat storage materials. Latent heat storage materials are also called phase change materials (PCMs). This section of the article discusses the performance of solar cookers loaded with some thermal energy storage material.

Shrestha *et al. [79]* developed a solar box cooker that is 22 cm X 51 cm X 51 cm in size. The aperture area of the cooker was 0.16m^2 with double glazing. The booster mirror was used with a size of 0.21 m^2. The author used stone pebbles with black coating and uncoated. The mass of the pebble stone used was 7.5 kg. They used three cooking utensils; each contained 400 g of water. The author found that black-coated stone pebbles produced the best results; F_1=0.23 and F_2=0.27 were the figures of merit. The maximum temperature reached 99^{o}C, with 688 W/m^2 of solar radiation.

Kritika *et al.,* [102] used phase change material (PCM) in the solar box cooker (Fig. 35). The arrangement comprised a container-type sun-oriented cooker that used styrofoam to insulate the GI sheet. Its external surface measured 57.5 cm x 57.5 cm and stood 17.5 cm tall. It was darkly painted to improve thermal conductivity and absorptivity. The inward plate absorber had dimensions of 47.5 cm x 47.5 cm and a height of 8.75 cm. They used three aluminium pots with capacities of 1.5 L and 0.75 L. Magnesium Nitrate Hexahydrate, which was used as PCM on the pot's base surface. The authors concluded that the maximum solar irradiation with PCM in an aluminium pot was 920 W/m^2, and the highest temperature reached was 120^{o}C. The figures of merit were found to be F_1=0.13 and F_2=0.72. Energy efficiency was 31.37%.

Fig. 35 Solar box cooker using PCM [102]

Bhavani *et al.,* [103] tested a solar cooker made up of a twofold glass front with a thickness of 4 mm, a 100 cm gap and a hole (2 cm) between them and a bar plate (Fig. 36). The solar box cooker comprised inward front dividers (compressed wood, 2.5 cm thickness). The dimensions of the case were 30 cm tall and 35 cm long. The outer box's overall dimensions were 110 cm. A framework was insulated with 5 cm thick glass fleece and installed on the cooker's base side and sidewalls. A 5 cm hole connects the base glass cover to the cooker top, and the absorber plate (5 cm tall) was chosen for the cooker base. The absorber plate comprised a copper sheet covering a Cr2O3-MOS2-Fe2O3 nanocomposite. The cooking vessel was made of aluminium and had a base side with a cover distance of 18 cm and 20 cm in height. With the nanocomposite material, the author concluded that the thermal efficiency of the cooker was 56.21-31.77%. The maximum absorber plate temperature reached 163.74^{o}C with solar radiation of 1037 W/m^2.

Fig. 36 Solar box cooker with nanocomposite material [103]

Cuce [104] experimented on a cylindrical solar cooker with a microporous absorber to calculate energy efficiency and to select the most efficient among the solar cooker range with an ordinary absorber with triangular semi-circular porosity (Fig. 37). The author constructed a matt black solar box cooker using stainless steel. The external diameter was 500 mm. The cooker's aperture area was 0.0706 m^2. The cylindrical box-type of copper cooking pot was 160 mm in diameter and 80 mm tall. A single glazing was used. 0.5 kg of water was used for the experiment. The best results obtained by the trapezoidal absorber plate with the highest temperature were 151.1^{o}C and 34.6-21.2% thermal efficiency.

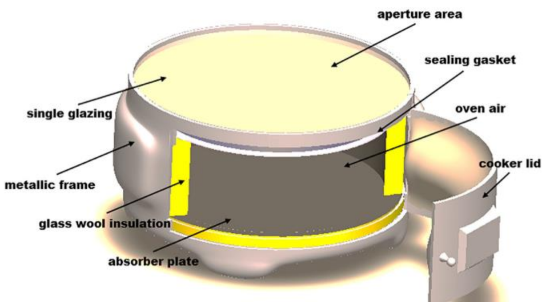

Fig. 37 Cylindrical solar cooker [104]

Saxena *et al.,* [105] tested three thermal energy storage materials in a box cooker, as shown in Fig. 38. Inside the box, a GCP-infused tube was used as the first configuration, paraffin wax was used as the second, and a third configuration was a GCP and paraffin wax mixture. They used black painted plywood with a 0.7 cm thickness of 640 x 640 x 200 mm^3 for the outer box. A plywood thickness of 0.5 cm was used to design a cooker's aperture area of 485 x 515 mm^2. It was laminated with a 0.5 mm-thick aluminium sheet painted with dull black paint. Double glazing was provided using a 2 mm thick glass sheet with a gap of 10 mm and a distance of around 15 cm from the lower absorber tray between the outer and inner boxes with 5 mm thick glass wool insulation. A 522 x 548 mm^2 adjustable booster mirror was attached to the box cooker's upper cover to increase the solar intensity. Aluminium black painted 106 mm diameter with a length of 71 mm, three-round cooking vessels were used. The cooker was placed on a galvanised stand of 1 m in height. The authors found the best results for the third configuration. The thermal efficiency was calculated as 53.81%. The figures of merit and cooking power were calculated as F_1=0.13, F_2=0.37, and 68.81 W, respectively. For 1 kg of water, the maximum temperature reached 140^{o}C with solar radiation of 750 W/m^2.

