Design and Performance Evaluation of an Enhanced Solar Thermal Collector

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Abstract: This research aims to design and analyze a Scccs2 solar collector with a convex front surface and a corrugated absorber surface that reflects the incident solar radiation via mirrors. The design features a convex front surface that increases the angle of solar radiation capture, while a wavy and convex absorber surface increases the surface area exposed to the sun. In addition, reflective mirrors are used to direct solar radiation to copper tubes mounted above the absorber surface, increasing the efficiency of the Scccs2 solar collector. The new geometry significantly increases the efficiency of the Scccs2 solar collector in converting solar energy into thermal energy.The testing also demonstrates the effect of adding the absorber surface and tubes in a wavy - convex shape on the performance of the Scccs2 collector. To increase the collector's ability to retain thermal energy, two tanks (B1-B2) are installed inside the collector. Scccs2 records (Tout= (65-95) °C, B2= (45-85) °C) for the period from November 2024 to June 2025. The Scccs2 model is capable of operating in partly and completely cloudy weather. In partly cloudy weather, Scccs2 records (Tout= 70°C, B2= 50°C). In completely cloudy weather, it records (Tout= 49°C, B2= 32°C).

1 INTRODUCTION

In recent years, the globe has turned to the study of solar energy as an alternative energy source, turning sun rays into heat. Solar energy is clean, does not harm the environment, and can be utilized indoors. Scientists and researchers must use this energy to develop models and technologies.

In the Middle East, the sun's rays are strong where the Arab country is located between the equator and latitude (37), and between longitude (17) west longitude of Greenwich (60) east of Greenwich, hence the need for energy has grown [1].

Solar energy is one of the most significant types of renewable energy since it uses the sun's radiation to carry heat and light sources; this energy form may be used in a variety of applications [2]-[6].

Solar energy may be utilized for water heating; a solar heater can use sun irradiation to generate hot water [6], [7].to make a substantial contribution to ecologically friendly energy sources, solar-poared heaters must finally demonstrate a positive energy balance throughout the duration of their lives. The industry may lessen its environmental effect and ensure that clean energy production coexists happily with environmental protection by including ecological considerations into the design of solar heaters [8], [9]. Solar water heaters are utilized as auxiliary systems to decrease the consumption of conventional fuel by preheating water in industrial and home sectors [10].

2 EXPERIMENTAL WORK

2.1 Solar Collector Design and Materials Used

All industrial components are inspected and tested, and the new engineering prototype of the Scccs2 solar water heater is put into operation after being exposed to direct solar radiation.

Scccs2 Fabrication Process; The following tools and materials are used to build the new Scccs2 design:

Copper pipe (a diameter of 0.0095cm and a length of 12m), A plastic hose, valves to control the speed of water flow and matt black paint, Mercury thermometer, electronic thermometer and Graduated glassware, 2 galvanized iron cylindrical tanks with a capacity of 3L (diameter 0.098m, height 0.4m, and thickness 0.003m), Iron plate rolled into a convex sine wave shape (length 1.55m, width 0.6m, thickness 0.002m) for manufacturing the absorber surface of Scccs2, Transparent glass panels (2 pieces (length 0.64m, width 0.24m, thickness 0.003m) & 2 pieces (length 0.64m, width 0.415m, thickness 0.003m)), Reflecting mirrors (length 0.1m, width 0.04m, thickness 0.002m) are fixed on the absorber plate to reflect solar radiation towards copper tubes (a diameter of 0.0095 cm and a length of 12 m) fixed 5 cm above the mirrors, Aluminum clips [11]. (length 0.05 m) to fix the copper tube on the absorber plate and Iron plate for the construction of the Scccs2 structure:

1) Two side panels (length 0.6 m, width 0.25 m, thickness 0.002 m), One rear deck (length 1.15m, width 0.6m, thickness 0.002m) and two side ribs (length 0.25m, thickness 0.002m).
2) Two roof and base panels (Straight rear rib (length 1.15m, thickness 0.002m) & convex front rib (length 1.12 m, thickness 0.002m)).

