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Review Article

The Various Designs of Storage Solar Collectors: A Review

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Abstract. The use of solar energy to heat water is the more critical application of solar energy. Researchers are trying to develop different methods to improve the efficiency of solar water heaters to meet the increasing demand for hot water due to global population growth. To reduce the cost and increase the efficiency of solar heaters, the solar collector and the storage tank are combined into one part, and this system is called solar storage collector. It can be defined as geometric shapes filled with water, painted black, and placed under the influence of sunlight to gain the largest amount of solar energy. This article presents the various designs of solar storage collector. This review showed that design variables and design shape significantly affect the efficiency of the solar heating system. Climate and operational factors also have a strong influence on the performance of solar heating. Furthermore, scientists and researchers have also used nanotechnology, solar cells, and mirrors to improve other stored solar collectors' performance. Finally, recently published articles indicate an increase in interest in improving the efficiency of solar storage collector by creating new designs that enhance the economic and practical viability.

Keywords: Designs; Storage solar collectors; Solar energy; Solar heating system

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1. Introduction

Solar power plays a vital role in international energy programs (Ravi Kumar, Krishna Chaitanya and Sendhil Kumar, 2021; Ahmed and Bawa, 2018). Increasing global fuel consumption, accompanied by severe pollution and rapidly rising fossil fuel prices, has increased interest in solar energy (Ahmed and Hussein, 2018). As a result, the energy market's use of renewable energies increased from 4.5% to 5% in 2019 (BP, 2021). At the same time, the practical applications of solar energy are not without problems (Ahmed and Mohammed, 2017). Solar energy has a discontinuity because it disappears at night and in cloudy weather. This reduces its importance and makes it necessary to store solar energy (Khalil Ahmed and Aziz Mohammed, 2017). Thus, for solar energy to be competitive with the rest of fossil fuels, it needs to be converted to another type of energy with maximum efficiency (Nayak and Tiwari, 2008) (Mohammed, Khalil and Emad, 2018). Hot water is used in various applications, and solar energy can be used effectively and cheaply to heat water using unique systems called solar water heaters (Duffie and Beckman, 2013). Solar heaters are one of the most efficient and least expensive solar energy systems today. Also, the solar heater system is characterized by its simplicity of installation, ease of manufacture, and the absence of the need for costly maintenance operations. In 2016, the total capacity of solar heating systems was 435.9 GW (Butuzov, 2018). Solar heaters consist of three main parts: the solar collector, the collection and preservation tank, and the connecting pipes. Solar heaters are one of the most widespread solar systems, and there are millions of these systems distributed in various countries of the world (Smyth, Eames and Norton, 2006). Solar heaters are among the applications that do not need relatively high temperatures, as the boiling point of water does not exceed 100°C. Solar heaters are classified into two main classes (Shukla *et al.*, 2013). First, the thermo-siphon system. When the tank is mounted on top of the solar collector, solar radiation heats the water and decreases its density. Due to the decrease in density, the water moves upward (Jaisankar *et al.*, 2011). To provide heat at night or under cloudy conditions, an auxiliary electric water heater is installed close to the water intake point to provide the required water temperature (Omer Kh. Ahmed, 2018). Fig.2 displays the second design of solar heating systems, called forced circulation systems, which require a pump that circulates the water (Roberts and Forbes, 2012). The operation of the pump is monitored by an electronic system that rotates the pump when necessary (Ahmed, Daoud, *et al.*, 2020). A

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characteristic feature of this system is the need for a non-return valve which prevents the operating fluid from returning to the collector at night to diminish heat loss from the solar collector (Tian and Zhao, 2013). It also requires additional electric heating to provide hot water when there is no solar radiation at night or in cloudy weather (Sharafeldin and Gróf, 2018). Water is the most widely used fluid to store power in solar heating systems, especially for uses that require low or medium operating temperatures, as water is inexpensive and has a large heat capacity in addition to other distinct properties (Ahmed and Bawa, 2019). According to Islam, Sumathy and Ullah, (2013), for a conventional collector, approximately 15% of the total cost is associated with labor cost. Also, 35% of the collector cost is associated with the absorber plate and plating. The current cost per unit collector area for air or water circulated flat plate collectors is £150 per square meter, and a professionally installed system cost is around £2,000 or more. This high upfront cost is one of the most critical factors motivating people to avoid using solar heating systems. Also, traditional solar systems suffer from high heat loss problems due to conduction, convection and radiation. Leaks through joints, pipe corrosion, and the need for additional space for installation are increased components. Thus, engineers and researchers try to find new systems that reduce the initial cost needed to manufacture solar energy systems (Frid, Mordynskii and Arsatov, 2012).

The traditional models of solar water heaters consist of two major parts: the solar collector and the storage tank. The need to merge these two parts came up in part, and this type of solar water heater is called a solar storage collector (Devanarayanan and Kalidasa Murugavel, 2014). This design provides an attractive alternative to a solar water heater system. As a result, the cost of the solar water heater system is reduced, and system efficiency is improved. Also, this type of solar collector reduces the environmental pollution caused by the conventional energy systems due to reducing the components of the solar heater (Hazami *et al.*, 2010). The main advantage of a solar storage collector is that it does not require controls, pumps, sensors, or any other mechanical or moving parts, so the maintenance requirements are minimal. Also, one of the most important disadvantages of solar storage collectors is the high thermal losses at night (Faiman, 1985). Different storage solar water collectors have been investigated and constructed to provide hot water for various uses and multiple operating conditions (Singh, Lazarus and Souliotis, 2016). This article will review the various designs and performance enhancements in storage solar water collectors and study the characteristics of each design.

2. Historical View of the Solar Storage Collector

The first patent for the solar storage collector was published in the United States in 1891 (Souliotis *et al.*, 2015). This solar heater was named (The Climax Solar-Water Heater). The collector contained four small iron cylinders. The volume of each cylinder was (29 liter), painted a dull black, and mounted in a wooden insulated. A glass lid is applied to the top of the design. This invention was built by Walker (Walker, no date) with the added concentrated mirrors that concentrate the solar radiation upon the design. To increase the ratio between the collector area and the unit volume of the installation, Haskell (Souliotis *et al.*, 2015) suggests replacing the cylindrical vessel with a flat tank. The front surface of the collector is provided with fins to increase heat transfer from the absorbent plate to the storage water. Many solar storage collector patents were present until 1911, and only a few were commercially marketed (Souliotis *et al.*, 2015). Japanese researchers presented a series of new designs for solar storage heaters. Yamamoto is the first Japanese researcher to have obtained the patent of the solar storage collector (Butti and Perlin, 1981). Another Japanese design is a plastic bag. It is a rectangular cubit made of plastic material and is dyed black to increase the absorption of solar radiation. Tanishita, (1970) presented a combined collection and storage tank concept used in many commercial models.

3. Classification of the Solar Storage Collector

The diligent work of researchers to develop methods of utilizing solar energy has caused the invention of many storage solar collectors. Many researchers presented many practical and theoretical designs and tried to reach high-efficiency designs for storage solar collectors. The designs of storage solar collectors will be divided according to the method of solar radiation absorption as;

3.1. Non-concentrating storage solar collector (NCSSC)

This design is the oldest type of storage solar collector and is distinguished by its high efficiency and low economic cost, and the first of these designs appeared in the early seventies of the twentieth century. Chinnappa and Gnanalingam, (1973) analyzed a pressurized type solar water heater (Fig.1). This design consists of a coil of 7.62 cm diameter tubes wrapped in a square shape with a total length of 13.5 m, placed in a wooden box isolated from the bottom and sides, and contains two glass covers on the front side. The thermal efficiency of this design was about 46%. (Garg, 1975) suggested a novel design of a solar storage heater, as shown in Fig. 2. The capacity of the proposed heater is 90 liters and manufactured in the form of a parallelogram tank (112 * 80 * 10 cm). Test results showed that this heater could prepare 90 liters of hot water with an average temperature of 50 to 60 °C in winter and from 60 to 75°C in summer measured at 4:00 pm. The optimum distance between the top and bottom plate of the heater is found at 10 cm. (Chauhan and Kadambi, 1976) investigated how a collector-cum-storage model of a solar water heater could be implemented. It was of 70 liters capacity, combining collections and storage. The system had a heat efficiency of 71.8% under constant flow conditions. Sodha *et al.*, (1979) analyzed the solar storage water heater, which consisted of an insulated rectangular reservoir measuring (1.22*0.9*0.2) m and whose upper surface was sufficiently blackened and covered in glass.

