Results in Engineering 25 (2025) 104394

Contents lists available at ScienceDirect

Results in Engineering

journal homepage: www.sciencedirect.com/journal/results-in-engineering

Review article

Recent developments in solar water heaters and solar collectors: A review on experimental and neural network analyses

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ARTICLE INFO

Keywords:
Solar water heater
Solar collector
Design modification
Artificial neural network
Efficiency enhancement

ABSTRACT

Solar water heaters (SWHs) and solar collectors (SCs) are crucial renewable energy technologies that have developed attractiveness in recent years, as a result of their several benefits over traditional energy sources. To further enhance their thermal performances and efficiencies, researchers and engineers have implemented various modifications in the systems. The modifications include integrating SWHs with storage collectors, combining SWHs with photovoltaic cells, integrating thermosyphon and twisted tapes, enriching collectors with nanofluids, phase change materials and using different types of evacuated tube SCs. Furthermore, improvement in materials, design and operating conditions have led to performance enhancement of parabolic trough and linear Fresnel SCs. In addition, the modifications have enabled SWHs to be more cost-effective and resulted to efficient SCs, making them increasingly attractive for several commercial, industrial and residential applications. Recent studies are expected to enhance their performance and economic suitability, making them more viable and sustainable energy devices. Hence, an elaborated discussion on various state-of-the-art modifications in SWHs and SCs to enhance their efficiencies and the application of artificial neural network (ANN) in SWHs and SCs is reported in this comprehensive review, which is lacking in the earlier studies. This compendious article provides the techniques for enhancing both SWHs and SCs to leverage renewable, abundantly available, sustainable and environmentally friendly solar energy. It also expatiates on their future considerations, as a scope for further works and towards advancement in clean energy devices.

1. Introduction

A solar water heater (SWH) utilizes heat energy from sun to heat water for various applications, including bathing, cleaning and warming. Solar water heating is an economical and ecologically beneficial replacement for conventional water heating, since it can dramatically lower energy expenditures and carbon emissions. Many studies have been carried out on solar collector (SC) and SWH around the globe to fulfil the requirements for the hot water for several applications.

Many researchers have presented various reviews on SC and SWH during the recent decades. Jaisankar et al. [1] reviewed variety of

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https://doi.org/10.1016/j.rineng.2025.104394
Received 12 December 2024; Received in revised form 24 January 2025; Accepted 17 February 2025
Available online 18 February 2025

Nomenclature

ANN	Artificial Neural Network
CFD	Computational Fluid Dynamics
CNT	Carbon Nano Tubes
CPC	Compound Parabolic Concentrator
ETC	Evacuated Tube Collector
ETSC	Evacuated Tube Solar Collector
ETSWH	Evacuated Tube Solar Water Heater
FPC	Flat Plate Collector
ICS	Integrated Collector Storage
ICSSWH	Integrated Collector-Storage Solar Water Heater
LCSHS	Liquid-Coupled Solar Hot Water Systems
LCSHS	Low Cost Solar Heater in Series
LCSHP	Low Cost Solar Heater in Parallel
LFC	Linear Fresnel Collector
LFR	Linear Fresnel Reflector
MHPAs	Micro Heat Pipe Arrays
NER	Non-Evacuated Receiver
NN	Neural Network
PCM	Phase Change Material
PTC	Parabolic Trough Collectors
PV	Photovoltaic
PVT	Photovoltaic–Thermal
PV-THPWH	Photovoltaic-Thermal Heat Pump Water Heater
SAHPC	Solar-Assisted Auto-Cascade Heat Pump Cycle
SCC	Solar Cavity Collector
SDHE	Single/Double Hybrid Effect
SHW	Solar Hot Water
SWH	Solar Water Heater
TES	Thermal Energy Storage
TRNSYS	Transient System Simulation

methods for developing the efficiency of SWH. After a thorough examination of the shortcomings of previous research, the research gap and potential changes are also analyzed. Ferrer [2] studied the commercial parameters associated with SWHs for selected towns in South Africa. Salgado-Conrado and Lopez-Montelongo [3] examined the challenges to solar water heating system installation in Mexico and how the Mexican government has been attempting to overcome these difficulties. Sellami et al. [4] conducted review analysis and found outlines a practical initiative, including the creation of a solar water prototype for small-scale industrial replication. Qiu et al. [5] carried out preliminary studies of the economic benefits of evacuated tube SWHs, which are primarily the result of innovations in China, where flat plate SWH technologies are more prevalent. Naidoo [6] investigated into the attitudes of low-income households and beliefs regarding using SWHs, as well as the socioeconomic effects related to their utilization. Smyth et al. [7] conducted a review and analysed the ICSSWH evolved from the first solar water heating systems, which were only black tanks in the sun. Mostafaeipour et al. [8] reviewed several studies to identify and rank the parameters that are related to the adoption of SWH systems in the province of Yazd. Shrivastava et al. [9] performed an examination of the modeling of a SWH, including early studies using TRNSYS. Discussions also include assumptions, modeling of various components, and the benefits and drawbacks of simulation. Dagdougui et al. [10] evaluated several cover designs while examining the thermal behavior of a FPC. Benli [11] reviewed and examined the ability of solar radiation in various nations, and SWHs were examined using climatic and geographic data from six Turkish cities. Using a geographic information system, Rosas-Flores et al. [12] provided the first study in urban and rural consumers of Mexico by implementing SWH. Singh et al. [13] addressed numerous concentrating and non-concentrating ICSSWHs systems, employing PCM. Lin et al. [14] presented study on residential SWHs, which helped to accumulate greater financial value. Chang et al. [15] reviewed the causal link of SWH and simulate important control acts. The findings revealed that if the Taiwanese remains to provide NT $\$2250/m^2$ in subsidies for SWH installation. Alipour et al. [16] reviewed articles related to sociodemographic and various separate significant factors influencing the performance of the SWH. Al-Mamun et al. [17] studied the various design characteristics of key components in SWH. Researchers also found the relation between such critical components with the thermal performance of the SWH. Jaiswal et al. [18] studied the addition of various nanofluids and its property values like stability, thermal conductivity, heat transfer ability towards the solar water heater efficiency.

More also, Jing et al. [19] assessed the economic parameters of SWH in Malaysia, considering the payback of employing SWH. The advantages are reanalysed based on yearly effective sun radiation. Urban et al. [20] focused on the two techniques to comprehend how altering financial and policy-making of China, as well as how they relate to change consumer and producer behaviors, stimulate and confront different avenues for low carbon innovation. Devanarayanan and Kalidasa [21] analyzed the advancements in ICSSWH that use CPC collectors. In the review article of Vengadesan and Senthil [22], all stakeholders of solar energy are given a bird's eye perspective of current advancements, useful approaches, economic significance, the need for solar water heating and associated challenges. A review by Nair et al. [23] revealed a current examination of utilization of PCM in many types of TES systems. Following that, a full analysis of the many innovative ways employed in latent heat, wall heating, incorporating PCM into household hot water tanks, and underfloor heating is presented. The key findings of the investigated works are then distilled for consideration and adaption in the future [24]. Liu et al. [25] created PCM composites for thermal energy storage that are both affordable and effective to recycle PIR foams.

Magendran et al. [26] engrossed primarily on the TES and associated features. The study emphasized the need of choosing materials from macro to nanoscale levels depending on various features and encapsulation techniques in solar heating applications. The PV/T tube structure and working fluid were looked into by Cui et al. [27] to help this technology realize its full potential in energy systems. For various solar heating applications, a wide range of interior tubes and novel PCMs are reviewed in detail. Alehosseini and Jafari [28] concentrated on different PCMs, their nanoencapsulation techniques, phase change fibers, as well as their prospective uses in energy storage in a variety of disciplines. Douvi et al. [29] discussed solar energy storage technologies, along with methods for producing household hot water using the latent heat contained in phase transition materials. Kalidasan et al. [30] made an effort to compile the global trends and practises that have been incorporated into solar thermal systems using PCM. Javadi et al. [31] studied the radiation storage that used the PCM to create residential hot water. Zayed et al. [32] conducted review on many advancements of these materials and how they are used with Flat Plate SWH. Similarly, Kee et al. [33] investigated the composition of polymers and porous materials, the loading of nanoparticles, in solar water heating applications. Analysis of TES with PCM for use in SWH were reported by Shukla et al. [34]. The related investigations are divided into sensible and latent categories based on the collector and storage method utilized. The design criteria, mathematical techniques and simulations employed to produce parabolic trough solar systems were reviewed by Hafez et al. [35], along with a description of their applications. The study demonstrated optical efficiency levels that are close to 63 % and that theoretically reached a peak of 75 %. Kumar et al. [36] analyzed hybrid nanoparticles in SWH and indicated that a significant improvement in energy efficiency is obtained using nanofluids. Aggarwal et al. [37] reviewed the several heat transfer augmenting techniques, merits, applications of SWH and utilization of effective energy retaining systems in SC. Hasan et al. [38] analysed the effect of adding nanofluids and changing various design parameters towards the efficiency enhancement in direct absorption solar collector. Al-jarjary et al. [39] studied the addition of PCM, evacuated tubes and structural design improvements in integrated solar collectors solar water heaters. Garcia-Rincon and Flores-Prieto [40] studied the flat plate solar collectors integrated with various nanoparticles to enhance the thermal efficiency stability.

The global emphasis of scientists and researchers has changed dramatically as a result of the rise of artificial intelligence (AI). AI is a branch of computer science that aims to solve problems in a manner akin to that of human intellect. The development of various AI strategies has resulted from the significant progress made in the practical applications of machine learning since its last breakthroughs in the early 1990s. The goal of incorporating AI applications into a strategy is to improve computer abilities related to human cognitive processes, including as perception, learning, logical reasoning, and problem-solving. AI's exceptional efficiency allows it to classify and analyse vast amounts of data using regression analysis, advancing a variety of industries. To address these problems, a variety of statistical techniques have been used, including response surface methodology, partial least squares regression, multiple linear regression, and the k-means clustering algorithm. The findings of studies comparing AI models to statistical methods showed that the former performed very well in terms of accuracy and precision across a range of activities. But based on statistical testing, the latter have offered knowledge that is scientifically sound. Artificial Neural Networks (ANNs) are AI models that are developed using artificial perceptrons that are modelled after biological neurones. Complex processes in a variety of scientific fields have been modelled and optimised using these ANNs. For this, ANNs are appealing due to their capacity for self-learning and self-adaptation. Because of its nonlinearity, simplicity, and resilience, ANNs are being utilised to represent complex systems. Hence several researchers focussed on ANN to develop suitable algorithm for various research applications. Elsheikh et al. [41] conducted review about the use of artificial neural network (ANN) analysis in the optimization of various solar energy device efficiencies. Kashyap et al. [42] summarized the significant applications of several developed and repeatedly used neural network models in solar radiation forecast. Qazi et al. [43] detailed the importance of ANN analysis in solar radiation measurements and solar systems design considerations. The conclusion arrived in this article indicated that the ANN provides high accuracy with prediction error less than 20 %. Hafeez et al. [44] studied the importance of the ANN in finding significant results with simplicity, high accuracy for various applications. Bobeica and Iorga [45] reviewed the systematic analysis of various application of ANN in finding outputs particularly in prosthodontics. Soori et al. [46] analyzed the impact of ANN in supply chain management, since it is a significant technique in the manufacturing process. Olabi et al. [47] reviewed the application of ANN in partially shaded photovoltaic systems and also indicated the directions for future research pertaining to ANN in Photovoltaic systems. Shoaei et al. [48] analyzed various artificial intelligence and machine learning methods including ANN in renewable energy utilizing methods for several applications. Hence various researchers carried many analyses using ANN and particularly for many renewable energy techniques like solar water heating, solar collector methods and found a significant outcome for future research process.

This research mainly focuses on comprehensive evaluation on various ideas, classifications, usage of ANN analysis in several SWH and SC techniques, designs of components related with the water. Also, the current techniques to improve the performance of SWHs and SCs were discussed in this review article. The range of years and journals are shown in Fig. 1. The percentage distribution of journals matching to different parameters of SWHs and SCs is shown in Fig. 2.

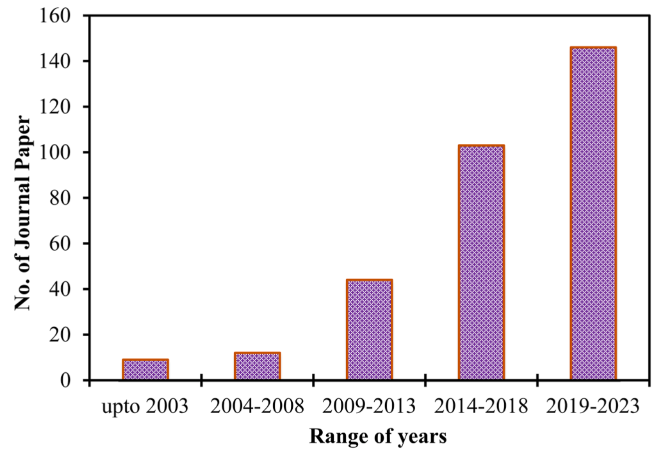

Fig. 1. Distribution of years and number of journal articles.

2. Various modifications and experimental and computational analysis in SWHs to enhance the thermal performance

The best cost-effective techniques of generating hot water are the SWH, because it uses the natural sun rays to generate hot water. This system includes the solar collectors (SCs) with highly absorbing or reflecting characteristics along with the storage tank, pumps and controls. The principle of this system includes thermosyphon, which is the cost-effective mode of heat generation. Studies on various integrations of SWHs for the improvement of thermal performance is subsequently discussed.

2.1. SWH integrated with absorber coil

An absorber is made off copper and coated with black, for high rate of heat absorption. The absorber is in a form of coil attached in the solar heater for acquiring higher thermal efficiency. Fayaz et al. [49] indicated that titanium (Ti) particles coated in the absorber increased the surface temperature of the absorber and subsequently the performance of the solar system. Sadeghi et al. [50] analyzed cylindrical SWH with the absorber coil and cylindrical solar water heater with copper coil absorber inside, as shown in Fig. 3. According to the findings, a reduction in residence time of the fluid causes a development in flow rate. In terms of energy efficiency, argon and air have maximum values of 52.14 and 48.17 %, respectively. The research outcome of Balaji et al. [51] demonstrated an increasing temperature differential in the Flat Plate SWH while employing a simple absorber tube at the similar irradiance. The efficiency of rod Flat Plate SWH was 13 % compared to conventional copper tube Flat Plate SWH. Prabhu et al. [52] conducted enviro-economic analysis in FPSWH with modified absorber and indicated that the modified absorber reduced energy costs by 22 % and CO_2 emissions by 58 %, related to the traditional system. Barbosa et al. [53] studied the two economic solar heater variants were built and thermally analysed for this investigation. When compared with LCSHS, LCSHP demonstrated greater performance. For LCSHP and LCSHS, the highest temperatures and efficiency were respectively 49.7 °C and 40.9 % and 47.8 °C and 37.8 %. Sable [54] experimentally investigated into the efficiency of low-cost concrete SC and this research reveals the full economic analysis along with the environmental advantages. Several tests are conducted for various water flowrates during the summer, winter and rainy seasons to determine how the collector functions year-round. According to test results, the daily average water temperature is between 50 - 69 °C. Touaba et al. [55] discovered an inventive SWH system associated with FPC. In less than three hours, the system reaches a pleasant heating temperature of 50 °C, with a peak efficiency of 80 % and a mean rate convergence of 65 %. Mokhlif et al. [56] showed the effectiveness of integrated SWH of a metal absorber with a

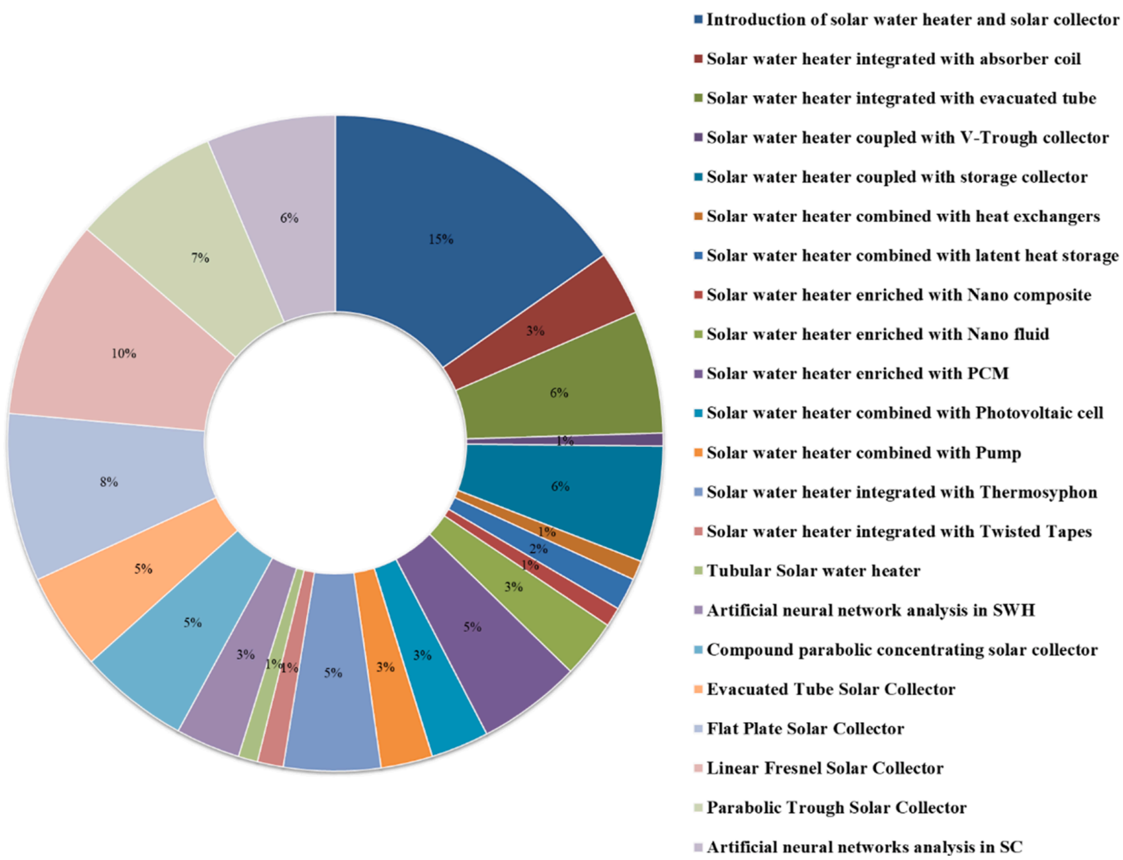

Fig. 2. Percentage distribution of the number of journals on different parameters of SWHs and SCs.

