buildings

Review

Recent Advancements in Augmentation of Solar Water Heaters Using Nanocomposites with PCM: Past, Present, and Future

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Abstract: Energy consumption in India is massive, and even the quantity used for household tasks is substantial. The majority of the requirement is satisfied by using fossil fuels, which are the traditional methods. Heating water is the most frequent home application. Accordingly, this article examines studies from the previous ten years. The information in this article demonstrates that using renewable energy is the greatest way to cut back on both the use of fossil fuels and carbon emissions while heating water for residential use. Solar, hydroelectric, wind, and biofuels are the most significant renewable sources for improving building efficiency that can be used for an extended period of time. The solar water heater is a common example of how solar energy is being used in homes more frequently. In order to identify key issues and solutions related to employing solar water heaters as an effective water heating application in both commercial and residential buildings, this article compiles research data from earlier studies (2012–2022). The literature survey was carried out using Scopus, a specialized database. Sixty-six dedicated research publications having search keywords plus recently published articles that matched the inclusion criteria were chosen for this review study. The study's findings show that there is a greater inclination of researchers towards research and development in the field of domestic solar water heaters. The research publications that are being presented are all from the past 10 years (2012–2022) and stress the use of solar energy in increasing building efficiency. The study highlights how flat plate solar collectors with distilled water as the heat transfer fluid and a phase-changing substance as the thermal energy storage could potentially be enhanced. The thermal conductivity of paraffin wax and distilled water was improved by 75% of the researchers by using 0.05 to 0.5% concentrations of Al and Cu oxide nanoparticles, making it useful in solar water heaters. A total of 78% of researchers are interested in domestic water heating applications since they use a lot of energy in both urban and rural settings.

Keywords: solar water heater (SWH); phase changing material (PCM); nano fluid (NF) and thermal energy storage (TES); building efficiency; thermal energy

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1. Introduction

Energy is used in some way by our daily activities. The main energy sources in the past were coal, wood, and animal manure. The biggest drawback of these sources is that they will eventually run out, which will make renewable energy sources even more crucial [1]. New energy types have been created to solve this problem. The most important long-term sustainable energy sources are solar energy, hydroelectric energy, wind energy, biofuels, and ocean wave energy. With the potential to be a viable renewable resource in the future, solar energy is a significant source of energy for both domestic and commercial applications. Due to its clean, abundant reserves, and pollution-free properties, solar energy has been addressing key interests as a type of renewable energy [2]. For engineering applications, solar energy provides a sizable reserve that may be gathered at a reasonable cost. Several countries rely on solar energy to meet their energy needs. The solar water heater is one of the most widely used household applications of solar energy (SWH).

The main issue with solar energy is that it is intermittent, and therefore unavailable during the night. As a result, thermal energy storage is required to store solar energy so that it can be used at night or when it is cloudy. One of the most intriguing ways to store solar thermal energy is through phase-changing materials (PCMs) [3]. Various PCMs, including organic and inorganic materials, eutectic mixes, and salt hydrates, are currently available for heat energy storage. The choice of PCM is influenced by thermal properties such as high latent heat, high heat capacity, and thermal conductivity in both solid and liquid phases [4,5]. Phase equilibrium, low vapor pressure, high sensitivity to volume change, and very high density are all desirable physical properties of PCMs [6]. According to previous research, PCMs have low thermal conductivity, undergo significant volume change, excellent cooling properties, and low heat-exchanging capabilities. Some of the inorganic PCMs, such as salt hydrates, show excellent thermal properties, but at the same time, these PCMs show super cooling and phase separation issues [7].

