Engineering and Technology Journal
Journal homepage: https://etj.uotechnology.edu.iq

The impact of electronic control systems on improving the performance of the solar heater

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HIGHLIGHTS

- Heater performance was compared without and with an electronic control system
- Heat exchanger conditions were discussed to determine temperature, gain and efficiency
- The coefficient of total heat loss and its relation to efficiency was discussed with and without the control system
- Hot water temperature increase relative to heat exchanger water flow rate was discussed

ARTICLE INFO

Handling editor: Mohammed A. Fayad

Keywords:
Electronic control system; Fouling factor; Heat exchanger; Manufactured solar heater; Waste recycling.

ABSTRACT

In this study, the effect of an electronic control system (ECS) on the performance of a solar heater fabricated from recycled materials was investigated . The study found that the maximum thermal energy output before installing the ECS stood at 378 W, which was significantly improved to 450 W after integration, indicating a commendable enhancement in the efficiency of the solar heater. The thermal efficiency of the solar heater also saw a substantial jump from 71.7% to 82% after connecting the ECS. The study also uncovered the temperature disparity between the trapped and ambient air (max. ΔT = 20.4 °C) influenced heat loss from the space between the glass cover and the two heat exchangers. To address this issue, the sides and base of the heater assembly were insulated with foam material to minimize heat loss. Furthermore, the ECS was programmed to regulate the water flow rate in the solar collector to prevent the water temperature from surpassing 65 °C in winter and 40 °C in spring and autumn. The study harnessed solar panels to provide electricity to the ECS, which enabled the technology to adapt the solar heating process according to environmental conditions and user needs. The study's findings demonstrate the potential of utilizing an ECS for recycling waste solar heaters, leading to enhanced heat transfer efficiency and long-term financial and environmental benefits.

1. Introduction

Recent studies have given great importance to the actual use of solar energy, especially after the pollution that invaded the atmosphere globally and in particular industrial areas. Due to the large consumption of fossil fuels such as oil and gas in developed countries and the proximity of their depletion, the need has become very urgent to use alternative energies such as solar, wind, and others as auxiliary energies that work in tandem with electrical energy, especially since alternative energies are clean energies that do not cause any kind of pollution in the environment. The researchers [1] provided an update to a previous survey on heat transfer technologies on electronic panels, focusing on using flexible panels and environmentally friendly components while comparing heat pipes and water or air cooling to examine how heat is transferred in electronic equipment. Considering the operating conditions and mechanical and electronic systems during thermal design. This study improved the performance of a solar heater by optimizing heat transfer techniques from the sun to the air and water using radiation and convection heat exchangers. The electronic control system was enhanced to regulate water flow for efficient heat transfer. Utilizing solar light, the researchers investigated the effects of temperature and humidity on the process of creating water from wet air. Because the water harvesting system was designed with intelligent control, high temperatures and evaporation rates were the results. In the current study, the E.C.S linked to the solar heater increased the heater's thermal efficiency, even though the intelligent control in their research mentioned reducing humidity. Additionally, this control system raised the water collection system's efficiency to 60% [2]. The vapor strain is key to the thermal performance of the solar water heater [3]. Solar water heating systems transfer heat through collectors, with optimal pricing ranging from $0.49 to $0.91. Medium flow is recommended for glazed tubes, while decreased flow is suitable for export tubes [4].

Three distinct kinds of finned tubes with varying degrees of fins were employed in the study that the researchers [5] described. Several pitch ratios have been tried to find the optimum situation that provides the greatest possible heat transfer rate. The measured fin pitches were (P = 1.6, 2.5, and 3.75 mm). The direction of fluid flow in the pipes and heat exchanger is indicated by the number of fins (23), which have fin thicknesses of 380, 284, and 212. According to the source [6], serpentine

http://doi.org/10.30684/etj.2024.145174.1652
Received 09 December 2023; Received in revised form 14 January 2024; Accepted 19 January 2024; Available online 03 April 2024
2412-0758/University of Technology-Iraq, Baghdad, Iraq

heat exchangers are employed in the current study and have the biggest impact on expanding the surface area available for solar radiation absorption. When compared to solar paint and black chrome paint (PVD sputtered selective paint), whose performances changed to 7% and 21%, respectively, in the realm of pigments, it was discovered through an investigation into the chemical properties of moist electrical coatings that the black chromium beauty variant is capable of absorbing up to 90% of the thermal energy generated by both solar and absorption codes [7]. One was covered with chromium trioxide paint in two different solar complexes, while the other was coated with an absorbent coating with a darker black hue. According to the study, the substance covered in trioxide of chromium improved at collecting solar light and had lower thermal emissions than the primary collector [8]. Revealed that all of the thicknesses of solar paints studied had an identical (0.94), proving that the thickness of solar paint has a crucial influence on the. The heat elimination factor FR and average warmth loss coefficient UL have been computed for extraordinary Al fin thicknesses with a 1x solar paint coating thickness. It has been shown that these parameters increase with decreasing Al fin solar absorber thickness [9].

Copper pipes and aluminum fins were employed in the heat exchangers, and a control system based on electronics was used to manage the water flow. On cold days, the heat exchanger has a maximum thermal efficiency of 58% and can reach a maximum temperature of 64 °C [6].

A study at the University of Technology in Baghdad, Iraq, investigated the performance of a solar water heating system with specific dimensions (125 cm x 110 cm) and found that increasing the flow rate of water through the collector resulted in significantly higher water temperatures, indicating improved thermal efficiency. The study suggests that this technology has the potential to be adapted for various applications, including construction and residential use, and could provide a sustainable alternative to traditional water heating methods [10]. This design is very close to current research. Still, the development carried out in the research involved adding an electronic control system to the system, which resulted in better temperature control and increased efficiency in heating the resulting water in a short time. In a parallel-float arrangement, both the heated and unheated liquids enter the heat exchanger at the same point and exit along the same path. In contrast, the fresh and unheated fluids enter the heat exchanger from different sides and float in opposite directions in the counter-float type [11]. The two fluids move vertically toward each other through the small heat exchangers, and this type of float test is known as a cross-float. Plate and shell-and-tube heat exchangers are two other common types used in industry [12]. Transparent insulation material technology has been used to design effective flat-panel solar energy collectors to increase efficiency and prevent overheating. Using a simulation tool for nesting, three design versions were tested in the laboratory and installed on the rooftop of a hospital building. In winter and spring, the collected energy was 2.5 and 1.4 times larger than that of ordinary collectors [13]. The examiner suggested that any improvement methods or tools used in the heat exchanger should be more advantageous than the advantages of higher pumping efficiency and higher heat switching efficiency [14]. In peer-reviewed articles and papers on solar thermal collectors that use solar energy to heat homes and businesses at the lowest cost, delve into various types, theoretical analyses, functional elements, and hybrid systems—research performance testing methodologies and criteria [15]. Heat exchangers are employed to transfer heat between liquid streams over a range of temperatures. In addition to their pleasant and comfortable aspects, researchers have also investigated the weight loss caused by balancing the flow of fluids [16].

A novel approach to augmenting hot water output was discovered by combining fundamental and enhanced architectural models. An electronic control system that controls a single-axis tracker ensures optimal thermal energy efficiency. Experimental comparisons were made between a heater without a control system, a heater with a control system, and an improved flat-plate collector system [17]. Heat exchanger fouling indicates a major source of corruption. Fouling now also results in pressure-driven effectiveness rather than only reducing heat production. The expansion of various retailers' sizes creates a pleasant and competitive environment for the warm temperature exchanger center, which ostensibly reduces the effectiveness of stylish heating [18]. Researchers have examined integrated collector systems, active and passive systems, an related to solar water heating. The system's effectiveness was enhanced through experiments that also investigated the system's impact on workplace health and safety. An analysis was conducted on current solar energy programs and potential technologies from 2012 to 2024 [19]**.** The 3D CFD model of the flat-panel solar collector was used to evaluate the impact of operational and technical parameters on thermal efficiency. The model was generated by ANSYS Design Model 14.0 and commercial CFD software ANSYS Fluent 14.0. The model employed the general continuity, Navier-Stokes, and K-turbulence models to detect fluid motion. Solar ray tracing was used to calculate the solar load and solar energy intensity. Water proved to be more efficient in the model due to its high density and thermal conductivity [20].