2.2 Solar Collector Scccs2 Manufacturing

Iron sheets with a thickness of 0.002m and different areas are used to fabricate the Scccs2 structure. The structure is in the shape of a parallelogram, as shown in Figure 1. The front surface of the collector is designed as a convex shape. The convex-wavy absorption surface is fixed inside the collector structure on the convex side, 0.09 m from the convex edge. The absorption surface of the solar collector is an iron sheet (1.55m long, 0.6m wide and 0.002m thick). Reflective mirrors are fixed on it. A copper tube (0.0095 m in diameter and 12 m long) is fixed in a Z-shaped path [1], [12] above the absorption surface (at a distance of 0.05m) using aluminum brackets. Therefore, the path of the copper tube is similar to the path of the absorption plate (wavy-convex) to match the new geometric design of the collector. To increase the absorption of solar radiation and raise the efficiency of the collector, the copper tube, Two tanks (B1, B2), and the visible parts of the absorption plate are painted in matte black, as shown in Figure 1.

In Figure 2, An air chamber is added behind the absorber to act as a thermal insulator, preventing thermal energy loss from the rear surface of the collector and helping to conserve the heat gained. The Scccs2 is manufactured using steel sheets. The dimensions of the collector's side panels are (0.6 m long, 0.25 m wide and 0.002 m thick). The dimensions of the rear deck panel are (1.15 m long, 0.6 m wide and 0.002 m thick). As for the collector roof and base, the straight rear side is 1.15 m long, and the convex front side is 1.12 m long. The center of convexity is 0.5 m from the center of the rear side. The two side sides are 0.25 m long, from the rear side to the ends of the convex side. Lead-brazing and electric welding is used to assemble the Scccs2 body parts in local fabrication workshops.

Figure 1: The manufacturing steps of Scccs2, and the installation location of the absorber plate and copper tube.

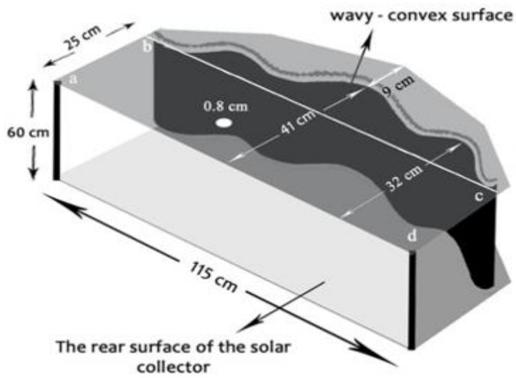

Figure 2: The structure of the collector, the absorption surface, and the buffer chamber.

2.3 The Insulating Room

The engineering design of the Scccs2 collector includes an air room between the absorber surface and the back of the collector. This room is tightly sealed to take advantage of the global warming phenomenon effect. The benefit of this chamber is that it prevents the loss of thermal energy from the back of the collector (due to the global warming effect and thermal balance within the room), instead of using expensive and environmentally harmful thermal insulators when they deteriorate. Figure 3 shows the dimensions of this room and the location of the absorber surface.

2.4 Convex Front Surface and Absorption Surface (Wavy-Convex) to Scccs2

In the new Scccs2 engineering model, the front surface is designed in a convex shape to increase the solar radiation capture angle and align with the horizontal movement of the sun. This eliminates the need to rotate the Scccs2 solar collector to be perpendicular to the sun, as it is demonstrated in this research. To increase the absorbing surface area, it is designed in a wavy, convex shape. Reflective mirrors (0.1 m long, 0.04 m wide and 0.002 m thick) are installed on the absorbing surface to reflect the incident solar radiation toward the copper pipe. This increases the amount of thermal energy inside the collector, thus increasing the water temperature. The copper pipe (diameter 0.0095m, length 12m) is installed 0.05 m above the absorbing surface and adopted the wave-like shape of the absorbing surface. Figure 3, shows the stages of manufacturing the absorber surface (length 1.55 m, width 0.6 m, thickness 0.002 m). Using a metal bending machine, the absorber surface resembles a sine wave, with three peaks and four concave surfaces.