The use of nanometer-sized solid particles dispersed in common liquids is one method that has been developed to deal with these restrictions. Nanofluid (NF) is a term that refers to the suspension of particles ranging from one to one hundred nanometers in a typical base fluid. Choi and Eastman [8] were among the first researchers that utilized nanoparticles (NP) to enhance the thermal conductivity of fluids. In addition to exhibiting superior characteristics after suspension in a base liquid, NP also demonstrate greater stability compared to other millimeter- or micron-sized particles. The thermal conductivity of NF is substantially higher. Numerous studies have been conducted recently on a variety of NFs to enhance, experimentally and theoretically, the heat transmission in thermal engineering devices. In order to determine the thermophysical parameters of NFs, such as their density, viscosity, and specific heat, they have also used a number of production, characterization, and modeling techniques [9]. The improved thermophysical behavior of NF could present an excellent opportunity to intensify innovation in heat transfer, which can play a key role in HVAC application, power generation, microfabrication, thermal therapy for cancer treatment, and chemical and metallurgical sectors. Recent research on NF has focused on identifying methods to measure thermal conductivity [10]. Recently, Abouali, Ahmadi, and Kamyar looked at computer simulations and CFD-based model systems that used NFs and analyzed them [11,12]. Saidur et al. [13] noticed how NFs could be used in various areas, such as cooling electronics, heat exchangers, medical applications, fuel cells, and nuclear reactors. NF is also essential in SWH applications. We have examined the problems with using NF, such as how stable the nanoparticle dispersion is over time and how expensive it is.

In the literature, researchers have targeted finding the best way to use alternative energy sources to reduce the consumption of fossil fuels and CO_2 emissions. As the price of fossils fuels-based energy is increasing day-by-day, renewable energy (solar) will be the energy of the present and the future. The amount of solar energy transferred to the earth in one hour is more than the entire world uses in a year [14]. Several changes were considered in order to find the best way to improve solar system efficiency while also making energy more stable and long-lasting. This paper examines the research that has been conducted on how NF can be used in SWH systems. According to the articles reviewed, SWH has a lot of potential for using solar energy, with a thermal energy storage (TES) system. Even after the sun goes down, the TES can keep the heat on [15,16]. Researchers can obtain a stable energy output from PCMs as TES for buildings applications. The low thermal conductivity of PCMs primarily influences how they absorb and emit heat. It is crucial for future studies because of the behavior and PCM impact relationship that was discovered [17]. In this way, tiny pieces of metal oxide, known as NPs, improve the thermal properties of PCMs. As a result, the majority of this review focuses on how NPs and NFs affect the efficiency of domestic SWH systems, as well as how they affect the economy and the environment when these systems are used.

The study's main objectives can be divided into three categories: (a) to classify solar energy's application-based driving force; (b) to study the techniques for boosting SWH with different designs of solar collectors; and (c) to study the application of PCM with different concentrations of NPs.

2. Methodology

A direct search of the literature is incorporated into the technique for article selection and country-wise distribution, as outlined in Figure 1.

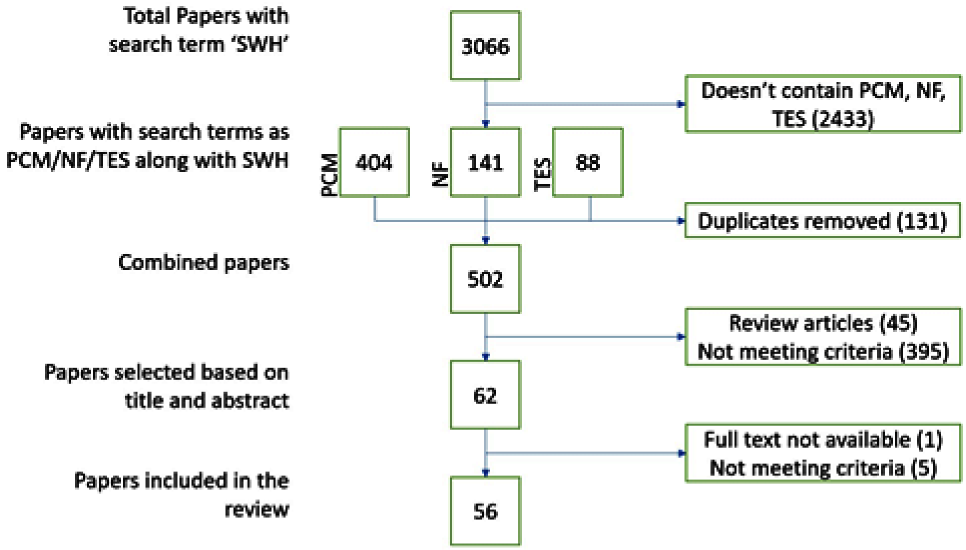

Figure 1. Methodology adopted: flow diagram for article selection.

