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Design considerations of solar water heating system: a review

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Abstract

Solar energy is considered as one of the best alternative sources of energy since it is clean and sustainable for the environment. Extensive research on various aspects of solar water heating systems has been done in order to increase the overall efficiency of the system and optimize the design. The size of the system depends on temperature required to the customer, solar radiation, arrangement of the solar system, geographical condition and so on. Hence, it is important to design the SWH system, considering such parameters to assure maximum benefit to the user. This paper exclusively discusses the design aspect of the components of the SWH system. The first part of the paper deals with the summary of different system components that includes collector, storage tank, heat exchanger and coating on pipes. The second part of the paper discusses the advancement in the system in terms of various parameters such as overall efficiency, temperature, flow rate etc. The paper also includes the discussion on the use of simulation tools, numerical modelling and researches in heat transfer components that show prominent technological advancements in SWH systems. In addition to that, the paper comprises ample discussions regarding the use of SWH systems in a developing country like Nepal. Different tracking and data acquisition systems used in the countries having similar climatic, topographic and geopolitical conditioning were studied to draw optimum information on design of the solar system for Nepal. The review shows that a major portion of the SWH system design includes the collector sizing and its design because the overall system efficiency depends majorly on the collector efficiency. The various approaches for improvement in performance and efficiency, and adaptation with the recent advances has helped to enhance and upgrade the design of solar water heating systems.

Keywords: Solar water heating; Collector; System orientation; Storage tank;, Thermal efficiency

1. Introduction

An effective solution for increasing global demand for energy is the utilization of renewable energy sources. Solar energy is taken as an alternative source of energy for numerous domestic and industrial applications. Solar energy is generally used for lighting, electrification, air-conditioning and space heating purposes. With the increasing solar thermal technologies, solar thermal water heating systems are the promising technology to harness the plenty of free available solar thermal energy. Also, the domestic water heating systems are contributing for significant reduction in household energy consumption and offering savings on heating costs.

There is large potential for use of solar energy resources in Nepal with the solar insolation ranging from 4-5 kWh/m^2 per day and on an average of more than 6.5 hours of sunshine per day [1]. The experiment by Bajracharya et. al., shows that the efficiency of the flat plate collector of present design, during 8 hours of current exposure, was around 22.24% [2]. The study on high altitude SWH feasibility in Nepal shows that the SWH had to generate and store hot water under extreme conditions such as ambient temperatures, as low as −20°C. It had to withstand snow storms, hail, high UV radiation and high altitude intensive solar radiation >1200W/m^2 [3]. The average loss of energy of collectors installed in low latitude countries is around 10-35% and in some cases as high as 50% due to incorrect slope and azimuth angle of the collector [4]. This directly has an impact on annual energy received. Also the tilt angle has greater influence on the efficiency of the collector [5]. The study by Helwa et al. showed that tracking the solar system around a tilted-axis increases its annual solar radiation by 11% over the fixed-tilt system [6].

The optimization of such various design parameters is expected to improve the performance of large solar thermal systems and the solar heat cost could be reduced [7]. Most of the research conducted shows that the optimum collector area and the storage tank volume are major design components to be considered in order to assure the maximum system efficiency with minimal payback time [8]. Generally more research and development work are needed to further improve the existing level of efficiency for solar water heating system to serve effectively as a viable alternative to the conventional means of hot water generation [9].

The available literature is reviewed to understand the design considerations of the SWH components, the technological advancement in the SWH System and the need of update and development in Nepal regarding efficiency upgrading, quality assurance and economic viability. Thus, construction, arrangement, applications and sizing of the solar water heating system are focused as the design considerations.

