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Impact of Design Parameters in Thermal Solar Water Storage Tank Systems: (A Review)

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Abstract

This work provides a historical overview of water storage tanks used for solar energy collection, with a focus on the impact of different geometric configurations on thermal performance and energy storage efficiency. The designs of cylindrical, spherical, rectangular and triangular tanks were reviewed to analyse their effects on thermal gradients, heat retention and energy storage capacity. Within the scope of nominal processes, the study primarily aimed to identify the factors influencing the choice of tank shape in terms of size, capacity and aspect ratio. Another key objective was to assess what enhances heat storage in the tank to improve thermal efficiency. Comparing cylindrical shapes to other shapes, such as spherical, rectangular, and triangular , it offered the optimal performance with the needed requirements for the objects that have a smaller surface area-to-capacity ratio in addition to the lower heat loss. Furthermore,when the tilt angle with horizontal axes of the storage tank was at 0°, the tanks' ratio reduction had remarkable impact on thermal stratification . The results might provide valuable information for the thermal storage system'sdesign in solar water heating for improving thermal efficiency. This work provides the basis for research exploiting high-temperature solar energy storage technologies and their applications in building sustainable energy systems.

Keywords: *thermal stratification ,solar thermal system;; water tank; geometric design; n; insulation cover.*

1. Introduction

With increasing demands for sustainable energy resources and the rapid development of novel solar thermal technologies. ,these resources and technologies have been used widly in building and industrial heating application of the on roof integrated solar collector water storage systems. For example, the fluid circulation for linking all devices is reduced since collectors and storage tanks form a proper single component [1]. Comparing with traditional designs, it has been Recognized many pros of the integral systems, such as a space saving and better general feasibility. To illustrate, System performance depends on a number of parameters as the geometry of the combined storage tank is one of them. As a matter of fact,the tank geometry is a main factor to achieve the maximum thermal performance which influences ultimately on the thermal stratification,the heat retention time (usability) and the overall energy gain. To maximize the potential of the incoming solar energy,the thermal stratification should be well achieved in order to keep the hot water at the top of the tank and cold make-up water is delivered at the bottom, [2]. Whilst previous studies have explored various aspects of solar thermal systems, such as material properties, insulation techniques and fluid dynamics, the influence of tank geometry on thermal performance has not been comprehensively addressed.

The present work aims to highlight the influence of tank geometry on energy storage, water depth and overall thermal efficiency within an integrated solar collector water storage tank (ISCWST) device. By reviewing studies that combine computational fluid dynamics (CFD) simulations with experimental analyses, the thermal performance of cylindrical, spherical, rectangular and triangular-shaped tanks is examined. Key parameters such as temperature distribution, heat loss rates and overall energy storage efficiency under typical operating conditions provide valuable insights for optimising solar storage systems. One of the main challenges to maintaining thermal stratification is the load profile of the system and the nature of water withdrawal—whether continuous or intermittent. Additionally, the temperature of incoming freshwater, which is beyond control, notably influences system thermal performance during the charging heat (daytime heating). Notably, thermal stratification tends to be enhanced during the day when solar energy is available, whilst after sunset, the tank gradually begins to lose a portion of its stored heat. The findings of this study aim to support broader adoption of solar water heating systems by promoting cost-effective and efficient solutions accessible to a larger segment of households. Furthermore, the study offers guidance on optimal task design to maximise the use of solar radiation as a renewable energy source. Additionally, the study outlines a systematic design approach for thermal water storage tanks in solar systems, intended to benefit future generations of solar energy technologies.

2. Solar Collector Water Storage Tank History

The concept of using solar energy for water heating dates back to ancient civilisations. The Greeks and Romans employed solar architecture techniques to warm their homes and public baths, establishing the foundational principles of solar water heating [3]. The modern era of solar water heating began in the late 19th and early 20th centuries. In 1891, Clarence Kemp of Baltimore patented the first commercial solar water heater, known as the 'Climax' solar water heater. As described by Belessiotis and Papanicolaou [4], this device featured a black-painted tank exposed to sunlight to heat water, making a considerable advancement in the practical use of solar energy.

Advertisement for the Climax solar water heater, 1892. The price of this, Kemp's smallest unit, had just dropped from $25 to $15.

Fig. 1. First commercial solar water heater [4]

Kemp's invention sparked widespread interest and laid the groundwork for highly advanced solar thermal systems. Kemp also patented the first commercial solar water heater enclosed in a wooden box, as shown in Figure 1, effectively creating what is currently known as the first 'batch water heater'. During the 1920s and 1930s, solar water heaters gained popularity in the United States, particularly in sunny states such as Florida and California [5]. These early systems typically featured a black-painted metal tank mounted on rooftops, which absorbed solar radiation and transferred the heat to the water inside. However, the rise of cheap fossil fuels and the growing convenience of electric and gas water heaters led to a remarkable decline in the use of solar water heaters by the mid-20th century.

The energy crisis of the 1970s reignited global interest in renewable energy sources, including solar thermal systems. This period also marked considerable improvements in solar collector technology, particularly the development of flat-plate and evacuated tube collectors [6]. Known for their 'improved efficiency' in capturing solar energy, these collectors notably enhanced overall system performance when paired with well-insulated storage tanks.

In the decades following the 1980s, research and development in solar thermal technologies, particularly low-temperature systems, provide notable contributions to sustainable solutions for hot water production and space heating. These advancements led to the creation of specially engineered systems designed for greater efficiency and practicality. Over time, researchers developed automatic solar collectors integrated with water storage tanks to enhance the performance of solar water heating systems. These integrated devices combine necessary functions for thermal energy collection and storage into a single, compact unit. Mirunalini et al. [7] developed a simple and low-cost integrated system that minimises heat losses from a newly designed cylindrical tank, coupled with an improved matching collector.. Recently, new technologies, such as advanced surface coatings, high-quality insulation, and improved tank designs, have made these systems more reliable and productive. More than 600 projects worldwide have utilized domestic, commercial and industrial scale tank systems with i solar collectors integration. These systems play a crucial role in supporting the global transition from fossil fuels to alternative, renewable energy sources. As technology continues to evolve, ongoing research focused on performance improvements and cost reductions will help ensure that solar thermal systems remain a key contributor to global energy sustainability [8].

3. Solar Water Heating (SWH) System Main Components

The primary applications of solar water heating (SWH) include domestic water heating (which is the focus of this research), swimming pool heating and various high-temperature applications. A typically solar water heating system comprises solar collectors, a storage tank, heat transfer fluid, a backup water heater, pipelines, controls and valves. The storage tank is equipped with pressure relief valves to ensure safety, and the system allows for the isolation of solar collectors when necessary. Additionally, air vents are installed at the highest points in the piping to release trapped air and maintain system efficiency.

3.1. SWH Collectors

These devices capture and concentrate solar energy within tubes that contain a circulating heat transfer fluid. Solar water heater collectors are mainly divided into the following categories tailored for the described key applications: glazed flat-plate collectors, unglazed flat-plate collectors, evacuated tube collectors, parabolic trough collectors, integrated collector storage systems and thermosiphon systems, as shown in Figure 2 (a, b, c, d, e, f).

3.2. Heat Transfer Fluid

The heat transfer fluid used in solar water heating systems can be either potable water in direct systems or an antifreeze solution in indirect systems. Antifreeze is crucial in areas with freezing temperatures; otherwise, the system must be shut down and drained during winter to prevent damage. Consequently, indirect systems are commonly used in such climates. Antifreeze formulations typically include either propylene glycol or ethylene glycol, which is hazardous. The US Food and Drug Administration has classified propylene glycol as ‘generally recognised as safe’ for use in food-related applications. Consequently, a mixture of propylene glycol and water is the primary anti-freeze solution used in solar hot water systems.

3.3. Water Storage Tank

The storage tank holds water heated by the solar collectors. In some systems, the collectors may also be integrated with tanks that activate heat exchangers and (or) provide supplementary water heating functionality. The required tank size is determined by the volume and duration of hot water demand, as well as the system’s capacity for hot water production. A dedicated solar water tank typically offers better performance compared to a traditional water heater. In systems that use a single tank, a split configuration is recommended to optimise thermal performance and reduce necessary heat loss to the solar array. Section 4 discusses various tank shapes in detail.

3.4. Connected Pipes

The water or antifreeze solution circulates through pipelines connecting the solar collectors, tank(s) and end users. Copper piping is typically used between the collectors and the storage tank due to its durability and heat resistance. In contrast, PVC or cross-linked polyethylene is commonly used for piping between the storage tank, auxiliary water heater (if present) and the end users.

