An Optimal Design of a Solar Cooker under Qassim Weather

Ahmed Ali Aldubayyan **, ‡, Mohamed Nejlaoui *, ****, Abdullah Ayed Alrwili**, ***

* Department of Mechanical Engineering, College of Engineering, Qassim University, Unaizah 56452, Saudi Arabia

**School of Water, Energy and Environment, Cranfield University, Cranfield MK43 0AL, UK

***Mechanical Engineering Department, Engineering College, Northern Border University, King Fahad Road Arar 92341, Saudi Arabia

**** Mechanical Engineering Laboratory, National Engineering School of Monastir, University of Monastir, Tunisia

(Ahmed.Aldubayyan@cranfield.ac.uk, m.nejlaoui@qu.edu.sa, abdullah.alrwili@cranfield.ac.uk)

‡ Corresponding Author; Ahmed Ali Aldubayyan, School of Water, Energy and Environment, Cranfield University, Cranfield MK43 0AL, UK, Tel: +44 7943 960723, Ahmed.Aldubayyan@cranfield.ac.uk

Received: 12.0.2023 Accepted:01.10.2023

Abstract- The Middle East, notably Saudi Arabia, faces an increase in the need for energy for cooking as a result of population expansion in both urban and rural areas. Traditional cooking requires a variety of resources, including petroleum, coal, wood for fires, and other biomass-based materials. All of which damage forests and accelerate climate change due to greenhouse gas emissions. As an alternative, Solar energy can be an inventive replacement for conventional energy sources for cooking. In this study, the design optimization, fabrication, and thermal evaluation of a solar cooking system was investigated. The optimal solar cooker design with the best thermal performance was found using the multi-objective colonial competitive method executed under Matlab. The optimal solar cooker design was fabricated and experimentally tested under the Qassim climate. A k-type thermocouples were used to measure the temperature of the inside pot and the absorber plate. It is noted that the obtained optimal results were in strong correlation with experimental and literature findings. Moreover, it is stated that the initial and second reflectors should be tilted at a position of 120 degrees for the highest solar cooker efficiency per day. It has also been demonstrated that the efficiency of the system is significantly affected by changing the insulator thickness from 0.002 to 0.05 m.

Keywords Efficiency, optimization, Algorithms, Renewable energy resources, Testing.

Nomenclature

List of symbols			
SOCOS	Solar cooking system	N	Day number
A_b	Bottom surface area of SOCOS	N_g	Number of glass covers
A_e	Edge surface area of SOCOS	T_a	Inside air temperature
A_{pot}	Area of pot	T_a	Ambient temperature
A_R	Reflector area	T_f	Food temperature
A_T	Absorber plate area	T_p	Absorber plate temperature
c_a	Specific heat of air	T_∞	Ambient air temperature
c_f	Specific heat of food	t	time
c_p	Specific heat of absorber plate	U_b	Bottom loss coefficient
F_m	Absorber plate efficiency factor	U_e	Edge loss coefficient
F_{R-c}	View factor of reflected radiation	U_t	Top loss coefficient
Gr	Grashof number	P_{rw}	Prandtl number of water
H_b	Beam component of solar radiation	U_O	Over loss coefficient

H_c	Solar radiation constant	Q_u	Useful energy in SOCOS
H_R	Reflected Solar radiation	**Greek abbreviations**	
H_T	Total solar radiation in SOCOS	α	Absorber Plate absorptance
h	Hour angle	β	SOCOS tilt angle
h_w	Wind heat transfer coefficient	η	SOCOS thermal efficiency
k_i	Thermal conductivity of insulation	ϵ_g	Glass cover emittance
k_{oil}	Thermal conductivity of oil	ΔT_f	Food temperature difference between end and beginning of test
t_s	Specific boiling time	Δt	Time to increase food temperature by ΔT_f
L	Altitude Angle	ϵ_p	Absorber plate emittance
L_i	Thickness of insulation	ρ	Reflectance of reflector
M_a	Mass of inside air	σ	Stefan-Boltzman constant
M_f	Mass of food	τ	Glass cover transmittance
MOCM	Multi-objective Colonial competitive algorithm	$\varphi i\,.\, i = 1.2$	First and second reflector tilt angle
M_p	Mass of absorber plate	δ	Declination angle
P_r	Prandtl number	SD	Search domain
Q_u	The useful energy	DEV	Design variables

1. Introduction

Cooking is one of the main domestic duties that demands energies for human nutriment. Energy sources support the consumption of various hydrocarbons (such as petroleum, firewood, charcoal, etc…) for food preparation. An important number of people in towns and villages continue to cook with firewood due to the higher price of petroleum-based items and electric power used for cooking [1]. The combustion of agricultural waste, fuel, or charcoal, farming represent a source of greenhouse gases [2]. Energetic specialists are becoming more aware for the negative effects of climate change as a result of consumption of polluting energies like petroleum, petroleum-based biomass, charcoal, etc. Due to the Sun's enormous promise, particularly in Saudi Arabia, a solar cooking systems (SOCOS) has become an incredibly tempting option. The main two kinds through which SOCOS might be distinct are boxed and concentrating versions [3]. While the box-type allows sunlight to penetrate a glass door immediately for food preparation, the concentrated version uses a reception container placed in the solar's ray-focusing concentrate ([4]; [5]). Tawfik et al. [6] conducted studies on tracking-type bottom convex mirrors in order to improve the heat transfer efficiency of a box-type SOCOS. Based on a photo-thermal coefficient of 0.165, they concluded that SOCOS can reach an efficiency of 42.5%. Yang et al. [7] developed SOCOS's computational frameworks in order to analyze the impact of thermal power via cylindrical polyamide covering. Yadav et al. [8] study of quantitative analysis of visibility resulted in recognizable warming graphs using warmth in symphony. Clement et al. [9] developed a design, fabrication, and thermal evaluation of a solar cooking system integrated with an Arduino-based tracking device and sensible heat storage (SHS) materials. They obtained a SOCOS efficiency ranged between 34.5 and 40.3%. Herez et al. [10] proved that box type SOCOS are easier to construct as well as more versatile than solar concentrated designs. In fact, with instances of intense sunlight, water temperatures of 100 °C can be reached while employing a box SOCOS to prepare meals. This sort of temperatures is adequate for cooking food while bringing waters to a boiling. The use of SOCOS for cooking at home is encouraged particularly in areas having abundant sunlight such as Saudi Arabia [10].

