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A review of water heating system for solar energy applications☆

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ABSTRACT

Solar energy is one of the widely used renewable energy that can be harnessed either by directly deriving energy from sunlight or indirectly. Solar water heating system, on the other hand, is one of the applications of solar energy that has drawn great attention among researchers in this field. Solar collectors, storage tanks and heat transfer fluids are the three core components in solar water heater applications, which are reviewed in this paper. This paper discusses the latest developments and advancement of a solar water heater based on the three basic components that may affect the thermal performance of the system. It also reviews the development of various types of solar collectors in solar water heater, including both the non-concentrating collectors (flat plate collector, evacuated tube collector) and the concentrating collectors (parabolic dish reflector, parabolic trough collector). All these are studied in terms of optical optimization, heat loss reduction, heat recuperation enhancement and different sun tracking mechanisms. Among the non-concentrating and concentrating collectors, the parabolic dish reflector collectors show the best overall performance. The use of nanofluids as a heat transfer fluid was also discovered in this paper.

Contents

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1. Introduction

Today, fossil fuel has been primarily used to heat and power homes and fuel cars [1]. It is convenient to use coal, oil and natural gas for meeting human's energy needs [2], but the limited supply of these fuels has become the main constraint for people to persist them as the continuous sources on Earth [3,4]. In recent years, high advancement in Malaysia's economy has steered to a vividly increases in energy consumption, particularly electrical energy used in commercial and domestically building [5]. As energy plays a crucial role in the daily needs of humans [6], there are many alternative energy sources that can be used instead of fossil fuels [7,8], and one of them is renewable energy (RE) [9]. RE can be described as energy that can be generated by natural sources such as sunlight; which is a primary source of energy [10]. The major gains of RE is that no fuel is necessarily required, which eradicates the emission of carbon dioxide (CO_2); one of the factors in air pollution. Insufficient fossil fuel supplies and disproportionate gas emissions resulting from increasing fossil fuel consumption have become the worst contribution to the current global energy problem. It was recounted that the present petroleum consumption was 105 times faster than the amount nature can create [11]. Predictably, at this huge rate of consumption, the world's fossil fuel reserves will diminish by 2050 [11,12] and the global demand for energy would turn to be approximately 30 and 46 TW by 2050 and 2100, respectively [13]. Even though the fossil fuels supply more than 90% of energy demand, they indeed convey a vertical figure in environmental cost [14].

In China, the application of RE in buildings is a promising solution toward the conflict between the growing energy demand and environmental protection [15]. It could also provide a solution to the problem, as they are inexhaustible and have less adverse impacts on the environment than fossil fuels [16]. Particularly, solar energy systems are able to offer significant environmental protection such as the reduction of ecological footprints [17]. This energy cannot be exhausted and is constantly renewed. Economical, environmental friendly and safe should be the consideration in making decisions of the type of energy source for future demand. Solar energy can be harnessed either by directly or indirectly deriving energy from sunlight [18]. In reality, the most worthwhile thing about this energy is that it can be used without polluting and harming the earth.

In addition, solar energy is the most highly potential of the alternative energy sources, and universally available sources. It is an attractive concept because of the combination of solar energy and the heat pump [19], which can improve the quality of the energy available and show potential for different applications [20]. The application of solar energy includes water heating in the domestic sector, health institution and tourism sector [18,21]. One of the popular devices that harnesses solar energy which can replace the electric water heater [22] is the solar water heater and its system is called solar water heating system [23,24]. Therefore, this paper provides a review of various solar collectors in solar water heating systems and its applications. The review consists of an introduction to solar water heater systems including the active and passive systems, basic components of solar water heating and its latest researches and advances of solar water heaters.

2. Development of solar water heating system

The history of the advantages of solar water heating system has been around for many years because it is the easiest way to use the sun to save energy and money. One of the earliest documented cases of solar energy involved pioneers moving west after the Civil War. They would place a cooking pot filled with cold water in the sun all day to have heated water in the evening. The first solar water heater that resembles the concept, and is still in use today, was a metal tank. It was painted black and placed on the roof where it was tilted toward the sun. Practically, the concept really worked but it usually took all day for the water to heat and then as soon as the sun went down, it cooled off quickly because the tank was not insulated. The different applications of solar energy had been discovered broadly such as utilizing the water heating system [25], solar air conditioning, food drying [26], lighting and cooking [27]. Out of the total energy consumption in homes, almost 20% of water heating is consumed for an average family. This advantageous situation can happen because it is a cost-effective way to reduce energy costs from gas, electricity, or propane sources [28], and also pollution free [29], which is most beneficial to homeowners as they produce large amounts of hot water every day [30].

Subsequently, solar water heater is a device of a solar water heating system that is rightly needed in every home as it has many benefits to people, community and also the environment which functions to heat water and produce steam for domestic (i.e., for bathing, washing, and cleaning) [31] and industrial purposes using solar energy. Its system plays a vital role in collecting energy from the sun through its panels or tubes, followed by the production of hot water [14]. This system is generally installed at the terrace or where sunlight is available and heats the water during the day. Then, the hot water will be stored in an insulated storage tank and ready to be used for household utilities especially in the mornings [31,32]. Indeed, the solar water heater had effectively entered the global market commercially since the 1800s [33]. It is not only a safe, simple and reliable technology, but also reasonable in terms of costs [34]. Acceptance of the technology is usually not an issue for the user as it is a "behind-the-screen" technology [35]. Moreover, simplicity, technological feasibility, and economical and commercial viability are the strengthening factors of solar water heaters which made them popular among the RE products all over the world [36,37]. For instance, the most popular categories of hot water heaters in the China market are electric water heaters, gas water heaters, and solar water heaters [38].