2. Solar water heating system

Solar water heating (SWH) is one of the simplest and oldest ways to harness renewable energy and can contribute both to climate protection and sustainable development efforts. Today, the global SWH market is growing rapidly and SWH is considered among the country's most commercialized renewable energy technologies [10]. SWH systems are generally very simple using only sunlight to heat water. A working fluid is brought into contact with a dark surface exposed to sunlight which causes the temperature of the fluid to rise. This fluid may be the water being heated directly, also called a direct system, or it may be a heat transfer fluid

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such as a glycol/water mixture that is passed through some form of heat exchanger called an indirect system [11]. A solar water heater consists of a collector to collect solar energy and an insulated storage tank to store hot water. The solar energy incident on the absorber panel coated with selected coating transfers the heat to the riser pipes underneath the absorber panel. The water passing through the risers gets heated up and is delivered to the storage tank. The recirculation of the same water through an absorber panel in the collector raises the temperature to 80 °C (Maximum) on a good sunny day. The total system with solar collectors, storage tanks and pipelines are called solar hot water systems [12]. The technology employed has been reasonably developed and can be easily implemented at a low cost. Several configurations exist for this purpose. These configurations may be grouped into two: passive solar hot water system (PSHWS) and active solar hot water system (ASHWS) [12].

1. Passive Solar hot water system

   This hot water system depends on the heat driven by the convection to circulate water or heating fluid in the system. This system can be further categorized into: integrated collector storage and thermosiphon SWH system. The integrated collector storage system utilizes a tank that can act as both a storage and solar collector apparatus. Thermosiphon system uses natural convection flow to transport the heat fluid or water from the collector to the storage tank.

2. Active Solar hot water system

   Active solar hot water system uses one or more pumps to circulate the working fluid in the system, unlike passive systems broadly, the active systems are of two categories. They are: Closed loop system (Indirect) and Open loop system (Direct).

   (a) Closed loop system (Direct)

   In a closed loop system, heat exchangers are installed to protect the system from hard water obtained from borewells or from freezing temperatures in the cold regions.

   (b) Open loop system (Indirect)

   In the other type, either thermosiphon or forced circulation system, the water in the system is open to the atmosphere at one point or another. The thermosiphon systems are simple and relatively inexpensive. They are suitable for domestic and small institutional systems, provided the water is treated and potable in quality. The forced circulation systems employ electrical pumps to circulate the water through collectors and storage tanks.

The solar collectors employed in these configurations could be flat-plate, concentrating, or evacuated tube types. The flat-plate solar collector appears to be the most commonly used because of low cost and ease of design and construction. They are often used for low and medium temperature applications but may be applied on high load situations by using more than one collector, connected in series. The concentrating & evacuated tube collectors are used for industrial or commercial applications where high load temperatures of up to 100 °C are required [13].

Content of the system and operation method is important for total performance. The choice of system depends on heat requirement, weather conditions, heat transfer fluid quality, space availability, annual solar radiation, etc. The minimum requirements of the system are typically determined by the amount or temperature of hot water required during winter, when a system's output and incoming water temperature are typically at their lowest. The design considerations according to the types, complexity, and size of a solar water heating system is mostly determined by [9]

- Changes in ambient temperature and solar radiation between summer and winter.
- The changes in ambient temperature during the day-night cycle.
- The possibility of the potable water or collector fluid overheating.
- The possibility of the potable water or collector fluid freezing.

A natural thermosiphon SWHS has been constructed at a high altitude research station in a remote northwestern region of Nepal by Malla et al. and presented the results of a validated TRNSYS model that has been used to predict its performance and to test various operational strategies after recording on a data logger about water temperatures at four positions in the tank measured at 10 minute intervals. The study showed the prediction from the model indicates that the design target of 550 showers can be provided each week if these showers are limited to 10 liters at 35 degrees Celsius and the center is operated between 9 am and 3 pm [14]. Balbonas and Dervinis researched about SWH model and found when the outside temperature is 10 degrees Celsius, energy losses can be reduced as when the outside temperature is 10 degrees Celsius, energy losses can be reduced as: 40% if the insulation thickness increased from 5.5 cm to 7.5 cm, 51% if the insulation thickness increased from 5.5 to 10 cm and 63% if the insulation thickness increased from 5.5 to 15 cm [15].

