World Journal of Advanced Engineering Technology and Sciences
eISSN: 2582-8266
Cross Ref DOI: 10.30574/wjaets
Journal homepage: https://wjaets.com/

(RESEARCH ARTICLE)

Check for updates

DEVELOPMENT AND EMPIRICAL PERFORMANCE EVALUATION OF A LOW-COST PASSIVE THERMOSYPHON SOLAR WATER HEATER USING LOCALLY SOURCED MATERIALS

Abdul Salam Yusuff [1,*], Ujam Oluchi Promise [2] and Mohammad-Jamiu Babatunde Balogun [3]

[1] Department of Electrical Electronics Engineering, African Institute of Science, Administration and Commercial Studies (IAEC), Lome Togo.
[2] Department of Mechanical Engineering, African Institute of Science, Administration and Commercial Studies (IAEC), Lome Togo.
[3] Department of Electrical Engineering, Bayero University, Kano, Kano State, Nigeria.
* Corresponding Author

ORCID Details
Abdul Salam Yusuff: https://orcid.org/0009-0006-4020-0842
Mohammad-Jamiu Babatunde Balogun: https://orcid.org/0009-0007-6871-3102

World Journal of Advanced Engineering Technology and Sciences, 2026, 21(01), 046–053

Publication history: Received on 07 August 2026; revised on 01 October 2026; accepted on 03 October 2026

Article DOI: https://doi.org/10.30574/wjaets.2026.21.1.0463

Copyright © 2026 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution License 4.0

ABSTRACT

This study presents the design, fabrication, and empirical performance evaluation of a cost-effective domestic solar water-heating prototype operating by passive thermosyphon circulation. The system uses locally sourced materials: an insulated wooden casing, a matte black aluminium absorber plate, 10 mm copper riser pipes, a 4 mm tempered-glass cover, and a 5 L insulated storage tank. The collector casing measured 63.5 cm by 30.8 cm, providing an aperture area of approximately 0.196 m^2. During a representative outdoor test from 08:00 to 18:00, water outlet temperature increased from 25.0 °C at 08:00 to 66.5 °C at 14:00; the largest recorded inlet-to-outlet temperature difference was 40.0 °C. A theoretical thermal-energy equivalent of approximately 837 kJ was calculated by applying this maximum temperature difference to the nominal 5 kg water inventory; it is not a direct measurement of energy stored in the tank. The estimated material and fabrication cost was NGN 120,000. The results demonstrate the practical feasibility of a locally fabricated passive solar heater for small domestic applications. Because solar irradiance, calibrated uncertainty, and repeat-day measurements were not recorded, collector efficiency and economic payback are not reported.

Keywords: Solar Thermal Energy; Flat-Plate Collector; Thermosyphon; Domestic Water Heating; Low-Cost Prototype; Thermal Performance

1 INTRODUCTION

Domestic water heating commonly depends on electricity or fossil fuels, both of which expose households to operating costs and contribute to upstream environmental impacts. Solar thermal water heating uses incident solar radiation directly as heat and can therefore reduce demand for conventional energy where adequate solar exposure is available

[1,2]. Flat-plate systems are especially relevant to domestic applications because they are mechanically simple, can be built from common materials, and need no electricity when configured as a thermosyphon loop [3,4].

Nigeria has a solar resource that can support small-scale thermal applications, but adoption is constrained by the price of imported systems, limited technical awareness, and the need for designs that can be fabricated and maintained locally. Earlier Nigerian work has demonstrated the feasibility of natural-circulation solar water heaters, while wider literature identifies collector construction, insulation, flow resistance, and tank elevation as critical design factors [4,5].

This work develops a domestic-scale flat-plate thermosyphon water-heater prototype using locally accessible materials. Its objectives were to document the prototype configuration, measure the daytime water-temperature response, calculate a theoretical thermal-energy equivalent based on the maximum measured temperature difference, and provide a material-cost schedule. The study contributes a practical fabrication case and a measurement-based baseline for subsequent, more fully instrumented testing.

