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Investigation of Thermal Energy Efficiency of Different Area of Galvanized Iron Sheet Absorber Solar Water Heater

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Abstract: The increasing global demand for energy, coupled with the environmental consequences of fossil fuel consumption, has intensified the search for sustainable and renewable energy sources. Among these alternatives, solar energy has emerged as one of the most abundant, clean, and viable options, particularly in regions with high solar radiation such as Nigeria. Solar energy collectors are the main component of solar water heating systems, therefore evaluating their thermal absorption performance and efficiency are of utmost important. This research aims at investigating the thermal energy efficiency of different area of galvanized iron sheet absorber solar water heater in temperate climate of Sokoto State, Nigeria. This was achieved by outlining specific objectives that guided the study. These are; to investigate the mean thermal energy absorption performance of two solar collectors with different areas; to determine difference in thermal energy output of the solar collectors' base on area and to investigate the mean thermal energy efficiency of two solar collectors with different areas. Solar water heating systems were constructed based on some design assumption and the set up was put in place in accordance with the latitude of the location. The required parameters were measured and recorded from the hours of 9:00am to 16:00pm with an interval of 30minutes for six (6) days and the analysis was carried out base on the average data collected using descriptive statistics and a paired sample t-test. It is found out that the mean thermal energy efficiency of the collector with area 0.54 m^2 reaches to about 36% while that of area 1.04 m^2 is 28%. This shows that the solar collector with the smaller area produces better efficiency with a mean difference of 8% when compared to that with larger area. However, the thermal energy absorption performance of solar plate collector of area 1.04 m^2 is 59.32ºC and that of solar collector of area 0.54 m^2 is 64.20ºC thereby producing a mean difference of 4.88ºC. The study's hypotheses proposed that there is significant difference in mean thermal energy absorption performance, mean thermal energy output and the mean energy efficiency of two different solar collectors with different cross sectional areas. Findings from this research also provide valuable insight into the effectiveness of utilization of solar energy from the conventional method of heating water.

Keywords: *Solar Water Heater, Thermal Collector, Radiant, Rays.*

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I. INTRODUCTION

The increasing global demand for energy, coupled with the environmental consequences of fossil fuel consumption, has intensified the search for sustainable and renewable energy sources. Among these alternatives, solar energy has emerged as one of the most abundant, clean, and viable options, particularly in regions with high solar radiation such as Nigeria. Solar water heating systems represent one of the most efficient and cost-effective applications of solar energy, as they directly convert solar radiation into thermal energy for domestic and industrial use [4].

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A solar water heater typically consists of a collector, storage tank, and circulation system, with the absorber plate playing a critical role in determining overall system performance. The absorber is responsible for capturing solar radiation and converting it into heat, which is then transferred to the working fluid, usually water. Materials commonly used for absorber plates include copper, aluminum, and galvanized iron sheets. Among these, galvanized iron sheets are widely used due to their affordability, availability, corrosion resistance, and mechanical strength, especially in developing countries [2].

The thermal efficiency of a solar water heater largely depends on several factors, including the material properties, surface characteristics, and geometric configuration of the absorber plate. A higher thermal conductivity material has a better heat absorption as well as provided better efficiency of the system. In particular, the surface area of the absorber plays a significant role in determining the amount of solar radiation absorbed and the rate of heat transfer to the fluid. Variations in absorber area can influence heat gain, thermal losses, and overall system efficiency. Therefore, investigating the effect of different absorber areas on thermal energy efficiency is essential for optimizing the design and performance of solar water heating systems [3]. A flat plate solar collector performs with all modes of heat transfer such as conduction, convection and radiation [8]

In regions such as Nigeria, where energy access remains a challenge and solar radiation is abundant throughout the year, improving the efficiency of low-cost solar water heaters can have significant socio-economic and environmental benefits. The use of locally available materials like galvanized iron sheets can further enhance the feasibility and adoption of such systems in rural and urban communities.

[6] Deals with design consideration of the solar water heaters to obtain hot water for the domestic and industrial applications. Design of solar water heating system is important to assure maximum benefit to the users, so they concentrate and analyze absorber plate materials, absorber and glazing coating along with the changes in the design. Designing a solar water system involves appropriate selection of each component of the desired capacity and location of installation for solar water heater to produce hot water. Various factors and correlations for design of collector, storage tank and insulating material are briefly discussed. Constructional element of a flat plate solar collectors and operational characteristics are clearly defined and shows its importance to get better thermal performance.