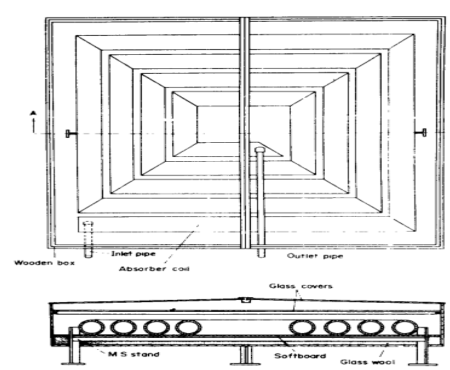


Fig. 1 The design was presented by (Chinnappa and Gnanalingam, 1973)

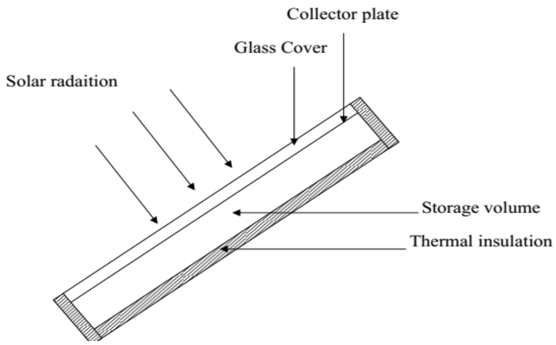


Fig. 2 Schematic of the compact solar collector was invented by (Garg, 1975)

Nahar and Malhorta, (1982) have developed solar water heaters for storage. It was composed of a rectangular galvanized steel tank of 1.12*0.8*0.1 m and a capacity of 90 liters. The heater was sloped 41° horizontally and oriented southward during the winter season. A transparent PVC lid is used in place of a glass lid to avoid glass breakage during transportation and maintenance. The results also showed that covering the front panel with insulation at night keeps the water temperature elevated. Garg and Rani, (1982) theoretically and experimentally investigated the impact of using an insulating cover during cooling hours and using an insulated baffle plate inside the bowl adjacent to the absorption plate (Fig.3). Goetzberger and Rommel, (1987) also studied the suitability of these solar storage collectors for European countries. Also, a baffle plate was used to improve the collector's performance was achieved by (Kaushik, Kumar and Garg, 1995). The article's results confirmed that the thickness and material type of the baffle had little impact on the system performance. Also, the transient analysis of the solar storage collector using the finite difference technique was achieved by (Kaushik *et al.*, 1994). The article confirmed that the efficiency of the water with night insulation is 17% higher than that without night insulation. Kumar and Rosen, (2010) used a corrugated surface as an absorbent surface to enhance the integrated storage solar collector (Fig. 4). The corrugated surface raises the area of the absorbent plate exposed to solar radiation, allowing the collector to absorb more solar energy. Also, the use of the corrugated surface increases the thermal losses during the night.

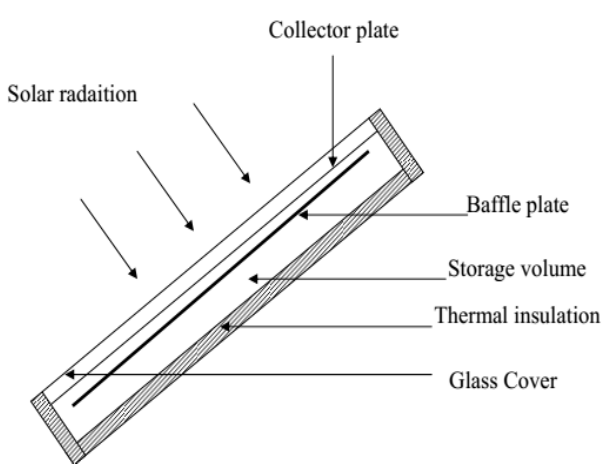


Fig. 3 System with Baffle plate (Garg and Rani, 1982)

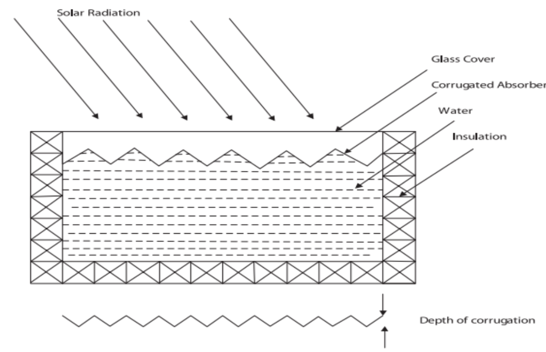


Fig. 4 Integrated solar storage collector with a corrugated surface (Kumar and Rosen, 2010)

Ahmed, Ahmed and Ali, (2014) analyzed the effect of the shape, and the surface on the efficiency of the solar storage collector. The effect of three different absorbent plate shapes has been studied: flat, wavy, and zigzag shapes. The results confirmed that the zigzag shape of the front face of the solar collector showed better performance and higher temperatures than the other two designs. (NAHAR, 1983) studied the solar storage collector's yearly performance and the effect of placing two double glass covers on the front face of the system. The outcomes of the system showed that supply 100 liters of hot water at 60°-70°C in the afternoon. The efficiency of the system was 70.1%. Sokolov and Vaxman, (1983) and Vaxman and Sokolov, (1985) studied the concept of an integrated compact solar water heater, both in terms of analysis and experimentation. The collector and the water tank are combined in the proposed method, with water flow induced by thermosiphon power (Fig.5). The results revealed that such a system's performance was higher than that of traditional systems. Furthermore, the experimental findings corroborated theoretical expectations. Garg, Bandyopadhyay and Sharma, (1981) used a black rock to improve the efficiency of the solar storage collector and the absorption of solar energy. (Garg, Avanti and Datta, 1998) developed a non-dimensional method to predict the performance of the solar storage collector. They used three-dimensional numbers: Brooks Number (X), Heywood Number (Y), and Yellot Number (Z) for this purpose. Rehim, (1998) introduced a new experimental design for a solar storage collector. This novel collector is shaped like a cube and has five surfaces, four of which serve as roofs for liquid flat-plate collectors, and three of which receive all solar radiation incidents on them. The results confirmed that the new integrated water heater model could generate 175 liters of hot water per day at an average temperature of 40 to 60°C, as a function of solar intensity and environmental conditions.

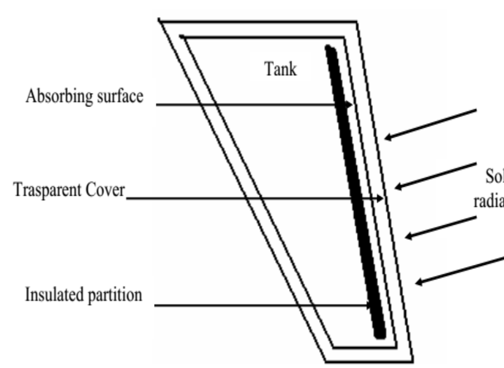


Fig. 5 Schematic view of triangular (TRI) system

Sopian *et al.*, (2004) presented a new design of storage solar collector as shown in Fig.6. The design of the storage area was a sandwich construction, with the core material made of polyurethane foam, which combines the rigidity and lightness of the structure with adequate thermal insulation. The ultimate temperature of water in the storage tank was 63 °C for a clear day. Kumar and Rosen, (2011b) improved the thermal performance of the rectangular storage collector by adding extended storage volume to the original volume, as shown in Fig. 7. The total volume of the modified storage solar water collector has two volumes. Volume (1) is subjected to solar radiation, while volume (2) is fully shielded on all sides. The energy balance equations for each volume are written and solved to demonstrate the impact of the additional volume on the integrated solar collector's efficiency. The results show that the greatest storage water temperature was obtained when the ratio of volume 1 to volume 2 was 7/3.

Mohamad (1997) used the thermal diode to enhance the performance of the solar storage collector. The design provides a thermal diode to prevent reverse circulation at night-time. The thermal efficiency of the new design, about 50%, is comparable with classical storage solar collectors.

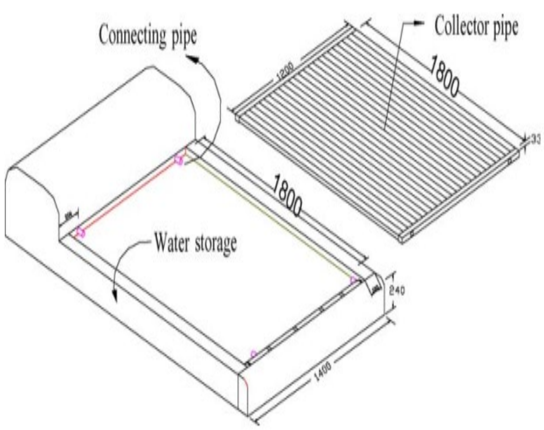


Fig. 6 Non-metallic solar collector provided by Sopian et al. (Sopian *et al.*, 2004)

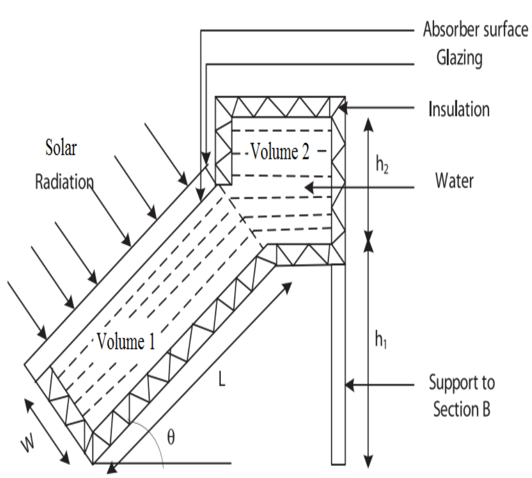


Fig. 7 Modified integrated collector(Kumar and Rosen, 2011b)

Nieuwoudt and Mathews, (2005) presented a novel design of a compact solar collector (Fig.8). The model is characterized by its simple design, lack of breakable parts, the possibility of converting it easily, and the water inside it can be heated to a temperature of up to 60 °C by mid-afternoon. Mohsen, Al-Ghandoor and Al-Hinti, (2009) presented a thermal analysis for a compact solar collector. The outcomes of the article concluded that the optimum depth of the tank is 10 cm, which can provide hot water for 24 hours. Fraisse *et al.*, (2014) developed and tested another design of the integrated solar collector. The design differs from the classical storage collector's systems. The resulting annual energy performance is promising, with 40% of the solar fraction for a collector area of just 2 m.