Solar energy is one of the most significant renewable sources, particularly in Iraq, where the sun rises and sets annually. Iraq has access to solar energy, but it is still rarely used. A solar heater for the house is being constructed for this small-scale study. The electric heater is one of the devices that requires a high current to operate. A 120-liter electric heater of medium size is enough for a family of no more than five members. It needs at least 15 amps to operate. In rural and remote areas that have not yet received national electricity depend on private generators, which constitutes an economic burden on families who cannot afford to pay large sums to equip them with electricity, and its value exceeds 150,000 Iraqi dinars per month. Living in one of these neighborhoods, I conducted several experiments with my students until I came up with the idea of using the heat exchangers that we took from the old, idle air conditioners and were used as solar collectors, as will be explained in paragraph 2.2. After conducting several experiments during March and April, the atmospheric air temperature increased in April, which led me to redirect the research idea towards adding an electronic control system that is programmed so that the highest temperature of the water coming out of the heater in winter does not exceed 65 °C and in spring does not exceed 40 °C. The control system is installed on the cold inlet water pipe. The basis of its operation controls the speed of water flow and reduces it, thereby reducing the amount of water (mass) entering the solar collector. Thus, the water temperature rises rapidly because it has little mass. An air heater driven by sunlight and wavy fins linked to the absorber in parallel with the airflow was employed in an experimental study [21]; the greater number of waves in the fin indicated higher efficiency. Along with comparing the absorption and performance of the fins, the impacts of fin arrangement, flow, and solar radiation intensity on thermal efficiency were also examined. However, the current study focuses on applying heat exchangers with serpentine, wavy fins in solar water heaters. The latest discoveries validate the effect of the heat source on the system's thermal efficiency [21].

Connecting the electronic control system to the cold water pipe inside the solar collector and programming it to control the water flow rate so that it does not exceed 0.5 liters per minute increases the rate of water overheating. As indicated in the appendix, the electronic control system is programmed so that the hot water temperature does not exceed 65 ℃ in winter and 40 ℃ in spring and autumn. This modern technology powered a solar heater made of two heat exchangers (two radiators were taken from an old, discarded air conditioner). These heat exchangers were placed in a wooden box (with a glass cover) mounted inside an iron structure on a drawing board that could be moved up and down, where they were directed towards the angle of latitude of Baghdad (33.2 º north of the horizon line) to obtain the maximum amount of solar radiation incident on the solar collector cannot penetrate the glass due to its transformation into a long heat wave after being a short light wave. The heat exchangers (pipes and serpentine fins that enhance the absorption surface area) and the air trapped in the gap absorb heat. The water heats up quickly due to the three methods of heat transfer used here: radiation from the sun falling on the collector, the transition from the air in the gap to the two heat exchangers, and the connection from the wall of the copper pipe in the exchanger to the water flowing inside. The electronic control system regulates the amount of water and its speed, and the heater is highly efficient. The lack of a control system makes it impossible to control the amount and speed of water flow, and the heating process is slower and less efficient.

Solar water heaters use solar radiation to heat water and are energy storage systems used for domestic and commercial purposes. Thermal performance gauges measure heat loss coefficient, solar collector rate, conversion efficiency, system efficiency, and energy conversion efficiency. These indicators help evaluate the effectiveness of a solar water heater and a hybrid solar thermoelectric research system, enabling users and developers to understand the system's efficiency and identify areas for improvement. The main goal is to reduce electrical energy consumption and protect the environment from pollution. Using heat exchangers from old air conditioners as collectors in solar heaters and integrating an electronic control system were relatively unexplored research areas. Limited research has shown promising results in efficiency and heating levels, and the product was introduced to the market after further improvements.

2. Materials and methods

2.1 Materials

Figure 1 shows stages of design and assembly of a solar heater from consumable tools (waste). Figure 1A represents two heat exchangers taken from an old air conditioner, cleaned, and then dyed. Figure 1B represents a wooden box inside an iron structure with dimensions of 119 cm x 58 cm x 28 cm. Inside the box are placed exchangers. This structure was placed on a moving drawing board that is tilted at an angle of 33.2° from the latitude of the city of Baghdad. The final shape of the solar collector is shown after the sides and base are wrapped with aluminum foil and the glass cover is installed, which is a glass plate with a thickness of 4 mm fixed with a special putty to prevent rainwater leakage. Figure 2 and Figure 4B show the electronic control system (ECS) parts with an analog valve and a picture of the ECS, respectively. Techniques (Assembling device parts) Radiator number 2 is used for an old air conditioner in a waste warehouse. Then, the two heat exchangers are cleaned, thoroughly washed, and checked to ensure that one of their pipes does not have a hole from which the fluid leaks. Those heat exchangers are then dried outside under the sun's rays. Figure 1 shows the next step: the exchangers are dyed dark black to provide the highest heat absorption and the least reflectivity. Over time, a vertically moving table creates different inclination angles to obtain the maximum amount of solar thermal energy. The angle is determined as 33.2° from the horizon (latitude of Baghdad), as shown in Figure 1C. A wooden box is designed to be mounted on an iron structure, and heat exchangers are placed inside it, as shown in Figure 1B. Then, the sides of the base are coated from the outside and inside with aluminum foil, and the glass cover is fixed from above, as shown in Figure 1C. A hole is made in the back side of the wooden box so that the ends of the two heat exchanger tubes come out of it, as shown in Figure 4A. The measurements of the solar collector box (119 cm x 58 cm x 28 cm) (length x width x height) are taken. The two heat exchangers are connected in series.

One of the two pipes coming out of the exchanger is cut and welded with a reverse pipe to the other exchanger pipe so that the water flows from the two exchangers with one external pipe connected to a hose to pour the water coming out of the solar collector into a tank collecting hot water. This tank is isolated from the surroundings with glass wool to keep the water hot inside for a longer period. Two small holes are made in the water transfer pipe to insert the thermocouple sensor inside each hole to measure the temperature of the water entering and exiting through these two holes. To preserve heat inside the solar collector box, which houses the exchangers, a fiberglass insulator is used to seal all openings in the sides of the box, increasing efficiency and increasing the water heating rate.

3. Optimizing and designing experiments

In Table 1, the steps of assembling the solar heater device are sequenced. Figure 1A shows the two heat exchangers that were taken from a tank, thrown into the waste storage at the institute, and cleaned and examined in a water basin. There were no leaks in them. Then, they were painted in a matte dark black color and placed inside a wooden box, as in Figure 1A, which is installed on an iron structure fixed on a repaired waste drawing board. The solar collector is installed on it, as in Figure 1B. Figure 1C shows the box wrapped inside and out with cheap aluminum foil used in kitchens. Then, a hole was made in the back of the box in the middle to exit the two hot water pipes coming out of the pool. An ordinary bottle with a thickness of 5 mm was placed. The rear hatch is sealed to prevent heat exchange with atmospheric air.

Table 1: Practical steps from project start to results

No.	Working steps	History	Working hours	Notes
1	Heat exchangers were obtained from the waste storage at the Institute for the preparation of technical trainers	2022-10-3	8:30-10:00	Sunny temperature 15.5 °C
2	The exchangers were thoroughly washed and checked for holes in the pipes or fins, then left to dry in the sun.	2022-10-3	10:00 – 11:30	temperature 17.7 °C
3	The heat exchangers are dyed dark black	2022-10-6	9:00-11:45	A- See Figure 1
4	The structure of the solar mosque was prepared from an engineering drawing board, and an iron structure was installed on its surface. top of it, a wooden box without a cover was installed	from 10/10 to 20/10/2022	Daily from 9:00- 11:55 a.m.	See Figure 1B
5	The sides and base are wrapped with aluminum foil from the inside, then the heat exchangers are placed inside the collector box, and the glass cover is placed	from 23/10 to 26/10/2022	Daily from 9:00- 11:55 a.m.	See Figure 1C
6	A hole is made for the collector box from the back for the connections of the two pipe exchangers	29/10 to 2/11/2022	Daily from 9:00- 11:55 a.m.	See Figure 4A
7	The inspection is carried out first before installing the electronic control system.	During the month of 11 and 12 of the year 2022	Weekly on Sunday only: 9:00 a.m. to 2:00 p.m.	Comparison between exchangers 1 and 2 is made as in Figure 11
8	The electronic control system is obtained and then programmed to determine temperatures in winter and summer.	During January 2023	Weekly on Sunday only: 9:00 a.m. to 2:00 p.m.	It has been programmed so that the temperature of the water leaving the heater in winter does not exceed 65 °C and does not exceed 40 °C in spring and autumn.
9	After leaving the device in February and starting to complete the experiments during March, the second exchanger was found to have a blockage, which was replaced with another exchanger from the store, and the same steps were performed on it 1-3	During February 2023		
10	The readings were taken before connecting the control system and after linking.	During March and April	Three days a week from 9 a.m. to 1:30 p.m.	The weather was different; it encountered rainy days, sunny days, dusty and cloudy. However, in all weather conditions, the results after connecting the control system were higher in terms of temperature, the amount of energy that water gained, and thermal efficiency.