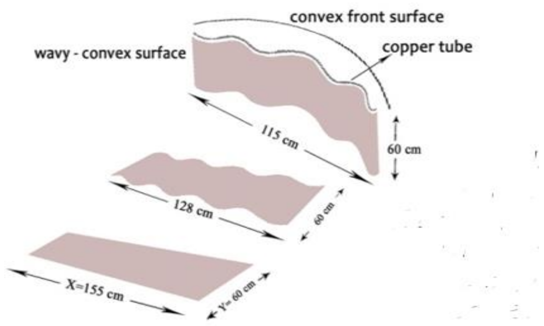

Figure 3: Schematic diagram of the measurements and manufacturing stages of the absorbent surface.

The Scccs2 solar collector's engineering design is capable of capturing and retaining thermal energy (Fig. 4), raising the temperature of the water passing through the copper tube and tanks (B1, B2). Two tanks (B1, B2) (3L capacity, 0.098m diameter, 0.04m height, and 0.002m wall thickness) are installed inside Scccs2 on the edges of the absorbent surface. B1 receives the external tank water; while B2 collects the usage water coming from the collector.

To take advantage of the global warming effect, a transparent glass cover (thickness of 0.003m) is placed on the convex front surface of the Scccs2, making the solar collector as shown in Figure 5.

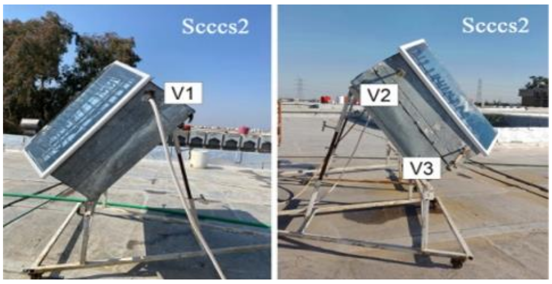

Figure 4: Shows the locations of valves V1, V2, and V3 in Scccs2.

Figure 5: The finish shape of the Scccs2.

In Basra; in summer, the solar collector is perpendicular to the sun at 15° with the horizon, and 45° in winter [1], [11] - [13]. The Scccs2 does not need to be rotated horizontally to be perpendicular to the sun, due to the convex of the front surface and the convex and waviness of the absorber surface; this is one of the advantages of this model.

Measuring Instruments; Mercury and Electronic Thermometer & AWOS Solar Radiation Meter.

- Use a mercury thermometer to calibrate an electronic thermometer and measure temperatures.
- The electronic thermometer is locally manufactured to accurately measure temperature and humidity. It can measure

more than one temperature simultaneously, saving time and effort.

- An automatic weather station (AWOS) at Basra International Airport measures atmospheric elements, including solar radiation.

3 RESULTS AND DISCUSSION

3.1 Solar Collector Efficiency in Different Weather Conditions

The Scccs2 solar collector is tested under different weather conditions using two testing methods to determine the efficiency of the collector's engineering design.

Vertically; the collector's angle of inclination relative to the horizon is fixed in summer or winter, then the collector is rotated horizontally to be perpendicular to the sun every hour during daytime operation. The other method is to stabilizing the collector horizontally in the direction it faces the sun at 11:00 a.m.

The collector Scccs2 is supplied with water via valve V1, which passes through tank B1. The water then passes through a copper pipe, reaching the end of the pipe. The copper pipe branches into two branches: The first branch connects to valve V2 to record the water temperature (Tout). The second branch connects to tank B2, which is the water collection tank (Ttank), and then the water comes out from B2 through valve V3 to record the water temperature (Ttank). After testing the Scccs2 during daylight hours (from 9:00 a.m. to 2:00 p.m. for the months of November 2024 to June 2025), the results are recorded under various weather conditions, using the two previous examination methods, the results are as shown in Table 1 And Figures 6 and 7.

Table 1: The results are recorded by Scccs2 under different weather conditions.