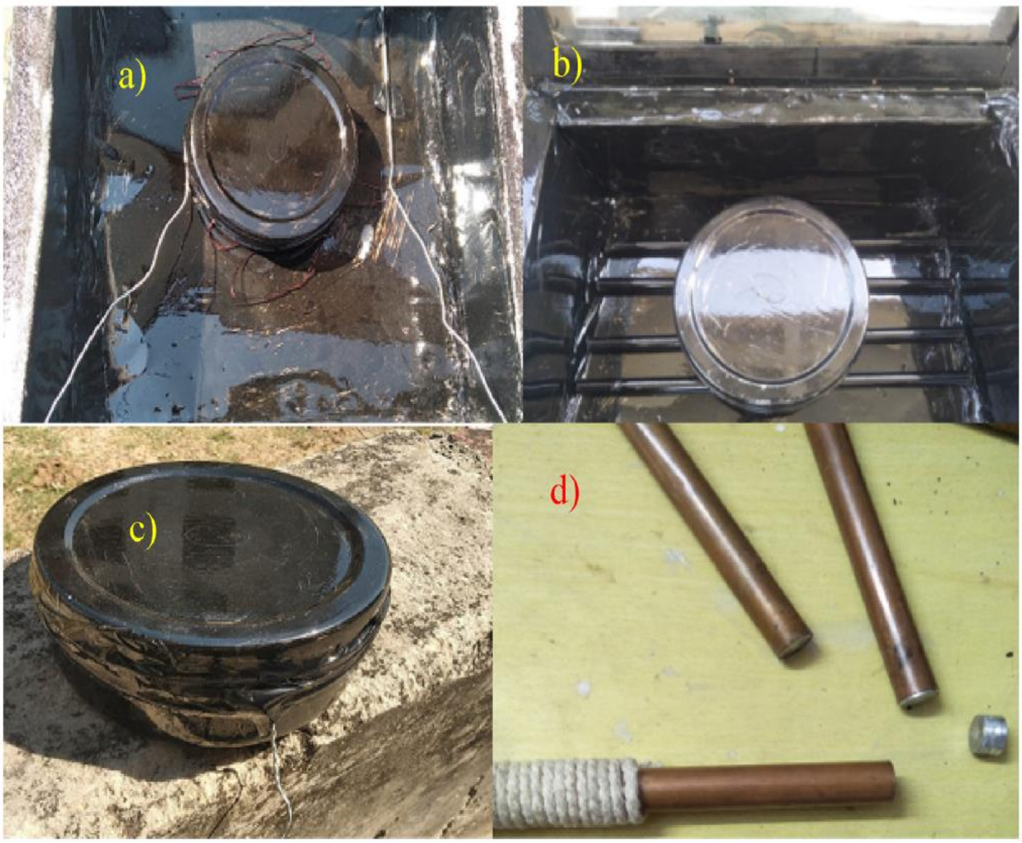

Fig. 38 Solar box cooker with flexible solar collector tubes [105]

Palani Kumar *et al.,* [106] tested the internal and external aspects of the solar cooker. It consisted of a glass cover with a thickness of 4 mm, 120 cm x 120 cm, and a plate with an absorber plate (copper metal) of size 100 cm x 100 cm. The industrially accessible base side was used (Fig. 39). The copper plate region was coated with nanoparticles (Al_2O_3) made of dark paint to cover the absorber plate, and the base side of the absorber plate was attached to a copper loop filled with the phase change material ($C_{18}H_{36}O_2$). The copper loop diameter was 1.5 mm. Copper loop blended with nanoparticles. And it was coated with black paint. The vessel was 10 cm in diameter. The thermal efficiency with PCM and nanoparticles was concluded to be 75.47%.

Fig. 39 Solar box cooker with PCM and Nanoparticles [106]

Talbi *et al.*, [107] tested the various square solar cookers (Fig. 40) using three outside reflectors whose job was to catch the most incredible solar radiation and reflect it towards the cooker's inside. Two-fold coating (Windows 1 and 2) to keep the heat inside the vessel, four inside reflectors (Cooker sides) whose job was to divert sun-powered radiation on the absorber, and the absorber to convert sunlight-based radiation into heat. A thermally protected box (wood, stops, hardened steel) to limit heat loss. The authors concluded that the maximum temperature reached 140ºC with solar radiation of 1000 W/m2 with a box-type cooker with three reflectors. The thermal efficiency and cooking power were calculated as 22.5 W and 93%.

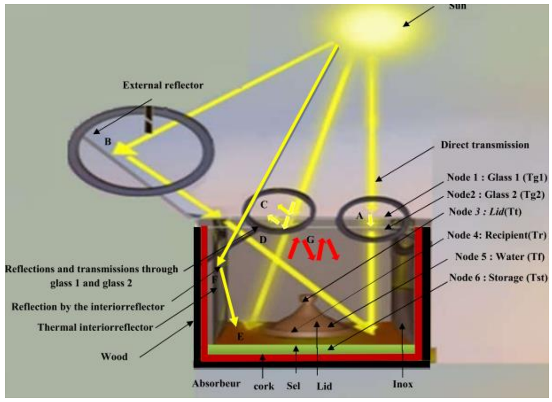

Fig. 40 The solar box cooker with three reflectors [107]

Sharma *et al.*, [108] tested different types of solar cookers. They consisted of a PCM compartment and cooking vessel, a twofold glazed box-type solar-powered cooker with a reflector 50 cm X 50 cm in size. The authors inferred that the most extreme temperature for 1 kg of the water came to 172.3ºC with sun-powered radiation of 916 W/m^2. The figures of merit were viewed as F_1=0.14 and F_2=0.37.

4.10 Comparison

A comparison of the thermal performance of solar cookers with thermal energy storage is given in Table 5. It shows that the solar cooker developed by Shrestha et al., [79], having double glazing and booster mirrors with back pebble stones, is the best-performing solar cooker in this category.

Table 5. Comparison of experimental results of the box-type solar cooker with thermal energy storage

Sn	Author (s)	Material	Insulation	Area (m^2)	Efficiency (%)	Cooking power (W)	Maximum temperature	F_1	F_2
1.	Shrestha *et al.*, [109]			0.16			99ºC	0.23	0.27
2.	Kritika *et al.*, [102]	GI sheet	Styrofoam		31.3			0.12	0.72

3.	Sundarrajan Bhavani *et al.*, [103]	Plywood	Glass wool		56.2		163.74ºC		
4.	Cuce [104]	Stainless steel	Glass wool	0.07	34.6-21.2	15.4	151.1ºC		
5.	Saxena *et al.*,[105]	Wood	Glass wool	0.23	53.8	68.8	140ºC	0.13	0.37
6	Palani Kumar *et al.*,[106]	Plywood	Glass wool		75.4				
7.	Talbi *et al.*,[107]	Wooden			93	22.5	140ºC		
8.	Sharma *et al.*, [108]	Aluminium sheet	Glass wool	0.25	28		172.3ºC	0.14	0.37

4.11 Tracking Mechanism

Solar tracks are commonly used to place photovoltaic (PV) panels (solar panels) to stay aligned with the Sun's beams and position space observatories to identify the Sun's orientation. Consequently, they shall collect the maximum amount of solar energy [28]. Considering this thought, researchers have used solar tracking for box-type cookers. This section of the article presents the thermal performance of solar cookers with a tracking mechanism.