According to the quick development of software engineering, significant efforts have been taken to use such tools to increase the efficacy of SOCOS. The parametric study of the SOCOS performances has been covered extensively in the literature. Mbodji and Hajji [11] conducted a statistical investigation to ascertain how heat barriers and design variables (DEV) variability affect the SOCOS functioning. A quantitative parametric assessment regarding the SOCOS effectiveness was conducted by Badar et al. [12]. It is proven that doubling the cover glass increases SOCOS effectiveness. A box type SOCOS' thermal analysis was created by Verdugo [13]. The author looks into how Nigeria's erratic weather affects the development of SOCOS capabilities. To identify an environmentally favorable source, S.Z. Farooqui [14] created a computational parametric analysis of a SOCOS. When assessing the SOCOS's performance, heat leakage and glazing temperature were taken into account.

Despite the importance of the parametric analysis of SOCOS, certain literatures [15,16] have demonstrated that such analysis cannot address the mutual impact among all DEV. On the other hand, optimizing the DEV that influence the SOCOS performances received a lot of research attention. The Taguchi approach was used by Hosseinzadeh et al. [17] to determine the optimal set of DEV that affect SOCOS useable energy. The considered DEV are the vacuum's total strain and the absorber's emissions. Chatelaine et al. [18] evaluate the SOCOS performance utilizing the genetic algorithms. The developed strategy may forecast the plate temperature with a median absolute error of roughly 5%. Kahaer et al. [19] carried out a SOCOS dimensionally optimization by using the monitoring random experimentation method. The findings indicate that, a ratio of 2.66 (height to length ratio of SOCOS) provides the highest seeking effectiveness. Balachandran et al. [20] determine the most appropriate group of DEV for enhancing SOCOS productivity using the response surfaces approach. The considered DEV are the SOCOS panels location, quantity of glass coverings, and tilting mirrors orientation. The response surface method is also utilized by Wassie et al. [21] to investigate the effect of different reflectors on the performance of solar box cookers.

Numerous optimization strategies were used, as we've mentioned, to analyze and improve the SOCOS performances. The major drawback of other conventional optimization method is the difficulty to alternate between exploitation (convergence speed) and exploration (solution diversity) challenges [22–24]. In fact, by increasing the convergence speed, algorithm cannot explore all feasible solutions of the search space which degrades the population diversity and vice versa [22-24]. As an alternative, the MOCM was recently proposed as an effective method to optimize a wide range of engineering problems with the best compromise between convergence speed and solution diversity [25]. In fact, MOCM use the attraction and repulsion (AR) strategy during the search of solutions, in order to alternate between exploitation and exploration challenges [25]. For the best of our knowing, no research on applying MOCM for optimizing the SOCOS has been discussed in previous studies. The main objective of this paper is to develop an optimal design of the SOCOS by using the MOCM method. The optimal design will be fabricated and experimentally investigated under the Qassim weather in Saudi Arabia. The obtained results will be compared with several literature works.

2. Solar cooker structure

The SOCOS is made up of five basic parts, as shown in Fig. 1: the cooking box, the absorber plate, the insulation material, the glass covers and reflectors 1 and 2.

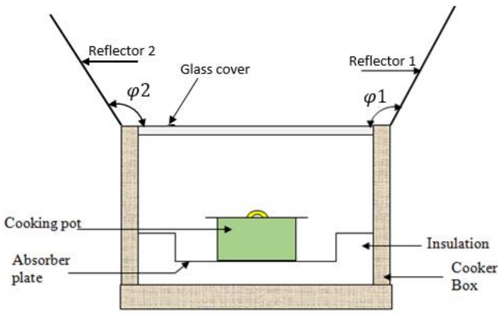


Fig 1. Schematic representation of a box type SCS

Energy from the sun traverses the layer of glass immediately and once it has been rebounded via the reflections. When travelling by the glazed covering, a considerable portion of the light which reaches it is absorbed.

3. Mathematical modelling of solar cooker

The thermodynamic formulas that control the function of the SOCOS are identified through the application of energy equilibrium to the various SOCOS parts. The syntax for those formulas is as follows [26]:

$$M_f\, c_f\, \frac{dT_f}{dt} + M_p c_p\, \frac{dT_p}{dt} + M_a\, c_a\, \frac{dT_a}{dt} = A_T F_m \left[H_T \alpha \tau^{N_g} - U_o\left(T_f - T_\infty\right)\right] \quad (1)$$

$$H_T \alpha \tau^{N_g}\left(A_T - A_{pot}\right) = M_f\, c_f\, \frac{dT_f}{dt} + M_p c_p \frac{dT_p}{dt} + M_a\, c_a \frac{dT_a}{dt} + \left[\mathrm{U_t}\left(\mathrm{A_T} - \mathrm{A_{pot}}\right) + U_b A_b + U_e A_e\right]\left(T_p - T_\infty\right) \quad (2)$$

Based on the heat transfer inside the pot, we can write [26]

$$M_a\, c_a\, \frac{dT_a}{dt} = U_t A_T \left(T_p - T_a\right) \quad (3)$$

The top loss coefficient is given by [26]:

$$\mathrm{U_t} = \frac{\sigma(T_p - T_\infty)(T_p{}^2 - T_\infty{}^2)}{(\epsilon_p + 0.00591 N_g h_w)^{-1} + \frac{2N_g + f - 1 + 0.133\epsilon_p}{\epsilon_g} - N_g} + \left\{\frac{N_g}{\frac{C}{T_p}\left[\frac{(T_p - T_\infty)}{(N_g - f)}\right]^e} + \frac{1}{h_w}\right\}^{-1} \quad (4)$$

Where

$$f = (1 + 0.089 h_w - 0.1166 h_w \epsilon_p)(1 + 0.07866 N_g)$$

$$C = 520(1 - 0.000051\beta_2) \quad For\ 0° < \beta < 70°$$

$$e = 0.43\left(1 - \frac{100}{T_p}\right)$$

The SOCOS total loss of heat ratio is given by [26]:

$$\mathrm{U_o} = \mathrm{U_t} + \frac{\mathrm{U_b}}{\mathrm{F_m}}\left(1 + \frac{\mathrm{A_e}}{\mathrm{A_b}}\right)$$
(5)

Where the edge loss coefficient is:

$$\mathrm{U_e} = \frac{(\mathrm{U_e A_e})}{\mathrm{A_T}} \quad (6)$$

The bottom Loss coefficient is:

$$\mathrm{U_b} = \frac{\mathrm{k_i}}{\mathrm{L_i}} \quad (7)$$

The overall thermal efficiency of the solar cooker is given by:

$$\eta = \frac{\mathrm{Q_u}}{\mathrm{H_T A_T}} \quad (8)$$

Q_u is the Useful energy, expressed by:

$$\mathrm{Q_u} = \mathrm{M_f\, c_f}\, \frac{\mathrm{dT_f}}{\mathrm{dt}} \quad (9)$$

For a SOCOS with mirror reflectors, the total solar radiation entering the cooker, H_T , include reflected solar radiation. This reflected solar radiation is noted H_R [26]:

$$\mathrm{H_R} = \rho\, \frac{\mathrm{A_f}}{\mathrm{A_T}} \mathrm{F_{R-c}} \cos\theta_t \mathrm{H_T} \quad (10)$$

$$F_{R-c} = \frac{c + R - s1}{2R} + \frac{c + R - s2}{2R} \quad (11)$$

$$s1 = (c^2 + R^2 - 2cR\cos\varphi 1)^2 \quad (12)$$

$$s2 = (c^2 + R^2 - 2cR\cos\varphi 2)^2 \quad (13)$$

C and R represent respectively the reflector width and the reflector height.