[5] Worked on helical internal grooved solar flat plate collectors to enhance their conversion efficiency by reducing heat loss from the collector surface. In an experiment conducted in three ways, case-I: plain tube, case II: internal groove with 0.43 pitch and case-III: internal grooved with 0.44 pitches. Every case analyzes with two identical mass flow rates of 0.01 Kg/sec and 0.015 Kg/sec.

[9] investigated the performance of two different types of evacuated tube collector and reported that the performance evacuated tubes collector with heat pipe design was better than that of water-in-glass design and it efficiency has been found to be 15 to 20 higher.

[10] studied the analysis of thermal efficiency of a passive solar water heater and it was reported that the peak temperature of the heated water was about 83ºC, while the maximum daily average useful efficiency was about 42%.

[11], carried out a review of solar water heating systems and it was concluded that there is a need to work on the generated design procedure to select, install and monitor the solar water heating systems as per the availability of solar radiation and local geographical condition.

[12], carried out a study on energy analysis of a flat plate solar collector. The energy efficiency was reported to be 5.96%; it was concluded that the largest energy loss is caused by the temperature difference between the absorber plate surface and sun, accounting for 72.86% of the total energy rate.

Despite the growing interest in solar water heating technology, there remains a need for detailed studies that examine how design parameters such as absorber surface area affect system performance, particularly when using cost-effective materials like galvanized iron. Understanding these relationships will contribute to improved system design, enhanced energy efficiency, and broader utilization of renewable energy technologies.

Hence, from the above reviews, most of the researchers dealt with either solar thermal collector efficiency or design performance of a single system. This research paper investigated the efficiency of different area of solar collector where the temperatures outlet, inlet and collector were compared. This study therefore, investigated the thermal energy efficiency of different areas of galvanized iron sheet absorbers in solar water heaters. The findings are expected to provide valuable insights into optimal design configurations and promote the development of efficient, affordable, and sustainable solar thermal systems.

➢ *Statement of the Problem*

Many researchers have investigated the performance different solar water heater systems at different location in the world. But most the literature either investigated the performance of one system alone while solar compares the performance of different types of solar water heater. In most cases the area of the solar collector would be known but the quantum of thermal energy generated by the solar water heater cannot be predicted. Moreover, there are instances where the amount of thermal energy need for a specific application is known but the approximate collector area for generating such amount of thermal energy cannot be predicted. These two cases pose a serious problem and this research is designed to address these problems.

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➢ *Objectives of the Study*

- To investigate the mean thermal energy absorption performance of two solar collectors with different areas.
- To determine difference in thermal energy output of the solar collectors base on area.
- To investigate the mean thermal energy efficiency of two solar collectors with different areas?

➢ *Research Questions:*

- Is there any difference in the mean thermal energy absorption performance of two solar collectors with different areas?
- Is there any significant difference in thermal energy output of the solar collector base on area?
- Is there any difference in the mean thermal energy efficiency of two solar collectors with different areas?

➢ *Null Hypotheses:*

- H01. There is no any significant difference in the mean thermal energy absorption performance of two solar collectors with different areas?
- H02. There is no any significant difference in thermal energy output of the solar collector base on area?
- H03. There is no any difference in the mean thermal energy efficiency of two solar collectors with different areas?

II. MATERIALS AND METHOD

In this study, two glass sheets were used as transparent glass with an area of 1.04m^2 and 0.54m^2 respectively. This is because glass is a good insulator with sunlight and heat transparency. It has a good insulating response against visible light transmission. The absorber plate was made of galvanized iron sheet which is a good conductor of heat. It is malleable and relatively cheap. Both the absorber plate and the fluid flow channel (pipes) were painted black to increase absorbance and retention of the absorbed heat which form the heat exchanger. The water storage tank was made of galvanized iron which is a good conductor of heat and sun ray. The experiment was set up at Sokoto Energy Research Centre for six days (i.e between 8th to 13th May, 2026) between the hours of 9:00am to 4:00pm. Plate 1 shows the experimental set up for thermal energy assessment of black-painted galvanized iron sheet absorber solar water heater.

Plate 1: An Experimental Setup for Thermal Energy Assessment of Blacked-Painted Galvanized Iron Sheet Absorber Solar Water Heater.