In addition to the system, a collector functions to collect solar energy from sunlight whereas a storage tank stores hot water that has been produced through the system itself. In making sure that the water is always hot, the tank must be insulated well to avoid heat losses, as mentioned earlier [39]. Solar energy can be acquired when the absorber panel coated with selected coating transfers the heat to the riser pipes underneath the panel. The water will pass through the riser to be heated up and then channeled to the storage tank. The recirculation of the same water through the absorber panel in the collector raises the temperature up to 80 °C (maximum) on a good sunny day. This is recognized as a complete system of hot water using solar energy with the use of equipment such as a solar collector, a storage tank and pipelines and is known as the solar water heating system. The existing solar water heater today consists of a cylindrical glass tube that works as the receiver of solar energy and a copper coil through which the water flows, that is placed inside the glass tube and acts as the collector [40]. The technical and environmental performance of a solar water heater is examined using the method of life cycle assessment (LCA) [41,42].

Nevertheless, there is still much to do to improve the performance of solar water heaters which include improving the thermal stratification of the storage tank, enhancing the performance of the collector, boosting the heat transfer techniques (consist of collector designs, collector tilt angles, coating of pipes, fluid flow rates, thermal insulation, integrated collector storage, thermal energy storage, use of phase change materials (PCM) [43], and insertion of twisted tapes) [44], and optimizing the controller. Besides, optimizing the hot water tank structure and enhancing the immersed heat exchange performance is also considered as one of their best ways [45].

3. Solar water heating system

One of the most widely known solar thermal applications is the solar water heating system [46]. The solar water heating system uses natural solar thermal technology [47,48] which is where solar radiation is converted into heat and transmitted into a transfer medium such as water, water antifreeze or air. This system is often feasible for replacement of electricity and fossil fuels used for water heating [49]. Generally, the system is very simple because it requires only sunlight to heat the water. It works when the working fluid is brought in contact with a dark surface (high absorptive) that is exposed to sunlight, which then causes the temperature of the fluid to rise [3]. This fluid may be caused by the water being heated directly, which is called a direct system, or it may be a heat transfer fluid (such as a glycol or water mixture) that is passed through some form of a heat exchanger and called an indirect system. These systems can be classified into two main categories; active system and passive system [50] as shown in Fig. 1. The active system can be divided into two which are the open loop and close loop system whereas the passive system uses the system of thermosiphon and integral collector storage (ICS).

Almost all solar water heating systems used in temperate climates are active systems that make use of pumps to circulate the heat transfer fluids [24]. Theoretically, these systems commonly use flat plates or evacuated tube collectors, which absorbs both diffused and direct solar radiation and function even under clouded skies. Water is heated in the collectors and a pump is used to circulate a water glycol mixture used as the heat transfer fluid [51]. A solar controller triggers the pump when the difference between the temperature of water at the bottom of the tank and the heat transfer fluid at the outlet from the collector exceeds a set value. A solar coil at the bottom of the hot water tank is used to heat water. This fluid has some desirable properties such as low freezing and high boiling points. Their ease of operation and low cost makes them suitable for low temperature applications below 80 °C. An auxiliary heating system is used to raise the water temperature during periods when there is less heat available from the solar collector [52]. The solar water heating system proves to be an effective technology for converting solar energy into thermal energy. The efficiency of solar thermal conversion is around 70% when compared to the solar electrical direct conversion system that has an efficiency of only 17% [53].

There are two types of solar water heating systems; active and passive solar heating systems. The active system consists of the open loop system and closed loop system; whereas the passive system contains thermosiphon and integrated collector storage (ICS).

3.1. Active system

Active solar water heating systems use collectors to heat a fluid, storage units to store solar energy until needed and distribution equipment to provide the solar energy to the heated spaces in a controlled manner [54]. In combination with conventional heating equipment, a solar water heating system provides the same levels of comfort, temperature stability and reliability as a conventional system. A building that has been heated is often referred to as a “solar house”. The term solar house is also applied to buildings that include integral parts of the building elements that admit, absorb, store and release solar energy and thus reduce the needs for supporting energy to comfort heating [55]. In simple definition, the active system uses electrical pumps [56], valves and controllers to circulate water or other heat transfer fluids trough the collectors [57]. This system is also known as forced circulation system and it can be an open loop (direct) active system or a closed loop (indirect) active system [50]. Open loop (direct) active system heats the actual household water in the solar collectors. Once heated, the water is pumped into a storage tank and then piped to spouts for use in home [58]. Since this system uses regular household water in the collectors, it should only be used in areas that do not experience freezing conditions. However, a closed loop (indirect) active system uses heat to transfer fluids that is usually a water-antifreeze mixture [58]. After the heat-transfer fluid is heated in the solar collectors, it is pumped into a storage tank where a heat-exchanger transfers the heat from the fluid to the household water [59].

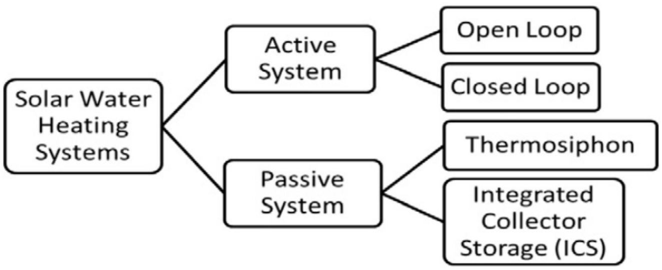


Fig. 1. Solar water heating system.

