Prediction of Thermal Parameters for Flat Plate Solar Water Heater by Machine Learning - a Review

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Prediction of thermal parameters for flat plate solar water heater by machine learning - A Review

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Abstract— **The world has been in greater need of energy over the past few years; thus, researchers have been working consistently on the development of solar energy-based applications. Solar based applications are one of the best options because it is endlessly abundant and perfect for both industries and domestic applications. The present review is majorly focused on studying the possibilities of using solar water heaters and optimizing a heating process with advanced machine learning for micro or/and small-scale industries in India. Small-scale industries such as hospitals, chemical plants, and waste management plants continuously require hot water they primarily rely on electric heaters or/and gas heaters. These heaters run directly or indirectly on fossil fuels and may cause harm to the environment. To avoid the consumption of fossil fuels and to use solar energy as a primary energy source of heating, introducing solar water heating integrated with machine learning is worth exploring. Various thermal parameters such as mass flow rate, irradiation, tilt angle, wind speed, and designing parameters have their effects on the performance of solar water heating systems. The present article review conducted on the study of thermal parameters, nanofluid as a working heat transfer fluid, and machine learning use in solar water heating applications which can enhance the system performance.**

Keywords— Solar water heater, machine learning, thermal parameters, and flat plate collector.

I. INTRODUCTION (*HEADING 1*)

The demand for energy sources is rising along with the worldwide energy demand, which is growing daily. A vast quantity of energy has been consumed solely to heat water in clinics, homes, and multiple processes in numerous sectors. Numerous options such as renewable energy resources can help diminish fossil fuel utilization [1]. There are not many direct environmental sources that we can use to meet the need for energy. To meet the demand, we also need to concentrate on the renewable energy component for the future. Solar energy is receiving the most attention out of all the renewable energy sources that are currently accessible. The solar thermal heating system is the primary subject of this literature. The efficiency of a solar heating system can be increased by utilizing flat plate collectors, heat pipes, inclination (tilted) angles, nanofluids, radiation levels, wind speeds, mass flow rates, and phase change materials, among other aspects. This literature contains a substantial quantity of experimental reviews, literature reviews, and research. Several fossil fuels are used to meet the demand, but solar energy is a backup option that has great promise for meeting the needs of several commercial, industrial, and residential applications, particularly water heat heating. The solar radiation, system requirements, and system location all affect how a solar thermal heat system is installed, so these factors must be taken into consideration when developing [2]. In the 1760s and early 1800s bare tank heaters developed by the USA of two small boxes (filled with water) were fabricated inside a rectangular box then in 1891 1st commercial solar water heater was developed by the USA with a new design patented with an integration of a hot box for better heat accumulation [3]. Late 1980s Solar water heaters with FPCs composite copper-aluminium absorbers for FPCs is launched by Canada [4]. Enhancing heat transfer efficiency in SWHS involves considering factors like solar collector parameters, radiation, region, and water tank temperature, as reviewed in studies across Asia, America, and Europe.

The systems' performance can be enhanced so that certain parameters and methodologies can be introduced in the future hence the efficiency of flat plate collector solar water heaters can be enhanced by introducing data science such as machine learning.

A. *Latest development and applications*

According to research, fossil fuels currently provide 75% of the energy needed and account for 33% of global warming. Water heated by solar energy is more economical and environmentally friendly since it is derived from solar radiation. The majority of solar heating apparatuses are designed to heat water for diverse uses and objectives. Mesaysiyoum Gudeta et al., [6], stated below Table 1 which displays the temperature needed in Egypt for different industrial applications. The purpose of a solar water heater is to heat water and produce steam for domestic use, such as bathing, washing, and cleaning. It is an essential component of any solar water heating system, benefiting individuals, communities, and the environment alike [7] and industrial purposes using solar energy. Its system plays a vital role in collecting energy from the sun through its panels or tubes, followed by the production of hot water [8]. Besides, optimizing the hot water tank structure and enhancing the immersed heat exchange performance is also considered as one of their best ways [9]. Besides, there is a need to enhance the solar water heaters' performance, increasing the thermal stratification of hot water storage tanks by increasing the collector performance. The heat transfer features can be improved with designs, tilt angles, pipe coatings, thermal storage, flow rates, thermal insulation, and integrated collector storage [11].