2 MATERIALS AND METHODS

2.1 System configuration and operating principle

The system was configured as a passive thermosyphon solar water heater. Solar radiation passes through the glazing and is absorbed by the black aluminium plate. Heat is conducted to the water in the copper pipes. As water warms, its density decreases and it rises to the tank; cooler and denser tank water returns to the lower collector header. This buoyancy-driven circulation removes the need for a pump, provided that the tank is located above the collector and pipe resistance is kept low [6,7].

Table 1: Main prototype components and specifications.

Component	Specification	Purpose
Collector casing	Treated wood; 63.5 cm × 30.8 cm × 6.604 cm	Houses collector assembly
Absorber plate	1.0 mm aluminium sheet with matte black coating	Absorbs solar radiation
Glazing	4 mm tempered glass	Reduces convective and radiative heat loss
Riser network	Copper pipes; 10 mm nominal diameter; 10 m procured	Transfers heat to water
Storage tank	Plastic; 5 L capacity; elevated above collector	Stores heated water and supports thermosyphon flow
Insulation	Locally sourced sawdust collector lining and reflective-foam tank wrap	Reduces heat loss

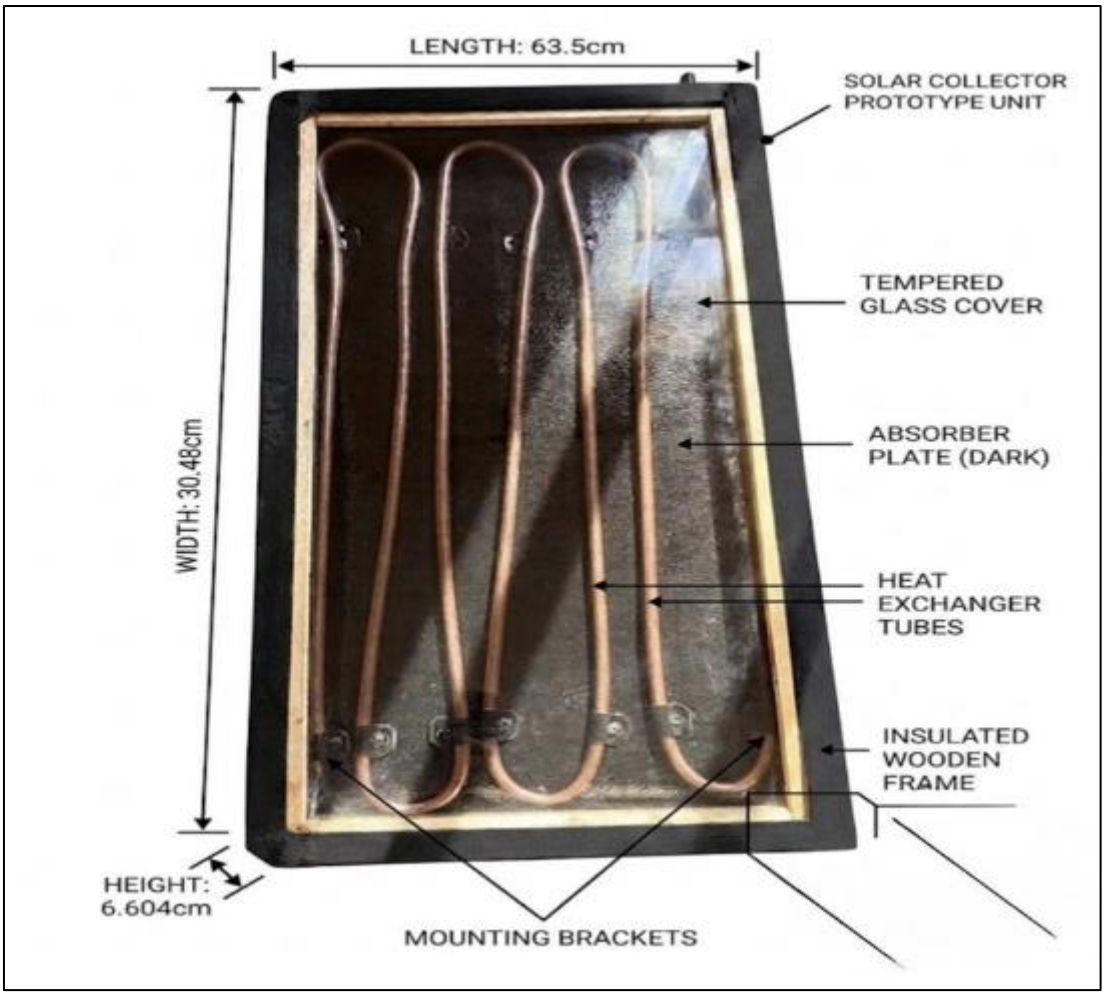


Figure 1: Labeled photograph of the fabricated solar collector unit.

2.2 Fabrication and assembly

A treated-wood collector box was fabricated and lined with locally sourced sawdust, which was not separately itemized in the recorded bill of engineering materials. The aluminium absorber plate was cleaned, coated with matte black paint, and fitted with a serpentine copper-tube network connected to upper and lower headers. A 4 mm tempered-glass cover was sealed over the collector. The insulated 5 L tank was mounted above the collector, with the hot-water line connected from the collector top to the upper tank region and the return line connected from the tank base to the lower header. The unit was placed outdoors without shading and oriented for maximum daily solar exposure. The collector was inclined at approximately local latitude plus 10 degrees, as reported in the project record.



Figure 2: Physical construction of the collector and elevated storage-tank assembly

2.3 Test protocol and data analysis