A. Heat exchangers **B. The wood box is the pit inside the structure** **C. The solar collector is tilted at an angle of 33.2º from the horizon (latitude of the city of Baghdad)**

Figure 1: Stages of design and assembly of a solar heater from consumable tools (waste)

3.1 The electronic control system

Figure 2 shows a picture of the components of the ECS, and it is connected to an inlet valve that connects to the water pipe connected to the liquefaction water tap, where the water temperature is according to the temperature of the atmospheric air surrounding the water pipe. Figure 3 shows the electronic control system, and Number 11 is given, as in Figure 3, in which the solar collector's components are shown after connecting the electronic control system. Then, as shown in Figure 3A, which shows the use of a thermocouple to record temperature readings (water entering and leaving the collector), the temperature difference was observed before and after connecting the control system.

Figure 3B depicts the electronic control system connected to the cool water pipe. Connecting a solar water heater to an electronic control system has numerous benefits and drawbacks. An outline of a few of them is provided below:

3.1.1 Benefits

3.1.1.1 Boost energy efficiency

The electronic control system can modify the heating process more efficiently, reducing energy consumption and saving electricity.

3.1.1.2 Temperature control accuracy

The electronic system enables accurate temperature control, providing optimally heated water.

3.1.1.3 Integration with renewable energy systems

The electronic control system can connect with other renewable energy systems, enhancing the system's overall efficiency and integration.

3.1.1.4 Reduce heat loss

The electronic control system can enhance the heating process's efficiency by reducing heat loss during idle moments.

3.1.1.5 Adjust to shifting external circumstances

The electronic system makes it possible to modify the heating procedures in response to shifting environmental factors, improving the system's performance in varied weather conditions.

3.1.2 Disadvantages

3.1.2.1 Higher investment cost

Adding an electronic control system to a solar heater comes at an extra expense, which can influence customers' willingness to invest.

3.1.2.2 Maintenance complexity

The electronic system may require additional maintenance, increasing maintenance costs and calling for technical expertise.

3.1.2.3 Dependency on electrical energy

The electronic system depends on electricity to function, increasing the need for an electrical energy source.

3.1.2.4 Compatibility issues

The electrical system's components may not work well with other systems, requiring proper integration and fine-tuning to prevent compatibility issues.

3.1.2.5 Utilization complexity

The electronic system's operation may further complicate the use of the solar heater, requiring users to become proficient with its interface.

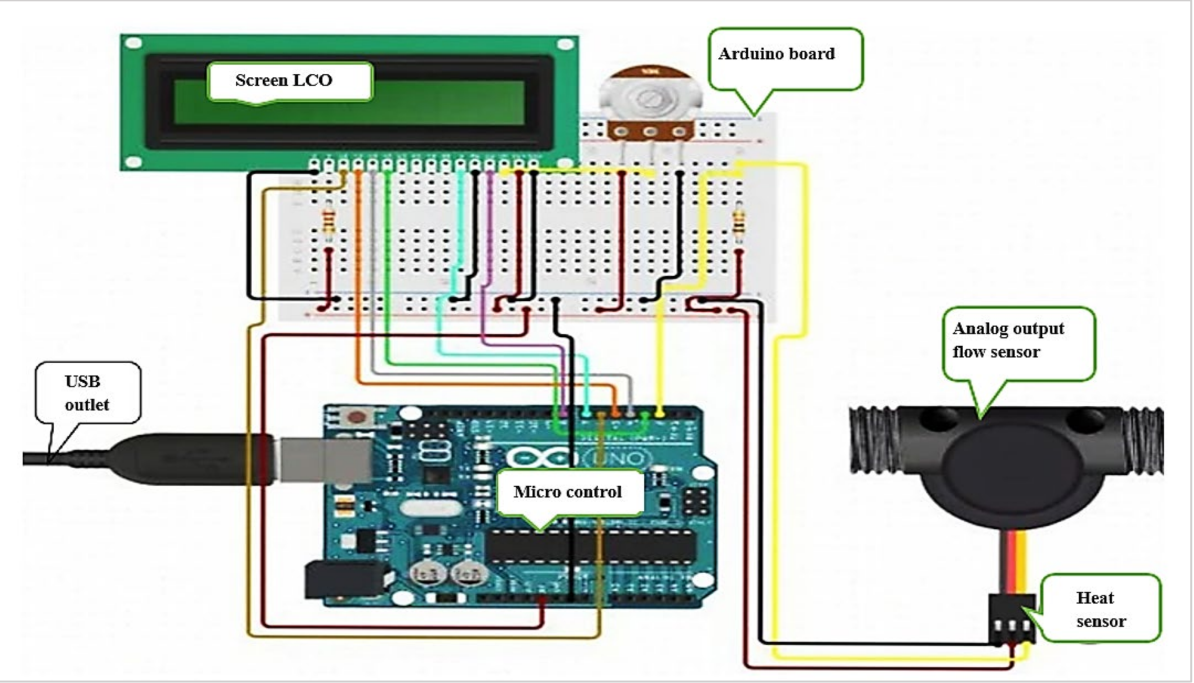
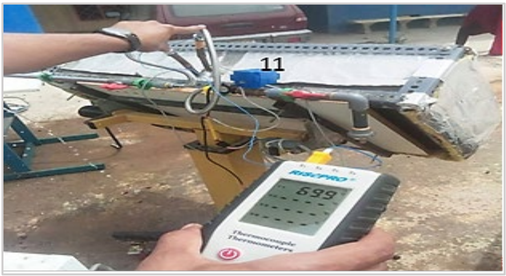


Figure 2: Electronic control system parts with analog valve



(A) **(B)**

Figure 3: A- shows the connection of the E.C.S (11) on the water pipe joining the faucet and its effect on the temperature of water discharged from the solar collector, which was measured with a thermocouple device. B- The electronic control system is connected to the cool water pipe

Consumers and developers should consider several factors when deciding whether to link an electronic control system to a solar water heater. These factors include the advantages and disadvantages of the system. Figure 4 shows the connection of the solar heater parts before installing the control system, and Figure 5 shows the connection of the solar heater parts after installing the control system. By increasing the amount of heat absorbed by the tightly coupled copper pipes and the aluminum fins surrounding the pipes, the solar heater's functioning mechanism prolongs the system's exposure to sunlight or heat absorption time. Heat transfer occurs through conduction, whereby the water within the system absorbs the heat. Subsequently, the heat is conveyed to the water in the piping through natural convection until it reaches the exterior. The glass wool covering surrounding the hot water collection tank provides insulation between it and the outside world. The water is contained within a larger tank, enclosed at the top, and insulated internally to prolong the duration of its high temperature. Then, from 8:00 a.m. to 3:00 p.m., the water temperatures within and outside the system are monitored.