B. *Heat Transfer mode with recent innovation.*

Mainly two types of heaters are thermosyphon and forced convection. Thermosyphon is a natural convection process where density difference is noticed by water or heat transfer fluid circulation. In these systems, sunlight passes or hits the circulating fluid passing through the collector, where the heat transfer fluid absorbs the heat and flows into the storage tank. This is due to the increase in temperature, leading to a decrease in the working fluid density. This kind of system's main advantages is easy installation, good efficiency, unaffected by utility blackouts, and they do not require any external sources to pump the heat through the pipes [12]. The main drawback of this system is the strict guidelines of plumbing and failure to avoid bubble blockage. The primary and vital factor to be considered for a thermosyphon system is the environmental condition that regulates hot water production.

Zhang et al., introduced loop thermosyphon (LT) to overcome the existing problems such as freezing and corrosion related to conventional SWH systems [13]. The basic diagram of the thermosyphon system is shown below.

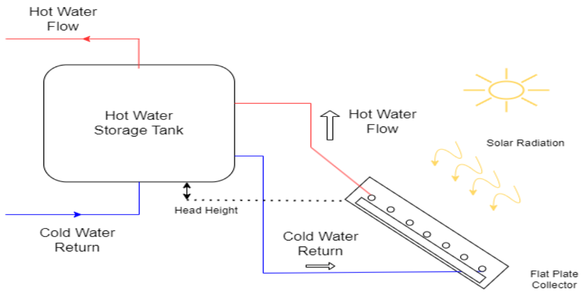

Fig. 1. Schematic of Thermosyphon system

Chien et al., [14] studied a two-phase thermosyphon SWH system, both theoretically and experimentally as a result the system achieved the best charge efficiency of 82%, which was higher than a typical thermosyphon SWH system. Chong et al., [15] suggested a cost-effective prototype using a V-through collector combined with a forced circulation SWH system, which shows 74.04% optical efficiency and excellent thermal efficiency. Recently, Balaji et al., [16] designed FPC combined with two types of internal heat transfer enhancers, such as rod heat transfer enhancer and tube heat enhancer, which show maximum exergy efficiency of 11.3% and 10.9%, respectively. Many studies have been reported on the forced circulation SWH system. There is a need to focus and research on the natural circulation SWH system shortly.

Redpath et al., [17] The result showed an average difference between the efficiency of 5.1% between the thermosyphon heat-pipe evacuated tube solar water heating and acrylic model manifold They concludes that the use of thermosyphon was cost-effective compared to the forced circulation system. Moreover, the thermosiphon's concept is just simple and requires less maintenance due to the absence of control forces and instrumentations [10].

C. *Solar collector selection*

The temperature variation between the ambient air and the collector determines the collector's efficiency; the greater the difference, the lower the solar radiation intensity, and vice versa [18]. Two of the most common types of solar thermal collectors that are non-concentrated are evacuated tube collectors (ETC) and flat plate collectors (FPC). The FPSC with the highest heat absorption efficiency was the one with a smaller radiation-exposed area. The depth of the solar collector is crucial. Flat plate collectors (FPC) are widely and easily affordable. In comparison to alternative thermal collectors, it requires less maintenance [19]. When hot water is used for cleaning, bathing, and swimming pools, FPC is usually chosen for residences and small businesses.

Colangelo et al., [20] reported the requirement for low reflectance and high transmittance to solar radiation while generating various FPC solar absorber types. Several researchers have indicated that they are interested in conducting both simulation and experimental research to improve the solar collectors' thermal performance. One of the most significant variables influencing thermal performance is the design and development of FPC, as several researchers demonstrate, Matrawy and Farkas were the first to provide information on FPC layout [21]. The most often used configuration is the parallel tube collector, and Hottel and Whiller examined its thermal performance [22]. Still, the disadvantages of the parallel tube structure include increased heat loss from the collector as a result of irregular fluid distribution through the pipes and unequal distribution of temperature over the surface of the absorber plate. According to the results, 10% more efficiency was produced by two parallel tube collectors operating in the same circumstances as one parallel tube collector and 6% higher than that of a serpentine type. Increasing the heat transfer fluid flow rate is another important factor in improving FPC efficiency. Analysis of the temperature distribution and flow rate in a 12.53 m2 FPC described by Fan and Furbo [23] applying both theoretical and experimental techniques employing CFD.