Fig. 3. Cylindrical solar water heater with copper coil absorber inside [50].

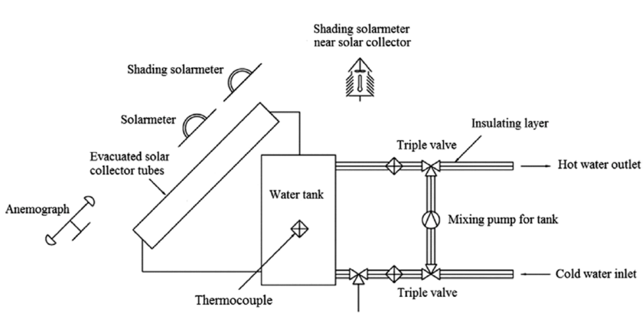

Fig. 4. Schematic diagram of water-in-glass evacuated tube SWHs [59].

corrugated form and found an improvement in efficiency of 4.6 % when compared with the traditional system. Experimental analysis with different component materials was conducted by Muhumuza et al. [57]. Average efficiencies for ICSSWHs 1, 2 and 3 were 46.8, 52 and 47.9 %, respectively. A combined SWH with a grooved receiver surface was studied by Yassen et al. [58]. Among the various methods, it was evident that the heaters can be more efficient than traditional SWH, because the absorber coil helps to increase the surface area of the heater, which allows it to absorb more solar radiation.

2.2. SWH integrated with evacuated tube

Combining ETC with FPC can help to cut down on heat loss. The heat absorbent is coated on the inner tube to provide an efficient mechanism of absorption. This part shows the several enhancement techniques for SWH incorporated with evacuated tube. Summary of studies of SWH integrated with evacuated tube is presented in Table 1.

Finally, it was concluded that SWHs integrated with evacuated tubes are good choice for homeowners, who want to save money on their energy bills, reduce their environmental impact and have a reliable source of hot water. Equally, the V-trough SWH with a concentration ratio of 1.8 enhances the optimum thermal efficiency significantly.

2.3. SWH coupled with V-trough collector

SWH performance can be enriched by coupling the absorber with the V-shaped trough collector. Chong et al. [78] investigated into the stationary V-trough SWH performance. The picture of V-trough SWH prototype with insulation and glass is shown in Fig. 5.

Table 1
Summary of studies of SWH integrated with evacuated tube.

S/ No.	Author	Description	Main findings	Ref
1	Liu et al.	Suggested a high-throughput screening approach of extrinsic Water-in-Glass Evacuated Tube-SWH features, comparing their anticipated heat collection. Schematic diagram of water-in-glass ETC-SWH is shown in Fig. 4.	Forecasted heat collection rates for each set of inputs for Water-in-Glass Evacuated Tube-SWH.	[59]
2	Budihardjo and Morrison	Analysis and simulation of thermosyphon circulation in single-ended tubes for Water-in-Glass Evacuated Tube-SWH.	Simulated and analysed thermosyphon circulation in single-ended tubes.	[60]
3	Tang and Yang	Comparison of energy savings between evacuated tube systems (30 tubes) and a two-panel flat plate system of 3.7 m^2.	Evacuated tube systems exhibited slightly less energy savings compared to a flat plate system.	[61]
4	Zhang et al.	Study on reverse flow and its effect on heat dissipation in SWHs.	Reverse flow contributes 8–10 % of the total heat dissipation in systems with thermosyphonic residential SWHs compared to flat-plate collectors.	[62]
5	Tang et al.	Investigation of ETC-SWH systems for performance comparison.	Heat loss in solar tubes results in minimal fluctuations in the daily thermal efficiency of SWHs due to climate changes.	[63]
6	Bracamonte	Study on the thermodynamic efficiency of Water-in-Glass Evacuated Tube-SWH.	Water-in-Glass Evacuated Tube-SWH exhibits strong internal thermodynamic efficiency and minimal thermodynamic irreversibility.	[64]
7	Bracamonte et al.	Examined flow patterns and effects of stratification in relation to tilt angle using 3D numerical models and experimental setups.	Kinetic energy peak of SWH occurs around solar noon, when energy intake is highest.	[65]
8	Yao et al.	Numerical study of flow and heat exchange capacity of SWH at various starting temperatures (273 to 313 K).	Higher temperatures improve heat transmission, while moderately low temperatures hinder it.	[66]
9	Redpath	Experimental observation of thermosyphon ETSWHs for different home types (semi-detached, detached, terraced).	Technological viability of thermosyphon ETSWHs for home hot water generation in northern marine regions.	[67]
10	Redpath et al.	Experiment on heat-pipe ETSWH tested outside in the Northern Maritime Climate.	Heat transfer connections and flow patterns analyzed, with variations in recorded temperatures and Nusselt numbers revealing fluid flow interactions.	[68]
11	Kumar and Mylsamy	Study on the heat storage capacity of Nano-Embedded PCMs with CeO_2 nanoparticles.	CeO_2 nanoparticles significantly enhance the heat storage capacity of paraffin in Nano-Embedded PCMs.	[69]
12	Sharshir et al.	Study on hybrid solar systems and their effectiveness in reusing drain water.	Reusing drain water raises the effectiveness of the single SS system to approximately 90 %.	[70]
13	Sharshir et al.	Investigation of various water mass flow rates for a humidification-dehumidification system.	Optimal performance achieved at a 2.5 L/min flow rate.	[71]
14	Omara et al.	Theoretical analysis of double layer square wick solar stills at a 30° slope.	Water productivity enhanced by 114 % over traditional stills with an average daily efficiency of 71.5 %.	[72]
15	Daghigh and Shafieian	Examined the effectiveness of a SWH featuring an ETSC through both theoretical analysis and empirical testing.	Efficiency of SWH with ETSC peaked at approximately 5.4 %.	[73]
16	Arab and Abbas	Study on ETSWH potential for enhancing SWH efficiency.	Achieved up to 50 % efficiency with ETSWH.	[74]
17	Chow et al.	Assessed financial viability of two distinct SWH types across different climatic regions in China.	Single-phase system exhibited a more favourable cost payback period and was viable except in extremely cold regions.	[75]
18	Aggarwal et al.	Experimental analysis on evacuated tube SWH integrated with copper and aluminium fins.	ETSWH with copper fins attained 59 % thermal efficiency, and with aluminium fins, 51 %.	[76]
19	Theeyzen and Basim Freegah	Analysis using wire meshed models in rise tubes of SWH to enhance thermal efficiency.	Models A, B, and C enhanced thermal efficiency by 15, 32, and 42 %, respectively, compared to conventional SWH.	[77]

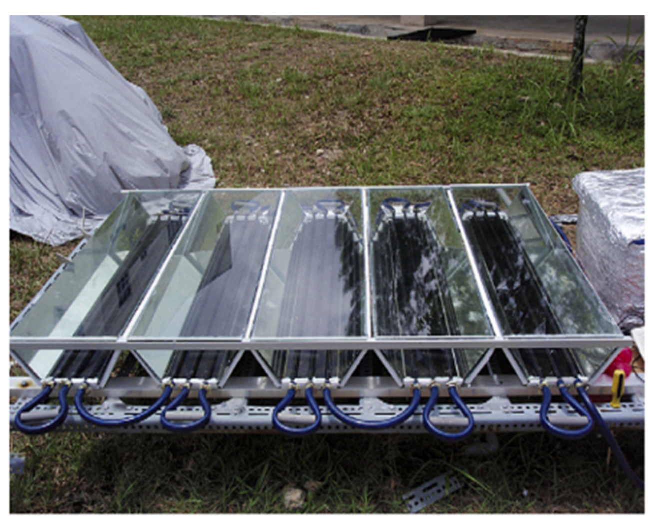

Fig. 5. Picture of V-trough SWH prototype with insulation and glass (the storage tank, the reflector and absorber are insulated by the extruded polystyrene) [78].

2.4. SWH coupled with storage collector

To capture, convert and store solar energy, a SWH combined with a storage collector is a highly effective solar thermal system that makes use of both a SC and a storage tank. This system offers a consistent supply of hot water, especially in areas with plenty of sunlight. And the summary of studies of SWH coupled with storage collector is presented in Table 2.

2.5. SWH combined with heat exchangers

Koffi et al. [98] conducted a practical examination of a prototype SWH equipped with a thermo-siphon system and indicated that the mean daily efficiency was approximately 50 %. Too et al. [99] assessed pumped circulation SWHs utilizing a two-pass design. The total heat transfer coefficient-area (Fig. 6) was obtained between 150 and 213 W/K. Tse and Chow [100] considered both a circular tube type heat exchanger and an indirect thermosyphon SWH. A heat exchange design aimed at minimizing total friction loss in the thermosyphon flow was proposed, as opposed to conventional helical coil and shell designs.

2.6. SWH combined with latent heat storage

Material phase transition properties is used for latent heat storage. Bazri et al. [101] analyzed compact evacuated heat pipe SWH integrated with latent heat storing reservoir. The efficiency of the new design ranges from 36 to 54 %, but on a normal overcast or wet day, this efficiency rises to 47 to 58 %. The new casing and finned tube latent heat system was tested in conjunction with a flat plate SWH by Shalaby et al. [102]. Fig. 7 depicts the schematic of a flat plate SWH combined with a PCM and water storage tank. Results signified that efficiency of 65 % was attained and that 52 % of the total stored energy is made up of energy released from PW. The effectiveness of mannitol, which is utilized to retain solar thermal energy and deliver hot water, was examined by Ling et al. [103]. Outcome shows that mannitol has a high energy storage capacity. Bouadila et al. [104] investigated the storage method using paraffin, as a PCM. According to the findings, the SC maintains a consistent usable heat of 400 W for 5 h after sunset and has 25 to 35 % energy efficiency range. Murali and Mayilsamy [105] used a stratified tank with two distinct input sites and a discharging mode to examine SWH, employing latent TES. The results show that adding latent TES to a storage tank with an attached diffuser and an open bottom intake enhances stratification and efficiency.

2.7. SWH enriched with nano-composite

Nano-composites are materials that possess a solid structure characterized by the presence of an inorganic matrix situated within an organic phase, or an inorganic matrix situated within another inorganic phase. The separation between these distinct phases is established with a minimal dimension in the nano-scale range. By combining an all-glass evacuated tube SWH with a PCM and nanocomposite PCM, Manirathnam et al. [106] investigated without PCM, PCM and nano composite PCM energy efficiencies of the system were predicted to be 1.7, 2.2 and 3.3 %, respectively. The three occurrences' relative energy efficiencies were found to be 33.9, 38.2 and 41.6 %. The effectiveness of a SWH was experimentally studied by Mandal et al. [107] to observe how the use of a PCM doped CuO nanocomposite as a storage medium influenced its performance. In accordance with the research, pure wax typically exhibits a thermal conductivity of approximately 0.21 W/mK. However, when a nanocomposite containing 1 wt % PCM CuO is employed, the thermal conductivity increases to 0.36 W/mK. Al-Kayiem and Lin [108] revealed various performance outcomes: efficiencies of 48 % excluding PCM, 50 % including PCM and 51 % with a Cu-PCM. In conclusion, the integration of nano-composite materials, such as PCMs and PCM-doped nanocomposites, in SWHs leads to significant improvements in energy

Table 2
Summary of studies of SWH coupled with storage collector.

S. No.	Author	Description	Main findings	Ref
1	Souliotis et al.	Experimental research on ICSSWH.	ICS possess maximum efficiency.	[79]
2	Smyth et al.	Design development of a new ICSSWH.	Patent-pending double vessel thermal diode features; thermal efficiencies of 22 % throughout the day and 39 % achievable.	[80]
3	Muhumuza et al.	Techniques for increasing heat retention of ICSSWH	Addressed techniques for improving heat retention.	[81]
4	Souliotis et al.	Modeling of ICS using ANNs and TRNSYS.	Novel strategy for forecasting; merging ANNs with TRNSYS for difficult systems.	[82]
5	Souliotis et al.	Experimental investigation into flat plate thermos phonic unit and ICSSWH.	Solar devices perform well during the day but have limitations at night.	[83]
6	Souza et al.	Analysis of convective processes in hollow with peak aspect ratio.	Need for stratification mechanism in the cavity.	[84]
7	Ziapour and Aghamiri	Numerical simulations on ICSSWH system.	Trapezoidal ICSSWH outperforms rectangular and triangular designs in efficiency.	[85]
8	Swiatek et al.	Modification to improve temperature stratification.	Improved temperature stratification in ICSSWH.	[86]
9	Kumar and Rosen	Merging ICSSWH with expanded storage section.	New design shows 5 % higher efficiency compared to rectangular ICSSWH.	[87]
10	Benrejeb et al.	Influence of truncation on thermal performances of ICS with CPC reflectors.	Increased optical efficiency and radiation dispersion.	[88]
11	Harmim et al.	Integrated collector storage SWH with linear parabolic reflector.	Heat loss factor between 2.18–3.11 WK-1 at night; efficiency between 36.4–51.6 %.	[89]
12	Kumar and Rosen	Study on receiver's exterior design.	Efficiency decreases but can be improved by continuous hot water withdrawal.	[90]
13	Allouhi et al.	Upgraded ICSWH system.	Best outcomes achieved with mass flow rate of 0.0015 kg/s.	[91]
14	Helal et al.	Geometrical characteristics of single cylindrical horizontal tank ICS.	Highest thermal efficiency achieved with specific ratio (Tm - Ta)/ IT P 0.064	[92]
15	Wang et al.	ICSSWH with lap-joint-type MHPAs and latent heat storage.	Peak efficiency of 61 %.	[93]
16	Smyth et al.	Integrated collector storage SWH energy performance study.	Focus on energy performance of ICSSWH.	[94]
17	Benrejeb et al.	New design of ICSSWH with CPC.	New design more efficient than the old system.	[95]
18	Panahi et al.	Prototype ICS water heater coupled with CPC.	Mirror component achieved highest average daily efficiency of 66 %.	[96]
19	Pambudi et al.	Analysis of different solar collectors.	V-corrugated zinc and trapezoidal aluminium have better lifespan than square shaped polycarbonate.	[97]

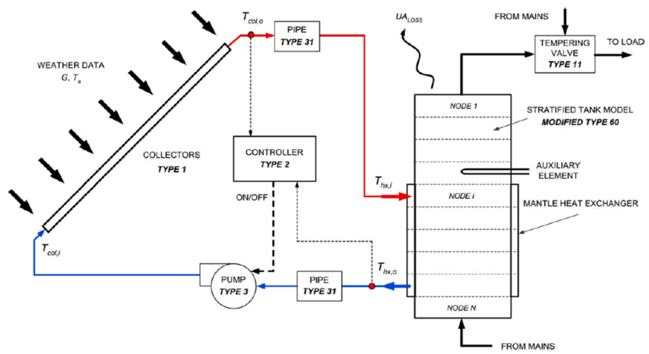

Fig. 6. Schematic of a TRNSYS model for a solar water heating system with a mantle heat exchanger [98].

efficiencies. These advancements in the field pave the way for more sustainable and efficient utilization of solar energy, contributing to a greener and more environmentally friendly future.