Garnier, Muneer and Currie, (2018) performed a practical and theoretical study of a solar storage collector installed on the house's roof and is characterized by simple installation and low cost, as shown in Fig. 9. The laboratory results indicated an increase in the storage water temperature of the new design by 6.3 °C.

Fig. 8 Model provided by Nieuwoudt and Mathews(Nieuwoudt and Mathews, 2005)

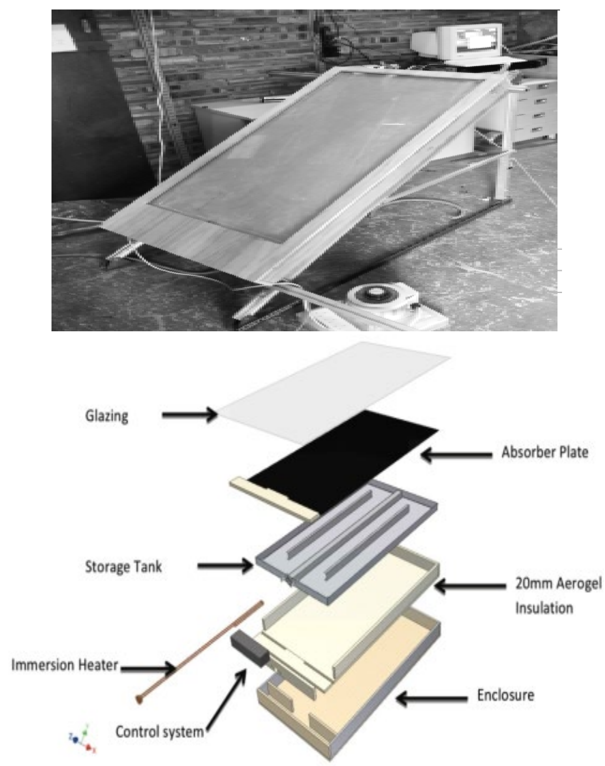


Fig. 9 Solar storage collector was invented by (Garnier, Muneer and Currie, 2018)

Parkash, Garg and Datta, (1985) presented a mathematical model to enhance the performance of storage solar collectors. Tarhan, Sari and Yardim, (2006) used the phase change material to enhance the performance of the trapezoidal storage solar collector. Taheri, Ziapour and Alimardani, (2013) used a layer of the black-coloured sands immersed into the water storage tank to enhance the performance of the solar collector, as shown in Fig.10. The daily heat output was above 70%, and the maximum temperature of water stored in the collector was approximately 90 °C. Cruz, Hammond and Reis, (2002) presented a trapezoidal-shaped solar storage collector as in Fig 11. Measured energy savings for this design varied from 30 to 70%. Hazami *et al.*, (2010) used a layer made of concrete that performs the function of both absorbing and storing solar thermal energy. The results proved the effectiveness of the design and its ability to supply hot water for long periods during the day. Ecevit and Apaydn, (1989) presented another design of storage solar collector and named triangular built-in-storage collector as shown in Fig.12.

Mozumder (2013) presented another design for the storage solar collectors in the form of a cube, the south east, south west, and upper sides of the cube are covered with an overlay cover to increase heat gain. Other studies have been conducted to improve and achieve the performance of solar collector heater systems, such as (Soponronnarit *et al* 1994; Currie *et al.*, 2008).

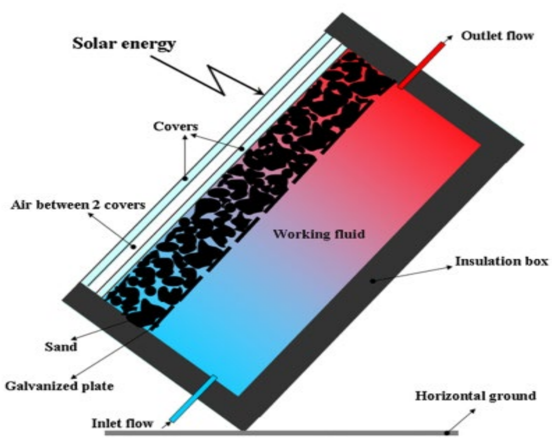


Fig. 10 The compact solar water heater was invented by (Taheri, Ziapour and Alimardani, 2013)

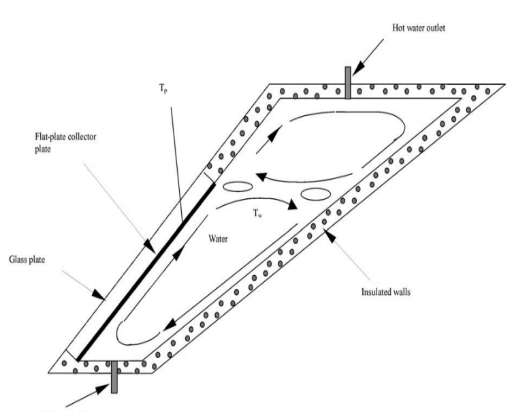


Fig. 11 Trapezoidal-shaped solar storage collector invented by (Cruz, Hammond and Reis, 2002).

Gertzos, Caouris and Panidis, (2010) inserted a heat exchanger into the solar storage collector. Computational Fluid Dynamics (CFD) techniques were used to analyze the influence of a heat exchanger. The results showed that the best thermal performance is achieved when the heat exchanger is in contact with the front and back sides of the tank. The results also showed that the optimum diameter of the heat exchanger tube is 16 mm, and its length is 21.5 m. Gertzos and Caouris, (2008) studied the flow pattern inside the solar storage collector practically and numerically. The article results showed that the circulation of water inside the tank significantly improves the collector's efficiency. Also, they studied the location and dimensions of the feeding ports and the dimensions of the interconnecting fins on the performance of the flat plate storage collector. The optimal design increases the outlet temperatures up to 8 °C.

A special type of storage solar collector was studied by Hazami *et al.*, (2005). This design consists of a concrete block containing a capillary heat exchanger, as shown in Figure 13. As a result, the stored water temperature inside the collector rose to 50°C for the day in December. AL-Khaffajy and Mossad, (2013) studied the effect of having more than one row of heat exchangers on the performance of the solar storage collector. The effect of the cross-sectional type of heat exchanger tubes was also studied, and two types were selected: round and oval tubes.

Ziapour and Aghamiri (2014) proposed a simulation of a redesign for an integrated solar collector. As seen in Fig.14, this design's storage tank is divided into two volumes. The top volume (Va) is greater than the base volume (Vb), accumulating the most heat above the design. Also, the design contains a baffle plate fixed parallel to the absorber plate. This improved design showed that its efficiency is higher than other designs and the greatest efficiency was when the volume ratio (Va/Vb) was greater than 4.

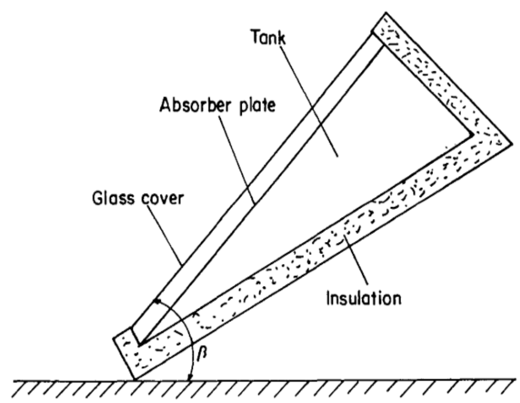


Fig. 12 Triangular built-in-storage collector invented by (Ecevit and Apaydn, 1989)

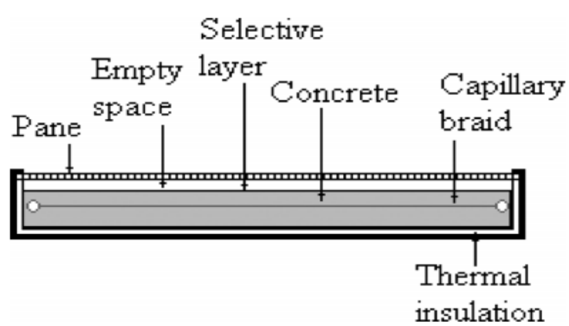


Fig. 13 The model studied by Hazami *et. al* (2005)

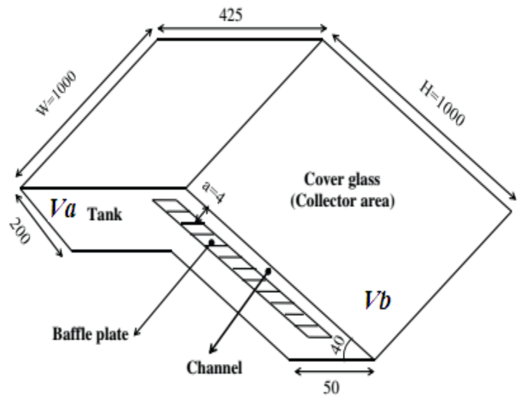


Fig. 14 The Improved storage solar collector was improved by (Ziapour and Aghamiri, 2014)

Fig. 15 Triangular collector (Omer Khalil Ahmed, 2018a)

Kumar and Rosen, (2011a) presented five designs to reduce the heat losses from the solar storage collector. This design includes (1) a Single glass layer without night insulation; (2) a Single glass layer with night insulation; (3) Double glass layer without night insulation; (4) transparent insulation with single glass layer; and (5) insulating baffle plate with a single glass layer. The perfect performance was noticed for the first design and three designs. (Sridhar and Reddy, 2007) used the Fluent program to achieve a transient analysis of the performance of the solar storage collector. The effect of many variables such as the angle of inclination of the collector, the heat transfer coefficient from the front face, the depth of the collector and others were studied. Kaushika and Reddy, (1999) and Reddy and Kaushika, (1999) study the effect of transparent insulation on the performance of integrated-collector-storage solar water. This transparent insulation reduces the heat transfer from the front face of the solar storage collector. Also, Chaurasia and Twidell, (2001) studied the effect of transparent insulation on the performance of the solar storage collector. The storage efficiency of the integrated solar collector was 39.8% with the transparent glazed insulating material compared to 15.1% with the cover glass. Dharuman, Arakeri and Srinivasan, (2006) designed a solar storage collector. The maximum water temperatures were ranged between 50 and 60 °C.