Testing was conducted in Kano State, Nigeria, under mostly sunny conditions with occasional cloud cover. Inlet temperature denotes water entering the lower collector header from the tank, while outlet temperature denotes water leaving the upper collector header and returning to the tank. Ambient, inlet, and outlet temperatures were manually recorded at approximately two-hour intervals. The project report identifies a digital thermometer, stopwatch, and measuring container, but does not record the thermometer model, resolution, accuracy, or a specified stabilization time. The representative sequence reported here covers 08:00 to 18:00. The measurement record does not contain solar irradiance, wind speed, calibrated instrument uncertainty, or per-day replicate readings. Accordingly, the results are presented as measured temperatures rather than a validated collector-efficiency value.

The collector aperture area derived from the reported collector length and width was 0.1956 m^2. A theoretical thermal-energy equivalent based on the maximum measured temperature difference was calculated from $Q = mc_p\Delta T$, where Q is the calculated thermal-energy equivalent, m is water mass, c_p is the specific heat capacity of water (4186 J kg^{-1} $°C^{-1}$), and ΔT is the maximum measured outlet-to-inlet difference [1,6]. For a 5 L tank, m was approximated as 5 kg and ΔT as 40.0 °C. This calculation does not establish that the whole tank increased by 40.0 °C and must not be interpreted as a direct calorimetric measurement of stored tank energy.



Figure 3: Completed passive thermosyphon solar water-heater assembly.

3 RESULTS AND DISCUSSION

3.1 Measured temperature profile

Table 2 presents the representative temperature record. Outlet temperature increased rapidly from late morning, reaching 58.1 °C at 12:00 and a maximum of 66.5 °C at 14:00. The largest inlet-to-outlet difference, 40.0 °C, occurred at 14:00. Thereafter, outlet temperature decreased as ambient temperature and solar input declined. The pattern is consistent with the expected daytime behavior of an unpumped flat-plate thermosyphon system [3,7]. For context, Agbo and Unachukwu [4] reported that a much larger 3.4 m^2 collector with 150 L storage could deliver water up to 80 °C on clear days in Nsukka. The 66.5 °C maximum observed here should not be treated as an efficiency comparison because collector area, storage volume, and test conditions differ substantially.

Table 2: Representative measured temperature data for the solar water heater.

