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OPTIMIZING HEAT TRANSFER IN INNOVATIVE SOLAR WATER HEATERS USING RECYCLED MATERIALS: ENHANCING EFFICIENCY AND SUSTAINABILITY

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ABSTRACT

The study demonstrates the efficiency of using recycled materials to create solar water heaters, in particular in enhancing heat transfer. The innovative heater surpasses traditional commercial models in performance, offering a sustainable solution for residential water heating. The research, conducted in Baghdad, Iraq, entailed reusing heat exchangers from an outdated air conditioner to serve as a solar water heater collector. Equipped with a thermal insulator ,and an electronic control system, the heater achieved impressive results, raising the water temperature to 55 o C in just 30 minutes with a thermal efficiency of 83.122%. While the commercial heater took an hour and a half to heat the water to 57 o C. By integrating features such as serpentine fins, black coating and foam insulation, the system increases heat absorption and reduces losses. The electronic control system enhances the efficiency of heat transfer, which makes the homemade solar heater a viable and affordable option whose manufacture costs no more than 30,000 IQD while the commercial one costs 179,000 IQD. Both are environmentally friendly for residential use. In general, the research emphasizes the possibility of using recycled materials to develop efficient and sustainable solar water heating systems.

KEYWORDS

An Electronic Control System; Commercial Heater; Efficiency; Recycled Parts; Solar Collector; Thermal Performance.

1. INTRODUCTION

Numerical analyses were conducted to determine the effect of heat transfer from solar rays through the glass cover and absorption coefficients. Parameters such as energy absorbed, air gap, surface area, paint type, number of glass covers, and dimensions were studied to compare the efficiency of a Locally Manufactured Flat Plate Solar Water Heater (LMSH) with a Commercial solar water heater (CSH) standard. The temperature of the absorption plate rises as the glass transfer coefficient does. By raising the absorbed energy coefficient, the solar collector's thermal efficiency was improved. In Blida, Algeria, a solar-powered water heater was installed; its thermal efficiency was 29.212%, while the usual exercise efficiency was 1.81%. (Said et al., 2015)**.** A study (Cerón et al., 2015) evaluated the influence of operating conditions and design options on the effectiveness of solar collectors, predicted the efficiency curve of flat-panel fluid collectors. Thermal efficiency, solar system running time, and solar energy storage techniques were covered (Daghigh and Shafieian, 2016). (Tambunan et al., 2018) In addition to design and performance enhancement elements, suitable coatings with suitable glass transfer and absorption coefficients were employed in the design of a solar water heater. (Gao et al., 2018)**,** shown that an oscillatory heat pipeline collection in the shape of a flat plate was able to overcome the decreased effectiveness, excessive beginning temperature, and weak pressure resistance of traditional solar collectors.

A study (Jehhef and Siba, 2018) assessed that convection thermal currents near Hot Walls and high obstacle temperatures decrease with increasing tilt angles. On the other hand, there are no noticeable differences between the heated walls and the height of the parapet. This research was of great use in determining the angle of inclination of the collector for the locally manufactured solar heater, so determining the angle of latitude of the city where the project experiments were conducted was the most appropriate to reach the largest quantity of radiation that strikes the collector in order to raise the water's temperature and shorten the time needed to heat it. In order to compare the simulation results to the initial case, where the energy efficiency increased by 4.904%, the solar thermal flat panel collector's design parameters—mass flow rate, fluid inlet temperature, absorption plate thickness, riser pipe outer diameter, pipe spacing, and insulation thickness—were examined (Huy et al., 2019).

Solar hot water collectors, which made use of solar energy to distribute warmth at reasonable costs, were the subject of discussions, theoretical analyses, functional components, hybrid systems, techniques, and performance testing criteria (Evangelisti et al., 2019). A thermal performance enhancer and a flat-panel solar water heater's convection effect were compared. (Balaji et al., 2019). To identify the best convection method (Balaji et al., 2019) examined the heat transfer impact of a flat plate solar water heater with and without thermal performance modifiers. Based on solar irradiation, this study examined the Grashof, Rayleigh, and Richardson numbers. The solar water heater business, thermal technology, and financial feasibility were investigated as the main topics of discussion in Chapter 2 (Agathokleous et al., 2019) stressed how important it is to have the lowest cost as well as greater reliability, performance, and simplicity of maintenance. The review (Vengadesan et al., 2020) discussed the importance of convective heat transfer coefficients and design elements in enhancing the efficiency of a solar water heating system conversion efficiency had reached 70%,. Similar to the current study, design considerations such the use of heat exchangers with serpentine fins and the installation of an electronic regulator system on the cold-water pipe were taken into consideration, and the thermal efficiency was 88%. (Azha et al., 2020) developed a 3-D fluid dynamics computational system to investigate the effects of operating and technical parameters on a flat solar collector's thermal effectiveness. Studies on the most recent advancements in enhancing the thermal efficiency of low-temperature solar collectors, including compound equivalent capacitors, vacuum tube collectors, and flat panel collectors, demonstrated that solar radiation transformed into heat was utilized as a working medium by solar collectors (Gorjian et al., 2020). Chromium trioxide and a dark black dye were utilized to examine the coating types used in two solar collectors; the first one showed low emissions and high selectivity in energy absorption (Alaskaree, et al., 2020). The main purpose was to assess the amount of dry solid waste and work on separating recyclable waste materials to reduce waste to be disposed of in open landfill sites, where it leads to various environmental and health problems (Hamza, 2020) as in our current research, where heat exchangers were used in old air conditioners that had been thrown into the waste store from idle and consumed electrical appliances, and those exchangers were used as a solar collector for a locally manufactured heater and after the success of its work and heating the water well as at the source (Ekram H. Alaskaree, 2024) then an electronic control system was connected in our current research, which led to reducing the heating time to the minimum can.