Farooqui [110] built a gravity-based solar cooker, as shown in Fig. 41. A roundabout steel line with a length of 'PR' and an inward measurement of '2r' was adapted to the state of a half-circle with a range of 'R'. The top surface of the line was cut up to half its total length (PR/2). In the centre, an opening was bored, the width of a small piece of steel pole (about 1.5 cm long) and slightly narrower than the inward distance across the 'r' of the steel pipe. A 3 cm long bolt was strung through the hole. A bolt was attached to the steel pole via the steel pipe cut, causing any force applied to the nylon harmony to stretch the spring and move the upward bolt along the steel pipe cut. The global positioning framework was built on a wooden 2R square board with equal side lengths. 'Another rectangular wooden board with characteristics similar to the foundation of the sunlight-based cooker was chosen as the highest point of the global positioning framework. When power was applied to the nylon harmony, the top finish of the upward bolt attached to the steel bar and moveable through the cut in the steel pipe was embedded inside a free opening in the rectangular wooden board (top). Hence, the board moved alongside the bolt. The author concluded that F_1=0.1258 and F_2=0.369 were the figures of merit. The highest temperature reached 90ºC with solar radiation of 689.15 W/m^2. The cooker's aperture area was 0.167 m^2 for 1.37 kg of water.

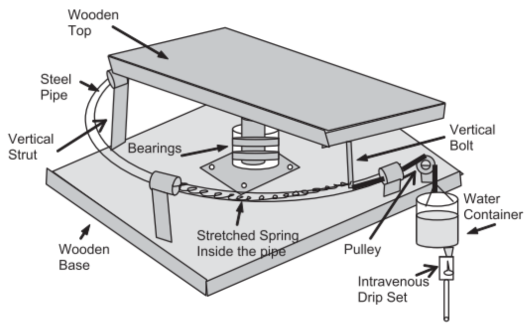

Fig. 41 Gravity-based sun tracking mechanism for solar box type cooker [110]

Tawfik *et al.*, [111] proposed a new sunlight-based cooker outfitted with three interior promoter mirrors and an outside following kind base allegorical reflector (TBPR) (Fig. 42). In this case, TBPR functions as a supporter reflector. TBPR was constructed of a wooden casing and joined with anodised aluminium as a reflecting surface with an 85 % reflectivity. The new solar cooker design was a right-point triangle-shaped two-walled wooden bureau (each mass 3 mm thick) with a single 3 mm thick glass cover on top. A pit between wooden dividers was lined with a thin layer of glass fleece as a protective measure. The wooden bureau's lower part comprised two 3 mm-thick pieces of wood with glass fronts separated by a 5 mm air hole. This may enable a decrease in base heat loss. The authors discovered that F_1=0.11 and the overall efficiency of the cooker was 12.5%. The maximum temperature was 145°C, with 891 W/m^2 of solar radiation.

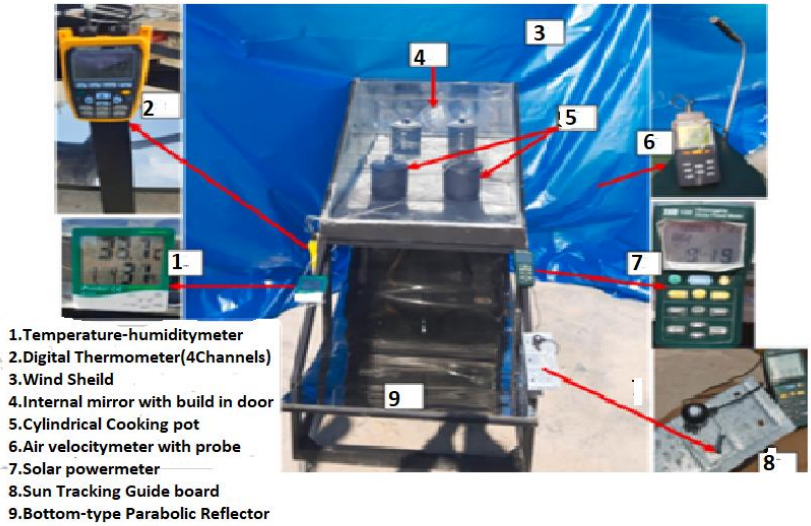

Fig. 42 Solar box cooker equipped with TRPR [111]

Hamoud *et al.,* [112] built a tilted box-style solar cooker. The outer box was constructed of 8 mm-thick wood. The cooker's aperture area was 0.27m^2. The inner tube is made of blackened aluminium that is 0.7 mm thick. The inner box had two heights and a square base (52 cm x 52cm) (35cm at the back and 25cm at the front). The outer layer was double-layered insulation, the inner layer was glass wool, and the outer layer was foam, with a total thickness of 2.54 cm. The three-dimensional manual control mechanism was used for sun-tracking. The author revealed that Figures of merit for 2 kg of water were calculated as F_1=0.1354 and F_2=0.4934. The cooking power was calculated as 63.53W.

Weldu *et al.,* [113] created a box-type sun-oriented cooker built from pressed wood with a thickness of 12 mm (Fig. 43). As an interior reflector, aluminium foil was used to adhere to the inside sidewalls of the cooker. Three side dividers were angled at 105° to the cooker's foundation. Besides the sun and the reflector, these side dividers benefit from allowing a few extra sun rays into the cooking vessel between the absorber plate and the glass cover, despite the thick air layer. The simple cover reduced absorber plate convection losses. The trapezoidal-shaped profile of the glass cover has a thickness of 4 mm and a transmissivity of 0.83. Copper, aluminium, and treated steel were used to make absorber plates. Two metallic strip allies were used to assist in changing the reflector point. As the sun changed its height in the sky, the glass was routinely changed to an ideal plot for the examination. For the sunlight-based cooker, the perfect point of a reflector can give extra sun-oriented radiation contrasted to the decent point of the reflector. The mirror was similar in size to the glass in front of the cooktop. The reflector's average height was 550 mm. It had a 105° reflecting point and faced directly into the sunbeams. During the investigations, two round objects, barrels, were used as cooking vessels. They were made of aluminium and treated steel metal and had a width of 180mm and a depth of 100mm. To improve absorptivity, the exterior surfaces of the vessels were painted dark. The protection material chosen should also be excellent at retaining heat, accessible, and durable. As a result, sawdust with a thickness of 50 mm was used as a protective material. The authors determined that the thermal efficiency of the cookers was 37.24 %. F_1=0.154 and F_2=0.145 were the calculated figures of merit. The maximum temperature is 89.8°C, with 789.6 W/m^2 of solar radiation.