4. Design Optimization of SOCOS

It is shown from (Eq. 8) that the SOCOS efficiency is strongly dependent of many DEV, including the absorption plate area, reflectors dimensions, reflection tilt angles, insulating thickness. In follows, the effect of these DEV on the evolution of SOCOS efficiency has been developed.

4.1. Sensitivity of SOCOS efficiency to DEV variation

The variation of DEV (The reflector tilt angle, reflector surface area, the absorber surface area and insulator thickness) and how they have affected SOCOS efficiency are investigated. In fact, in each case, we vary only one DEV and the others considered as constant as presented in Table 1. The efficiency was calculated at every hour (between 8:00 am and 16:00 pm) and the average daily efficiency has been recorded.

Table 1. DEV of SOCOS [13,21]

DPs	values
Transmittance of the glass cover, τ_c	0.88
Thermal conductivity of plate, k_p(W/mK)	48.5
Number of glass cover	1
Ambient temperature, (°C)	24
Absorber emissivity, ε_p	0.17
The absorber plate's absorption capacity, α	0.95
Insulator thermal conductivity, k_i (W/m°C)	0.035
Absorber plate surface area, A_T (m^2)	0.16
First or second Reflector surface area, A_R (m^2)	0.15
Insulator thickness, L_i (m)	0.05
First or second Reflector tilt angle, $\varphi 1$ *or* $\varphi 2$ (°)	105

According to Fig.2, it is noted that the reflectors tilt angles have a great influence on the evolution of the SOCOS efficiency. In fact, by changing the reflectors tilt angles, the efficiency can vary between 42% and 74%.

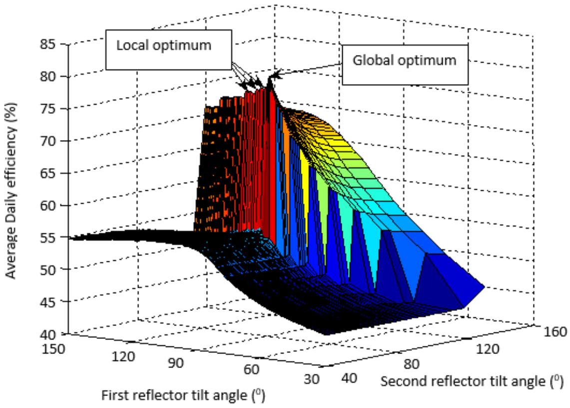


Fig 2. Evolution of SOCOS efficiency as function of reflectors tilt angle

This large variation in term of efficiency prove the high sensibility of the SOCOS efficiency to reflectors tilt angles. In fact, a small variation in the first or second reflector tilt angle contribute to a large variation of the solar cooker efficiency. Moreover, as function of first and second reflector tilt angles, we can find several local or global optimum in term of SOCOS efficiency as presented in figure 2.

On the other hand, the impact of the second reflector dimension on the evolution of the SCS efficiency has been presented in figure 3. In fact, the following figure illustrate the efficiency evolution as function of the second reflector's size (length and width). It is noted that the efficiency of the SCS is increased by increasing the reflector's size. In fact, the amount of solar energy reflected from the reflectors to the SCS box grows as the reflector surface area increases.

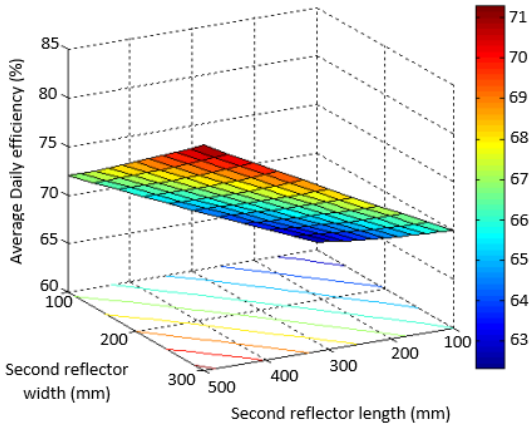


Fig 3. Efficiency evolution as function of second reflector dimensions

Fig. 4.a shows that as the absorber plate surface area grows, the energy efficiency also rises. This is because the amount of useful energy increases by increasing the absorber plate surface area. Moreover, Fig. 4.b shows the effect of the insulator thickness on the SOCOS efficiency. It is noted that the increase of insulation thickness leads to an increase in efficiency especially in the insulation thickness range of 0.002 to 0.01m. Moreover, the SOCOS's efficiency slightly increased as the insulation thickness increased from 0.01 to 0.05 m. In fact, the increase of thermal insulation thickness would reduce heat losses and enhance the SOCOS's efficiency

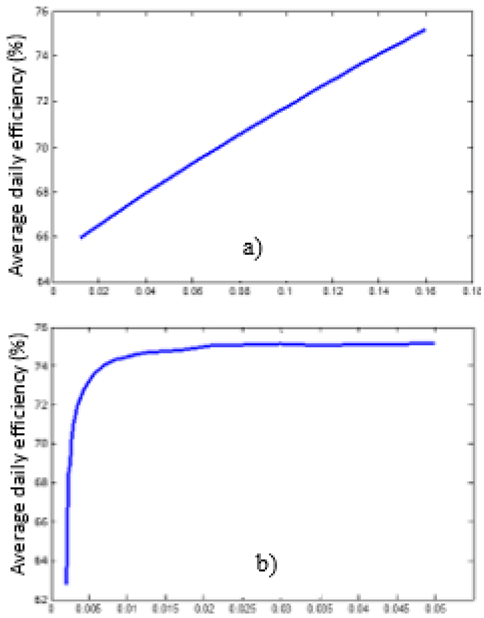


Fig 4. Efficiency evolution as function of: a) Absorber surface area b) insulator thickness

It is clear that a small variation of the DEV influences the efficiency of the SOCOS. Thus, it is important to find the optimal DEV through a design optimization of the box type SOCOS

4.2. Formulation of the optimization problem

The best SOCOS DEV combination set that maximizes the energetic efficiency (fitness function) is sought after. The variable DEV are defined in specific search domains (SD) as given in table 2. The formulation of the optimization problem can be given by:

$$\begin{cases} Maximize\ \eta \\ Under\ constraint: \\ \quad DEV \in SD \end{cases} \tag{14}$$

Table 2. SD of the DEV

DEV	SD
First and Second Reflector length, $Lr1$ *and* $Lr2$ (m)	[0.1, 0.5]
First and Second Reflector width $lr1$ *and* $lr2$ (m)	[0.1, 0.3]
First and Second Reflector tilt angle, $\varphi1$ *and* $\varphi2$ (°)	[30, 160]
Absorber plate surface area, A_T (m2)	[0.01, 0.16]
Insulator thickness, L_i (m)	[0.002,0.05]

The MOCM, will be utilized to resolve the aforementioned optimization design problem.