Joudi, Hussein and Farhan, (2004) proposed a redesign of a solar storage collector for domestic hot water supply and named a rectangular collector. It is designed to serve as a collector and storage tank within a component. This new model has several advantages over the others. It is efficient during the day because there are no heat losses during water circulation. Hamood and Khalifa, (2012) presented a lab study on the built-in solar water heater in the form of a prism. The water temperature rises on August was discovered to be 25.2 C. In November, the rise in water temperature was 15.5 °C and 13.6 °C in January. Ahmed *et al.* (2019) carried out a pilot study of the Rectangular storage collector with a numerical investigation using the ANSYS software. The most significant scientific fact mentioned in this study is that the ratio between the absorbent plate and the storage volume must not be less than 12. Ahmed, (2018a) experimentally investigated the performance of a triangle solar collector as exposed in Fig. 15. To increase the absorption of solar energy, the sunny area is painted black glass, or another transparent material can cover the sun-facing sloping side. All other sides are insulated by thermal insulation. The experimental study revealed that the tank's average temperature reached 40 °C in November. This research aims to create an inexpensive, reliable and effective solar water heating system for home use. Khalil Ahmed, (2017) did an empirical and theoretical study on a cylindrical storage collector. It has been suggested in this paper that a cylinder be cut in an angled cut plane. Summer and winter weather conditions with and without hot water withdrawal were tested. The average storage temperature in the cylindrical collector had a maximum range of 25 °C. On a typical spring day, the temperature profile at the tip of the cylindrical header was 58 °C. In general, the performance of the solar collector developed was similar to that of conventional flat-plate solar water heaters. Omer Khalil Ahmed, (2018b) presented a redesign of a solar storage collector to demonstrate its utility for domestic purposes. This new collector is referred to as the wedge collector. It can be used as a reservoir for storing water instead of the standard cubic or cylindrical container used for domestic purposes (Jassim, Ahmed and Altuğ Karabey, 2020; Ahmed and Daoud, 2018). According to the research, a storage collector is derived from the cut of a two-plane cylinder, the first plane being vertical and the second plane being a 45° incline. Table 1 shows the summary of the study suggested for the non-concentrating storage solar collectors (NCSSC).

3.2. *Photovoltaic/storage solar collector*

The high temperature of the solar cell has resulted in decreases in the effectiveness of the cell. Therefore, the researchers aim to reduce the temperature of solar cells and use excess heat from solar cells for a variety of purposes (Omer and Zala, 2018; Ahmed *et al*, 2019). In addition, many thermal applications are now available, which rely on the integration of solar panel technology into other solar applications such as solar collectors (Ahmed *et al.*, 2019), the Trompe wall (Abed *et al.*, 2020) (Ahmed *et al* 2019), solar chimneys (Ahmed, Hussein, *et al.*, 2020), solar ponds (Ali, Ahmed and Abbas, 2020), and others. A photovoltaic/solar collector is a collector that is a combination of photovoltaic and thermal systems. In this type of collector, the absorbed black metal plate is replaced by a solar cell that absorbs heat and generates electricity simultaneously. These types of manifolds are very efficient. Additionally, it is the simplest PV/thermal solar collector type for its low-cost and straightforward design. Over the past few years, numerous studies have been carried out to study the efficiency of hybrid PV/storage solar collectors.

Ziapour, Palideh and Mohammadnia, (2014) presented a simulation model of solar storage collector combined with the PV cell as shown in Fig. 16. The results indicated that the overall effectiveness of the proposed design depended on the solar panel filler factor, collector water volume, and collector area. The results showed that increasing the volume of water from the collector and the high filling factor of the solar cells increases the system's overall efficiency. Furthermore, increasing the surface area absorbed by the solar panel reduces the overall effectiveness of the proposed system.

Ziapour, Palideh and Baygan, (2014) studied comparing performance between four solar photovoltaic/storage collector models, as shown in Fig. 17. Absorbent plates made of aluminum with wings, absorbent plates made of aluminum without wings, Tedlar absorbent plates and absorbent plates painted in black are among the different absorbent plates. The solar collector with an aluminum absorber plate with fins was the strongest of the other models in the sample.

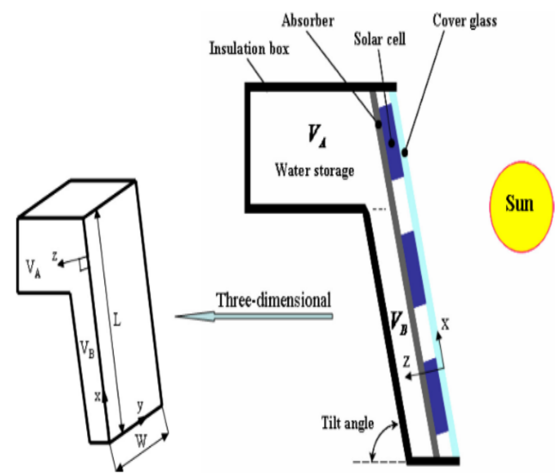


Fig. 16 PV/storage collector, which presented by (Ziapour, Palideh and Mohammadnia, 2014)

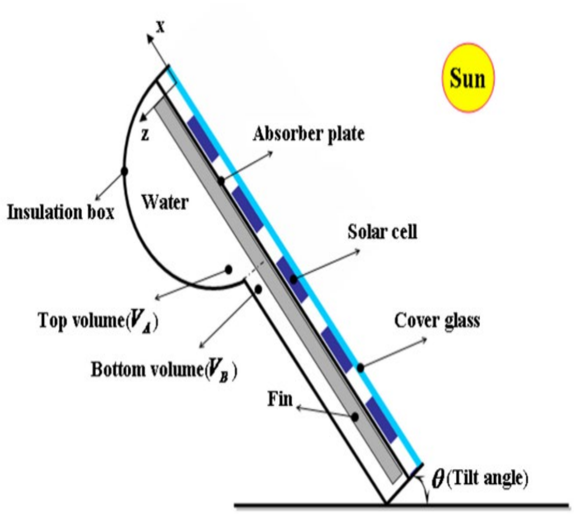


Fig. 17 Proposed design of PV/storage solar collector studied by.(Ziapour, Palideh and Baygan, 2014)

An energy analysis of an integrated PV-thermal system was investigated by Radziemska, (2009). The design illustrated in Fig. 18 has been carried out under this section. The results show that the exergetic efficiency is equal to 30.6%, while the electricity efficiency is lower due to the higher temperature of the PV module and is equal to 11.1%. Al-nimr, Al-darawsheh and Al-khalayleh, (2018) presented a new concept of the hybrid storage water collector, as shown in Fig.19. It includes two concentric cylinders, a thermoelectrical generator, two mirrors and a heat exchanger. The basic idea is to use the heat generated by the thermal generator to heat the water from the collector. Abdullah et al (2019) and Abdullah and Ahmed, (2019) proposed a new PV storage collector design. A solar cell was connected to a tilted metallic surface of a rectangular storage collector in this article. To assess the efficacy of the new design, two realistic models were developed. A photovoltaic (PV)/solar storage collector was the first concept. The second model was called a rectangular storage collector, and it shared many of the same characteristics as the first model, as seen in Fig.20. According to the findings, the PV/storage collector's overall efficiency is higher than that of the second model. Table 2 shows the summary of the results of studies related to the voltaic storage solar collector

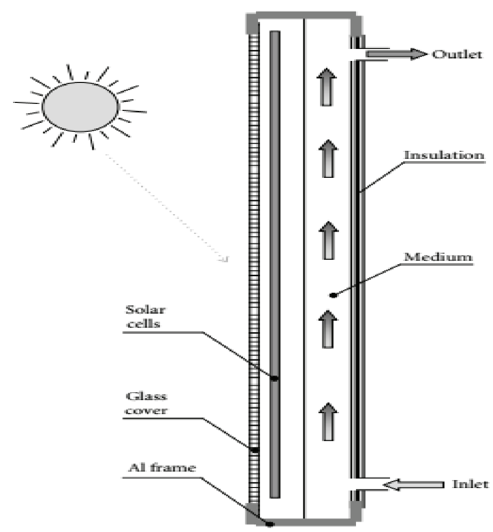


Fig. 18 Integrated PV/T collector was suggested by (Radziemska, 2009)

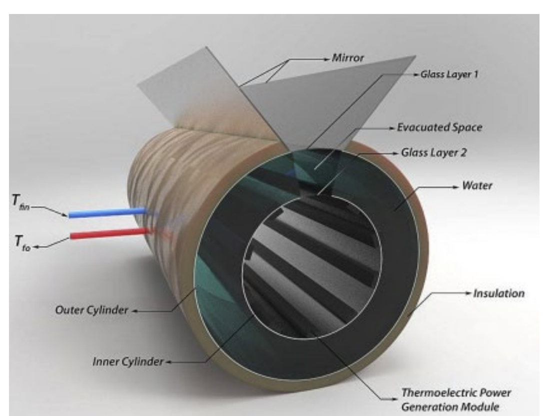


Fig. 19 A novel solar thermal collector design by (Al-nimr, Al-darawsheh and Al-khalayleh, 2018).