Time	Ambient (°C)	Inlet (°C)	Outlet (°C)	Outlet – inlet (°C)
08:00	26.0	25.0	25.0	0.0
10:00	28.5	25.2	35.4	10.2
12:00	31.0	26.0	58.1	32.1
14:00	33.5	26.5	66.5	40.0
16:00	31.2	27.0	54.5	27.5
18:00	28.0	26.8	41.3	14.5

Figure 4 shows the separate ambient, inlet, and outlet temperature trajectories. Figure 5 isolates the outlet-to-inlet temperature difference, which reached its maximum at 14:00 and is the temperature difference used only for the theoretical thermal-energy-equivalent calculation.

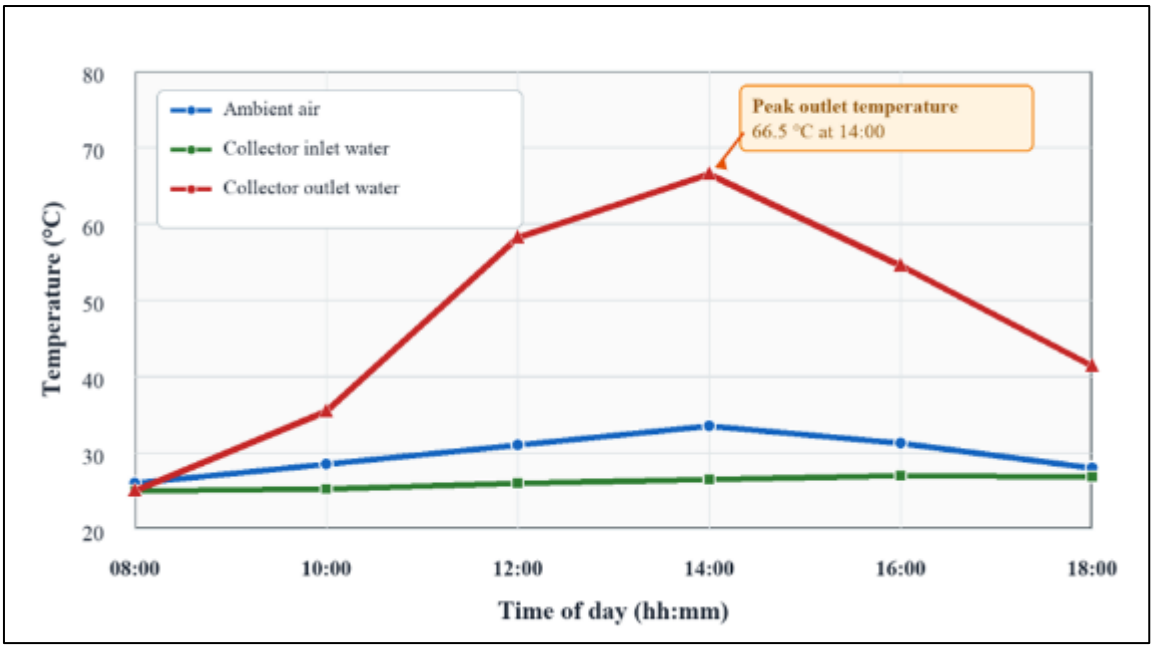


Figure 4: Measured ambient, inlet-water, and outlet-water temperature profiles during the representative test sequence.

