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Research Article

Performance parameters, design considerations, social adoption, and computational techniques for solar box cooker development: current status and future possibilities

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ABSTRACT

Practical utility of solar cookers is on rise nowadays. However, due to certain technological challenges this is not catching very fast. Present review paper encompasses studies and future possibilities for solar box cooker research. Various aspects like thermal performance parameters, various phases of designs improvements, social acceptability issues and computational methods of analysis have been discussed in relation to Solar box cookers so that technical difficulties may be minimized. This paper discusses about introduction to solar box cookers, advantages, disadvantages, various practical considerations that are key factors for any SBC. Further, there is a handsome discussion on the various computational techniques like Computational fluid dynamics, Artificial intelligence techniques, IoT etc. Introduction, review of applications till date, and future possibilities related to research using application of these computational techniques have been presented. Emphasis has been given to future possibilities for solar box cookers development so that it could be a well-accepted future technology.

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INTRODUCTION

Of energy consumptions in various sectors, energy consumed for cooking shares a major part of total yearly energy consumption. These can be served by well-organized solar appliance-based cooking implement. Conventional fuels like coal, kerosene, firewood, animal dung dry cakes and various kinds of agricultural biomass wastes are still in current use even when cooking gas and electrical cooking appliances have taken over the major cooking share. As per world energy statistics (2017)[1], almost 30% of total energy consumption is used for residential purposes, across the globe (Figure 1a). Further, Figure 1b indicates that for European Union, cooking needs shared 6.1% of energy of residential purposes in year 2019. Depending on geographical locations of a place and social culture etc. this

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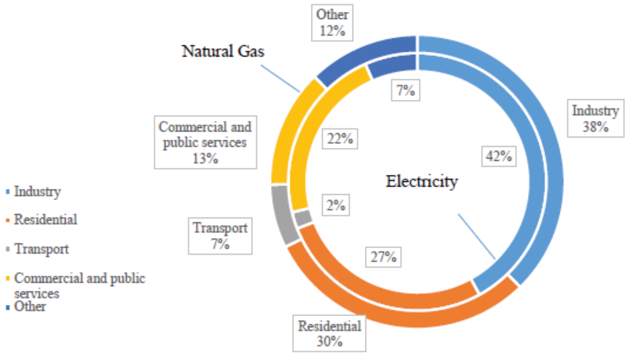

Figure 1a. Primary global energy consumption sectors from natural gas and electrical energy sources [1].

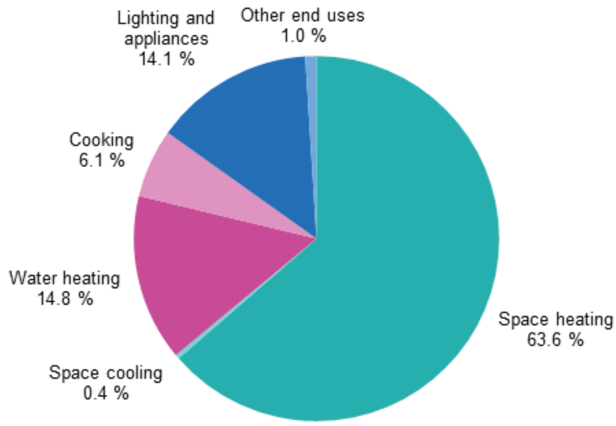

Figure 1b. Final energy consumption in the residential sector by fuel in European Union in 2019 [2].

percentage share of may vary. Now, sustainable energy technologies based on non-conventional resources are becoming need as future energy planning. Solar energy-based systems (SEBSs) are playing major role in it. Hence solar cookers can have profound presence in current energy needy scenario.

Solar cookers, in general, may be subdivided under following classes (shown in Figure 2).

a. According to manner of transfer of received solar energy to cooking vessel: Direct and indirect type solar cookers.
b. As per device configuration of solar cookers: Box type cooker, concentrator-based cooker, and panel type cooker.
c. As per thermal storage arrangement components: Latent heat storage device and sensible heat storage device.

Further, the basic construction of solar cookers of two different kinds of Solar box cooker (SBC) are shown in Figures 3 and 4. Figure 3 gives most basic schematic of conventional SBC. This consists of an insulated box (may of plastic/metal/wood etc.). At the base of cooker, an absorber plate of higher conductive and high specific heat metal is kept on which cooking vessels/pots are placed. Cover of SBC is provided with reflector sheet so that incoming solar radiations is reflected to glazing sheet or cover which is made of glass or some transparent material. It converges the incoming solar radiation, which falls upon it after being deflected by reflector situated at SBC cover plate, on to absorber plate surface. Cooking vessel consists of good conductor materials. These are placed on absorber plate directly or over the lugs provided (Figure 4). Reduction in carbon footprints, clean energy supply, reduction in conventional fuel utilization rates, environmental benefits by reducing deforestation, as well attainment of low i.e., around 165°C (for conventional SBC) to higher temperature i.e., around 290°C (parabolic solar cookers, vacuum tube cookers and hybrid cookers) are very advantageous features of solar cookers. Vacuum tube-based cookers are proven to be effective even in cloudy and freezing cold environments.

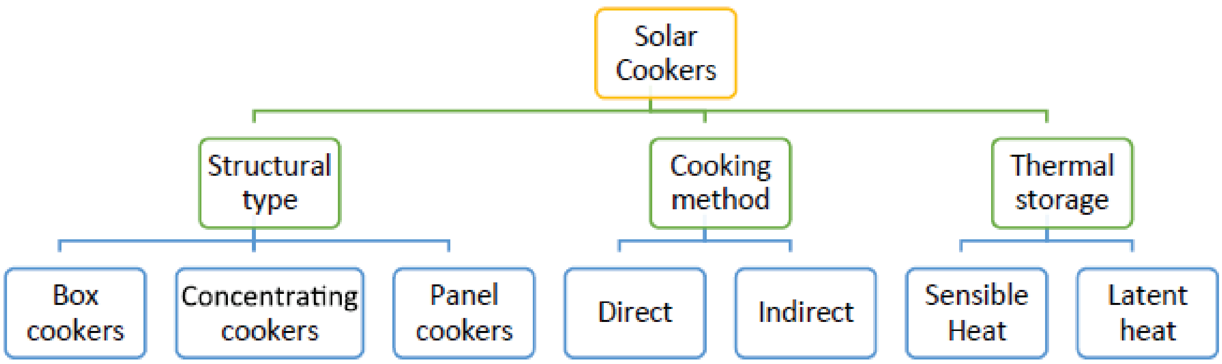

Fig. 3. A general classification of solar cooker.

Figure 2. A general classification of SBCs [3].

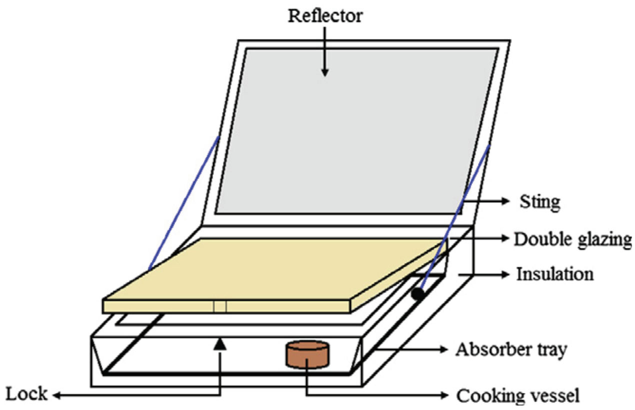

Figure 3. SBC constructional elements [4].

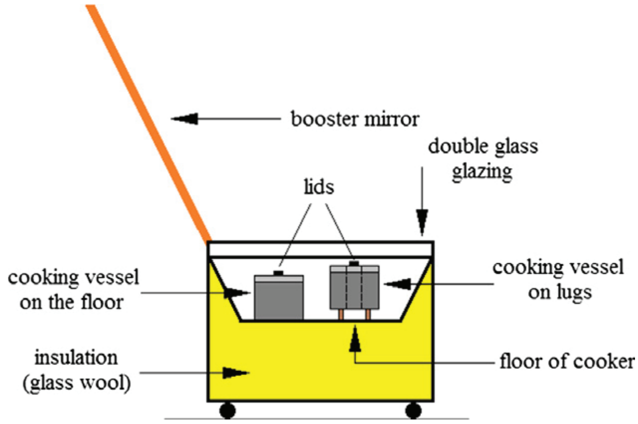

Figure 4. SBC with cylindrical cooking vessel on its floor (without and with lugs) [5].