2.1. Search of the Literature

This study aims to present the most recent developments in thermal efficiency enhancement methodologies used to augment SWH and eliminate the obstacles that stand in the way of utilizing the SWH system in a variety of domestic and industrial applications by providing an overview of those developments. To compile the most recent research articles, the Scopus database was utilized. "Solar water heater", "Phase changing materials", "Thermal energy storage", and "Nanofluid" were among the search terms that brought up a total of 3066 articles, conference papers, and review papers (Figure 1). All of the articles that were published in the journals with peer reviews were considered. The current analysis draws on a total of 56 different pieces of literature (Table 1). To familiarize the reader with the performance of SWH, nanocomposite PCMs were studied.

Table 1. Search terms and combinations used.

Rejection Criteria for the Study	440 Papers N Found Not Suitable after Reading Abstract	6 Papers Were N Found Not Suitable After Reading the Full Text
Review papers	45	1
Applications of PCM without NF	171	4
SWH applications without NF and PCM	198	-
NF applications with water heaters without solar energy usage	26	-
No full text is available	-	1

The selection of papers was based on the following criteria: (a) the paper had to discuss the usage of PCMs as TES in SWH application; (b) the PCMs reported in the article had to be thermally enhanced with the application of NF. The following were among the factors for dismissal: (a) the study evaluated SWH without employing any TES technique; (b) the SWH application did not incorporate NF.

2.2. Data Extraction

According to the predetermined objectives, the information gathered from the research papers is organized into factors such as country and application. Table 2 was created to see if there was a pattern in the use of SWH across the country. It is worth noting that India has one of the highest rates of research in this field. Another categorization was performed in order to compile the various methods that are commonly used to evaluate thermal performance. When compared to existing strategies, these are just as effective at bringing about performance improvements.

Table 2. Country-wise research trend of solar water heater from 2012–2022 and major research findings.

Authors	Country	Year	Application	Performance Enhancement
Swaroop Kumar Mandal et al. [7]	India	2020	SWH	It has been found that better results can be achieved using 1.00 wt% CuO-PCM Nanocomposite.
Ansu et al. [8]	Hungary	2020	SWH	An increment of 52.09% in thermal conductivity has been observed.
Hawwash et al. [9]	Egypt	2017	SWH	Increasing the percentage of the alumina NF improves the thermal efficiency of the flat plate solar collector. 0.5% volume fraction of alumina NF was found optimum.
Ahmadi et al. [10]	Iran	2016	SWH	An increment in thermal efficiency up to 18.87% has been observed.
Mahbubul et al. [11]	Pakistan	2018	SWH	Up to 66%, thermal efficiency was achieved with 0.2% NF.
Munuswamy et al. [12]	India	2015	SWH	Overall thermal performance improved with NF.
Sadeghi et al. [13]	The Netherlands	2021	SWH	It enhanced the volume fraction of Cu_2O/distilled water and improved the thermal characteristics.
Sundar et al. [14]	India	2017	SWH	An increment in thermal performance has been observed.
Sivakumar et al. [15]	India	2013	SWH	An increment in thermal efficiency has been observed.
He et al. [16]	China	2015	SWH	The thermal efficiency of the flat plate collector increases up to 23.83%.
El-Shafai et al. [17]	Egypt	2020	SWH	Maximum enhancement in thermal conductivity (22.56%) has been achieved.
Ouyahia et al. [18]	Algeria	2016	SWH	An enhancement in heat transfer rate has been observed.
Sheikh et al. [19]	Vietnam	2017	SWH	With aluminum oxide NPs, the efficiency of solar collectors may be enhanced by 5.2%.
Maustafa Mahdi et al. [20]	Iraq	2020	SWH	With NF, the thermal value improved by about 10% higher than without NF load conditions.
Michael and Iniyan [21]	India	2015	SWH	NF significantly improved the thermal performance compared to distilled water alone.
Singh Rajput et al. [22]	India	2019	SWH	There is a 21.32% enhancement observed in solar collector efficiency.
Ram Kumar et al. [23]	India	2019	SWH	The maximum efficiency attained with TiO_2 NF plane tube collector is 58%.
Rajput et al. [24]	India	2017	SWH	There is a maximum of 30.58% improvement observed in collector efficiency with NF.
Darbari and Rashidi [25]	Iran	2021	SWH	It is found that thermal efficiency increases with the addition of Cu and CuO NPs.
Kabeel et al. [26]	Egypt	2015	SWH	Efficiency enhancement of up to 11% was obtained by increasing the NPs to 3% concentration.
Sundar et al. [27]	Portugal	2021	SWH	The thermal efficiency of the collector is further enhanced up to 68.48% at 0.3% NF concentration with a wire coil.
Delfani et al. [28]	Iran	2016	SWH	NFs improve the collector efficiency by 10.29% more than the base fluid.
Owolabi et al. [29]	Malaysia	2016	SWH	The embodied energy emission rate, collector size, and weight can be reduced by 9.5% using NFs.
Ling et al. [30]	China	2017	SWH	The eutectic + SiO_2 composite has a thermal conductivity of 5% higher than pure eutectics.
Gupta et al. [31]	India	2020	SWH	Thermal conductivity improved by 45–127% with different NPs and PCM+TiO_2 combinations, giving better results.
Sobhansarbandi et al. [32]	USA	2017	SWH	Observed constant day output and prolonged supply of hot water until night.
Kumar and Mylsamy [33]	India	2020	SWH	1% combination of nano-enhanced PCM given better thermal performance.
Shabtay and Blackc [34]	USA	2014	SWH	60% charging and discharging time of PCM reduced with graphite.
Manirathnam et al. [35]	India	2020	SWH	Thermal conductivity improved by 22.53%.
Manoj Kumar and Mylsamyc [36]	Hungary	2019	SWH	Thermal efficiency increased up to 22.78% with Nanocomposite.
Mirzaei [37]	Iran	2017	SWH	Thermal efficiency increased up to 29.5% with NF.
Saw et al. [38]	Malaysia	2013	SWH	Thermal efficiency increased up to 8.4% with Nano-enhanced PCM.
Vinet and Zhedanovc [39]	USA	2019	SWH	NPs displayed capabilities to increase the specific heat capacity up to 46.15%.
Pasupathi et al. [40]	India	2021	SWH	The thermal conductivity of paraffin was amplified up to 33.34% with NPs.
Manoj Kumar et al. [41]	India	2020	SWH	Maximum efficiency up to 65.56% has been attained with a 2.0% mass fraction of NPs.
S. K. Mandal et al. [42]	India	2020	SWH	The maximum heat transfer rate and Rayleigh number are obtained as 5.7 KW and 8.84 × 107 pertaining to CuO nano-doped PCM composite.
Al-Kayiem and Lin [43]	Malaysia	2014	SWH	The best performances analyzed were at 10-degree inclination with the highest efficiencies up to 52%.
Swaroop Kumar Mandal et al. [44]	India	2018	SWH	Observations show that the presence of CuO NPs is ineffective during the night.