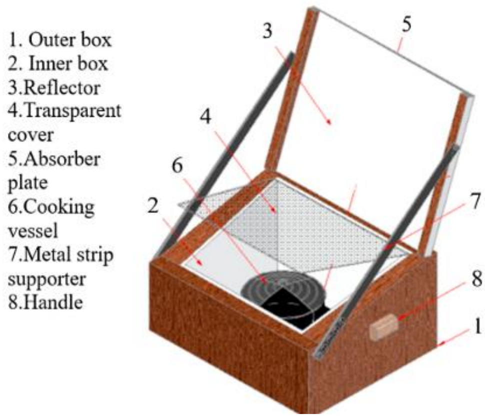

Fig. 43 Solar box cooker with optimal reflector tracking [113]

Kadhim *et al.*, [114] tested a sun-oriented box cooker, as shown in Fig. 44. 2 cm thick wooden box (47 cm x 50 cm x 50 cm) and an inward 2 cm thick wooden box (22 cm x 39 cm x 39 cm) were placed between them, with polystyrene (3 cm) on the sides and (23 cm) on the base. The absorber plate, which was darkly painted and made of aluminium, was placed on the four sides of the pot, creating a cooking space. The cooking area was protected by a glass cover with dimensions (46 cm x 46 cm) and a thickness (5 mm). The cooking pot was made of aluminium and measured 9.7 cm in height and 20 cm in width. A mirror board (44 cm x 44 cm) focused the sunlight-based radiation on the cooking area. The cooking power was measured as 56.09 W.

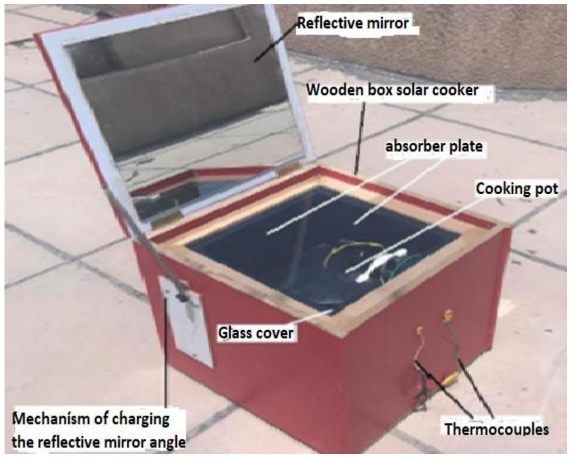

Fig. 44 Tracking solar box cooker [114]

4.12 Comparison

Table 6 compares the thermal performance of box-type solar cookers with a tracking mechanism. It shows that the solar cooker developed by Weldu et al., [113] is the best-performing solar cooker in this group.

Table 6. Comparison of experimental results of the box-type solar cooker with a tracking mechanism

Sn	Author (s)	Material	Insulation	Area (m^2)	Efficiency (%)	Cooking power (W)	Maximum temperature	F_1	F_2
1.	Farooqui [110]	Wooden		0.167			90°C	0.12	0.36
2.	Tawfik *et al.*,[111]	Wooden frame	Glass wool		12.5		145°C	0.12	
3.	Hamoud A. *et al.*,[112]	Wood	Double insulation layer comprising glass wool on the inner layer and foam on the outer layer	0.27		63.53	172.75 °C	0.13	0.49
4.	Weldu *et al.*,[113]	Plywood	Sawdust		37.24	45.25	89.8°C	0.15	0.41
5.	Kadhim *et al.*,[114]	Wooden box				56.09	109°C		

4.13 Other miscellaneous designs

This section compares different box-type solar cooker designs and their thermal performance. Jawale *et al.,* [115] have investigated the Mirror reflection and solar cooker with a Fresnel lens in the shape of a box (Fig. 45). The Authors used a pyramidal-shaped box-type cooker with a 5 mm thickness of insulating material attached inside the cooker from each side. Aluminium foil is attached as an inner reflector after insulating the material. A black colour absorber plate of 2 mm thickness was attached to the container's bottom. A glass cover was used to reduce heat loss. The mirror was mounted on a wooden frame with a hinge. The structure also includes a side plate with a groove, and the mirror was chosen to reflect all solar radiation inside the cooker. Linear Fresnel lenses were held in place in the frame by two side plates for concentrating solar radiation; they can move in response to solar radiation by tightening and loosening side plate bolts. The gap between the plates of the absorber and the Fresnel lens was 600 mm. With 1 kg of water in the cooking pot, a Fresnel lens and a mirror in the cooker, the authors discovered that the final temperature reached 96ºC with 900 W/m^2 of solar radiation. The first and second figures of merit were F_1=0.13 and F_2=0.38, and cooking power was estimated at 33.17 W.

Fig. 45 Pyra-box cooker with Fresnel lens [115]

Nayak *et al.,* [116] constructed a box-type solar cooker suitable for an industrial zone (Fig. 46). The Cooker was made of an aluminium trapezoidal cavity (aperture size of 0.226 m^2) filled with air inside the hole. The top plane glass allowed solar radiation to enter, reducing convective heat losses from the cooker. The outer cavity was insulated with glass wool to reduce convective and heat loss. The absorber or bottom plate was selectively coated to maximise heat gain while minimising heat loss. With a 30° inclination, the absorber plate's total surface area was 47.5 cm x 47.5 cm, and the bottom surface area was 36.6 x 36.6 cm^2. Surface layers of copper oxide, nickel black, and black chrome have proven to be the most helpful and are now widely used in industry. A selective surface with an absorptivity of 0.90 and an emissivity of 0.1 was used in this case. The glazing material was tempered glass with a thickness of 4 mm. The Authors found that with 1 kg of water, the maximum temperature reached 93.6ºC with 710 W/m^2 solar radiation. F_1 was calculated to be 0.12, and F_2 was estimated to be 0.44.

Fig. 46 Box-type solar cooker [116]

Chaudhari *et al.,* [69] created a solar-powered box cooker with a dryer with a cooking capacity for 4-5 persons (Fig. 47). The outer dimensions of the cooker were 700 mm x 600 mm, and the inner dimension of the cooker was 640 mm x 540 mm. The glass wool was used as insulation with a 25 mm thickness. The aperture area of the collector was 0.382 m^2. The transparent glass cover was 5 mm thick, and the mirror was a reflector. The heating element system is used at the bottom of the cooker. The authors found that merit figures F_1=0.11 and F_2=0.41. The thermal efficiency of the cooker was 28.9%. The average cooking power was 84.1 W. The water reached a temperature 95ºC with solar radiation of 700 W/m^2.