Air gap spacing, collector tilt, absorption plate temperature, coating emission, winds heat transmission coefficient, and ambient temperature were among the variables that were computed, as the maximum absolute error was achieved in U_t values not exceeding 2% (Alam et al., 2021). Four shade percentages were suggested as a way to keep hot water use constant and avoid overheating. Under various circumstances, the system's efficiency averaged 50%; however, a 62% efficiency was achieved due to a rise in solar radiation intensity and temperature differential (Chidiac et al., 2022). Optimizing the operating parameters of flat solar collectors in heat supply systems—which control their weight, size characteristics, and thermodynamic variables—is one of two strategies to increase their thermal efficiency. This can be accomplished by employing charging tubes to distribute the cooling fluid flow uniformly or by heating the water at a low velocity with a high-temperature slope across the orientation of the liquid movement (Ismailov, 2022).

(Ekram H. Alaskaree, 2024),investigated the impact of an electronic control system see Fig.3 on a solar heater made of recyclable materials. The findings demonstrated a significant increase in thermal energy output and thermal performance, rising from 71.7% to 82%.

By insulating the base and the side walls, the method also coped with the temperature difference between the trapped air and the ambient air. In addition, the technology controls the speed of the water, which enabled the heating method to adapt to user requirements and ambient conditions. He highlighted how important latent heat transfer is for increasing efficiency. Solar water circulation within the heating system was also examined. This device was used in our current research after confirming the success of its work in the previous research by (Ekram H. Alaskaree, 2024) and then its efficiency and duration of heating the water was compared with an expensive 4-form solar commercial heater and gave us amazing results in the period necessary to heat the water except that the capacity of the commercial heater is much larger, so it takes about two hours to heat the water in it. A study compared air cooling and coupled fins as heat sinks in order to investigate the use of fins on solar panels from behind for passive cooling. The fins increased the electrical and thermal efficiency and reduced the cell temperature by more than 3.7 degrees Celsius, while the thermal and electrical efficiency increased by more than 58.3% and 16.54%, respectively (Raad H. Abed et al., 2024). While the Serpentine fins in the heat exchangers used in the current research have increased the surface area to absorb the Rays and thus increase the heating of the water, especially since the exchangers are placed inside an insulated box from five sides and the upper side is glass from which the Rays escape and are trapped inside.

In this current study, solar water heaters were developed using heat exchangers from non-working air conditioners. The exchangers, made of copper pipes and aluminum fins, were reused as solar collectors with an electronic control system that manages the flow of water. Compared with commercial flat heaters, recycled exchangers have shown better performance, efficiency, and thermal energy gain. By reusing old hardware components, a homemade solar heater provides a cost-effective and sustainable option for hot water supply in residential and commercial environments. A structured experiment was conducted to assess how well a solar water heater constructed from recycled materials performs compared to conventional heaters, to reduce electricity usage and promote sustainable energy options. The study seeks to assess the sustainability and resource efficiency of a solar heater crafted from recyclable materials, as well as advocate for sustainable energy decisions by examining the heater's functionality, cost, and ecological footprint. The study highlights the advantages of incorporating recycled materials into renewable energy technologies and evaluates the efficiency of a solar heater in contrast to a conventional heater. The project aimed to enhance the performance of home heaters in comparison to regular commercial heaters. Connecting the heater to the control system resulted in increased efficiency and improved heating. Tailored solutions are created according to the specific circumstances and requirements of the community, utilizing native resources and methods to lower expenses while enhancing effectiveness. Using creativity to combine technologies, like heat exchangers and insulated wooden boxes, resulted in improved performance. The system control is fine-tuned for maximum performance, backed by detailed documentation containing clear images and tables. The programming software's thorough explanation regulates the water flow's pace. The efficiency of the home and commercial heaters was directly compared as part of the data analysis, which showed some significant variances. To confirm the results, field experiments were conducted in various weather conditions, demonstrating that the system can operate effectively even in less-than-ideal circumstances like cold and cloudy weather. The project showcased new and useful ideas for heating homes.

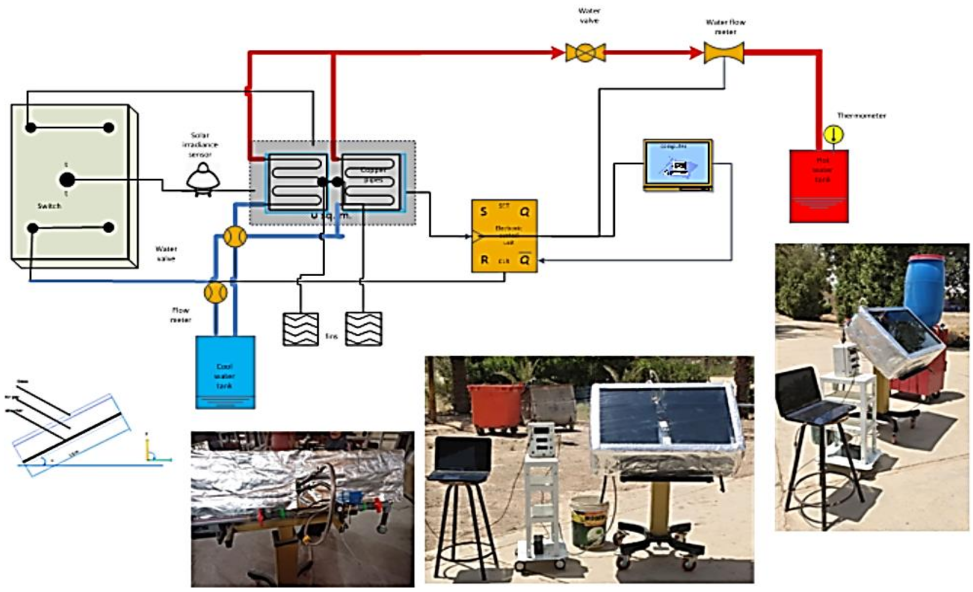

Fig. 1. The locally designed heater, and its accessories, and the system loop.

2. METHODOLOGY

This study compares the efficiency of a solar heater made from recycled waste materials with a typical commercial heater. The main objectives are to assess energy efficiency, cost, and environmental impact. The solar heater is constructed using recycled materials such as wooden boxes, plastic pipes, radiators, and exchangers from old air conditioners. The locally produced sun heater (LMSH) and a commercial solar heater (CSH) are compared experimentally. To maximize heating and manage water flow, the LMSH is outfitted with an electronic control system Fig. 3 and coated in foam insulation.