Weather	Rotate Scccs2 towards the sun			Stability Scccs2 towards the sun		
	Date	Tout	Ttank	Date	Tout	Ttank
Sunny	04/06/2025	97	84	05/06/2025	97	83
Partly cloudy	23/12/2024	70	50	22/12/2024	70	50
Overcast	24/12/2024	49	32	25/12/2024	47	31

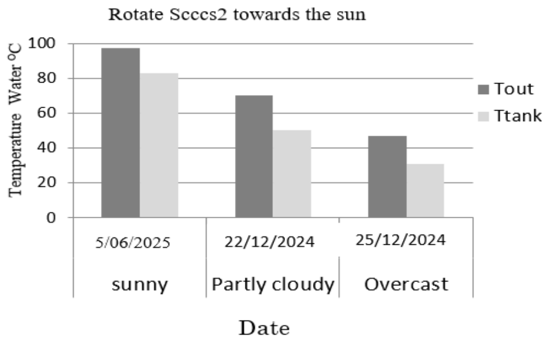

Figure 6: A graph showing the results recorded by Scccs2 under different atmospheric conditions when the collector is moved towards the sun.

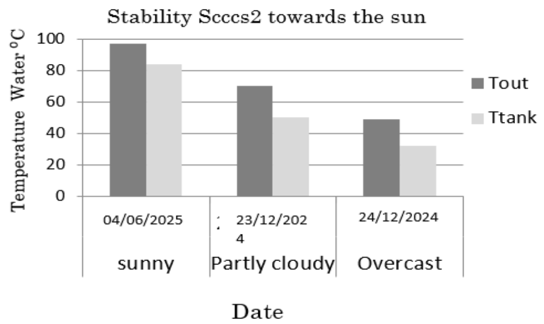

Figure 7: A graph shows the results recorded by Scccs2 under different weather conditions, with the collector facing the sun at 11 AM without movement.

As shown in Table 1 and Figures 6 and 7, it is clear that the solar collector operates efficiently in various weather conditions. The collector's operation is affected as the cloud density increases due to its reliance on reflecting the solar radiation falling on the mirrors. By exposing the complex to solar radiation, the average water temperature is recorded for the period from November 2024 to June 2025, in addition to the solar radiation for the same period, as shown in Table 2 and Figure 8. As well as the thermal efficiency according to (1), (2) [14], [15].

$$\eta = m.\ Cp\ (Tout - Tin)\ /\ I.\ Ac \quad (1)$$

$$A=2(2.\ \pi.\ r1.\ h1+\pi.\ r1^2+\pi.\ r1^2)+(2.\ \pi.\ r2.\ h2) \quad (2)$$

Where:

- η is the thermal efficiency, m is water mass (6.8499 kg);
- Cp is the specific heat of water (4.186 KJ/kg.oC);
- Tout is Temperature of the water coming out of the collector;
- Tin is Source water temperature;

Table 2: Average monthly water temperature and solar radiation [6].

Jun-25	May-25	Apr-25	Mar-25	Feb-25	Jan-25	Dec-24	Nov-24	Month
43	40	30	19	14	14	16	15	T-in ^{O}C
95	93	84	79	72	73	71	75	Scccs2-T(out) ^{O}C
83	80	64	61	47	48	47	56	B2-T(tank) ^{O}C
3365	3121	3256	2619	2227	2175	1526	1757	Solar Radiation (I) W.h/m^2
30	29	33	45	51	55	72	68	η %

- *I* is the incident solar radiation intensity;
- *Ac* is the collector area (0.64 m^2), this is the area that includes the area of the two tanks and the copper tube. It is approximately equal to a third of a square meter, and it is the effective area for heat absorption.

From Table 2 and Figure 8 it is clear that the solar collector operates with high efficiency, with increasing solar radiation intensity. After examining and testing of the new engineering design of the Scccs2 complex using the two previously mentioned testing methods, and recording the results (Tables 1 and 2), it is found that the convex-wavy design simulates the horizontal movement of the sun and does not require movement toward the sun during working hours. This demonstrates the success of the engineering design. This model can be used in remote and rugged locations, such as oil fields, farms, mountainous areas, laboratories, and exploratory missions.

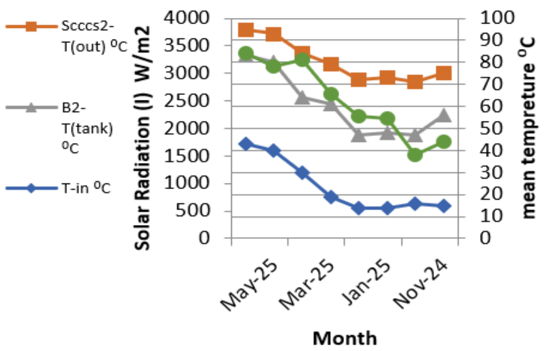

Figure 8: The average monthly water temperature and solar radiation.