2.8. SWH enriched with nanofluid

A fluid containing nanoparticles, also known as nanoparticles, is referred to as a nanofluids. Mirzaei [109] examined the performance of aluminium oxide (Al_2O_3) and copper oxide (CuO) nanofluids under ideal operating circumstances in a passive SWH system. According to the results, when the working fluid rate of increases, the efficiency of solar heating systems decreases, and CuO nanofluid produces greater increased output power than Al_2O_3 nanofluid. Sundar et al. [110] reported that the passive methods were employed to develop heat transmission of the SWH was studied with Al_2O_3 nanofluids and twisted tape inserts. Results indicated that heat transfer enhancement of the tube using nanofluid was 21 % and it increased to 49.75 % using a twisted tape with an H/D ratio of 5 was introduced into the tube. Kumar et al. [111] scrutinized the pressure drop properties of water and titanium oxide (TiO_2) nanofluids. With a rise in nanoparticle concentration, the relative viscosity of nanofluids rises. Fattahi [112] investigated into the numerical simulation for varied Reynolds numbers and nanoparticles concentration. When compared with other designs, the rectangular duct reduces pressure loss by 5 % at the highest Reynolds number. For volume fractions of 1 and 2 %, the performance assessment requirements of the rectangular duct are 13.9 and 8.9 %, respectively, higher than the triangular duct, which has a lowest performance value.

Darbari and Rashidi [113] analyzed SWH with various nanofluids, using a numerical simulation. According to the findings, copper nanoparticles are added first, followed by copper oxide, to increase efficiency among the different nanoparticles. As the atmospheric temperature rises from 20 to 40 °C, there is a corresponding 5.5 % increase in efficiency. Wang et al. [114] examined into the direct solar vapor creation made possible by carbon nanotube nanofluids. Utilizing a solar illumination power equivalent to 10 times the intensity of the sun, a notable evaporation efficiency of 47 % was attained using a carbon-nanotube nanofluid with a concentration of 19×10^{-4} vol %. Akbarzadeh et al. [115] examined how the usage of corrugated walls in conjunction with nanoparticles impacts the effectiveness of solar heaters. According to the data, enhancing the nanoparticle concentration in the straight, triangular and sinusoidal ducts from 0.00 to 0.04 enhances PEC values by 60.9, 70.9 and 71.9 %, respectively. Michael and Iniyan [116] assessed the efficiency of CuO nanofluid produced from copper acetate using an indirect-type flat plate SWH and the indicates that the inclusion of nanoparticles to the heat transfer fluid improves thermal efficiency. Chandran et al. [117] examined the performance of the SWH by adding TiO_2 nanofluid in the heat exchanger of the SWH. Results indicated that the heat transfer rate enhanced by 75, 71 and 63 % for a baffle angle of 30°, 20° and 10°. Finally, the utilization of nanofluids in SWHs supports enhancement of their performance and efficiency. Various nanoparticles, including CuO, Al_2O_3, TiO_2 and copper nanoparticles, have been investigated for their impacts on heat transfer, efficiency and thermal behaviour. The results signified that the incorporation of nanoparticles significantly improves the performance of SWHs.

2.9. SWH enriched with pcm

A PCM enables to sustain the heat by releasing latent heat in night time and cloudy places. The Summary of studies of SWH enriched with PCM was shown in the Table 3.

Among the various studies illustrated above, it was arrived that the performance of SWH enriched with PCMs under various operating conditions has been increased phenomenally. Research has emphasized the significance of factors, such as radiation, initial water temperature and appropriate numerical techniques for accurately modeling PCM integration and system thermal performance.

2.10. SWH combined with photovoltaic cell

A hybrid arrangement that integrates two distinct solar technologies to produce energy and heat water is a SWH coupled with PV cells. This

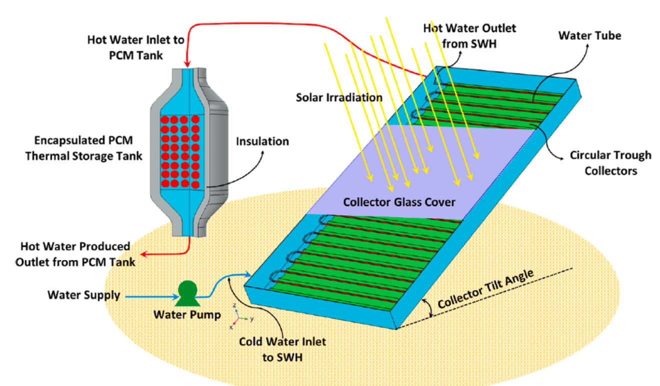

Fig. 8. Schematic diagram of the phase change material enriched SWH [122].

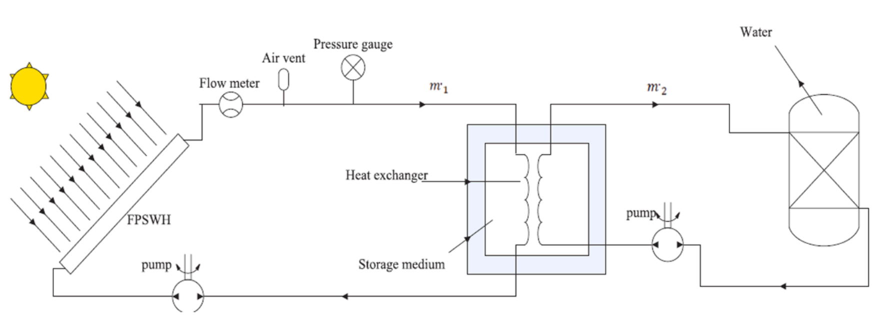

Fig. 7. Schematic diagram of flat plate SWH integrated with PCM and water storage tank [102].

Table 3
Summary of studies of SWH enriched with PCM.

S. No.	Author	Description	Main findings	Ref
1	Abokersh et al.	Comparison of Forced Recirculation SWH System with unfinned and finned U-pipe ETSC.	Compact solar water performs better than standard Forced Recirculation SWH under various conditions due to low thermal inertia.	[118]
2	Dhinakaran et al.	Study on alternative energy sources using nanofillers.	Nanofiller increased water temperature by 33 % over conventional type.	[119]
3	Xue	Efficiency investigation of SWH with a SC coupled.	Efficiency decreases with an increase in diffuse radiation fraction and higher starting water temperature.	[120]
4	Bouhal et al.	Use of PCM in storing reservoirs for hot water.	Numerical technique selection is critical for modeling phase change methods and system efficiency.	[121]
5	Avargani et al.	CFD model to explore PCM's role in mitigating outlet temperature fluctuations. Fig. 8 depicts the schematic diagram of the PCM-enriched SWH.	PCM-enriched SWH can maintain consistent hot water temperature year-round.	[122]
6	Xie et al.	Form-stabilized PCM for tankless SWH.	No chemical interaction between SA and PCM; useful for tankless systems	[123]
7	Li et al.	Development of composite PCM for tankless SWH.	SA/EG6 composites have 63.3 % faster melting times and release heat faster.	[124]
8	Ding et al.	Study on the use of PCM in SWHS to lower energy requirements.	PCM use in SWHS reduces the need for electric auxiliary heaters.	[125]
9	Awani et al.	Novel SWH thermosyphon design.	New design results in twice the water temperature compared to old design.	[126]
10	Chaabane et al.	Numerical study of an ICSSWH with myristic acid as PCM.	Latent heat storage performs better during the day than sensible heat storage.	[127]
11	Wheatley and Rubel	Design for testing various PCM mixes in SWHs.	Design is lightweight, affordable, and 10 % more efficient, compliant with Australian and NZ standards.	[128]
12	Anita and Ramachandran	Use of PCM to store solar energy for night access.	Energy loss during charging and discharging phases correlates inversely with efficiency.	[129]
13	Abdallah	Study on solar chimney and SWH combination in Assiut, Egypt.	Minimum airflow rate of the chimney must be 0.69 kg/s for optimal performance.	[130]
14	Mellouli et al.	Parametric analysis of SWH with PCM.	Ideal PCM parameters: melting temperature of 313 K, density of 3200 kg/m^3, latent heat of 520 kg/kg	[131]
15	Chargui and Tashtoush	Closed-loop tankless SWH with PCM for heating football fields in Tunisia.	Thermal energy efficiencies of 25.9 % in winter and 31.9 % in summer.	[132]
16	Fazilati and Alemrajabi	Experimental study on PCM's effect on SWH efficiency.	PCM extended hot liquid generation for 24.9 % longer.	[133]

device is quite effective and can save a lot of energy, especially in locations with lots of sunlight. Batista da Silva et al. [134] studied dissemination of distributed photovoltaic generating technology in the residential sector. As a result, the research uses both Brazilian SWHs industry characteristics as well as parameters from PV markets in other nations. In their study, Ziapour and colleagues [135] simulated an improved ICSSWH system alongside a PV panel. The simulation outcomes revealed that the impressive total effectiveness of the PVT system can be recognized to the substantial packing factor of PV cells. Tiwari et al. [136] indicated that enhancing the flow rate and decreasing the receiving temperature have opposite effects on daily total efficiency of the integrated photovoltaic thermal solar system. In their research, James et al. [137] endeavoured to develop an efficient approach for utilizing an on-grid PV-THPWH system in conjunction with a present flexible frequency controller. The schematic representation of the PV-thermal heat pump water heater with a variable frequency drive compressor can be observed in Fig. 9. The PV-THPWH system, as per the findings, was capable to lower the operating heat of the PV panels by 25 %, resulting to a 20 % improvement in PV power generation. Additionally, it was discovered that the performance indicators had increased energy efficiency by 15 % and PV efficiency by 34 %. According to Yamaguchi et al. [138], the following three phases make up the comprehensive analytical framework of their research: a study of customer preferences, forecast of technological dissemination based on consumer preferences. The research findings revealed that achieving cost-effective reductions in CO_2 emissions could be more efficiently accomplished through policy measures aimed at promoting the widespread adoption of photovoltaic systems that reduce initial costs. Wei et al. [139] used 96 samples to conduct surveys regarding the available roof space in houses within the city of Xian. Additionally, information on the advantages of DSWH and building integrated PV systems was gathered from relevant literature sources. Given the declining trend of building integrated PV in China, it is hypothesized that DSWH is typically more advantageous than building integrated PV. In their study, Tewari and Dev [140] underscored the efficiency of an innovative household SWH that incorporated a glass-to-glass PV module. Their findings revealed total thermal energy gains of 909 kWh for this modified SWH system. Dubey and Tiwari [141] reported that a photovoltaic SWH with a volume of 200 Ls was constructed and tested outdoors for the New Delhi composite climate. The data show that the increase in glazing area causes the instantaneous efficiency to improve significantly from example A to case C, from 33 to 64 %. The experimental HyPV/T unit's performance was assessed and compared to that of a flat integrated collector storage sun water heater (ICSSWH). The heat retention performance indicated that the ICS unit, without any glazing, achieved a retention efficiency of 8.3 % [142]. Research have focused on various aspects of this hybrid system, such as the simulation and optimization of system performance. Therefore, real-time controllers and variable frequency controllers have been explored to enhance system performance and energy efficiency.

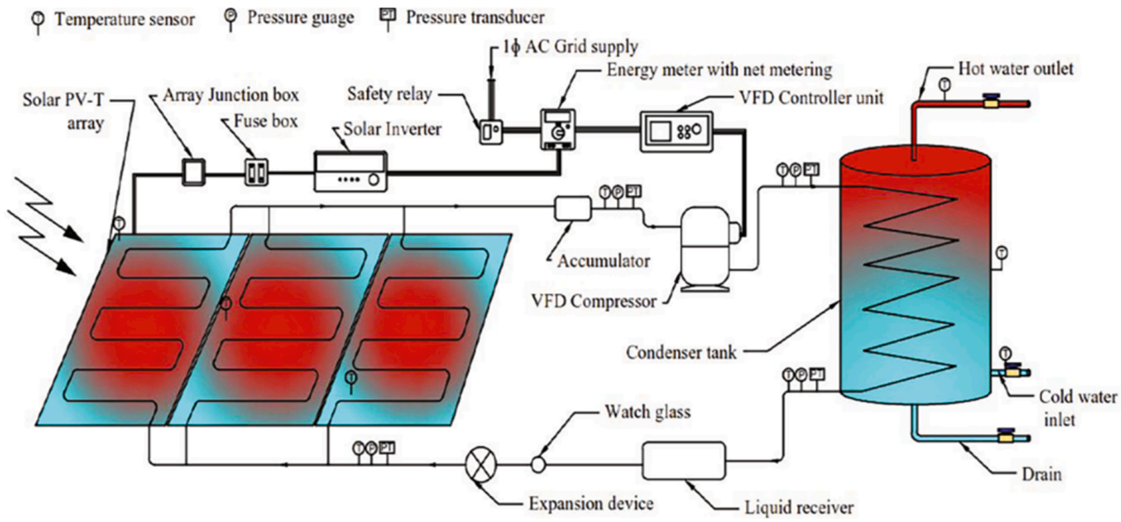

Fig. 9. Layout of the variable frequency drive compressor-based photovoltaic-thermal heat pump water heater [137].

2.11. SWH combined with pump

Pumps are employed to circulate a heat-transfer fluid, specially designed to prevent freezing, and this warms the water that goes into the storage tank; as the flowrate varies with the efficiency. In their research, Chen et al. [143] provided detailed insights into the direct expansion solar-aided ejector-compression heat pump water heater. They also introduced a sub-cooling control strategy aimed at regulating the adjustable ejector. Results indicated that, with the mean warming capability increasing by 5.4 and 7.2 %, while concurrently reducing power consumption by 6.3 and 7.0 %, in comparison to systems incorporating two different ejector throat areas. Kong et al. [144] constructed direct-expansion solar-assisted heat pump and tested to deliver domestic hot water. It was observed that increasing the intensity of solar radiation, while simultaneously reducing the compressor speed can improve the system's Coefficient of Performance. Lv et al. [145] proposed a novel SAHPC for small water heaters that uses the zeotropic combination of R32/R290. The scheme of the solar-aided auto-cascade heat pump cycle system is shown in Fig. 10. According to simulation studies, the SAHPC has a volumetric heating capacity that is 4.23–9.85 % and 4.3–7.68 % more than that of the CAHPC under the same operating circumstances. In their study, Wanjiru et al. [146] introduced a control method for heat pumps and water heaters combined into energy systems. This control method has the potential to contribute 7.5 kWh of energy (equivalent to 35 % of the power not consumed) back to the grid, simultaneously reducing daily electricity costs by approximately 19 %. Kong et al. [147] investigated into the direct-expansion solar-assisted heat pump system with variable capacity was conducted in the East China region of Qingdao. According to experimental findings, the average Coefficient of Performance for the base scenario taken into consideration was greater than 4.0 and 3.0, respectively, for the bright and cloudy days.