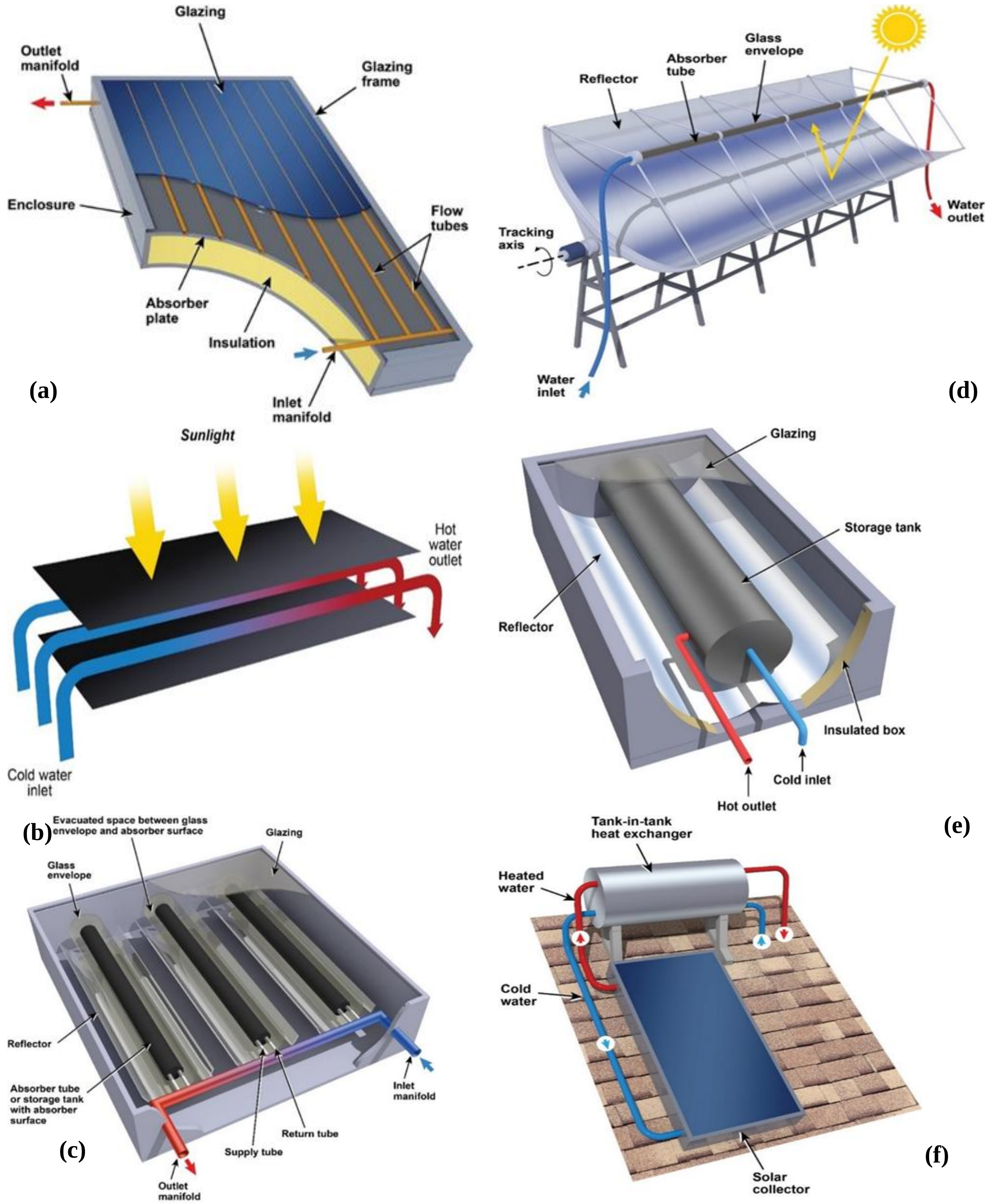

Fig. 2. Solar water heater, a) Flat-plate, glazed solar hot water collector, b) Flat-plate, unglazed solar hot water collector, c) Evacuated tube collector, d) Parabolic trough collector, e) Integral collector/storage system, f) Thermosiphon system [9]

3.5. Control System

Automatic or manual valves are used to activate, deactivate or divert the flow within solar water heating systems. Additionally, a safety pressure release valve is included to prevent overpressure conditions.

4. Shape of the Solar Water Storage Tank

The shape of the water tank plays a crucial role in determining the thermal efficiency and energy storage capacity of an integrated solar energy system. Key characteristics, such as the temperature distribution within heat-producing layers and the surface area exposed to solar radiation, are heavily influenced by the tank's geometry and overall engineering design, both of which notably affect system performance. This section explores the effect of various tank shapes on thermal behaviour, beginning with cylindrical and spherical configurations and concluding with triangular and rectangular tank designs.

4.1. Cylindrical Tanks

Structurally, one of the most common shapes in solar water heating systems is the cylinder tank, valued for its high structural efficiency and ease of manufacturing. Arslan and Igci [10] developed a performance modelling for vertical cylindrical tanks equipped with a mantle heat exchanger, evaluating their thermal performance during discharging and consumption modes. Aiming to improve thermal stratification and optimise performance parameters, a three-dimensional transient CFD simulation was employed to analyse the flow and thermal fields within the mantle solar storage tanks. The study found that high fluid temperatures flowing through the mantle heat exchanger notably improved thermal stratification within the tank.

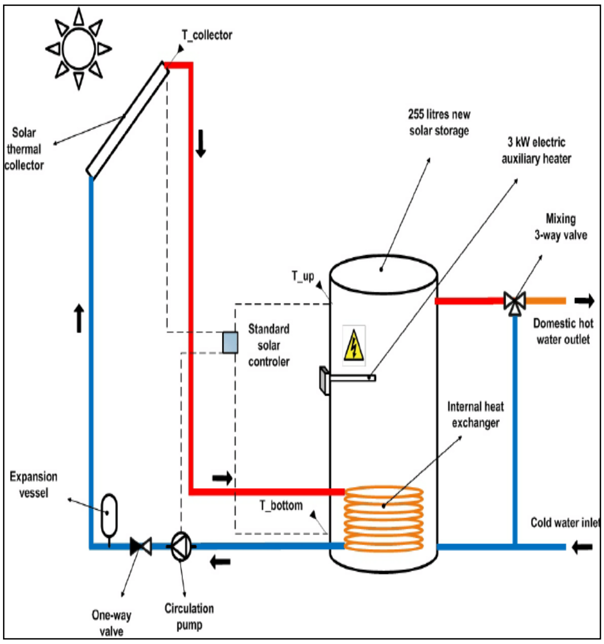

Fig. 3. Solar Water Heater System [9]

A higher Grashof number enhances the tank's thermal performance by promoting natural convection. However, extended discharge times can reduce the tank's capability to consistently supply hot water for consumption. Several figures illustrate the enhancement of natural thermal stratification, in which hot water rises to the top whilst cold water settles at the bottom, as depicted in Figure 3. This stratification is necessary for maintaining a sufficiently high temperature at the point of use.

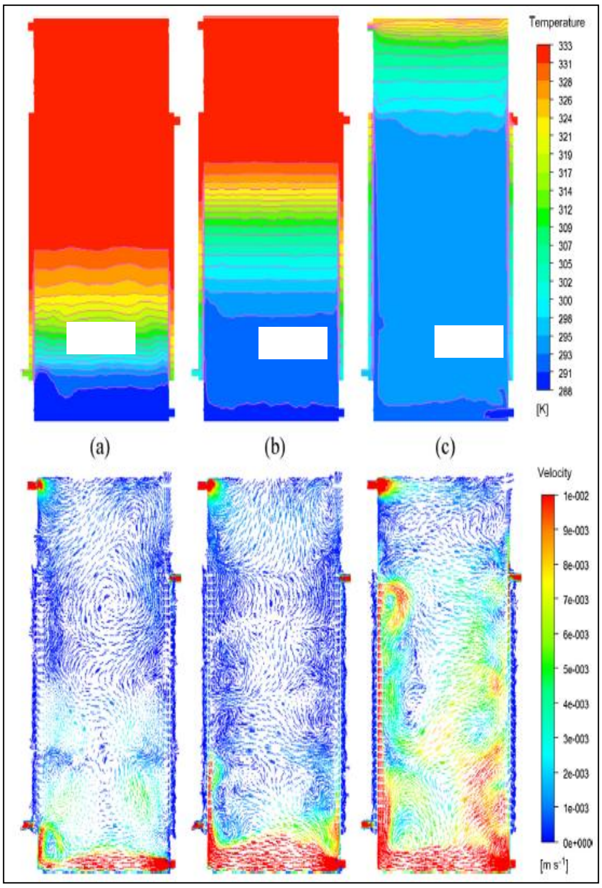

Fig. 4. Temperature contours (above) and stream wise (below) inside the tank for higher Grashof number [10]