Table 2. *Cont.*

Authors	Country	Year	Application	Performance Enhancement
Liu et al. [45]	China	2019	SWH	Combining expanded graphite with the alloy can improve the composite PCM's thermal conductivity, which is 162.4% higher than the pure alloy.
Sobhansarbandi et al. [46]	USA	2017	SWH	The result shows more constant output, even on a cloudy day, and prolonged heat output until nighttime.
Alshukri et al. [47]	Iraq	2021	SWH	Increase in the thermal efficiency with a range of (33.8% to 45.7%) and (23.8% to 26.7%).
Dhinakaran et al. [48]	India	2020	SWH	The nanofiller improved the distilled water temperature by 33%.
Li et al. [49]	China	2019	SWH	The melting time of Stearic acid/expanded graphite was shortened by 63.3% compared with that of expanded graphite.
Sahota and Tiwari [50]	India	2017	Solar Still	CuO NF has given better results and better annual performance of solar still.
Mahian et al. [51]	Iran	2017	Solar Still	NF heat exchangers can enhance the performance indices by about 10%.
Rabbi and Sahin [52]	Hungary	2020	Solar Still	Thermal efficiency and exergy efficiency with water–Al_2O_3–SiO_2 hybrid NF resulted in 37.76% and 0.82%, respectively.
El-Said et al. [53]	Egypt	2016	Solar Still	The observed output shows an increment in freshwater production at decreasing cost.
Khairat Dawood et al. [54]	Egypt	2020	Solar Still	Thermal efficiency increased by 250%, which reduces the cost of water.
Muraleedharan et al. [55]	India	2019	Solar Still	Maximum efficiency of 53.55% is obtained at 0.1% nano heat transfer fluid.
Mishra et al. [56]	India	2021	Heat Exchanger	The thermal conductivity of beeswax improved from 0.25 to 0.76 w/mK.
Tlili et al. [57]	Vietnam	2020	Heat Exchanger	Mass flow improved by 34%.
Khoshvaght-Aliabadi et al. [58]	Iran	2017	Heat Exchanger	Up to 14 % enhancement in heat transfer coefficient with NF.
Chaurasia and Sarviya [59]	India	2021	Heat Exchanger	Nusselt number improved by 421%, as well as thermal performance.
Misale et al. [60]	Italy	2012	Heat Exchanger	A slight improvement was observed with NF.
Lin et al. [61]	China	2020	Heat Exchanger	Heat power transfer improved by 50%.
Wu et al. [62]	China	2018	Heat Pump Water Heater	The volume of hot water increased up to 194%.