3.2. Passive system

On the other hand, a passive solar water heating system can be well-defined by comparing with the active system in terms of two bases; the first is the role of the collector and storage that are combined together into a structure of the building. For example, windows and rooms can serve as collectors while storage can provide sensible heat of the building structure and their contents as temperature changes [46]. Meanwhile, the second is that this system delivers no moving fluids (mechanical energy) but fluid and energy is moved by virtue of the temperature gradients established by absorption of radiation [5]. In other words, the passive system uses the method of natural convection heat transfer [56] and without mechanical devices [54], to circulate water or transfer fluids between a collector and an elevated storage tank which is placed above the tank [60] as shown in Fig. 2. In this system, if the fluid is gradually heated up, it will result in the decreasing of the fluid density. Starting with the collector, for example the flat plate collector (FPC), it collects the radiation from the sun and at that moment, the fluid in the collector will absorb the heat, causing the fluid density to decrease as well as affecting the upsurge of fluid to the top of the collector and gushing into the storage tank. Afterward, the fluid will turn out to be cool at the bottom of the tank and flow back to the collector. This phenomenon will circulate continuously until there is no sun as the source of energy [50].

3.2.1. Thermosiphon

The best examples of passive systems are the thermosiphon in Fig. 3 and the integrated collector storage (ICS) [61]. The thermosiphon system is the most common type of solar water heating system in the market and most commercially available [62]. It uses this type of roof-mounted flat plate collector, storage tank and connecting pipe together [63,64]. However, caution and care should be taken when installing such a system as the combined weight of the solar collector, storage tank and the water itself might be too much for the design of the supporting roof [65]. Moreover, the thermosiphon's concept is just simple and requires less maintenance due to the absence of control forces and instrumentations [28]. The efficiency of a collector depends

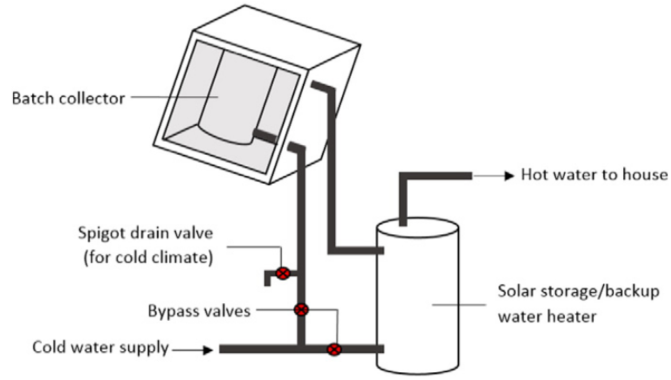


Fig. 2. Passive solar heating system [50].

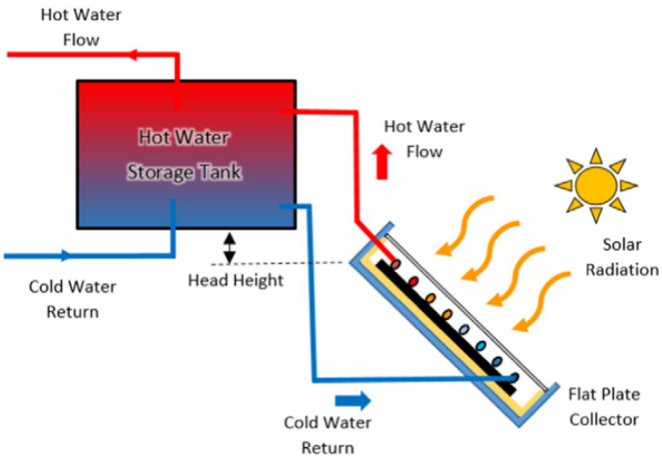


Fig. 3. The schematic diagram of the thermosiphon hot water system.

on the difference between collector and ambient temperature; the greater the difference between collector temperature and ambient temperature, the lower the intensity of solar radiation [13].

This system also heats potable water (drinking water) or a heat transfer fluid and uses natural convection to transport it from the collector to storage [66]. Thermosiphoning will occur when the water in the collector expands and become less dense as the existing heat is increased by the solar energy, causing the heated water to rise through the collector header into the top of the storage tank [46]. Later, the cold water there will flow down the collector toward the bottom of the tank [1]. In the storage tank, hot water will accumulate near the top when the water is heated during the day. To take into account the periods of low solar radiation levels, storage tanks are normally sized to hold about a 2-day supply of hot water. It should be noted that the water flowing through the collectors is potable water that goes to the user. Any quantity of hot water used will then be replaced through the freshwater inlet (from the cold water storage tank or main supply) which later will enter the storage tank near the bottom so as not to break the stratification [67].

As mentioned before, the circulation process will be continuous as long as the sun is shining. As the difference of the driving force between the hot and cold water is only a small density, a proper size that should be used to minimize pipe friction is definitely larger than the normal pipe sizes. Connecting lines must also be well insulated to prevent heat losses and sloped to prevent formation of air pockets which would stop the circulation. At night, or whenever the collector is cooler than the water in the tank, the direction of the thermosiphon flow will reverse, thus cooling the stored water, unless the top of the collector is placed well below (about 30 cm) the bottom of the storage tank [68].

The performance of a thermosiphon solar water heater can be affected by the effect of thermal conductivity of the absorber plate of a solar collector which is found using the alternative simulation system [66]. Compact solar water heaters in which the absorber plate forms an integral part of the storage tank have many advantages over both the conventional thermosiphon and forced convention types. They are relatively cheap to fabricate and install while they perform equally well during the day as the conventional types. However, they tend to lose accumulated energy during periods of low insulation when the absorber plate temperature falls below that of the water. Even on clear days, they need to be covered in the late afternoon and throughout the night if hot water is expected the following morning. Alternatively, the hot water may be transferred to a second storage tank or to the domestic electric heater for nighttime storage [69].