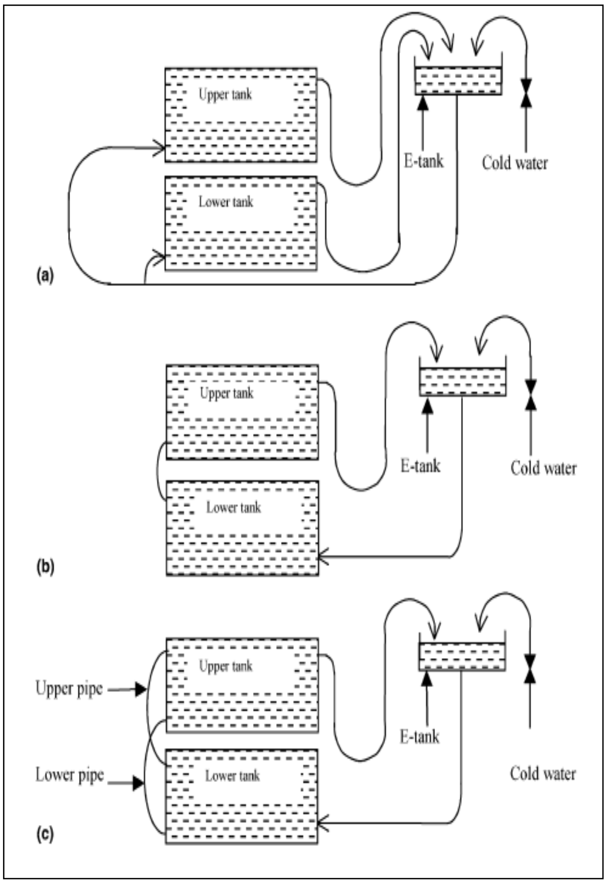

Fig. 5. Water flow pattern details for a) P, b) S1, c) S2-tank connections [11]

Madhlopa et al. [11] conducted an experimental study on the influence of surface pipe configuration on water temperature stratification in an integrated solar collector system using two horizontal cylindrical tanks. The experiment evaluated three modes of operation: a connected P-tank, an S1-tank and an S2-tank interconnection. The tanks were interconnected using insulated hose pipes (IHP) with a diameter of 12.7 mm, arranged in parallel for the P-tank configuration, in series with one IHP for the S1-tank interconnection and in series with two IHPs for the S2-tank. These connections linked the lower and upper tanks, as shown in Figure 5.

During heat charging, the lower tank displayed temperature stratification, whereas the upper tank did not. In the S2-tank mode, both tanks demonstrated satisfactory stratification. The S1-tank mode is suitable for a double-tank ICSSWH when the water temperature is expected to be equal to or less than that of the upper tank, as well as in configurations that rely on an inter-tank thermosiphon for natural fluid circulation. Figure 6 shows a designed ICSSW system featuring two cylindrical galvanised iron tanks, each with a capacity of 61.8 L. The upper tank is insulated with waste cotton, whilst the lower tank is covered with clear glass to allow the entry of solar radiation. The system is designed to absorb most of the reflected beam radiation at normal incidence angles, with radiation losses peaking in June. The lower tank and its wide acceptance angle enable substantial capture of incident diffused radiation.

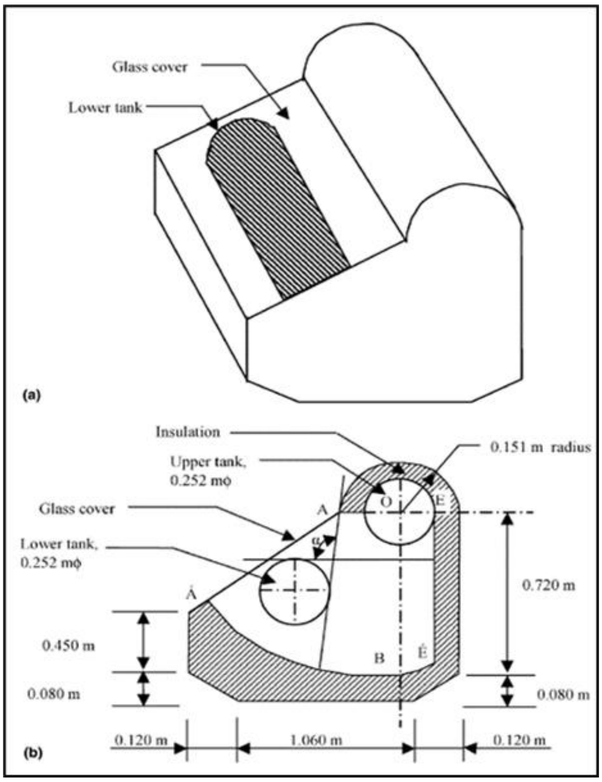

Fig. 6. Schematic presentation of an ISCWST showing the following: a) perspective view, b) cross-section of the system with AA´ = 0.940 m, A ´ BE´ = parabolic section, OB = focal length of the parabola (0.711 m), EE´ = vertical section (0.705 m), B = the vertex of the parabola [11]

Yu et al. [12] proposed a new structure for cylindrical hot water tanks by placing phase change material (PCM) on the tank side, addressing the issue of limited hot water capacity. Domestic hot water tanks often integrate PCMs at the top due to their potential to increase thermal storage density. Experiments were conducted on a 150 L cylindrical hot water tank to evaluate its thermal performance and analyse the impact of thermal gradients when using materials with latent heat. The use of polyurethane foam insulation substantially enhanced the thermal performance of the cylindrical hot water tank, extending the cooling time from 65 °C to 40 °C. The concentration and location of PCM also influenced the thermal stratification within the tank. At Ulster University, Smyth et al. [13] developed new prototypes of low-pressure horizontal cylindrical solar water heating systems, as shown in Figure 6, featuring a patented double thermosiphon container. Simple and inexpensive ICSSWT systems were constructed using open water tanks painted black and exposed directly to sunlight. An energy performance assessment was conducted, and the designs of various prototypes were evaluated under experimental conditions simulating solar radiation. The study demonstrated that design changes, such as buried welded final covers, transparent covers, targeted insulation and sealing of final cover fittings, can substantially enhance the performance of solar water heating systems. The improved model achieved a daily efficiency of 22% over 24 h, was simple to install and was suitable for large-scale production at a reasonable cost, particularly for use in developing countries.

Gao et al. [14] conducted a study to examine the effect of the initial temperature on the thermal gradient during the discharge mode of a vertical cylindrical hot water storage tank. Digital data were used to analyse the tank's typical solar characteristics. Vertical cylindrical hot water storage tanks are widely used in practical applications, and in solar water heating tanks, the effects of the initial temperature on flow dynamics, heat distribution and thermal mixing mechanisms are thoroughly investigated. The physical experiment validates the simulation results by introducing non-dimensional energy and thermal layer thickness to assess the reservoir's thermal gradient. The density difference between the hot and cold-water areas is more pronounced, indicating a notable thermal difference. This finding leads to a lower initial mixing level and a higher rate of hot water production. The hot water production rate increases by approximately 11% when the initial temperature is raised from 313K (40°C) to 353K (800°C). The non-dimensional average thickness of the thermal layer can be expressed as the thickness of the water's temperature transition zone, which decreases in parallel with the initial temperature. The initial temperature decreases significantly, from 313K to 333K. The degree of thermal differentiation linearly increases with the initial reservoir temperature and the non-dimensional time. A 0.3 increase in thermal differentiation represents more than 70% of the total improvement over the entire discharge period. When the initial temperature rises from 313K to 353K, the average dimensionless energy decreases from 0.46 to 0.29, resulting in a 17% increase in the thermal gradient. The cylindrical shape provides an optimal surface-to-volume ratio, reducing heat loss through the tank walls. Additionally, the design of cylindrical tanks facilitates efficient insulation and compact packaging, further reducing thermal losses. Considering these characteristics, CFD simulations and experimental studies have shown that cylindrical tanks generally offer superior thermal performance compared to other shapes [15].

4.2. Spherical Tanks

Spherical tanks offer the best surface area-to-volume ratio, theoretically reducing heat loss. However, their use in solar thermal systems remains limited. The spherical shape helps achieve more consistent temperature distribution within the tank because is allows for more even heat distribution and reduces thermal gradients that are often more noticeable in tanks with flat surfaces or boundaries. Despite these advantages, the complexities of heat transfer within spherical tanks, along with the relatively limited effectiveness of convection currents compared to cylindrical tanks, makes this design less favourable for optimising thermal performance.