Fig. 47 Solar box cooker [69]

Kumar et al. [94] created a multipurpose solar cooker (Fig. 48) using a toughened glass cooker of 50 cm x 50 cm. The absorber plate was 32.6 cm x 32.6 cm in size. This plate was made of aluminium and darkly painted to absorb the most intense solar energy. The depth of the cooker was 49.2 cm. The authors found that 2 kg of water in two different pots reached 98.6ºC with solar radiation of 866.03 W/m^2. The figures of merit were calculated as F_1=0.117 and F_2=0.467.

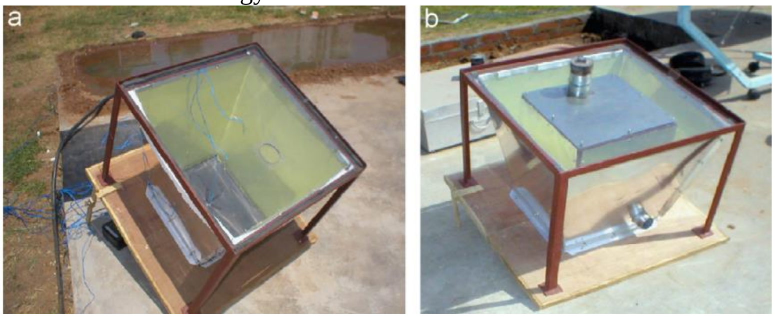

Fig. 48 Solar cooker for multipurpose as cooker/dryer [117]

Harmim *et al.,* [118] modelled a crate-type sun-powered cooker with a topsy-turvy CPC of 45^0 (Fig. 49). The inside dimensions were 0.7 m by 0.25m and 0.3 m high. The simple cover had a two-layer coating that was 4 mm thick, 0.7 m long, and 0.3 m wide. The distance between the two glasses was 10 mm, with a width of 0.7 m and a thickness of 0.3 mm. The inner case dividers were made of 0.3 mm-thick steel sheets. The absorber plate was made of an aluminium sheet with a surface area of 3 mm thickness and was protected by a glass fleece with a thickness of 0.05 m. It was painted matte dark. An entryway is provided on a parallel side of the container to access the cooking pot. The reflector was framed by two straight concentrator segments (lower parabola and upper parabola). Each component was constructed from small rectangular mirrors that had been gathered and secured to a wooden framework. According to the authors, the maximum temperature for 1.5 kg of water reached 90ºC with solar radiation of 737.5 W/m^2. The overall efficiency was calculated to be 10.6%. The merit figures were calculated as F_1=0.16 and F_2=0.35.

Fig. 49 Solar cooker along with asymmetric compound parabolic concentrator [118]

Joshi *et al.,* [119] examined the SSB, SSBH, and ISSBH. The SSB sunlight-based cooker had dimensions of 0.30 X 0.30 X 0.15 m^3, and the inward box was 0.23 X 0.23 X 0.07 m^3. The cooker's external and internal boxes were made of aluminium (Fig. 50). A wooden frame separated them and lined the space with glass fleece. The interior of the box was darkly painted with slate paint. Two 0.04 m thick transparent window glass sheets have been fixed over it with a wooden casing that can be opened and a 0.04 m. Depending on the season, the reflector's slant can vary from 0° (closed cover) to 120° from the even plane. The inside area measured as 0.16 m^2. One 0.2 m wide aluminium pot was kept inside for cooking. The SSB sun-oriented cooker was converted into an SSBH sun-powered cooker with only minor modifications. The element size of each sunlight-powered charger was kept constant at 0.30 X 0.30 X 0.005 m^3. Each sunlight-powered charger weighs 0.518 kg due to the cells being mounted on the FRP (Fibre-Reinforced Plastic) sheet, which is solid and lighter than glass. The proficiency of mono-glass-like Si cells was 19.3 per cent, and the productivity of sun-powered chargers was 15%. Five 15-watt photovoltaic panels were linked together using pivots. The cooker was linked to a configuration of five PV boards. These sun-facing PV boards are detachable. Inside the SSBH sun-powered cooker's crate, one dish-type DC warmer was on the absorber plate. The dish-type DC radiator in the ISSBH solar cooker had been replaced by three-pole type warmers every 25 W limit. These pole-type warmers were installed between the ISSBH sun-oriented cooker's external and internal boxes. According to the author, an improved small-scale cooker produced the best results, with a 38 % increase in efficiency with a 0.23 x 0.23 m^2 aperture.

(a) (b) (c)

Fig. 50 Cooker with PV panel [119]

4.14. Comparison

Table 7 compares the thermal performance of some miscellaneous box-type solar cooker designs. The solar cooker developed by Harmim *et al.*, [95] has emerged as this group's best-performing solar cooker.

Table 7. Comparison of experimental results of the box-type solar cooker with a unique design

Sn	Author (s)	Material	Insulation	Area (m^2)	Efficiency (%)	Cooking power (W)	Maximum temperature	F_1	F_2
1.	Jawale *et al.*, [115]	Wooden	glass wool			33.4	96°C	0.13	0.38
2.	Nayak *et al.*, [116]	Aluminium	Glass wool insulation	0.22			93.6°C	0.12	0.44
3.	Chaudhari *et al.*, [69]		Glass wool	0.38	28.93	84.1		0.11	0.41
4.	Kumar *et al.*, [117]						98.6°C	0.11	0.46
5.	Harmim *et al.*, [120]	Wooden frame	Glass wool	0.43		78.9	166°C	0.15	0.47
6.	Joshi *et al.*, [119]	Aluminium	Glass wool	0.05	38.1	75			

Until now, the article has compared the thermal performance of various types of solar cookers in different groups (clusters) and has emerged with the best design in every group. In the forthcoming section, the article presents the trend in innovations in box-type solar cookers, investigating overall best-performing solar cookers, the effect of absorber plate area, cooking mass and solar irradiation on the performance of solar cookers. Regression analysis is also presented to establish the regression equation to estimate the absorber plate area of the solar cooker.

5. Results and discussions

5.1 Trend

The trend indicates a general development or change. In the case of solar cookers, the trend illustrates how box-type solar cookers have developed to date. In the history of solar cooking, it has been found that the first box-type solar cooker was demonstrated in 1976. Since then, there has been continuous ongoing research. Table 8 presents the trend in the development of box-type solar cookers in the last two decades.