The parameters measured are the solar radiation, ambient temperature, temperature of the water at the top of the tank, collector inlet temperature, collector outlet temperature, and absorber's surface temperature. The solar radiation was measured using Pyrometer and the temperature parameters were measured by a four channel data logger and infrared thermometer. The water temperature in the storage tank was measured by submersing the thermocouple connected to channel 1 of data logger, i.e data logger's channel 1 is dedicated to measure water temperature in the tank. Channel 2 thermocouple is dedicated to measure inlet water temperature. This was achieved by inserting the thermocouple into a small hole that was drilled through the pipe. The pipe outlet temperature was also measured using similar procedure as inlet water temperature but with channel 3. The ambient temperature was measured by channel 4 thermocouple place freely closed to the solar water heater. The absorber's surface temperature was measured using the infrared thermometer placed at the top and bottom side of the absorber. A descriptive statistics comprises of mean and standard deviation was carried out to find the nature and strength of the relationship among the parameters using t-test.

The performance evaluation of the solar water heating systems depends on the system and environmental condition. The incident energy on the collector can be determined from;

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$$Q_c = AG \qquad 1$$

Where Q_c(W) is the incident energy on the collector, A (m^2) is the area of the thermal collector and G (W/ m^2) is the Incident solar radiation.

For the useful energy absorbed by water inside the collector can be calculated using;

$$Q_f = \dot{m}C\Delta T \qquad 2$$

Where Q_f (W) is the energy absorbed by water, $\dot{m}$ (kg/s) is the mass flow rate , C (Jkg-1K-1) is the specific heat capacity of water, $\Delta T(K)$ is the temperature difference between inlet and outlet temperature of water.

Therefore, the energy efficiency of the water heating system can be determined from;

$$\eta = \frac{\dot{m}C\Delta T}{AG} \qquad 3$$

Where, η is the efficiency of the system [7]

III. RESULTS

The data collected were analyzed using descriptive and correlation statistics. The following tables present the mean data obtained from the field work that was carried out for six (6) days from 9:00am to 4:00pm.

Table 1 AREA I Mean Values

Time	G(W/m²)	T*a* (°C)	T*in* (°C)	T*out* (°C)	T*t* (°C)	T*c* (°C)	E1 (%)
9:00	527	34.13	36.73	44.73	38.53	40.00	34.13
9:30	589	36.10	39.30	49.40	41.60	43.43	36.10
10:00	668	37.53	41.53	53.67	44.24	46.48	37.53
10:30	744	39.07	45.77	57.8	47.54	50.37	39.07
11:00	808	39.80	48.77	61.40	49.99	53.39	39.80
11:30	871	41.00	51.97	63.87	52.28	56.04	41.00
12:00	912	42.93	55.40	66.77	55.03	59.07	42.93
12:30	896	43.13	58.10	68.03	56.42	60.85	43.13
1:00	896	43.90	58.70	69.97	57.52	62.06	43.90
1:30	870	44.67	60.47	71.80	58.98	63.75	44.67
2:00	808	43.77	59.00	68.37	57.04	61.47	43.77
2:30	787	43.87	58.37	67.00	56.41	60.59	43.87
3:00	718	43.83	59.00	67.50	56.78	61.09	43.83
3:30	603	43.87	59.40	66.80	56.69	60.96	43.87
4:00	425	43.17	58.13	64.37	55.22	59.24	43.17
Mean tot.	**741**	**41.38**	**52.71**	**62.76**	**52.29**	**55.92**	**41.38**

Table 2 AREA II Mean Values

Time	G(W/m²)	T*a* (°C)	T*in* (°C)	T*out* (°C)	T*t* (°C)	T*c* (°C)	E2 (%)
9:00	551	34.80	37.27	40.80	34.73	54.87	34.80
9:30	625	35.70	39.23	43.97	36.50	56.80	35.70
10:00	677	37.27	41.03	46.33	37.17	59.17	37.27
10:30	764	38.07	41.63	47.3	40.47	63.57	38.07
11:00	857	39.50	42.77	49.30	41.63	65.00	39.50
11:30	893	41.13	46.43	52.13	42.83	67.23	41.13
12:00	920	43.37	48.23	54.57	44.70	69.43	43.37
12:30	936	44.53	52.20	58.17	45.50	69.77	44.53
1:00	913	44.60	52.13	58.57	47.43	69.43	44.60
1:30	824	44.33	54.33	60.00	48.37	68.33	44.33
2:00	795	44.67	56.03	60.97	48.57	67.07	44.67
2:30	777	44.97	54.45	61.27	49.53	63.93	44.97
3:00	665	44.50	55.70	60.80	49.30	63.37	44.50
3:30	567	44.43	54.73	60.00	49.60	63.07	44.43
4:00	494	44.30	54.40	59.30	49.27	62.00	44.30
Mean tot.	**751**	**41.74**	**48.71**	**54.23**	**44.37**	**64.20**	**64.20**