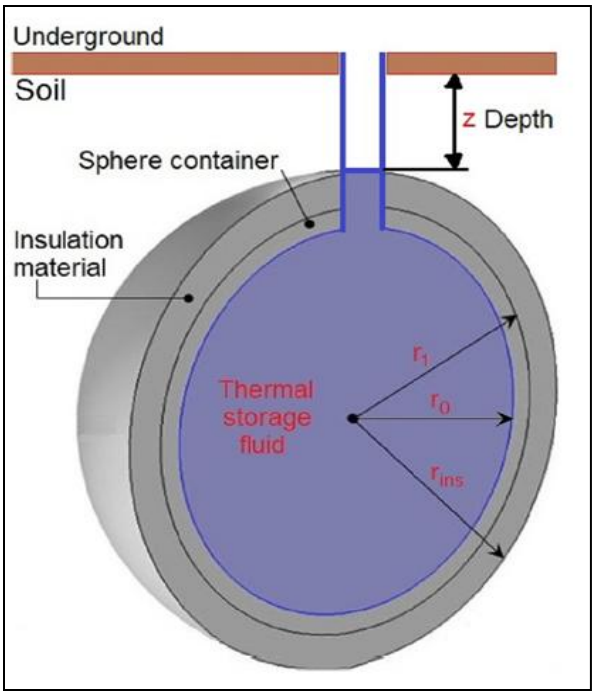

Fig. 7. Spherical Tanks [17]

In contrast, spherical tanks can be valuable in certain situations where heating efficiency and limited horizontal space are notable concerns [16]. Advanced manufacturing techniques and new materials may help overcome some of the practical limitations of spherical tanks, potentially making them a more viable option for specific applications.

4.3. Rectangular Tanks

Rectangular tanks, often chosen for their simplicity and ease of installation, exhibit different thermal characteristics. The flat surfaces of rectangular tanks can result in uneven temperature distribution and reduced thermal stratification, as demonstrated by Chung et al. [18]. Heat tends to escape readily from the corners and edges, leading to increased overall heat loss. Rashidov et al. [19] developed a calculation model for the water distributor in a multi-layer thermal storage tank used in solar heating systems and hot water supply. They formulated a non-linear second-degree equation for fluid motion along the path, accounting for Archimedean forces. A uniformly perforated water distributor with a constant cross-section is installed throughout the tank's height. This design enables solar heating systems to achieve a substantial temperature gradient, with the upper layers of the thermal water storage tank being hotter than the lower layers. The layer-by-layer charging principle, which involves supplying hot water from the collector to the appropriate layer, is widely employed in solar-powered hot water supply and heating systems. Considering the difficulty of achieving a good thermal gradient in storage tanks, the potential for increasing solar energy percentage is typically limited to no more than one-third of its value. A numerical solution has been developed to design self-organising active elements for temperature-based selective water distribution along the height of the layered assembly. Agreement between the calculated and the experimental data has been confirmed. The model incorporates various factors such as water velocities, external flow velocities, distances from stop ends, nominal opening lengths, cross-sectional areas, hole areas, surrounding and dispersing water entities, density changes, friction coefficients, flow rate coefficients, gravitational acceleration, nominal opening parameters, water distributor parameters and the adjusted Richardson number. However, rectangular tanks can offer advantages in situations with limited space or where a low-profile installation is necessary. Enhancements, such as internal baffles, can improve thermal stratification and mitigate heat loss issues. Additionally, modular designs facilitated by rectangular tanks are beneficial in large-scale solar thermal applications that require the connection of multiple units [20].

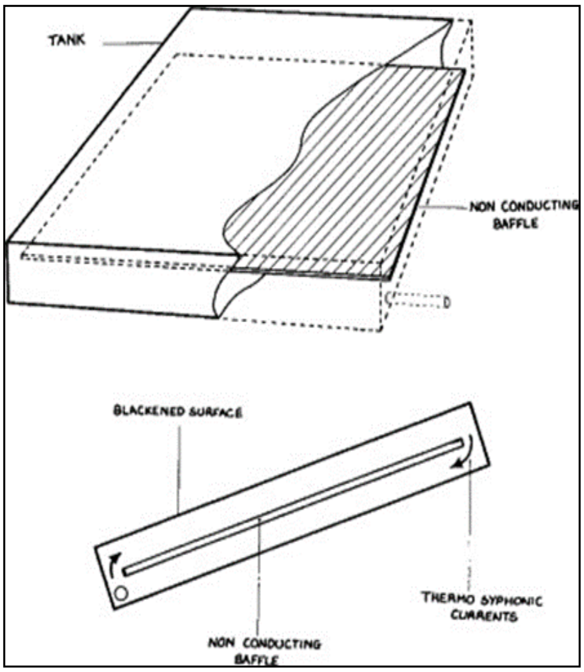

Fig. 8. Rectangular Tanks [21]

4.4. Triangular Tanks

The design and implementation of a triangular water storage tank integrated with a solar heating system is a novel approach to addressing the challenges of water storage and heating in remote or off-grid locations, as shown in Figure 6. As the standard solar water heating systems generally have medium in cubic or circular storage, , the heat transfer and volume can be less effective According to Abokersh et al. [5١], the triangular tank for the MS storageand the three triangular tank structure for the MS tank can enhance heat transfer, thermal stratification limit footprint. Therefore, the main goal of the triangular tank design is for its ability to lead to the transfer of heat through the entire body of water, maximizing efficiency. Natural convicting currents will be formed as a result of the tank's conical shape , through which the temperature distribution becomes more even and the heated water volume's circulation is enhanced. Research on this phenomenon has been conducted by by Hudon and his colleagues as well [22]. To redistribute the CO_2, a series of triangles are aligned to attenuate uneven heating and uneven distribution, . Because of an equal temperature distribution in the storage volume, it couldlead to an improved solar heating efficiency. The study results suggest that the triangular design provides superior in thermal aspect along with increasing storage capacity and reducingfootprint Relative to regular rectangular or round tanks, this designoffers advantages in areas with limited roof and ground space. The application of a triangular shaped configuration has been examined for an integrated storage solar water heater as an alternative to the conventional rectangle design. The impact of the triangular shape on the heater efficiency and heat retention is analyzed by using mathematical modeling and experimental validation. Triangular solar water heaters aim to improve heating and cooling efficiency. The results show that the heating rate is faster in sunlight compared to a rectangular tank. However, whilst night cooling is a key factor for these heaters, the study does not provide an explanation regarding the impact of the shape on the cooling process. Suggested improvements include adding a second cover with an insulating baffle plate or applying a suitable coating to the absorber surface to minimise heat loss during the night [2٤].

Badescu et al. [2٣] compared different tank shapes and found that cylindrical tanks are superior in terms of thermal efficiency but may be relatively impractical. Whilst spherical tanks are tactically preferred for minimising total heat loss, they are difficult to construct and prone to stratification problems. Rectangular tanks, though offering less surface area for heat transfer, allow for greater flexibility in design and installation. Therefore, the thermal performance requirements and practical constraints must be considered when choosing tank geometry. Cylindrical tanks typically prevail over other designs for integrated solar collector water storage due to their neat and compact design, favourable stratification properties and excellent thermal inertia. However, advancements in materials and fabrication techniques could make other shapes more practical, broadening the range of options available for designing solar thermal storage systems.

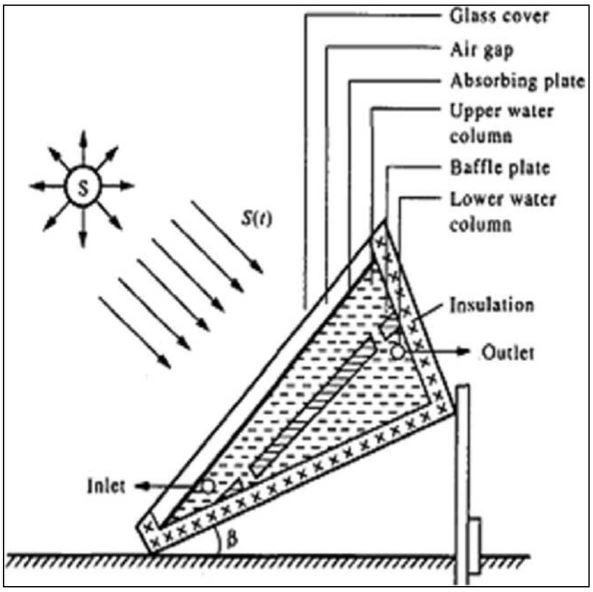

Fig. 9. Triangular Tanks [25]

5. Influence of Parameters on the Selection of Tank Shape

The following parameters influence the selection of the tank shape:

5.1. Volume and Capacity

The capacity of storage tanks to produce and store thermal energy is a crucial parameter for the performance of solar energy collectors integrated with water. Yari et al. [26] highlighted the importance of selecting an ideal tank size that allows it to fulfil its thermal duty without losing a considerable amount of collected solar energy. The study compared the tank's capacity with the performance and efficiency of energy storage in a thermal tank's solar collector, revealing that a larger tank capacity requires more intense solar radiation and a longer duration to heat the water inside. Hidalgo et al. [27] conducted a study to investigate the relationship between the size of the solar water storage tank and the energy storage efficiency of the solar collector system. The study found that this relationship depends on multiple factors, including the size of the solar collector array, the expected demand for hot water and local climatic conditions, because weather patterns can notably vary from one place to another. Thus, the previously mentioned thermal energy storage capacity can help alleviate pressure during peak demand periods, including cloudy days when solar radiation decreases. Large tanks can store additional heat. However, increasing the tank size also leads to higher heat losses and greater costs, with no proportional increase in energy storage capacity. According to Chang et al. [28], the ratio of reservoir volume to collector area is a critical governing parameter that must be considered in reservoir design. The tank can retain all the heat generated by the solar collectors with minimal loss, provided that this ratio is optimised through insulation, proper orientation of the solar collectors and several other factors mentioned in the next section of the research. Typically, a storage capacity ranging from 50L to 75L per square metre of facility space yields the best results. This finding has been demonstrated by the ICSSWT facility on Jeju Island, South Korea, which operates effectively during the winter season. This ratio ensures optimal energy storage without overloading the tank or the collector system. Additionally, the study by Villasmil et al. [29] emphasises the importance of isolating the reservoir, which plays a key role in determining the effective storage capacity.

Table 1,
Volume, capacity and surface area of geometric bodies' relationship with different shapes.

Parameter	Cylinder D/H = 1	Sphere	Rectangle	Triangle
"V" Volume (m^3)	V = $\frac{D^2}{4} \times \pi \times H$ V=$\frac{D^3}{4}\pi$	V = $\frac{D^3}{6} \times \pi$	V = a^3	V = $\frac{1}{2} \times b \times H^2$
"A" Surface Area (m^2)	A = 2 × $\frac{D^2}{4} + D \times \pi \times H$ When, $H = \frac{3}{2} \times D^2 \times \pi$	A = $D^2 \times \pi$	A = $\frac{6}{a}$ = $\frac{6}{\sqrt[3]{V}}$	A = (b × H) + L × $(S_1 + S_2 + H)$

High-quality insulation is essential for reducing heat loss from the tank. This feature becomes particularly important when dealing with larger tanks or unexpected thermal leaks, especially when higher heat levels are required. As demand fluctuates over different seasons and days, high-capacity and energy-efficient reservoirs can be produced by using advanced insulation materials and methods. For example,, a bigger tank can generate sufficient heat during the shorter daylight hours of winter to ensure a continuous supply of hot water steam. However, during summer the solar tank could get excessively warm, making it necessary to prevent overheating or stagnation. While a big tank offers adequate storage capacity, practical considerations such as availability, infrastructure, make up and installation complexity. There is an inherent trade-off between the required tank size, thermal benefits and practicalities. To balance the benefits of big reservoirs and the installation and maintenance advantage , modular tanks that are interconnected through other smaller tanks were proposed [30].

The comparative approach in this section shows that the previous favourable state - where either none or all present tanks have the desired gas levels- is not universal and only a complementary result is directly yielded for tanks of various sizes or rectilinear dimensions. Additionally, the optimal size of the tank depends heavily on the desired application and use, including anticipated hot water consumption and exact needs of the solar collector system. However, It is critical for the development of a solar heating system with an efficient energy storage the ratio of the volume of the tank to the collector area and the selection of insulation thickness . In general, the performance of a built-in solar collector water storage tank is influenced by both its size and capacity. There is a trade-off between the high thermal insulation requirement and the need to prevent the user from feeling through the thermal insulation. This balance must also account for installation limitations. Advances in insulation and tank design have made it possible to create larger storage tanks, enhancing systems efficiency, and reducing the scale of the systems for more compact units which produce higher overall energy yields \.

5.2. Aspect Ratio (Height to Diameter Ratio)

Aspect ratio (H/D), the ratio of height to diameter of a tank is another critical factor in the design of integrated solar collector water storage tanks. Such balance is of great significance for the absorber considering its close connection and contribution to storage of solar heating energy, thermal stratification maintaining and heat storage, as a faulty aspect ratio can greatly decrease the efficiency of the absorber. Different tank formations inhibit fluid flow and, consequently, heat loss from the tank's walls, which, in turn, influences overall performance. This section investigates the effect of aspect ratios on the effectiveness of solar thermal storage systems [30]. Aiming to calculate the aspect ratio, the length (L), width (W) and height (H) of the tank are measured. The aspect ratio is evaluated as follows:

- Length to Width Ratio: This is the most commonly used
  Aspect Ratio (L:W) = L/W
- Length to Height Ratio: Useful in some contexts:
  Aspect Ratio (L:H) = L/H
- Width to Height Ratio: Another perspective:
  Aspect Ratio (W:H) = W/H

Kurşun and Ökten [31] conducted a numerical study to examine the effects of tank tilt angles relative to the horizontal axis (α) and the aspect ratios of the water tank.

The numerical analyses were conducted within angle values ranging from 0° to 60° and aspect ratio values ranging from 0.5 to 1. The findings demonstrate that repositioning the hot water tank at various angles, such as α = 0°, improves thermal stratification. Decreasing the aspect ratio of the tank substantially impacted thermal stratification only when the angle α equalled 0°. The most remarkable temperature differential in the hot water tank was observed at a tilt angle of α = 45° and an aspect ratio of D/H = 0.5. The following are classifications of aspect ratios:

5.2.1. High Aspect Ratio

Tanks with a high aspect ratio (taller height relative to diameter) are generally highly effective at promoting thermal stratification. The increased height allows for a more pronounced temperature gradient due to the greater vertical distance, allowing hot water to rise and cool water to sink. This configuration minimises mixing and maintains distinct thermal layers. High aspect ratio tanks are particularly advantageous in systems where maintaining a high outlet temperature is critical [32]. However, these tanks may require robust structural support and can be challenging to install in spaces with height limitations. Additionally, the increased surface area of the tank walls can lead to high heat losses if inadequately insulated. Garnire et al. [33] conducted an experimental and computational study of an ICSSWT using a high aspect ratio at Edinburgh Napier University during the winter. The effect of water withdrawal and the environmental impact on the design were analysed numerically. Compared to previous research, the experimental results of the new ICSSWH collector show an increase in bulk temperature of 6.3 °C with a maximum and average percentage increase in temperature stratification of 67% and 133%, respectively, after 8 h of charging. However, the increased aspect ratio alters the heating and cooling characteristics of the SWH, causing it to gain and lose heat at a greater rate than the original design.

5.2.2. Low Aspect Ratio Tanks

According to Çomakli et al. [34], tanks with a low aspect ratio (wider diameter relative to height) tend to have a more compact design, making installation in spaces with height restrictions easier. However, maintaining thermal stratification in these tanks can be highly challenging due to the short vertical distance. This configuration can lead to increased mixing of hot and cold water, reducing the effectiveness of the stratification. Despite these challenges, low aspect ratio tanks can be beneficial in applications where space constraints are a primary concern. Baffle or diffuser hole designs can also help promote stratification and reduce mixing. Lowering the profile offers improved stability and easier insulation compared to taller, vertical-type tanks.

5.2.3. Optimal Aspect Ratio

Ji et al. [35] optimised the aspect ratio AR to accomplish a suitable trade-off between the benefits of thermal stratification and the effortless installation, as well as structural considerations. Many studies have found out that 2:1 (H:D) aspect ratio provides a practical compromise, positively promoting stratification while maintaining hands-on dimensions for installation and insulation. nonetheless, the optimal AR depends on a specified application requirements , preferred temperature behaviour, the volume of water to be stored, and the space available for installation.and the space available for installation). For example, a tank with a height of two meters and a diameter of one metre supplies adequate volume for effective stratification, along adequate surface area for heat absorption. The most effective method to determine the optimal aspect ratio is to combine CFD models with experimental tests according to each system and operating condition.

Comparison across different aspect ratios shows that higher aspect ratio tanks are generally achieve better thermal stratification, resulting in improved energy storage efficiency. . Innovative designs and high-quality insulation can help address practical challenges related to installation and structural support, even though taller tank walls may increase heat loss. Although low aspect ratio tanks are easy to install and insulate, achieving proper stratification often requires specific design considerations. Lastly, the aspect ratio of ICS water storage tanks is a key factor in determining their thermal performance and energy efficiency. Optimizing this parameter allows designers to enhance their efficiency and effectiveness of solar thermal storage systems, contributing to more sustainable energy solutions [36].