II. REVIEW OF THERMAL PARAMETERS

There exist additional methods for augmenting heat transfer processes (which include pipe coating, design of collector, different tilt angles of collector, thermal insulation, incorporated storage of collector, rates of fluid flow, the application of phase-change materials (PCM), and storage of thermal energy [24], and the installation of tapes that are twisted) [11], improve the collector's performance, and optimize the controller to boost solar water heater performance.

A. *Experimental thermal parameters*

From the previous research, several thermal parameters have been focused on forecasting the result of thermal heating systems such as mass flow rate [25], tilt angle [26], irradiation [27], nanofluid [28], and PCM [29] as well.

1) *Tilt angle*

Mesaysiyoum Gudeta et al., (2022) [6], analyzed that tilt angle has more effect on collection of Exergy. The research results of the impact of exergy are displayed in Table 2 below for different places of Ethiopia as different places have different latitude angles.

Aashish et al., (2023) [26], showed the current study developed and tested an evacuated tube collector solar water heater (ETC-SWH) in the warmer months in the Indian city of Hisar (29°08′25.1°N 75°44′22.0°E). May 2022 saw the calculation of the improved ETC-SWH thermal performance at 6 various tilt angles of ETC as (15°, 20°, 25°, 30°, 35°, and 40°). At the tilt angle of 15°, the highest thermal performance of the ETC-SWH was determined with 75.04% efficiency, as Table 3 shows how tilt angle effects thermal performance and its efficiency.

TABLE I. ANALYSIS RESULT OF EFFECT OF EXERGY FOR DIFFERENT PLACES OF ETHOPIA

Places	***Exergy (KWH/YEAR)***	***Emissions of CO_2 per Kg/year***	***Max. annual cost saving***	***Payback period (years)***
Addisababa	1.21E+06	326,700	6.12E+04	6.43
Dire Dawa	1.26E+06	340,200	6.36E+04	6.18
Hawassa	1.21E+06	326,700	6.11E+04	6.44

TABLE II. EFFECTS OF TILT ANGLE ON THERMAL FACT AND ITS EFFICIENCY

Tilt angle	***Efficiency***	***Payback (Years)***	***Tilt angle***	***Efficiency***
40°	57.04%	2.26	40°	57.04%
35°	57.50%	2.25	35°	57.50%
30°	62.20%	2.14	30°	62.20%
25°	63.40%	2.04	25°	63.40%
20°	69.70%	1.94	20°	69.70%
15°	75.04%	1.67	15°	75.04%

2) Mass flow rate

K. Parmar et al., (2017) [30], experienced that Major heat loss is carried by an Invalidation tube & it rises simultaneously with tube temperature. By collecting data on different climatic days, the solar water heater's thermal efficiency was found to depict its need in a tropical environment. The obtained result from the author shows that coupled tanks verily hold in and conferred the stored hot water in the absence of sunshine, with minimum losses. To enhance thermal performance, materials also play a vital role. Several assumptions are also made to experiment with solar thermal heating systems.

Researchers found efficiencies for different flows as they found that a mass flow rate of 0.019 kg/s has the highest efficiency on different days and at different times, approximately 72.05 %. During summer & winter Heat dissipation and the collector efficiency factor showed a significant increase. A water heater is selected based on our needs for different seasons.

Nugroho Agung et al., (2023) [25], also experimented in the Indonesian region of Central Java in a hot climate. Water was used in both an open and passive SWH system over nine days to test the system's performance. These findings as bellowed Table 5 indicated that in SWH using V-corrugated zinc collectors, higher flow rates were more effective. Because V-corrugated collectors can produce 50% energy efficiency and have a low production cost, it was advised to use them. Due to more installation, flexible FPCs are widely used which will comprehensively enhance the efficiency of solar radiation [31].