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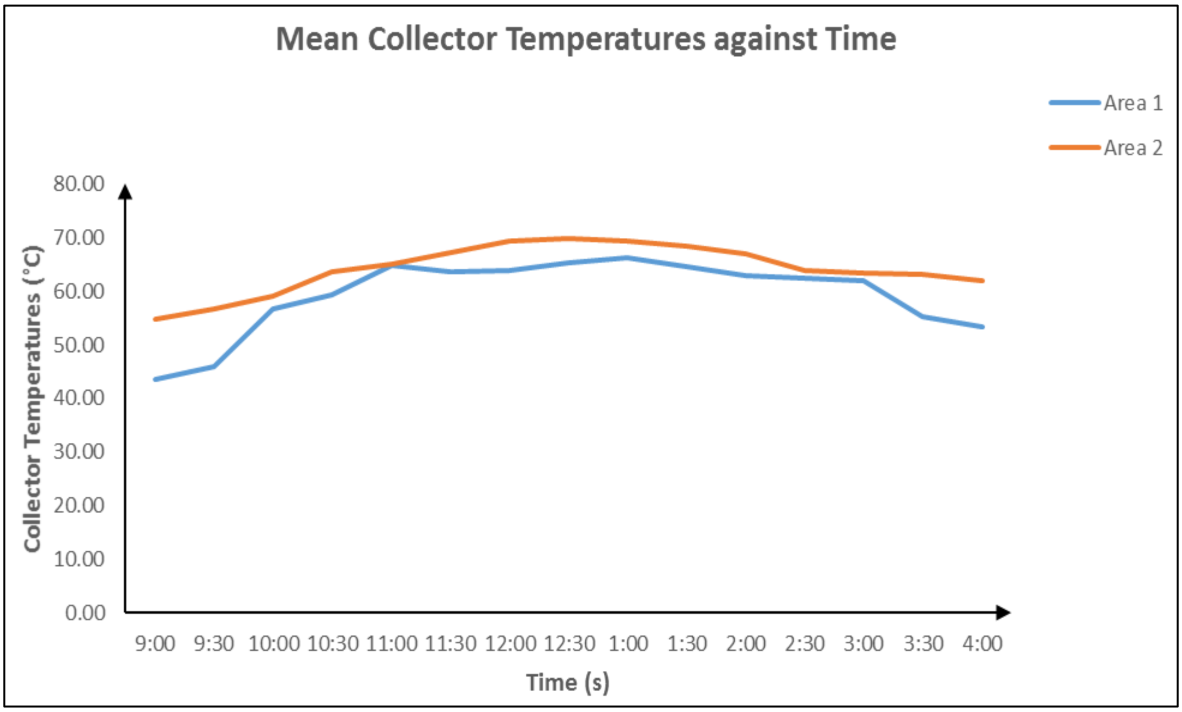

Fig 1 Variation of Collector Temperature with Time.

It is observed from figure 2 that the collector temperature for Area 1 increases from 43.63°C at 9.00am to a maximum of 66.17°C at 1.00pm while for Area 2 the collector temperature attains its highest value of 69.77°C at 12.30pm from which the temperature continue to decline to about 62.00oC around 4:00pm, while that of Area 1 decreases to 53.23°C at the same particular time.