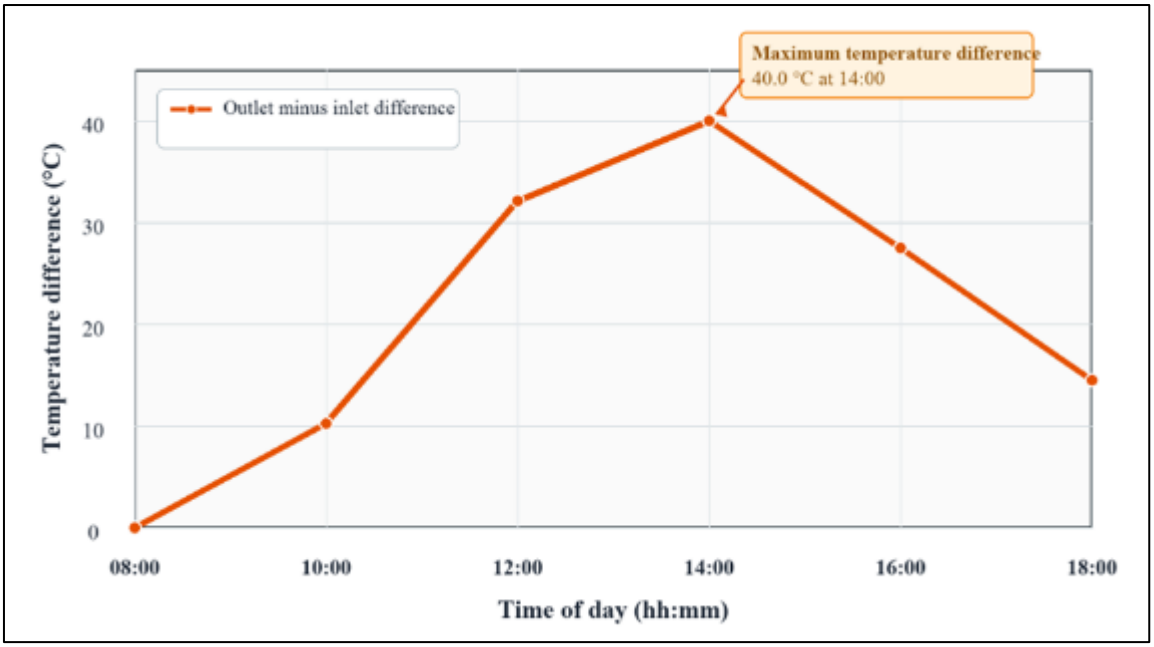


Figure 5: Measured outlet-minus-inlet water-temperature difference during the representative test sequence.

3.2 Theoretical thermal-energy equivalent

Applying the maximum measured inlet-to-outlet difference of 40.0 °C to the 5 kg nominal water inventory gives Q = 5 × 4186 × 40.0 = 837,200 J, or approximately 837 kJ. This is a theoretical thermal-energy equivalent, not experimentally measured stored energy, because the instantaneous 40.0 °C collector temperature difference is not evidence that the entire tank inventory experienced the same rise. A defensible collector efficiency would require simultaneous irradiance measurements, a defined time interval, a verified collector area, and a measured tank-temperature change; these were not available in the project record [1,2].

Table 3: Derived performance indicators from the documented prototype and representative data.

Indicator	Value	Interpretation
Collector aperture area	0.1956 m^2	Calculated from 63.5 cm × 30.8 cm collector plan dimensions
Maximum outlet temperature	66.5 °C at 14:00	Peak temperature recorded in the representative sequence
Maximum inlet-to-outlet difference	40.0 °C at 14:00	Largest recorded water-temperature difference
Theoretical thermal-energy equivalent	≈837 kJ	Q = mcpΔT for 5 kg and the 40.0 °C maximum measured difference; not measured stored energy
Collector efficiency	Not reported	Solar irradiance and replicate data were not available

The temperature profile supports the qualitative observation of natural circulation and useful domestic heating. Peak water temperature exceeds the range commonly required for washing and should be mixed with colder water before bathing. The observed fall after 14:00 also highlights sensitivity to time of day, cloud cover, wind-driven losses, and thermal leakage. Better pipe-to-plate bonding, improved edge insulation, selective coatings, and longer-term storage-loss testing are appropriate next steps [3,8,9].

3.3 Estimated cost and practical implications

Table 4: Estimated bill of engineering materials and fabrication cost for the prototype.