The LMSH generates a higher heat energy output compared to the commercial heater due to its design and control system. The commercial solar heater is made of copper coated with a dark substance to absorb sunlight, heating water in pipes within a metal frame. (Alaskaree, et al., 2020) compares the use of expensive chromium trioxide dye in previous research with a cheaper black dye in the current experiment, highlighting the effectiveness of the control system in reducing costs while maintaining efficiency. The research methodology involves designing, assembling, and implementing the solar heaters, followed by a comparison of their efficiency. Ultimately, the study aims to determine which type of heater is more efficient and environmentally friendly.

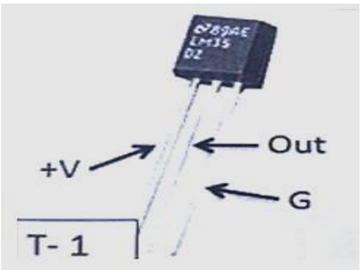

Fig. 2. The temperature sensor (LM 35)

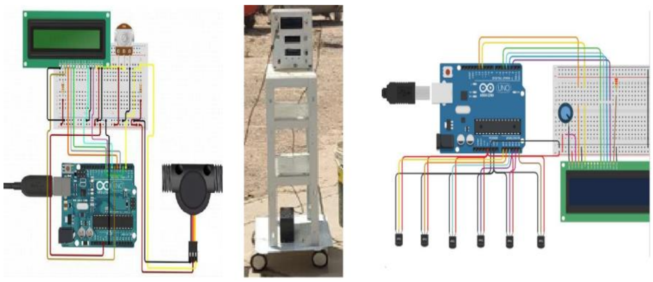

Fig. 3 .A control system, its parts, and their connection Appendix

Fig. 4. Standard Commercial Solar Water Heater(CSH)

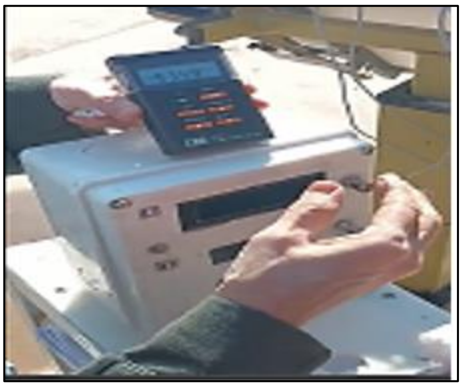

Fig. 5. Solar radiation intensity measuring instrument

3. MATERIALS AND METHODS

3.1. System Description

An engineering drawing board that is 0.5 meters above the ground and movable up and down is one of the materials used to build a local solar heating system. The board was positioned

33.2 degrees from the horizon at Baghdad latitude. It was topped with a black-painted iron structure that measured 1 m in length, 0.7 m in width, and 10 cm in height. A wooden box measuring (0.9*0.6*0.09) m^3 was positioned inside the wooden box with a door. Table 1 shows the glass cover (0.89*0.59*0.009) m^3.

Two heat exchangers, thermal insulation foam, adhesives, aluminum foil, and black dye make up the heater. Aluminum foil was used to wrap the wooden box from the inside and paint it. To make sure there were no holes in the copper pipes, the heat exchangers were examined. As illustrated in Fig.1, dye them black after ensuring they are hole-free.

After that, the exchangers were put together inside the box and joined in a row such that the right side had a cold-water inflow pipe. Water entered the first exchanger and then the second, from which the hot water pipe emerged. The hot water pipe uses conduction to absorb heat from the copper exchanger tube walls. By transporting the solar rays that were reflected from the glass to the air space between the exchangers and the glass cover, these pipes were able to generate heat. The computer, control system, and shape of a locally made solar heater (LMSH) are depicted in Fig.1. The connections between each component of the heating system are depicted in Fig.1. One of its advantages is that it dims on a potential difference (3.0-4v), and its output is precisely proportional to the temperature Fig. 6. 10 mV/^{o} C, with a very good precision of 0.5 ^{o} C per 25 ^{o} C for each changing range.

3.2. Commercial Solar Heater (CSH) Parts.

It is crucial to remember that the heater's "theory of operation" is predicated on a closed-circuit system with a stainless-steel heat exchanger before introducing the components see Table 2. It is anticipated that the solar heater will be more economical, energy-efficient, and less harmful to the environment.

By comparison, a traditional commercial heater will be bought, and the solar heater will be built from recycled materials like cardboard boxes, newspapers, and plastic bottles see Fig. 4. In contrast, a conventional commercial heater will be purchased, and the solar heater will be constructed using repurposed materials including plastic bottles, cardboard boxes, and newspapers. In contrast, a conventional commercial heater will be purchased, and the solar heater will be constructed using repurposed materials including plastic bottles, cardboard boxes, and newspapers. The experimental setup will include temperature, energy production, and cost measurements. Sensors and data recorders will also be added to provide a controlled environment. The solar heater can be built using recycled materials including cardboard boxes, newspapers, and plastic water bottles, and a standard commercial heater will be bought for comparing. Temperature, energy production, and cost measurements will all be part of the experimental setup. For offering an atmosphere of control, sensors and data recorders will also be included.

Table 1. Details of commercial solar heater collectors (CSHC) and locally produced solar heater collectors (LMSHC)

	Manufactured solar collector	Commercial solar heater
Box Length (cm)	95	611
Box width (cm)	59	61
The thickness of the box (cm)	26	20
Heat Exchanger	Number of exchangers 2	-
Aluminum Fins space available	0.45 cm	-
Fin/Coil Dimensions	Length: 20.32 cm, Width: 20.32 cm, Height: 8.89 cm	-

Table 2. A Standard Commercial Solar Water Heater Component (Agathokleous *et al.*, 2019)

Name of part	Details
Tank for hot water	Its cylindrical body is composed of treated and lubricated steel.
Material for thermal insulation	50 mm thick polyurethane
Solar water Collector	Estela 316, an internal body heat exchanger that complies with international standards EN102043.1, and heat-treated glass that is 4 mm LIT thick.
The surface that absorbs	It is composed of copper, and every weld is laser-etched and lubricated using specific materials from ALIMCO, a German business.
Base of the heater	For ease of installation, the stand is composed of 3 mm thick treated galvanized iron that is supported by Aluminium parts.
Connectors	Every connector has copper ends, insulated thermal insulation, and is composed of stainless steel.