To consider the goal, the information gathered from the articles was further classified in Table 3, such as the specified design of the solar collector and the flow methodology used. The employment of various NPs concentrations with PCMs/distilled water was the subject of the next classification. This classification was also necessary to understand the role of PCMs in various solar collectors. Table 3 shows different NPs used for thermal conductivity improvement, i.e., CuO and Al_2O_3 are used in 38% of the previous literature research [7–9,12–17,19,21,22,25–27,35,37–39,42–44,48,50,52–55,57–60]. Authors have used other nanoparticles, such as graphene [10,20], CNT/MWCNT [11,24], and TiO_2 [18,23], to improve heat transfer characteristics. From Table 3 it was concluded that 71–75% of researchers took 0.005–0.5%, and 25–29% took 1–5 percent of NPs by weight. Other NPs, such as SiO_2, FeO_2, ZnO, and expanded graphite, were also used by the researchers (Table 3).

Table 3. Application of nanoparticles (with concentration) in solar water heating applications (2012–2022).

Serial Number	Type of Solar Collector			Type of Flow		Percentage of Nano-Particle Used in Fluid											Reference
	Flat Plate	ETC	Parabolic Collector	Turbulent Flow	Laminar Flow	Al_2O_3	TiO_2	CNT/MWCNT	SiO_2	CeO_2	FeO_2	ZnO	Expanded Graphite	Graphene	CuO/Cu_2O	SiC	
1	1				1										0.25/0.5/0.75/1		[7]
2	1					1/2/3/4/5											[8]
3	1				1	0.005/0.01/0.015/0.02/0.025											[9]
4	1				1									0.01/0.02			[10]
5		1			1			0.05/0.1/0.2									[11]
6	1				1	0.2/0.4									0.2/0.4		[12]
7		1													1/2/3/4		[13]
8	1			1		0.1/0.3											[14]
9	1			1		0.4											[15]
10	1				1										0.01/0.02/0.04/0.1/0.2		[16]
11						0.0625/0.125/0.2									0.0625/0.125/0.2		[17]
12							0.05/0.1										[18]
13						0.02	0.04							0.01			[19]
14		1			1									0.2			[20]
15	1				1										0.05		[21]
16	1				1	0.1/0.2/0.3											[22]
17	1				1		0.3										[23]
18	1				1			0.1/0.2/0.3									[24]
19	1				1	1/2/3/4/5	1/2/3/4/5								1/2/3/4/5		[25]
20	1				1	1/2/3											[26]
21	1			1											0.1/0.3		[27]
22	1				1			0.015/0.02/0.025									[28]
23	1				1						0.5						[29]
24									5/10/15/20								[30]
25		1			1		0.2/0.5/1		0.5		0.5	0.5					[31]
26		1			1			Y									[32]
27		1			1					0.5/1/2							[33]
28		1			1								Y				[34]
29		1			1										0.4/0.5	0.4/0.5	[35]
30		1			1				1								[36]
31	1				1	0.1									0.1		[37]
32	1				1										1		[38]
33		1				1/2/3	1/2/3	1/2/3							1/2/3		[39]
34		1			1				0.5/1/2								[40]
35		1			1				0.25/0.5/1	0.25/0.5/1							[41]
36	1				1										0.25/0.5/0.75/1		[42]
37	1				1										1		[43]
38	1				1										0.25/0.5/0.75/1		[44]
39													10				[45]
40		1			1			Y									[46]