4.3. MOCM approach

Recently, Bilel et al. [25] developed a stochastic MOCM that was influenced by imperialist competition. This algorithm integrates the attraction and repulsion operators in order to obtain the best compromise between convergence and diversity. These operators are guaranteed by the multi-points crossover and the random replacement mutation concepts [25]. Moreover, the fast non-dominated sorting approach is used to find the non-dominated solutions forming the Pareto front. Figure 5 shows the flowchart of the MOCM. The MOCM begins with a generation of an initial population randomly. Each element of the population is a country. The most powerful country is called “imperialist”. The remaining countries are considered as “colonies”. The normalized cost of the nth imperialist is given by [25].

$$C_n = \max_i \{Cost_i\} - Cost_n \tag{15}$$

$$Cost_n = \sum_{j=1}^{r} \frac{\left|f_{j,n} - f_j^{best}\right|}{\left|f_j^{max} - f_j^{min}\right|} \tag{16}$$

where $Cost_i$ and $Cost_n$ are the cost of the ith and the nth imperialist, respectively. r is the number of objective functions and $f_{j,n}$ is the value of the objective function j for the imperialist n. f_j^{max} and f_j^{min} are maximum and minimum values of the objective function j in each iteration, respectively. f_j^{best} is the minimum or the maximum of the objective function according to the optimization process.

The normalized power of nth imperialist is calculated as:

$$P_n = \left| \frac{C_n}{\sum_i C_i} \right| \tag{17}$$

Due to imperialists’ powers, the colonies of the initial population are divided among them to form the initial empires. Each initial empire is composed of one imperialist and several colonies.

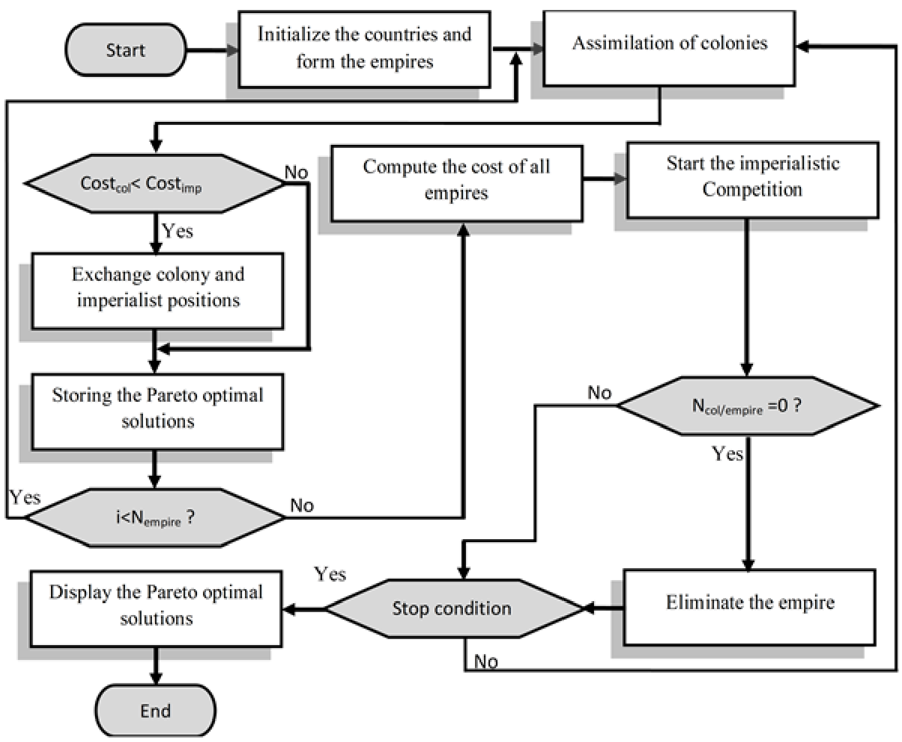
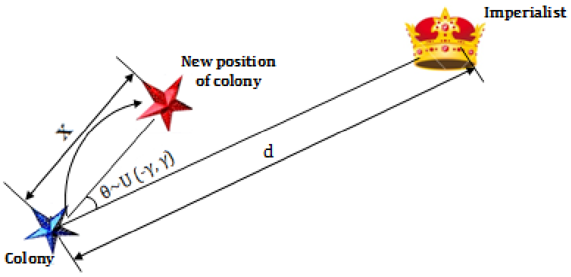
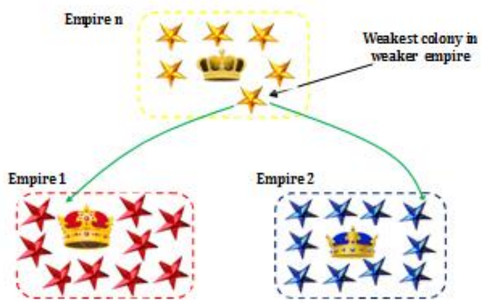


Fig 5. MOCM flowchart

After forming the initial empires, the colonies start moving towards their relevant powerful imperialist (Figure 6a). In this movement, θ and X are numbers generated uniformly $X \sim U(0,\beta \times d)$ and $\theta \sim U(-\gamma,\gamma)$. d is the distance between the imperialist and the colony and β must be greater than 1. γ is a parameter representing the direction deviation[25,27]



a)



b)

Fig 6. Enhancement of countries characteristics; a) Assimilation b) competition

During the imperialists competition all empires, based on their power, try to acquire the weakest colonies of other weak empires (as depicted in Figure 6b). The weakest empires lose their colonies and collapse. The MOICA algorithm stops when all the weak empires collapse except the powerful one [25].

5. Results of the Design Optimization

Figure 7 exhibits the optimization results as well as the evolution of the optimal SOCOS efficiency as function of iteration numbers.