3.2.1. Experimental parameters

Temperature, power output, and cost are some of the important characteristics that we will specify to measure to ensure an orderly environment for the experiment. To regularly collect relevant data, we will install sensors and data recorders Appendix. Here is how the experiment will be set up:

1. Temperature: use thermocouples to measure the temperatures of the two heaters.
2. Power output: use a kWh meter to determine the power output of each heater.
3. Cost: using energy bills, determine how much each heater costs in terms of energy use.
4. Experiments were conducted from 3-9-2023 to 9-2-2024

3.2.2. Information Collection:

Here both heaters will be tested under similar conditions, such as ambient temperature and humidity. Periodically, the following information will be recorded:

1. energy input: determine the amount of energy, such as electricity, that is supplied to each heater.
2. efficiency: get the efficiency ratio of each heater by calculating (output power / input power) * 100.
3. other related metrics: specify more measurements, including solar heater weight and waste output.

A systematic method for assessing the environmental impact, financial feasibility and energy efficiency of heating systems.

- Examine performance data through statistical analysis.
- Examine outside factors like the weather and the location.
- Talk about any biases or limitations in the experiment.
- Report findings in a structured format
- Analyze and contrast heaters' efficacy, affordability, and impact
- Provide overview of main results and implications for further investigation
- Propose topics for future research and design enhancements
- Peer evaluation for feedback and confirmation of results
- Document and publish experiment details for broader dissemination.

3.2.3. Detailed Mechanisms:

- Heat retention by convection: the hot air trapped in the gap between the glass cover and the heat exchangers cannot get out, which leads to the occurrence of the greenhouse effect. This is due to the effect of long-wavelength infrared radiation, which further heats the air inside and, accordingly, the water in the pipes.
- Conduction through insulated walls: foam insulation around the Collector reduces heat loss to the environment. This insulation helps to transfer more heat from the absorbed solar energy to the water instead of losing it through the walls of the Collector.
- Optimal water flow: by connecting a control system that controls the flow rate of cold water entering the system, the heater ensures that the water spends enough time in the collector to absorb maximum heat. Slower flow rates allow for greater heat exchange, resulting in a higher delta value. Conclusion: Fig. 11 shows the superior thermal efficiency of a domestically manufactured solar water heater compared to a commercial model. The increased heat gain is attributed to such effective design features as serpentine fins, black coating, convective heat retention caused by an air gap, and foam insulation. In addition, the cold-water pipe control mechanism improves the water flow, ensuring the efficiency of heat absorption and retention, resulting in a higher temperature difference between the water inlet and outlet. These design

improvements demonstrate the possibility of creating more efficient and cost-effective solar water heaters for residential use.

3.3. Mathematical modeling

This study examined solar irradiance, fluid temperatures at the collector's input and output (Ti), and ambient air temperature (Ta). When water was utilized as the working fluid (I), it was altered. The system's thermal performance was predicted using the steady-state mode, which ignored transient factors like wind speed and airborne dust. As anticipated, solar radiation rises until the sun's vertical rotation at solar noon (1:00 pm). After that, the sunbeam starts to tilt westward, drifting away and delaying its arrival on Earth (the collector's absorbing surface). As a result, both the temperature and the air temperature around the solar collector drop. Until dusk, when none of its rays reach Earth, it keeps descending. This served as the foundation for designing the solar-heated components. The gadget has a solar cell panel, a storage battery, and an electronic control system, as mentioned in the paragraph before this one. η is equal to the solar collector's energy output divided by the solar energy projected onto the collector's surface. Eq. 1 (Gao et al., 2018) illustrates how the real useable energy is evaluated over time to ascertain the collector's efficiency.

$$\boldsymbol{\eta_{th}} = \frac{\frac{\mathbf{QCOLL}}{\mathbf{Ac}}}{\mathbf{I_b}} = \frac{\dot{\mathbf{m}}.\mathbf{C_p}(\mathbf{Tc_2} - \mathbf{Tc_1})}{\mathbf{I_b}.\mathbf{Ac}} \tag{1}$$

here $\dot{Q}_u$ as exposed in Eq. 2 (Ferahta et al., 2012) & (Ferahta et al., 2020)

$$\dot{\mathbf{Q}}_{\mathbf{u}} = \dot{\mathbf{m}}_{\mathbf{W}}\,\mathbf{C_W}\,(\mathbf{T_{W2}} - \mathbf{T_{W1}}) - \dot{\mathbf{m}}_{\mathbf{C}}\,\mathbf{C_C}\,(\mathbf{T_{C2}} - \mathbf{T_{C1}}) \tag{2}$$

The quantity of heat engrossed by the solar collector is calculated by Eq. 3 (Touaba et al., 2020).

$$\dot{Q}_{abs} = I_b\,.A_p.F_t.(\tau_g\alpha_p) \tag{3}$$

α_p= 0.97, τ_g= 0.95, F_{sh}= 0.98, F_d= 0.97, Ft= F_d. F_{sh}

A sequence of finite differences can be used to represent the thermal equilibrium Eq. 4 (Touaba et al., 2020).

$$\mathbf{I_T(\tau\alpha)_e A_p = m_w C_w\left(\frac{\Delta T_w}{\Delta t}\right) m_c\, C_c\left(\frac{\Delta T_c}{\Delta t}\right) + U_L A_a(T_p - T_a)} \tag{4}$$

Calculate the total heat transfer coefficient (from the bottom of the collector and above) as in Eq. 5 (Rostami et al., 2022).

$$\boldsymbol{U_L = U_b + U_t} \tag{5}$$

Using a technique developed by Duffy and Beckman, as shown in Eq. 6, that may get an explicit formula for U_b and U_t. (Touaba et al., 2020).

$$U_b = \frac{K}{L} \tag{5}$$

Where K and L are the thermal conductivity and thickness of the insulation, respectively (Vengadesan et al., 2020).