Hematian et al. experimentally analyzed flat plate solar collector efficiency and the result showed the collector provided with natural convection gave high efficiency when compared to collector with the forced convection and the heat loss in the forced convection is considerably lower than the natural convection. The results showed that the average air speed in the forced convection was about 21% higher than the natural convection [16]. Hashim et al. discussed the major scenarios for solar thermal applications in Iraq by using the solar water heating for flat plate collectors. The results presented demonstrate the water at flow rate 5.3L/min heated more than the flow rate 6.51L/min because the collector observed the radiation of the sun slowly which causes the higher efficiency and effectiveness of the collector, so the maximum temperature was (51.4 and 49 °C) at flow rate (5.3 and 6.51L/min) respectively [17]. Ogueke et al. reviewed the SWHS and found that the best efficiencies of PHWSs are in the range of 30%–50%. Those of the ICS are of the order of 30% while those of the thermosiphon systems are of the order of 50%. Efficiency of active SHWSs is about 35%–80% higher than that of the passive system. The closed loop thermosiphon SHWSs in most situations perform better than the open loop ones, are less climate selective, and generally are more suitable for use in regions that experience very cold temperature [9]. Zhanga et al. made comparative study on annual performance between loop thermosiphon SWHS and conventional SWHS and found that under the discontinuous and continuous heating modes, the annual effective numbers of supplying days of the SWH system are 139 and 168, respectively; while they are 153 and 173, respectively, for the LT-SWH system. It was found that the average annual heat loss ratio is 15.07% for the SWH system and 6.15% for the LT-SWH system and the static payback period of the LT-SWH system, which ranges between 3.2 and 4.8 years, is a little longer than that of the SWH system [18].

3. Component design

The main components of solar water heating systems are collectors, storage tank, heat exchanger and piping (Fig. 1). These components have been improved significantly. Various researches have been undergoing in order to improve the system overall efficiency and to make the system functional under various operating

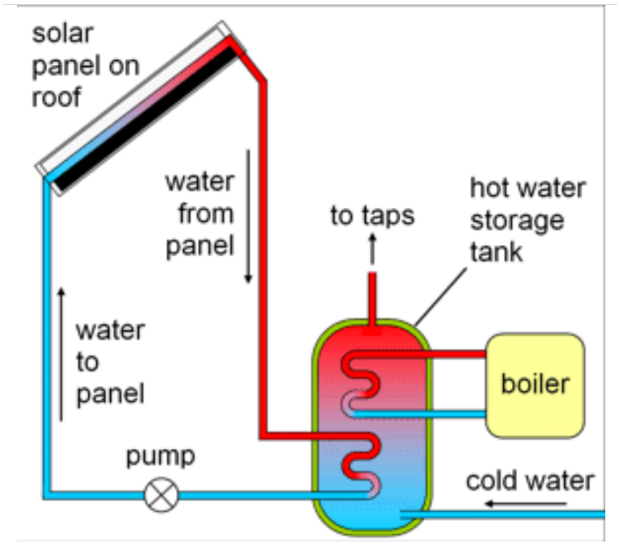

Figure 1: Schematic Diagram of components of Solar Water Heating System [52].

circumstances. Various studies made on the design considerations are discussed in this section.

3.1. Collector

A solar collector is a heat exchanger which converts the solar energy into thermal energy by the virtue of fluid flow inside it. Flat plate solar collector is a widely used collector. The efficiency of the SWH depends upon the effectiveness of the flat plate collector. Kulkarni and Deshmukh conducted an experiment that focused on the factors affecting the performance of solar water heater collectors such as temperature difference, solar radiation, and incoming cold-water temperature. Instead of conducting the tests for the whole year, the tests were conducted for about fifteen days and the results should be extrapolated to obtain annual performance. Evacuated tube collectors have lower thermal losses as compared to flat plate collectors and hence are less affected by ambient conditions [13]. Patil and Deshmukh researched on design consideration for the solar water heater to obtain hot water for the domestic and industrial applications and concluded that designing a solar water system involves appropriate selection of each component for the desired capacity and location of installation for solar water heater to produce hot water [19].