Note that the monthly thermal efficiency results for the Scccs2 solar collector in Table 2 reveals a discrepancy in efficiency. The collector's efficiency in winter differs from its summer efficiency. These differences arise for several reasons:

1) During the summer and winter seasons, the collector operates stably, delivering high, comparable results. The collector has a high capacity to retain heat and convert it into useful thermal energy.
2) It is well known that solar radiation intensity varies from month to month, and its value affects the thermal efficiency result (as shown in Equation 1). Most solar collectors are directly affected by this. However, the decrease in solar radiation in the Scccs2 during the winter did not significantly affect the Scccs2's heat collection capacity. In the summer, however, the collector's behavior is directly affected by the increase in solar radiation intensity. This is all due to the success of the new solar collector engineering design.

The high output results of the solar collector result from its ability to collect and retain thermal energy, and its ability to overcome variables (radiation intensity and continuous movement of the collector toward the sun), thus converting that energy into useful energy.

3.2 Water Heat Gain

In this model, the water gains heat from the exposure of the two tanks (B1, B2) and the copper tube to direct solar radiation. The water temperature also increases due to the reflection of solar radiation from the reflective mirrors, and the temperature increases further due to the presence of the global warming effect inside the solar collector.

3.3 Inspection and Testing

There are two testing methods to determine the design's effectiveness in simulating the horizontal movement of the sun:

1) Rotating the collector horizontally after fixing the angle with the horizon (15° in summer, 45° in winter) during daylight hours to be perpendicular to the sun.
2) The collector is positioned perpendicular to the sun at 11:00 AM during its daytime operating hours (fixing the horizontal and vertical angles). This ensures the collector remains stationary in this horizontal position without

rotation. The second test aims to demonstrate that the collector's geometry (wavy-convex) yields the same results as the first test, and that the solar collector operates efficiently.

Rotating the Solar Collector. At the beginning of each testing day at 9:00 am, the solar collector is oriented perpendicular to the sun by manually adjusting its tilt angle relative to the horizon (15° in summer, 45° in winter). The collector is also rotated horizontally every half hour during daylight hours. Figures 9 and 10 show the readings record on December 2, 2024 (sunny, 20°C) and December 22, 2024 (partly cloudy, 19°C).

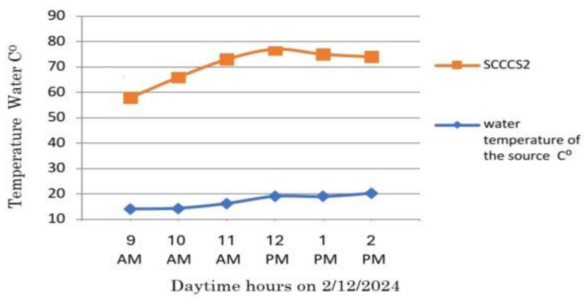

Figure 9: Illustrates the operating behavior of the collector and the temperature of the produced water on December 2, 2024.

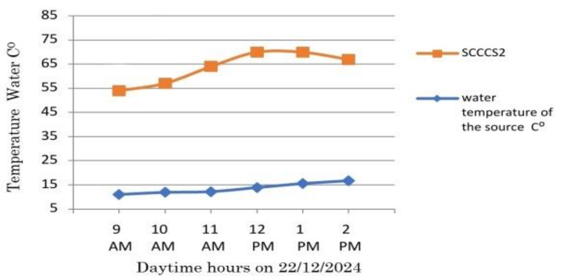

Figure 10: Illustrates the operating behavior of the collector and the temperature of the produced water on December 22, 2024.

Stability of the Solar Collector. At the beginning of each testing day at 9:00 am, the solar collector is oriented perpendicular to the sun by manually adjusting its tilt angle relative to the horizon (15° in summer, 45° in winter). The collector remains fixed – horizontal – perpendicular to the sun at 11:00 am without rotation during daylight hours. The graphs in Figures 11 and 12 present the readings records on 1/12/2024 (sunny 20°C) and 23/12/2024 (partly cloudy 20°C).