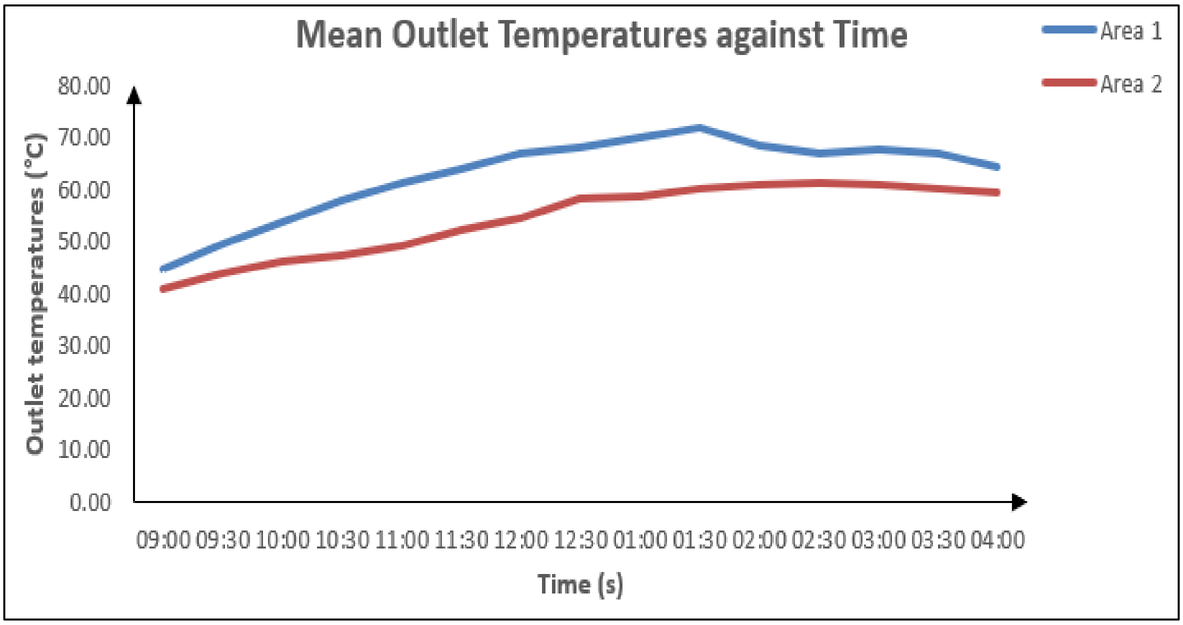

Fig 2 Variation of Collector Outlet Temperature with Time.

Figure 2 shows plots of daily variation of water temperature at the outlet of the collectors. It is seen from collector with area A1 that the outlet temperature during morning hours (9:00am) is 44.73°C and then continue to rise until it attains a value of 71.80°C at 1:30pm from which the temperature continue to decreased till it reaches a value of 64.37°C at 4.00pm. Likewise also for Area 2 collector the outlet temperature attains its highest value of 61.27°C at 2:30pm and decreased to 59:30°C at 4:00pm.

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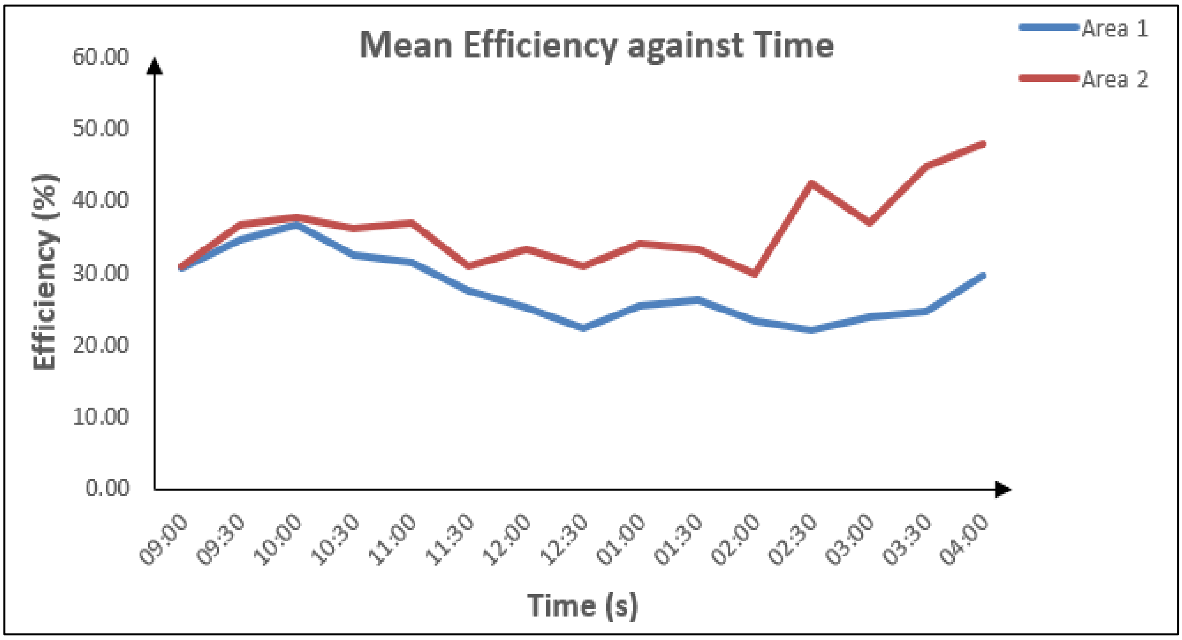

Fig 3 Variation of Efficiency with Time.