Tsung-Ching Chen et al. investigated and theoretically studied the collector efficiency of double- pass sheet-and-tube solar water heaters with attaching internal fins on tube wall and external recycle. The operation of such a double-pass device with external recycle is represented graphically and compared with those in the single-pass device without external recycle under the same working dimensions. It was found that the double pass internally finned collector performs better than single pass without internal fins and the optimal operating condition for collector efficiency improvement associated with a small amount of hydraulic dissipated energy increment, say 24.3% is achieved at I_0 = 1.0 kJ/m^{2}s, m=9 kg/s, R=1, n = 4 and N_f=2 [20]. Badgujar et al. conducted experimental investigations on solar flat plate collectors by changing the geometry of the fin. Lots of experimentation have been done to improve the heat transfer rate of solar water heater by adding fins of helical, rectangle, circular, trapezoidal section as well as twisted shape. It was concluded that the inverted modified raise tube (F4) gives the highest temperature output amongst other raiser tubes with fin [21]. Chittireddy et al. studied a flat plate solar collector with an air conditioning radiator as a heat absorber for a domestic Water heater with the presence of high- density corrugated fins attached to the tubes increased the absorption of incident solar radiation. The flat plate collector was enclosed by double glazing which admitted solar radiation and minimized convection heat transfer losses to the environment. The shell of the collector was insulated to reduce conduction losses. An experimental program that was devised to verify the accuracy of the thermal performance model. Under certain circumstances close agreement was obtained between model predictions and experimental measurements, making the performance model of the flat plate solar collector a useful design tool. The flat plate collector efficiency was found to be 51.5%, 61.7% and 56.5% for one, two and three covers plates respectively [22].

Balaji et al. studied the effect of with and without solar flat plate water heater extended surface by using a data acquisition system. A tube and rod are used as an extended surface inside an absorber tube. The extended surfaces are frictionally engaged with the inner side of the tube wall, and it is kept in the axial flow direction of the fluid flow path. It was found that the various performance factors such as friction factor and non-dimensional numbers are analyzed. The results show that the outlet temperature of the extended surface absorber tube collector is 8°C higher when compared to the plain tube collector [23]. Kalogirou compared different types of collector and resulted in two axes tracking with the Heliostat Filed Collector having point absorber give the higher concentration ratio and wide range of temperature (150-2000) °C when surveying various types of solar thermal collectors and applications [24]. In 2002, Al-Madani evaluated the thermal performance extensively throughout the months of March and April where a maximum temperature difference of 27.8 °C between inlet and outlet of the solar water heater at a mass flow rate of 9 kg/h was achieved and the study result showed that the maximum value during the experimental period was found to be 41.8% [25]. This reveals a good capability of the system to convert solar energy to heat which can be used for heating water.

Ong and Tong experimented on performance of solar water heaters depending upon collector and storage tank design and sizing and weather conditions (solar radiation intensity and ambient temperature). The outdoor tests were conducted on several evacuated tube solar collectors (U-tube and heat pipe types) under natural and forced convection. The long- and short-term test procedures employed allowed us to compare the performances of the various systems as if they were tested simultaneously side-by-side. The experimental results showed that the natural convection heat pipe system was capable of heating water to 100 °C and performed best among the systems tested [26]. Michaelides researched the modeling and simulation of solar water and space heating for Cyprus with the use of models in TRNSYS (Transient Systems) program to compare the various types of SWH and solar space heating systems. The thesis study concluded that collector efficiency is a function of collector size and the tilt angle also affects the efficiency of the collector [27].

Vasanwala et. al studied solar water heater by evacuated tube and noticed that evacuated tube solar collectors are more efficient than other collectors in which 170 To 180 °C maximum temperature can be achieved [28]. Sivakumar et al. experimented on the elliptical heat pipe solar collector which was designed, fabricated and tested for different mass flow rates and L_c/L_e ratios. The performance analysis of the above test results showed that when the water flow rate was 18 kg/h, it is performing better than the others (i.e. 24 kg/h, 30 kg/h & 36 kg/h). It has been found that when the L_c/L_e ratio was 0.5384, its performance was better than the others (i.e. 0.1764, 0.3333) [29]. Mazarron et al. checked feasibility of SWH with evacuated tube collectors at different operational temperatures and found the energy that is collected and delivered to the tank decreases with increasing the required temperature due to a lower performance of the collector and losses in the pipes. The result also included annual system efficiency reaching average values of 66%, 64%, 61%, 56%, and 55% for required temperatures of 40 °C, 50 °C, 60 °C, 70 °C & 80 °C [30].