6. Improving the Efficiency of the Thermal Storage Tank:

6.1. Stratification

One of the key factors affecting the energy storage efficiency of of integrated water storage tanks is the temperature gradient established within the tank. Thermal tratification occurs when l layers of different temperatures are formed within the reservoir , heated water, being less dense, rises to the top, while cooler, denser water settles at the bottom as shown in Figure 7. The temperature gradient between the water supply pipe and the discharge pipe affects maintaining hot water at the top for immediate use, while colder water at the bottom continue to be heated by the solar collector. This section explores the phenomenon of stratification, its impacts on system performance and improvements across various tank geometries. The storage capacity of available for installation Proper arrangement of large tanks enhances stratification by offering a greater vertical volume which promotes the formation of thermocline cells in the thermal layers. Although exposing the system to high value of heat increases stored thermal energy, it may extend longer to accomplish the correct temperature, potentially decreasing overall efficiency. According to Han et al. [37], thermal stratification is critical requirements for optimal efficient solar thermal systems. System efficiency depends on sufficient heat mixing and insisting a considerable temperature difference between the inlet and the outlet. Well stratified tanks specified by low energy requirement for water heating with low heat loss, can significantly improve overall system efficiency

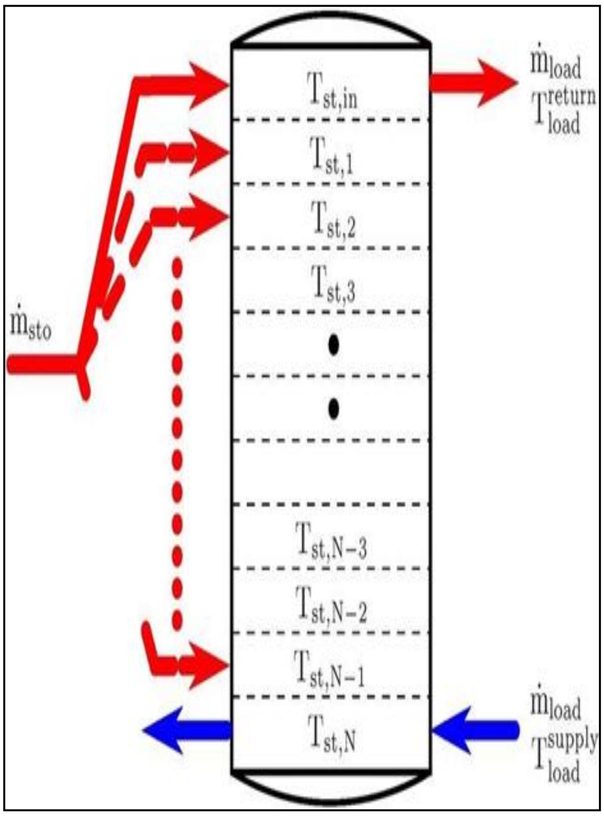

Fig. 10. Stratified Storage tank [37]

6.1.1. Factors Influencing Stratification

Tank geometry is considered main factor influencing the stratification within a water storage tank. The tank's shape and ratio determine its thermal performance. Tall and high-aspect-ratio tanks promote stronger stratification by allowing the formation of multiple thermal layers across a larger vertical volume.. Selection of inlets and outlet's locations and design are important to preserve stratification. A stable temperature variation along the tank height can be sustained by strategically positioning the inlets near the bottom to supply cold water and the outlets near the top to withdraw the hot water. The inflow and outflow patterns of water flow rates in and from the tank can either support or disrupt stratification..Low flow rates generally boost stratification by minimising mixing. Effective thermal insulation supports this process by minimizing heat losses and preserving distinct temperature gradients. Incorporating internal baffles and well-designed diffusers can improve the thermal stratification by addressing the water flow into channels and preventing mixing of hot and cold layers.

6.1.2. Enhancing Stratification

Several approaches can be implemented toenhance stratification in the integrated solar collector water storage tank..

- Optimization of Inlet configuration: This design can use diffusers or baffles at the inlet can enhance the uniform distribution of incoming cold water, thereby reducing turbulence, minimizing mixing, and promoting thermal stratification.
- Layered Inlets: Installing multiple inlets located at different heights can promote feed water at specific temperature layers and maintainingstratification.
- Flow Control: The flow control technique delays water inflow and outflow from the tank, strengthening the temperature gradient.
- Insulation Techniques: Advanced insulation materials and methods reduce the heat loss and sustaining's the vertical temperature gradient.
- Tank Shape Optimisation: According to Kumar et al. [38] that selection of the appropriate tank shape and aspect ratio, inherently promotes stratification and enhance thermal performance eventually. To assess and develop tank performance,accurate stratification sensing and monitoring must be implemented Temperature sensors with multi-level in the tank can provide a comprehensive data of the temperature gradient profile. to improve stratification, such as flow rates and inlet configurations , feedback received from these sensors can be employed for system parameter adjustment
- Reviewing various tank designs options, when the tanks with high ratios are paired, with optimised inlet/outlet designs, exhibit superior thermal differentiation. Rectangular tanks frequentaly maintain effective thermal layering and might require novel design features, barriers as an example to preserve stratification. In comparison withthe cylindrical and triangular tanks which are commonly more effective in maintaining thermal layers without the need auxiliary elements. Although spherical tanks offer a hypothetical advantage for their minimal surface area-to-volume ratio, achieving and conserving the stratification within the layers is tough. The thermal gradient within the tank can affect the overall performance of water storage solar heating systems. The thermal performance and energy storage efficiency of solar heating systems can be significantly expanded by understanding the factors influencing the stratification and applying associated design methods into application.

6.2. Insulation

Insulation is a key element in ISCWSTs, as it significantly improves energy- saving performance by reducing heat loss. High-quality insulation assist on the preserve of the stored hot water by minimizing thermal losses to the surrounding environment, as reported by Reddy et al. [39] This section outlines the basic types of insulation materials in which solar thermal water storage tanks, along with the various mounting methods applied to improve temperature retention and reduce standby losses. Effective insulation of a solar significantly lowers heat transfer to the surroundings, which is necessary for maintaining stable thermal stratification and ensuring the availability of a multi-day hot water buffer.. To low heat losses, a thick layer of high-quality insulation surrounding the tank contributesTherefore,it could consume less backup energy for keeping water hot. Rao et al. [25] studied various designs of integrated collector storage solar water heater (ICSSWH) and proposed several ways to reduce heat losses. tThese techniques include a insulated night covers, baffle plate structures, PCMs andreverse thermosyphon valves . ICSSWH systems are considered inexpensive. However, there are some limitations in their commercialization due to high non-collection heat loss and the absence of accurate designs for storage tanks. Thus, , various approaches have been proposed To overcome this drawback , such as using insulated covers, double glazing, and selective absorber coatings to reduce the heat loss. Additional heat retention methods, such as baffle plates, inner sleeve structures, thermal diodes and reverse thermosyphon designs, can further enhance thermal performance and minimise heat loss.

6.2.1. Types of Insulation Materials

Various insulation materials are used in solar water storage tanks, each featuring unique properties and suitability for different applications, such as:

- Foam Insulation: Rigid foam boards, such as polyurethane or polystyrene, provide excellent thermal resistance and are commonly used due to their high R-value per inch of thickness. These materials are lightweight, easy to install and offer good moisture resistance.
- Fibreglass Insulation: Fibreglass batts or blankets are widely used due to their cost-effectiveness and excellent thermal performance. However, proper sealing is required to prevent moisture accumulation and reduce thermal bridging.
- Vacuum Insulation Panels (VIPs): VIPs offer superior thermal resistance by creating a vacuum within the panel. Whilst they provide excellent insulation efficiency, their high cost and handling complexity can be limiting factors.
- Reflected Insulation: Reflective foils and coatings can be applied to reduce heat loss by reflecting radiant heat away from the tank.
- Insulation Disks: This material is typically used in combination with other insulations to improve overall performance. Aerogels, known for their extremely low thermal conductivity, are highly insulating advanced materials. Despite their high cost, these disks are still employed in situations where the cost is insignificant, such as when comparing space requirements with high-performance insulation [40].

6.2.2. Insulation Techniques

Proper insulation of solar water storage tanks requires selecting appropriate materials and applying proper installation techniques, such as the following:

- Continuous Insulation: Maintaining insulation along the tank perimeter without gaps or thermal bridges is critical. Overlapped and sealed joints in the insulation panels may be crucial to this achievement.
- Multi-Layer Insulation: Multiple layers of insulating materials can work together, utilising the best properties of each material to maximise thermal performance. A layer of foam board with a reflective foil backing could offer conductive and radiant heat resistance.
- Sealing and Waterproofing: Preventing moisture from penetrating the insulation layer is crucial, enabling the insulation layer to perform to its full potential. Condensation and moisture, whether from faulty flashing or general wall/roof construction, substantially reduce the effectiveness of insulation materials. However, adopting embedded waterproof barriers as a coating markedly enhances the protection of these materials.
- Shielded Jacketing: Encasing the insulated tank in a protective casing or housing can help protect the insulation from physical damage and weather conditions, improving the longevity and ensuring thermal effectiveness [41].