Table 1
Summary of the study suggested for the non-concentrating storage solar collectors (NCSSC)

Author of the Article	Location	Parameter	Type of study	Major findings
(Chinnappa and Gnanalingam, 1973)	Sri Lanka	Thermal efficiency	Experimental studies	The total energy collection for the year was about 1250 kWh. The efficiency of the collector was 46%.
(Garg, 1975)	India	Thermal performance	Experimental and mathematical study	The efficiency of the system was 70%.
(Chauhan and Kadambi, 1976)	USA	Performance of the model under four different modes of operation.	Experimental study and mathematical model	The system had a heat efficiency of 71.8% was attained at the mass flow rate of 75.9 kg/hr.
(Sodha *et al.*, 1979)	India	Effect of insulation during the night	Mathematical model	The thermal efficiency was 37% for summer season and 27% for winter season.
(Nahar and Malhorta, 1982)	India	Using PVC film instead of the glass cover.	An experimental study	The cost of a solar water heater was reduce by 18%.
(Garg and Rani, 1982)	India	Effect of insulated baffle and insulation cover	Numerical and experimental investigation	Using the insulation cover improved the collector efficiency by 70 %. Using the baffle plate improves the collector efficiency.
(Goetzberger and Rommel, 1987)	Germany	Performance of the under the European conditions	numerical studies	Thermal efficiency ranging from 36-45% .
(Kaushik, Kumar and Garg, 1995)	India	Effect of baffle plate on the performance of the collector.	Numerical study	The presence of the baffle plate improved the performance of the collector.
(Kaushik *et al.*, 1994)	India	Effect of the tilt angle, night insulation, flow pattern on the performance	Numerical study	The efficiency of the water with night insulation is 17% higher than that without night insulation.
(Kumar and Rosen, 2010)	Canada	Effect of corrugated absorber surface on the performance	Mathematical model	The corrugated surface improves the performance, and the efficiency reaches 48%.
(Ahmed, Ahmed and Ali, 2014)	Iraq	Three types of the absorbed plate (zigzag, wavy, and flat) shapes were selected and their effect on the performance.	Experimental study	The zigzag absorber plate was the best storage collector was the best. the water temperature difference between the outlet and inlet temperature is 14 °C at noon.

Table 1 ..(continued)
Summary of the study suggested for the non-concentrating storage solar collectors (NCSSC)

Author of the Article	Location	Parameter	Type of study	Major findings
(NAHAR, 1983)	India	Yearly performance of the storage solar collector.	Experimental and economic analysis	The efficiency of the system was 70%.
(Sokolov and Vaxman, 1983)(Vaxman and Sokolov, 1985)	Israel	Yearly performance	Experimental study	The maximum bulk efficiency was 53%.
(Garg, Bandyopadhyay and Sharma, 1981)	India	Effect of rock bed on the performance.	Experimental investigation	Thermal efficiencies of the system integrated with the rock bed ranged between (39.34-63.91)%.
(Garg, Avanti and Datta, 1998)	India	Year-round performance analysis	Mathematical model	Developed a non-dimensional method to predict the performance of the collector.
(Rehim, 1998)	Egypt	New design of storage solar collector was presented.	Heat retention	In a PV/T method, PCM was seen to be an efficient way of retaining heat for later removal of heat.
(Sopian *et al.*, 2004)	Malaysia	Non-metallic unglazed solar storage collector.	An experimental approach	The total system average efficiency was 45%.
(Kumar and Rosen, 2011b)	Canada	Performance of storage solar collector integrated with the extended storage section.	Mathematical model	There is a 5% efficiency improvement for the new design compared to the traditional design
(Mohamad, 1997)	Turkey	Used the thermal diode to enhance the performance of the solar storage collector.	mathematical model is	The thermal efficiency of the new design, about 50%, is comparable with classical storage solar collectors.
(Mohsen, Al-Ghandoor and Al-Hinti, 2009)	Jordan	Study the optimal depth of the storage tank	An experimental study	The outcomes of the article concluded that the optimum depth of the tank is 10 cm.
(Nieuwoudt and Mathews, 2005)	South Africa	New design of integrated solar water heater.	Experimental study	The water temperature reaches 60 °C in winter and does not fall below 40 °C in the evening.
(Fraisse *et al.*, 2014)	France	Performance of novel type of the storage solar collector	Experimental study	The resulting annual energy performance is promising, with 40% of the solar fraction .
(Garnier, Muneer and Currie, 2018)	United kingdom	A solar storage collector installed on the house's roof	A practical and theoretical study	The laboratory results indicated an increase in the water temperature by 6.3 °C.
(Tarhan, Sari and Yardim, 2006)	Turkey	Using the phase change materials to enhance the performance of the collector.	Experimental study	The use of Phase change materials lowered the values of the peak temperatures by 15% compared to the control heater.

Table 1 ..(continued)
Summary of the study suggested for the non-concentrating storage solar collectors (NCSSC)

Author of the Article	Location	Parameter	Type of study	Major findings
(Taheri, Ziapour and Alimardani, 2013)	Iran	Used a layer of the black-colored sands immersed into the water storage tank	Experimental study	The collector daily efficiencies was higher than 70%.
(Cruz, Hammond and Reis, 2002)	Portugal	A trapezoidal-shaped solar storage collector	Experimental study	Measured energy savings for this design varied from 30 to 70%.
(Hazami *et al.*, 2010)	Tunisia	A solar storage collector based on concrete matrix	Experimental study	Results confirmed that energetic and exergetic efficiencies of system were 32% and 23.5% respectively,
(Ecevit and Apaydn, 1989)	Turkey	Triangular built-in-storage collector	A practical and theoretical study	Efficiency of the system was 0.63 under
(Soponronnarit, Taechapiroj and Tia, 1994)	Thailand	Comparative study of the performance of triangular and rectangular storage collector.	Experimental work	The outcomes of the article showed that the efficiency of triangular and rectangular storage collector were 59% and 63%.
(Gertzos, Caouris and Panidis, 2010)	Greece	Inserted a heat exchanger into the solar storage collector	Numerical solution	Three main parameters, which influence the performance, are studied: The position, length, and diameter of the heat exchanger.
(Hazami *et al.*, 2005).	Tunisia	Using a concrete block containing a heat exchanger	Experimental work	the stored water temperature inside the collector rose to 50°C for the day in December
(Ziapour and Aghamiri, 2014)	Iran	This design's storage tank is divided into two volumes .	Numerical analysis	The efficiency of the collector was 70% at noon.
(Chaurasia and Twidell, 2001)	United Kingdom	Effect of transparent insulation on the performance.	Experimental work	The storage efficiency of the integrated solar collector was 39.8%.
(Dharuman, Arakeri and Srinivasan, 2006)	India	Storage collector for building energy conservation	Experimental study	The overall efficiencies of about 40% was obtained.
(Joudi, Hussein and Farhan, 2004)	Iraq	New design for heating and storage the water	Numerical analysis	The mean tank temperature reached 37 °C in the 1st of January and 46 °C in the 21st of June
(Ahmed, Daoud and Mahmood, 2019)	Iraq	Performance of rectangular storage collector.	Experimental study	Outcomes showed that the outlet water temperature was 28 °C.
(Omer Khalil Ahmed, 2018a)	Iraq	Performance of a triangle solar collector	Experimental investigation	Daily efficiency was found to be 62.2%.
(Khalil Ahmed, 2017)	Iraq	Cylindrical storage collector	Empirical and theoretical study	The average storage temperature was 25 °C.
(Omer Khalil Ahmed, 2018b)	Iraq	Wedge storage collector	Empirical and theoretical study	used as a reservoir for storing water instead of the standard cubic or cylindrical container.

Table 2
A summary of the results of studies related to the PV/ Storage solar collector

Author of the Article	Location	Parameter	Type of study	Major findings
(Ziapour, Palideh and Mohammadnia, 2014) (Ziapour, Palideh and Baygan, 2014)	Iran	Storage collector integrated with PV panel	Simulation model	The efficiency of the system depended on the solar panel filler factor, collector water volume, and collector area.
(Radziemska, 2009)	Poland	Performance of the PV/storage collector	Experimental work	The results show that the exergetic efficiency is equal to 30.6%, while the electricity efficiency was equal to 11.1%.
(Al-nimr, Al-darawsheh and Al-khalayleh, 2018)	Jordan	New concept of PV/storage collector.	Mathematical model	The efficiency of the system was 86%
(Abdullah, Ahmed and Ali, 2019)(Abdullah and Ahmed, 2019)	Iraq	New design of PV/solar collector	Experimental study	the overall efficiency was 63.02% under load condition, whereas it was 40.88% without load condition.