Thus, it is best to consider collectors with low thermal losses like evacuated tube collectors to flat plate if applicable to the desired location. Moreover, the efficiency of the collector can be improved by adding fins of helical, rectangle, circular, trapezoidal section as well as twisted shape. Additionally, glazing and the number of cover plates are also significant factors for efficiency, which can be essential for consideration for design of the SWH.

3.2. Storage tank

Storage tank is an essential component of the solar water heating system which plays a crucial role in determining the overall performance of the system. A storage tank is generally used for providing hot water at preferred temperature to the end uses from the collection of solar thermal energy generated. A storage tank could be made up of steel, glass, concrete or other materials to store the hot water. Steel is commonly used material among them as it is easy to manufacture. Rhee et. al., studied the temperature stratification from thermal diodes in which four hot water storage tank designs involving double chimney style thermal diodes intended for solar water heating were examined experimentally. All three designs involving thermal diodes exhibited improved stratification during cooling, which impacts system performance when solar heat is not being collected (i.e., during the night). There appears to be substantial margins to improve the stratification performance by optimizing the geometric variables of the thermal diodes and partitions, as well as the number of diodes used at each level [31].

Myeong Jin ko analyzed optimum design of a solar water heating system based on life cycle cost using a genetic algorithm and found that determination of the optimal configuration and sizing of the SWH system must be done by comparing the feasible designs obtained by using the proposed method instead of simply adjusting the solar fraction depending only on the designer's experience and intuition [8]. Chengchu Yan et al. analyzed the method for optimum design as significant energy mismatch existed in solar water heating systems as the time and amount of solar energy are usually different from that of hot water demand. The mismatch causes a part of the energy harvested by the system to be wasted. The optimal method was achieved by a simplified energy model based on hourly energy matching among different components of the system and is developed for determining the operating performance of the system in different collector areas and volumes and validation in TRNSYS. It was found that the optimized tank volume is strongly dependent on the collector area while the impact of tank volume on the optimization of collector area is very limited [32]. Abu- Mulaweh studied the solar collector rotation as the sun position/angle was changing, indicating the functionality of the control system that was designed. Temperature water measurements in the storage tank were recorded every 10 minutes and lasted for 5 hours which showed the thermosiphon effect [33]. The solar collector was observed being rotating as the sun position/angle was changing. It was found that the thermosiphon effect can take place through a system created by difference in the fluid.

Ogie et al. analyzed the design and construction of SWH where the water gets heated and flows into a storage tank through the thermosiphon principle and the maximum fluid outlet temperature, collector temperature and insolation were found to be 55 °C, 51 °C and 1480 W/m^2 respectively on a sunny day [34]. The system was tested on a normal sunny day, rainy day and cloudy day between the hours of 7 am and 6 pm and the results were tabulated. Rhushi Prasad et al. made an attempt to compare the performance fixed flat plate water heater with that of the heater with tracking by conducting experiments. Flat plate water heater which is commercially available with a capacity of 100 liters/day is instrumented and developed into a test-rig to conduct the experimental work. The research resulted in an average of 4 °C in the outlet temperature and the comparison showed that there is an increase of about 21% in the percentage of efficiency [35]. Mori et. al., designed SWHS for cold climate and concluded that multiple tank systems are more efficient than single tank with thermal stratification. The system with two tanks was designed. The one with high temperature was used for hot water supply with auxiliary heat sources and the one with the low temperature was used for pre-heating for ventilation and road heating [36]. Furbo et al. confirmed that the thermal performance of the SWH system can be increased by using tow draw-off levels from the solar tanks instead of one draw-off level at a fixed position. The study reported that the best position of the second draw off can either be fixed in the middle or just above the mid-point of the tank [37].