Due to impetus caused by energy crisis and environmental concerns (primarily) there has been a great thrust in the research on the solar energy-based systems (SEBSs), and so naturally on the SBC research. There is rise in practical use and installation of the SBCs. However, due to certain bottlenecks, primarily technical, adoption rate is not as fast as expected and needed before situation gets worse. Effect of strong wind leading to convective heat loss effects, possibility of cooking of some selective kind of foods, prolonged cooking durations, its bulk size, ineffectiveness of cooking in the evening/night-time and in cloudy days are some negative features of solar cookers. Researchers are working to reduce and remove these so that SBC could become a technology of future. To overcome the technical challenges as quickly as possible, experimental as well as computational techniques are being looked upon. Some of the computational techniques are computational fluid dynamics, Artificial intelligence, Internet of things etc. To present a quick consolidated overall picture of solar cooker research scenario for the readers, compilation of some of the review papers of solar cooker and solar dryers, have been compiled in Table 1. It has been observed by the author that for improving adoption of SBC three aspects are very important, (a) Understanding of performance parameters and protocols for proper testing of SBC performance, (b) Design modifications suiting to geographical locations so that reception, absorption and utilization of solar energy can be increased, (c) Current stature of social and commercial adoption, and (d) Computational method for analysis of SBC design modifications. Present research paper encompasses review of all these aspects pertaining to SBC, at one place, which is still lacking in the previous review works.

REVIEW OF PERFORMANCE PARAMETERS AND TEST PROTOCOLS FOR SBC

For various SBC, enhancement of thermal performance is primary issue. SBC should be designed so to enhance effective reception of solar radiation and to enhance effective utilization of gained radiation. Performance parameters involve two aspects i.e., type of parameter chosen and (b) objective function to be selected for better judgment of thermal performance of the SBC. In addition, performance testing protocol or testing methodology to be adopted for judgment of thermal performance parameter is very important. Table 2 is enlisting various thermal performance parameters in brief. Although mostly, Figure of merit has been used, but there is choice of performance parameters on case-to-case basis. Using fundamental energy balance equations, Funk and Larson (1998) developed and refined the three-parameter model for predicting solar cooker performance [20]. With the support of series of experiments followed by regression, Kumar (2004 and 2005) experimented with the fiber body double-glazed box type cooker. Optical efficiency ($F'\eta_o$) and heat capacity *(MC)'* of cooker have been selected and calculated by linear regression using second Figure of merit, F_2. These two i.e., $F'\eta_o$ and *(MC)'* have been found to be very critical in thermal design parameters for the solar cookers [21-22]. As per Geddam et al. (2015), heating characteristics curves are also used as performance indicators (with optical efficiency and heat capacity as design parameters) [23]. Purohit and Puohit (2009) and Purohit (2010) has worked with optical efficiency factor ($F.\eta_o$) and standardized cooking power (*Ps*) [24-25]. Soria-Verdugo (2015) has proposed a convective heat transfer model for performance analysis of solar cooker. This calculates number of days in which the absorber plate temperature exceeded 100 °C, for broad spectrum of solar radiation and environmental temperature [26]. Mahavar et al. (2015) have introduced a new concept of Optimum load range (OLR) for solar cookers. This reflects good thermal and hence good cooking performance. This concept is based on effect of heat exchange between cooker load and cooker interior upon temperature rise rate of cooker loads. It is calculated by profiles of basic thermal performance parameters, which can be computed by data obtained from operating solar cooker under

Table 1. Compilation of some recent review papers related to solar cooker related research

S.N.	Author, review year (No. of papers reviewed)	Purpose / Theme of review papers
1	Wentzel and Pouris (2007) (32 papers) [6]	The user rate and impact data have been summarized based on various factors depending on cookers technology, environmental factors, and end-user factors etc. from study of its impact in South Africa climate.
2	Sharma et al. (2009) (37 papers) [7]	Different types of latent heat storage materials, their desirable properties and way of placement have been discussed.
3	Lakhar and Samdarshi (2010) (27 papers) [8]	Different TPPs in terms of various objective parameters, correlations and testing protocols have been discussed for SBC.
4	Muthusivagami et al. (2010) (22 papers) [9]	A comprehensive collection of applications of heat storage material in solar cookers, with a clear focus on bridging the solar energy supply - consumption mismatch.
5	Cuce and Cuce (2013) (220 papers) [10]	This encompasses, (a) Recap of cooking technology, (b) Thermodynamic assessment and geometrical parameters affecting it, and (c) Qualitative assessment of solar cooker thermal yield
6	Yadav and Bhagoria (2013) (66 papers) [11]	This encompasses primarily the Selection of turbulence model for solar air heater analysis using CFD
7	Harmim et al. (2014) (28 papers) [12]	This encompasses the research phase solar cooking in Algerian Sahara with a focus on developing compound parabolic concentrator (CPC) equipped non-tracking SBC - in conjunction with absorber plate.
8	Chauhan et al. (2015) (42 papers) [13]	Deployment of various solvers, analysis, plotting and programming softwares in design, development, modeling, testing and analysis of dryers have been discussed.
9	Omprakash et al. (2016) (119 papers) [14]	Emphasized the application of CFD and ANFIS tools in solar dryer efficiency improvement and design development.
10	Nkhonjera et al. (2017) [15]	This encompasses; observing various designs of energy storage system, its comparisons, and its effect of cooker performance.
11	Herez et al. (2018) [16]	This includes economic (payback period) and environmental concerns (computation of CO_2 emission) for Lebanon due to use of solar cooking.
12	Indora and Kandpal (2018) [17]	This paper brings out the need of spreading awareness about institutional solar cooking to the users and manufacturers and its potential, through appropriate policy and incentives.
13	Aramesh et al. (2019) [3]	This encompasses following, (a) Different Designs of solar cookers, (b) Direct and indirect solar cooker, (c) Heat storage materials, and (d) Social aspects.
14	Elsheikh et al. (2019) [18]	This includes application of different artificial neural network (ANN) architectures for optimizing and predicting different solar energy (SE) devices performance and to device guidelines for it.
15	Pushpendra and Gaur (2022) [19]	This includes a succinct review of modifications conducted in the hybrid solar dryers to make the dryers more efficient.

no-load and under different loads. Table 4 gives a brief coverage on test protocols and procedure for SBC performance prediction [27].

Development of test protocols (case specific as well as benchmark) and TPP for various solar cookers have been paid attention by many researchers. Some of these are enlisted in Table 3. Kumar et al. (2011) has stated that exergy-based evaluation is very practical, comprehensive, and realistic approach [28]. Further, Kumar et al. (2012) has applied this exergy-based approach in performance analysis for SBC of different geometrical configurations with clear focus to make the suggested protocol to be independent of geometrical configurations. The results obtained have been very promising [29]. Collares-Pereira et al. (2018) have modified the test procedure of estimation of Figure of merit for performance characterization of SBCs. This have simplified the procedure so that with simple instrumentations Figure of merit may be obtained without compromising advantages of previous procedures [30]. Yettou et al. (2018) has brought out one new method for predicting the solar cooker efficiency based on solar irradiance map. This method was proven sound for many cities of Algeria country [31].

Table 2. Thermal performance parameters, its expressions and permissible range for SBC. [8,21,22]

Performance parameter	Expression	Permissible range
First figure of merit, F_1	$\frac{T_{px} - \bar{T}_a}{\bar{G}}$	0.12 – 0.16 m² °C/W
Second figure of merit, F_2	$F'\eta_o C_R = \frac{F_1(MC)_w}{AF_2} \ln\left[\frac{1-(1/F_1)((T_{w1} - \bar{T}_a)/\bar{G})}{1-(1/F_1)((T_{w2} - \bar{T}_a)/\bar{G})}\right]$	0.254 – 0.490
Standard cooking power (W), P_s	$\frac{700MC_w\Delta T}{600\bar{G}}$	348.833 W at ΔT=50°C
Utilization efficiency, η_u	$\frac{Q_F}{Q_{in}} = MC_w\Delta T/\bar{G}A_p\Delta t$	7.4 – 29.6 %
Specific boiling time (min m²/kg), t_s	$\Delta t\ A_c/M$	25.843 – 85.757 min m²/ kg °C
Characteristic boiling time (min m²/kg), t_c	$t_s\bar{G}\ /\ G_{NR}$	20.1 – 66.7 min m²/ kg °C
Solar cooker efficiency, η	$\frac{(MC_w + M_1C_u)(T_{w2} - T_{w1})}{CA\int_0^{\tau}\bar{G}dt}$	27.5 %
Time required achieving the maximum temperature of the cooking fluid, $d\tau$	$(MC)'_w\ dT_w/[F'\ \eta_o\ I - F'^{U_L}\ (T_w - T_a)]A$	As per the sensible heating characteristic curves