$$U_t = \tau\varepsilon_b 4\sigma\bar{T}^3 \frac{T_p - T_s}{T_p - T_a} + [\frac{1}{h_{p-c} + h_{r,p-c}} + \frac{1}{h_w + h_{r,s-c}}]^{-1} \quad (6)$$

$$h_{r,s-c} = \varepsilon_c \sigma \frac{(T_c^2 - T_s^2)(T_c^2 + T_s^2}{(T_c - T_a)} \quad (7)$$

Utilizing Eq. 11 and 12, get the h w wind convection coefficient (w/m^2.^{o} C) (Touaba et al., 2020).

$$T_s = 0.0552 T_a^{1.5} \quad (8)$$

$$h_{r,p-c} = \frac{(T_p^2 + T_c^2)(T_p + T_c)}{\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_c} - 1} \quad (9)$$

$$h_w = 5.7 + 3.8\,V \quad (11)$$

$$T_C = T_P - \frac{U_t(T_p - T_a)}{h_{p-c} + h_{r,p-c}} \quad (12)$$

The thermal efficiency (Vengadesan and Senthil, 2020). Whereas in Eq. 13.

where ηcol, I, and Acol are the collector's efficiency, irradiance, and collector area, respectively.

$$\eta_{col,} = \frac{Qu}{IAcol.} \quad (13)$$

4. RESULTS AND DISCUSSION

The most significant findings of the comparison between a commercial and locally produced solar heater will be covered in this section based on the parameters (outgoing water temperature, water flow rate in the exchanger pipes, heat efficiency, and incident solar radiation intensity) and how they relate to the amount of time that the sun is exposed during the day. The temperature variations between residential and commercial solar water heaters between 9:30 am and 3:30 pm are depicted in Fig. 6. The Locally Manufactured Flat Plate Solar Water Heater achieved a temperature difference of 24.167 °C at 1:55 pm, outperforming the commercial heater which only reached 9.631 °C.

Additionally, the homemade heater has a quicker temperature rise, demonstrating superior efficiency in water heating. Although the homemade heater has a smaller capacity, it is more cost-effective than the expensive commercial heater. The utilization of recycled materials along with clever design probably helps with this. The aluminum fins on the heat exchanger tubes help to boost the surface area for absorbing solar radiation, while the black coating improves heat absorption. By overseeing different factors and modifying pump speed or valve positions, an electronic control system can effectively regulate temperature with accuracy. This helps avoid excessive heat buildup and promotes effective energy use. The system also controls the beginning and ending processes, starting the pump in the morning and stopping it in the evening to avoid losing heat. In chilly environments, an anti-freeze shield stops freezing by moving heated water through the collector. Fault detection notifies users of problems, which helps prevent damage and ensure continuous operation. Certain controllers utilize

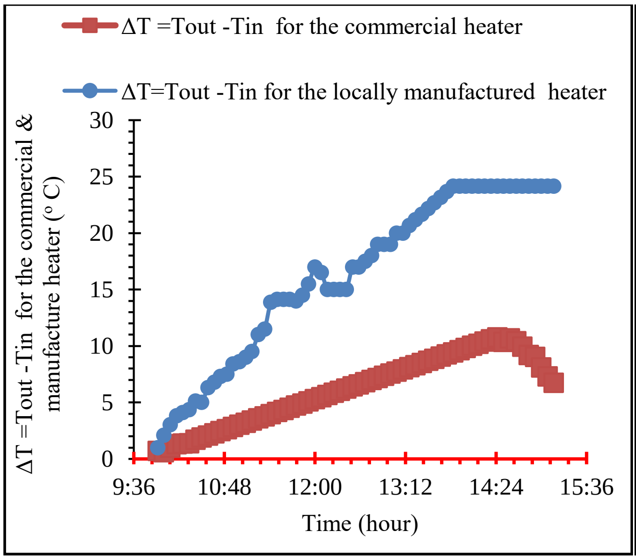

Fig. 6. The relationship between the temperature difference and time in hr. for (LMSH) and a (CSH)

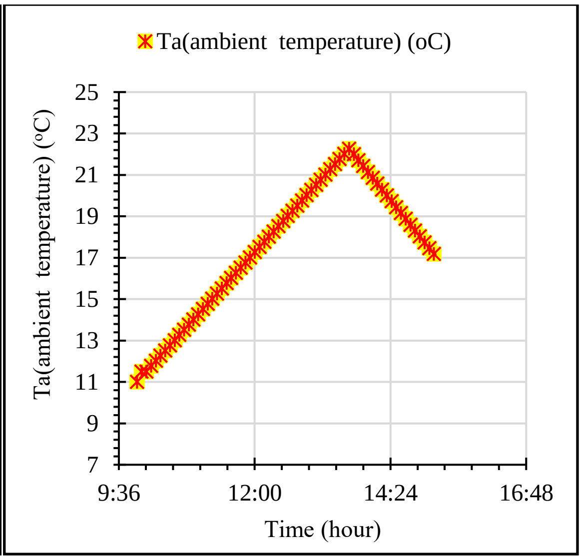

Fig. 6. The relationship between the air ambient temperatures(Ta). and time in hr.

predictive algorithms to enhance energy consumption efficiency by taking into account weather predictions and user habits. User-friendly interfaces make it possible for users to customize water temperature and operating hours, finding a balance between comfort and energy efficiency. In general, these systems improve effectiveness and prevent harm in different situations by using proactive control and automation. The behavior of air temperatures during solar radiation Hours follows a predictable pattern. The use of solar energy: Fig. 7 demonstrates the effective use of solar energy. The maximum air temperature of 21.77 degrees Celsius at 1:25 PM indicates a successful heat transfer from sunlight to the surrounding air. Sun angle and temperature change: As planet Earth rotates on its center line, the sun's location in the sky changes. The sun's rays strike the Earth straight as it emerges in the morning. This results in higher air temperatures, as shown in your data. However, as the angle of the sun decreases towards sunset, the intensity of solar radiation decreases. Thus, air temperatures gradually decrease. Solar energy beam inclination: The inclination of the Solar Beam indicates the angle at which sunlight reaches the Earth's surface. When the sun is directly overhead (near noon), the Solar Beam is more vertical, which leads to higher temperatures. When the sun moves toward the horizon, the solar Rays become more oblique, which reduces the heating effect. In short, your feedback corresponds to the basic principles of solar energy absorption and heat transfer.