TABLE III. FLOW RATE EFFICIENCY RELATION [25]

Mass Flow Rate (Lph)	***Efficiency (%)***
120	34%
180	40%
240	50%

3) Wind speed

Balaji et al., (2018) [32] experimented and discovered that the booster of rod velocity offers a greater rate of heat transfer than that of the tube velocity enhancer arrangement, though with little gain in pumping power. The tube and rod velocity boosters have improvements in effectiveness of 10% and 15%, respectively, in contrast to the standard tube. Active solar water heating systems have a pump to circulate the water and are more efficient than passive solar water heating systems. The majority of applications for active solar water heating systems are in industry as well and they have greater complexity. In an indirect solar-powered water heating system, the water obtains heat by buoyancy due to the variation in temperature between two regimes; a pump is not necessary to circulate the water.

4) Other General Parameters

Li Peng et al., (2023) [33] examined research on solar water heaters' use of thermal power-keeping equipment and highlighted a few of the most significant findings. Among the primary findings of the reviewed literature is that several variables, including the storage unit's characteristics and operating state, have an impact on how well the systems work when combined with the thermal storage component. In addition to extending the hours that solar heaters operate, using storage units can increase energy and productivity. Additionally, the study indicates that the quantity of solar power resources influences the frequency of power savings. Furthermore, it could be indicated that by utilizing certain concepts, the systems' performance can be enhanced so that certain parameters and methodology can be introduced in the future hence it could be done to increase flat plate collector solar water's efficiency. This is the actual gap of industries that cannot take hot water continuously from the solar water heater so they have to wait to heat the water again to utilize hot water; the time taken to heat water again can be reduced by controlling the parameters of the solar water heater.

Miguel Angel et al., (2022) [34] stated that in Mexico the material's poor thermal conductivity, which is approximately 2000 times less than the suggested collector tubing material copper, was a major cause of concern. The fact that the surface of a typical solar collector can reportedly reach temperatures higher than those of conventional heaters without significantly affecting overall performance suggests that researchers should focus on addressing the issue of the solar collector's inability to heat above 95 °C in future designs.

TABLE IV. SUMMARY OF THERMAL PARAMETERS AFFECTS THE SWHS

Parameters	**Author**	**Machine learning techniques**	**Place**	**Latitude angle**	**Optimum value**	
Tilt angle	Mesaysiyoum Gudeta et al., (2022) [6]	-	Addisababa	9.0192°N, 38.7525° E	0◦ to 39.5◦	
			Dire Dawa	9.6049°N, 41.8585° E	0◦ to 42◦	
			Hawassa	7.0477°N, 38.4958° E	40◦ to 40◦	
Tilt angle	Aashish et al., (2023) [26]	-	Hisar, India	29°08′25.1″N 75°44′22.0″E	40°	
Energy loss, reduced temperature, the tilt angle, thermal efficiency	Lan Xu et al., (2022) [37]	ANN, LS-SVR, ANFIS and available correlations were examined to distinguish the highest accurate tool	Japan		LS-SVR has higher accuracy	
Mass flow rate	K. Parmar et al., (2017) [30]	-	Vadodara, India	22.3072°N, 73.1812° E	0.019 kg/s	
Mass flow rate	Nugroho Agung et al., (2023) [25]	-	Region of central java Indonesia	7°30′S 110°00′E	240 Lph	
thermal efficiency,friction factor,Nusselt's number, and Coefficient of heat transfer	Zafar et al., (2022) [28]	Extreme Gradient Boosting and Boosted Regression Tree	arid environment		modern machine learning methods and hybrid neural networks has more efficiency than other techniques	
Estimate cycle life using temperature information.	Radha Raman Chandan et al., (2022) [36]	machine-deep-statistical model			greater accuracy and fewer prediction errors than the current approach	
Wind velocity	Balaji et al., (2018) [32]	-	-	-	Compare to Plain tube	
					rod enhancer 15% more	tube enhancer 10% more
Solar irradiation time-varying heat demand and process temperature	Fitsum Bekele Tilahun et al., (2023) [35]	Overall system's control concept	India		Solar storage	Solar fields
					increased by 8.3%	increased by 23.7%