Table 3. Test protocols for performance prediction of SBC

S.N.	Author	Relevant performance parameter / Design parameter / Objective function	Basis of test protocol	Purpose of test protocol
1	Mullick et al. (1987) [32]	F_1, F_2 and time factor	No-load test, full-load test, water (sensible) heating characteristics curves	Thermal test procedure for SBC.
2	Mullick et al. (1996) [33]	F_2	Part and full load test and water (sensible) heating characteristics curves	To fetch the guidelines for initial water temperature and testing temperature-intervals
3	Funk (2000) [34]	Effective solar cooking power	Standard procedure for the performance testing and reporting of the SBC on international basis	A useful tool for applying to the solar cooker fort different designs
4	El-Sebaii and Ibrahim (2005) [35]	F_1, F_2 , t_s , t_c boiling times and overall thermal (utilization) efficiency η_u.	Procedure by Mullick et al. (1996) and Funk (2000) were adopted	Initial and overall cooking power, heat loss coefficient were monitored to indicate that best performance is achieved for full loads
5	Purohit and Purohit (2009, 2010) [24,25]	F_1 and F_2	Optical efficiency factor, standardized cooking power	Procedure for analysis of overall error in evaluated performance parameter due to instrumental errors
6	Kumar et al. (2011) [28]	instantaneous energy and instantaneous exergy efficiencies	Exergy based evaluation of solar cooker	For Truncated pyramid SBC (TPSBC)
7	Kumar et al. (2012) [29]	Peak exergy factor, quality factor, exergy temperature gap product and Heat loss coefficient.	Exergy based evaluation of solar cooker	Incorporated test protocol for multiple SBC geometries
8	Geddam et al. (2015) [23]	Optical efficiency	Rendering of sensible heating based characteristic curves	Gives basis for material selection for components SBC. Very simple procedure, performable with simple instrumentation
9	Soria-Verdugo (2015) [26]	Convective heat transfer model	Environment temperature and broad spectrum of solar radiation	Number of days in which the absorber plate temperature exceeded 100°C

REVIEW OF DESIGN CONSIDERATIONS OF SBC: VARIOUS ASPECTS

Solar Tracking of SBC and its Optical Parts (Including the Accessories)

For best performance of SEBS, direct solar irradiations is important. To manage maximum possible duration of direct solar irradiations the computation of faultless tracking locale, communication arrangements self-diagnosis of faults and control mechanism for tracking drives are very important [36].

Solar tracking of SBC (or any other solar device) refers to orienting it towards facing the sun so that it gets maximum exposure to solar irradiations. This is done manually or by solar tracker device, intended specifically for this purpose. In many cases, SBC is made such that without even manual adjustments it may work fine throughout the day for a given altitude-latitude-longitude based locations. Algifri and Al-Towaie (2001) have estimated the optimum position / orientation of SBC for any location, day of year and time of day. Procedure for reflector performance factor and orientation factor calculations as function of the sun's elevation angle, the solar azimuth, and reflector tilt have also been ascertained [37].

By optimizing the location of SBC and its components as per given locality, the solar tracking needs may be minimized. Such SBC has been designed by Harmim et al. (2013) for Adrar (Algerian Sahara) location for which SBC was integrated with fixed asymmetric CPC to function as booster-reflector and step styled absorber-plate without any tracking needs [38]. Further a no-power solar tracker system for SBCs was designed by Farooqui (2015) has developed. Tracking is achieved by help of hydraulic based spring-loaded geared system. The azimuthal adjustments have been accommodated by the help of optimized size of booster mirror placed at optimized azimuthal angle for a day. This system proved to be quite fine for six hours daily cooking. Adopting these ways, need of manual adjustments of cooker along the altitudes can be avoided [39].

Hybridization with Auxiliary Units Like Other Conventional or Nonconventional Systems

Hybridization with auxiliary provisions of thermal energy proves to be added advantage for SBC. Such auxiliary arrangements may be done through conventional or non-conventional modes of assistive thermal supply units. Joshi and Jani (2015) have worked on five foldable attached solar panel types of hybrid solar cookers (Figure 5). The photovoltaic power assisted cooker makes it convenient to be available for long time, user friendly and reliable. Based on Figure of merit calculations this system is proven to be efficient [40].

Mahavar et al. (2017) has suggested the alternative arrangement of electrical back up for SBC to improve the efficiency at regular times and to improve the reliability in the cloudy and evening times, by overcoming limitations of SBC. Such arrangement can reduce payback period as well as increase the net present value (NPV) in respect to various conventional cooking fuels [41]. Saxena and Agarwal (2018) and Heydari et al. (2021) have developed solar cooker and solar dryer, respectively, integrated with an assistive hot air supply (Figure 6), for augmenting the forced convective heating (obtained by halogen lamp plus small fan unit combination) to promote the heat transfer rate and to bring reduction in cooking time by minimum possible direct heat energy consumption [42,43]. Performance testing has been carried based on η_{th}, F_1, F_2, P_{cook}, overall heat loss coefficient and heat transfer coefficient. This arrangement is first of its kind of SBC which is efficient in any sort of climatic circumstances. Cuce E (2018) has developed a cylindrical solar cooker (Figure 7) [44].

Size, Design and Placement of Box And Cooking Vessel

A usual practice has been to fabricate the SBC of square or rectangular box shaped. For solar cooking usually conventional cooking pots are utilized. Testing different shapes for solar boxes are undergoing so that geometrical advantages can be encashed for improving the optical receptivity of SBC and its utilization for incident solar irradiation. Sharaf

(a) **(b)** **(c)**

Figure 5. (a) SS-SBC (b) SSH-SBC with solar panels (folded) (c) SSH-SBC with solar panels (opened). Here the terms SS and SSH refer to Small scale and Small scale hybrid. [40].

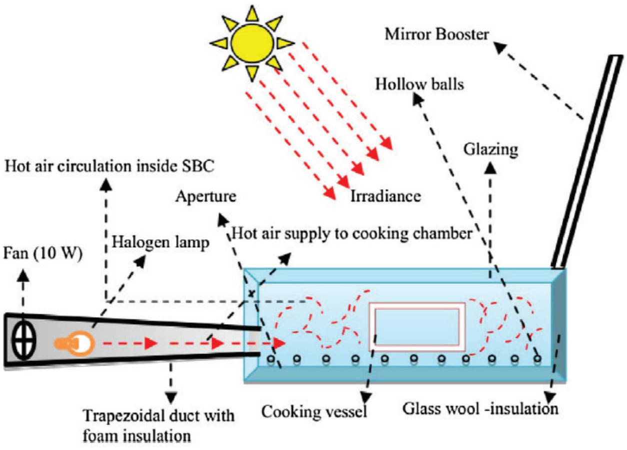

Figure 6. Schematic diagram of a SBC hybrided with artificial forced convection [42].

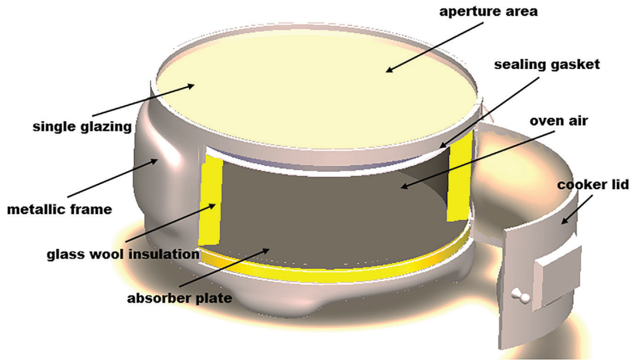

Figure 7. Constructional details of cylindrical solar cooker [44].

(2002) has tested experimentally the conical solar cooker for the purpose of grilling, boiling of water, frying as well as cooking beans. Conical shape is suggested as low priced, easy to design, and efficient solar cooking systems [45]. Further, Kumar et al. (2008) have designed, fabricated, and tested truncated SBC to obtain a tracking-free solar cooker. Figure of merit has been calculated and compared with the BIS (Bureau of Indian Standard) for SBC. This design may be recommended for household dryers as well [46]. Kumar et al. (2010, 2011) have worked more on truncated pyramid box cooker with multipurpose home utility and have conducted thorough exergy-based performance analysis, proving the possibility of truncated model for solar cooking. Truncated conical non-tracking SBC can be a multipurpose solar devise that can have provisions for solar cooking and solar water heating. Performance of such devise has been proven to be comparable with flat plate solar water heater. In addition, it is financially and physically more viable [47,28].

Instead of conventional cooking vessels or utensils, the customized cooking pots are more useful for solar cooking purposes. The vessel design, its material, added geometrical configurations etc. is proved to be helpful for improving the cooking efficiency. Kumar et al. (2001) have designed, developed, and then analyzed the SBC combined with evacuated tube solar collector. This has distinct energy collection unit and cooking unit - duly coupled with a heat exchanger. Performance predictions have been done for various operating and climatic conditions (using experimental and analytical approaches) for its utility in Delhi [48]. Harmim et al. (2008) have worked out effect of finned vessel in solar cooker performance in Algerian Sahara on the experimental platform using double exposure solar cooker. Experimentally it is demonstrated to reduce cooking time [49].