Table 8. The trend in innovations in the box-type solar cooker

Sn	Author(s)	Year	Innovation
1.	Kerr and Cole [21]	1976	Simple box-type solar cooker (first attempt)
2.	Ali [76]	2000	External and internal mirrors
3.	Sharma *et al.*, [108]	2000	Double-glazed box-type solar cooker with reflector, with Acetamide PCM aluminium cylindrical cooking pot with inner fins
4.	Nahar [121]	2001	Double reflector with a hot box
5.	Amer [85]	2002	Double-exposure box cooker
6.	Nahar [71]	2002	Hotbox solar cooker with engine oil as storage material
7.	Ekechukwu and Ugwuoke [90]	2002	Plane-reflector augmented box-type solar-energy cooker
8.	Negi and Purohit [122]	2005	Box-type solar cooker with non-tracking concentrator
9.	Subodh Kumar[123]	2005	Double-Glazed Solar Cooker
10.	Harmim *et al.*, [124]	2010	Solar cooker with the finned absorber plate
11.	Harmim *et al.*,[118]	2012	Asymmetric compound parabolic concentrator
12.	Harmim *et al.*,[120]	2013	A non-tracking solar cooker with a fixed compound parabolic concentrator as booster-reflector and absorber-plate.
13.	Farooqui [110]	2013	A gravity-based tracking system
14.	Folaranmi [89]	2013	Double-glazed box-type solar oven with reflector
15.	Kahsay *et al.*,[91]	2014	Solar box cooker with internal reflectors
16.	Sethi *et al.*,[101]	2014	Inclined box-type solar cooker with parallelopiped cooking vessel
17.	Jawale *et al.*, [115]	2017	Fresnel Lens and Mirror Reflector
18.	Coccia *et al.*, [125]	2017	Multiple Reflectors
19.	Vengadesan and Senthil [100]	2021	Finned cooking vessel
20.	Hamoud *et al.*, [112]	2021	Tilted box–type solar cooker with a tracking mechanism

5.2 Effect of insulation

Heat loss from the solar cooker is a significant factor that decides the overall performance of any solar cooker. Several investigators have used different insulation materials to reduce heat loss from solar cookers. Fig. 51 illustrates the frequency of varying insulation materials used in the box-type solar cooker. Fig. 51 shows that wooden material was used most in the box-type solar cooker. However, Table 9 shows that plywood is the best material for constructing solar cookers since it gives the highest thermal efficiency.

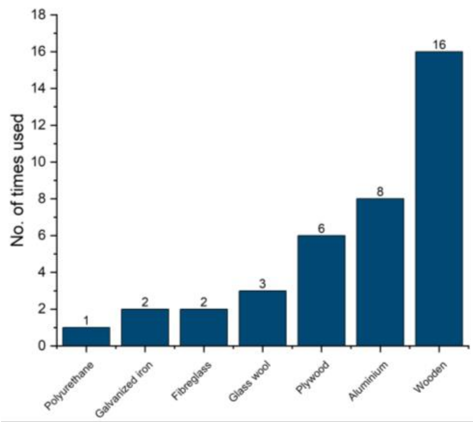

Fig. 51 Different types of insulation used

Table 9. Insulation material and corresponding thermal efficiency

Sn	Author(s)	Material	Thermal efficiency (%)
1.	Bhavani *et al.*, [103]	Plywood	56.2
2.	Vengadesan and Senthil [100]	Aluminium	56.0
3.	Nahar [121]	Aluminium	30.5
4.	Sharma *et al.*, [108]	Aluminium	28
5.	Coccia *et al.*, [125]	Wooden	28
6.	Nahar[71]	Wooden	27.5
7.	Jawale *et al.*, [115]	Wooden	27
8.	El-Sebaii and Ibrahim[94]	Wooden box	26.7
9.	Tawfik *et al.*, [111]	Wooden frame	12.5
10.	Harmim *et al.*,[118]	Wooden frame	10.6
11.	Ali [76]	Glass wool	9.7

5.3 Variation in cooking mass, maximum temperature, absorber plate area, and solar irradiation

The variations in the highest cooking temperature, cooking mass, and solar irradiation are depicted in Fig. 52. It demonstrates that when the value of solar irradiation is high, the cooking temperature is also high. Similarly, the temperature is lower for bigger cooking masses. The depth of food should be as small as possible in the cooking pot to achieve a greater heating temperature and a shorter cooking time.

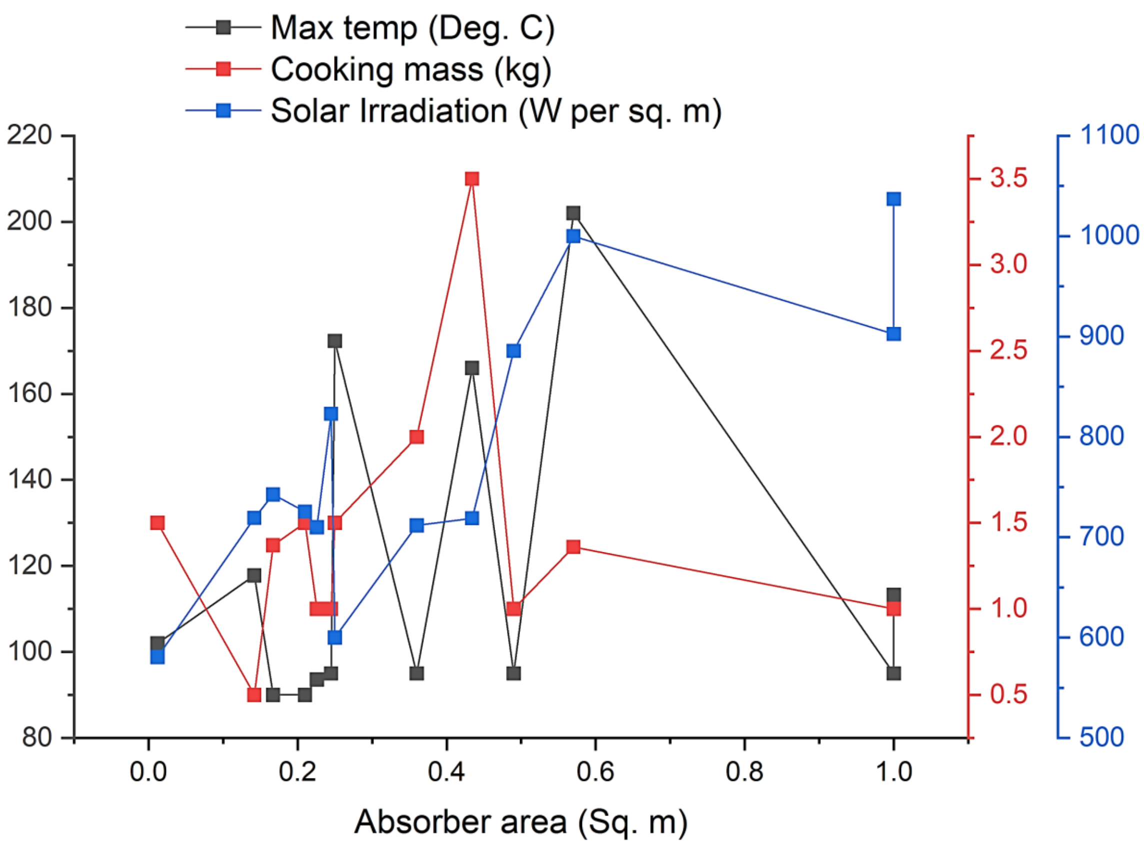

Fig. 52 Variation in cooking mass, maximum temperature, absorber plate area, and solar irradiation