Dehghan et al. experimentally investigated the thermal performance of a vertical water tank. Under realistic conditions, hourly measurement of the temperature distribution inside the tank, collector's flow rate, and its inlet and outlet temperatures were considered in evaluating the thermal characteristics of the system. Experiments were conducted during the summer time and it was observed that the thermal stratification was well established for at least 11 h of a day [38]. Helwa et al. found the experimental results concluded that the thermal stratification inside the tank was highly dependent on the pre-assumed load pattern. In comparison with a vertical storage tank, for the same given input conditions, the thermal performance of a horizontal tank was inferior [39].

The configuration and sizing of the storage tank are some of the factors to be considered for optimum design of SWH. For cold climates, multiple tank systems are found to be more efficient than single tank with thermal stratification. The tow draw-off levels from solar tanks as well as the selection of vertical storage tanks over horizontal tanks in some cases are seen to produce better efficiency according to these researches in this component.

3.3. Heat exchanger

Heat exchangers are generally made up of conductive materials such as stainless steel, aluminum, steel, cast iron, bronze and copper. It is used in an indirect type of SWH system to transfer absorbed solar heat from the working fluid to the storage tank. Heat exchangers are mostly made up of copper because of good thermal conductivity and resistance to corrosion.

Upadhyay et al. studied improving efficiency of SWH and the water was raised to the temperature of the maximum of 80 °C on a good sunny day. An Absorbent plate of solar collector was formed with a corrugated sheet to accommodate the water pipes and headers in the groove to maintain good contact with the pipe. Efficiency is enhanced by 68% after using fins as the surface area and heat transfer rate was increased [40]. Herrero Martin et. al., developed an experimental side by side solar collector test under the requirement of EN12975-2 and performance test under the same operating conditions such as mass flow rate, inlet fluid temperature and weather conditions were performed. The enhanced collector was modified by inserting spiral wire coils of dimensionless pitch p/D=1 and wire-diameter e/D=0.0717 with each riser. The study resulted the optical efficiency coefficient in the enhanced solar collector about 15% higher than the thermal losses coefficient is lower than the standard one (when the flow rate was 0.04 kg/s) which means a reduction in the thermal losses as well as a decrease of the loss coefficient by 30% [41]. Parent et al. analyzed the performance of the shell and tube HX external to the storage tank, in which fluid flow was induced by natural convection. Compared to the immersed coil type configuration this design was found to be more practical and the effectiveness of the heat exchanger could reach as high as 90% [42]. A numerical model was developed to analyze the external flow over a vertical flat plate to evaluate the convective heat transfer coefficient by Shah and Furbo [43] for the research on the performance of the vertical mantle heat exchanger. Simulation results had shown that the temperature stratification in the inner tank was not affected by the mantle fluid as long as the fluid flow was restricted within the mantle gap until it reached the thermal equilibrium level with the water in the inner tank [43]. Farrington and Bingham tested and analyzed the efficiency of load side immersed heat exchanger with the coil in tank heat exchanger which contained several loops of tubing made up of either single or double walls immersed in a storage tank. The result confirmed that a smooth coil heat exchanger outperformed the finned heat exchanger with the same outside surface area [44]. Taherian et al. experimentally validated the dynamic simulation of the flat plate collector of a closed thermosiphon solar water heater with horizontal mantle-type storage tank and by the simulation the mean efficiency of 68% was obtained [45]. Smith et. al., studied the influence of helical tapes in a tube on heat transfer enhancement. A helical tape is inserted in the tube with a view to generate swirl flow that helps to increase the heat transfer rate of the tube. Twist ratio of 0.5 yields the highest Nusselt number which is about 50% above the plain tube [46]. It was concluded that the twist pipes could be inserted inside the flow tubes in SWHS for enhancing heat transfer ratio. Decreasing values for twist-pitch to tube diameter ratio lead to increasing values of heat transfer rate and pressure drop as well. Heat transfer increased by 18-70% and pressure drop increased by 87-12% compared to plain tube collectors within the range of investigated parameters [47].