Rao and Subramanyam (2003, 2005) have shown that placing the cooking vessel over lugs may lead to improve cooker performance because bottom surface also begins to participate in heat transfer. This was compared with conventional style of placing of cooking vessel [50-51]. Further, Reddy and Rao (2007) have designed a central cylindrical cavity-based cooking vessel for a double-glazed type of SBC. This new vessel is found to be 6% more efficient than its competitive conventional vessel. It is advantageous to place cooking vessels on thermally conductive lugs than to place on cooker absorber plate floor. This leads to higher temperature of thermic fluid of cooker [5].

Sethi et al. (2014) have designed and developed a parallelepiped shaped cooking vessel, kept it within inclined SBC, concluding to be proficient in winters. Such new design of vessel and inclined placing of cooker have been found beneficial in reducing the time taken to boil the water (S_{boil}) by 37% and enhancing the standard cooking power (P_n) by 40% than the conventional vessel placing and conventional cooker placing (i.e., horizontally) styles [52].

Configuration Selection and Placing of Heat Storage Material and Absorber Plate

Storage material and its proper placing style may become one of the important aspects of SBC for the purpose of its wide commercial acceptance. There are two kinds of heat storage materials employed in solar cookers:

(a) Sensible heat storage materials: These include sand, engine oil, vegetable oils, metal matrixes, certain kind of stones, etc.

(b) Latent heat storage materials (alternately referred as phase change material): These include acetamide, acetanilide, stearic acid, some vegetable oils, erythritol, magnesium nitrate hexahydrate etc., to count few of the many PCMs.

Buddhi and Sahoo (1997) has designed, fabricated, and tested SBC with latent heat storage suiting to Indian climates and concluded its benefit for food cooking in late evening. It was found that placing style of heat storage material also matters a lot [53]. Use of tilted absorbing surface for retaining the irradiation could permit for two times meals even in winters (Nahar, 1990), by increasing $\eta_{overall}$ by 24.6% (even without frequent tracking) as compared to horizontal absorbing surface which resulted in only single meal a day [54]. Suitably designed commercial grade acetamide PCM for thermal storage-based SBC could prove its worth even for winter evenings as compared to standard SBC – without affecting noon cooking performance. PCM with melting temperature between 105°C - 110°C could make possibility of night cooking [55]. Double exposed absorber plate (acting as sensible heat absorber) based novel design of solar cooker could lead inner air temperature rise for about 15% more than the normal case [56]. Similar incident was reported for SBC with used engine oil (as storage material), which gave an effective inner cooker temperature rise of 23°C and efficiency rose to 27.5% [57]. In the more demanding situations like of residential schools and public cooking centers (involving large cooking yield) use of absorber plates (as sensible heat storage) aided with concentrator could be used fruitfully to cook for up to 30 children [58]. Similarly incorporating flat plate collector incorporated in PCM based cooking unit and indirect solar cooker with wickless heat pipes has been proven its suitability as indoor cooking unit [59]. In solar cooking, increase of stagnation temperature and reduction in water heating time are important. Nearly 7% higher stagnation temperature was achieved for SBC furnished with plate like fin-integrated absorber plate with respect to SBC with plane absorber plate [60]. This naturally reduced water heating timings. SBC performance can be further enhanced by angular setting of absorber side walls and arrangements of internal reflection [61]. Used vegetable oils are easily available and these could also be used as energy storage materials to enhance SBC performance. Sunflower oil gave good energy and exergy thermal performance both under high and low power charging situations [62]. For PCM performance upper cycle temperature based thermal loading, phase change enthalpy and temperature range, physical stability and life span are important factors. For example, one PCM material Galactitol is good for medium temperature range (150°C – 200°C) but failed due to instability and low lifespan [63].

Cuce E (2018) and Cuce PM (2018) have done investigations of cylindrical solar cookers with micro porous absorbers (made by low dense and high heat capacity natural stone named Bayburt stone), explored on the effect of variation in shapes (triangular, trapezoidal and rectangular etc.) of porosity upon the thermal performance figure, boiling time, energy, and exergy efficiency [44,64]. Chen et al. (2008, 2016) conducted 2-D theoretical investigations for some selected PCMs (like magnesium nitrate hexahydrate, stearic acid, acetamide, acetanilide and erythritol) based on the enthalpy approach. Different heat storage container materials were considered (like Al, Cu, SS, glass etc.) for containing the PCMs. For SBC, acetamide and stearic acid may be deployed as good latent heat storage material. Thermal conductivity and thickness of container material and its boundary temperature have important role in melt fraction amount and thus on the effectiveness of use of PCM as storage material [65,66].

Incorporating any kind of energy storage materials would require certain design changes so that common problems related to any of the material (sensible / latent) may be made overcome. During phase transformation process the melting interface tends to go away from heat transferring surface, which is overcome by closely spaced side walls of cooker. Similarly, other problems may also occur, which needs to be investigated.

Effect of Design and Placement of Multiple Reflectors, Concentrators, and Booster Mirrors

Suitable choice of reflector is imperative for maximizing reception of solar radiations upon its absorber plate. Reflectors in the cooker are also called primary reflectors, which are thus reflected on to secondary reflectors. These secondary ones, which are also called concentrators, are placed right below the cooking vessel, mostly. These divert the solar energy on cooking vessel to begin heating process. As per overall design choice of solar cookers, reflectors

Figure 9. Non-imaging concentrator based reflective solar cooker [68].

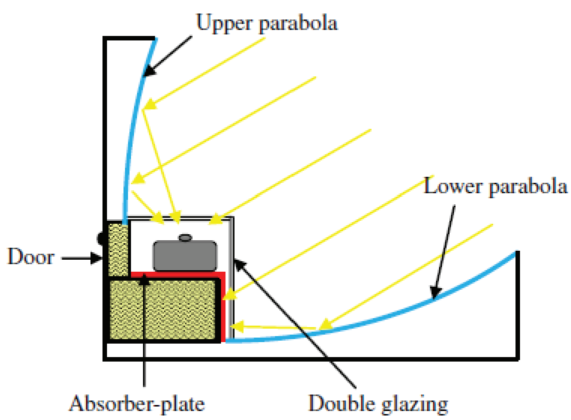

Figure 10. Schematic of non-tracking SBC with stepped absorber and asymmetric booster-reflector [38].

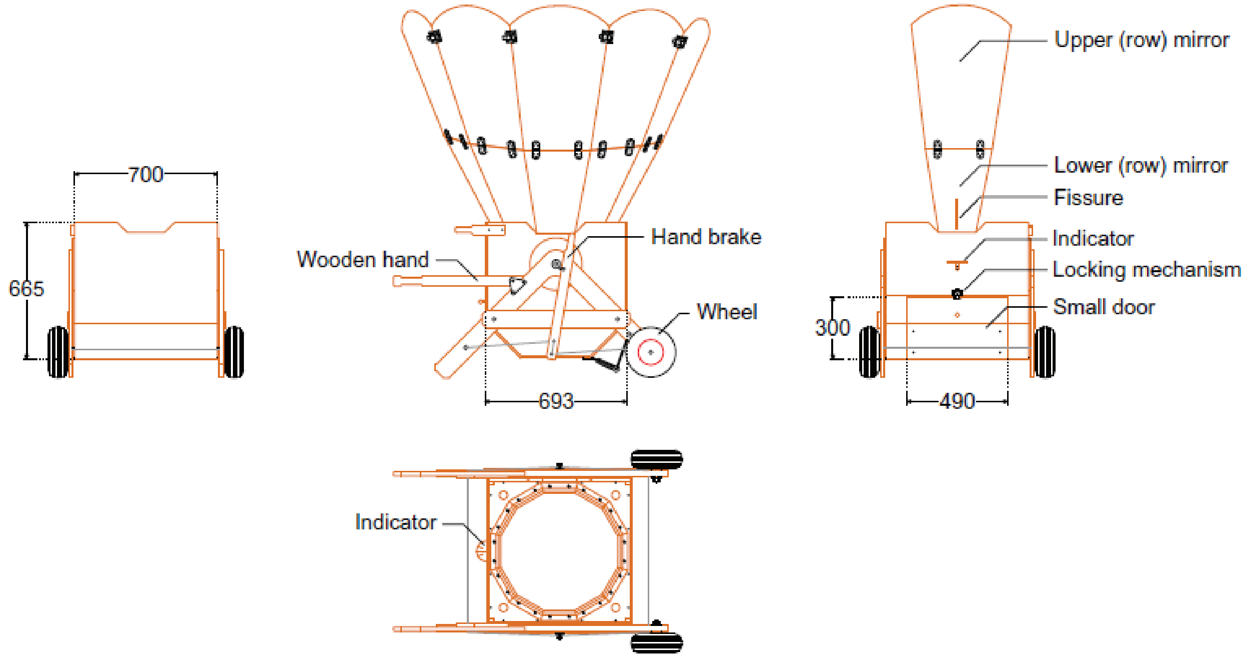

Figure 11. SBC with multiple (Dodecagonal) reflectors [69].