5.4 Investigation of the overall best-performing solar cooker for commercialisation

Literature shows that there is a variety of box-type solar cooker designs. Researchers have used several innovative methods to improve the thermal performance of box-type solar cookers. Hence, similar innovations are clubbed, and a group is formed to compare their thermal performance. Table 10 summarises the best-performing solar cooker design in different groups (clusters), formulated before the start of review work for easy, quick and perfect comparison of solar cookers.

After studying Table 10, the best-performing box-type solar cooker design can be investigated and optimised to bring it to the commercialised stage. By doing so, a faster solar cooking design can be brought to the market, increasing the popularity of solar cookers and solar cooking and subsequently increasing its market demand. It will be a tiny step towards the achievement of SDG-7.

Table 10 shows that the highest Figures (F_1) of merit are found for box-type solar cookers with energy storage developed by Shrestha *et al.*, [109]. Hence, this solar cooker design is the overall best design compared with all the groups. The present investigators should develop this cooker design at the commercial stage. With these findings, both the objectives of the current review work have been fulfilled.

Table 10. Final comparison and investigation of the overall best-performing solar cooker (consolidated report of review work)

Sn	A cluster of solar cookers as per innovations	Author (s)	Area (m^2)	Energy efficiency (%)	Cooking power (W)	Maximum temperature (°C)	F_1	F_2
1	Simple solar cooker with a single reflector	Chatelain *et al.*, [75]	0.4		30.9	116	0.15	0.31
2	Simple solar cooker with multiple reflectors	Farooqui [82]				90	0.14	0.31
3	Box-type solar cooker with double exposure	El-Sebaii [94]	1	26.7		95	0.15	0.19
4	With the innovative cooking vessel	Sethi *et al.*, [101]			22.2		0.16	0.54
5	Solar cooker with energy storage (pebble stones)	Shrestha *et al.*, [109]	0.16			99	0.23	0.27
6	Solar cooker with a tracking mechanism	Weldu *et al.*,[113]		37.2	45.2	89.8	0.15	0.41
7	Miscellaneous design	Harmim *et al.*, [120]	0.43		78.9	166	0.15	0.47

5.5 Regression analysis and derivation of the regression equation to find absorber plate area given solar irradiation and expected cooking temperature

The Absorber plate area is the vital component that decides any solar cooker's fabrication cost. Henceforth, the estimation of precise absorber plate area is essential. A regression equation has been investigated using MINITAB software based on collected data to handle this difficulty. It is estimated to be "*Absorber area (sq. m) = -1.134 + 0.00227 Max temp (°C) + 0.0313 Cooking mass (kg) + 0.001541 Solar Irradiation (W per sq. m)"*. The detailed regression analysis output is given in Table 11. Its residual plots are shown in Fig. 53.

The required absorber area can be calculated from the regression equation for a cost-effective box-type solar cooker design. The perfection of the derived regression line equation is checked in Table 12. Table 12 shows that the regression line equation precisely gives the absorber plate area value with a zero mean error value. Therefore, the design engineer can confidently use this equation to find the absorber plate area for the specified solar irradiation values, cooking mass and required cooking temperature.

Table 11. Regression analysis output (MINITAB)

Regression Analysis: Absorber versus Max temp (De, Cooking mass, Solar Irradi

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	0.140993	0.046998	7.37	0.042
Max temp (°C)	1	0.023783	0.023783	3.73	0.126
Cooking mass (kg)	1	0.002763	0.002763	0.43	0.546
Solar Irradiation (W per sq. m)	1	0.120683	0.120683	18.93	0.012
Error	4	0.025497	0.006374		
Total	7	0.166490			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0798393	84.69%	73.20%	0.00%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-1.134	0.310	-3.66	0.022	
Max temp (°C)	0.00227	0.00118	1.93	0.126	1.86
Cooking mass (kg)	0.0313	0.0475	0.66	0.546	1.60
Solar Irradiation (W per sq. m)	0.001541	0.000354	4.35	0.012	1.20

Regression Equation

Absorber area (sq. m) = -1.134 + 0.00227 Max temp (Deg. C) + 0.0313 Cooking mass (kg) + 0.001541 Solar Irradiation (W per sq. m)