3.3. *Cylindrical vessels solar storage collector*

The solar collector and the collector tank are combined into one part to reduce the cost and since the outer surface of the collector must receive radiation, it cannot be thermally insulated. Hence, heat loss in the surroundings during the night is high. Consequently, engineers began to search for alternative ways to reduce heat losses, the most important of these methods being concentrators. The main goal of using concentrates in storage solar collectors. Enhance the performance of the collectors is being by reducing heat loss. However, the use of selective coating and vacuum absorbers reduced a significant amount of heat loss. The cylindrical storage solar collector which is called sometimes (Compound parabolic concentrating storage solar collector (CPCSSC) has been more beneficial for solar thermal applications requiring fluid temperatures over 60 °C. Previously published studies on this type of complex were reviewed in detail and explained the operational and design variables wonderfully by Devanarayanan and Kalidasa Murugavel, (2014). Kalogirou, (1997) introduced an integrated collector storage parabolic composite concentrator (CPC) and proved that the initial cost of the system presented here is 13% cheaper than the corresponding flat plate collector for the same slot space and storage size.

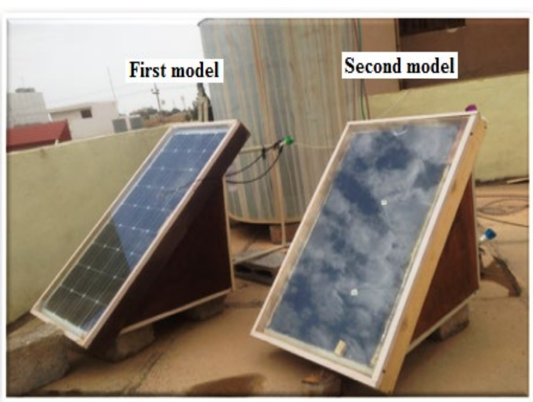


Fig. 20 A photographic view of the practical models (Abdullah, Ahmed and Ali, 2019; Abdullah and Ahmed, 2019)

Souliotis and Tripanagnostopoulos, (2004) presented a comparative study of built-in solar systems like CPC. The practical results showed that the efficiency of the system, which includes selective absorption surfaces, high transmittance of the glass cover and high reflectivity of its reflective surface, works with sufficient efficiency, and is similar to the thermal performance of conventional solar systems that include selective surfaces. (Schmidt and Goetzberger, 1990) used an involute reflector to increase the solar radiation incidence on a cylinder dyed black. Efficiency during the year was 32% with the ability to process the fluid at a temperature of 45 °C. Saroja and Nithiarasu and Seetharamu, (1997) presented a mathematical model to predict the performance of the cylindrical storage solar collector. Two configurations of the solar storage collector were presented by Tripanagnostopoulos and Yianoulis, (1992). The purpose of these two designs is to reduce heat losses, especially at night. The lowest value for the thermal loss coefficient was (2.75 W/m.K) compared to the coefficient of thermal losses for the other designs, and the highest value for the thermal efficiency was 70%. Tripanagnostopoulos *et al.*, (2000) presented a novel design to enhance the performance CPC solar collectors using flat bifacial absorbers. The practical outcomes confirmed that the maximum efficiency of the proposed CPC collector was 71% and a water temperature of about 180 °C. The thermal efficiency of an ICS solar water heater has been designed and engineered by Helal, Chaouachi and Gabsi, (2011). As shown in Fig. 21, this configuration consisted of a single horizontal cylinder mounted in a reflector made up of three parabolic branches. In addition, the geometrical dimensions are examined. When the ratio ((Tm-Ta)/ It.=0.064) is the highest, the system's thermal efficiency remains the highest. The results of the article also showed that the coefficient of thermal losses for the proposed design ranged between (3.7-3.9 W/m^2.K). Also, Helal *et al.*, (2010) presented an assessment of the storage solar collector's thermal performance and compared it with other types of solar heaters. Souliotis *et al.*, (2013) developed and constructed a three-cell solar collector. As can be seen in the figure, the analysis included three models of solar vessel collectors of different dimensions compared to a flat plate thermo-symphonic unit (FPTU).

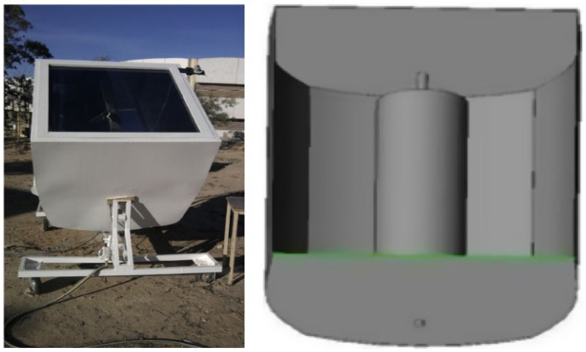


Fig. 21 Experimental side of (Helal, Chaouachi and Gabsi, 2011).

These solar collectors are more efficient than adequate during the year, according to the findings. ICS could be considered the most promising model in terms of heat efficiency. The thermal efficiency of the three designs was more than 60% for different operating conditions.

Borello *et al.*, (2012) have come up with a new concept of solar storage collectors. This design includes four symmetrical tubes with a diameter of 12 cm and a capacity of 90 liters. The results concluded that the method of water withdrawal greatly affects the thermal performance of the system. Smyth, Eames and Norton, (2004) presented a techno-economic assessment of solar storage collectors. The article contained a distinguished evaluation of solar collectors in Irish weather conditions. Also, Smyth, Eames and Norton, (2001) used the inner sleeve to increase heat transfer inside the cylindrical solar storage collector. The solar storage collector includes a vessel consisting of an outer absorbing section and an internal perforated inner sleeve manufactured from a material with low thermal conductivity. Four different configurations were presented. These designs reduced the heat transfer by about 20%. Muhumuza *et al.*, (2019) improve the heat retention of a standard thermal diode for solar storage collectors. In comparison, an ICSSWH base thermal diode has a heat retention yield of 20% and a heat loss coefficient of 2.25 W/K, respectively. (Khalifa and Abdul Jabbar, 2010) presented a study to compare the performance between a solar heating collector and a conventional one under Iraqi conditions.

In this study, six cylinders were connected in succession; each cylinder had a diameter of about 80 mm, dyed black instead of the absorbent plate and tank in the traditional collectors. The results showed that the instantaneous collector efficiency ranged between 0.4-0.78, while the conventional efficiency of the conventional collector under the same conditions ranged between 0.21 - 0.35. Kalogirou, (1999) enhanced the performance of the compound parabolic collectors (CPC) storage collector by adding a small cylinder in front of the large cylinder placed in the center of the parabola. The presented design can save about 12 liters of hot water with a cost increase of about 8%. The built-in cylindrical solar collector was analyzed using TRNSYS and artificial neural networks Souliotis, Kalogirou and Tripanagnostopoulos, (2009). The findings of this study show that the results of this advanced method can be used to predict the efficiency of an integrated solar collector with great accuracy. Kaneesamkandi, (2014) suggested a new method to reduce the cost of an integrated solar collector using a flat reflector, as shown in Figure 22. The thermal efficiency of this device was 10% to 15% lower than that of the other integrated storage collector. In Iranian weather conditions. Panahi *et al.*, (2019) analyzed the output of the integrated parabolic collector in combination with a parabolic concentrate (CPC). Mirrors, steel plates, and aluminum foil were used as reflection surfaces.

Kessentini and Bouden, (2013) displayed cylindrical storage with a parabolic composite concentrator (CPC). The presence of the parabolic composite concentrator increases the temperature of the storage water and increases the efficiency of the design. Kaptan and Kilic, (1996) presented a built-in solar heater manufactured from five tubes. Each tube is 1.8 meters long. The tube diameter is 12 cm, with a total capacity of about 87 liters. A buffer plate is placed inside each tube. (Smyth *et al.*, 2005) proposed a new solar water heater concept, as shown in fig (23). To boost the efficiency of the solar water heater, a parabolic concentrator made up of a secondary cylindrical reflector is used in this paper. The new design's glass baffles minimize convective heat loss and improve the design's thermal efficiency. Smyth et al, (2003) and Smyth et al (2001) presented a new method to reduce the heat losses from the solar storage collector. A new idea was presented in this article, as shown in Fig. 24. Design A utilized a 1.0-m-long cylinder, which was enclosed fully within a reflector. Design B utilized a 1.5-m-long cylinder, which was enclosed partially within the reflector.