In a nutshell, more conductive material can be used for making heat exchangers. Several considerations such as enhancement of collector with inserting spiral wire coils, the influence of helical tapes in a tube and using smooth coil heat exchanger over the finned heat exchanger can be undertaken to increase the efficiency of the heat exchanger

3.4. Coating of pipes

The research of coating of pipes has gained much attention in many developing countries. The advantage of using electro deposited chrome selective surfaces and other performance of the solar water heating systems are evaluated by Santamouris et al. The result showed that the use of chrome selective coatings is economically sound [48]. A test at the solar energy center with IIT, Delhi was conducted by Arif and the result revealed that even for low temperature applications of 50°C and above, solchrome solar selective coatings and solchrome solar selective coating fin and tubes increase the thermal efficiency of solar collectors by more than 30%, as against the use of black paint or any other coating [49]. Ehab developed SWHS with coating which was fabricated by embedding a metal particle composed of a nickel-aluminum (Ni-Al) alloy into black paint. After a year of application, it was found that the coating showed better performance compared to the untreated black paint by an average of 5°C [50]. Tharamani et al. developed the use of Cu-Ni alloy coating as a selective surface for solar energy. The result showed that the coating surface had the high absorptance and a low emittance rate [51].

Thus, for design consideration of coating of pipe is one of the ways to increase the thermal efficiency. Some of the properties of coating such as high absorption and low emittance should be assessed before selecting the pipe. Moreover, for cost effectiveness the use of coating such as the chrome selective coating can be a better option.

Table 1 shows the salient features of the study with their findings output forwarded by the various authors for different components of SWH components. The system output provides us with ample factors that can help in the decision making for design consideration for each component contingent with the applicability of such factors to be used in each process of selection.

4. Conclusion

This study deals with the review of the SWH system design considerations in major components like collector, storage tank, heat exchanger and pipe coating. The design of solar water heating systems must be done to assure maximum benefit to the users, especially for a large system. The review shows that a major portion of the design includes the collector sizing and its design because the overall system efficiency depends majorly on the collector efficiency. Flat-plate collectors are found to be the most common solar collector for solar water-heating systems in homes and solar space heating systems. Multiple tank systems show better thermal stratification. Use of simulation tools like TRNSYS, numerical modelling and researches in use of fins show technological advancements in this field. Many researchers concentrated their efforts to optimize the design of the components of solar systems in order to increase the efficiency of solar systems and majority of them have suggested the optimum tilt angle and extended surface (fins) as major variants for solar collectors to increase the collector efficiency. Therefore, the major factors that influence the design of the solar water heating system are ambient conditions, solar collector tilt and array arrangement, and the optimum fluid (water) flow rate to reduce the thermal losses and increase useful energy gain.

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Table 1: Salient features of different SWH design components with their system outcome.