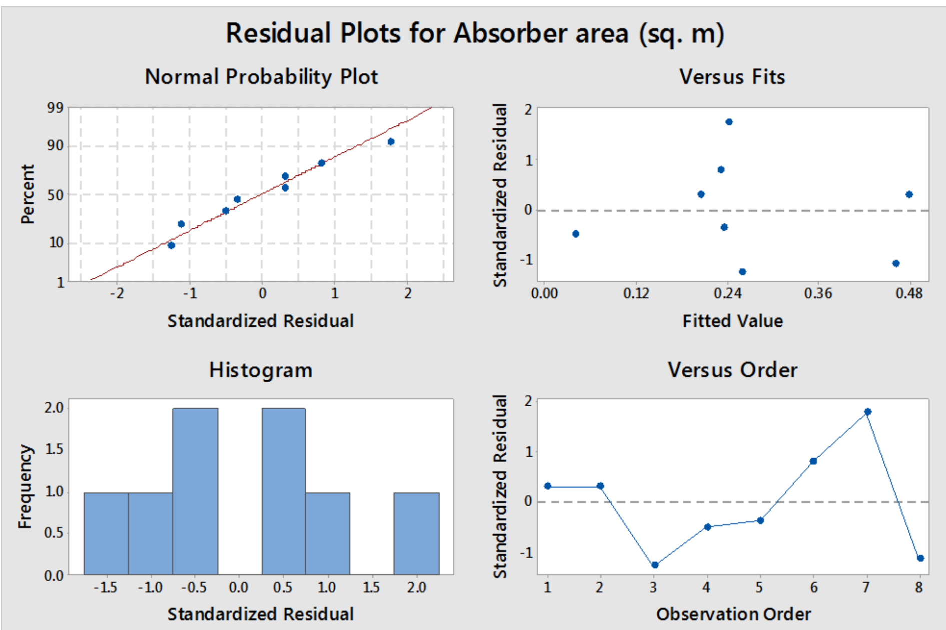

Fig. 53 Residual plot

Table 12. Calculation of the precision of the regression line equation

Sn	Max temp (°C)	Cooking mass (kg)	Solar Irradiation (W per sq. m)	Absorber area (sq. m) (Actual)	Estimated area using regression equation (sq. m)	Error in the estimated area using the regression equation (sq. m)
1	93.6	1	710	0.22	0.2	0.02
2	95	1	885.6	0.49	0.47	0.02
3	90	1.3	742.5	0.16	0.25	-0.09
4	102	1.5	580.5	0.01	0.03	-0.02
5	90	1.5	725.5	0.21	0.23	-0.02
6	172.3	1.5	600	0.25	0.22	0.03
7	95	2	711.7	0.36	0.24	0.12
8	166	3.5	719	0.43	0.46	-0.03
Average	112.9	1.6	709.3	0.27	0.26	0.00

5.6 Future trends

Box-type solar cookers will change throughout time thanks to new materials, better ways to store energy, and designs that put the user first, all of which will be made possible by supportive regulations. Some significant trends are given in Table 13.

Table 13. Some important future trends

Trend Area	Expected Development	Rationale / Impact
Material Innovation	Shift to composites, recycled polymers, lightweight alloys	Enhances durability, insulation, and portability
AI-Based Design Optimisation	Advanced regression models and simulation tools	Precise absorber plate sizing; real-time adaptation to solar conditions
IoT & Remote Monitoring	Sensors for temperature, solar irradiance, Bluetooth/Wi-Fi modules	Enables remote tracking, recipe guidance, and performance analytics
Policy & Carbon Credits	Subsidies, carbon credit eligibility, and green certifications	Encourages adoption; aligns with climate and rural development goals
Educational & Entrepreneurial Use	Solar cookers as Science, Technology, Engineering, and Mathematics (STEM) tools and rural business assets	Promotes skill development, SHG-led services, and community innovation

6. Conclusions

Several designs of box-type solar cookers have been demonstrated in the literature. Nevertheless, no review articles present the latest design of the best-performing box-type solar cooker, which can be further optimised to bring the box-type solar cooker to the widespread market. Hence, this review work has been undertaken.

From the present review work, the following conclusions have been drawn:

- The journey of box-type solar cooking started in the late 20th century in 1976. Investigators are developing various innovative, energy-efficient, cost-effective box-type solar cookers.

- A box-type solar cooker with energy storage has emerged as the latest overall best-performing box-type solar cooker design.
- Present researchers should optimise this design to bring it to commercial status.
- Wooden material was the most commonly used material in the box-type solar cooker. However, plywood is found to be the best material for the construction of solar cookers.
- Achieving a greater heating temperature suggests a shorter cooking time. Hence, the depth of the food in the cooking pot should be as small as possible.
- The Absorber plate area is the vital component that decides any solar cooker's fabrication cost. Henceforth, the estimation of precise absorber plate area is essential. A regression equation has been investigated using MINITAB software based on collected data to handle this difficulty. It is estimated to be "*Absorber area (sq. m) = -1.134 + 0.00227 Max temp (°C) + 0.0313 Cooking mass (kg) + 0.001541 Solar Irradiation (W per sq. m)*"
- The perfection of the derived regression line equation is checked and found to precisely give the value of the absorber plate area with zero mean error value. Therefore, the design engineer can confidently use this equation to find the absorber plate area for the specified solar irradiation values, cooking mass and required cooking temperature.

Future scope of work

A review of the various solar box-type cookers revealed that a box-type solar cooker with three reflectors and black pebble stones could be used as a thermal storage medium with a finned-type cooking vessel. No investigator has tested this design to date.

Nomenclature

$(MC)_w$	Product of mass and heat capacity of water, KJ/^{o}C
A	Aperture area, m^2
A_{ap}	Area of Absorber plate, m^2
A_{cv}	Area of cooking Vessel, m^2
A_{gc}	Area of the glass cover, m^2
C_{pw}	Constant pressure specific heat, kJ/kgk
C_w	Specific Heat of water, J/KgK
Ex_{in}	Exergy input, J
Ex_{out}	Exergy output, J
F_1	First Figure of merit
F_2	Second Figure of merit
G	Solar Irradiation, W/m^2
h_{air-gc}	Heat Transfer coefficient between air and glass cover, W/m^{2}K
h_{ap-air}	Heat transfer coefficient between absorber plate and air, W/m^{2}K
h_{ap-gc}	Heat transfer coefficient between the glass cover and absorber plate, W/m^{2}K
h_{cv}	Heat transfer coefficient of liquid inside the cooking vessel, W/m^{2}K
h_{cv-air}	Heat transfer coefficient between the cooking vessel and the air inside the cooking vessel, W/m^{2}K
h_{cv-gc}	Heat transfer coefficient between the glass cover and cooking vessel, W/m^{2}K
K_{cv}	Thermal conductivity of cooking vessel, W/mK
m_{air}	Mass of air, kg
m_{ap}	Mass of absorber plate, kg
m_{liq}	Mass of liquid, kg
M_w	Mass of water in a cooking pot, kg
P	Cooking power, W
t	Time, sec
T_a	The ambient temperature at the time of stagnation, ^{o}C
T_{air}	The temperature of the air, ^{o}C
T_{cv}	The temperature of the cooking vessel, ^{0}C
T_{fw}	The final temperature in water, ^{0}C
T_{gc}	The temperature of the glass cover, ^{0}C
T_s	Stagnation temperature for absorber plate, ^{0}C
T_{w1}	The initial temperature in water, ^{o}C
T_{w2}	The final temperature in water, ^{o}C
w_{cvb}	The thickness of the cooking vessel bottom, m
α_{ap}	Absorptivity of the absorber plate
α_{cv}	Absorptivity of the cooking vessel
Δt	Change in temperature, ^{0}C

τ_{gc}	Transmissivity of a glass cover
η	Thermal Efficiency (%)

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