Fig. 22 A integrated storage collector along with the reflecting mirrors(Kaneesamkandi, 2014)

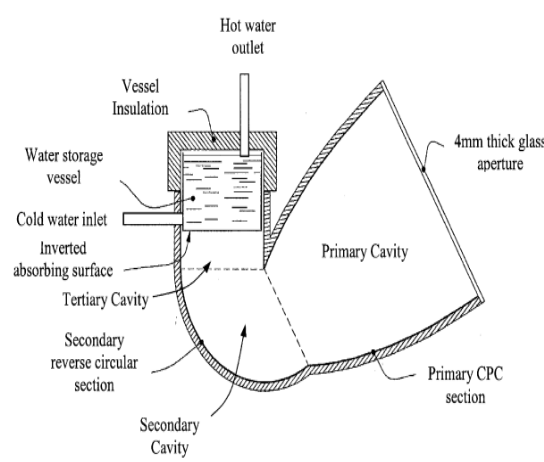


Fig. 23 The solar water heater manufactured by (Smyth *et al.*, 2005)

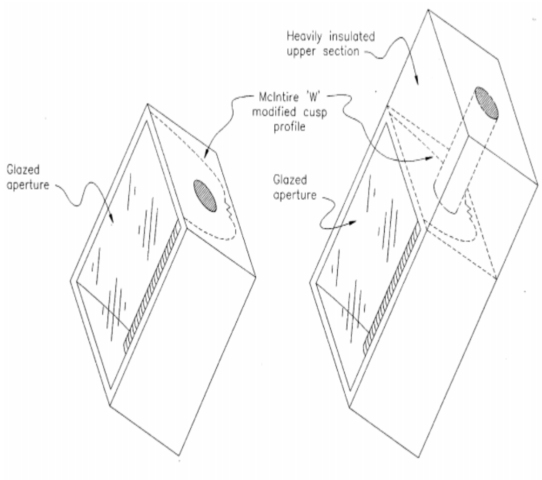


Fig. 24 A new idea of solar storage collector was presented by (Smyth, Eames and Norton, 2003)

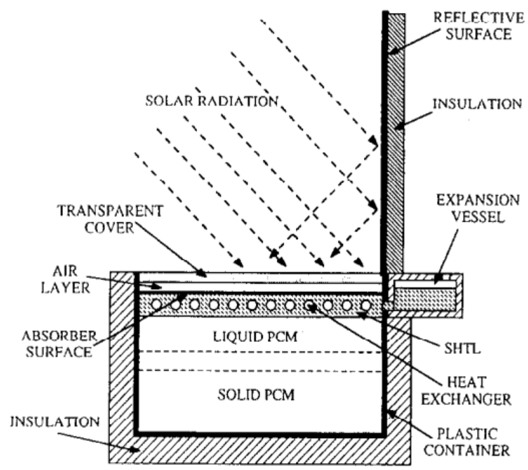


Fig. 25 Detailed outline of the integrated solar collector was proposed by Rabin et al.(Rabin *et al.*, 1995)

4. Improving the Performance of Storage Solar Collectors

One of the most critical issues with solar energy is the need for an energy storage method that provides night or cloudy energy(Pugsley *et al.*, 2020). Several methods were used to store solar energy, and the use of variable phase materials was an essential means in this regard (Abbas, Ahmed and Abdulkareem, 2021; Mettawee Eman-bellah Sayed and Assassa, 2006; Zayed *et al.*, 2019). Rabin *et al.*, (1995) used a Salt Hydrate Phase Change (GMP) material to improve the efficiency of the solar storage collector, as shown in fig.(25). The proposed design includes a heat exchanger in an area containing phase change material. Heat is transferred from the heat exchanger to be stored in the changeable phase material and used when needed. The study results showed that the thermal performance of the solar collector is primarily dependent on the thickness of the phase shift material. As shown in Fig. 26, Eames and Griffiths, (2006) used a transient finite volume order to estimate the energy density and heat retention for a rectangular cross-section storage solar collector with water and various concentrations of phase change material (PCM). Using erythritol as a phase change material, Li, Zhai and Cheng, (2018) enhanced a solar storage sensor (PCM). As Figure 27 shows an experimental and numerical study was done to study the system's performance during the loading process. According to the results, the integrated solar system with composite PCM has good thermal properties, with a daily thermal performance of 39.98 percent.

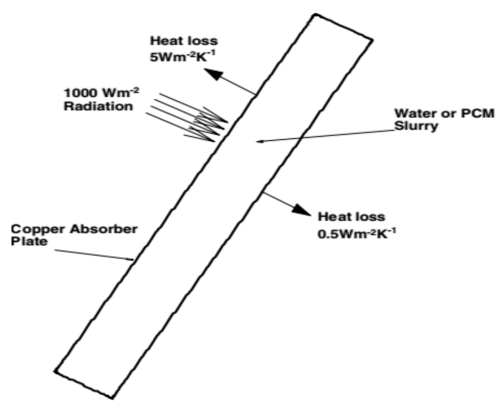


Fig. 26 Scheme of the model studied by (Eames and Griffiths, 2006)

(a) storage solar collector (b) nano materials

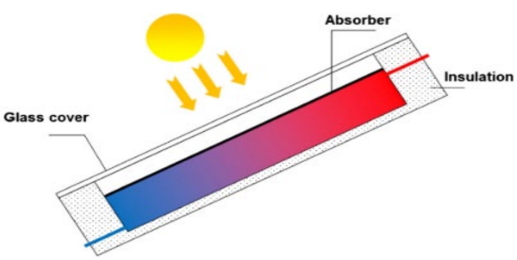
Fig. 27 Photograph of the experimental set-up(Li, Zhai and Cheng, 201

Table 3
Summary of the study suggested for the cylindrical vessels solar storage collector

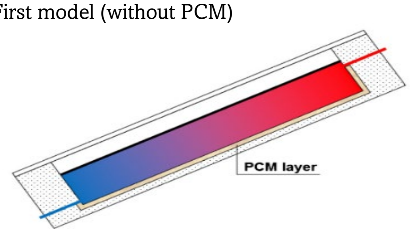
Author of the Article	Location	Parameter	Type of study	Major findings
(Kalogirou, 1997)	Cyprus	performance and economic assessment.	Technical note	The initial cost of this system was 13% cheaper than the classical collector.
(Souliotis and Tripanagnostopoulos, 2004)	Greece	Number of glass covers and type of selective surface	Experimental investigation	The daily efficiency rate was 70% depending on the type of absorbent surface and the number of glass covers.
(Schmidt and Goetzberger, 1990)	Germany	Used an involute reflector	Experimental work	Efficiency during the year was 32% with the ability to process the fluid at a temperature of 45 °C.
(Saroja and P. NITHIARASU and Seetharamu, 1997)	Malaysia	Effect of the design parameters	Mathematical model	The wall and the fluid temperature decrease with the increase in the value of Pr number.
(Tripanagnostopoulos and Yianoulis, 1992)	Greece	Effect of design parameters	Experimental work	The lowest value for the thermal loss coefficient was (2.75 W/m.K), and the highest value for the thermal efficiency was 70%.
(Tripanagnostopoulos *et al.*, 2000)	Greece	Three design of CPC collector.	Experimental investigation.	The maximum efficiency was 71% and a water temperature was 180 °C.
(Helal, Chaouachi and Gabsi, 2011)	Tunisia	A single horizontal cylinder mounted in a reflector made of three parabolic branches	Experimental & mathematical assessment	When the ratio ((Tm-Ta)/ It.=0.064) is the highest, the system's thermal efficiency remains the highest.
(Souliotis *et al.*, 2013)	Greece and Spain	Effect of concentration ration	Experimental study	The thermal efficiency of the three designs was more than 60% for different conditions.
(Borello *et al.*, 2012)	Italy	Effect of the draw-off process	Experimental work	The method of water withdrawal greatly affects the thermal performance of the system
(Smyth, Eames and Norton, 2004)	UK	Techno-economic assessment	Experimental work	The efficiency of the collector was 43.6%.
(Smyth, Eames and Norton, 2001)	UK	Used the inner sleeve to increase heat transfer.	Experimental work.	These designs reduced the heat transfer by about 20%.
(Muhumuza *et al.*, 2019)	UK	Using a thermal diode	Experimental study	The new system improves heat retention efficiency at least 35% and reduces the heat loss coefficient to 1.46 W/K.
(Khalifa and Abdul Jabbar, 2010)	Iraq	the comparative study between the storage and the conventional systems	Practical investigation	The instantaneous collector efficiency ranged between (0.4 - 0.78).
(Kalogirou, 1999)	Cyprus	Adding a small cylinder in front of the cylinder	Experimental assessment	Improve the storage water temperature about 6%
(Kaneesamkandi, 2014)	Saudi Arabia	Using a reflecting mirrors	Experimental study	The thermal efficiency of this device was 10% to 15% lower than that of the other collector.
(Panahi *et al.*, 2019)	Iran & UK	Three type of reflector	Experimental study	The results confirmed that mirror has the mean daily efficiency was (66.7%), followed by steel sheet (47.6%) and aluminum foil (43.7%).
(Kessentini and Bouden, 2013)	Tunisia	Using a CPC reflector	Numerical & practical study.	Reduces the total heat losses of the system by 47% and increases its daily efficiency from 18% to 25%.
(Kaptan and Kilic, 1996)	Turkey	A baffle plate is placed inside each pipe.	Theoretical and experimental study	The mean thermal efficiencies were ranging between (50-55)%.
(Smyth *et al.*, 2005)	UK and Ireland	A new design were proposed.	Experimental study	The thermal efficiency for proposed design were ranged between (48.1-59.3)%.
(Smyth, Eames and Norton, 2003)	UK and Ireland	A new idea to reduce the heat losses.	Experimental work	The thermal efficiency of the system was 57.5%

El Qarnia, (2009) used three types of phase change materials (Stearic acid, Paraffin wax and n-octadecane) to enhance the performance of the integrated solar collector. Theoretical analysis was presented in the article. The outcomes also confirmed that Stearic acid offers an acceptable option for use in the integrated solar collector. Allouhi *et al.*, (2018) used a layer of nanomaterial in its lower part. To improve the efficiency of the solar storage collector. Three different models have been described in this article, as shown in Fig. 28. This study demonstrated that the system's best performance was a mass flow rate of 0.0015 kg/s with an MCP thickness of 0.01 m.