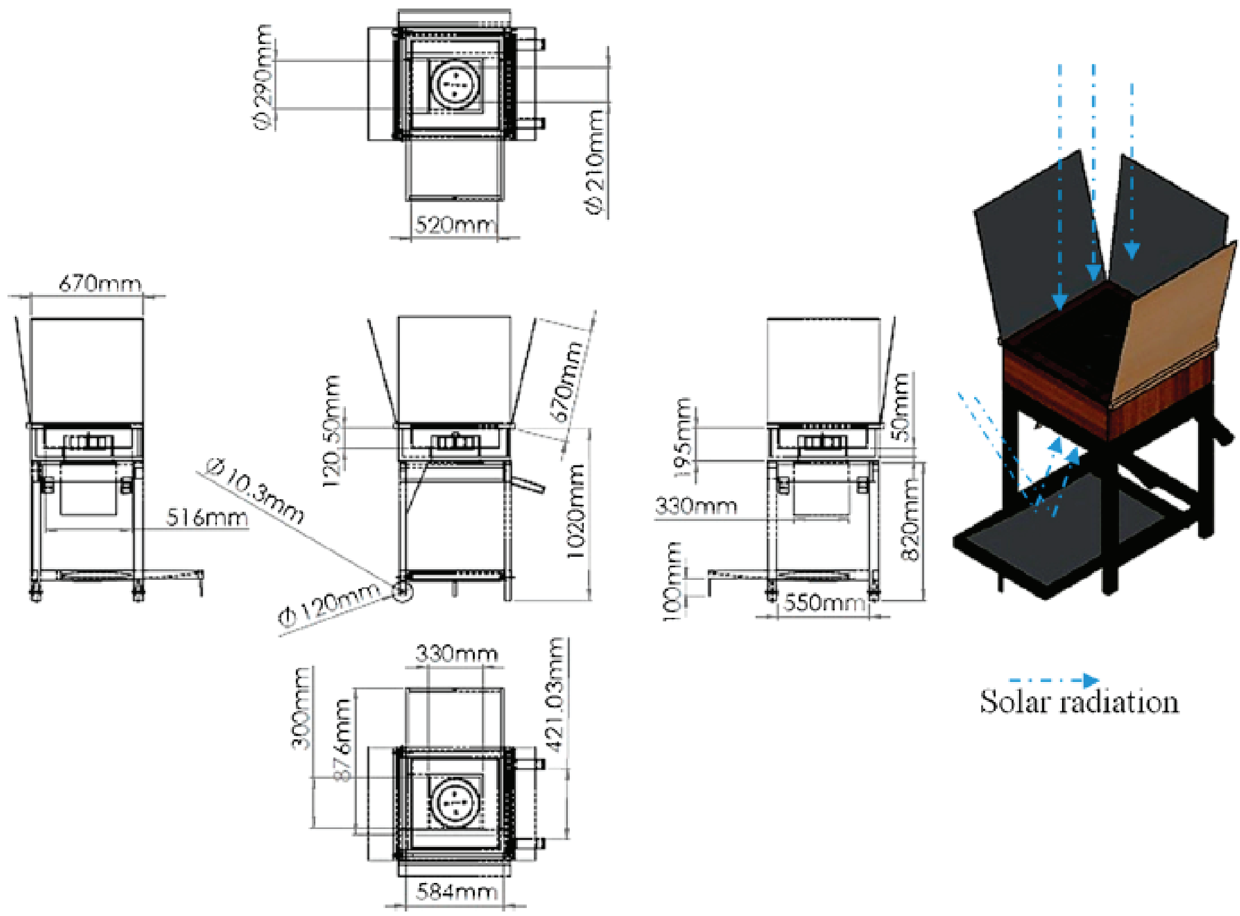

Figure 12. Double exposure SBC [70].

Table 4. Major findings pertaining to role of various aspects of design consideration for SBC improvement

S.N.	Aspect of design consideration	Important attribute
a	Solar tracking of SBC and its optical parts	Automated tracking is very much needed in conserving future of SBC.
b	Hybridization with auxiliary units	Selection of suitable detachable auxiliary units and its need-based design may be helpful for SBC performance improvement and adoption.
c	Size, design and placement of box and cooking vessel	For cooking vessels, thermally favorable design, material type, and its location within SBC can lead to more efficiency improvement than conventional cooking vessels.
d	Configuration selection and placing of heat storage material and absorber plate	Nano based sensible and latent heat storage materials along with its encapsulations as well as placing location are focal issues.
e	Effect of design and placement of multiple reflectors, concentrators, and booster mirrors	Suitable decision about this aspect lead to multiple meals in a day even without intensive need of tracking of cooker.
f	Material selection for box cooker components	Lightweight, low costly and effective insulating / optical / thermal properties (as needed for different components) are key areas of research presently.

may be flat plate type, compound concentrating collectors, cylindrical parabolic collectors. Growth of investigations on reflector and concentrator designs as well as its material is catching up. These are very strong aid to solar cooker which otherwise may remain almost like an open box heater by sun light. Nahar (2001) have designed double reflector (with transparent insulation type material, TIM) managed SBC. Additional reflectors result in less strain on tracking system as tracking requirement intensity drops down by more than 2 hours [67]. Hence this leads to non-frequent need of attention on cooking operation. Further, Franco et al. (2004) found the suitability of incorporating concentrators with solar cookers for faster rate of cooking as needed in community cooking situations [58].

Edmonds (2018) have developed a new non-imaging concentrator consisting of a cylindrical guided 8-flat reflective panels (Figure 9) [68]. Such model is light in weight, cheap and maintained simplicity of the traditional pan style. Weldu (2019) developed and tested (at Bahir Dar, Ethiopian climate condition) the solar cooker tracking type of reflector. Such reflector performed better than standard type of reflector [71].

Use of booster mirrors to enhance performance of SEBSs is well recognized and accepted. Even two meals per day may become possible by such provision. Various research contributions (e.g., study of the geometry, design, and arrangements etc. of mirror boosters) have come up to study the the booster mirror energy contribution to pave more to economic viability [50,51]. Further, Mirdha and Dhariwal (2008) have tested various combinations of booster mirrors with different designs of conventional box type cooker [72]. Negi and Purohit (2005) have developed a model of SBC employed with non-tracking concentrator using suitably positioned plane reflectors [73]. Harmim et al. (2012) have constructed and assessed SBC equipped with asymmetric CPC (Figure 10) [38]. Coccia et al. (2017) has fabricated and established a solar cooker with high concentration ratio (11-12) multiple (Dodecagonal) reflectors was manufactured and tested in conjunction with two rows of booster mirrors (Figure 11) [69]. Sagade et al. (2018) have devised a term “Effective concentration ratio” (ECR) to serve as good way to assess the impact of deployment of booster reflector [74].

Material Selection for Box Cooker Components

In the development of SBC for its adoptability in an industrial sector, selection of suitable material play important role. Nayak et al. (2017) affirms need for consideration of local users’ standpoint for ascertaining accessibility of materials needed. It is well established fact that material properties of components affect the performance parameters of solar cooker. Mahavar et al. (2012) have shown that for single-family solar cooker (SFSC) the compact size, expedient design, lightweight low-cost hybrid insulation materials and specially designed lightweight polymeric glaze materials, etc. are important aspects [75]. As applicable to other areas of technology, in SBC technology too, material selection affects the concerns of economic viability, compactness, overall weight of units and performance etc. Key point of all these have been identified in Table 4.

REVIEW ON SOCIAL AND COMMERCIAL ADOPTION OF SBC

There have been many investigations in solar cookers and as a result some satisfactory designs have come up. Still there is slow rate of acceptance of solar cooker not only in the individual household level but at commercial, industrial and various community levels. There should be increased efforts in this part so that various stages of lacuna or bottlenecks on the way of popularization of SBC can be overcome. Wareham (1997) discusses that government support, awareness campaign for positive of solar cooker and negatives of conventional systems, high quality solar cooking unit (like affordable, light weight, efficient, rigged, family sizing, stickability etc.), good production finalities

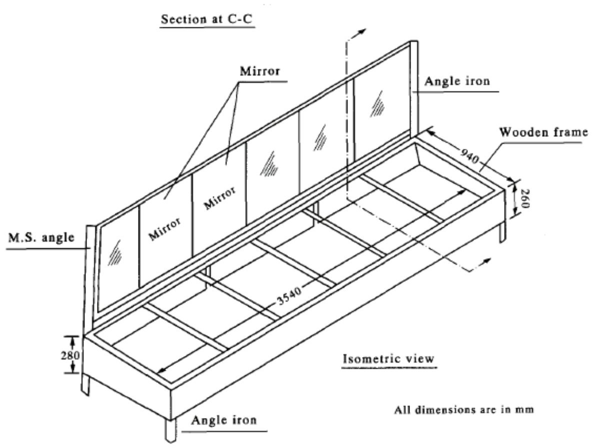

Figure 13. Schematic of community size solar cooker [77].

and cheap material etc. are necessary for successful solar cooker project [76].