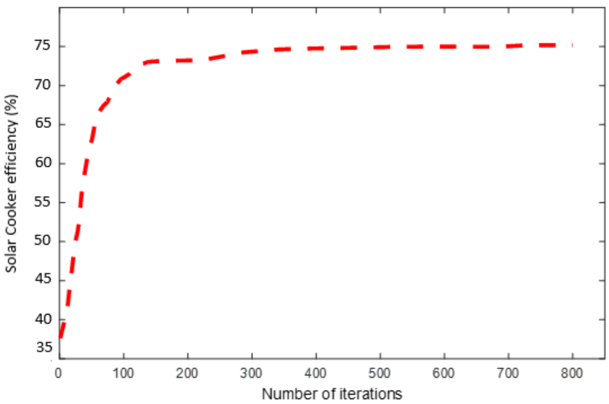


Fig 7. Optimization results

It is crucial to retain that the MOCM required eight hundred trials to find the optimal SCOS solution. The aforementioned design optimization represents the set of suitable DEV offering the highest possible SOCOS efficiency. Information about the optimal DEV is detailed in Table 3.

Table 3. The optimal DEV

Optimal DEV	value
First and Second Reflector lengths, $Lr1$ and $Lr2$ (mm)	500
First and Second Reflector width $lr1$ and $lr2$ (mm)	300
First and Second Reflector tilt angle, $\varphi 1$ and $\varphi 2$ (°)	120
Absorber plate surface area, A_T (m^2)	0.16
Insulator thickness, L_i (m)	0.05
SOCOS maximum Efficiency (%)	74.93

The optimal SOCOS construction permits a highest efficacy of 74.93%, as shown in the table above. In Fig. 8, we show the evolution of the SOCOS efficiency during 10/2/ 2023 (from 8:00 to 16:00h). The same figure illustrates also the evolution of SOCOS efficiency as function of first and second reflectors time angles. It is noted that the maximum efficiency is obtained at midday and with 1200 for both first and second reflectors tilt angles. To ensure the maximum hourly efficiency, the first and second reflector tilt angles should be 90 and 1500, respectively, at 8 am. After that, we should rotate both reflectors tilt angles by 7.50 degrees clockwise every hour. At 4 pm, the tilt angles of the first and second reflectors become 150 and 90^0, respectively.

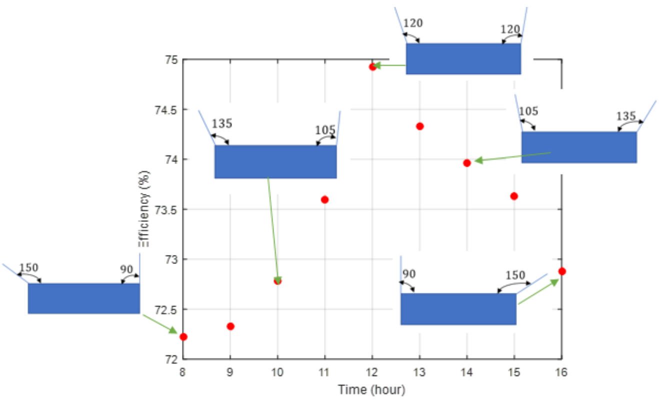
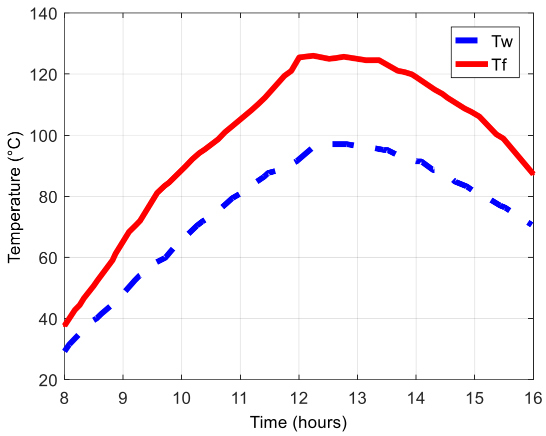
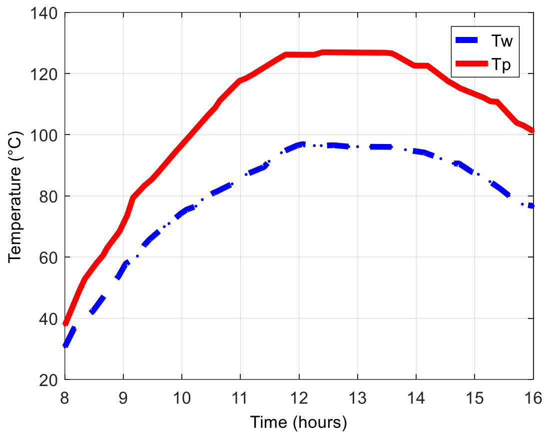


Fig 8. SOCOS's optimum efficiency-to-time tradeoff

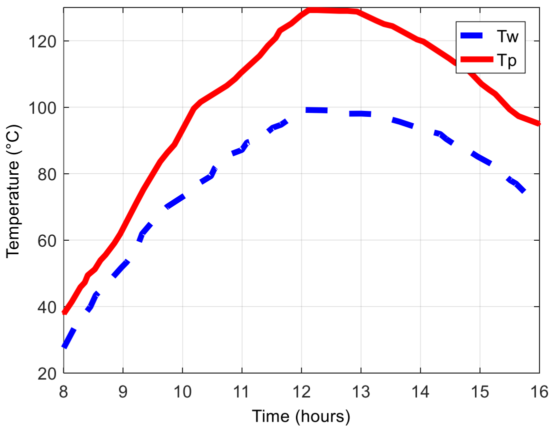
The same optimization attempt was carried out on February 15, 2023, and February 20, 2023. Comparable outcomes in regards to SOCOS efficiency and optimal DEV were found. The efficiency values obtained on 15 and 20 February, respectively, are 74.94% and 74.97%, with identical optimized DEV (Table 3). For more detail, Figure 9 illustrates the evolution of plate and water temperatures on February 10, 15, and 20, 2023. It is noted that the behavior of the water and plate temperatures over time is comparable. Moreover, the water's temperature is lower than the plate ones. This is due to the energy loses of the SOCOS. Furthermore, the reached plate temperatures were between 120°C and 133 °C. The water temperature will range from 80°C to 96°C.



a)



b)



c)

Fig 9. Evolution of water and plate temperatures;

a) 10/2/ 2023 b) 15/2/ 2023 C) 20/2/ 2023

6. Experimental Setup and procedure

The SOCOS was constructed utilizing the components shown in table 4 depending on the optimal DEV.

Fig. 10 displays the manufactured SOCOS in full view.

The experimental tests on the SOCOS were carried out during the successive days 10, 15, and 20, February 2023. Each experiment starts from 8 am to 16 pm in the afternoon. Readings were taken every 30 minutes' time interval to observe changes in temperature and also the variation of the SOCOS efficiency. The SOCOS was placed in an open space which is subjected to the sun light all the time in the college of engineering at the university of Qassim, Saudi Arabia (26° 5' 38.7168" N). Two K type thermocouples were installed at different location on SOCOS. These locations are: water inside the pot and the absorber plate.