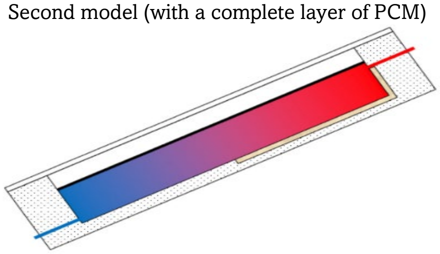
Motte *et al.*, (2019) submitted a numerical study to improve a highly integrated solar collector with a phase change material (PCM). The article was intended to reduce thermal losses during the night with a high volumetric PCM thermal density. The thermal analysis of the system integrated with PCM was presented. In addition, Sun and Wang, (2016) have introduced a new integrated passive solar collector storage wall design using phase change materials. The use of phase change materials saves energy and improves comfort conditions within the test room. Chaabane, Mhiri and Bournot, (2014) digitally researched the solar storage water heater (ICSSWH) using a phase change material (PCM). Two models were presented; the first model contains sensitive thermal materials (water), while the other models contain phase change material. This PCM cylinder contains two types of dephasing materials (myristic acid and graphite RT42) and three rays (0.2 m, 0.25 m, and 0.3 m).



a) First model (without PCM)

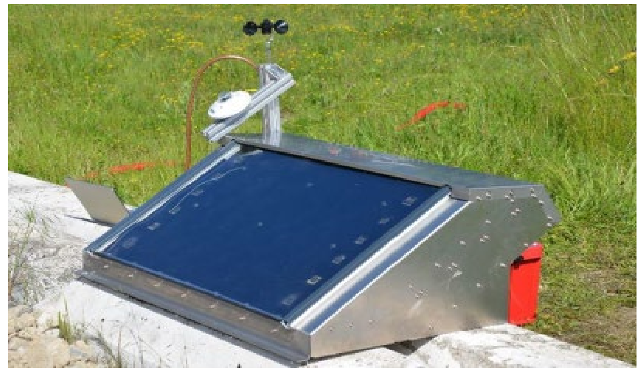


b) Second model (with a complete layer of PCM)

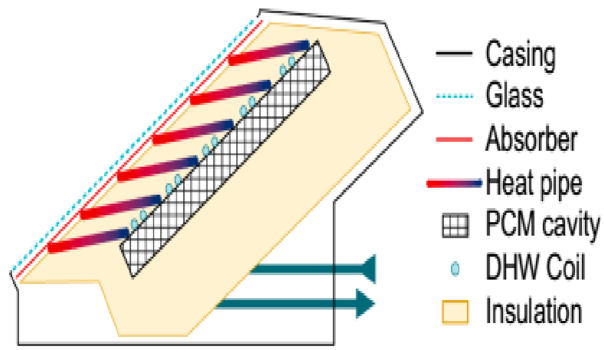


c) Third model (with half layer of PCM)

Fig. 28 Different models of Integrated solar collector(Allouhi *et al.*, 2018)



a) Experimental setup



b) Scheme of the model

Fig. 29 Storage solar collector was studied by (Bilardo *et al.*, 2019)

Simulation results indicate that when myristic acid is used as a PCM, the phase change material unit is more efficient than the other model. Also, Chaabane, Mhiri and Bournot, (2013) used radial fins of rectangular profile to increase the efficiency of storage solar collector. A fluent program was used in this study. Bilardo *et al.*, (2019) modelled and analyzed the efficiency of a new solar storage collector using a phase change material, as shown in Figure 29. The mathematical analysis was performed using an electrical analogue schematic in an Engineering Equation Solver (EES) environment. The calculated values allowed an overall energy evaluation and comparison with similar systems to identify the advantages and disadvantages of this modern technology.

A practical assessment of the thermal performance of the integrated heat pipe evacuated tube solar collector system using phase change material (Chopra *et al.*, 2020). Two models of the exhaust pipe collector were presented in this paper. There was no phase change in the exhaust tubes of the first model. In the second model, the vacuum tube collector was incorporated with phase change material (SA-67), as shown in the Fig. 30. The results indicate that the daily effectiveness of the integrated system with phase change materials was 37.56%, 35.31%, 36.69%, 32.34% and 32.73% above that of the vacuum pipe collector without phase change material for water flows of 8, 12, 16, 20 and 24 L/Hour respectively. Souliotis *et al.*, (2017) used a thermal diode device to improve the performance of the built-in solar collector. The experimental set-up contained a horizontal cylinder with an asymmetric reflector trough (CPC), as shown in Fig. 31.

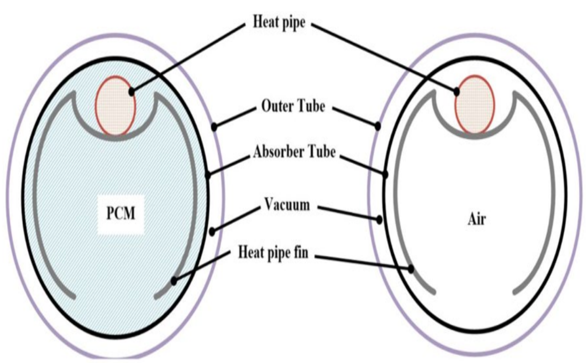


Fig. 30 Cross-section of an evacuated tube (a) with PCM (b) without PCM (Chopra *et al*., 2020).

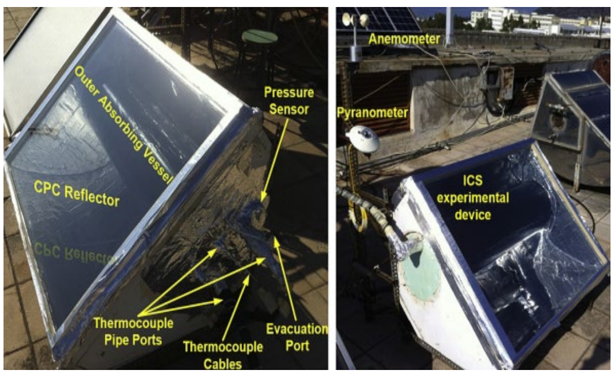


Fig. 31 The improved water storage collector was invented by (Souliotis *et al*., 2017)

The storage space includes two concentric cylinders: the external absorbent cylinder and the internal storage cylinder. The space between the rings of the concentric cylinder is partially deflated and contains a small amount of water in the form of phase change material (MCP). The results indicate that steam pressure plays an essential role in the performance of the improved storage collector.

5. Discussions

The researchers' primary objective is to reach an economical and suitable solar water heater system for household needs. The various designs were reviewed and presented in the previous paragraphs, especially in Tables 1, 2, and 3. Modern trends in the design of the storage solar collector aim to reduce heat loss and increase the amount of solar energy absorbed during the day in order to provide homes with hot water on the next day or cloudy days to be competitive with traditional solar water heating systems. The cumulated solar thermal capacity in operation at the end of 2020 was 501 GWth corresponding to 715 million square meters of collector area(Weiss and Spörk-Dür, 2021). China is currently leading in the number of solar heaters that have been installed in the world because of the low cost of installing solar heaters in China in comparison with other countries of the world as shown in Fig. 32(Islam, Sumathy and Ullah, 2013).

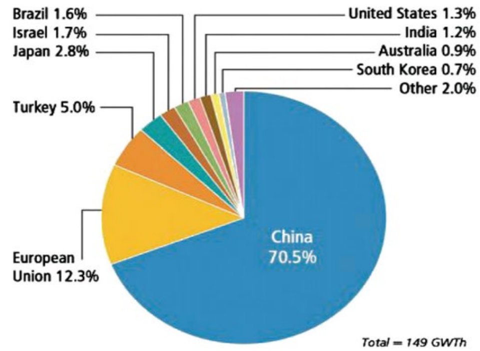


Fig. 32 Global solar heater(Islam, Sumathy and Ullah, 2013)

In terms of the environmental impact, the use of solar heaters is the least polluting compared to solar cells because the raw materials do not contain any environmental pollutants and the simplicity of the manufacturing process, and the absence of any chemical processes.

The researchers confirmed that area density is an important factor to enhance the performance of the storage solar collector. Where the area density means the ratio of the sunlit area to the storage volume. Therefore, in order to enhance the design, it's necessary to increase the ratio of the front area to the volume (area density). and this ratio must be more than 12 for domestic uses. Also, the researchers confirmed that covering the sunlit area of the system with insulation during nighttime improves the performance of the storage solar collector (Abdullah, Atallah and Ahmed, 2022). It is also possible to improve the thermal performance of storage solar collector systems by improving thermal insulation. These systems suffer from increased thermal losses from the front face of the system during the night, and the impact of this problem can be reduced by covering the front face with a thermal insulator (Chaurasia and Twidell, 2001).

6. Conclusions

A solar storage collector, integrating the storage tank and collected in a unit, is an attractive alternative to the conventional solar water heating system. This paper examines the different models for solar storage collectors. Furthermore, this review revealed that the design variables and design form have a significant impact on the efficiency and performance of the solar heating system. Climatic and operating factors have a significant impact on the efficiency of a solar water heater. In addition, scientists and researchers have used nanotechnology, solar cells and mirrors to enhance the performance of various stored solar collectors.

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