The thermosiphon solar water heater still remains today, many decades since their first appearance, and has been one of the most interesting technologies for exploitation of solar energy. Their remarkable efficiencies, combined with simplicity of construction, autonomy in operation, absence of moving parts and thus the minimization of necessary maintenance, make them an attractive alternative to pumped solar systems [70].

3.2.2. Integrated collector storage

Meanwhile, another example of the passive systems is the integrated collector storage (ICS). It is a combination of the solar collector and thermal storage tank [71] which incorporates both components in a single unit [72]. Apart from being one of the simplest forms of solar water heater in the market and becoming a very popular choice when choosing solar water heaters [73], it also reduced the cost [74], as they integrate the collector and the heat storage in the same construction [75]. Its design varied [5,66], consisting of several metal tanks where the energy will be absorbed on their exposed surfaces, enclosed in an insulated box with a transparent cover on the top to admit solar radiation. The outlet at the top of one tank is connected to the bottom of the inlet of the next tank to create a series. The purpose of having some layers of glazing over the tanks and the insulated box is to reduce heat loss to the collector as storage [76,77]. Then, the solar heated water is drawn into an auxiliary heater inside the house as needed. These systems are less expensive and simple; however there are usually weaknesses in which more heat is lost at night. Moreover, in North Carolina, the ICS system does not provide adequate freezing protection [7].

4. Components of solar water heater

Generally, the solar water heater consists of several basic components; the solar radiation collector panel, storage tank and heat transfer fluid [78,79], as shown in Fig. 4. Besides, there are also several additional components such as the pump (necessary in active system only), auxiliary heating unit, piping units and heat exchanger.

4.1. Solar collector

Firstly, the major component of solar water heater is the solar collector [80]. It is a special kind of heat exchanger that transforms the solar radiation energy to internal energy of the transport medium [81,82] in which it absorbs the incoming solar radiation, and converts it into heat, then transfers the heat to a fluid (usually air, water, or oil) flowing through the collector [66]. Besides that, it is also a device that can reduce fossil energy consumptions [83]. The collected energy will be carried from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank from which it can be drawn for use at night and/or cloudy days. There are basically two types of solar collectors: the first is non-concentrating or stationary [84] and the second is concentrating [85]. A non-concentrating collector has the same area for intercepting and absorbing solar radiation, whereas a sun-tracking concentrating solar collector usually has concave

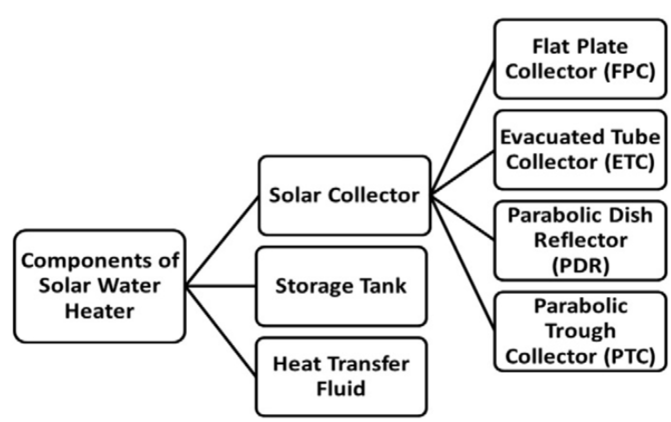


Fig. 4. Components of the solar water heater.

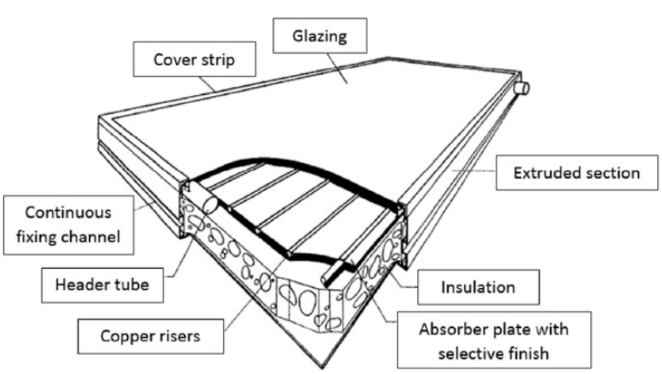
reflecting surfaces to intercept and focus the sun's beam to a smaller receiving area, thus increasing the radiation flux.

4.1.1. Solar collector selection

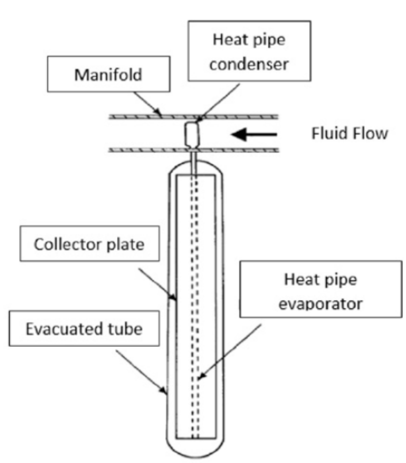
As it has been the major component of the water heater, it is no wonder if a large number of it is available in the market [24]. Hence, in choosing the right solar collector there are some considerations that must be employed in terms of heating requirements and the environmental conditions [50]. It can also be categorized in terms of the collecting characteristics, the way the collectors are mounted [86] and the types of heat transfer fluid. As mentioned earlier, the collecting characteristic can be non-concentrating collectors and concentrating collectors. For non-concentrating, it can be a flat type that has no medium to concentrate the incoming solar radiation, while for concentrating, it has reflectors to concentrate the energy falling on the aperture on to a heat exchanger with a surface area that is smaller than the aperture. Other than that, in terms of the ways the collectors are mounted, it can be static or adjustable. To follow the track of the solar radiation, it must consider the tilt angle first, which involves the heat transfer fluid (water, water ethylene glycol solution and air) [9].