Lloyd and Kerr [148] combined the findings from the worldwide research into a solitary guide appropriate for solar and heat pump. According to the findings, heat pump systems and solar systems with a permanently attached electric boost backup function similarly over a wide range of ambient temperatures. According to Abdullah et al. [149], they optimized the technological and economic aspects of the equipment's used in organizing a standalone photovoltaic system driven evaporative cooler. The economic analysis conducted also highlights the benefits of scaling the PV arrangement to power both EVAP-C for space cooling and the heat pump water heater, as opposed to powering only the EVAP-C. Aguilar et al. [150] showed a financial viability and ecological advantages of a solar aided compact water heater. In contrast to a boiler, the system was proven to consume non-renewable primary energy 79 % less and emit 82 % less CO_2.

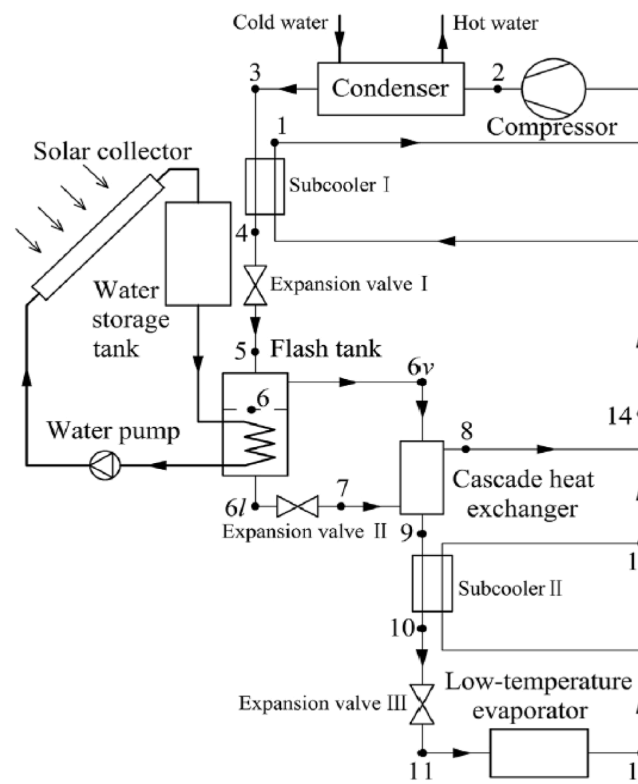

Fig. 10. Scheme of the solar-assisted auto-cascade heat pump cycle system [145].

2.12. SWH integrated with thermosyphon

The water that flows through the solar panels in thermosyphon systems is not forced to circulate. The load loss is low, since it is not a forced circulation. Consequently, the tubes that create grill of the SWH have a round section and the largest feasible diameter. This system is simple, reliable and requires no external power source and suitable for limited access to power. Summary of studies of SWH integrated with thermosyphon is presented in Table 4.

Research have explored different aspects of thermosyphon SWHs,

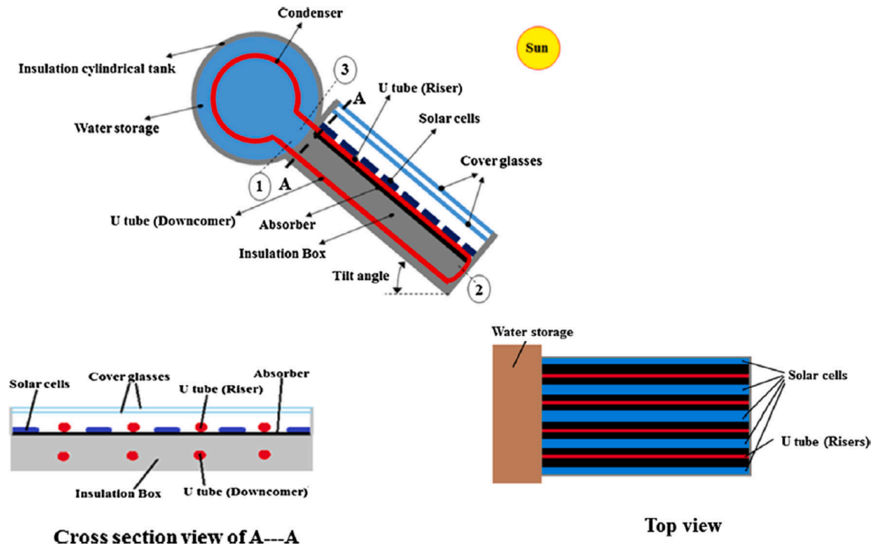

Fig. 11. Schematic representation of the proposed new design of a passive photovoltaic thermal SC system [153].

focusing on factors such as the diameter and inclination angle of the riser, filling ratio, design modifications and performance optimization.

2.13. SWH integrated with twisted tapes

Twisted tapes are used within the SC of a solar system, recognized as an integrated twisted tape SWH to optimize heat transmission and system efficiency. Small devices, called twisted tapes, are put into the water flow route to increase turbulence and heat transmission. This device can protect a maximum energy and is perfect for locations with strong solar radiation. Saravanan et al. [166] tested a V-shaped SWH equipped in the same working environment at two different twist ratios ($Y = 3$, 4 and 5). Correlations for the friction factor and Nusselt number have been established to complement the investigational readings, with the differences between the correlations and the experimental results falling within a range of ±10.2 % for the Nusselt number and ±4.4 % for the friction factor. Thulasi et al. [167] extensively detailed how a SWH maintains water temperature while using Epsom salt as a PCM and the proposed SWH has an efficiency of up to 92 %, which is greater than the normal SWH efficiency of 82 %. Kumar and Prasad [168] investigated various mass flow rates for a SWH employing twisted tape inserts with twist pitch to tube diameter ratios ranging from 3 to 12. Across the range of values considered, the heat transfer in the collectors with twisted tape inserts increased by 18–70 % in comparison to flat or plane collectors. Jaisankar, Radhakrishnan and Sheeba [169] investigated twisted tape SWH with different twist ratios. According to the findings, the twisted tape collector has a quicker rate of heat diffusion and pressure drop than the standard one. The twist ratio rises with the swirl formation, heat transmission and friction factor. A SWH integrated with twisted tapes in the SC can optimize heat transmission and improve system efficiency. Twisted tapes are small devices inserted into the water flow path, creating turbulence and enhancing heat transfer. This technology is particularly beneficial in areas with strong solar radiation, as it can save a significant amount of energy.

2.14. Tubular SWH

A tubular SWH is a type of heating that utilizes solar energy to heat liquid. According to Vasanthaseelan et al. [170] reduced the stated problem with ETCs by creating turbulence inside the ETC utilizing two distinct types of turbulators, specifically coiled turbulators and matrix turbulators. The primary findings showed that the turbulators' presence greatly raised the mean temperature of the ETC tube via promoting turbulence. Bait [171] proposed a SS with a tubular SC and assistance to desalt salty water. According to the findings, the traditional and modified SS yearly yields were calculated to be 405 and 550 kg/m^2, respectively. The upgraded solar unit is competitive and practical because of its high distilled water output and small footprint. Marmoush et al. [172] made an attempt to combine tubular daylight device and SWH into one system, which presented a revolutionary combined power-saving approach. The Merged TDD/SWH system with serpentine collector (a) 8 coil turns and (b) 22 coil turns and schematic of the combined tubular daylight device with SWH are shown in Figs 12 and 13. According to the outcomes, the combined system was able to transfer a reasonable light rate and raise temperature of the water. The outcomes demonstrated a considerable and directly proportionate impact of the collector number of spins on SWH performance.

2.15. Artificial neural network analysis in SWH

Artificial neural network (ANN) is a simple neuron-based processing technique for capturing and validating the experimental values for further utilization in the latest modifications carried in any equipment's. Normally the neuron model utilized in developing any ANN schemes can consist of several groups of links called synapses. These synapses have its own weight, external bias and summation output. An activation variable is utilized to develop a mathematical formulation for the particular study Karabacak and Cetin [173]. Several researchers have conducted ANN analysis in solar water heaters to arrive significant conclusions and further implications. Yaici and Entchev [174] conducted ANN analysis to find the thermal efficiency of the Solar Thermal Energy Systems utilized in SWH applications. The output signifies that the effectiveness obtained using this ANN provides accurate results even the input information is inaccurate due to various noise levels. Results signifies that the accurateness and consistency are high using ANN technique for analysing the efficiency of the difficult energy systems. It was also indicated that ANN technique is a significant way to calculate the condition checking, troubleshooting, efficiency measurement and analysis of solar thermal energy systems. Kalogirou and Panteliou [175] utilized the ANN technique to evaluate the performance of the thermosiphon solar domestic water heating systems. To evaluate output, two types of networks were used in this investigation. Coefficients generated in the investigation were compared the current ANN models to find the efficiency. Hence it was found that, the ANN technique as related to conventional method provides a long term efficiency of new developed systems without a necessity of carrying broad and extensive period tests.

Table 4
Summary of studies of SWH integrated with thermosyphon.

S. No.	Author	Description	Main Findings	Ref
1	Zar and Li	Effects of riser diameter and slope on two-phase thermosyphon SWH.	Greater latitude locations need higher inclination angles for optimal solar heat input.	[151]
2	Li et al.	Introduction of a thermosyphon to reduce installation and maintenance costs.	New insert-type loop thermosyphon heats water twice as fast as traditional systems.	[152]
3	Ziapour and Khalili	Investigation of a new PV panel design coupled with wickless heat pipe SWH. The schematic representation of the novel scheme of an inactive photovoltaic thermal SC is shown in Fig. 11.	Five loops ideal for wickless heat pipes, with a maximum tank water temperature of 72 °C.	[153]
4	Chien et al.	Experimental and theoretical examination of two-phase thermosyphon SWH.	Charge efficiency of 82 %, higher than standard SWH; increased by 3–4 % based on observations.	[154]
5	Chen et al.	Reduction of heat dissipation in thermosyphon SWH.	18 % improvement in system characteristic efficiency compared to standard systems.	[155]
6	Jaisankar et al.	Thermal performance of thermosyphon SWH with helical and twisted tape schemes.	Left-right twisted tape collector outperforms other schemes as solar intensity increases.	[156]
7	Jaisankar et al.	Experimental analysis of heat transmission in thermosyphon SWH.	Nusselt number drops by 10.9 % for rod twist and 18.9 % for spacer twist.	[157]
8	Saravanan et al.	Experimental studies on V-shaped thermosyphon SWH.	19.01 % increase in efficiency with minimum twist ratio compared to standard V-trough collector.	[158]
9	Zelzouli et al.	Investigation of collector performance in thermosyphon SWH.	Peak efficiency achieved when incoming water temperature is high; storage losses affect long-term performance.	[159]
10	Sae-jung et al.	Forecasting hot water temperature in TSSWH.	Mean efficiency of 56.43 % with mathematical models and experimental analysis.	[160]
11	Tang et al.	Analysis of collector outlet water temperature in thermosyphon domestic SWH.	Flat-plate collectors with non-solar selective absorbers freeze at night, while those with selective absorbers do not.	[161]
12	Abas et al.	Investigation into environmentally friendly refrigerants for thermosyphon-driven SWH.	CO_2 showed a collector efficiency of 82 % in moderate sunlight.	[162]
13	Koffi et al.	Performance of SWH with internal exchanger and thermosyphon system.	Efficiency of approximately 57.9 % based on heat flux, temperature, mass flow rates, and collector efficiency.	[163]
14	Kalogirou	Efficiency of thermosyphon SWH and advantages of renewable energy systems.	Solar energy systems demonstrate superior efficiency and economic viability.	[164]
15	Abas et al.	Invention of thermosyphon-driven SWH system using supercritical CO_2 fluid.	SWH system with SC efficiency of 85 % in low-sunshine areas.	[165]

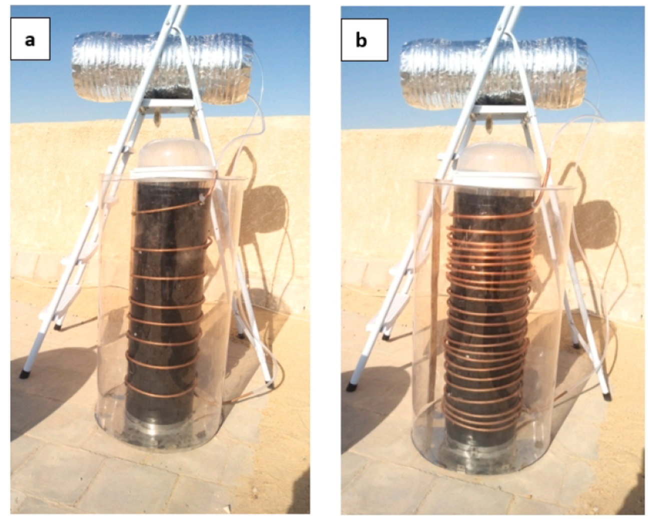

Fig. 12. Merged TDD/SWH system with serpentine collector (a) 8 coil turns and (b) 22 coil turns [172].

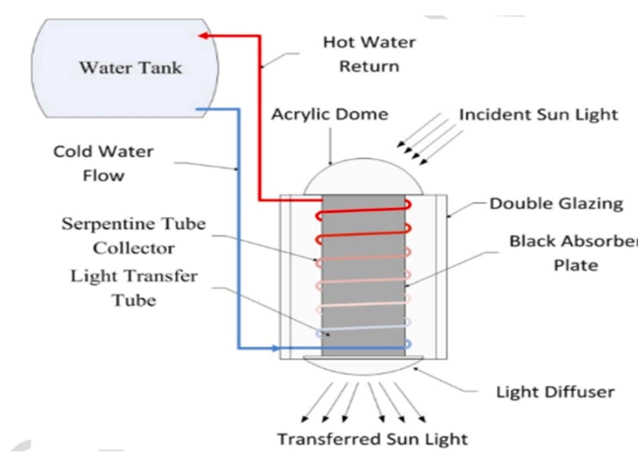

Fig. 13. Schematic of the combined tubular daylight device with SWH [172].

And enable the design engineers to analyse the appropriateness of a scheme for a particular use rapidly and simply. Eldokaishi et al. [176] conducted study by developing a ANN model in hybrid solar thermal storage system integrating PCMs. An experimentally confirmed mathematical model for the method is utilized to create the training and analysing datasets for the ANN model. Results indicated that, as related to the Monte Carlo and Latin hypercube sampling techniques the Sobol sequence offers minimum error in the testing. He et al. [177] indicated that the consistency of Solar Hot Water systems can be enhanced using Adaptive Resonance Theory class of neural networks with integrating certain sensing tools as compared to conventional techniques. Cetiner et al. [178] reported experimental investigation in solar hot water generating system and indicted that the system attained an efficiency of 40 % by utilizing maximum solar radiation. It was also concluded that the ANN study conducted in this work indicated a similar efficiency attainment as compared to experimental study. Kalogirou et al. [179] developed an ANN to find the useful energy deprived and the increase in temperature in the collected water of solar domestic water heating systems with the least input information. An ANN was developed for 30 identified cases, changing the collector area from 1.8 m^2 to 4.4 m^2. The outcomes specified that the recommended technique can effectively be recommended for the temperature increase in the collected liquid. Kulkarni et al. [180] examined the precision of computed total conductance as related to corresponding thermal resistance with ANN technique. ANN provided design parameters and total conductance of hot water storing vessel in SWH methods with minimum design input and more accuracy. The peak error attained in the ANN was 2.62 %. Jahangiri Mamouri and Benard [181] In this study, the performance of an evacuated tube collector solar water heater for Michigan's climate is evaluated. Suitable empirical relations were introduced using System Advisor Model and analysed the effectiveness of the solar water heater with minimal expenses. This paved the way for performing many modifications with minimal expenses and obtaining adequate increase in the performance of the SWH. Assari et al. [182] The effect of changing of the position of the entry and exit of the water on the thermal stratification in a horizontal cylindrical tank was estimated mathematically and experimentally. Simulated temperature profile for each item was related with the experiment, which specified an extreme deviance of up to 7 %. In an experimental case at 1 p.m., an average temperature of 49 °C was attained while the simulation outcome indicates a 47 °C. Hence, the numerical and experimental temperature variance of 1.9 °C with the error 3.9 % was noticed. A suitable position for the hot fluid entry caused a better thermal stratification in the storage tank.

3. Several modifications and experimental and computational analyses to improve the thermal performance of SC

Solar thermal collectors harness sunlight to warm a fluid, typically featuring a flat plate coated with a heat-absorbing material and protected by a transparent cover.

3.1. Compound parabolic concentrating SC

A CPC trough collector is a type of solar thermal collector that is used to capture and concentrate sunlight for the purpose of generating heat or electricity. The design of the CPC trough collector is established on a parabolic curve that is modified into a compound parabolic shape to increase the efficiency of the collector.