Table 3. *Cont.*

Serial Number	Type of Solar Collector			Type of Flow		Percentage of Nano-Particle Used in Fluid											Reference
	Flat Plate	ETC	Parabolic Collector	Turbulent Flow	Laminar Flow	Al_2O_3	TiO_2	CNT/MWCNT	SiO_2	CeO_2	FeO_2	ZnO	Expanded Graphite	Graphene	CuO/Cu_2O	SiC	
41		1			1							5			5		[47]
42	1				1	0.3/0.4											[48]
43	1				1								2/6/10				[49]
44	1				1	0.03–0.2	0.03–0.2								0.03–0.2	0.1	[50]
45	1								0.5/1/2								[51]
46	1					0.1			0.1						0.1		[52]
47						01/02/03											[53]
48		1	1		1										3		[54]
49	1					0.025/0.05/0.075/0.1/0.2											[55]
50													7.5/15				[56]
51	1				1	Y									Y		[57]
52	1				1	0.1/0.3											[58]
53				1											Y		[59]
54						0.5/3											[60]
55													Y				[61]
56													25				[62]

MWCNT—multiwall carbon nanotubes; Y—NP available, but concentration not disclosed.

2.3. Obtained Results from the Reviewed Works

To find the relevant documents, the search terms "solar water heater", "PCM", and "Nanofluid" were directly entered into the Boolean formula. The majority of the papers discussed how PCM affects domestic SWH performance, but only a few looked at how NF can be used to improve SWH. The procedure extracted 503 documents, which were then re-filed based on the full text, yielding 56 papers, which are further extended up to 110+ articles. We will go over the information from these articles in greater detail in the following sections.

2.3.1. Distribution of Research Articles

When the article was distributed by country, India received the greatest share (36%), followed by China and Iran (nearly 11% each). The main suppliers were Egypt, the United States of America, Malaysia, and Hungary. China, Iran, and the United States of America all have more than a hundred days of sunshine per year [63]. In contrast, India has access to solar energy more than 300 days out of the year [64]. The majority of the articles discovered during the search process are from recent years. These data indicate that researchers see a bright future for solar energy harvesting.

2.3.2. Water Heating Applications by Utilizing Solar Energy

In this study, 78% of the articles were based on domestic SWH applications. In comparison, 11% were based on solar stills and other heat-exchanging devices. The deviation of 78% of articles towards domestic SWH applications gives hope of reducing a significant amount of carbon emission in water heating energy applications. A survey found that more than 80% of SWH applications are installed in residential buildings, and the rest (20%) belongs to public buildings and industries [65]. This survey shows that domestic SWH has more potential to harness this renewable energy source. The cost-effective appliances for solar water heating present an excellent view of solar energy utilization. However, low heat transfer rates and limited availability are still big hurdles in the path of SWH, which has drawn the attention of researchers [47].

2.3.3. Solar Collectors

These reviewed data point to the extensive adoption of flat plate collectors, accounting for 65% of all research articles. SWH systems that use evacuated tubes made of borosilicate glass with a special coating to absorb solar energy are called evacuated tube collector systems (ETC). Most flat plate collectors are used for low-temperature applications, while ETC is used for high-temperature applications. Nowadays, ETC is also very popular in domestic SWH. About 33% of the investigators have used ETC. An ETC has better thermal performance compared to a flat plate collector. Some of the earlier research reported that the cost of a NF-integrated heat collector is almost the same as a conventional heat collector [66–70]. In contrast, a NF-integrated solar collector is thermally more efficient than a conventional one. This becomes even more important considering the year-wise distribution of sunshine and the article percentages in those countries (Table 4).

Table 4. Country-wise distribution of article share having maximum yearly sunshine hours.

Country	Articles Share	Sunshine Hours (Yearly)	Reference
India	36%	2684	[68]
China	11%	2990	[69]
Iran	11%	2826	[70]
Egypt	9%	3958	[66]
United States	7%	4015	[67]