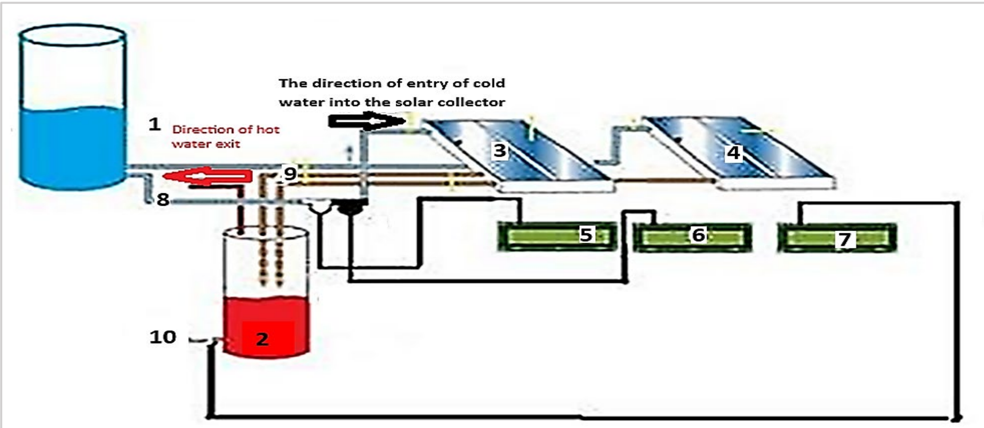


Figure 4: The diagram of the Solar water heater system without Electronic control system

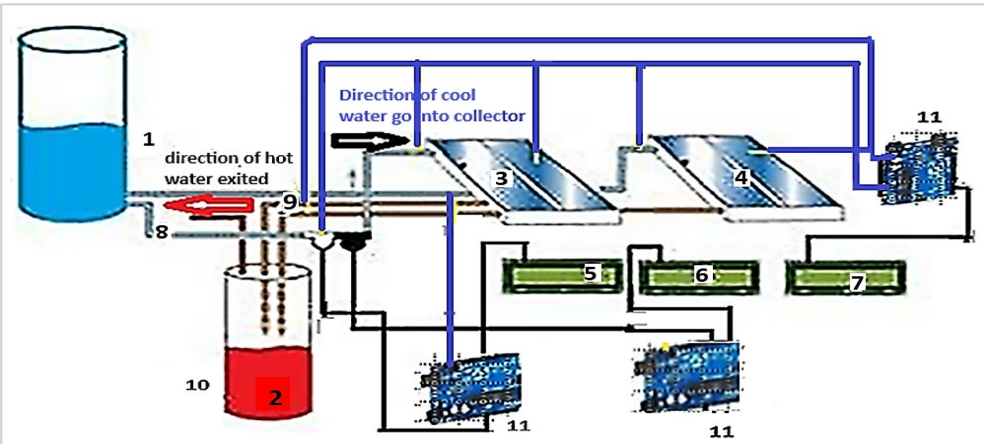


Figure 5: The diagram of the Solar water heater system with Electronic control system

1- Tank of cold water
2- Hot water tank
3- First heat exchanger
4- Second heat exchanger
5- Flow water meter
6- Input temperature of water
7- Output water temperature
8- Cold water pipe
9- Hot water pipe
10- Hot water
11- Electronic control system

4. Theoretical aspect

To estimate the efficiency of the solar collector, the real useful thermal energy is calculated for a given period and then divided by the intensity of solar radiation received during that period multiplied by the area of the absorption surface, see Equation (1) [22]:

$$\eta_c = \frac{\dot{q}_u}{A_a \int_0^t I\,(t)dt} \tag{1}$$

where q_u is calculated in Equation (2) [23]:

$$\dot{q}_u = \dot{M}_w C_w (T_{w,out} - T_{w,in}) + \dot{M}_c C_c (T_{c2} - T_{c1}) \tag{2}$$

The change in the temperature of the water flowing in the solar collector is calculated theoretically as Equation (3):

$$\begin{aligned} &\text{The energy absorbed from the absorptive surface (q p)} \\ &= \text{the energy absorbed by the water (q w)} \\ &+ \text{the energy gained by the mass of the material of} \\ &\text{the solar collector (q c)} + \text{the amount of heat lost from the base, sides,} \\ &\text{and cover of the solar collector}(Ub + Us + Ug)Aa(Tp - Ta) \end{aligned} \tag{3}$$

Thus, Equation (2) of thermal equilibrium is written in the formula of finite differences as in Equation (4) [24]:

$$I_T(\tau\alpha)_e A_a = \dot{M}_w C_w \left(\frac{\Delta T_w}{\Delta t}\right) + \dot{M}_c C_c \left(\frac{\Delta T_c}{\Delta t}\right) + U_L A_a (T_p - T_a) \tag{4}$$

It is concluded that the amount of heat transferred in this element (dL) as given by Equation (1) and determined UL the total heat transfer per unit length (W/m.℃) by taking the difference of the component of the pipe (dL) (Figure 6) to measure the flow rate and temperature of the water exiting the system [6]. The process depicted shows the heat transfer from the hot air trapped in the gap between the glass cover and the heat exchanger tubes through convection to the wall of the heat exchanger tubes, followed by heat transfer from the outer wall to the inner wall of the exchanger tubes through conduction, and finally, heat transfer from the hot air to the cold water due to the temperature difference in the pipes.

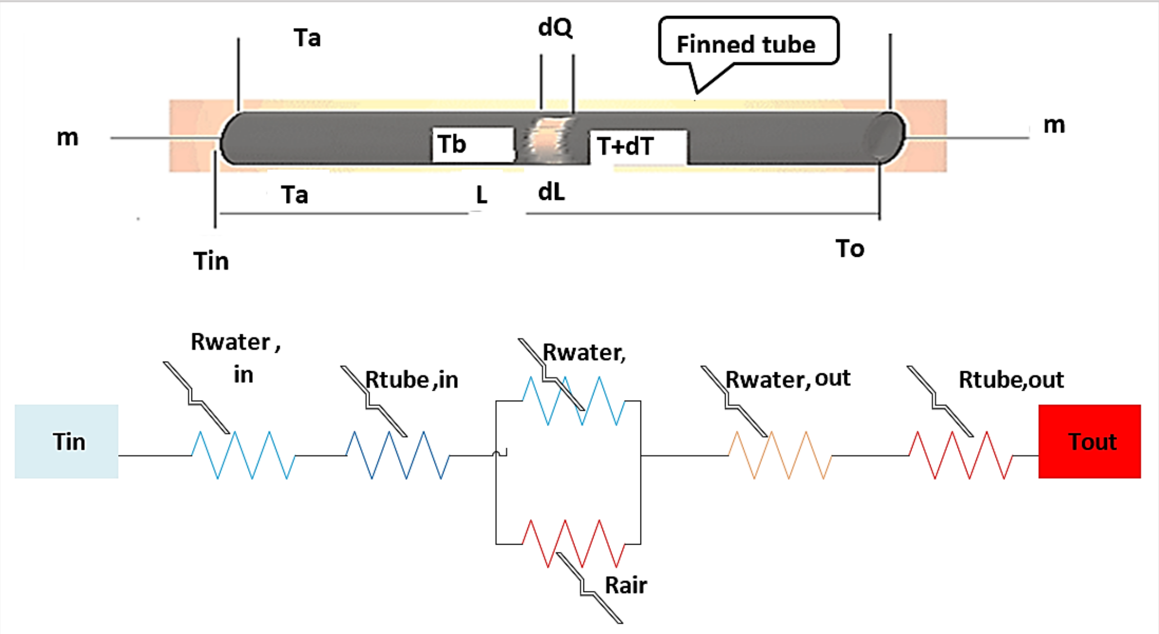


Figure 6: A single-stream heat exchanger, the heat from the hot air bath is transferred to the water flowing into the pipe

$$\acute{\emptyset} = U_L(T_a - T)\,\mathrm{d}L \tag{5}$$

$$U_L = \acute{\emptyset}/L(T_{out} - T_{in}) \tag{6}$$

where: UL: the pipe length's heat transfer coefficient,T: the temperature at which the element is in equilibrium (d L). Equations (4–9) calculates the system's efficiency using Equation (7) [16],[5]:

$$\acute{\emptyset} = \eta \, \acute{\emptyset}_{MAX} = \eta \, C_{Min} \, (T_{out} - T_{in}) \quad (7)$$

$$\eta = \acute{\emptyset} \, / C_{Min} \, (T_{out} - T_{in}) \quad (8)$$

$$\acute{\emptyset} = \dot{m}_c \, C_{pc} \, \Delta T_c \quad (9)$$

$$\acute{\emptyset} = \dot{m}_w C_{pw} \Delta T_w \quad (10)$$

if

$$\dot{m}_c C_{pc} = \dot{m}_w C_{pw} \quad (11)$$

$$\text{Then } AT_w = AT_c \quad (12)$$

$$A_S = n \times I_T \times D_S \times L \quad (13)$$

where As = 13× π×(1.5/100) ×2 =1.23 m^2

The surface area of the exchangers from Equation (13) is employed to calculate the surface area of all the pipes' combined surfaces and the area of heat transmission through a tube See Table 3. As a result of this resistance, the heat exchanger's share of heat transfer has decreased (R_{wall}) Equation (10) [22],[5]:

$$\mathrm{R(wall\,)} = \frac{\mathrm{l\,n}\left(\frac{\mathrm{Do}}{\mathrm{Di}}\right)}{2\pi \mathrm{KL}} \quad (14)$$

where L is the tube's length, and K represents the wall material's heat conductivity. The total thermal resistance (R_{total}) becomes equal to Equation (15) [5] at that point.