4.1.2. Types of solar collector

There are mainly three types of solar collectors [87] that is used in solar water heating systems such as flat plate solar collector (FPC), evacuated tube solar collector (ETC) and concentrated solar collector (parabolic dish and parabolic trough collector) [66]. Flat plate solar collector (FPC) shown in Fig. 5a is one of the types of stationary collectors [24] and also the major component of any solar water heating system [53]. It is also a popular collector device [88]. Some of the components of this FPC are absorber plates, copper risers, insulations, and glazing and header tubes [53]. The absorber plate is usually coated with a blackened surface (high absorptive) in order to absorb as much heat as possible [24]; however various color coatings have also been proposed [106]. Copper risers, on the other hand, are welded to the absorbing plate and connected at both ends by large diameter header tubes. The function of insulation is to minimize heat loss from the back and sides of the collector while a header tube is to admit and discharge the fluid [89].



(a) Flat plate collector (FPC)



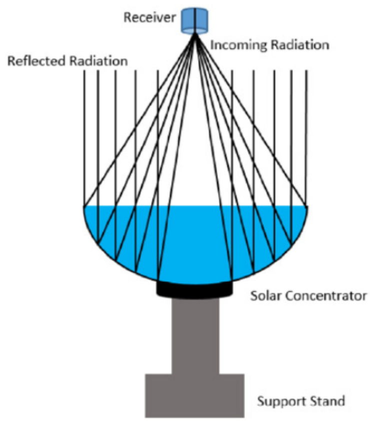
(b) Evacuated tube solar collector (ETC)

Fig. 5. Non-concentrating solar collectors) [68]. (a) Flat plate collector (FPC) (b) Evacuated tube solar collector (ETC).

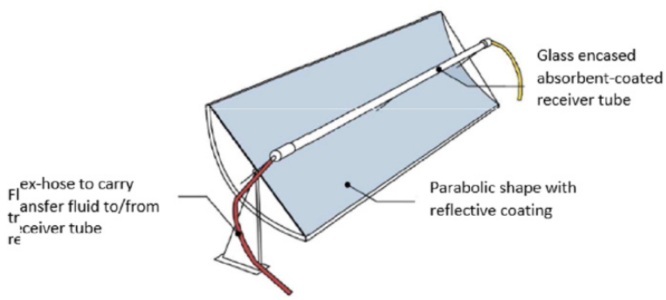
The two basic functions of a collector can be described as first, heating the fluid (water, water and antifreeze additive, and air) and second, collecting as much solar energy as possible at the lowest possible total cost. The concept of how it works starts with solar radiation passing through the transparent cover. Then, the absorber surface will play its role by absorbing the energy or heat from the sun. Fluids that have been heated will be later transferred to fluid tubes and carried away to the storage. Although this solar collector have a long effective life however, it still has adverse effects of the sun's ultraviolet radiation, corrosion and clogging because of the acidity, alkalinity or hardness of the heat transfer fluid, freezing of water, deposition of dust, breakage of the glazing because of thermal expansion, hail and vandalism [24]. Apart from FPC, evacuated tube solar collectors (ETC) are also a type of stationary collector [66]. Based on Fig. 5b, the basic components of this collector is the header pipe, manifold, heat pipe, and evacuated tube [68]. When the solar collector absorbs sunlight and converts them into usable heat, it is called a solar thermal system; the heat generated can be used to provide hot water and space heating for home. Once sunlight passes through the outer glass layer of the evacuated tube, then, it will be absorbed by a dark layer which becomes hot. After that, the heat pipe transfers heat to the insulated manifold box at the top of the collector. The heated liquid will circulate through another heat exchanger and give heat to a process or water at storage tank [68].

The water in the glass evacuated tubular solar water heater is the most widely used form of ETC because it has higher thermal efficiency than other ETCs employing metal-in-glass manifolds, simpler construction requirements and lower manufacturing costs. It typically consists of 15 to 40 flooded single-ended tubes with direct connection to a horizontal tank. The solar absorber tube consists of two concentric glass tubes sealed at one end with an annular vacuum space and a selective surface absorber on the outer surface (vacuum side) of the inner tube. The heat transfer in this collector is driven purely by natural circulation of water through the single-ended tubes. The water in the tubes is then heated by solar radiation, causing it to rise to the storage tank and replaced by colder water from the tank. Other than that, there is also parabolic dish reflectors (PDR) and parabolic trough collectors (PTC) which are categorized as concentrated solar collectors. The main use of this type of concentrator is for parabolic dish engines; a system that involves an electric generator using sunlight instead of crude oil or coal to produce electricity. The major parts of a system are the solar dish concentrator and the power conversion unit. Parabolic dish systems that generate electricity from a central power converter collect the absorbed sunlight from individual receivers and deliver it via a heat transfer fluid to the power-conversion systems. The need to circulate heat transfer fluids throughout the collector field raises design issues such as piping layout, pumping requirements, and thermal losses.