The quality and effectiveness of insulation directly affect the thermal performance of solar water collector storage tank systems. Well-insulated tanks effectively minimise heat losses and sustain high water temperatures for extended periods. This condition optimises the efficiency of the solar thermal system and enhances user comfort and convenience by maintaining a continuous hot water supply. In extremely cold climates, these energy savings multiply due to substantial heat losses through conventional insulation. Low usage of such auxiliary heating systems helps conserve energy, resulting in highly sustainable and overall energy-efficient preserved insulating water tanks [42]. Considering their notably higher thermal resistance and cost implications, high-performance insulating materials, such as vacuum insulation panels or aerogels, are unlikely to find widespread use. Despite the proven durability of spray foam insulation, fibreglass is only second for its performance and affordability. Cost, thermal performance, ease of installation and exposure conditions should be considered in the selection of appropriate insulation materials and techniques. Overall, insulation is an integral part in the design and operation of ISCWSTs. The correct selection of materials and insulation methods can efficiently suppress heat loss and preserve thermal stratification, contributing to general energy savings. Solar thermal systems will be highly sustainable and feasible as insulation technology advances.

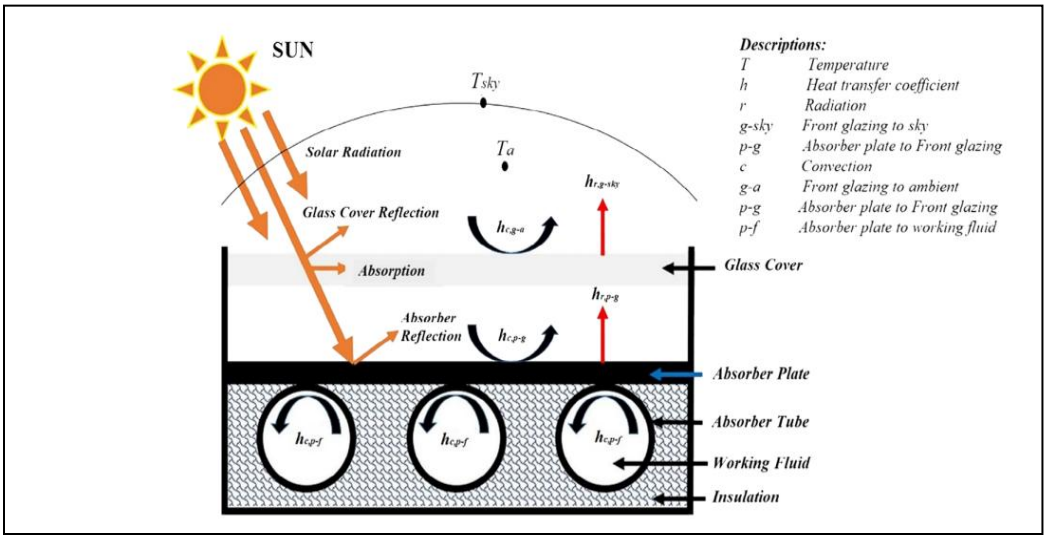

Fig. 11. Schematic illustration of a Solar Water Heater System [47]

6.3. Placement and Orientation

The placement and orientation of ISCWSTs are crucial considerations that can substantially affect system performance and efficiency. Proper placement, which ensures optimal solar exposure and minimal shading, facilitates efficient heat transfer between the solar collectors and the storage tank. Singh et al. [43] explored tank placement and orientation as influencing factors on strategies to maximise solar energy harvesting and improve thermal performance. Placing the tank in a location with unobstructed access to sunlight for most of the day ensures maximum energy capture. Factors such as nearby buildings, trees and topographical features are essential to avoid shading and to maximise solar irradiance on the collectors.

6.3.1. Roof vs. Ground Mounting

ISCWSTs can be either roof-mounted or ground-mounted. Both configurations are space-efficient and help minimise the overall system footprint, making them suitable for residential applications with space constraints. Ground-mounted systems provide greater flexibility in terms of tank size and orientation, allowing for easier maintenance and access. The choice between roof and ground mounting primarily depends on factors such as available space, structural considerations and aesthetic preferences [44].

6.3.2. Orientation

Madhlopa et al. [11] examined the orientation of the tank relative to the sun, influencing the amount of solar energy captured throughout the day. The tanks are oriented to maximise exposure to sunlight during peak demand hours for optimal performance. In the northern hemisphere, the ideal orientation shall generally be south facing, whilst that in the southern hemisphere is the oppositive.

The tilt angle should be adjusted based on latitude to optimise solar incidence angles. Conducting a shading analysis is critical to identifying potential obstructions that may cast shadows on the solar collectors or storage tank.

Tools such as solar path diagrams, shade analysis software and on-site assessments can help periodically determine the extent and timing of shading throughout the year. Mitigation measures, such as tree pruning, building modifications or elevated mounting, can minimise shading and maximise solar exposure [45]. In addition to solar exposure, thermal considerations should also influence tank placement and orientation.

Placing the tank in a location with minimal temperature fluctuations and exposure to extreme conditions should be considered to help maintain thermal stability and reduce heat losses. Adequate ventilation and airflow around the tank can also prevent overheating, ensuring efficient heat dissipation [46]. Integrating the solar collector water storage tank into the building design can further enhance aesthetic appeal and energy efficiency. Architectural features such as awnings, pergolas or integrated solar shading devices can be designed to accommodate solar collectors and storage tanks [48]. This integration not only maximises solar energy capture but also improves the overall visual appeal of the building. Adaptive strategies such as adjustable tilt mounts and single- or dual-axis tracking systems can enhance solar collector orientation and increase solar energy capture throughout the day [49]. These systems dynamically adjust the tilt and azimuth angles of the collectors to follows the sun's path, ensuring optimal solar exposure at all times. Although highly complex and costly, these dynamic components offer the potential for high energy yields and improved overall system performance [50]. Therefore, a comparative analysis of various placement and orientation strategies reveals that careful consideration of solar exposure, shading and thermal factors is essential for maximising energy efficiency. Ground-mounted tanks offer more flexibility in orientation and tilt angles, whilst rooftop mounting optimises space utilisation in areas with limited available space. Adaptive strategies provide additional opportunities for fine-tuning solar energy capture, though they involve higher upfront investment and maintenance costs. Overall, the placement and orientation of ISCWSTs are critical determinants of system performance and efficiency [5٢].

Table 2,
Summary of (Geometry of the tank, thermal stratification, thermal efficiency and economic cost).

Ref.	Authors	Nature of the work	Geometry of the tank	Thermal Stratification	Thermal Efficiency
[10]	Arslan and Igci 2015	Experimental and Numerical	Cylindrical	Good, due to their height to diameter ratio	Good because shape allows for effective heat distribution and collection
[17]	Dolgun et al. 2023	Experimental	Spherical	Good, due to their uniform geometry	Very efficient in terms of surface area-to-volume ratio
[52]	Ding et al. 2023	Experimental and Numerical	Rectangular	Poor, the wide base can lead to mixing	Medium due to greater heat loss at the corners and edges
[23]	Badescu 2008	Experimental	Triangular	Considered challenge due to their narrow design, which may encourage mixing	Variable, depends on the tank size

7. Summary

ISCWSTs are a crucial component in harnessing solar energy for domestic and industrial water heating applications. The geometric design of these tanks notably influences their thermal performance, energy storage efficiency and overall effectiveness. The in-depth analysis of this study of various geometric parameters, such as shape, volume, aspect ratio and insulation, provides valuable insights into optimising the design and operation of solar thermal systems. The tank shape, whether cylindrical, spherical, rectangular or triangular, affects key factors such as thermal stratification, heat retention and heat loss characteristics. Cylindrical tanks emerge as a favourable option due to their efficient stratification properties and ease of implementation. The balance between thermal demand and heat losses is key wen sizing a tank in terms of volume and capacity. Tanks with high aspect ratios promote good thermal stratification but can pose challenges in installation and insulation design. Whilst different materials and construction methods affect the performance, effective insulation remains critical for minimising heat loss and maintaining good thermal stability. Careful placement and orientation, including factors such as solar exposure, shading analysis or integration within building design, can substantially enhance system efficiency by optimising energy captured and managing module operating temperatures. Ground-mounted tanks allow for flexibility in orientation, whereas rooftop mounting can maximise space usage. Adaptive strategies, such as tracking systems that adjust solar collectors to follow the sun throughout the day, provide additional chances for optimising solar energy capture but have higher initial installations.