Equations (14 and 15) are used to determine the coefficient of heat loss by calculating the heat transfer resistance through the wall of the exchanger pipe. In Equation (16), UL represents the coefficient of total heat loss. Equation (16) represents the power calculated by multiplying the coefficient of total heat loss by the surface area and the temperature differences. Ai refers to the wall's inner surface region where the two fluids are separated, while Ao refers to the wall's outer surface region. In other words, Ai and Ao represent the surface areas of the dividing wall contacted by the inner and outer fluids, respectively. When one fluid circulates inside a tube while the other does not.

$$R_{total} = R_i + R_{wall} + R_o = \frac{1}{h_i A_i} + \frac{\ln\left(^{D_o}/_{D_i}\right)}{2\pi KL} + \frac{1}{h_o A_o} \quad (15)$$

$$U_L A_S = \frac{1}{R_{total}} \text{ then } \acute{\emptyset} = \frac{\Delta T}{R_{total}} = U_L A_S \Delta T = U_i A_i \Delta T = U_o A_o \Delta T \quad (16)$$

$$A_i = \pi D_i \, L \quad \text{and } A_o = \pi D_o \, L \quad [5] \quad (17)$$

5. Results and discussion

Figure 7 depicts the thermal dynamics of the solar heater, showcasing the intricate relationship between ambient air temperature (Ta) and hourly time between March 21 and April 4. A detailed analysis of these data reveals a striking increase in Ta during April, resulting in a commensurate enhancement in the amount of heat gained by the water. This observation underscores the crucial role of surrounding air temperature in influencing the solar heater's performance. The fundamental thermodynamic processes are explained in Equation 1, which also shows how the higher Ta in April causes water to absorb heat more effectively, increasing the efficiency of the solar heater. The enhanced capacity of water to absorb heat as the outside temperature rises is responsible for this occurrence. This finding is significant because it highlights how much the surrounding air's temperature affects the solar heater's efficiency. To maximize the efficiency and design of solar heaters, further investigation into the thermodynamic principles underlying this link is essential, as this discovery underscores. A better understanding of these dynamics will enable us to create solar heating systems that are more effective and efficient, which could have a substantial impact on various sectors and applications. Figure 8 [25], shows how dirt and debris accumulate on the edges and surfaces of the pipes from the outside and on the fins, which act as an insulator that prevents or reduces heat transfer by conduction to the water inside the pipes, and that the silt layer indicates increased heat transfer resistance.

The accumulation of dirt and other contaminants on the pipes and fins substantially negatively impacts the operation of solar heaters. These pollutants' insulating qualities cause a decrease in heat transfer efficiency, resulting in increased heat and energy loss. It is crucial to clean and purge the pipes and fins regularly to preserve system performance at its best. On March 20, 2023, we conducted our experiment and found a strong correlation between the temperature of the hot water as it exited the system and the amount of time it flowed. In Figure 9 compared to the second heat exchanger, which only experienced a maximum temperature increase of 2 °C due to fouling, the water departing the first heat exchanger significantly increased.

This suggests that eliminating impurities can improve heat transfer efficiency considerably, leading to a heating system that operates more efficiently. Although the water temperature that exited the system did not significantly change due to the constant air temperature throughout the day, it did peak at 3:00 p.m. This implies that the solar heater was operating at its highest efficiency level during this period. In conclusion, dirt and contaminants on fins and pipes can significantly lower a solar heater's efficacy. Regular maintenance and cleaning can help ensure peak performance and increase heat transfer efficiency. Prioritizing impurity reduction can increase the solar heater's overall efficiency and heating capability, as in Equation (3) [16].

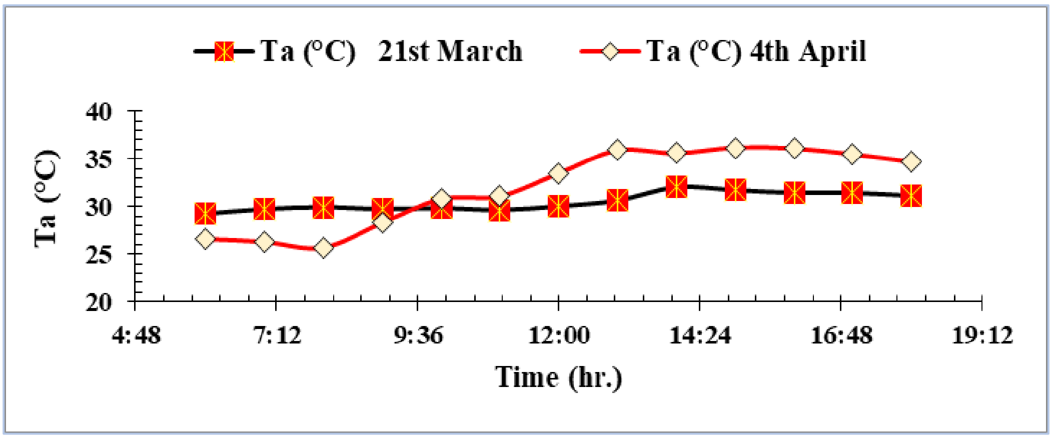


Figure 7: The relationship between the temperature of the air surrounding the solar heater and the time per hour in March and April, and then the comparison between them

Figure 8: Ash accumulates on the heat exchange tube's inside surface[25]

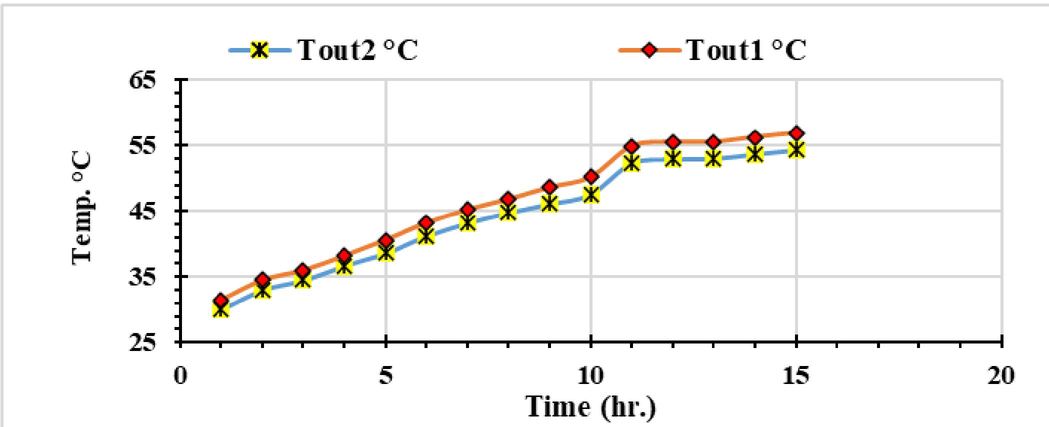


Figure 9: The relationship between the hot water temperature readings with time for the first and second exchangers

Figure 10 illustrates a significant difference in temperature values between the water exiting the collector when the electronic control system is connected to the cold water pipe within the collector and when it is not. A noticeable increase in temperature is observable when the control system is connected, and this is attributed to the system's ability to regulate the amount and speed of water flowing into the exchanger pipes, thereby preventing the flow rate from exceeding 0.5 liters per minute. This controlled water flow results in accelerated heating of the water, as the system maximizes the heating of water by efficiently controlling the flow of water to enhance the performance of the thermal collector. In essence, the connection between the electronic control system and the cold water pipe has a pronounced impact on the temperature difference in the water emerging from the collector, as the control system's ability to manage water flow into the exchanger pipes leads to more rapid water heating. The temperature differential of the water coming out of the collector is essentially determined by the connection between the electronic control system and the cold water pipe, as the control system's capacity to regulate the flow of water into the exchanger pipes causes the water to heat up more quickly. The relationship between a solar heater's efficiency and time (8:00 a.m. to 3:30 p.m.) is shown in Figure 11. The solar heater's efficiency is compared before and after adding an electronic control system to the cold water pipe that enters the collector. When the control system is linked, the solar collector's maximum efficiency is 82%, whereas its maximum thermal efficiency was recorded at 72% before the control system's connection. The electrical system's ability to regulate the water flow rate into the solar collector accounts for this discrepancy. Lowering the water flow rate reduces the volume of water that enters the collector, which decreases the quantity of solar radiation that passes through the glass cover and is converted into long-wave radiation that passes through the glass and cannot be converted back. The air space between the glass cover and the absorbing surface is where these heat waves are trapped (heat exchangers with copper pipes and aluminum serpentine fins improve the surface area to absorb heat). Hot air convection currents are produced inside the gap due to the subsequent rise in air temperature. The walls of the copper pipes in the exchanger tubes and their serpentine fins receive heat from the surrounding air, which is then conditionally transferred to the water within. An increase in solar heater efficiency offsets the increase in heat output for water caused by temperature differentials.