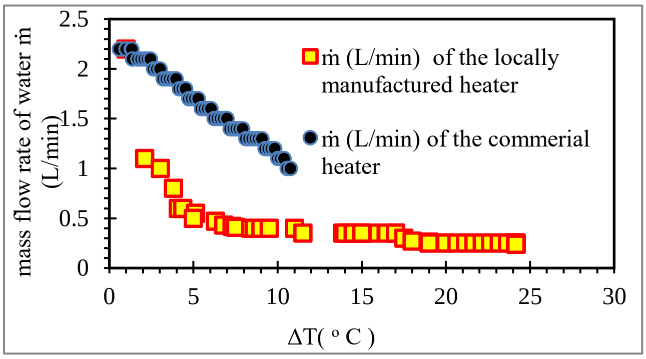

Fig. 7. The connection between the mass flow rate of water with the temperature differential (Tout – Tin) for both LMSH and CSH is compared.

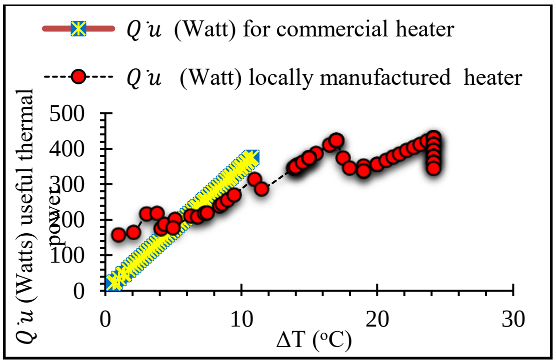

Fig. 8. useful changes in thermal energy as a function of temperature.

locally manufactured solar heater (LMSH) and explore the reasons behind its superior performance: Mass Flow Rate and Temperature Differential: Fig. 8 shows a comparison between the mass flow rate of water and the temperature differential ([ΔT]) for the locally made solar heater (LMSH) and the commercial solar heater (CSH). As water flow increases, [ΔT] decreases. This is because, with a larger water flow, more water needs to be heated over an extended period. The electronic control system, linked to the LMS, plays a crucial role in maintaining optimal conditions. LMSH vs. CSH Performance: The LMS outperforms the CSH due to its electronic control system. Without this control system, the CASH lacks precise regulation of water flow and temperature. The LMSH achieves hotter water in less time, enhancing user comfort and energy efficiency. Electronic Control System Adjustments: When the outlet temperature is below the set point, the microcontroller reduces the flow rate. This allows the water more time to heat up, ensuring efficient energy transfer. Conversely, if the outlet temperature exceeds the required level, the microcontroller raises the flow rate to maintain a constant supply of hot water. Factors Contributing to LMSH’s Superiority: Serpentine Fins and Black Coating: These enhance solar radiation absorption by increasing the surface area of the collector. Air Gap and Heat Retention: The trapped air between the glass cover and heat exchangers creates convection currents, retaining heat. Foam Insulation: By insulating the collection box's base and sides, heat loss is reduced, and total efficiency is increased.

The temperature differential ([ΔT]) between the hot water leaving the solar collector and the cold water entering it is compared with the quantity of heat that the collector's water gains in Fig.9. The main points are as follows: Comparing Commercial Heaters (CSH) with Homemade Heaters (LMSH): The commercial heater (CSH) continuously loses thermal energy to the handmade heater (LMSH).This superior performance is attributed to several factors, as mentioned earlier: Serpentine Fins and Black Coating: These enhance solar radiation absorption by increasing the collector's surface area. Air Gap and Heat Retention: The trapped air between the glass cover and heat exchangers creates convection currents, retaining heat. Foam Insulation: Insulating the sides and base of the collector box minimizes heat loss, improving overall efficiency. Heat Energy and Temperature Differential: The LMSH achieves a remarkable maximum heat energy output of 625.6 W. Its temperature differential ([ΔT]) is 35.2°C. In comparison, the CSH's peak power output is 607.7 W at a 20.7°C temperature difference. Overall Efficiency: The LMSH's ability to capture more thermal energy makes it an efficient choice for sustainable water heating. The combination of design features and the electronic control system contributes to its impressive performance.

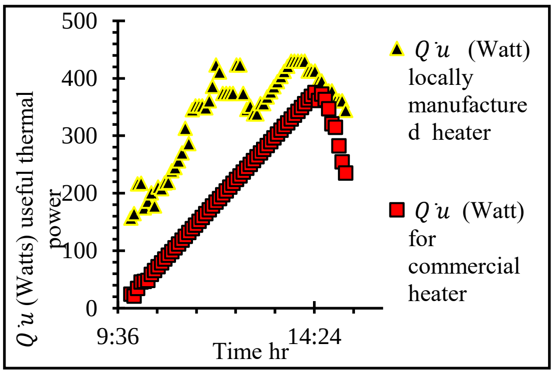

Fig. 9. The relationship between thermal power with time in hr.

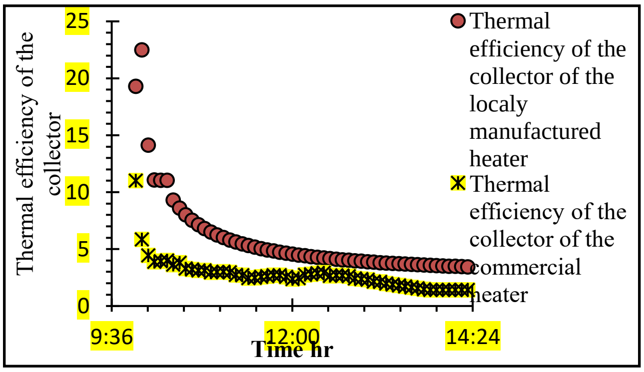

Fig. 10. Comparison of the thermal efficiency of the collector relationship between the (LMSH) and the (CSH) with time.

Fig. 10, Peak Thermal Energy: At 2:30 PM, both heaters reached their peak thermal energy output. The locally manufactured solar heater (LMSH) achieved 429.9 W, while the commercial heater (CSH) reached 372.3 W. About two hours after the sun started to slope toward sunset, there was a simultaneous peak. Energy Variation Over Time: Up to 2:20 pm, the energy progressively increases. After then, it gradually begins to decrease. Until sunset, this decreasing tendency persists.