Fig. 6a shows the point-focus collector that tracks the sun in two axes, concentrating solar energy onto a receiver located at the focal point of the dish. The dish structure must fully track the sun to reflect the beam into the thermal receiver. For this purpose, tracking mechanisms similar to the ones described in the previous section are employed and doubled so the collector is tracked in two axes. The receiver absorbs the radiant solar energy, converting it into thermal energy in a circulating fluid. The thermal energy then can either be converted into electricity using an engine generator coupled directly to the receiver, or it can be transported through pipes to a central power-conversion system. In



(a) Parabolic Dish Reflector (PDR) [68]



(b) Parabolic Trough Collector (PTC) [128]

Fig. 6. Concentrating solar collectors. (a) Parabolic dish reflector (PDR) [68] (b) Parabolic trough collector (PTC) [128].

fact, this system can achieve temperatures in excess of 1500 °C. Like parabolic troughs, parabolic dishes are often called distributed-receiver systems because the receivers are distributed throughout a collector field [68]. Going through the advantages, this solar collector is the most efficient of all collector systems because it is always pointed toward the sun. In addition, its concentration ratio is in the range of 600 to 2000 and is automatically very efficient in thermal energy absorption and power conversation systems. In addition, it has a modular collector and receiver units as well that can either function independently or as part of a larger system of a dish [23,38].

Meanwhile, the parabolic trough collector (PTC) as shown in Fig. 6b is made by bending a sheet of reflective material into a parabolic shape [68]. Parabolic concentrating systems focus the direct solar radiation parallel to the collector axis onto a focal line [90]. A metal black tube, covered with a glass tube to reduce heat losses, is placed along the focal line of the receiver when the parabola is pointed towards the sun, causing parallel rays on the reflector to be reflected onto the receiver tube [16]. A receiver pipe is installed in this focal line with a heat transfer fluid flowing inside it that absorbs concentrated solar energy from the pipe walls and raises its enthalpy. The collector is provided with a one-axis solar tracking system to ensure that the solar beam falls parallel to its axis [91]. It is sufficient to use a single axis tracking of the sun and thus, long collector modules are produced. The collector can be orientated in an east–west direction, tracking the sun from north to south, or orientated in a north–south direction and tracking the sun from east to west [16]. The former tracking mode only requires very little collector adjustment during the day with the full aperture always facing the sun at noontime. However, the collector performance during the early and late hours of the day is greatly reduced due to large incidence angles (cosine loss). North–south orientated troughs have their highest cosine loss at noon and the lowest in the mornings and evenings when the sun is due east or due west [68,92].

Deng et al. [93] revealed the thermal performance for the novel flat plate solar water heater with micro heat pipe array absorber. The micro heat pipe array (MHPA) is sprayed with solar selective coating and arranged closely as the absorber of the collector. The collector's instantaneous efficiency showed that the slope and intercept of the instantaneous efficiency curve are 5.6 and 0.85, respectively. The test results showed that the daily effective heat gains on the three typical days in different seasons are 13.43 MJ/m^2, 11.05 MJ/m^2, and 7.42 MJ/m^2 respectively, corresponding to the solar irradiation of 18.9 MJ/m^2, 17.2 MJ/m^2, and 14.7 MJ/m^2. Subsequently, the daily average thermal efficiencies are 71.05%, 64.25%, and 50.49%, respectively. The results can be the basis and reference for practical application of the novel solar water heater (SWH). Liu et al. [94] observed a large-scale solar water heating system (SWHS) with flat plate collectors based on micro heat pipe array (MHPA-FPCs). The test results proved that high solar irradiation, high ambient air temperature and low initial water temperature could achieve higher system efficiency. The daily system efficiency could reach up to 62% with large solar irradiation and small temperatures between the collectors, temperatures and the ambient temperatures. Under different conditions, the average system efficiency approached 50%. The test results presented excellent characteristics for the large-scale of SWHS with MHPA-FPCs [94].

Recently, the use of phase change material (PCM) in solar collectors has expanded among researchers. It showed better performance compared to the traditional evacuated tube used in solar collectors. Xue [95] investigated the characteristic of domestic solar water heater with a solar collector coupled phase-change energy storage. The solar collector is an all-glass evacuated tubular type, and its area is 1.272 mm^2. The core component of the solar collector is the collector tube with 1800 mm in length. The outer diameter of the tube is 58 mm. On the outer surface of the inner glass tube, Cu/Al/stainless steel is magnet-sputtered as solar selective coating. There are 10 tubes in the collector. Inside each collector tube, a PCM storage unit is built in. The diameter, wall thickness, and length of the unit are 42.16 mm, 1.53 mm, and 1.720 mm, respectively.

Few researchers ran a numerical study on solar collectors for solar water heating thermal performance. Li et al. [96] had a numerical study on the flow and heat transfer performance of solar water heater that uses an elliptical collector tube as a solar collector. The results indicated that the temperature distributions of all the tube cross sections are alike, but their velocity profiles are very dissimilar. The fluid velocity near the wall decreased with decrease in the ratio of the cross section major and minor axis. It induced the reduction in the circulation rate through the collector tubes, which is not conducive to heat transfer. The mean Nusselt number of the solar water heater with $b/a = 1$ (b and a here are respectively the major and minor axis of collector tube cross section) are respectively 59% and 19% larger than the solar water heaters with $b/a = 0.6$ and 0.8 for temperatures ranging from 273 K to 313 K. The predicted results matched fairly well with the experimental data [96]. Table 1 shows the summary of the evaluation from the solar collector component of the solar water heating system.

4.2. Storage tank

Other than solar collectors, another component of a solar water heater is the storage tank, where it was integrated into or located above a solar collector [97]. It can be both in single unit and integrated unit. In a single unit, the storage tank is separate from the collector while the integrated unit is the combination of storage tank and the collector [53]. In a solar water heating system, a well-insulated storage tank is required to avoid heat losses. This is because the material of the thermal storage tank is made of high pressure resisted stainless steel and covered with insulated fiber and aluminium foil [27]. In some cases, there are some solar water heaters that use pumps to recirculate warm water from the storage tanks through the collectors and exposed piping. Its function is commonly to protect the pipes from

Table 1
Summary of solar collector and storage tank.