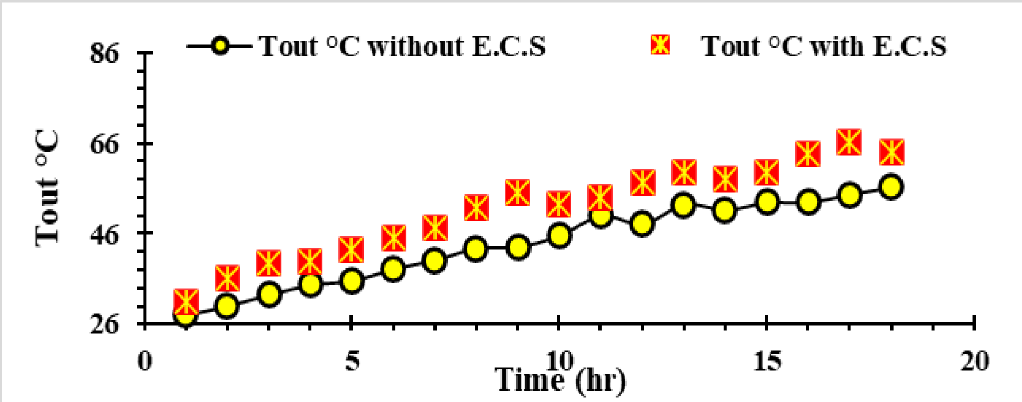


Figure 10: The relationship between the hot water temperature readings and the time of the heater before connecting the electronic control system(E.C.S) and after connecting it

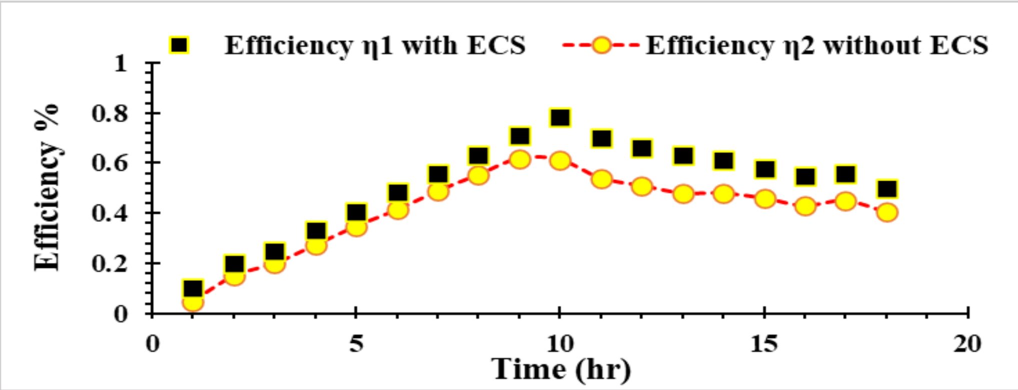


Figure 11: The correlation between the thermal efficiency of the solar thermal collector and the duration in consideration and its association with the efficiency and duration before and after the integration of the electronic control system (ECS)

Table 2: Temperature readings from heat exchangers 1 and 2 and tap water entering and exiting exchangers between 8:00 a.m and 3:30 p.m

Time hour	Temperature T_{in} °C	Heater exchanger2 T_{out2} °C	Heater exchanger 1 T_{out1} °C	Water mass flow rate $\dot{m}$ (L/min)
8:00 a.m.	27	30	31.5	1
9:15 a.m.	26.88	33	34.5	0.9
10:00 a.m.	27.1	36.7	38.2	0.7
11:15 a.m.	27.5	41.2	43.2	0.5
Noon.	28	44.8	47.8	0.4
12:30 p.m.	28.4	47.6	51.16	0.3
01:15 p.m.	29.95	52.3	55.87	0.25
02:00 p.m.	29	53	56.5	0.15
03:30 p.m.	28.7	54.3	59.87	0.1

The temporal correlation between the quantity of heat gained by water before the electronic control system is connected and the elapsed time is displayed in Figures 12 and 13. The change in the rate of temperature difference, which is directly proportional to the amount of heat transmitted, is what causes the increase in thermal energy acquired after connecting the E.C.S. Figure 12's Q4 curve shows the maximum power gain values (6660 W) at a total heat transfer loss coefficient of 30 W/ m.°C. Figure 13's Q4 curve shows the maximum energy values (7140 W) gained at the same total loss coefficient. The maximum power gain values (6660 W) are recorded at 30 W/ m.°C for the total loss coefficient, as shown by Equation (7) [16]. In summary, Figures 12 and 13 illustrate the relationship between time and the amount of heat gained by the water before the electronic control system was connected. The findings show that heat gain increases with time, with the Q4 curve exhibiting the highest gain values.

Table 3: The results of the heat transfer rate and its efficiency at different temperatures during different daylight hours after connecting with the electronic control system. As=1.062 m^2

Q́6 W	Q́5 W	Q́4 W	Q́3 W	Q́2 W	Q́1 W	ΔT °C	η1% with E.C.S
595.5	42.5	770	370	74	37	3	40.7
1230.25	93.37	1698.1	1000.4	123.16	65.38	11	49.0
1510.2	111	2040	1080	157	78.7	10.5	54.0
1797.9	140.3	2499	1236	187.4	89.5	11.4	59.0
2195.1	159.6	2958	1442	228.7	174.6	13	61.0
2583.25	199.05	3646.5	1812	267.5	138.4	15	65.0
3100.6	221.7	4131	2005	299.8	157.8	17.4	69.0

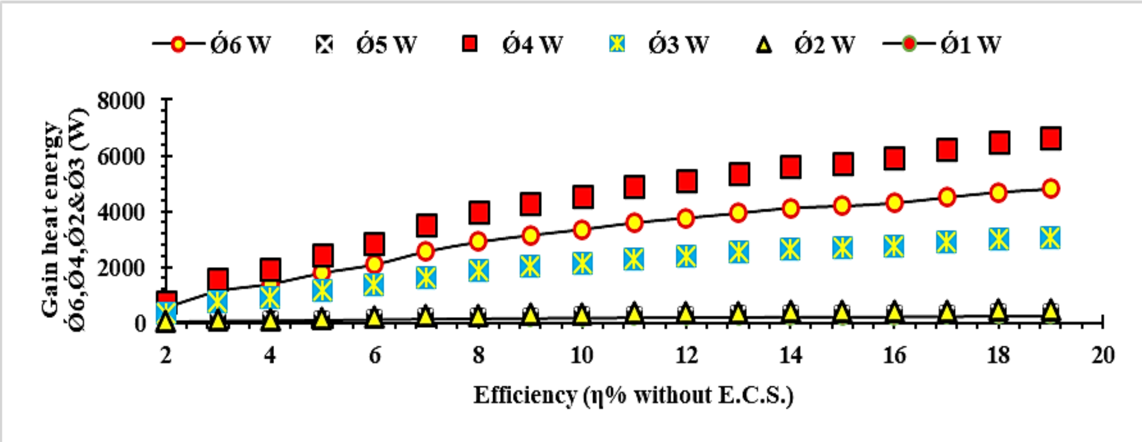


Figure 12: The correlation between solar collector efficiency and heat energy rate before the electronic control system is connected