3.1.1. Compound parabolic concentrating SC integrated with nanofluid

A compound parabolic concentrating trough collector integrated with nanofluid concentrates solar energy into a tube carrying a nanofluid using a parabolic trough-shaped reflector. Nanofluids are liquids that include microscopic particles that improve their thermal characteristics. Typically, these particles have a size of less than 100 nm. Arora et al. [183] examined CPC collectors, arranged in a series with partial coverage, were affected by their integration with a dual slope SS coupled helically coiled heat exchanger. This integration also involved the use of a nanofluid based on single and multiwall carbon nanotubes mixed with water. Enhancement in the HTCs of the PVT-CPC collector of roughly 46.4, 46.7 and 76.7 %. single-wall CNT and multi-walled CNT percentage enhancements are found to be 65.7 and 28.1 %. Korres et al. [184] investigated into a CPC based on nanofluids in a laminar flow environment. Syltherm 800/CuO, a nanofluid with a volumetric nanoparticle concentration of 5 %, was under investigation at temperatures ranging from 25 to 300 °C. At end, it is discovered that the improvements in exergy and total efficiencies can reach 2.60 and 2.76 %, respectively. CPC SCs provide versatile and efficient solutions for solar thermal applications. When integrated with nanofluids, these collectors demonstrate enhanced heat transfer capabilities, leading to increased overall efficiency and exergy efficiency.

3.1.2. Compound parabolic concentrating SC combined with photovoltaic cell

A hybrid solar system combines two distinct solar technologies to produce energy and heat, such as a compound parabolic concentrating SC and a photovoltaic cell. The CPC increases the radiation absorption by concentrating it with mirrors into a compact region. The concentrated sunlight is then converted into energy using a photovoltaic cell. The heat of the concentrator can also be utilized to warm water or air for household or commercial purposes. This type of device is quite effective and can save a lot of energy, especially in regions with strong solar radiation. Saini et al. [185] focused on a photovoltaic thermal collector configuration where N collectors are linked in series and partially covered. The integration involves a CPC to evaluate the efficiency while considering different solar cell materials. With a total of six collectors, each operating at a mass flow rate of 0.012 kg/s, this arrangement is capable of achieving a water temperature of 98 °C. Omidvar et al. [186] stated the hybrid techniques using solar energy plays a significant role in the generation of power and proper utilization of the generated heat energy. Chen et al. [187] optimized and reduced the thermo-ecological cost of a cutting-edge hybrid system that uses solar energy. A simple internal combustion engine-based natural gas system. Results indicated that the system with a 400 kW ICE and a 100 % photovoltaic covered ratio has the lowest the thermo-ecological cost, 2.36 J/J in the following thermal load mode.

Jaaz et al. [188] indicated that the development of photovoltaic modules can be the foundational step. When the water jet impingement was at its maximum level during the cooling process, the electrical efficiency attained a 7 % increase. The effect of water depth on efficiency, overall thermal efficiency and productivity has been taken into account in the studies of PVT-CPC active solar distillation systems, according to Singh and Tiwari [189]. Fig. 14 depicts the flow diagram of the dual slope SS combined with N partly covered PVT-CPC linked in series. In their study, Singh and Tiwari [190] employed N identical PVT-CPC setups to evaluate basin type SS systems. Under the same climatic conditions and within the same basin area, an active solar distillation system surpassed a similar single slope system with a water level of 0.14 m by 16.3, 21.5, 8.6, and 5.8 %, respectively. According to Liu et al. [191], these issues were addressed by the proposal of a unique form of CPC photovoltaic/thermal collector with microencapsulated phase change slurry and indicates that the maximum electrical efficiency was 11.8 %.

3.1.3. Other types of compound parabolic concentrating SCs

The design of Concentrating Parabolic Collectors (CPC) is versatile and can be adapted to a wide range of applications and performance requirements. In their study, Gilani and Hoseinzadeh [192] led a numerical assessment of the impact of incorporating a CPC into a Solar Water Heating (SWH) system, comparing its energy savings over the course of a year to the performance of a standard Flat Plate Collector (FPC). They considered various locations worldwide, each with dissimilar levels of solar radiation and electricity prices based on their latitudes. Xia et al. [193] focused on enhancing the construction and optical characteristics of a CPC with a cylindrical absorber. They described a method to separate the absorber and reflector within the CPC, effectively addressing the issue of gap loss. This improved CPC design led to an 8.3, 4.8, 7.4 and 2.9 % increase in solar energy absorption during the spring, summer, autumn, and winter, respectively. Davididou et al. [194] employed the photo-Fenton process at pH 2.8 to treat the artificial sweetener saccharin in a CPC pilot plant. To maintain the pH at 2.8, they used olive mill wastewater as an iron chelating agent, preventing the water from becoming excessively acidic. In the study by Waghmare and Gulhane [195], they discussed a method for optimizing the placement of a tubular receiver in a CPC with a low acceptance angle of 6°. Low acceptance angles result in the reflected rays concentrating in a specific pattern below the common parabolic focus. This approach leveraged the collector's surface for solar flux reflection, utilizing calculations based on GRT iterations and accounting for manufacturing

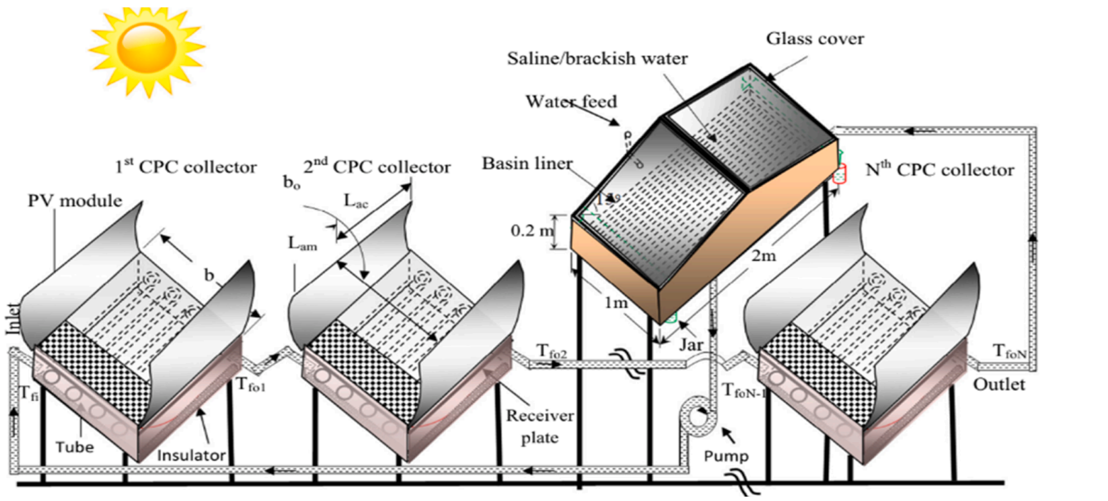

Fig. 14. Flow diagram of a double slope active solar still integrated with N partially covered photovoltaic thermal compound parabolic concentrator collectors connected in series [189].

imperfections.

Waghmare and Gulhane [196] reduced optical losses, an optical assessment enhanced the overall performance of SCs. It also includes research and analysis of how solar radiation behaves as it hits and reflects off of collectors. The difference in the incidence angle from +3° to −3° can be compensated for by the acceptance angle of 6°. As a result, optical tests are carried out at extremes of +3° to –3° with an optimum incidence angle of 0°. According to Waghmare and Gulhane [197], ray tracing is often used to design the components of SCs. This study uses a unique method of surface areal irradiance to compute the solar flux concentration on the tubular receiver of a CPC. This study can support engineers to choose the size and position of tubular receivers, based on the amount of heat required. On the basis of reflector and receiver area, the SAI approach provides a way for designing and/or comparing any non-imaging SCs. In their study, Ma et al. [198] described the development of a distinctive medium-temperature selective coating-based CPC evacuated tube SC. Experimental results from a steam system application showed that, on sunny days, this unique CPC SC could yield steam from water, with temperatures ranging from 108 to 145 °C. Furthermore, Gang et al. [199] established and tested an experimental rig for a CPC SWH system with a U-pipe configuration. The winter performance of this system remained consistent, achieving a total thermal efficiency of over 43 % under all conditions. It boasts a thermal efficiency exceeding 48.9 % and an exergetic efficiency exceeding 4.7 %.

3.2. Evacuated tube SC

An evacuated tube collector (ETC) is a form of solar thermal collector that converts solar radiation into thermal energy that can be utilized to heat water or space heating.

3.2.1. Evacuated tube SC enriched with nanofluid

Nanofluids are liquids that contain very small particles that are dispersed throughout the fluid. Ghaderian et al. [200] experimentally studied the performance of an ETSC water heater with an internal coil to measure the impact of a CuO/distilled water nanofluid. CuO volume content was inversely correlated with ETSC performance, with 0.06 % of CuO increasing efficiency to 51.4 % and 0.03 to 41.9 %. Nevertheless, the average temperature output showed an increase of almost 14 % at concentrations of 0.03 to 0.06 %. Elshazly et al. [201] emphasized the crucial element in improving the effectiveness of a solar collector is the augmentation of the convective heat transfer coefficient between the absorber and the tubes that house the working fluid, leading to the growing adoption of nanofluid as working fluids in solar thermal systems. The research indicates that employing a hybrid mixture of multi-walled CNT and Al_2O_3 in a 50:50 ratio results to a 20 % improvement in efficiency when related with using Al_2O_3 alone.

3.2.2. Evacuated tube SC enriched with PCM

PCMs can absorb and store more heat than the heat transfer fluid alone. Therefore, combining them with ETCs can assist to increase the performance of the solar thermal system. Sadeghi et al. [202] conducted experimental application of a shape-stabilized PCM onto a tankless, direct-absorption, ETSC. This innovative approach addresses the challenge of direct solar energy storage. By incorporating this collector-storage arrangement, the thermal efficiency during stagnation mode escalated from 66 to 82 %. According to Kumar et al. [203], many residential and commercial processes, including solar-powered drying, space and water heating and water desalination, employed thermal energy from sun. Its energy and exergy performances were calculated, using several numerical models. This review can support researchers in categorizing, contrasting and mesmerizing them for better comprehension. ETSC have shown great potential in harnessing solar energy for water and space heating. Research on nanofluid and phase change material enrichment has demonstrated improved efficiency and temperature output. Integrating evacuated tube collectors with SWHs enhances system performance, especially during unfavourable weather conditions.

3.2.3. Evacuated tube SC integrated with SWH

Combining ETCs with SWHs can improve performance of the system and decrease carbon emissions. Heat transfer fluid passes via a heat exchanger, heating water in a storage tank. Dinesh et al. [204] discovered that employing a flat diffuse reflector and a wavy diffuse reflector improved the tank water temperature by 4 and 6 °C. The wavy diffuse reflector boosted the temperature of the water by 2 °C, when compared with the flat diffuse reflector. Al-Joboory [205] studied how to enhance the performance of ETSC when subjected to load circumstances and weather. The alternate approach employs 20 wickless heat pipes with diameters of 16 mm and lengths of 1750 mm. The working fluid is methanol, which is charged at a fill charge ratio of 50 %. According to testing results, the heat pipe system outperforms the thermosyphon of 32.4 % when there is continuous loading. According to Gunasekaran et al. [206], all-glass evacuated tube type SWH are preferred over other types for the majority of applications. This is because they run more efficiently with fewer design constraints. Utilizing twisted tapes increased the efficiency of the ETC type SWH by 6.8 %. Selvakumar et al. [207] established a novel system with an ETC and parabolic trough. The innovative method can provide instant hot water at 60 °C when there is little sun energy. The procedure of producing instant hot water can boost its heating efficiency by 30 % by using a parabolic trough and an evacuated tube. Gudeta et al. [208] used the MATLAB/SIMULINK tool to model SWH systems, using heat pipe evacuated tube collectors. The results indicated that, at mass flow rates of 120, 450 and 900 kg/h, the solar system efficiencies were 27.4, 47.5 and 53.4 %, respectively.

3.2.4. Other types of evacuated tube SCs

Evacuated tube SCs come in a variety of designs that are intended to boost solar thermal systems' effectiveness and efficiency. These collectors gather and transform solar energy into heat more efficiently by utilizing a variety of technologies and design elements. These collectors can aid the lowering energy expenses and carbon emissions by improving performance. Ayompe et al. [209] provided a TRNSYS model that has been validated for forced circulation SWH used in temperate locations. The collectors delivered heat to the load of 17, 14 and 7 % for the FPC system and 18, 17 and 8 % for the ETC system. The FPC system increased the heat given to load and the heat collected, respectively, by 7.6 and 6.9 %. For the ETC system, the model overstated each of the three parameters by 13.7, 12.4 and 7.6 %. Khan et al. [210] studied the useable energy and losses during pasteurization, thorough thermal evaluations of both procedures. In the aperture regions of SC and ETC, the available energy was calculated to be 8.2 and 5.7 kWh, respectively. Efficiency was determined to be 57.71 and 74.88 %, respectively, for SC and ETC, as expected. For SC and ETC, field efficiency values were discovered to be 54 and 71.41 %, respectively. This study found that ETC is stable, effective and simple to develop.

Mishra et al. [211] anlaysed the precise thermal modeling of a CPC and a U-shaped ETSC. Theoretical models have moreover undergone experimental validation. The highest water temperature differential between the input and exit in an ETC—CPC system is determined to be 24 °C, when compared with 17 °C in an ETC system without a CPC. The yearly thermal energy gain for the ETC and ETC—CPC systems, respectively, is determined to be 1461.63 and 1859.66 kW h. On energy, energy payback time is raised by 6.2 and 11.6 %, while EPF is lowered by 5.7 and 25 %. Sabiha et al. [212] stated the reasons why evacuated collectors are preferred, different types of evacuated collectors, their structures, uses, and difficulties have all been covered in-depth. The maximum and average collection efficiencies of the open thermosyphon improved by 6.6 and 12.4 %, respectively. Water and nanofluid collection efficiency are typically 36 and 61 %. In comparison with traditional FPC with overall efficiency of 12–20 %, solar heat pipe collectors perform better with overall efficiency of 25–69 %.

Moreover, Morrison [213] examined a variety of evacuated tubular SC-equipped household water heaters over the course of three years. It was discovered that the evacuated tube modules evaluated for this study have good thermal performance for applications involving water heating at temperatures below 60 °C. Just 12 % less energy was discovered to be saved annually by a thermosyphon evacuated tube system with 30 tubes that were each 1.2 m long over diffuser of 2.2 m than by a flat plate collector system with 3.8 m of low iron glass chrome black selective surface. Efficiency of an ETSC with inserted baffles was experimentally studied by Kumar et al. [214], using an indoor solar thermal simulator. Fig. 15 depicts schematic of the evacuated tube solar air collector with inserted baffles. The largest temperature rise of 43 °C was attained with a flow rate of 100 kg/h.

3.3. Flat plate SC

The FPC is made up of a flat, rectangular panel composed of a thermally conductive material like copper or aluminium, with a dark-colored absorber plate on the bottom and a transparent cover on top. FPCs are simple and dependable, with a long durability and minimal conservation. They are ideal for home and small business applications when space and affordability are critical factors.