Table 4. SOCOS components

Item	Material	Item	Material
Absorber plate	Mild steel	Reflector 1	Glass
External box	Wood	Reflector 2	Glass
Transparent cover	Glass	Insulator	Glass wool

Fig 10. The fabricated SOCOS

6.1. Experimental results

The obtained experimental results of plate temperature, are illustrated in Figure 11. For comparison reasons, we present also in the same figure the optimization results of plate temperature.

Figure 12 illustrate the obtained experimental and optimization results in term of water temperature.

6.2. Comparison between optimization and experimental results

The relative error between optimal and experimental results can be given by [28,29]:

$$E = \left| \frac{P_{exp} - P_{opt}}{P_{exp}} \right| \quad (18)$$

Where P_{exp} *and* P_{opt} represent the SOCOS performances (Temperature or efficiency) obtained experimentally and by optimization, respectively.

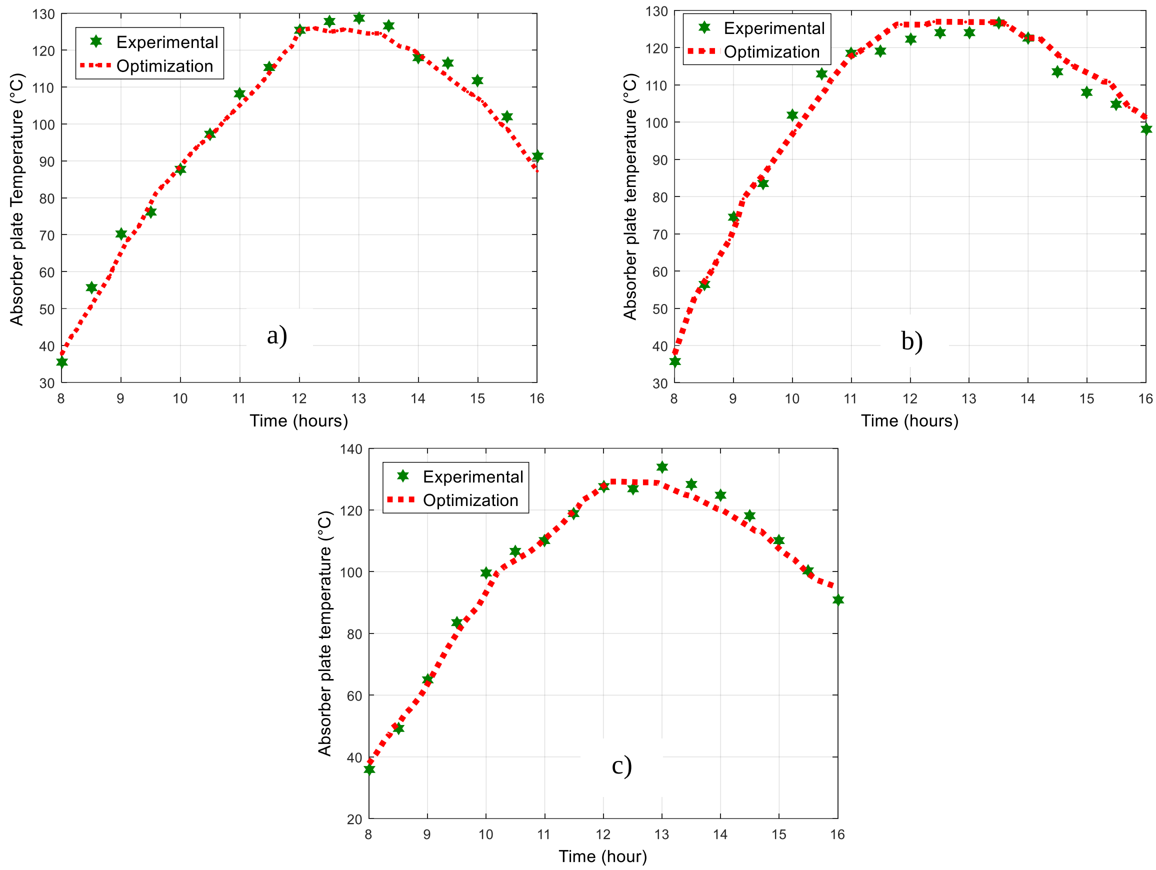


Fig 11. Plates temperatures acquired through optimization and experimentation

a) 10/2/ 2023 b) 15/2/ 2023 c) 20/2/ 2023

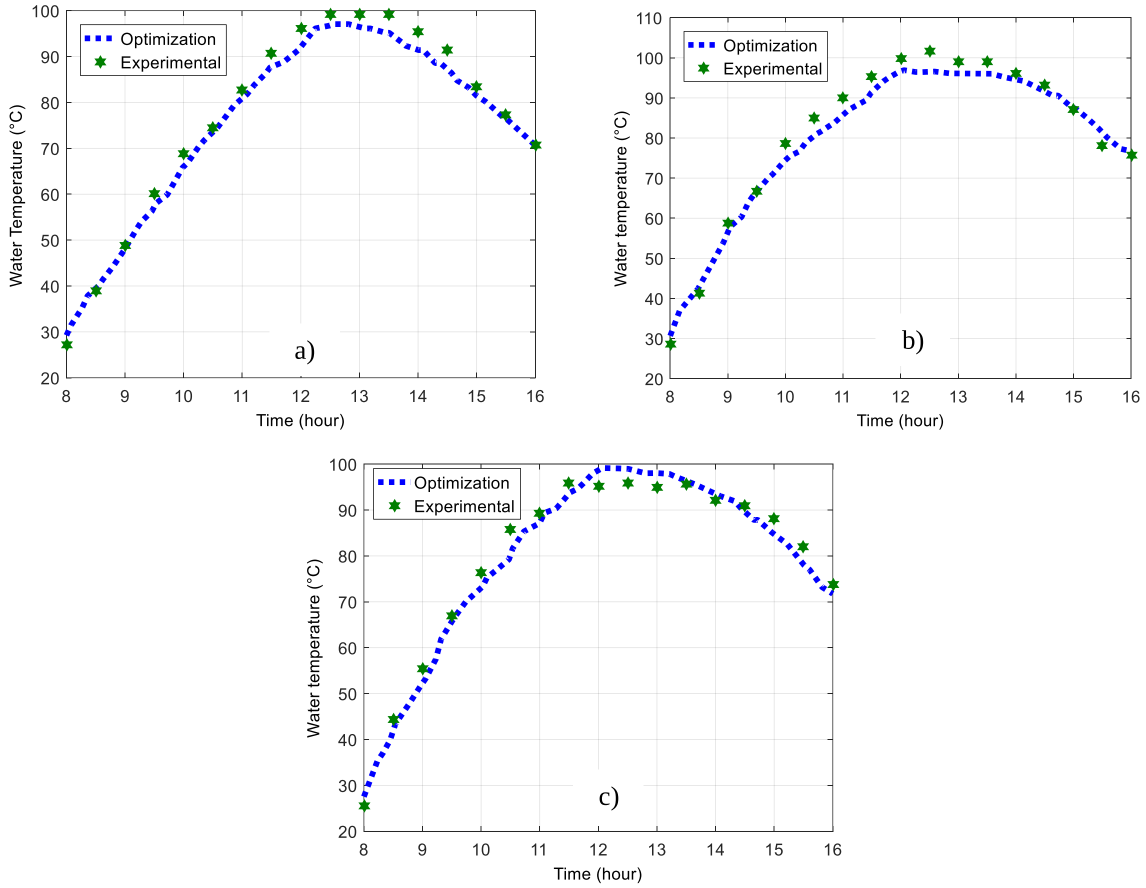


Fig 12. Water temperatures acquired through optimization and experimentation

a) 10/2/ 2023 b) 15/2/ 2023 c) 20/2/ 2023

The error between experimental and optimal results in terms of plates and water temperatures are summarized in Table 5. Moreover, Table 6 compares the efficiency acquired through optimization to the ones acquired through experimentation.

Table 5. Comparison results in terms of temperatures

Date	Tempe-rature	Maximum E (%)	Average E (%)
10/2/2023	Tp (°C)	5.76	3.87
	Tw (°C)	5.33	3.64
15/2/2023	Tp (°C)	4.88	3.32
	Tw (°C)	5.76	3.78
20/2/2023	Tp (°C)	6.44	4.18
	Tw (°C)	5.21	3.52

Table 6. Comparison results in terms of efficiency

Date	Optimization	Experimental	E(%)
10/2/2023	74.93	77.56	3.5
15/2/2023	74.94	77.32	3.2
20/2/2023	74.97	77.12	3.03

From Tables 5 and 6, one can note that the relative error between SOCOS performances (efficiency and temperature) obtained experimentally and those founded with optimization do not exceed 4.5 %. Therefore, the obtained results are in agreement, which validates the developed optimization through MOCM and the adopted hypotheses.

6.3. Comparison of the obtained findings with literature

To confirm the efficacy of the proposed SOCOS, their performances are also compared with the literature ones in Table 7. This comparison has been conducted in terms of maximum SOCOS efficiency and the efficiencies' error to experimental results. It is noted from Table 7, that the proposed SOCOS provides the maximum efficiency value compared to literature ones and the minimum error to experimental findings. This comparison proves the consistency of the proposed SOCOS and the importance of the adopted design optimization methodology.

Table 7. Comparison of SOCOS efficiency with literatures

Performance	Maximum efficiency (%)	E(%)
Nejlaoui et al. [15]	59.88	22.35