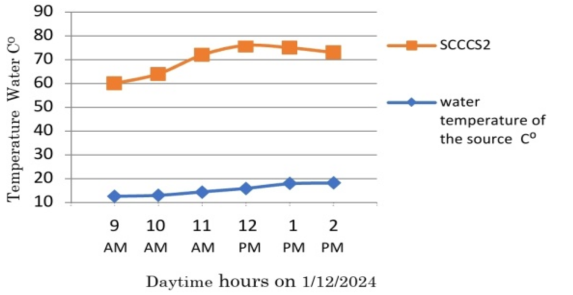

Figure 11: Illustrates the operating behavior of the collector and the temperature of the produced water on December 1, 2024.

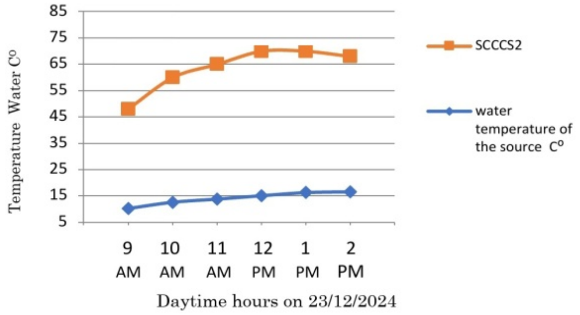

Figure 12: Illustrates the operating behavior of the collector and the temperature of the produced water on December 23, 2024.

Performance evaluation shows that the Scccs2 solar collector delivers nearly identical results whether it is rotated to track the sun or fixed in place. This confirms that its wavy-convex design effectively follows the sun's horizontal path, eliminating the need for horizontal adjustments and enabling reliable operation in remote or off-grid locations such as oilfield labs, agricultural stations, and other field installations.

Compared to conventional flat-plate and evacuated tube collectors (Box, C1, C2, Z1, Z2, H), the Scccs2 demonstrates superior performance. Typical collectors achieve water temperatures of 65–75 °C in summer and 40–65 °C in winter, whereas Scccs2 consistently reaches 62–98 °C in summer and 49–85 °C in winter. Traditional collectors require frequent horizontal rotation to maintain optimal solar alignment, but Scccs2 achieves high efficiency with a fixed horizontal angle, aligned perpendicularly to the sun around 11:00 AM. In addition, conventional systems use glass wool or foam for thermal insulation, which are environmentally harmful and difficult to dispose of. Scccs2 employs a sealed air chamber for insulation, providing effective heat retention without negative environmental impact.

3.4 Thermal Insulation and Thermal Energy Loss

The principles of thermal physics are used to prevent the loss of thermal energy from the rear surface of the collector, and equations (3), (4), [16] are used to prove the efficiency of the air room as a thermal insulator. Therefore, the energy losses from the rear surface of the collector must be calculated with. The loss is calculated for January 20, 2025 (20 oC Sunny) at 12:00 PM. The result with the air room is q1=12 W/m2. This result confirms that the effectiveness of the air room, preventing thermal energy loss from the rear surface of the collector, and maintaining the temperature inside the solar collector.

$$q = \frac{K.A.\Delta T}{\Delta X}, \quad (3)$$

$$\Delta T = (T2 - T1). \quad (4)$$

3.5 Cost of Manufacturing the Scccs2 Solar Collector

The symbols and variables used throughout this study are summarized in Table 3. The materials used for manufacturing the collector are listed in Table 4. Based on local market prices in Basra (1 USD = 1,320 Iraqi dinars), the total manufacturing cost is approximately 59,000 Iraqi dinars. Based on local market prices in Basra (1 US dollar = 1,320 Iraqi dinars), the cost of manufacturing the collector is 59,000 Iraqi dinars. This is a reasonable cost for low-income individuals, institutions, schools, swimming pools, and others.

Table 3: List of symbols, definitions, and units.