B. *Machine learning*

Fitsum Bekele Tilahun et al., (2023) [35], generated as industrial solar thermal systems are inconsistent, randomly and flexible behaviour, industrial STS design and management analysis are difficult tasks for the tools currently in use so researchers used machine learning (ML) to help with integration decisions, as it allows for multiple versions of one or more modules. As a result, the operation-based design approach proved to be feasible for the supply-level and process integration of STSs. Over-dimensioning is decreased by 10% to 30% when the STS design considers the radiation from the sun, process temperature, along time-varying heat needs Additionally, by improving the overall system's control concept, the energy efficiency of the storage and solar fields was enhanced by 8.3% as well as 23.7%, correspondingly, as opposed to state-of-the-art techniques, which shows how thermal parameters affects a system.

Zafar et al., (2022) [28], encountered various flow rates of nanofluid concentrations for various outcomes. The author developed prognostic models for each parameter using a Boosted Regression Tree (BRT) also by Extreme Gradient Boosting (XB Boost). The use of Taylor's graphical representations allowed for obtaining R2 values. R2 values, which indicate the improved diagnostic capabilities of developed models, were obtained by the models constructed using BRT varying from 0.9619 to 0.9994 and by XG Boost-based models from 0.9914 to 0.9997. It was discovered that the mean square error was too small between 0.000081 and 9.11. Following all of these tests, a practical methodology for increasing efficiency using hybrid NFs and cutting-edge machine learning techniques has been established.

Radha Raman Chandan et al., (2022) [36], employed a computer-deep-statistical model for the assessment of thermal storage systems' steadiness the source makes use of behaviour, property analysis, defect diagnosis, fault detection, life prediction, and state estimation. The simulation's results prove that, in comparison to the current approach, the recommended approach produces fewer errors in prediction while achieving a greater degree of accuracy. Compared to alternative techniques, a notable decrease in the amount of time dedicated to modelling, Evaluations, and instruction has been completed. The prediction model's accuracy was measured utilizing 3 distinct performance metrics: the root mean squared blunder, the average absolute error as well as the average percentage oversight.

Lan Xu et al., (2022) [37], developed an easy way to predict the nanofluid-based thermal efficiency of FPSC. The most effective transformation for problem modelling under consideration represents the FPSC's 3-quarter root of thermal efficiency, according to analysis. Following that, the Simulations of machine learning are employed to create a relationship within the transformed thermal efficiency and the size of nanoparticles, energy depletion, absorbed energy, dropped temperature, and angle of tilt of a flat plate. The most suitable tool for the task at grasp has been determined by comparing the prediction performance of available correlations, Artificial neural networks (ANN), least-squares support vector regression (LS-SVR), and adaptive neuro-fuzzy inference system (ANFIS). The findings show that the accuracy of the LS-SVR computational evaluation of the FPSC's thermal performance exceeds that of other correlations. With a mean squared error (MSE) of 0.00039, an associated coefficient of determination (R2) of 0.9931, and an absolute average relative deviation (AARD) of 2.77 percent, the most accurate paradigm anticipates 545 experimental datasets. The outcomes of these examinations demonstrated that the solar collectors' thermal effectiveness is maximized at the highest allowable amount of big fragments in nanofluids, the maximum value of energy captured parameters, as well as the lowest amount of energy lost and lowered temperature variables.