Clement et al. [9]	40.3	47.7
Wassie et al. [21]	67.7	12.21
Kakar et al. [16]	31.58	59.05
This work	74.97	3.03

Several foods have been cooked using the proposed SOCOS. The preparation times for various items are listed in Table 8. At least twice during these investigations, The SOCOS was opened in order to remove the pots containing the fully cooked food.

Table 8. The period of time needed for cooking certain foods

Food	Weight (g)	Cooking time (hours)
Macaroni	250	1h 33min
Rice	250	1h 21min
Potatoes	250	1h 13min
Eggs (three)	----	1h 09min
Meat	250	2h 12min
Chicken	250	1h 48min

Figure 13 shows photos of a pot of rice as an example of food that has been cooked both before and after cooking.

a)

b)

Figure 13. A pot of cooked rice by using SOCOS
a) Before cooking b) After cooking

The optimized and test results above stated that small SOCOS might be used instead of electrically or gas-powered cookers in the Qassim region of Saudi Arabia in order to reduce the amount of both gasoline and electricity utilized there. Moreover, the proposed SOCOS can replace the traditional cooking method with firewood in towns and villages. The proposed SOCOS can represent an environmentally friendly alternative to the significant reliance on fuels and anticipated environmental harm (climate change, release of greenhouse gases and deforestation)

7. Conclusion

The conceptual optimization, fabrication and experimental investigation of a SOCOS were provided in this paper. The sensitivity of the SOCOS efficiency to various DEV, such as insulation depth, absorption plate area, reflectors tilt angles, and reflectors sizes, was examined. The MOCM, recently published in literature, was used to carry out the optimization phase. The optimal results represented the best set of DEV that would maximize the energetic efficiency of the SOCOS. Based on the identified optimal DEV, a SOCOS experimental apparatus has been built and tested in Saudi Arabia at Unaizah-Qassim. The comparison results revealed a strong correlation between the optimized and experimental results with a relative error less than 5%. It is noted that the highest possible SOCOS efficiency can be reached at midday with 120^0 for both first and second reflectors tilt angles. Furthermore, it was also noted that the SOCOS efficiency was significantly impacted by a rise of insulating thicknesses from 0.002 to 0.01 m. However, the SOCOS efficiency show a slight enhancement as the insulating depth increased from 0.01 to 0.05 m.

The findings of this study demonstrated that the suggested SOCOS may successfully replace conventional cooking techniques, which pose a major threat to both people and the environment. In this work, we have considered the DEV at their nominal values (no variations in manufacturing, geometry, and material properties). In a future work, the robust optimization of the SOCOS under uncertain DEV will be investigated.