2.3.4. Thermal Energy Storage

The reviewed articles found that 38% of researchers used paraffin wax as the TES. In comparison, only 4% of researchers used hydrates and eutectic mixtures. PCMs as heat accumulators work with the idea of absorbing and releasing thermal energy throughout the day during the charging and discharging process. Paraffin wax plays a vital role to achieve the desired objective in SWH application. The melting point of paraffin wax is 53 °C to 60 °C with latent heat storage of approx. 190 kJ/kg-K and thermal conductivity of 0.20 W/mK [71] (Table 5). PCMs change phases from solid to semi-liquid and then to liquid. The phase change process can also occur in the reverse direction when heat is removed from PCMs. When solar energy is available during the day, the paraffin wax absorbs heat and the temperature of the paraffin wax rises. The intensity of the sun's radiation increases throughout the day, and the paraffin begins to change phase from solid to liquid (semi-solid) by absorbing more thermal energy, i.e., latent heat. As a result, the liquid-phase heat absorption process continues as sensible heating and behaves like a thermal reservoir [72,73]. About 52% of researchers used distilled water with NP as NF to improve domestic SWH and solar distillation. Between the temperature ranges of 40 °C to 52 °C, the PCM unit can store 5 times more energy than water. The appropriate amount of energy is delivered in a stable and consistent manner by the phase-change process. The sensible energy required to heat the PCM to 48 °C is only half that required to heat water. The choice of the fin pitch and the usage of expanded surfaces in the shape of aluminum fins resulted in an equivalent thermal conductivity of 23W/m-K. During sunshine, excess energy can be used in PCM thermal storage technology; this is called charging. The discharge process takes place when solar radiation is not accessible. Paraffin wax continuously loses heat to create a warming effect [74–77].

Table 5. Comparison of thermal properties of paraffin wax found in the literature [72–75].

Melting Temperature (°C)	Latent Heat (kJ/kg)	Specific Heat (Liquid) (kJ/kg-K)	Specific Heat (Solid) (kJ/kg-K)	Thermal Conductivity (W/m-K)	Reference
55	176	2.9	2.7	0.21	[74]
52	210	2.1	2.9	0.24 (solid)	[71]
59.9	190	2.0	2.15	0.24 (solid)	[73]
53	189	-	2.5	0.20	[72]

2.3.5. Nanoparticles-Embedded Nanofluid

Table 3 shows exhaustive applications of NPs to improve heat transfer characteristics. In the literature, authors used different NPs and evaluated how well they improve the thermal properties of base fluids. In contrast, in most research applications, CuO and Al_2O_3 are used alone (38%) or with other NFs (36%). About 71–75 percent of these researchers took 0.005–0.5 percent, and 25–29 percent took 1–5 percent of NPs' weight. Other NPs, such as TiO_2, SiO_2, FeO_2, ZnO, expanded graphite, and Carbon nanotube/multiwall carbon nanotube, were also used to speed up the rate at which the fluid transferred heat. As can be observed in Table 6, Al_2O_3, CuO, TiO_2, and carbon nanotubes are very cheap nanoparticles with the best thermal conductivity, costing between INR 2,000 and 15,000 per 25 g. This is the reason why 73 percent of researchers used these NPs to improve the thermal properties of the SWH [78,79].

Table 6. Thermal conductivity and cost comparison of NPs.

Sl. No.	Nano Particles	Thermal Conductivity (W/mK)	Cost Per Gram
1	Aluminum Oxide (Al_2O_3)	40	80
2	Copper Oxide (CuO)	76	622
3	Titanium dioxide	8.5	129
4	Carbon Nano Tubes	3000–6000	78

3. Discussion

Researchers are motivated to develop renewable energy-based water heating systems and to improve its efficiency. The efficiency of an SWH rises gradually from morning to noon, peaks at noon, and then progressively declines after midday as solar radiation drops. Higher productivity can be gained if the number of sunny days in a year is increased. In India, a higher amount of solar radiation in the summer months (May, June, and partial July), results in a higher fluid temperature, which can be highly beneficial for domestic SWH and solar still.

3.1. Effect of Collector

The efficiency of the collector determines how much energy is gathered from the radiation. The solar collector's energy efficiency is determined by the amount of energy it receives and the amount of energy it transmits to the fluid. The solar energy collected was utilized to boost the thermal energy of the tank's storage medium. In earlier research it was just water, but in later stages researchers have used PCM/nanocomposite PCM to improve the SWH thermal efficiency [80] (Table 5). The ability to maximize efficiency is a significant feature of the solar flat plate collector. One of the most important aspects of the collector is that it improves the heat transfer rate with the collecting area [81]. The evacuated tube is made up of double-layer borosilicate glass tubes that are thermally and chemically resistant. To ensure strong absorption of sunlight, the internal tube (absorber) is coated in a dark navy-blue tint. The entire mechanism is covered by the external glass tube. To obtain insulation, the air between the two layers of glass was vacuumed to create an evacuated space between the two tubes. This effect decreases the convection heat transfer loss [82–84].