Above figure (Figure 3) shows the efficiency variation of the solar collectors with time. Initially at 9:00am the efficiency of the system with area 1.04 m^2 is at 30.49% and continued to increase linearly to 36.47% until the hour of 10:00am. As the time advances, the efficiency of the system then fluctuates between the values of 32.45% to 22.02% until 4.00pm. This fluctuation arises as a result of sudden changes in the weather condition that in turns affected the incoming solar radiation.

In the case of solar collector with area 0.54 m^2, the efficiency at 9.00am (when the intensity of the radiation is low) is 30.85%. As the time advances, the efficiency increases 37.69% at 10:30pm and then fluctuates between different values until it attains the highest value of 47.75% at 4:00pm.

➢ *Hypotheses Testing*

- H01. There is no any significant difference in the mean thermal energy absorption performance of two solar collectors with different areas?

Table 3 Thermal Energy Test for the Two Different Collectors

Item	N	Mean	Std. Dev.	t-cal	Mean difference	df	P-val	Decision
Thermal energy of SC1	45	59.32	8.17					
				5.018	4.882	44	0.00	H_{03} Rejected
Thermal energy of SC2	45	64.20	4.74					

Table (3) present data on the mean thermal energy absorption performance of the two solar collectors with different cross sectional area. The result obtained shows that the solar thermal collector with area 0.54 m^2 has overall mean value of 64.20 at 4. 74 standard deviation and 59.32 for solar collector of area 1. 04 m^2 at standard deviation of 8.17. The mean difference in terms of the collectors' thermal energy performance is 4.882 at 44 degree of freedom. The correlation result of 0.602 shows a moderate positive correlation in the thermal energy absorption performance between the two solar collectors. The calculated t-value is 5.018 at alpha value of 0.05 and p-value of 0.00.

Therefore since the P-value is less than the alpha value ($P<\alpha$), the t-calculated is statistically significant and hence the null hypothesis H01 that was earlier stated is rejected. That is there is significant difference in the mean thermal energy absorption performance of the two solar collectors with different areas.

- H02. There is no any significant difference in thermal energy output of the solar collector's base on area?

Table 4 Thermal Output Test for the Two Different Collectors

Item	N	Mean	Std. Dev.	t-cal	Mean difference	df	P-val	Decision
Thermal output of A1	45	62.76	12.07					
				3.767	8.531	44	0.00	H_{03} Rejected
Thermal output of A2	45	54.23	9.78					

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The study findings on the thermal energy output of the solar collector base on its area as revealed in Table (4) indicates that the mean value of thermal output for a collector of area 1.04 m^2 is 62.76 at 12.07 standard deviation while that of the solar collector of area 0.54 m^2 is 54.23 at a standard deviation of 9.78. The mean difference between the thermal energy outputs of the two solar collectors is 8.531 at 44 degree of freedom. The table also indicates a calculated t-value of 3.767 and that of P-value as 0.00 at alpha value of 0.05.

Therefore, based on the above statistical analysis, since the P-value is less than the alpha value ($P<\alpha$) and t-calculated is statistically significant, it implies that the hypothesis that was earlier stated is rejected, so that alternate hypothesis is accepted. That is there is significant difference in the thermal energy output of the solar collectors' base on area.

- H03. There is no any difference in the mean thermal energy efficiency of two solar collectors with different areas?

The table below shows the result of the statistical test carried out to find the level of the relationship between the efficiencies of a solar collector with area A1 (1.04 m^2) and that with area A2 (0.54 m^2).