Water as a Heat-Conducting and Storage Medium: Water, being an excellent conductor and heat-storage medium, plays a crucial role. Even as solar radiation intensity decreases after 12:30 p.m., water retains thermal energy. This property contributes to the sustained performance of both heaters.

Fig. 11, which focuses on the thermal efficiency of solar collectors for two types of heaters. Here are the key points:

- Thermal Efficiency and Thermal Energy Gained: The thermal efficiency of a solar collector depends on the amount of thermal energy gained. As thermal energy increases, efficiency improves. Conversely, increasing the surface area of the collector facing the sun can decrease efficiency.

- Locally Manufactured Heater (LMSH) vs. Commercial Heater (CSH): The LMSH, despite having a smaller surface area, acquires higher thermal energy than the commercial heater. This results in higher thermal efficiency for the LMSH during irradiation hours. Interestingly, efficiency is highest in the early morning when solar radiation intensity is lowest.
- Factors Impacting Improved Performance: S-Shaped Fins and Dark Coating: The LMSH utilizes serpentine fins, enhancing the heat exchange surface area. The black coating on the absorber plate improves solar radiation absorption.
- Air Gap and Heat Retention: The trapped air between the glass cover and heat exchangers creates convection currents, retaining heat. Long-wavelength heat radiation within this space is hindered from easily passing through the glass, leading to improved heat preservation.

From this the effectiveness of the thoughtful design and optimization in the solar heating system is clear.

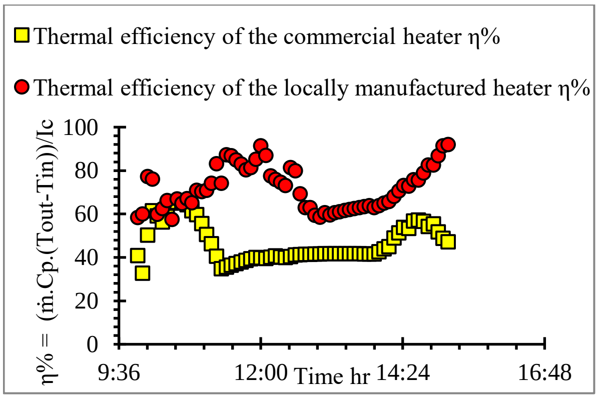

Fig. 12. The correlation between local and commercial solar heaters' thermal efficiency and comparative time

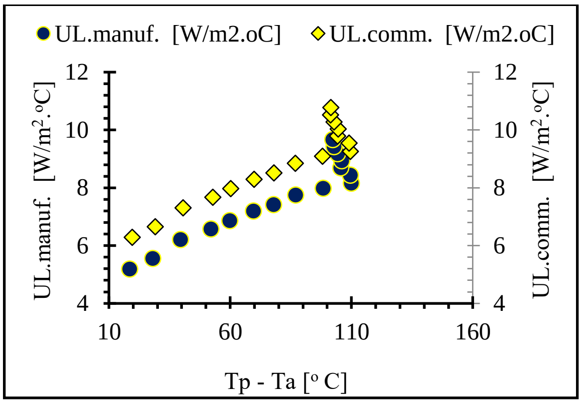

Fig. 13. Comparison of the total heat transmission rate as a loss from the bottom and top commercial and locally manufactured solar heater collector

The impact of foam insulation and the cold-water pipe regulator on solar heater efficiency, as well as the relationship between locally manufactured (LMSH) and commercial (CSH) heaters:

1. Foam Insulation: Foam insulation in the sides and base of the collector box minimizes heat loss through conduction. By maintaining elevated temperatures inside the collector, it improves overall heat transfer efficiency. Effective insulation ensures that less heat escapes, maximizing energy utilization.
2. Cold-Water Pipe Regulator: The control mechanism for the cold-water pipe manages water flow into the heater. By adjusting the flow rate, the system optimizes the time water spends in the collector. Longer exposure allows water to absorb more heat, enhancing overall performance.
3. Thermal Efficiency Comparison (LMSH vs. CSH): Fig. 12 contrasts the thermal efficiency of the LMSH and CSH over time. At 10:45, the CSH peaked at 66.2% efficiency. Around 02:35

pm, the LMSH reached its peak efficiency of 56.77%. Eq. 4 highlights the inverse relationship between efficiency and solar radiation intensity—efficiency decreases when radiation is directed westward.

4. LMSH Efficiency Variation: At noon, the LMSH achieved an impressive peak efficiency of 91.5%. As solar radiation intensity dropped, efficiency gradually decreased. However, it rose again by 3:05 p.m. Factors like solar flux intensity, cloud cover, and stored thermal energy influence this efficiency shift.

5. Performance Coefficient and Water Temperature: The performance coefficient

decreases as the water temperature at the collector outlet (Tout) increases. This is due to the balance between Tout and the temperature difference (Tout - Tin) in Eq. 12.

from Fig.13.

- Heat Transfer Rate Comparison (LMSH vs. CSH): The total heat transfer rate as a loss from the top and bottom of the solar collector for the commercial heater (CSH) and the locally produced heater (LMSH) is contrasted in Fig.13. Interestingly, the CSH loses heat at a faster pace than the LMSH.

- Reasons for LMSH's Lower Heat Loss: The LMSH benefits from thermal insulation: Sides, Base, and Edges: Insulating these areas minimizes heat loss. Glass Cover: The LMSH's glass cover is better insulated, reducing heat escape. Applying Eq. 6 to 8 reveals that the overall heat transfer coefficients (U_t and U_b) of the CSH are higher, leading to an increase in the overall heat loss (UL).

This work highlights the importance of insulation and design considerations in minimizing heat loss from solar collectors.

Due to biases and mistakes in accuracy, the study determines the measurement uncertainty value in Table 3. While bias error is associated with the accuracy and calibration of measurement equipment, precision error is linked to the repeatability of estimation. Because of the limited outdoor conditions, it was difficult to make precise estimations. The experiment was repeated to calculate precision error, yielding uncertainties based on bias error. A method for calculating bias error uncertainty is provided by the claim made by (Irshad et al., 2020) that R is a linear function for n independent normally distributed variables.