As per the Litterateur review, various thermal and design parameters are being studied by researchers, such as mass flow rate, tilt angle, surface area, and material properties, which are the parameters that can be considered in machine learning models for predicting thermal parameters in flat-plate solar water heaters. Different researchers use different hyperparameters for machine learning models, such as grid search, random search, Bayesian optimisation, and cross-validation, which are also crucial for machine learning models applied to predict thermal parameters in solar water heaters. Different authors had different approaches for the predictive capabilities of ML models. Since this is a review, a few of the methods are assumed and used by authors as Mean absolute error (MAE), mean square error (MSE), root mean square error (RMSE), and R square adjusted errors can be used to validate the predictive capabilities of ML models, especially when dealing with limited data availability. ML models are trained for predicting thermal parameters in one geographic location and can be generalised to other regions with different climate conditions too. ML can provide predictive insights, helping to forecast outcomes or trends. Additionally, ML techniques can automate tasks, saving time and resources. Ultimately, integrating ML to study thermal parameters can enhance accuracy, efficiency, and the depth of analysis, leading to more robust findings As ML models are used in various industries by many researchers, such as healthcare, chemical, pharmaceutical, laundry, hospitals, and other industries involved in energy production, distribution, and consumption, they are used for predicting thermal parameters in various systems such as power plants, boilers, and HVAC systems to optimise efficiency and reduce energy consumption. Solar, wind, and geothermal energy industries employ ML models to predict thermal parameters in solar panels, wind turbines, and geothermal systems to enhance energy production and efficiency.

III. CONCLUSION

Based on the available literature, solar water heating systems are among the most studied applications from a thermal science point of view however very limited literature is available when it comes to optimizing working, operation, maintenance, and production processes with the help of machine learning. In the present review paper, a detailed study was conducted on the study of thermal parameters as well as their effect on the thermal effectiveness of a solar water heater along with the possible integration of machine learning in the heating process. To use solar water heaters for small/micro-scale industries in India, it could be possible to regulate and optimize the heating process with the help of machine learning. This approach enables consumers to use solar energy efficiently and to plan their production/activities as per machine learning prediction.

IV. REFERENCES

[1] A. Sharma, A. Awasthi, T. Singh, R. Kumar, and R. Chauhan, “Experimental investigation and optimization of potential parameters of discrete V down baffled solar thermal collector using hybrid Taguchi-TOPSIS method,” Appl. Therm. Eng., vol. 209, no. June, pp. 1–7, 2022, doi: 10.1016/j.applthermaleng.2022.118250.

[2] V. G. Shelke, C. V Patil, K. R. Sontakke, and M. E. Student, “Solar Water Heating Systems: A Review,” Int. J. Sci. Eng. Res. , vol. 3, no. 4, pp. 13–17, 2015, doi: 10.13140/2.1.1910.5281.

[3] J. Goodwin, “Jack Goodwin,” no. 1980, pp. 1980–1983, 1982.

[4] H. Runqing, S. Peijun, and W. Zhongying, “An overview of the development of solar water heater industry in China,” Energy Policy, vol. 51, pp. 46–51, 2012, doi: 10.1016/j.enpol.2012.03.081.

[5] S. Faisal Ahmed et al., “Recent progress in solar water heaters and solar collectors: A comprehensive review,” Therm. Sci. Eng. Prog., vol. 25, no. October, pp. 1–9, 2021, doi: 10.1016/j.tsep.2021.100981.

[6] M. Siyoum Gudeta, S. Mekbeb, M. Shibeshi, and E. Gardie, “Performance analysis of solar water heater system with heat pipe evacuated tube collector on Moha soft drink industries in Ethiopia,” Case Stud. Therm. Eng., vol. 36, no. April, p. 102211, 2022, doi: 10.1016/j.csite.2022.102211.

[7] M. S. Murthy et al., “Concrete slab solar water heating system,” 2011 IEEE 1st Conf. Clean Energy Technol. CET 2011, no. June, pp. 332–336, 2011, doi: 10.1109/CET.2011.6041486.

[8] S. Rosiek and F. J. Batlles, “Renewable energy solutions for building cooling, heating and power system installed in an institutional building: Case study in southern Spain,” Renew. Sustain. Energy Rev., vol. 26, pp. 147–168, 2013, doi: 10.1016/j.rser.2013.05.068.