Component	Authors	Design descriptions	Efficiency/results
Solar colector	Deng et al. [93]	Micro heat pipe array (MHPA), spray with solar selective coating and arranged closely	Thermal efficiency = 0.71
	Liu et al. [94]	Flat plate collector based on microheat pipe array (MHPA-FPC) and large scale of SWH with MHPA-FPC.	Thermal efficiency = 0.62
	Xue [95]	Phase change material (PCM) in collector, all-glass evacuated tubular tube with area, A = 1.272 mm^2	It shows a better performance compared to the traditional evacuated tube used in solar collector.
	Li et al. [96]	Elliptical collector tube as solar collector and numerical study	The Nusselt number of solar water heater with $b/a = 1$ (b and a are respectively major and minor axis of collector tube cross section) are respectively 59% and 19% larger than the solar water heaters with $b/a = 0.6$ and 0.8.
Storage tank	Nam et al. [99]	Varied thermal load in multi-use heat pump water heater and the heat pump was on/off controlled	Efficient method to reduce the heat pump operation time and power consumption. Varied flow rate through the heat pump shows better performance compared to that of the constant flow rate.
	Li et al. [45]	Different positions of immersed coil heat exchanger inside a storage tank Experiment on charging and discharging performance of hot water tank	Discharging efficiency: Top-coil was higher 5% and 13.1% than that of the middle-coil tank and bottom-coil tank respectively Gap of the discharging efficiency reduced with the increasing of the flow rate Charging efficiency: Reduced with the rising of the position

freezing when outside temperatures is dropping extremely [50]. Solar thermal utilization system is one example where thermal stratification is gradually applied in many kinds of energy storage fields in order to adequately store and consume high quality heat energy. As solar radiation has a kind of staggering characteristic, thermal storage becomes very essential in long-standing operations of load heating [98].

There are few researches related to storage tank in order to improve the performance of solar water heating systems. Li et al. [45] investigated the effects of positioning an immersed coil heat exchanger inside a storage tank on the charging and discharging performance of the hot water tank. When the flow rate was 5 L/min, the discharging efficiency of the tanks with top-coil was higher by 5% and 13.1% than that of the middle-coil tank and bottom-coil tank, respectively. The gap of the discharging efficiency of the tank with different positions of the heat exchanger reduced with the increase of the flow rate. However, the charging efficiency reduced with the rising of the heat exchanger position. The numerical simulation was also carried out to analyze the annual performance of the solar water heating system (SWHS) with different positions of the heat exchanger by TRNSYS. The simulation results indicated that the SWHS had the lowest annual solar fraction and annual collector efficiency when the heat exchanger was on the top level of the tank.

Nam et al. [99] studied the characteristics of thermal storage tank for varying thermal loads in a multi-use heat pump water heater. The temperature within the storage tank, the heat pump on/off control was measured, and the water flow rate through the heat pump varied and the temperature of the hot water from the heat pump is maintained to be 60 °C. From the research, it was revealed that the on/off control of heat pump by measuring the temperature within the storage tank was an efficient method to reduce the heat pump operation time and power consumption for water supply in a multi-use heat pump water heater. By varying the flow rate through the heat pump, better performance was shown compared to that of the constant flow rate. The operation time and power consumption were decreased about 12.2% and 11.2%, respectively. Table 1 concludes the findings from the storage tank component of the solar water heating system.

4.3. Heat transfer fluids

Without heat transfer fluid, the solar water heater will be incomplete. Its purpose is to collect the heat from the collector and transfer the heat to the storage tank either directly or indirectly; with the help of a heat exchanger. There are some characteristics of fluids that should be highlighted in order to get better heat transfer fluids and to have an efficient solar water heater configuration. The heat transfer fluids should have a high specific heat capacity, high thermal conductivity, low viscosity, low thermal expansion coefficient, anti-corrosive property and low cost. Several examples of heat transfer fluids can be identified such as water, glycol groups, silicon oils and hydrocarbon oils. Water is the best among the fluids because it has its own advantages which are low cost, most readily available and thermally efficient. However it does easily freeze and can cause corrosion [50].

Nanotechnology, a new promising area of research which grows rapidly, are considered nowadays as one of the most recommended choices in order to improve the performance of the system [11]. Other than that, it also has an important function in promoting technology to the current world [100]. Nanofluid (nanoparticle-suspension) is a colloidal suspension with nanoparticles dispersed uniformly in a base fluid and has many unique characteristics in the thermal engineering field [101,102], due to its anomalous heat transfer properties [103]. Enlightened by the enhanced heat transfer of nanofluids, some researchers applied it in a common tubular thermosiphon to enhance its heat transfer performance. There is an investigation about the interface effect of carbon nanotube (CNT) suspension with surfactant on the thermal performance of a thermosiphon [104]. Besides that, the same results were found on another investigation on the thermal performance in the same miniature thermosiphon using CNT suspensions, but without surfactant [105]. The experimental results were similar to those using copper oxide (CuO) nanofluids [105]. Another researcher investigated the total heat resistance of a thermosiphon using pure water and various water-based nanofluids containing nanoparticles of aluminium oxide (Al_2O_3) (40–47 nm), CuO (8.6–13.5 nm) and laponite clay (discs of diameter 25 nm and thickness of 1 nm) [106]. Other researchers also investigated the heat transfer performance of the heat pipe using nanofluids consisting of R11 refrigerant and titanium nanoparticles with the particle size of 21 nm [107]. These heat pipes with nanofluids can be used in solar FPC in order to make the system more compact. Another study had been conducted to investigate the performance of thermosiphon using solar water heater with nanofluids [108].