3.3.1. Flat plate SC integrated with absorber tube and plates

Combining flat plate collectors (FPCs) with absorber tubes and plates is a novel way to improving solar thermal collector efficiency. This combination combines the benefits of FPCs with absorber tubes/plates, resulting to increased efficiency and performance. Roberts et al. [215] analyzed efficiency (η) of a glazed flat plate SWH, which is often measured in tests and represented as $\eta = \eta_0 - a_1 x - a_2 G x^2$ in terms of lowered temperature and global insolation. Changes to parameters, such lowering heat loss coefficients, might have an immediate influence on efficiency. Deeyoko [216] illuminated the performance of a flat plate SWH in terms of both thermal enhancers and absorber tube

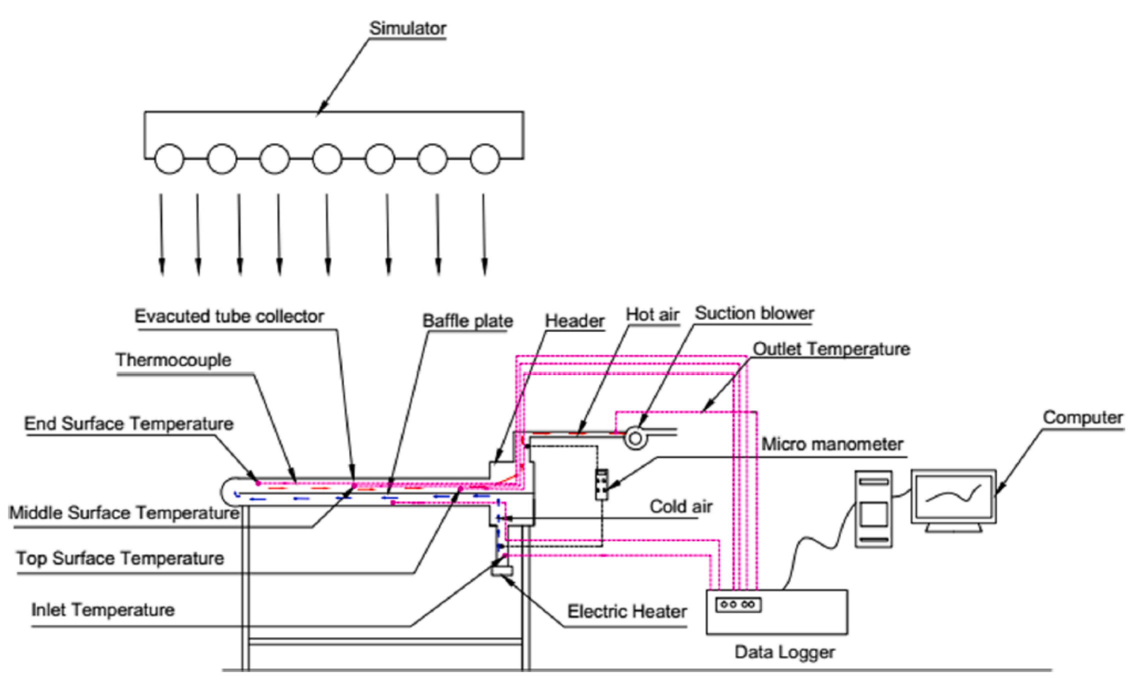

Fig. 15. Schematic of the evacuated tube solar air collector with inserted baffles [214].

performance. They found that, under all operating conditions, thermal performance enhancers outperformed basic tubes. Specifically, the rectangular thermal performance enhancer demonstrated 18–20 % higher energy efficiency compared to a plain tube at various mass flow rates. In a related study, Roberts [217] introduced the formula $\eta_R = \alpha - A\varepsilon - B$ to define the efficiency of a collector with an absorber featuring absorptance α and emittance ε, relative to the highest possible efficiency achievable by an ideal absorber. The efficiency of the absorber, in this context, can be expressed as $FM = \alpha - A\varepsilon$. It was also demonstrated that this efficiency can be primarily described as a function of the reduced temperature parameter, x, and is minimally influenced by other collector and ambient characteristics. Dhairiyasamy et al. [218] utilised barrier with internal cavity in the FPC and attained an increase in efficiency by 12 % when compared with the conventional FPC.

3.3.2. Flat plate SC with electro coating

A flat plate SC with electro coating is a solar system that uses flat plates coated with a thin layer of electro-deposited coating to enhance their performance. Combining FPCs with electro coating can assist to protect the panels from the corrosive effects of weather and exposure to the elements, increasing their lifespan and decreasing maintenance requirements. The selective coating, according to Lizama-Tzec et al. [219], functions as the brain of a solar heating system. It must absorb sunlight efficiently, heat the substrate and then transmit the heat to a fluid. Fig. 16 shows an image of the three flat-plate SCs that were tested under the identical air circumstances. According to the findings, electro-deposited, because they provide a suitable combination of a simple production technique and high optical properties. Kumar et al. [220] studied the impact of adding copper nanoparticles in SC and indicated that the addition of nanoparticles significantly enhanced the Nusselt number and heat transfer rate as compared to SC without nanoparticles. Mahariq et al. [221] indicated that the addition of tetra hybrid nanoparticles in SC increased the heat transfer property significantly as compared to basefluid. Morozova et al. [222] reported that the addition of graphene based nanofluids and surfactant sodium dodecyl sulfate in the SC enhanced the absorption of solar energy as compared to conventional fluid and subsequently enhanced the thermal performance.

3.3.3. Flat plate SC combined with storage collector

In situations where dependable, continuous power is essential, combining FPCs with ISC systems is a good technique to escalate the effectiveness and performance of solar thermal power generation and providing both hot water and space heating. Gertzos et al. [223] studied the thermal behaviour of a specific flat-plate ICSSWH. Mechanisms of both natural and forced convection are looked at. The service water outflow temperature is raised by the recirculation by up to 5 °C. The CFD model created has shown to be a valuable tool, since it predicts outcomes that are well in line with actual findings in both recirculation- and recirculation-free scenarios. The optimization must be carried out numerically because it is a challenging experimental endeavour. Similarly, Gertzos and Caouris [224] conducted experimental and numerical studies to analyze the parameters that have an impact on a flat plate ICSSWH efficiency. The flow field is seen using an experimental model constructed of Plexiglas. A method known as laser doppler velocimetry is used to monitor flow velocities. The ideal configuration enhances output temperatures by up to 8 °C and increases mean storage water velocity by 65 %. Gertzos et al. [225] used CFD analysis to conduct a quantitative examination of the variables that impact the temperature at which domestic hot water is generated by an immersed tube heat exchanger integrated within a FPC storage SWH. The heat exchanger was determined to be in touch with the front and rear walls of the tank at the ideal position, with an acceptable heat exchanger length of around 21.5 m and an ideal inner tube diameter of 16 mm.

3.3.4. Flat plate SC enriched with nanofluid

By incorporating FPC and the application of nanofluids with a thin layer to enhance performance, it becomes possible to improve the system's size, reduce its weight, and enhance overall performance, all while utilizing a smaller volume of heat transfer fluid. Jamal-Abad et al. [226] performed a study in which they utilized a direct synthesis technique to create a Cu-water nanofluid. This nanofluid was subsequently engaged as an experimental working fluid in a solar collector. The findings from this experiment established that increasing the nanoparticle concentration led to a 24 % improvement in collector efficiency for nanofluids. The collector efficiency ratio decreased from 1.5 to 1.4 when using a nanofluid with a concentration of 0.05 wt %.

3.3.5. Flat plate SC enriched with PCM

A PCM is a material that releases or absorbs enough energy to provide usable heat or cooling during a phase shift. And the properties of ideal PCM are illustrated in the Fig. 17. The first two basic states of matter, solid and liquid, are often where the transformation takes place. By integrating these two together the performance and the efficiency is increased. Badiei et al. [227] examined into a solar FPC combined with a layer of PCM, using a three-dimensional transient CFD model. Each component simulates heat transport and fluid dynamics using the numerical solution of energy and momentum equations. The basic average daily efficiency and total water heat gain of the FPC can be raised from 32 to 46 % by including PCM-1 with a 35.4 °C melting point. Just a 1 to 30 % increase in PCM-3 can enhance the daily average efficiency. The daily efficiency drops by 0.7 % on average and the thermal efficiency rises by 4 % in the summer day when the liquid component is raised by approximately 20 %.

3.3.6. Performance affecting flat plate SC in different condition

The performance of a FPC can be affected by several variables, including the operating conditions and the environment. Efficiency, heat loss coefficient and heat gain factor are three important factors that

Fig. 16. Photograph of the three flat-plate SCs that were investigated under the same atmospheric conditions [219].

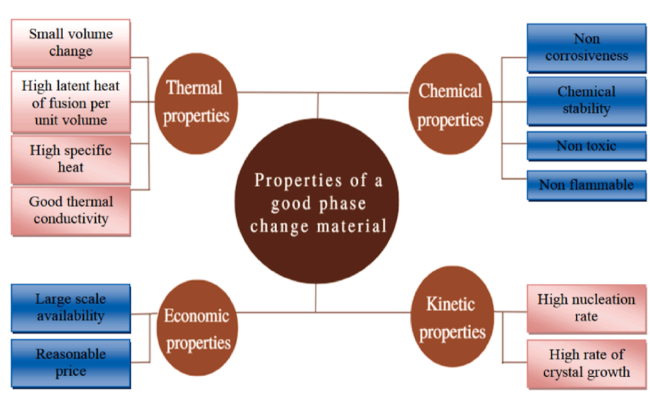

Fig. 17. Properties of phase change materials [37].

can be used to assess the performance of FPC. Alwan et al. [228] evaluated the thermal performance, usable energy and water temperatures at the FPC entry and exit. The effectiveness of the SC was best during noon, when it collected the most solar energy. As a consequence, the greatest rates of useable heat received throughout the four days of winter were determined to be 54, 66, 55 and 52 %. Deng et al. [229] described a unique flat plate SWH that makes use of MHPAs that are tightly spaced and coated with solar selective coating. The collector has the benefits of being resistant to freezing, having a large capacity for heat transmission, having very little heat loss, not requiring welding and not allowing leaks. The test results show that there are three typical days in three separate seasons with daily effective heat gains of 13, 11 and 7 MJ/m^2 at an equivalent to solar radiation of 19, 17 and 21 MJ/m^2. The thermal efficiencies on a daily basis are 71.05, 64.25 and 50.49 % of the SWH. A commercially available forced circulation residential scale system with a computerized subsystem that managed hot water draw-offs and an auxiliary immersion heater served as the experimental platform for this study. The solar portion was 32.2 %, the energy provided by the solar coil was 16.2 MJ/d, supply pipe loss was 3.2 MJ/d, collector efficiency was 45.6 % and system efficiency was 37.8 % on an annual average daily basis [230].

3.3.7. Other types of flat plate SCs

Unglazed, hybrid, concentrating and transpired SCs are other types of FPC with different designs and functions, suitable for specific low- or high-temperature solar thermal applications, such as pool heating, power generation and space heating. Summary of studies of other types of flat plate SCs is presented in Table 5.

The FPC provides a versatile and efficient solution for harnessing solar energy across a wide range of applications. By integrating absorber tubes/plates, electro coating, nanofluids, or PCM, the performance and efficiency of FPCs can be significantly enhanced. Moreover, the combination of FPCs with storage collectors and other types of flat plate collectors opens up possibilities for reliable and continuous power generation, hot water supply and space heating. Operating conditions and environmental factors play a crucial role in determining the performance of FPCs.

Table 5
Summary of studies of other types of flat plate SCs.

S. No.	Author	Description	Main Findings	Ref
1	Ananno et al.	Hybrid geothermal-PCM flat plate SCs.	20.5 % efficiency improvement compared to standard flat plate SCs with a 0.02 kg/s mass flow rate.	[231]
2	Tian et al.	Optimization of hybrid solar district heating systems based on the levelized cost of heat.	Lowest net levelized cost of heat can reach 0.36 Danish Kroner per kilowatt-hour, with a 5–9 % reduction in cost by incorporating solar collectors.	[232]
3	Aste et al.	Examination of PV-thermal collectors (water flat plate collectors).	Collector effectiveness increases as the W/D (width-to-depth ratio) decreases.	[233]
4	Ho et al.	Flat-plate SWH with rectangular flow conduits for recycling operation design.	Raising the recycling ratio increases fixed charge and energy consumption.	[234]
5	Naidu and Agarwal	Thermal boundary layer analysis using fourth degree polynomials for flat-plate SCs.	Overcomes limitations of lower-degree polynomials, though lacks experimental data for comparison.	[235]
6	Allouhi et al.	Insertion of heat pipes into FPC as heat extraction devices.	SWH maintains reasonable thermal efficiencies up to 33 %.	[236]
7	Hajabdollahi and Hajabdollahi	Thermo-economic modeling of a solar heater with FPC.	Efficiency increases by 0.123, 0.740 and 1.506 % for 0.5, 1.5, and 2.0 kW cases compared to 1 kW.	[237]
8	Yeh et al.	Influence of collector aspect ratio on the efficiency of flat-plate solar air heaters.	Increasing the aspect ratio increases efficiency by improving convective heat transfer and air velocity.	[238]
9	Yamali and Solmus	Theoretical analysis of solar water desalination system performance.	Productivity decreases by 30 % without a double-pass flat plate SAH and increases by 8 % with it.	[239]
10	Saraf and Hamad	Impact of tilt angle on the performance of flat plate SCs.	Altering tilt angle eight times a year affects solar energy collection and top loss coefficient.	[240]

3.4. Linear Fresnel SC

In Linear Fresnel Collector, flat mirrors are used to collect sun rays and focus them into a tube that passes past the reflectors' focal point. Water is flowing through the pipe, therefore steam is created there and utilized to generate electricity. Similar to parabolic trough concentrating solar-thermal power systems, linear Fresnel collectors are built in the form of several long arrays that are positioned in a north-south direction to maximize solar energy gathering. Instead of simply utilizing the steam to generate electricity, the linear Fresnel technology gives the option of storing energy for later use.

3.4.1. Various analysis in linear Fresnel SC

Several studies have revealed that LFC has somewhat lower optical quality and thermal efficiency than PTC because to the considerable influence of the angle of incidence and the cosine factor. The report focused on the findings of a thermal-hydraulic analysis of a Fresnel SC loop with a linear structure, using liquid metals or molten salt as the heat transfer fluid, as conducted by Bachelier and Jager [241]. The findings show that, when used as a heat transfer fluid, sodium has several advantages over solar salt and ultimately a potentially higher energy yield, because sodium exhibits one hundred times greater thermal conductivity. Abas and Martínez-Val [242] proposed a cohesive design that can boost efficiency without increasing costs, such phenomena are analytically examined. For a particular design, a ray tracing simulation over a year was performed, and the results showed a modest improvement in radiation collecting efficiency when compared with traditional designs.

Calise et al. [243] economically compared the LFR and ETSC, two alternative solar thermal technologies incorporated into a polygeneration plant. The findings indicate that during some winter weeks, the solar portion for producing freshwater for the ETC-based system is between 15 and 20 %, but it is zero for the LFR when the multi-effect distillation unit is supplied solely by the biomass auxiliary heater. Kincaid et al. [244] characterized the impacts of various mechanical error sources on collector performance by a thorough sensitivity analysis of the optical performance of hyper light linear Fresnel technology. The research also demonstrates that the mechanical error model, which is more accurate than the basic cone optics model, can forecast the LF collector performance under a variety of operating situations. Tsekouras et al. [245] investigated into a LFC with a trapezoidal cavity receiver from an optical and thermal perspective. The simulation findings demonstrated that the absorber heat losses varied between 181.2 and

986.0 W/m, respectively, for intake fluid temperatures of 150 to 375 °C. Lopez-Alvarez et al. [246] illustrated how the incidence angle affects the transmittance of the receiver glass envelope and use ray-tracing methods to quantify its effect on the yearly optical efficiency of an LFR plant. The fluctuation in the optical characteristics of the receiver glass envelope as a function of incidence angle affects yearly optical efficiency by 2.5 %. Zhu et al. [247] explored the technical limitations and upcoming possibilities of LFC in the power sector. First, numerous design concepts are used to illustrate the technical features and elements of the technology. Following that, the historical uses of linear Fresnel collectors at low and intermediate temperatures are discussed.

Bellos et al. [248] used solid work flow simulation to analyse a linear Fresnel SC with a flat plate receiver both computationally and empirically. According to the final findings, this SC can generate 2.9 kW of usable heat in the winter, 5.3 kW of heat in the spring and 8.5 kW of heat in the summer. Additionally, this collector can operate successfully with thermal oil up to 250 °C. From the study of Zhu [249], a set of MATLAB code for linear Fresnel collectors is built as part of an analytical technique called First OPTIC. First OPTIC method has undergone thorough validation, and it has been established that it can calculate intercept factors precisely and outperform ray-tracing methods in terms of processing speed. Cau and Cocco [250] investigated into the efficiency of medium-sized concentrating solar-thermal power employing an organic Rankine process power producing unit paired with PTC and LFC. Because they produce more energy per square meter of occupied space, linear Fresnel collectors are the favoured choice. However, using parabolic troughs results to higher energy output per square meter of SC and consequently, higher conversion efficiencies, because parabolic troughs have superior optical efficiency.