[9] S. Li, Y. Zhang, K. Zhang, X. Li, Y. Li, and X. Zhang, “Study on performance of storage tanks in solar water heater system in charge and discharge progress,” Energy Procedia, vol. 48, pp. 384–393,

[10] S. A. De Souza and W. D. Q. Lamas, “Thermoeconomic and ecological analysis applied to heating industrial process in chemical reactors,” Renew. Sustain. Energy Rev., vol. 29, pp. 96–107, 2014, doi: 10.1016/j.rser.2013.08.095.

[11] A. Jamar, Z. A. A. Majid, W. H. Azmi, M. Norhafana, and A. A. Razak, “A review of water heating system for solar energy applications,” Int. Commun. Heat Mass Transf., vol. 76, pp. 178–187, 2016, doi: 10.1016/j.icheatmasstransfer.2016.05.028.

[12] A. Mertol and R. Greif, “Review of Thermosyphon Solar Water Heaters,” Sol. Energy Util., pp. 537–569, 1987, doi: 10.1007/978-94-009-3631-7_28.

[13] T. Zhang, Z. W. Yan, L. Y. Wang, W. J. Zheng, and Y. H. Su, “Comparative study on the annual performance between loop thermosyphon solar water heating system and conventional solar water heating system,” Sol. Energy, vol. 197, pp. 433–442, 2020, doi: 10.1016/j.solener.2020.01.019.

[14] C. C. Chien, C. K. Kung, C. C. Chang, W. S. Lee, C. S. Jwo, and S. L. Chen, “Theoretical and experimental investigations of a two-phase thermosyphon solar water heater,” Energy, vol. 36, no. 1, pp. 415–423, 2011, doi: 10.1016/j.energy.2010.10.023.

[15] K. K. Chong, K. G. Chay, and K. H. Chin, “Study of a solar water heater using stationary V-trough collector,” Renew. Energy, vol. 39, no. 1, pp. 207–215, 2012, doi: 10.1016/j.renene.2011.08.002.

[16] K. Balaji, S. Iniyan, and M. V. Swami, “Exergy, economic and environmental analysis of forced circulation flat plate solar collector using heat transfer enhancer in riser tube,” J. Clean. Prod., vol. 171, pp. 1118–1127, 2018, doi: 10.1016/j.jclepro.2017.10.093.

[17] D. A. G. Redpath, P. C. Eames, S. N. G. Lo, and P. W. Griffiths, “Experimental investigation of natural convection heat exchange within a physical model of the manifold chamber of a thermosyphon heat-pipe evacuated tube solar water heater,” Sol. Energy, vol. 83, no. 7, pp. 988–997, 2009, doi: 10.1016/j.solener.2009.01.002.

[18] U. Sahaym and M. G. Norton, “Advances in the application of nanotechnology in enabling a ‘hydrogen economy,’” J. Mater. Sci., vol. 43, no. 16, pp. 5395–5429, 2008, doi: 10.1007/s10853-008-2749-0.

[19] H. A. Zondag, “Flat-plate PV-Thermal collectors and systems: A review,” Renew. Sustain. Energy Rev., vol. 12, no. 4, pp. 891–959, 2008, doi: 10.1016/j.rser.2005.12.012.

[20] G. Colangelo, E. Favale, P. Miglietta, and A. De Risi, “Innovation in flat solar thermal collectors: A review of the last ten years experimental results,” Renew. Sustain. Energy Rev., vol. 57, pp. 1141–1159, 2016, doi: 10.1016/j.rser.2015.12.142.

[21] K. K. Matrawy and I. Farkas, “Comparison study for three types of solar collectors for water heating,” Energy Convers. Manag., vol. 38, no. 9, pp. 861–869, 1997, doi: 10.1016/S0196-8904(96)00089-1.

[22] A. Hottel, H; Whillier, “Evaluation of flat-plate solar collector performance,” Trans. Conf. Use Sol. Energy, vol. 3, pp. 12–13, 1955.

[23] J. Fan and S. Furbo, “Buoyancy effects on thermal behavior of a flat-plate solar collector,” J. Sol. Energy Eng. Trans. ASME, vol. 130, no. 2, pp. 0210101–02101012, 2008, doi: 10.1115/1.2840611.