Ling et al. [109] revealed the performance of a coil-pipe heat exchanger filled with mannitol for the solar water heating systems. They found that 14 kg mannitol with latent heat activated can heat 100 L water from 30 to 50 °C in 6 h. The results showed that mannitol can store high-level energy and the thermal energy storage performance are affected by the inlet flow rate and temperature of heat transfer fluids [109]. An investigation of the solar water heating system performance using copper oxide/water (CuO/H_2O) nanofluids had been done by Michael and Iniyan [110] in two conditions; forced circulated system and natural circulated system. They found that the thermosiphon system showed significant improvement in performance

Table 2
Summary of heat transfer fluids.

Heat transfer fluids	Authors	Design descriptions	Advantages	Disadvantages
Nanofluids	Meibodi et al. [111]	SiO_2 nanoparticles dispersed in EG–water mixture as working fluids in solar plate collector	SiO_2 nanofluids has potential to improve the efficiency	SiO_2 in EG–water based nanofluids has low thermal conductivity.
Mannitol	Ling et al. [109]	The coil-pipe heat exchanger filled with mannitol	Mannitol can store high-level of energy and it can heat 100 L of water from 30 to 50 °C in 6 h	Thermal energy storage performance is affected by the inlet flow rate and temperature of heat transfer fluid.
Mixture based	Jahanbakhsh et al. [112]	Ethanol–water as working fluids	Enhanced the heat pipe performance at low heat flux with efficiency of 52% The concentrations of 50% and 75% show the best performance characteristics	–

compared to the forced circulation system. The thermo-physical properties of the synthesized nanoparticle and prepared nanofluids were compared theoretically and experimentally. Meibodi et al. [111] used SiO_2/EG–water nanofluids in solar plate collectors to investigate the solar system performance. The thermal efficiency and performance characteristics of solar collectors were obtained for mass flow rates of between 0.018 and 0.045 kg/s. It elucidated the potential of SiO_2 nanoparticles in improving the efficiency of the solar collector although it has a low thermal conductivity compared to other types of nanoparticles.

Jahanbakhsh et al. [112] used ethanol-water as a fluid heat transfer to analyse a heat pipe operated solar collector. From the results, it showed that the ethanol in the solution enhanced the heat pipe performance at low heat flux. The concentrations of 50% and 75% showed the best performance characteristics in transferring heat. An efficiency of 52% was obtained for the heat pipe operated solar collector. Table 2 simplifies the results from the heat transfer fluid of the solar water heating system.

5. Latest development and applications

On the whole, the solar water heater is a very universal application today [52]. There are many improvements like the evacuated tubes as collectors in which higher quality insulation are suggested for improving solar water heating systems. Unfortunately, it was not really effective because the cost is too high. Moreover, with an economical water heating system, it will minimize this drawback to a notable extent [113]; other than the improvement of the parabolic dish reflector design and the material of the collector (copper in high thermal conductivity). Furthermore, cost effectiveness and easily fabricated solar water heating system with high thermal efficiency are some of the latest developments as well. Kaçan et al. [114] had studied the effects of optimum independent parameters on solar heating systems including the influence of the four major variables, namely; outside, inside temperature, solar radiation on horizontal surface and instantaneous efficiency of solar collector. The energetic, exergetic and environmental efficiencies of the solar combi systems and system optimization was done by a combination of response surface methodology. Measured parameters and energetic–exergetic and environmental performance curves are found and a statistical model is created parallel with the actual data.

In order to increase the thermal efficiency of the system, the originality of the work is much needed; a stationary V-trough reflector must be joined to the solar absorber. The stationary V-trough is preferred due to its much simpler geometry compared to that of the compound parabolic concentrator. The optical performance of the stationary V-trough still remains unknown because the current V-trough is attached to a single-axis sun-tracking system due to its linear focusing capability. As a result, a detailed optical analysis of the novel stationary V-trough collector is a significant study to understand its performance as the sun's position changes throughout the day and year. Finally, practical viability is also discussed such as a detailed description of how a prototype V-trough solar water heater was constructed as well as cost analysis and payback period of the prototype [87]. Milani and Abbas [115] also focused on multiscale modelling and analyzed the performance of evacuated tube collectors for solar water heaters using a diffuse flat reflector (DFR) at the back of ETC array to improve the heat capture rate. Panaras et al. [116] investigated the performance of a combined solar thermal heat pump hot water system using component based simulation model and emphasized on the formulation of a simple and efficient approach for the modeling of the heat pump.

6. Conclusions

This paper has reviewed the state of the art solar energy applications, with the focus on the solar water heating system that can be divided into two systems: the active system (open loop and closed loop) and the passive system (thermosiphon and ICS). This paper also reviewed solar water heaters that have three basic components: solar collector, storage tank and heat transfer fluid and its advances in research. A variety of solar collectors has been discussed, including non-concentrating collectors (FPC, ETC) and concentrating collectors (PDR, PTC). Two different types of concentrating solar collectors of PDR and PTC have been described. Among the non-concentrating and concentrating collectors, the PDR collector showed the best overall performance in terms of optical optimization, heat loss reduction, heat recuperation enhancement and different sun-tracking mechanisms. After the extensive literature reviewed, it was found that no one observed the effect of a nanoparticle in the base fluid of the heat pipe of a solar collector with and without tracking. In addition, it has also been discovered that the use of nanofluids in the heat pipe is limited and not on a commercial scale.

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