The following is how to determine the percentage difference:

1. Calculate the two values' difference.
2. Calculate two values' average.
3. Take the difference value and divide it by the average.
4. Multiply the obtained solution by 100 to get the percentage (%).

Table 3 Analysis of Measured Value Uncertainty% (Irshad *et al.*, 2020)

Parameter	Standard value (x)	Uncertainty (əx)	Relative error (əx/x)
$\Delta T=T_{out}-T_{in}$	6.388804 -71.18644	±0.64798	-0.009102525
$T_B=T_{abs.\ plate}$(° C)	(-13.3333) -(-4.65116)	±0.0868	0.018666612
I (W/m^2)	0.175439 - 0.194553	±0.000191	-0.000982457
ṁ (L/min)	0.40467 - 0.589578	± 0.00185	-0.003136277
T_{in} (° C)	0.927357 - 2.173538	±0.0125	-0.005733422
T_{out} (° C)	3.389831 - 6.451613	±0.0306	-0.004745762

5. CONCLUSIONS

Reoriented solar heaters made from recycled materials are a successful alternative to conventional heaters. These locally manufactured heaters proved to be more thermal energy gainers than the sun as they recorded the highest power gain of 429.9 W while the highest power gained by the commercial heater collector was 372.3 W. The heating speed of the water in the factory heater was recorded at about 30 minutes compared to the commercial one. Using innovative materials such as electronic water flow control systems, copper pipes and aluminium fins, the thermal effectiveness of the solar heater has been improved, the highest efficiency (83%) and the highest temperature (55 °C) have been recorded. Research shows that these heaters are cost-effective, safe and environmentally friendly, reducing waste and saving resources. The interdisciplinary approach to integrating solar energy, engineering and waste management demonstrates the potential for innovation in sustainability. The study proposes various applications of solar heaters other than water heating, highlighting their versatility and effectiveness. The integration of electronic control systems enhances the performance of solar heaters, ensuring a constant supply of hot water and increasing the benefits of solar heating for home use.

Suggestions: By adding solar panels and batteries and converting the heater into a hybrid powered by thermoelectric energy, the produced heater can be improved to provide hot water even on overcast days or at night.

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Conflicts of Interest: The authors declare no conflict of interest.

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APPENDIX

Electronic control system programming

KODE heat sensor

```
#include <LiquidCrystal.h>
long  LM35;
LiquidCrystal lcd(12,11,5,4,3,2);
void setup()
{
 LM35 = 0;
 lcd.begin(16,2);
 pinMode(7, INPUT);
 pinMode(8, OUTPUT);
 pinMode(9, OUTPUT);
 pinMode(10, OUTPUT);

}
void loop()
{
   if (digitalRead(7) == 1) {
    LM35 = (analogRead(A0) * 0.0048828125) * 100;
    lcd.setCursor(1, 0);
    lcd.print("Summr System");
    lcd.setCursor(1, 1);
```

```
    lcd.print("Temprature");
    lcd.setCursor(12, 1);
    lcd.print(LM35);
    if (LM35 >= 45) {
      digitalWrite(8,HIGH);
      digitalWrite(9,LOW);
      digitalWrite(10,LOW);

    } else if (LM35 <= 35) {
      digitalWrite(8,LOW);
      digitalWrite(9,HIGH);
      digitalWrite(10,LOW);
    } else if (LM35 > 35 && LM35 < 45) {
      digitalWrite(8,LOW);
      digitalWrite(9,LOW);
      digitalWrite(10,HIGH);
    }

  } else {
    LM35 = (analogRead(A0) * 0.0048828125) * 100;
    lcd.setCursor(1, 0);
    lcd.print("Winter System");
    lcd.setCursor(1, 1);
    lcd.print("Temprature");
    lcd.setCursor(12, 1);
    lcd.print(LM35);
    if (LM35 >= 65) {
      digitalWrite(8,HIGH);
      digitalWrite(9,LOW);
      digitalWrite(10,LOW);

    } else if (LM35 <= 55) {
      digitalWrite(8,LOW);
      digitalWrite(9,HIGH);
      digitalWrite(10,LOW);
    } else if (LM35 > 55 && LM35 < 65) {
      digitalWrite(8,LOW);
      digitalWrite(9,LOW);
      digitalWrite(10,HIGH);
    }
    }
    }
```

Code Flowmeter

```
#include <LiquidCrystal.h>
LiquidCrystal lcd(12, 11, 5, 4, 3, 2);
int X;
int Y;
float TIME = 0;
float FREQUENCY = 0;
float WATER = 0;
```

```
float TOTAL = 0;
float LS = 0;
const int input = A0;
void setup()
{
Serial.begin(9600);
lcd.begin(16, 2);
lcd.clear();
lcd.setCursor(0,0);
lcd.print("Water Flow Meter" );
lcd.setCursor(0,1);
lcd.print("****************");
delay(2000);
pinMode(input,INPUT);
}
void loop()
{
X = pulseIn(input, HIGH);
Y = pulseIn(input, LOW);
TIME = X + Y;
FREQUENCY = 1000000/TIME;
WATER = FREQUENCY/7.5;
LS = WATER/60;
if(FREQUENCY >= 0)
{
if(isinf(FREQUENCY))
{
lcd.clear();
lcd.setCursor(0,0);
lcd.print("VOL. :0.00");
lcd.setCursor(0,1);
lcd.print("TOTAL:");
lcd.print( TOTAL);
lcd.print("L");
}
else
{
TOTAL = TOTAL + LS;
Serial.println(FREQUENCY);
lcd.clear();
lcd.setCursor(0,0);
lcd.print("VOL.: ");
lcd.print(WATER);
lcd.print(" L/M");
lcd.setCursor(0,1);
lcd.print("TOTAL:");
lcd.print( TOTAL);
lcd.print(" L");
}
}
```

```
delay(1000);
}
#include <LiquidCrystal.h>
LiquidCrystal lcd(12,11,5,4,3,2);
long  T1;
long  T2;
long  T3;
long  T4;
long  T5;
long  T6;
void setup()
{
  lcd.begin(20,4);
```