[24] M. K. A. Sharif et al., “Review of the application of phase change material for heating and domestic hot water systems,” Renew. Sustain. Energy Rev., vol. 42, pp. 557–568, 2015, doi: 10.1016/j.rser.2014.09.034.

[25] N. A. Pambudi, I. R. Nanda, and A. D. Saputro, The energy efficiency of a modified v-corrugated zinc collector on the performance of solar water heater (SWH), vol. 18, no. June. 2023. doi: 10.1016/j.rineng.2023.101174.

[26] M. Kumar, Aashish, B. S. Negi, Shimpy, R. Grewal, and H. Manchanda, “Assessment of an ETC based solar water heater at different tilt angles,” Mater. Today Proc., no. March, pp. 2–7, 2023, doi: 10.1016/j.matpr.2023.02.263.

[27] Y. Ji, J. Zhou, B. Emmanuel, L. Wang, L. Lu, and Y. Yuan, “Assessment of factors affecting the performance of a novel double condenser heat pipe Photovoltaic-thermal (PV/T) system in hot water mode: An experimental study in the lab,” Therm. Sci. Eng. Prog., vol. 37, no. January, pp. 1–6, 2023, doi: 10.1016/j.tsep.2022.101607.

[28] Z. Said et al., “Improving the thermal efficiency of a solar flat plate collector using MWCNT-Fe3O4/water hybrid nanofluids and ensemble machine learning,” Case Stud. Therm. Eng., vol. 40, no. June, p. 102448, 2022, doi: 10.1016/j.csite.2022.102448.

[29] V. R. Pawar and S. Sobhansarbandi, “Heat transfer enhancement of a PCM-porous metal based heat pipe evacuated tube solar collector: An experimental study,” Sol. Energy, vol. 251, no. February, pp. 106–118, 2023, doi: 10.1016/j.solener.2022.10.054.

[30] N. J. Patel, K. B. Khiraiya, K. R. Parmar, and S. K. Patel, “Parametric Analysis of Solar Thermal System Parametric Analysis of Solar Thermal System,” vol. 5, no. August, pp. 862–866, 2017.

[31] T. Zhang, W. Zheng, L. Wang, Z. Yan, and M. Hu, “Experimental study and numerical validation on the effect of inclination angle to the thermal performance of solar heat pipe photovoltaic / thermal system,” vol. 223, no. May, pp. 1–6, 2021.

[32] K. Balaji, S. Iniyan, and R. Goic, “Thermal performance of solar water heater using velocity enhancer,” Renew. Energy, vol. 115, pp. 887–895, 2018, doi: 10.1016/j.renene.2017.09.014.

[33] L. Peng, M. Salem, V. Blazek, L. Prokop, M. Al-Bahrani, and S. Misak, “Thermal energy storage applications in solar water heaters: An updated review,” Sustain. Energy Technol. Assessments, vol. 57, no. June, pp. 1–6, 2023, doi: 10.1016/j.seta.2023.103230.

[34] M. Á. Porta-Gándara, J. L. Fernández-Zayas, J. F. Villa-Medina, and N. Chargoy Del Valle, “Low thermal conductivity solar domestic water heater,” Case Stud. Therm. Eng., vol. 40, no. October, 2022, doi: 10.1016/j.csite.2022.102527.

[35] F. B. Tilahun, “Machine learning interfaces for modular modelling and operation-based design optimization of solar thermal systems in process industry,” Eng. Appl. Artif. Intell., vol. 127, no. January, pp. 1–8, 2024, doi: 10.1016/j.engappai.2023.107285.

[36] R. R. Chandan et al., “Machine learning Technique for improving the stability of Thermal Energy storage,” Energy Reports, vol. 8, pp. 897–907, 2022, doi: 10.1016/j.egyr.2022.09.205.

[37] L. Xu, A. Khalifeh, A. Khandakar, and B. Vaferi, “Numerical investigating the effect of Al2O3-water nanofluids on the thermal efficiency of flat plate solar collectors,” Energy Reports, vol. 8, pp. 6530–6542, 2022, doi: 10.1016/j.egyr.2022.05.012