SWH design components	References	Salient study features	System output
Overall Solar Water Heating System	TR Bajracharya et al. [2]	Two panels collector with each having an effective area of 1.55 m2 and 100 liters capacity storage tank	Efficiency of the flat plate collector of present design, during 8 hours of current exposure, was around 22.24%.
	Zhand and Malla [3]	SWH had to generate and store hot water under extreme conditions such as ambient temperatures, as low as −20°C.	The system operated on average intercepted solar radiation of 400W/m2 from 15:30-16:30PM
	Helwa et al. [6]	Different solar tracking systems layout: a fixed system facing south and tilted 40°, a vertical- axis tracker, a 6° tilted-axis tracker, and a two- axis tracker	The tracking the solar system around a tilted-axis increases its annual solar radiation by 11% over the fixed-tilt system
	Malla et al. [14]	A natural thermosiphon SWHS has been constructed at a high altitude research station with results validated with the TRNSYS model.	The design target of 550 showers can be provided each week if these showers are limited to 10 liters at 35 degrees Celsius and the center is operated between 9 am and 3 pm.
	Balbonas [15]	SWH model's energy losses can be reduced with increasing insulation thickness when outside temperature is 10 degree Celsius	Energy losses can be reduced as: • 40% if the insulation thickness increased from 5.5 cm to 7.5 cm. • 51% if the insulation thickness increased from 5.5 to 10 cm. • 63% if the insulation thickness increased from 5.5 to 15 cm.
	Hematian et al. [16]	Experimental analyzed flat plate solar collector efficiency.	Collector with natural convection gave high efficiency when compared to collector with the forced convection, the results showed that the average air speed in the forced convection was about 2% higher than the natural convection.
	Hashim et al. [17]	Major scenarios for solar thermal applications in Iraq by using the Solar water heating for flat plate collector.	Maximum temperature was (51.4 and 49°C) at flow rate (5.3 and 6.51L/min) respectively.
	Ogueke et al. [9]	Reviewed various types of SWHS models and compared the efficiencies.	The best efficiencies of PHWSs are in the range of 30%–50% and efficiency of active SHWSs is about 35%–80% higher than that of the passive system.
	Zhanga et al. [18]	Comparative study on annual performance between loop thermosiphon SWHS and conventional SWHS	Average annual heat loss ratio is 15.07% for the SWH system and 6.15% for the LT-SWH system. Collectors.
Collectors	Tsung-Ching Chen et al. [20]	Investigated the collector efficiency of double-pass sheet-and-tube solar water heaters with attaching internal fins on tube wall and external recycle.	The optimal operating condition for collector efficiency improvement associated with a small amount of hydraulic dissipated energy increment, say 24.3% is achieved at I_0 = 1.0 kJ m^{-2} s^{-1}, m=9 kg s^{-1}, R=1, n = 4 and N_f=2.
	Chittireddy et al. [22]	Studied flat plate solar collector with an AC radiator as a heat absorber for a domestic Water heater with presence of high-density corrugated fins attached to the tubes.	The flat plate collector efficiency was found to be 51.5%, 61.7% and 56.5% for one, two and three covers plate respectively.
	Kalogirou [24]	Surveyed various types of solar thermal collectors and applications.	Compared different types of collector and resulted two axes tracking with the Heliostat Filed Collector having point absorber give the higher concentration ratio and wide range of temperature (150-2000) °C.
	Al-Madani [25]	Evaluated the thermal performance was evaluated extensively throughout the months of March and April.	Maximum temperature difference of 27.8 °C between inlet and outlet of the solar water heater at a mass flow rate of 9 kg/h was achieved
	Sivakumar et al. [29]	Experimented on the elliptical heat pipe solar collector which was designed, fabricated and tested for different mass flow rates and L_c/L_e ratio.	The flow rate of 18 kg/h performed better than others when the L_c/L_e ratio was 0.5384.

Salient features of different SWH design components with their system outcome (Table 1 continued).

SWH design components	References	Salient study features	System output
Storage	Mazarron et al. [30]	Checked feasibility of SWH with evacuated tube collector at different operational temperature	The annual system efficiency reached average values of 66%, 64%, 61%, 56%, and 55% for required temperatures of 40°C, 50°C, 60°C, 70°C, and 80°C.
	Ogie et al. [34]	Analyzed the design and construction of SWH where the water gets heated and flows into a storage tank through the thermosiphon principle.	The maximum fluid outlet temperature, collector temperature and insolation were found to be 55 degree Celsius, 51 degree Celsius and 1480 W/m^2 respectively on a sunny day.
	Rhushi Prasad et al. [35]	Compared the performance fixed flat plate water heater with that of the heater with tracking by conducting experiments.	An average of 4 degrees Celsius in the outlet temperature was resulted and the comparison showed that there is an increase of about 21% in the percentage of efficiency
Heat Exchanger	Herrero Martin et al. [41]	Developed an experimental side by side solar collector test under the requirement of EN12975-2	Efficiency coefficient in the enhanced solar collector about 15% higher than the thermal losses coefficient is lower than the standard one
	Parent et al. [45]	Analyzed the performance of the shell and tube HX external to the storage tank, in which fluid flow was induced by natural convection.	Compared to the immersed coil type configuration this design was found to be more practical and the effectiveness of the HX could reach as high as 90%
	Smith et al. [46]	A helical tape is inserted in the tube with a view to generate swirl flow	Twist ratio of 0.5 yields the highest Nusselt number which is about 50% above the plain tube

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