Nahar et al. (1993) have tested an improved community size solar cooker (Figure 13). It was concluded that cooker of size 3540 mm x 940 mm x 280 mm could manage requirement of nearly 80 persons. This reflects its suitability for hostels, temples, canteens, restaurants, and other large gatherings etc. Reduction in payback period and higher life expectancy of the devise is attracting attention of users at personal and public levels [77]. Franco et al. (2004) asserts that advanced solar cooking as good alternatives for boarding education centers and public dining centers. Technologically advanced solar cooking units provide good alternative for public dining centers. This showed that cooking for up to 30 children is possible when concentrators and other aids are installed [58].

There have been many investigations for various possible design options with focus on local usage of a particular region of any country. Binark and Turkmen (1996) had developed and evaluated SBC for compatibility with Southeastern Anatolia (Turkey) [78]. Badran et al. (2010) designed portable water heater for Bedouin community [79]. Weldu (2019) developed and tested the solar cooker tracking type of reflector for Bahir Dar (Ethiopia) prevailing weather condition [71]. Hussein et al. (2008) explored good possibilities of solar cooking in upper and remote Egyptian areas due to blessed good sunshine marked by mean daily solar radiation upto 5–8 kW/m^2 day [59]. De Escobar (1996) researched on low-cost solar cooker and proposed it as alternative energy device in El-Salvador [80].

Nahar et al. (1996) had earlier developed and installed a solar cooker using locally available material, for boiling animal feed (likes husks, excreta of agricultural products, grass dried etc.). It was claimed to recover cost of cooker within 6 months (approximately) – which was not so professionally made [81]. Further, Panwar et al. (2013) have also emphasized the need of solar coking of animal feeds due to more utilizations of villager's time, high quality of animal fodder due to slow cooking, low cost of device and saving of various biomass-based fuels etc. [82]

At present, commercialization of solar cookers is still in question. Even though this technology has been more than 60 years ago, still this has not received very wide popularity. There is a challenge that solar cooking unit should be compact for household and small-medium scale food packaging industry. Large solar cooker may be utilized in the form of solar oven and solar dryers – especially in rural scenarios. Long array based solar cooker may be utilized in many of the schools by mid-day food providers. In many developing countries government sponsored schemes are provided with such arrangement for poor children. Thus, research exploration in such cookers may be highly useful and may gain a quick popularity if paid attention properly. The gain will be huge in terms of the economy and nutrition value of food being supplied to the poor children and environments. Training may also be provided at community levels for using these cooking units. Author expects that future researchers will be involved in overcoming the shortcomings in solar cooker technology as quickly as possible, Table 5.

REVIEW OF VARIOUS COMPUTATIONAL TECHNIQUES FOR POSSIBLE SBC ANALYSIS

Various computational techniques have been useful to analyze SBC [83]. Chauhan et al. (2015) have carried out a comprehensive review explicitly for various kinds of softwares (analysis softwares, programming softwares and documentation / plotting softwares) usage in design or parametric analysis of solar drying system [84]. Different computational techniques can be very useful in analysis, performance prediction, efficiency improvement, and developmental designs [14]. These techniques include Computational fluid dynamics, Artificial intelligence,

Table 5. Major findings pertaining to social and commercial adoption of SBC

S.N.	Aspects	Important attribute
a	Social adoption	Compactness, initial economics, and efficiency aspects are major hurdles in it. Cooking economy and nutritional protection of food are attractive incentives for adoption.
b	Commercial adoption	Long arrays of cooking devices, with automation arrangements and training to the personnel can be appealing in this. SBC technology improvements is mandatory.

Fuzzy logic and Neural network techniques, IoT etc. Each of these computational approaches has their own focus and strength. Hence attention is being paid to incorporate each of these computational techniques in analysis of solar cooker variations. Chauhan et al. (2015) have screened 42 papers in a recent review paper but that was of solar dryer [84]. Although dryer is a devise different than solar cookers, still concepts may be learned and utilized for purpose of studying solar cookers. In the forthcoming sub-sections, a few research on using Computational approaches for SBC are beings outlined.

Application of Computational Fluid Dynamics (CFD): Introduction, Status of CFD Implementation, Case Study and Future Directions

INTRODUCTION

Computational fluid dynamics, abbreviated as CFD, is a numerical simulation method for investigation of systems involving transport processes such as fluid flow, heat transfer, species transport, chemical reactions etc. This technique is very powerful tool in analyzing various industrial and non-industrial problems. It has got its strong foothold in many practical areas such as high speed aerodynamics pertaining to air vehicles, missiles, rockets, and ground vehicles, ship propulsion hydrodynamics, analysis of reacting flow in various engines and combustion chambers, flow analysis of stationary and rotating passages of the pumps, turbines and compressors, convective and radiative heat transfer analysis of energy system, distribution of pollutants in the environments, clinical health care sectors, manufacturing and production sectors, etc. There has been a tremendous growth in CFD analysis, and it has emerged as very important alternative and support for experiential analysis. There are various books and research papers which give a detailed account of its history, fundamentals, developments, and applications in multifarious practical applications.

CFD codes are structured based on numerical algorithm to tackle the governing equations related to concerned transport processes involved in the system under analysis. Mathematical modelling is prerequisite for CFD analysis of any physical transport phenomenon. A typical CFD code has three key components, namely pre-processor, solver, and post processor. Pre-processing involves the solution of the flow problems to a CFD code through user-friendly interface as well as further conversion of the input in form suitable to be handled by solver. This consists of,

(a) Definition of geometry of suitable dimensions as per region of interest of given thermo-fluid system,
(b) Discretization of the geometry into various non-overlapping elements (called grid generation or meshing),
(c) Selection of various physical processes and chemical processes to be simulated,
(d) Definition of properties of working fluids,
(e) Selection of appropriate boundary conditions justifying the prevailing physical boundary condition.

Solver component of the CFD codes involves.

(a) Selection and integration of various governing equations pertaining to various processes (taking place in the system under analysis) on each element or cell of grid (also called computational domain),
(b) conversion of governing equations using discretization techniques like Lattice Boltzmann method (LBM), Finite volume method (FVM), Finite element method (FEM), Boundary element method (BEM), Finite difference method (FDM) or spectral methods etc. into set of consistent algebraic equations,
(c) Implementation of boundary conditions at the boundary cells,
(d) Solution of these equations by suitable type of numerical methods, mostly in iterative manner.

Post-processing component is last essential step. In this, the huge systemic data obtained from solver of CFD code is made arranged and presented in required and useful pattern by various features like geometry and mesh display, line and shaded contour plots, vector plots, two dimensional and three-dimensional surface graphs, animated, graphs, etc. Apart from this, interpretation of these data visualization trends by an expert is key factor of post processing. Meaningful practically utilizable conclusions are more important than just the data and plots.

CURRENT STATUS OF CFD IMPLEMENTATION

Considering the research contributions involved in any category of solar cooker including SBCs, maximum attention paid by most of the investigators is either experimental investigations or analytical investigations. Application of CFD is spreading fast in analysis of solar thermal systems. Till current day, only some of the investigators have undertaken analysis of various aspects of SBCs using CFD.

Harmim et al. (2012a, 2012b) gives a crisp but comprehensive coverage of various mathematical research performed on SBCs [85,86]. These are as below.

(a) Transient analytical simulation of single glass SBC to predict cooker temperatures.
(b) Transient analysis of plane booster reflector integrated SBC.
(c) Multiparametric unsteady computer simulation of different forms of SBC, irrespective of reflector presence, for envisaging unsteady thermal behavior.
(d) Heat transfer modelling for plane booster reflector integrated SBC by duly considering the leading means of heat gain and loss.
(e) Mathematical model of SBC integrated with double glass and plane mirrored double glass reflector.
(f) Transient modelling of multi-step reflector SBC, with and without outer plane reflector.
(g) Steady and transient performance investigation, theoretical, of double exposure type solar cooker.

(h) Data analysis and mathematical modeling for a cylindrical SBC incorporated with three planar reflectors.

Table 6 briefs that how CFD has been adopted as computational procedure to analyze different cases pertaining to solar cooker. Amount of data collections by application of CFD study of different parametric case for different design can be a huge source of technical data. This data may be useful in the automated system for industrialization of solar cooker in big scale using modern technologies such as Big data analysis, Artificial intelligence and Internet of Things (IoT).