Table 5 Efficiency Test for the Two Different Collectors

Item	N	Mean	Std. Dev.	t-cal	Mean difference	df	P-val	Decision
Efficiency of A1	15	27.63	4.56					
				4.901	8.423	14	0.00	H_{03} Rejected
Efficiency of A2	15	36.05	5.34					

The result of the relationship in the thermal energy efficiency is indicated in Table (5) above. From the table, the mean efficiency of the thermal collector with area 1.04 m^2 is 27.63 at standard deviation of 4.56 and that of the thermal collector with area 0.54 m^2 is 36.05 at standard deviation of 5.34. The calculated t-value is 4.901 at degree of freedom of 14. The table also shows that the alpha value is 0.05 and P-value of 0.00.

Therefore, based on the above result, since the p-value is less than the alpha value ($P<\alpha$), the t-cal value is statistically significant and the null hypothesis H03 that was earlier stated is rejected. That is there is significant difference in the mean thermal energy efficiency of the two solar collectors with different areas.

IV. DISCUSSION

Solar energy collectors are the main component of solar water heating systems, therefore evaluating their thermal absorption performance and efficiency are of utmost important. When radiant energy strikes the surface of a solar collector, a proportion of it is reflected, part is absorbed and part may be transmitted through the solar collector. The balance between the absorbed input energy and the heat lost to the surrounding determines the temperature attained. The heat lost increases with the temperature and limit the ultimate temperature attained by the collector system. It also reduces the proportion of useful heat energy extractable from the system. Maximum temperatures and maximum useful power outputs are therefore obtained when highly absorbent is exposed to high intensity solar radiation.

The study findings as reveals from the hypothesis test shows the overall mean thermal energy absorption for a flat plate absorber with area 0.54 m^2 is 64.20ºC while that of the solar collector with area 1.04 m^2 is 59.32ºC. This indicates that the smaller absorber absorbs more thermal energy compared to that of area 1.04 m^2 with a mean difference of 4.88ºC.

The result of hypothesis test in Table 2, shows a significant difference in the thermal energy output between the two solar collectors with a mean difference of 8.53ºC. Area 1 collector produces a higher thermal energy output of 62.76ºC when compared to 54.23ºC produced by a collector of area A2. This output of 54 – 62% can be suitable for domestic uses at homes and other places that do not requires extremely high temperature. As opined by [10] that, using the appropriate solar collector to heat the water can easily attain required temperature.

Also from table 3, the result of the relationship in the thermal efficiencies of the two solar collectors indicated that a solar collector of area 0.54 m^2 has a higher efficiency of 36% while that one with 1.04 m^2 has an efficiency of 28%. This result is in line with the findings of [1] that the annual average efficiency of a well-designed solar water heating systems with flat plate collectors in temperate climate regions is typically around 35 – 40%. It is also in close relationship with [10] that studied the analysis of thermal efficiency of a passive solar water heater and found that the peak temperature of the heated water was about 83ºC, while the maximum daily average useful efficiency was about 42%.

The result also indicates that there is significant difference in the mean thermal energy efficiency of the two solar collectors. That means the area of the collectors also plays a vital role in the thermal energy efficiency of the solar heating systems. Likewise also it can be observed that the efficiency curve of both areas have a closely good agreement. The little difference that may be observed in the efficiencies arises as a result of the collectors' size and weather conditions, such as the wind speed.

The thermal efficiency of collector increase with increasing solar radiation and the decreases with increasing ((Tin – Ta)/G)) parameter.

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V. CONCLUSION

The performance of the flat plate solar collector has been investigated experimentally in Sokoto temperate climate. Six (6) days round energy performance analysis of a commonly installed Solar Water Heating Systems with Flat Plate Collectors was carried out using a field installation. Galvanized iron sheet has been used as an absorber plate for both systems. The components' temperatures and solar radiation intensity are measured and collected by the data logger. It is found out that the mean thermal energy efficiency of the collector with area 0.54 m^2 reaches to about 36% while that of area 1.04 m^2 is 28%. This shows that the solar collector with the smaller area produces better efficiency with a mean difference of 8% when compared to that with larger area. Further, there are other parameters that might affect the collectors' efficiency such as wind speed, solar radiation and ambient temperature. However, it is found that the thermal energy absorption performance of solar plate collector of area 1.04 m^2 is 59.32^oC and that of solar collector of area 0.54 m^2 is 64.20^oC thereby producing a mean difference of 4.88^oC. A mean difference of 8.53^oC was observed in terms of the thermal output energy assessment between the two collectors. The results also showed that the efficiency of solar collector is highly depending on design/size of absorber plate and other external weather conditions.

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