3.4.2. Linear Fresnel SC in steam, hydrogen and power generation

LFCs have great potential for use in various applications, including steam, hydrogen and power generation, and they are efficient and cost-effective alternatives to traditional fossil fuel-based technologies. Barbon et al. [251] investigated how wind speed and direction, affects heat dissipation from a receiver with a longitudinal tilt angle. For a wind speed of 10 m/s and a northerly direction, the heat losses in Almeria, Rome, Budapest, Berlin and Helsinki are roughly 120, 131, 143, 165 and 174 % of C1, respectively. Based on report of Gallego et al. [252], a LFC from the solar cooling plant in Seville is given an adaptive model predictive control method. Performance while switching from a proportional integral derivative controller and feed forward series controller. Gain scheduling generalized predictive controller, a more advanced control method that has undergone testing and demonstrated excellent performance at the actual plant, is compared. Mehrpooya et al. [253] established a novel technique that used solar energy to produce a continuous supply of hydrogen is suggested. The Rankine cycle can supply 42.78 % of the electricity needed by the electrolyser, according to the results.

3.4.3. Linear fresnel SC integrated with heat-exchanging fluids

Heat exchanging fluid is primarily used as an intermediate fluid to transmit heat from a source to other demands. Grena and Tarquini [254] suggested that molten nitrates be used as the heat transmission medium in a solar Fresnel linear concentrator. An examination of optical and thermal properties of the system is given, along with a discussion of its benefits and drawbacks in comparison to previous systems. The system is particularly made to function with molten nitrates. The fixed receiver is a benefit that is crucial in high temperature situations. Bellos and Tzivanidis [255] discovered a novel method for enlightening the efficiency of LFR. According to the final statistics, while the improvement in the nanofluid pumping effort requirement by up to 50 %, the highest efficiency development is only about 0.8 %. Morin et al. [256] discussed the main difficulties that large-scale direct molten salt plants will face in the future, along with the experimental solutions that were tried, as well as the outcomes of the tests. To sum up, all anticipated difficulties with the usage of molten salts in SC pipes of Novatec have been tested experimentally. Therefore, there was no reason for worry, regarding the use of molten salt as heat transfer fluid.

3.4.4. Performance affecting parameters of linear Fresnel SC

Performance of LFC depends on several factors including solar irradiance, collector design, tracking system, thermal energy storage and geographical locations. Alhaj et al. [257] suggested an improved multi-effect distillation method that is powered by steam produced by a linear Fresnel collector at 70 °C and pressure of 0.3 bar. This study also demonstrated that the total system capital cost is cheaper when a water storage system is used. Additionally, the addition of an air-cooled condenser decreased the amount of water used overall by the plant by 2 m^3 per m^3 of feed water. The performance of the air-cooled condenser varies by 300 % as a result of variations in the relative humidity and dry-bulb temperature. Heimsath et al. [258] performed a sensitivity analysis for a variety of geometric and material factors. One is a thorough model that applies computational fluid dynamics to convective simulations and combines the spatial distribution of reflected radiation with ray tracing. The second approach uses a heat resistance model and is quicker. The obtained findings show that for some geometries, the secondary mirror temperature has a considerable impact on heat loss. Alhaj and Al-Ghamdi [259] presented a solar-field-based plant architecture with a LFC that provided heat to a multi-effect distillation plant with thermal vapor compression. According to the findings, a solar field measuring 1 m^2 annually yields 8.5 m^3 of distillate. Electric pumping energy was reduced by 40 % as a result of the suggested control approach. Other findings demonstrate adaptability of the LFC when used in conjunction with thermal desalination. Lin et al. [260] discussed the efficiency of a LFC using various cavity absorber. The receiver with the highest optical efficiency, 81.2 %, was determined to have a triangular cavity. The thermal efficiency of Fresnel lens SCs with triangular cavity receivers was estimated to be roughly 30 % at 120 °C. Performance of a LFC with catoptric subsets in terms of optical, thermal and overall characteristics has been presented [261]. According to the results obtained, the LFC performance with the catoptric subsets is lower for large sun inclinations and similar to the collection with evenly dispersed mirrors for sun positions near to solar noon.

Zhou et al. [262] conducted a conceptual investigation into the intricate dynamic behaviours of the SDHE absorption chiller, the LFR SC, and the complete solar cooling system. Based on experimental data, elevating the hot water intake temperature from 141.5 to 155.4 °C allowed the SDHE absorption chiller to achieve thermal Coefficient of Performance values ranging from 0.73 for single effect to 1.09 for double effect. The results indicate that employing effective optimization techniques can lead to improvements of up to 12 % over the standard configuration, while a comprehensive optimization approach results in a 4.5 % enhancement compared to a basic uniform optimization [263]. Abbas et al. [264] presented a versatile function designed to provide the optimal focal length for a mirror when used in the context of a north-south-oriented collector with a flat, horizontally positioned effective target. Therefore, controlling the focal lengths is particularly helpful in limiting the efficiency loss caused by faults. The suggested rule is forgiving of focal length control faults up to 10 %. The function can serve as a guide for further work or as a place to start for more intricate refinements. Boito and Grena [265] examined several secondary reflector models for LFC. Despite having mean flux intensities that are around 46 % higher and circumferential flux intensities that are noticeably more homogenous than parabolic troughs, it is found that Fresnel collectors are approximately 23 % more efficient. Vouros et al. [266] introduced a unique ray-tracing optimization for secondary reflector design of LFC. The secondary-reflector profile of a general LFC is optimized, using a novel optimization technique. The findings indicate that over 90 % of the power might have been diverted to the absorber by the deduced ideal secondary reflector at a variety of incidence angles [267].

3.4.5. Simulation in linear Fresnel SC

Simulations in LFC can be used to study the dynamic behaviours of power systems under various scenarios, including changes in load demand, generator outages and disturbances. Facao and Oliveira [268] optimized a novel trapezoidal cavity receiver for a LFC through ray tracing and CFD simulations. In contrast to numbers presented in existing literature for LFC, the newly modelled cavity showcased elevated values for the simulated heat loss coefficient. This difference is due, in part, to the narrower aperture of the system when compared with prototypes now on the market and the fact that the new cavity is not evacuated. Moghimi et al. [269] focused on gathering the maximum solar energy while diminishing plant heat loss and plant cost to create cheaper solar electricity from an LFC plant. Fig. 18 depicts the Impact of the number of mirror on annual thermal efficiency and relative levelized electricity cost (LEC). The optimization of performance in this study is centered around the plant's performance over the course of a hypothetical summer day. A more practical approach was also explored by optimizing the curvature of an ideal fixed mirror. When compared to the less practical scenario of using curved mirrors, this design only led to a marginal 3.4 % reduction in performance.

3.4.6. Linear Fesnel SC with thermal energy storage

The integration of LFC with thermal storage systems offers improved energy efficiency, reduced energy loss, enhanced reliability and significant potential in various industries and applications. Buscemi et al. [270] analyzed the possibility to supply an existing Sicilian firm that makes durum wheat pasta with the thermal energy it needs each year using a solar industrial process heating plant. The acquired results demonstrate that the most thermal energy-demanding firms in the food industry, can greatly boost their sustainability by using the thermal energy produced with Fesnel SCs directly. The amount of thermal energy needed from the sun can be met in part by its average yearly contribution, which can increase solar energy output throughout the summer. Sebastian et al. [271] presented an innovative idea to boost the competitiveness of linear Fresnel technology inside the solar sector. Results demonstrate an improvement in yearly plant efficiency of more than 10 % when compared with traditional North-South Fresnel plants placed in high latitude regions, such as Almera. LFC is a technology that utilizes flat mirrors to collect sunlight and focuses it onto a tube, generating steam that can be used for electricity production. When the optical and thermal efficiencies of the LFC are slightly lower when compared with other solar technologies, such as parabolic trough systems, it provides advantages such as energy storage capabilities. Various studies have examined different aspects of the linear Fesnel SC, including thermal-hydraulic analysis, design optimization, performance affecting parameters, integration with heat-exchanging fluids, simulations and the potential for integration with thermal energy storage systems.

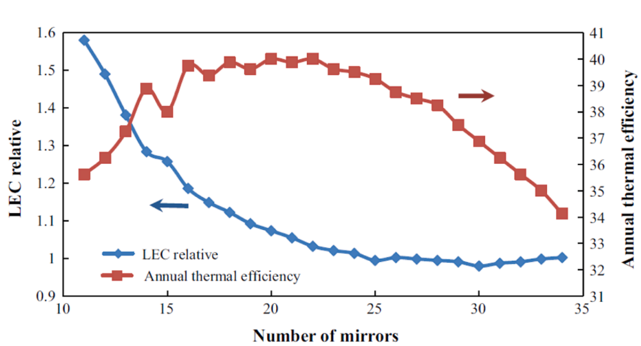

Fig. 18. Impact of the number of mirror on annual thermal efficiency and relative levelized electricity cost (LEC) [269].

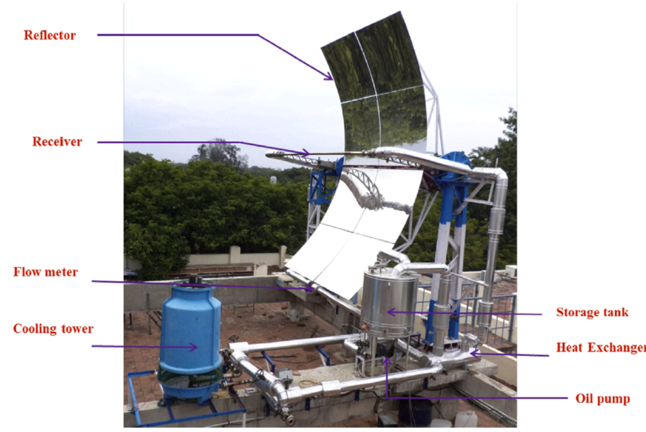

Fig. 19. Experimental setup of solar parabolic trough collector developed at IIT Madras [282].

3.5. Parabolic trough SC

A PTC is a solar technology that concentrates sunlight onto a tube containing a heat transfer fluid, which is then circulated through a heat exchanger to produce electricity or heat.

3.5.1. Parabolic trough SC enriched with nanofluid

Integrating a parabolic trough collector with nanofluid can increase energy efficiency and lower costs, but the potential drawbacks include nanoparticles settling out over time and long-term environmental concerns. Khan et al. [272] calculated the impact of a revolutionary double fluid PTC with a hybrid nanofluid-filled corrugated absorber tube on energy efficiency to reach the maximum energy efficiency. The findings also demonstrated that when the concentration of nanoparticles rises, PTC effectiveness increases. Alqarni et al. [273] introduced innovative methods for incorporating various turbulators within the tubes and introducing hybrid nanofluids with volume percentages of 0, 2 and 4 to improve the thermal efficiency and hydraulic performance of PTC. When operating under optimal conditions, the heat index number for the second type of turbulators is approximately 3.3 % greater when compared with the other type, as demonstrated.

3.5.2. Parabolic trough SC integrated with SWH

A PTC integrated with a SWH uses mirrors to focus light onto a fluid, which is heated and circulated through a heat exchanger to provide hot water. Isravel et al. [274] investigated the utilization of rings combined with twisted tapes to improve performance in PTC SWHs. It was found that using twisted tapes with connected rings and modified rings led to a remarkable enhancement in thermal performance, providing an escalation of 19 and 24 % related to using twisted tape alone. Chen et al. [275] experimentally determined how well a tiny solar heating system made up of ventilation tubes and PTC performed. According to the testing findings, the thermal efficiency of the PTC device was over 60 %, and the daily sun heating time for the typically insulated room at 39.87 °N latitude reached to 6–7 h. Avargani et al. [276] applied a connected modeling technique to tackle the challenging heat transport issue within the system. The study demonstrated that when the absorber pipe is placed in the optimal position, the thermal efficiency of the system reaches approximately 70 %, in contrast to less than 60 % when the absorber pipe is positioned at the focal line of the collector. Lamrani et al. [277] discovered the possibility of using a combined PTC latent heat thermal energy storage system to supply hot water for large buildings. The findings suggested that employing RT-55 as the phase change material (PCM) in the system outperformed the use of RT-42 and RT-65 for mass flow rates of 1800 l/h. This resulted in the system being capable of delivering liquid within temperature ranges of 85–36 °C during the daytime and 63–38 °C at night. Liao et al. [278] compared the performance of the PTC with LFC and indicated that the exergy efficiency of the PTC is 8 % higher than the LFC.

3.5.3. Other modifications in parabolic trough SC

Parabolic trough collectors are classified into three main types: the single-axis, the double-axis and the compact linear Fresnel reflector designs. Parabolic trough SCs include various reflective materials, improvements in the tracking mechanism and the integration of heat-exchanging fluids to enhance system performance. Summary of studies of other modifications in parabolic trough SC is presented in Table 6.

The integration of nanofluids with parabolic trough SCs shows potential for improving energy efficiency, with studies indicating that higher concentrations of nanoparticles can increase effectiveness. The addition of innovative turbulators and hybrid nanofluids has been shown to enhance thermal efficiency and hydraulic performance. And the impact of thermal conductivity with the heat energy liberation plays a significant role in the nanofluid utilised SC. The thermal conductivity of different metal oxide and metallic nanoparticles are shown in Fig. 20. Also the spectrum of electromagnetic radiation has equal importance with the heat absorption and liberation. The spectrum of electromagnetic radiation is depicted in Fig. 21. Further research and development are needed to address challenges, such as nanoparticle settling, long-term environmental concerns and economic viability to ensure the successful implementation of these advancements in parabolic trough SCs.

3.6. Artificial neural networks analysis in SC

Among all methods used in solar collector's optimization, intelligent method based optimization such as ANN is considered as a useful tool for modelling and simulation Herein, the applications of ANN in all the SC types was conferred to attain a significant outcome. Kalogirou [295] developed six ANN models for the calculation of the typical performance collector equation coefficients, collector heat capacity, the collector static temperature, the collector time constant, both at wind and no-wind conditions and the incidence angle modifier coefficients at longitudinal & transverse directions. The author compared the results of the ANN models with the conventional method and indicated that the performance of accuracy was satisfactory. It is also indicated that the quickness and evasion of the need to conduct long series of tests is the significant output of the ANN technique. Sozen et al. [296] developed an ANN model to predict the efficiency of the solar collectors with critical structures when other techniques have troubles. The higher and lower deviations was 2.56 and 0.0019 as compared to conventional methods and the merits of ANN model was rapidity, easiness and the capability to adopt for new test conditions. Farkas and Geczy-Vig [297] analysed the flat plate collector using ANN model to evaluate the thermal behaviour. Results specified that the output arrived based on the ANN was compared with the conventional system and signified a mean deviation of 0.9 °C for outlet temperature distribution. Hence it was concluded that the ANN provides a similar result as compared to experimental investigation and it can be effectively used for thermal behaviour study of flat plate collector. Farkas et al. [298] conducted modelling study using heat network method and Hottel-Vhillier in FPC. Results indicated that the values obtained with the neural network (NN) showed a good coincidence with the available values and it was suggested to implement this technique with other significant parameters evaluation. Fischer et al. [299] used ANN to evaluate the thermal performance of the ETC and conventional FPC. It was indicated that the ANN possess a significant scope for thermal performance evaluation of solar collector as compared to conventional method. Dikmen et al. [300] studied the thermal performance of the evacuated tube solar collector using ANN and adaptive neuro fuzzy inference system. The R^2-value for the thermal performance of collector is 0.8119 and it was measured as satisfactory. It was also arrived that this method is suitable to obtain very precise and

Table 6
Summary of studies of other modifications in parabolic trough SC.