Symbol	Symbol definition	Unit of measurement
Scccs2	Solar collector with a reflective absorbing surface using mirrors	
B1	The tank is connected to the source tank via valve V1.	
B2	The tank is connected to the source tank via valve V1.	
V1	Source water valve entering Scccs2	
V2	Collector water outlet valve from Scccs2	
V3	Use water valve exiting Scccs2	
H1	Dedicated port for measuring the front room temperature	
H2	Dedicated port for measuring the insulated rear room temperature	
T_{in}	External tank water temperature	C^o
T_a	Ambient air temperature	C^o
T_{out}	Scccs2 water temperature via valve V2	C^o
T_{tank}	B2 water temperature via valve V3	C^o
T_g	Collector glass temperature	C^o
T_b	Insulating room temperature	C^o
T_f	Front room temperature	C^o
m	Water mass (Scccs2)	Kg
C_p	Specific heat of water	$J/Kg.C^o$
T_1	Temperature gained	C^o
T_2	Temperature lost	C^o
I	Solar radiation intensity	$W .h/m^2$
A_c	Solar collector area (Scccs2)	m^2
r_1	Radius of cylindrical tank (B1, B2)	M
r_2	Radius of copper tube	M
h_1	Height (B1, B2)	M
h_2	Length of copper tube	M
K	Thermal conductivity coefficient	W /m . K
K_{air}, K_{Iron}, K_{Al}, K_{glass}	Thermal conductivity coefficient to (air, iron, aluminum, glass)	W /m . K
A	Area between the two heat loss zones	m^2
ΔT	Temperature difference between the two heat loss zones	K
ΔX	Thickness of the heat loss zone	M
q1	Loss between the front chamber and the outside air, where the thickness of the buffer chamber is ΔX	W/m^2
η	Thermal efficiency	

Table 4: Cost of Scccs2 manufacturing materials in the local market of Basra.

Materials	Number & Details	The cost I.D.
		Scccs2
Copper pipe (diameter 0.9499 cm)	12 m	12.000
A plastic hose	5 m	1.250
Valve to control the speed of water flow	3	1.500
Galvanized iron cylindrical tank (3 litre capacity)	2	6.000
Screws of different sizes	-	1.500
Matte black paint	2	2.000
spinning wheels	3	3.000
A square iron pipe with a side length of 3.81 cm	8.76 m	9.000
Transparent glass panels (0.3 cm thickness)	0.84 m^2	5.000
Iron plate (0.2 cm thickness)	3.5 m^2	10.500
Adhesive (silicone rubber)	1	1.000
Aluminum ruler (a 90-degree angle)	3.5 m	3.000
Aluminum brackets (5 cm long) for fixing the copper pipe	48	4.000
Mirror thickness is (0.3 cm)	0.65 m^2	4.250
Total	-	64.000

4 CONCLUSIONS

Easy to move, clean, and maintain. The Scccs2 can be manufactured in local workshops and laboratories.

Water gains heat in several stages, which increases the efficiency of the solar system in heating water.

The Scccs2 design is most suitable for Basra's weather and operated with high efficiency.

It features a wavy-convex absorber surface, which increases the surface area exposed to solar radiation, thus can increase the heat absorption and increasing the efficiency of the Scccs2 solar collector.

The Scccs2 solar collector's engineering design requires no horizontal movement toward the sun and operates with the same efficiency, meaning it remains fixed in the direction it is at 11 a.m.

The air’s room successfully prevents thermal energy loss from the back surface of the Scccs2 solar collector, by applying the basic principles of thermal physics.

Replacing thermal insulation and its environmentally harmful with air insulation is part of the Scccs2 collector design.

The temperature of the water produces from the solar collector Tout = 95°C, and the temperature of the tank water B2 = 84°C.

The Scccs2 solar collector operates efficiently in various weather conditions, including partly cloudy and completely cloudy weather.

The Scccs2 model features of a low manufacturing cost, making it suitable for low-income individuals, institutions, laboratories, schools, swimming pools, and others.

Scccs2 operates steadily and efficiently as solar radiation intensity increases, with its highest temperature recorded at 12 p.m.

Disclosure statement Author Declaration: The authors affirm that they have no conflicts of interest.

Observance of Ethics Standards: This article contains no research involving human or animal subjects

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