3.2. Effect of PCM and Nanocomposite PCM

The thermal energy transfer characteristics of PCM and PCM nanocomposite can be assessed using a typical heating system to compare their melting (charging) and solidification (discharging) cycles. Melt mixing was used to prepare PCM-metal oxide nanocomposite. PCM-metal oxide nanocomposites have opened new research areas. In the first stage, PCM was heated on a hot plate to its phase transition temperature and then molten PCM was mixed extensively with the produced NPs for 20 min using a magnetic stirrer to create a stable PCM nanocomposite. Finally, a homogenous dispersion of PCM nanoparticle nanocomposite was obtained by ultrasonically treating the produced composite for 15 min [85]. By substituting NF for water, efficiency can be increased. These additions increased the PCM's conductivity, increasing the quantity of solar energy transported from the absorber to the heat pipe through the PCM. The findings reveal that for the collector system with NF, the water temperature in the storage tank rises faster than for the system with only water working fluid. The maximum temperature is also higher than the pure water-based SWH system when NF is utilized as the working fluid in SWH [86,87].

Nano-enhanced PCM accumulates thermal energy in a shorter time in comparison to pure PCM. Due to their low cost, availability, limpness to the collector material and tank, low corrosiveness, easy dispersion in water, minimal scaling and fouling, and high thermal conductivity, Al_2O_3 and CuO-based NFs could be chosen as the best alternative as working fluids. In further research, it was concluded that TiO_2 nanoparticles, due to their high surface area and less agglomeration in the composite, are suitable for maximum thermal conductivity. TiO_2 also has a lower interfacial thermal resistance across the interface. Therefore, TiO_2 aids in better heat transfer within the percolation network than SiO_2, ZnO, and Fe_2O_3 metal oxide NPs [88,89].

3.3. Energy Movement through Nanoparticles

It was observed in the literature that solar panels with small NPs have a higher performance level in comparison to larger NP solar panels. This is due to the fact that NP-based NFs have higher thermal conductivity, resulting in a quick heat transfer, which contributes to the increased efficiency of the flat plate collectors [90–92]. Two different interpretations could be applied to this fact. On the one hand, when both the mass fraction and the number of particles are held constant, the number of small particles exceeds that of large particles. As a consequence of this, the small particles have a greater interface between the liquid and the particles than the large particles. As a result, there is a rapid and very effective exchange of heat. On the other hand, because of the tiny size effect caused by NPs, suspended NPs move in a random pattern. The micro-convection phenomenon occurs between particles and the liquid caused by the higher motion of the NPs. Due to micro-convection, there is an enhancement in the energy transfer process, which results in a thermal conductivity enhancement of NFs [93–95].

4. Conclusions

India is a country that produces solar energy. Currently, there are two major solar applications: electricity generation via photovoltaic cells and SWH. Solar energy is the most vital source of renewable energy that can be used for water heating applications in industry and residential buildings. Because of its low cost and high thermal efficiency, SWH is increasingly being used. However, many limitations have drawn the attention of researchers and have been thoroughly reviewed in this article. The critical points identified during the study are listed below:

1. It was observed that in the past decade (2012–2022) researchers are more focused towards renewable energy-based technologies to improve building efficiency and reduce CO_2 emissions. The most suitable example is SWH. Different methods and percentage improvements in thermal efficiency of SWH are evaluated in this article using the relevant articles available.
2. Huge energy consumption was seen in domestic water heating applications in rural and urban areas attracting 78% of researchers toward domestic SWH.
3. Most of the articles are based on flat plate solar collectors.
4. Distilled water is the first choice of the researchers as most of the articles used it as the heat transfer fluid, and paraffin wax is extensively used as TES in domestic SWH.
5. Cu and Al are the most popular nano particles due to their low cost and optimum thermal conductivity used in base fluids for improving thermal characteristics.

In the future, the study area can be extended to evaluate the use of advanced tools, such as ANN, fuzzy logic to analyze flow sensor application in buildings [96–102], advanced coating materials for photovoltaic applications and their thermal contact conductance analysis for rooftop solar plants and window paneling [103–108], and nano techniques for energy conversion and storage devices with a special emphasis on high performance piezoelectric nanogenerator for energy harvesting [109–111] in sustainable buildings.

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