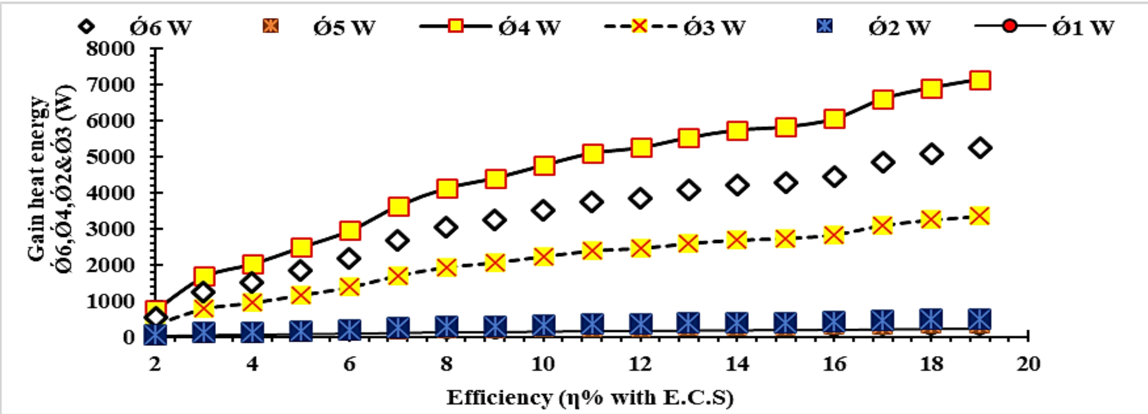


Figure 13: The relationship between the heat rate and the efficiency of the solar collector after connecting the electronic control system

The study revealed a significant correlation between the temperature of the hot water exiting the first and second heat exchangers and the water flow rate inside the heat exchanger pipes as showing in table 2 and figure 14. Analysis showed that due to the first heat exchanger's lower levels of fouling and pollution, its temperature was 4-5 °C higher. The accumulation of mineral deposits, fats, and filth on the pipe walls hinders heat transfer from the outer pipe wall to the water, resulting in a temperature difference between the two heat exchangers. This finding underscores the importance of keeping heat exchanger pipes free of debris and in good working order to ensure optimal heat transfer and temperature regulation. Regular cleaning and maintenance are crucial to avoid obstructions in the heat transfer process, which could result in lower temperature outputs and decreased efficiency. By prioritizing pipe cleanliness, we can enhance temperature control and guarantee effective heat transfer, ultimately improving system performance.

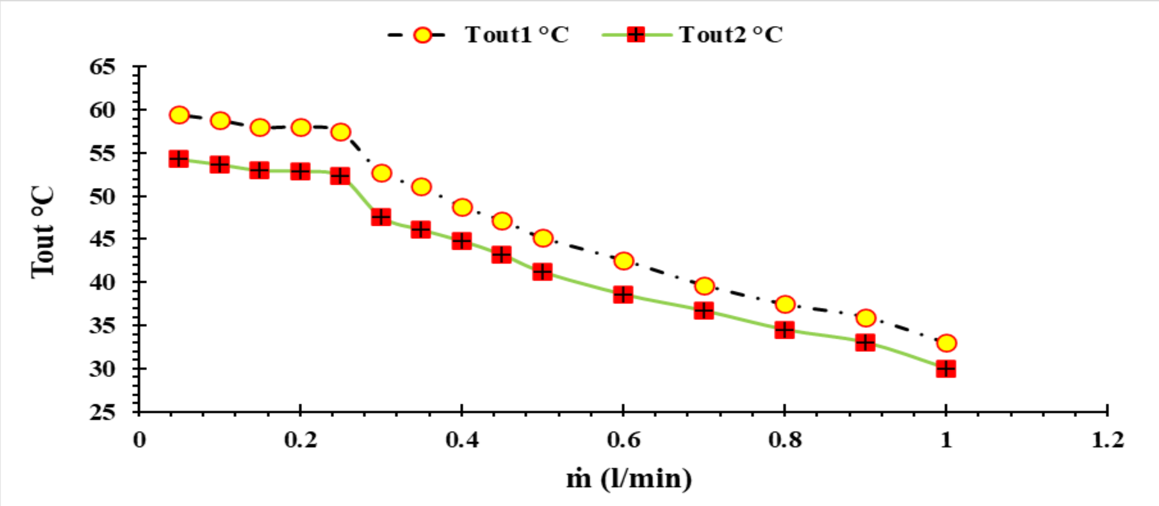


Figure 14: The relationship of the water flow rate with the degree of flow of the water coming out of the first ,and second heat exchangers

The relationship between the temperature of the hot water leaving the solar heater and the water flow rate in the heat exchanger's (solar collector) pipes is shown in Figure 15. Before the electronic control system was installed on the cold water pipe—the data collection aimed to examine how the electronic control system affected the hot water's temperature. The results showed that the hot water's temperature increased by 3-6 °C after the electronic control system was connected. The electronic control system is responsible for controlling the water flow rate into the solar collector at a rate of 1.0-0.15 liters per minute, which regulates the mass of water entering the collector and, as a result, the rate at which the temperature rises. In particular, a quicker temperature increase over a shorter period occurs when the water flow velocity falls as less water enters the collector.

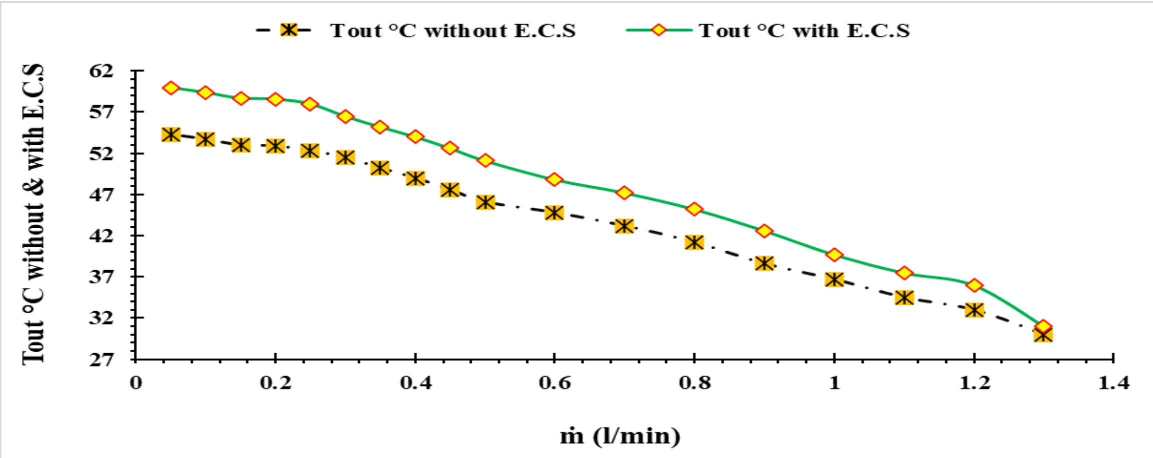


Figure 15: The relationship of the water flow rate with the hot water temperature coming out of the heater before and after connecting the electronic control system

A direct relationship between thermal efficiency and the coefficient of total heat transfer (UL) is seen in Figure 16 ,and in Table 4, where a lower UL value is associated with higher thermal efficiency. The installation of an electronic control system clarifies this relationship even more. According to this research, 30 W/m.°C is the lowest heat transfer coefficient at which the maximum thermal efficiency may be reached. This study revealed that adding an electronic control system to a solar heating system significantly enhanced its thermal performance. Specifically, the system's efficiency increased from 71.7% before installation to 82% after the control system was deployed. This improvement is attributed to the control system's capacity to optimize thermal energy gain and regulate water temperature by optimizing the quantity and velocity of water entering the system. Using mathematical Equations (8 and 16), the study demonstrated that the system's thermal efficiency is inversely related to the total thermal resistance (Rtotal) and directly related to the amount of thermal energy gained. The system's thermal efficiency was increased by lowering the Rtotal once the control system was installed. The electronic control system raised the temperature of the hot water pipe by three to six degrees Celsius, according to the study's investigation into its effects. This increase in temperature was attributed to the control system's ability to optimize the thermal energy gain and water temperature. Specifically, the study found that a minimum heat transfer coefficient of 30 W/ m.°C is needed to maximize thermal efficiency, achieved after the control system was installed. Overall, the study demonstrates the potential of electronic control systems to improve the thermal performance of solar heating systems and highlights the importance of optimizing thermal energy gain and water temperature in such systems.