S. No.	Author	Description	Main Findings	Ref
1	Eskandari	Hybrid solar-geothermal power plant providing electricity, heating, and cooling.	Achieved an exergy efficiency of 33.8 % under ideal conditions.	[279]
2	Natraj et al.	Concentrating solar energy method exposed to wind loads on open terrain.	Slope deviation increases with wind speed; aluminium trough has 4.62 % greater deviation than glass.	[280]
3	Mohammadi et al.	Implementation of a 5 MW PTC solar industrial process heat plant.	Optimal solar multiple of 1.5, producing 15,390 MWth annually with a 35 % capacity factor.	[281]
4	Reddy and Ananthsornaraj	Performance analysis of prototyped PTC system with evacuated and non-evacuated receivers. Fig. 19 depicts the experimental configuration of a PTC created at IIT Madras.	Maximum thermal efficiency: 66 % for ER, 64 % for NER with 0.12 kg/s mass flow rate.	[282]
5	Nascimento et al.	Algorithm to assess parabolic trough SC size based on thermal load and operating temperature.	Water performed better up to 300 °C; evacuated receiver can reduce PTC length by 9–160 %.	[283]
6	Subramanian et al.	Parabolic trough collector setups and heat absorption.	Aluminium sheet results in higher heat absorption.	[284]
7	Narayanan and Vijay	Heat transfer analysis at various temperatures in parabolic trough systems.	Heat transfer to water is the main challenge, with potential for improvement via design changes.	[285]
8	Felsberger et al.	CPV-T system using PTC with a new design and retrofit technique.	Achieved solar-to-DC efficiency of 30 %.	[286]
9	Thappa et al.	Comparison of two receiver tubes with the same parabolic reflector.	Altering absorber diameter affects energy gain and system efficiency in 400–600 K temperature range.	[287]
10	Chakraborty et al.	Thermal efficiency of LS-2 type smooth and helical absorber tube PTC.	Helical absorber tube PTC has 4–10 % higher efficiency than smooth absorber tube PTC.	[288]
11	Amiri et al.	Theoretical model to assess solar still efficiency.	Solar still system produces 0.97 Ls of freshwater daily, a 55 %increase from permanent PTC's winter production.	[289]
12	Ghazouani et al.	Optimal design and management strategy to decrease energy costs and increase renewable energy sources.	Achieved 40 % REF and EC of 0.05 USD/kWh for small capacities, 85 % REF and EC $<$ 0.2 USD/kWh for larger capacities.	[290]
13	Thakur et al.	Method to increase desalination unit water productivity using seawater.	Modified desalination unit increased full-day water production by 50.21 %.	[291]

(continued on next page)

Table 6 (*continued*)

S. No.	Author	Description	Main Findings	Ref
14	Bernard et al.	Use of CNT fluid as absorber tube in solar energy systems.	CNT fluid increases heat energy by 5.2–7.3 % compared to water.	[292]
15	Wu et al.	Numerical algorithm to determine the intercept factors of a PTC.	Algorithm efficiently computes intercept factors; ideal values: $\sigma = 0.125$, $d = 0$, $\beta = 0^\circ$, $\gamma = 0.9985$.	[293]
16	Singh et al.	Use of concentrated solar energy to generate steam.	Modified system with smaller trough collector and 40 °C fluid temperature can replace non-renewable energy.	[294]

predictable performance of evacuated tube solar collector. Du et al. [301] analyzed the straight through evacuated tube collector using computational fluid dynamics (CFD) and convolutional neural network. Results indicated that the CFD model provided poor accuracy as compared to convolutional neural network. Moghadam et al. [302] reported the impact of inclination angle towards the thermal performance of the solar flat collector using MATLAB. Results indicated that the latitude of the location plays a significant role in the solar radiation collection efficiency and consequently the thermal performance of the FPC. Heng et al. [303] conducted ANN analysis to evaluate the outlet water temperature in the parabolic trough solar collector. This technique provides the outlet fluid temperature with several radiation circumstances within short period. The results obtained in this technique are accurate and significant time reduction was obtained. Also it was suggested that the developed technique is more suitable to control simulators. Loni et al. [304] studied the performance of the parabolic dish concentrator with a rectangular tubular cavity receiver using two techniques namely numerical modelling technique and ANN. Various tube diameters of 35, 22, 10 and 5 mm and cavity depths of 2a, 1.5a, 1a, 0.75a and 0.5a were considered. The major advantage of this ANN technique as related to numerical modelling technique was economic consideration and time reduction. Results indicated that the ANN technique can exactly provide the thermal performance of the cavity receiver at various tube diameter and cavity depth with $R^2 = 0.99$. Facao et al. [305] analyzed the hybrid solar collector cum heat pipe systems using Radial Basis Function Networks and Multiple Layer Perceptrons ANN techniques. Results signified that ANN have several merits as related to energy balance based models such as rapid reaction, high accurateness, simple structure and insensitivity to uncertainties in the response variables. Lakshmipathy et al. [306] indicated that the Solar Cavity Collector (SCC) is a suitable alternate for FPC. Experimental results were compared with ANN and the results of both experimental and simulation has better coincidence. Results indicated that, SCC attains an efficiency of 77.7 and 41.3 % and attained an increase in efficiency of around 12 % in SCC as related to FPC. Delfani et al. [307] analyzed the efficiency of the nanofluid enriched direct absorption solar collector using ANN and experimental study. In the experimental investigation, nine collector models with dissimilar geometries were tested at various circumstances to examine the impact of the collector length and depth on the collector performance and also, to deliver the essential information for the ANN evaluation. The results obtained using ANN has good concurrence with the experimental investigation. ANN results indicated that the difference of the collector depth from 5 to 15 mm enhanced the collector efficiency about 9 %, while the collector length has minor effect on the collector efficiency. Masoumi et al. [308] conducted experimental validation, numerical and model development of an Asphalt Solar Collector which consequently developed an ANN. It was indicated that the ANN model is envisaged to develop parametric study and diminish the escalation in numerical modeling cost. The peak thermal efficiency and water temperature variation of the Asphalt Solar Collector are 24 °C and 45 % in August and 14 °C and 35 % in the November. Lecoeuche and Lalot [309] developed a Neural Network Output Error model and conducted performance analysis in solar collector. It was found that, Multiple Inputs Single Output model can be accurate in evaluating the performance of the solar collector. Ajbar et al. [310] analysed the ANN technique using Exponential Linear Unit in SC and indicated that the results obtained are 95 % accurate. Rawat et al. [311] developed algorithm using ANN to evaluate the heat transfer simulation of ternary hybrid nanofluid flow among parallel plates in PTC and indicated that the results obtained using ANN are more accurate. Shafiq et al. [312] investigated the heat diffusion efficiency of Darcy–Forchheimer tangent hyperbolic radiative inclined cylindrical film movement in PTC with an irregular heat sink / source utilizing the Levenberg–Marquardt method and back propagated ANN. Results obtained using this developed technique has negligible deviation. Castilla et al. [313] developed a ANN model for flat plate SC and indicated that the results obtained are having errors less than 10 %. Kuang et al. [314] enhanced the prediction of the accurate solution in ETSC using conventional neural network has lowest mean absolute error and root mean

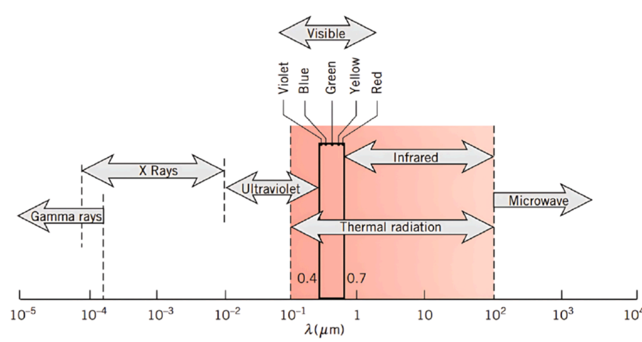

Fig. 21. Spectrum of electromagnetic radiation [38].

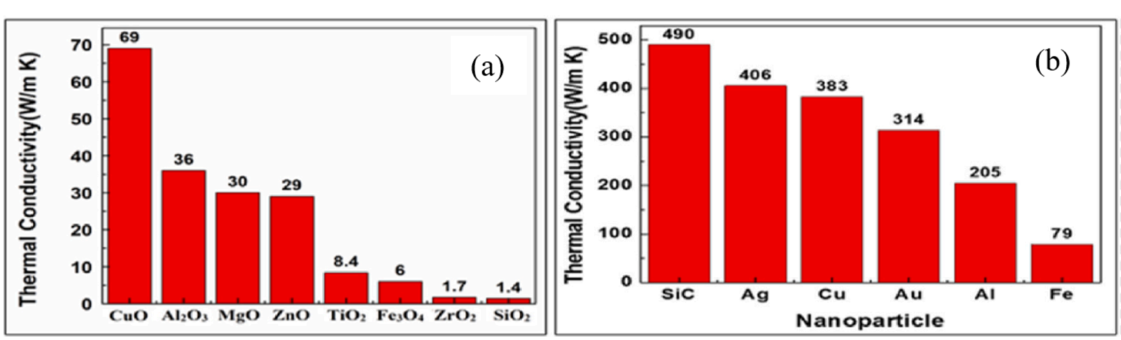

Fig. 20. (a) Thermal conductivity of different metal oxide nanoparticles (b) Thermal conductivity of different metallic nanoparticles. [18].

squared error. Conventional neural network results also indicated that the SC efficiency has direct correlation with the mass flow rate and solar irradiance than the wind velocity and ambient temperature.

4. Scope for future works

As the quest for production of more clean and sustainable hot water through renewable and environmentally friendly solar energy continues, the need to have increasing studies on SWHs and SCs is germane. This can be substantiated with the several current private, public and government sustainable development goals, policies and directives on sustainability, climate change, environmental protection and circular economy. Therefore, the following summarized future prospects are recommended for future studies towards advancing the designs, developments and applications of both SWHs and SCs.

- More experiments could be carried out to test the performance of different types of SWHs and SCs. This area can probably focus on developing more efficient and cost-effective modifications to SWHs and SCs. Researchers and engineers can explore new materials, such as advanced coatings and nanomaterials, as well as new designs and operating conditions to improve efficiency and performance.
- There can also be increased efforts to integrate these technologies with other renewable energy systems, such as wind and geothermal powers, to create hybrid systems that can provide a more consistent and reliable source of energy.
- Another area of future work may focus on improving the storage capabilities of SWHs and SCs. This could include developing new materials and designs for thermal storage systems, as well as exploring the potential of new technologies, such as phase-change materials and advanced thermal batteries.
- ANN is an effective technique in performance evaluation of SWHs and SCs. Furthermore, the other effective additions of ANNs are extreme machine learning (EML) and deep neural networks have peak accuracy than conventional ANNs in various applications. Hence it can provide new developments in SWHs and SCs performance evaluation and applications.
- Altogether, ongoing research and development in this field are critical to make SWHs and SCs more viable, as a sustainable energy source, and further reduce dependence on fossil fuels.

5. Concluding remarks

SWHs and SCs are promising technologies that can provide a pure and sustainable source of hot water. However, it is essential to consider various factors, such as location and cost, before deciding to invest in these technologies. This review article has discussed several types of SWHs and solar water collectors to provoke unto more reliable devices and efficient setup. Various designs and integrations of components have been studied, including integration of absorption tube, V-trough collector, exchangers, PCM for SWH and the collectors: parabolic trough, flat plate, compound parabolic and evacuate tube collectors. Also, this article has compendiously reviewed and presented better understanding on how to improve and enhance the temperature of the outlet fluid. Summarily, the following important concluding points can be deduced.

- Among the various studies conducted on the thermal performance of SWH integrated with absorber coils. SWHs integrated with absorber coils are a promising technology for providing hot water in a sustainable and cost-effective manner.
- SWH integrated with ETC uses evacuated tubes to collect solar energy. This type of SWH is more efficient than traditional, because it has a smaller heat loss coefficient, is less susceptible to damage from the elements, and can be used in a wider range of climates. More also, studies have shown that SWHs integrated with evacuated tubes can be more efficient than traditional by up to 28 %.
- The experimental result reveals that the stainless steel absorber had superior retention rates and coefficients of heat losses than the aluminium absorber tube, and overall thermal and optical efficiencies are 72 and 77 % respectively after being evaluated without any load.
- SWH integrated with heat exchanger can be more efficient than traditional heaters. It is observed that a prototype SWH with an internal exchanger and a thermosyphon system had a mean daily efficiency of close to 50 %. It is discovered that a parallel circular tube rings type heat exchanger can reduce overall thermosyphon flow friction loss while maintaining temperature stratification along the vertical height of the storage water tank.
- The incorporation of nano-composite materials in SWHs has shown promising results towards improving thermal energy storage capacity and overall efficiency. Studies have demonstrated the benefits of utilizing PCM and PCM-doped nanocomposites in enhancing the thermal conductivity and energy efficiency of solar water heating systems.
- The findings indicate that CuO nanofluids exhibit greater increase in output power when compared with Al_2O_3 nanofluids.
- The integration of PCM into SWHs offers promising advantages in terms of energy efficiency, temperature control and thermal energy storage. Studies have validated the effectiveness of PCM storage tanks, highlighting reduced power requirements and heat loss.
- The combination of a SWH with PV cells in a hybrid system provides significant benefits in terms of energy production and water heating. This integrated approach utilizes the capabilities of both technologies to maximize energy efficiency and reduce reliance on conventional energy sources.
- A SWH integrated with a thermosyphon system offers a passive and efficient way to heat water, using solar energy. This system is simple, reliable and does not require an external power source, making it particularly suitable for areas with limited access to electricity.
- ANN is an intelligent technique for finding the performance of the SWHs and SCs with minimal cost and the error percentage was also within the acceptable limit. Hence many modifications were analysed using ANN as an effective tool in performance calculations of SWHs and SCs.
- By incorporating nanoparticles, such as single-wall CNT and multi-walled CNT in water-based nanofluids, significant improvements in heat transfer coefficients have been achieved. Furthermore, when combined with PV cells, CPC collector provides a hybrid solar system that generates electricity and also collects thermal energy.
- Including innovative designs and technologies, such as compound parabolic concentrators and U-shaped collectors in SC enhanced the overall effectiveness and energy. These advancements contribute to a sustainable and renewable future for solar thermal systems.
- The findings highlight the potential of linear Fesnel SC in applications, such as steam, hydrogen and power generation, as well as their performance under different conditions and the benefits of thermal energy storage integration. Overall, the linear Fesnel SC presents a cost-effective and efficient alternative for sustainable energy solutions.
- Integration of PTC with SWHs has resulted to thermal augmentation ranging from 19 to 24 %, when compared with conventional systems. The use of helical absorber tubes increases efficiency levels by 3.5–10.0 % when compared with smooth absorber tubes. In addition, optimization studies have highlighted the impact of various factors on energetic efficiency and overall cost rate, with potential exergy efficiencies of up to 33.8 %.

Overall, the significant progress and potential of SWHs and SCs in delivering clean and sustainable hot water solutions. The optimization of system parameters, integration of innovative components, utilization of nanotechnology and the cost-effectiveness of these technologies have emerged as key findings. By improving thermal efficiency, enhancing heat transfer and incorporating advanced materials, SWHs and SCs offer a promising pathway towards a greener future. Their viability and economic benefits, coupled with their ability to reduce dependence on fossil fuels, make them attractive options for sustainable hot water production. Continued research and development efforts are crucial to address challenges and further refine these technologies for widespread adoption. Based on the above study, it indicates that future studies should carefully select the appropriate methodology to better understand the impact of specific parameters on technology adoption. The traditional factors and societal norms can also sway the significance of factors in various studies. Future studies should consider these cultural changes when scheming surveys or experiments. Addressing these issues in future research can help clarify the factors influencing the adoption of SWH systems and other RE technologies.

Also the Current inventions in SWH & SC systems concentrates on an effective design utilize solar energy more sustainably and efficiently for water heating application; to address current challenges, and focuses on the future research potentials. A hybrid system can be developed in industrial applications for improving the overall efficiency. The feasibility of using several nanofluids including phase change materials should be investigated in the SWH& SC system. Solar water heaters with several modifications in absorber coil, evacuated tube, V-Trough collector, storage collector, heat exchangers and solar collectors with CPC, Flat Plate, PTC can be carried out to enhance the efficiency of the SWH & SC.

CRediT authorship contribution statement

Rasaiah Naveenkumar: Writing – original draft, Conceptualization. **Rajaraman Venkateshkumar:** Visualization, Validation, Data curation. **Vinayagam Mohanavel:** Visualization, Validation, Formal analysis, Data curation. **Chelladurai Franklin:** Visualization, Validation, Formal analysis. **Sikiru Oluwarotimi Ismail:** Writing – review & editing, Formal analysis, Data curation, Conceptualization. **Manickam Ravichandran:** Writing – review & editing, Validation, Supervision, Conceptualization. **Sathish Kannan:** Visualization, Validation, Data curation. **Manzoore Elahi M. Soudagar:** Visualization, Validation, Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding statement

No funds, grants or other support was received for this work.

Data availability

No data was used for the research described in the article.

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