FUTURE DIRECTIONS

Application of CFD analysis is going to have multitudes of advantages for users of solar cooker, at outset. A few of possible advantages are being enlisted as follows.

(i) Parametric analysis is possible based on computer simulations. This can save multiple number of testings for different configurations and thus time as well as capital investments can be saved. For support of computer simulation a few simple experimentations can be used as these are already available.

(ii) The simulations may also be useful in designing the functionally graded material for solar cooker applications pertaining to body of solar cooker as well as body of vessels used for solar cooking units within solar cookers.

(iii) Scientific community can be blessed by dealing with complicated physical phenomenon which may occur in solar cookers. This includes modeling of solar radiation, modeling of phase change process clubbed with sensible heating / cooling and convective and radiative

Table 6. Applications of CFD in solar cooker analysis

S.N.	Authors	Type of solar cooking unit	Highlights of methodology adopted	Findings / List of key parameters in focus
1	Binark and Turkmen (1996) [78]	SBC equipped with cooking pots and mirrors arranged as adjustable reflective planes.	Fourth order Runge-Kutta method	Method is suited for analysis as the actual experimental results performed for several cooking vessels of different type and size.
2	Chen et al. (2008) [65]	Comparison of different PCM for 2D SBC	2D-CFD simulation using enthalpy-based approach	Effect of boundary wall temperature, thermal conductivity and thickness on 2D heat exchange in container has been analyzed using calculation of melting time and melt fraction for PCM.
3	Harmim et al. (2012a) [85]	SBC equipped with CPC (to serve as booster-reflector), absorber plate and cooking pots	Mathematical modelling of heat transfer	Included the effect of variation of parameters like solar radiation, cooker load and cloud affected blockages on dynamic behavior of cooker.
4	Terres et al. (2014) [83]	SBC with internal reflector	Mathematical modeling and transient numerical prediction of thermal behavior	Thermal function of solar cooker considering different fluid types, amounts and effect of radian modeling have been obtained.
5	Kumaresan et al. (2015) [87]	Double walled solar cooking unit (of all types)	3D CFD simulation	Type of food and type of cooking vessels have important bearing upon the surface heat transfer coefficient.
6	Chen et al. (2016) [66]	Solar cooker with parabolic sub-reflector	FEM based CFD simulation	Solar cooking effect on the temperature distribution of parabolic sub-reflector has been studied to determine the effect of high local temperature on the working and thermal designing of radio telescope.
7	Nayak et al. (2018) [88]	Top glass cover of trapezoidal shaped SBC	3D numerical analysis of convection and radiation augmented heat loss through the top glass cover	Parametric studies have been done by varying cooker depths, wind speed led heat transfer coefficients above the glass surface, plate emissivity.
8	Adetifa and Aremu (2018) [70]	Water heating tests performed for Heat storage material filled annular cavity (benzoic acid, stearic acid and palmolein)	Unsteady thermal analysis using CFD software ANSYS-Fluent	Heating power and sensible heat efficiency (STE) is affected by different heat storage materials. STESS as well as LTESS for low-temperature application of heat storage material filled annular cavity has been evaluated.

heat transfers, dealing with complicated boundary conditions during the cooking process in the cooker for different food products etc.

(iv) Various newer designs may also be tested, for example (a) the auxiliary heating by the hot air gained from some source (may it be air heater or else) can be used for hearing especially designed cooking vessels having circulating jackets for hot air / hot water, (b) sensible heating of e storage materials of various configurations in solar cooker by using the heated air or heated water, (c) effect of incorporation of different types of phase change material in glass cover of solar cooker, (d) effect of functionally graded fins of different configurations on The cooking vessels etc.

(v) Computational material science is an allied branch of CFD. This can be used for improving thermo-optical properties of cover glass plate, booster mirrors etc. Newer materials may be modeled and analyzed for obtaining suitable optical characteristics for the purpose of solar cooker applications.

There are many more ways to incorporate the CFD approaches for technological improvements to achieve better performing solar cooker designs.

Application of Artificial Intelligence (AI) Techniques: Introduction, Implementations Summarized and Future Directions

CURRENT STATUS

AI copycats human discernment, human learning and related cognitive procedures to unravel any sort of simple to complex problems. This is computational model-based procedure which has been incepted in year 1960s and its outbreak application begin to happen since 1990s primarily. It consists of three layers, which include input layer, hidden layers and output layer. There are many books and research articles through which the procedures of ANN can be learned [89]. There is a range of AI techniques, which include: (a) Case-based reasoning (CBR), (b) Rule-based systems (RBS), (c) Artificial neural networks (ANN), (d) Genetic algorithms (GA), (e) Cellular automata (CA), (f) Fuzzy models, (g) Multi-agent systems (MAS), (h) Swarm intelligence (SI), (i) Reinforcement learning and hybrid systems, (j) Compute vision and deep learning etc. In the present review paper, emphasis is being placed on the application of Artificial neural networks (ANN) technique.

Some of the techniques need previous data based on past cases for training and for capturing the relationship

Table 7. Applications of AI in solar cooker analysis

S.N.	Authors	Type of system studied	Highlights of AI adopted	Findings / List of key parameters in focus
1	Kurt et. al. (2008) [90]	SBC with and without reflector	ANN model for multiparametric optimization	Output layer parameters (absorber plate temperature, enclosure air temperature and pot water temperature) have been predicted for input layer parameters (daily varying ambient temperature, solar irradiations, and cooker pot with variable quantity of water) in different experiments.
2	Tripathy and Kumar (2009) [91]	Solar drying device meant for the potato pieces	ANN applied for deciding best parameter	Intensity of solar irradiation and surrounding temperature are important input parameters for ANN modeling.
3	Prabhu et al. (2017) [92]	Analysis of thermal Images obtained during the solar cooking process	Fuzzy based technique in image processing using MATLAB	Air leakage in / out of the solar cookers and loss of heat due to improper insulation or poor insulations are important factors to be controlled for solar cookers. Efficiency of solar cooker is reduced by air leakage.
4	Elsheikh et. al. (2019) [18]	SEBS like collectors, heat pumps, heaters, PV systems, stills, cookers, and dryers	Review of applications of ANNs for modeling of different SEBS	ANN is proven efficient, less data needy and good representations in development of empirical correlation compared to mathematical ways of regressions. It is savior for temporal and financial resources.
5	Carballo (2019) [36]	Solar tracking system for home-based solar cooker	Computer vision-based and deep learning-based approach and related hardware for enhancement of solar tracking system	Developed new approach for tracking as a substitute over traditional trackers. This is applicable to commercial cookers and any kinds of SEBS. These include parameters such as prediction blocks of cloud movements, detection of shadow, detection of atmospheric attenuation and concentrated solar radiation.

amongst various data. These methods include the ANN, CBR, GA etc. Results based on series of experimentations or CFD applications may be well arranged, and optimizations can be done by such tools / algorithms-based procedures. ANN model may give faster and optimized solutions of SBC thermal performance analysis. There are various other problems for which processes are well understood there RBS may be applied. CAs and MASs may be applied to very complex cases. CA based techniques are for behaviour prediction by simulating the space, time, state and local interactions based discrete systems. MASs are employed usually for strategies of resource management and stakeholder exploring management. Application of several of AI techniques (Table 7) in modeling various Solar energy-based systems (SEBS) has increased with recognition of its potential in judging thermal performance, in thermal design analysis, in tracking system designs etc. Furthermore, in upcoming future, solar cooker design can be implemented using Internet of Things (IoT). The heat energy that is developed in the solar cooker could be stored in thermo-chemical batteries. This stored energy in batteries can be used for working of some other home applications or even could also be used by solar cooker itself to cook food during off sunshine.

FUTURE DIRECTIONS

Various AI techniques may be applied for SBC research as per case specific problems. Some of the so many problems for which AI techniques may immediately be logged on to, are as follows.

1. Devising the functionally graded material for booster mirrors, reflectors etc. with favorable optico-mechanical properties for solar cookers. This can be very much helpful for other SBESs, as well.
2. For making a good solar tracking device suitable for any kind of location may be designed and tested.
3. Activation and non-activation of storage material, adjustment of placing style of storage material within the commercial solar cookers.
4. In-built programs may be coded with the cookers to calculate the thermal performance parameters of SBC while in operation. This data may be recorded also for future purposes.

Aesthetics quality of solar cookers and its advanced / efficient cooking vessels are also the important issues. Manufacturing difficulties may be simplified by these techniques.