References

1. K. E. Okedu and M. Al-Hashmi, “Assessment of the Cost of Various Renewable Energy Systems to Provide Power for a Small Community: Case of Bukha, Oman,” Int. J. SMART GRID, vol. 2, 2018, No.3, pp.172-182.
2. Polamarasetty P Kumar, Ramakrishna S S Nuvvuls, Muddala Venkatesh, M Vinay Kumar, A Review On the Estimate Solar PV Cell Variables for Efficient Photovoltaic Systems, International Journal of Smart Grid-ijSmartGrid, 7, no. 3, 2023
3. A. Aquilanti, S. Tomassetti, G.Coccia, M. Muccioli, G. D. Nicola, “Experimental characterization and performance comparison of four prototypes of panel solar cooker for low to high sun elevations”, Journal of Cleaner Production, DOI:10.1016/j.jclepro.2023, Vol. 390, 136158.
4. B. Najlaoui, A. Alghafis, M. Nejlaoui, “Robust design of a low cost flat plate collector under uncertain design parameters”, Energy Reports, DOI: 10.1016/j.egyr.2023.09.039, Vol 10, pp 2950-2961.
5. Y. Iwasaki, Y. Kazuto, K. Ikeda, and T. Goto, “A Basic Study on Electricity Demand for Energy Management,” in 10th International Conference on Renewable Energy Research and Application (ICRERA), pp 301–304, 2021.
6. M. A. Tawfik, A A Sagade, R. P. Behnke, H. M. El-Shal, W. E. Abd Allah, “Solar cooker with tracking-type bottom reflector: An experimental thermal performance evaluation of a new design”, Solar Energy; DOI: 10.1016/j.solener.2021.03.063, Vol. 220, pp 295-315.
7. X. Yang, D. Niu, M. Chen, K. Wang, Q. Wang, X. Xu, “An Operation Benefit Analysis and Decision Model of Thermal Power Enterprises in China against the Background of Large-Scale New Energy Consumption”, Sustainability, DOI: 10.3390/su12114642, Vol. 12, 4642.
8. V. Yadav, Y. Kumar, H. Agrawal, , A. Yadav, “Thermal Performance Evaluation of Solar Cooker with Latent and Sensible Heat Storage unit for Evening Cooking”, Aust. J. Mech. Eng DOI: 10.1080/14484846.2015, Vol. 15, pp 93–102.
9. A. Clement, E. Clinton, “Design, fabrication and thermal evaluation of a solar cooking integrated with tracking device and sensible heat storage materials”, Frontiers in energy research, DOI: 10.3389/fenrg.2022.821098, Vol.10, pp 1-13
10. A. Herez, M. Ramadan, M. Khaled, “Review on solar cooker systems: economic and environmental study for different Lebanese scenarios”, Renew Sustain Energy Rev, DOI: 10.1016/j.rser.2017.08.021, Vol. 81, pp. 421-432.
11. S. Batchelor, M.A.R Talukder, M.R. Uddin, S.K. Mondal, S. Islam, R.K. Redoy, R. Hanlin, M.R. Khan, “Solar e-Cooking: A Proposition for Solar Home System Integrated Clean Cooking”, Energies, DOI: 10.3390/en11112933, Vol.11, 2933.
12. A. W. Badar, S. A. Zaryab, Z. A. Abedin, M. Y. Khan, “Performance Modeling and Parametric Analysis of a Double Glazed Solar Oven”, Journal of Clean Energy Technologies, DOI: 10.7763/JOCET. 2016.V4.277 Vol. 4, No. 3.
13. A.S. Verdugo, “Experimental analysis and simulation of the performance of a box-type solar cooker, Energy for Sustainable Development”, DOI: 10.1016/j.esd.2015.09.006, Vol. 29, pp 65-71.
14. S. Z. Farooqui, “Determination of Performance Measuring Parameters of an Improved Dual Paraboloid Solar Cooker”, International Journal of Photoenergy, DOI: 10.1155/2017/9459531, Vol. 12, pp 1-13.
15. M. Nejlaoui, A. Alghafis, H. Sadig, “Design Optimization and Experimental Validation of Low-Cost Flat Plate Collector Under Central Qasssim Climate”, J. Appl. Comput. Mech., DOI: 10.22055/JACM.2020.34932.2515. Vol. 7, pp 811–819.
16. M. A. Kakar, J. K. Kasi, A. K. Kasi, M. Bokhari, M. Latif, M. Ayaz, “The Efficiency of a Solar Cooker in Pakistan’s Quetta Region”, Pol. J. Environ. Stud. DOI: 10.15244/pjoes/95034, Vol. 28, pp 4213-4220.
17. M. Hosseinzadeh, A. Faezian, S. M. Mirzababaee, H. Zamani, “Parametric analysis and optimization of a portable evacuated tube solar cooker”, Energy, DOI: 10.1016/j.energy.2019.116816, Vol. 194, 116816.
18. T. Chatelain, D. Mauree, S. Taylor, O. Bouvard, J. Fleur y, L. Burnier, A. Schüler, “Solar cooking potential in Switzerland: Nodal modelling and optimization, Solar

Energy, DOI:10.1016/j.solener.2019.10.071,Vol. 194, pp 788-803.

19. Y. Kahaer, N. Tashpolat, Q. Shi, S. Liu, "Possibility of Zhuhai-1 Hyperspectral Imagery for Monitoring Salinized Soil Moisture Content Using Fractional Order Differentially Optimized Spectral Indices", Water DOI: 10.3390/w12123360, Vol.12, 3360.
20. S. Balachandran, J. Swaminathan, "Advances in Indoor Cooking Using Solar Energy with Phase Change Material Storage Systems". Energies, DOI: 10.3390/en15228775, Vol.15, 8775.
21. H. M. Wassie, M. Z. Getie, Mulat S. Alem, T. B. Kotu, Z. M. Salehdress. "Experimental investigation of the effect of reflectors on thermal performance of box type solar cooker". Heliyon, DOI: 10.1016/j.heliyon.2022.e12324 Vol. 8, 12, e12324
22. M. Nejlaoui, "Multi-objective enhanced imperialistic competitive method for multi-criteria engineering issues", International Journal of Computer Applications in Technology, DOI: 10.1504/IJCAT.2022.129384, Vol. 69, No. 4
23. N. Mohamed, N. Bilel, A.S. Alsagri, "A multi-objective methodology for multi-criteria engineering design", Appl Soft Comput, DOI: 10.1016/j.asoc.2020.106204., Vol. 91, 106204.
24. B. Najlawi, , M. Nejlaoui, , Z. Affi, , L. Romdhane, "An improved Imperialist Competitive Algorithm for Multi-Objective Optimization", Engineering Optimization, DOI: 10.1080/0305215X.2016.1141204, Vol. 48, pp 1823-1844.
25. N. Bilel, N. Mohamed, A. Zouhaier, R. Lotfi, "An efficient evolutionary algorithm for engineering design problems". Soft Computing, DOI: 10.1007/s00500-018-3273-z, Vol. 23, pp 6197-6213.
26. H. Terres, A. Lizardi, R. López, M. Vaca, S. Chávez, "Mathematical Model to Study Solar Cookers Box-Type with Internal Reflectors", Energy Procedia, DOI: 10.1016/j.egypro.2014.10.150. Vol. 57, pp 1583-1592.
27. A. Yousfi, T.Allaoui, and C.Abdelkader, " Power quality improvement based on five-level shunt APF using sliding mode control scheme connected to a photovoltaic" ,Int. J. Smart Grid ijSmartGrid 1, 9, 2017
28. A. M. Colak, and O. Kaplan, "A review on the efficiency increment in a power system using smart grid technologies", In 2021 9th International Conference on Smart Grid (icSmartGrid), pp. 192-196, June 2021.
29. S. M. H. Zanjani, H. Shahinzadeh, A. B. Oskui, W. Yaïci, M. Longo, and S. M. Zanjani, "Performance Assessment of Heat Pump and Solar Thermal Heating with Seasonal Storage Systems for Smart Microgrid Research Center Building at IAUN," in 2022 10th International Conference on Smart Grid (icSmartGrid), , pp. 345–350, 2022.