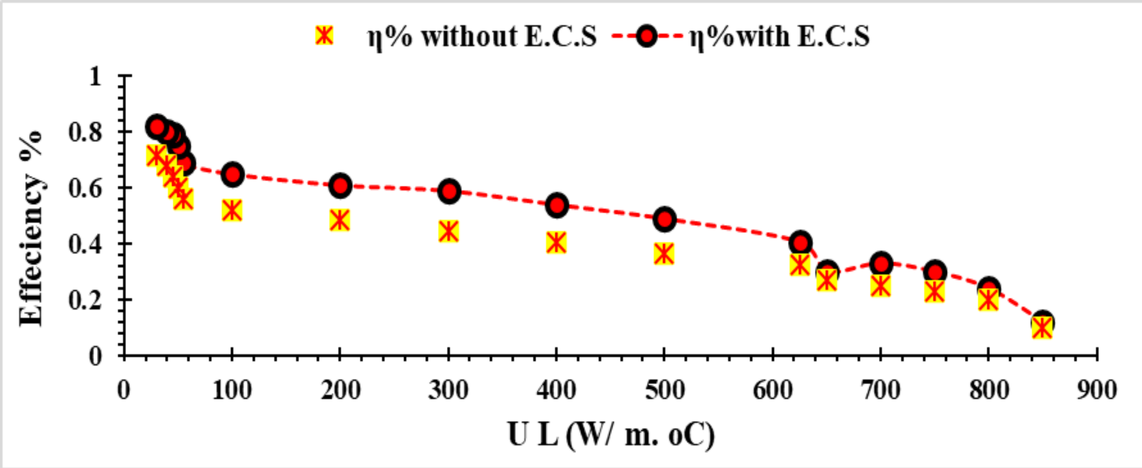


Figure 16: The relationship of UL the total heat transfer proportional to pipe length, in (W/ m^2.°C) with Efficiency% before & after connecting the electronic control system

Table 4: A model of the results of Efficiency % before and after connecting the electronic control system at different UL the total heat transfer proportional to pipe length, in (W/ m.°C)

Efficiency % (before connecting the electronic control system)	Efficiency % (after connecting the electronic control system)	UL the total heat transfers proportional to pipe length, in (W/ m.°C)
0.1	0.12	850
0.327	0.407	625
0.561	0.69	60
0.6	0.75	50
0.639	0.79	45
0.717	0.82	30

Table 5: The comparison between the present research and Jalil study [21]

	ṁ w (L/min.)	Tin°C	Tout°C	ΔT °C	U L (W/ m.°C)	Ǿ(Watt)	η%
The previous study	0.54	28	51.3	25.2	35	1791.33	60
The present research	0.5	28	59.44	28.2	30	2195.4	78.33

The comparison in Table 5 was made with a previous study in the reference [21] referred to, to find out what has been developed in the current study in increasing thermal efficiency and the amount of heat gained after connecting the electronic control system.

The study computes the uncertainty in measured values due to biases and precision mistakes. While bias error is related to the accuracy and calibration of measuring devices, precision error is related to the repeatability of estimation. The limited outdoor circumstances made it difficult to make precise calculations. The investigation was repeated to calculate the precision error, leading to uncertainties based on bias error. Irshad et al. [26] as in Table 6, proved a method to calculate bias error uncertainty by claiming that R is a linear function for n independent normally distributed variables.

Table 6: Uncertainty Analysis of the Measured Value [26]

Parameter	Standard value (x)	Uncertainty (∂x)	Relative error (∂x/x)
Gain heat energy Ǿ (*W*)	54 -7140	± 0.3	2.4
*T*a (°C)	25.7-36.2	± 0.6	0.85
*T*o (°C)	30 -59.87	± 0.216	0.92
*T*in (°C)	27- 29.95	± 0.04	1.27
η th% before connected with E.C.S.	0.1-0.717	± 0.0095	0.0232
η th% after connected with E.C.S.	0.12-0.82	± 0.011	0.027
UL (W/ m.°C)	850 - 30	± 1.4	3. 6
ṁ (L/min)	0.1	±0.0101	0.306

6. Conclusion

The study investigated the performance of two heat exchangers fabricated from recycled air conditioners and a solar heater before and after installing an electronic control system.

1) The results indicate that the electronic control system significantly enhanced the temperature and thermal efficiency of the solar collector.
2) The amount of silt and calcification on the inside surfaces was observed to be primarily responsible for the temperature variation in the hot water exiting each heat exchanger.
3) This emphasizes the importance of regular cleaning and maintenance to ensure peak performance.

4) The outcomes demonstrate the effectiveness and efficiency of the solar thermal energy system for heating water.
5) The higher temperature and thermal efficiency of heat exchanger tubes resulted from using aluminum foil for side and base insulation, reflecting light and trapping it inside the collector.

In conclusion, implementing an electronic control system in the solar thermal energy system improved performance and efficiency. This study's findings underscore this technology's potential for sustainable and eco-friendly water heating solutions.

7. Future recommendations

1. We recommend increasing the number of exchangers from 2 to 6. The results of using four exchangers have been tested, and the results were amazing. A liter of hot water was obtained at 40 degrees Celsius within three-quarters of an hour, and the device was incomplete without a glass cover.
2. We recommend increasing the size of the solar collector to suit the number of exchangers and to obtain a larger surface area to absorb solar radiation.
3. We recommend using a dark black dye mixed with a percentage of chromium trioxide [8], to increase heat absorption from the incident solar rays.

Nomenclature

Symbol	meaning	Symbol	meaning
A_a	The area of the air layer adjacent to the surface of the glass cover[m^2].	T_a	Ambient air temperature (°C)
Ap	The surface area of the absorption plate of the Collector[m^2].	T_{in}	inlet water temperature (°C)
		T_{c1}	collector temp. before heating (°C)
Cc	specific heat of the collector (J/(kg·°C)	T_{out}	outlet water temperature (°C)
		T_{c2}	collector temp. after heating (°C)
C_w	specific heat of water (J/(kg·°C)	T_P	Collector plate temperature (°C)
D i, D o, D s	The inner and outer diameter and total surface diameter cm	ΔTw	The temperature differential between the cold water entering the collector and the hot water exiting the collector (T_{out} - T_{in}) (°C)
Ai	Inner surface area cm^2		
As	Total surface area cm^2	ΔTc	The temperature differential between the final collector temp. The initial collector temp. (T_{c2} - T_{c1}) (°C)
Ao	Outer surface area cm^2		
dT_a/dt	Change in air temperature relative to time (°C/sec)	U_b, U_t	Bottom and Top heat transfer coefficients, respectively (W/ m.°C)
dT_c/dt	The change in the temperature of the base of the solar collector relative to time (°C/sec)	$\dot{M}_c$	The mass of the solar collector material (kg /sec)
dT_w/dt	The change in water temperature relative to time (°C/sec)	$\dot{M}_w$	The mass of water in the solar collector (kg/sec.)
hi	Inner Convective heat transfer coefficient (W/ m^2. K)	ho	Outer Convective heat transfer coefficient (W/ m^2. K)
I(t)	Solar radiation as a function of time	Ǿ$_u$	The amount of real useful thermal energy
I_d	Diffuse solar radiation falling on a horizontal surface (W/m^2)	U_g	Glass cover heat transfer coefficients (W/ m.°C)
I_h	Total solar radiation incident on a horizontal surface (W/m^2)	U_L	The total heat transfer coefficient (from the bottom of the collector and above) (W/ m.°C)
I_{th}	Theoretical total solar radiation incident on the surface of the solar collector (W/m^2)	Ǿ	The amount of energy absorbed by the solar collector (W)
I_T	Total solar radiation incident on an inclined surface (W/m^2)	$\dot{m}$	Water mass flow rate (l/ min)
K	The thermal conductivity (W·m^{-1}·K^{-1})	τ_g α_g	The product of the absorbency of the absorbing plate is multiplied by the Transmittance of the glass cover.
L	Length of pipe (cm)	ε_p	plate emissivity
$\dot{m}_c$	The mass flow rate of cold water (kg)	t	Time (sec)
$\dot{m}_h$	Water mass flow rate of hot water (l/min)	E.C.S	Electronic Control System
R_{in}, R_{out}	Thermal resistance, in and out (kg/kJ.m^2)	η c	The collector's efficiency
		η	The thermal efficiency
R_{total},R_{wall}	Thermal resistance total and wall (kg/kJ.m^2)	n	Number of layers

Author contributions

Conceptualization, E Alaskaree and Y. Breesam.; methodology, E Alaskaree and Y. Breesam; software, E Alaskaree and Y. Breesam; validation, E. Alaskaree; formal analysis, E. Alaskaree; investigation, E. Alaskaree; resources, E. Alaskaree; data curation, E. Alaskaree; writing—original draft preparation, E. Alaskaree; writing—review and editing, E. Alaskaree; visualization, E. Alaskaree; supervision, E. Alaskaree; project administration, E. Alaskaree. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability statement

The data supporting this study's findings are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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