Application Possibilities of Internet of Things (Iot) in Smart Industrial SBC Future

CURRENT STATUS

IoT implies interconnecting various objects like devices, people, animals, facilities, machines, services. Each of these are provided with unique identifiers so that communications, data transfers, actuations, operations, and control could happen without human-to-human or human-to-computer interaction [93,94]. Talari et al. (2017) stated that smart devices and smart objects which have embedded system for information communication are potential for IoT vision fulfillment for revolutionary ideas of smart world, smart towns etc. [95]. Due to neck break rise in market share for up 28 % of renewable energy resources in the worlds energy demands, the smart energy systems based

Table 8. 4-layered IoT framework [97]

Layer 1		**Information of the world**	
	Impact	(a) Changes in habits and practices	(d) Social, ethnical, legal, risk aspects
		(b) Changes in value creation	(e) Changed information spaces
		(c) New markets	(f) Regulation, etc.
Layer 2		**Product, process, and business model**	
	Potential	(a) Context aware services	(c) New products
		(b) Automation and integration	(d) New process
			(e) New business models
Layer 3		**Smart objects and smart environments**	
	Qualities	(a) Adaptivity and proactivity	(c) Context sensitivity
		(b) Intuitive interaction	(d) Increased data quality, etc.
Layer 4		**Information and communication unfractured**	
	Technology	(a) Network and connectivity	(e) Sensor and actuator
		(b) Embedding and user interface	(f) Localization and identification
		(c) Cloud and fog computing	(g) Processor and memory
		(d) Energy supply	(h) Architecture, etc.

Table 9. The main applications of IoT [95]

1. Smart homes a. Demand response b. Fire detection c. Temperature monitoring d. Society system e. Social network supporting	**2. Transportation and vehicular traffic** a. Travel scheduling b. Camera monitoring c. Environment monitoring d. Assisted driving e. Traffic jam reduction	**3. Surveillance system** a. CCTV b. Violence detection c. Public place monitoring d. People and object tracking Traffic police
6. Smart parking lot a. Number of cars b. Departure and arrival c. Environment monitoring d. Mobile ticketing e. Traffic congestion control	**IOT applications in smart cities (Some aspects)** **5. Environmental pollution and healthcare** a. Greenhouse gas monitoring b. Energy efficiency monitoring c. Renewable energy usage d. Air quality and noise pollution monitoring a. Health tracking b. Identification c. Disease sensing and identification d. Public health data gathering	**4. Weather and water system** a. Weather condition b. Water quality c. Water leakages d. Water level e. Water contamination

on renewable technologies may not be overlooked at all in building smart cities. SEBS plays a major role in this. These are very much tuned for incorporating IoT in ideas of smart cities, smart buildings, smart energy systems, smart wearables, streetlights, chargers, inverters, water purifiers, signals etc. [96, 97]. Various components of IoT based system are given in Four-layer "Internet of Things framework" [Table 8].

FUTURE DIRECTIONS

IoT based applications in the smart cities are mentioned in the Table 9. Some of the possibilities are being discussed briefly as follows.

(1) Smart devises are nucleus and drivers for fulfillment of commercial objectives of IoT. Hence development of smart solar cookers (with due sensors, actuators etc.) is going to be an integral part of smart houses and smart communities, smart industries etc. Various aspects like opening, closing, temperatures sensing, automatic tracking, changing of cooking vessel locations, manipulation of food, online cooking adjustments for various foods etc. may be many possible features which can gradually be managed by smart technology associated solar cookers. In this way application of IoT can be very much helpful for community cooking.

(2) Incorporation of IoT will be helpful in many aspects. These are as follows.
   a. Collection of automatic data based on online observation of operation of solar cookers and cooking process etc.
   b. Development of various components of solar cookers especially tracking arrangements, heat storage storage material and functionally graded type of glass materials for reflector, boosters, and concentrators.
   c. Data compilation, data analysis and collaboration between manufacturing sector of solar cookers (i.e., all its components), application sector of solar cookers etc.
   d. Quality testing and benchmarking of manufacturing sector as well as application sectors for the solar

Table 10. Major findings pertaining to the role of computational techniques for SBC analysis

S.N.	Aspects	Important attribute
1	Application of CFD	Very beneficial for multiparametric and predesign analysis of future possible SBC with ease.
2	Application of AI & IoT	Future smart homes may incorporate solar cookers as its integrated part. Thus, Internet of Things (IoT) based techniques may prove to be beneficial. On industrial or commercial sectors, remotely located automated control is possible by help of AI tools and IoT technologies. Application of embedded technology and ICT in various components of solar cooking systems may be another area of exploration.

cookers of different varieties in maintaining cooked food taste and quality, etc.

(3) On community cooking scale, on the small to medium scale industry such solar cooking-based automation using IoT may be a boon. For day-to-day cooking as well as for commercial product cooking like fruit pulps, cakes, drying / dehydrating of herbs and spices, food preservations etc. incorporation of IoT will enable to improve productivity of solar cookers. Many schools of world community may be provided with mid-day meals by nearby smartly arranged towns.

(4) IoT based technology developed for smart solar cookers can very well be extended to other SEBS for similar purposes. Hybridization of solar cookers with solar air heaters, enabling the placement of heat storage materials as per the requirement, end product-based adjustments, cooking vessels selections and placement locations and likewise factors may be online monitored and adjusted.

CONCLUSIONS

This article presents a review on main considerations pertaining to solar cookers like thermal performance, design aspects, social acceptance, and application of latest computational approaches. Present status of research in all these areas of SBC research has been reviewed. Such unified review approach, considering many aspects altogether, is novel aspect of the present review paper. Purpose of all these is to hasten technological improvements pertaining to SBC so that its popularity can be quickly accelerated for various sectors of present-day society.

Few additional suggestions are as follows.

(a) Incorporation of solar air heater and solar water heaters to support the large solar cooker cum dryer will additionally be beneficial. This will increase heat gain of SBC. Outlet hot air may be utilized to preheat water and food products which are to be cooked next. By direct contact type of solar water heaters (with some additional sieving arrangements) rate of cooking may be made faster.

(b) Newer models for SBCs may be proposed, and its mathematical model can be developed. This will be helpful for thermal performance measures.

(c) For concentrators, booster mirrors, reflector and receiver, good material may be designed with favorable optical properties. Development of good optical technology, optical materials and applications of AI may be helpful in designing smart solar cooker tracking systems.

(d) Development of functionally graded storage material (sensible or latent heat based) may boost performance of SBCs so that its effective operational time may be extended.

(e) Cost wise economy, pay back periods, ease of handling, appearances are other factors which are very important for gaining more receptivity of SBC which is judged by various avenues like social impact, technology adoption, utilization ratio etc.

NOMENCLATURE

A	Absorber area (m^2)
A_P	Aperture area (m^2)
Ac	Collector area (m^2)
A_t	Pot surface area (m^2)
C	Concentration ratio
C_R	Heat capacity ratio
C_u	Specific heat of cooking utensil (J/kg/^{o}C)
C_w	Specific heat of water (J/kg/^{o}C)
dt	Time interval (s)
dT_w	Temperature difference of w(^{o}C)ater
F_1	First figure of merit (^{o}C m^2/W)
F_2	Second figure of merit
F_0	Heat exchange efficiency factor
G	Solar irradiance (W/m^2)
$\bar{G}$	Average solar radiation (W/m^2)
G_{NR}	Reference direct normal radiation (W/m^2)
M	Mass of water (kg)
M_1	Mass of cooking utensil (kg)
Δt	Time required achieving the maximum temperature of cooking fluid
N	Number of pots
P_{cook}	Cooking power (W)
P_s	Standard cooking power (W)
t_c	Characteristic boiling time (min m^2/kg)
t_s	Specific boiling time (min m^2/kg)
T_a	Ambient air temperature (^{o}C)
$\bar{T}_a$	Average ambient temperature (^{o}C)
T_{ps}	Maximum plate surface temperature (^{o}C)
T_{px}	Maximum absorber plate temperature (^{o}C)
T_w	Water temperature (^{o}C)
T_{w1}	Initial temperature of water (^{o}C)
T_{w2}	Final temperature of water (^{o}C)
η_o	Optical efficiency
U_{tw}	Top heat loss coefficient [Represented as function of pot water temperature]
U_L	Total heat loss factor (W/m^2 ^{o}C)
$(M_C)_0$	Heat capacity of cooker's interiors (J/^{o}C)
(M_C)w	Product of mass of water and its specific heat capacity (J/^{o}C)
$d\tau$	Sensible heat period for solar cooker
S	Energy absorbed by cooker plate [$F' \eta_o I A$]
ΔT	Temperature difference (^{o}C)

Abbreviations

SEBS	Solar energy-based systems
CPC	Compound parabolic concentrator
BIS	Bureau of Indian Standard
SBC	Solar box cooker
SS-SBC	Small scale SBC
SSH-SBC	Small scale hybrid-SBC
FOM	Figure of merit
SPC	Solar pressure cooker
TPP	Thermal performance parameters
STESS	Sensible thermal energy storage system
LTESS	Latent thermal energy storage system

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AUTHORSHIP CONTRIBUTIONS

The author solely have contributed to this work.

DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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