Item	Material or activity	Quantity	Cost (NGN)
Collector casing	Treated wood	1	15,000
Riser pipes	Copper	10 m	46,000
Glass cover	4 mm tempered glass	1	9,000
Thermal insulation	Reflective foam; sawdust not separately itemized	2 yards + local sawdust	8,000
Storage tank	Plastic	5 L	3,000
Miscellaneous hardware	Fittings, sealant, tape	3	8,000
Fabrication and labour	Assembly, welding, machining	—	16,000
Transportation	—	—	15,000
Total			120,000

Copper piping represented the largest direct cost. The simple geometry, passive circulation, and use of non-specialized casing and insulation materials make the concept attractive for demonstration and small domestic applications. However, economic payback cannot be estimated from the available record because baseline water-heating energy use, equipment lifetime, maintenance costs, and local electricity or fuel tariffs were not documented.

3.4 Study limitations

The project was a prototype-scale investigation with a 5 L tank and a limited documented measurement set. Solar irradiance was not measured, there was no automated logger or uncertainty analysis, and daily replicate data were not preserved in the report. The results therefore establish proof of operation and temperature response, not a statistically generalizable thermal-efficiency comparison. Future testing should record irradiance, wind speed, water volume, tank temperature, inlet and outlet temperatures, and weather conditions at shorter intervals over clear and cloudy days. A separate overnight retention test and a comparison with an electric heater would strengthen thermal and economic conclusions.

4 CONCLUSION

A domestic-scale thermosyphon solar water heater was designed and fabricated with a treated-wood flat-plate casing, a black aluminium absorber, copper tubes, tempered-glass glazing, insulation, and a 5 L elevated storage tank. The

representative outdoor temperature record showed an increase in outlet water temperature from 25.0 °C at 08:00 to 66.5 °C at 14:00, with a maximum inlet-to-outlet difference of 40.0 °C. Applying that instantaneous difference to the nominal 5 kg water inventory gives a theoretical thermal-energy equivalent of about 837 kJ; it is not a direct measurement of energy stored in the tank. The estimated NGN 120,000 prototype demonstrates that passive solar water heating can be assembled from accessible components for domestic use. Before the system is positioned against commercial collectors or conventional water heaters, future work must obtain irradiance, repeat-day, uncertainty, heat-retention, and lifecycle-cost evidence.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Acknowledgments

The authors acknowledge the Department of Electrical Engineering, African Institute of Science, Administration and Commercial Studies (IAEC), Lome, Togo, for the academic setting in which the project was completed.

Disclosure of conflict of interest

All authors declares no conflict of interest to be disclosed.

REFERENCES

[1] Duffie JA and Beckman WA. (2013). Solar engineering of thermal processes. 4th ed. John Wiley and Sons.

[2] Kalogirou SA. (2014). Solar energy engineering processes and systems. 2nd ed. Academic Press.

[3] Michael JJ, Iniyan S and Goic R. (2015). Flat plate solar water heating systems A review on design considerations limitations and innovations. Renewable and Sustainable Energy Reviews, 50, 1298-1311.

[4] Agbo SN and Unachukwu GO. (2007). Design and performance features of a domestic thermosyphon solar water heater for an average-sized family in Nsukka urban. *Trends in Applied Sciences Research*, 2(3), 224–230. doi:10.3923/tasr.2007.224.230.

[5] Sambo AS, Bello MB and Ibrahim Y. (2011). Design construction and testing of a natural circulation solar water heater for domestic application. Journal of Engineering and Applied Sciences, 6(3), 184-191.

[6] Çengel YA and Boles MA. (2019). Thermodynamics An engineering approach. 9th ed. McGraw-Hill Education.

[7] Morrison GL and Ranatunga DBJ. (1980). Thermosyphon circulation in solar collectors. Solar Energy, 24(2), 191-198.

[8] Shariah A and Shalabi B. (1997). Optimization of design parameters for a thermosyphon solar water heater. Solar Energy, 61(4), 223-232.

[9] Dincer I and Rosen MA. (2011). Thermal energy storage Systems and applications. 2nd ed. John Wiley and Sons.