Overall, the design and implementation of an integrated collector-storage solar water heater ensures proper geometric shaping, insulation and orientation for installation. By optimising these factors, solar thermal systems can improve energy efficiency and serve as an alternative or partial substitute for direct firing systems that use fossil fuels. These systems contribute to sustainability and help reduce carbon oxide footprints. With ongoing research and advancements, solar thermal systems are becoming increasingly powerful energy producers, aligning with the global shift toward a substantially cleaner and more renewable future. Future work should conduct additional simulation studies using CFD algorithms in ISCWST, aiming to explore the insertion of baffles at the tank inlet to promote thermal stratification, tailored to the geometry of the tank.

Nomenclature

A surface area of the object, [m^2]
a side length, [m^2]
b base area, [m^2]
H height, [m]
V volume of the object, [m^3]

Abbreviation

CFD Computational Fluid Dynamics
ICD Integrated Coupled Design
IHP Insulated Hose Pipes
ISCWST Integrated Solar Collector Water Storage Tank
P-tank Parallel tank
SWH Solar Water Heater
S1-tank Interconnect the tanks in one series, with IHP
S2-tank Interconnect the tanks in two series, with IHP

8. References

[1] K. Jana; A. Ray; M. Majoumerd; M. Assadi, S. De. Polygeneration as a future sustainable energy solution–A comprehensive review. Applied Energy 2017,202,88-111. https://doi.org/10.1016/j.apenergy.2017.05.129
[2] M. Esen; A. Durmuş; A. Durmuş. Geometric design of solar-aided latent heat store depending on various parameters and phase change materials. Solar Energy 1998, 66,19-28. https://doi.org/10.1016/S0038-092X(97)00104-7
[3] M. Smyth; P. Eames; B. Norton. Integrated collector storage solar water heaters. Renewable and Sustainable Energy Reviews 2006,10(6),503-538. https://doi.org/10.1016/j.rser.2004.11.001
[4] V. Belessiotis; E. Papanicolaou. History of solar energy. Comprehensive Renewable Energy (Second Edition) 2012,3,118-136. https://doi.org/10.1016/B978-0-12-819727-1.00190-4
[5] M. Islam; K. Sumathy; S. Khan. Solar water heating systems and their market trends. Renewable and Sustainable Energy Reviews 2013,17,1-25. https://doi.org/10.1016/j.rser.2012.09.011
[6] C. Long. The Energy Crisis in 1970s Suburban Narratives. Running Out of Gas 2011,41(3), 342-369. https://doi.org/10.1353/crv.2011.0024
[7] M. Thirugnanasambandam; S. Iniyan; R. Goic. A review of solar thermal technologies. Renewable and Sustainable Energy Reviews 2010,14(1),312-322. https://doi.org/10.1016/j.rser.2009.07.014
[8] M. Al-Dulaimi; K.A. Amori. Effect of receiver geometry on the optical and thermal performance of a parabolic trough collector. Heat Transfer 2022,51(3)2437-2457. https://doi.org/10.1002/htj.22406

[9] M. Chaabane; H. Mhiri; Ph. Bournot. Thermal performance of an integrated collector storage solar water heater (ICSSWH) with a storage tank equipped with radial fins of rectangular profile. Heat and Mass Transfer 2012,49. https://doi.org/10.1007/s00231-012-1065-z

[10] M. Arslan; A. Igci. Thermal performance of a vertical solar hot water storage tank with a mantle heat exchanger depending on the discharging operation parameters. Solar Energy 2015,116,184-204. https://doi.org/0.1016/j.solener.2015.03.045

[11] A. Madhlopa; R. Mgawi; J. Taulo. Experimental study of temperature stratification in an integrated collector–storage solar water heater with two horizontal tanks. Solar Energy 2006, 80,989–1002. https://doi.org/10.1016/j.solener.2005.06.019

[12] D. Qin; Z. Yu; T. Yang; S. Li; G. Zhang. Thermal performance evaluation of a new structure hot water tank integrated with phase change materials. Energy Procedia 2019,158,5034–5040.https://doi.org/10.1016/j.egypro.2019.01.659

[13] M. Smytha; J. Mondola; R. Muhumuzaa; A. Pugsleya; A. Zacharopoulosa; D. McLarnonb; C. Forzanoc; A. Buonomanod; A. Palombod. Experimental characterisation of different hermetically sealed horizontal. Solar Energy 2020,206,695-707. https://doi.org/10.1016/j.solener.2020.06.056

[14] W. Gao; B. Liu; Y. Zhang; X. Ding; Q. Li; J. Wang. Effect of initial temperature of water in a solar hot water storage tank on the thermal stratification under the discharging mode. Renewable Energy 2023,212,994–1004. https://doi.org/10.1016/j.renene.2023.05.102

[15] L. Bernardo; H. Davidsson; B. Karlsson. Retrofitting domestic hot water heaters for solar water heating systems in single-family houses in a cold climate: A theoretical analysis. Energies 2012, 5,4110-4131. https://doi.org/10.3390/en5104110

[16] S. Yari; H. Safarzadeh; M. Bahiraei. Experimental study of phase change material performance as thermal insulation of a double-walled spherical tank under partial vacuum for storing solar energy. Energy Conversion and Management 2019,92,117317. https://doi.org/10.1016/j.enconman.2023.117317

[17] G. Dolgun; A. Keçebaş; M. Ertürk; A. Daşdemir. Optimal insulation of underground spherical tanks for seasonal thermal energy storage applications. Journal of Energy Storage 2023, 69, 107865. https://doi.org/10.1016/j.est.2023.107865

[18] J. Chung; S. Cho; Ch. Tae; H. Yoo. The effect of diffuser configuration on thermal stratification in a rectangular storage tank. Renewable Energy 2008,33(10),2236-2245. https://doi.org/10.1016/j.renene.2007.12.013

[19] Y. Rashidov; B. Aytmuratov; B. Abdullaeva; and K. Aytbaev. Calculation and experimental study of water distributor of stratification heat accumulator of solar heating system. E3S Web of Conferences 2023, 383, 04013. https://doi.org/10.1051/e3sconf/202338304013

[20] S. Ahmed; M. Khalid; M. Vaka; R. Walvekar; A. Numan; A. Rasheed; N. Mubarak. Recent progress in solar water heaters and solar collectors: A comprehensive review. Thermal Science and Engineering Progress 2021,25, 100981. https://doi.org/10.1016/j.tsep.2021.100981

[21] M. El-Reedy. Steel and concrete storage tank. Chapter 4-Onshore Structural Design Calculations
Power Plant and Energy Processing Facilities. (Elsevier) 2017.

[22] K. Hudon; T. Merrigan; J. Burch; J. Maguire. Low-cost solar water heating research and development roadmap. NREL/TP-5500-54793 August, 2012. https://doi.org/10.2172/1050127

[23] V. Badescu. Optimal control of flow in solar collector systems with fully mixed water storage tanks. Energy Conversion and Management 2008, 49(2),169-184. https://doi.org/10.1016/j.enconman.2007.06.022

[24] A. Mohamad. Integrated solar collector–storage tank system with thermal diode. Solar Energy 1997,61(3),211-218. https://doi.org/10.1016/S0038-092X(97)00046-7

[25] Y. Rao; A. Somwanshi. A comprehensive review on integrated collector-storage solar water heaters. Materials Today: Proceedings 2022,63,15–26. https://doi.org/10.1016/j.matpr.2021.12.424

[26] Y. Han; R. Wang; Y. Dai. Thermal stratification within the water tank. Renewable and Sustainable Energy Reviews 2009,13(5),1014-102. https://doi.org/10.1016/j.rser.2008.03.001

[27] M. Rodríguez-Hidalgo; P. Rodríguez-Aumente; A. Lecuona; M. Legrand; R. Ventas. Domestic hot water consumption vs. solar thermal energy storage: The optimum

size of the storage tank. Applied Energy. 2012,97,897-906.
https://doi.org/10.1016/j.apenergy.2011.12.088

[28] K. Chang; A. Minardi; T. Clay. Parametric study of the overall performance of a solar hot water system. Solar Energy 1982, 29(6),513-521.
https://doi.org/10.1016/0038-092X(82)90059-7

[29] W. Villasmil; L. Fischer; J. Worlitschek. A review and evaluation of thermal insulation materials and methods for thermal energy storage systems. Renewable and Sustainable Energy Reviews 2019,103,71-84.
https://doi.org/10.1016/j.rser.2018.12.040

[30] A. Bonanos; E. Votyakov. Sensitivity analysis for thermocline thermal storage tank design. Renewable Energy 2016, 99,764-771.
https://doi.org/10.1016/j.renene.2016.07.052

[31] B. Kurşun; K. Ökten. Effect of rectangular hot water tank position and aspect ratio on thermal stratification enhancement. Renewable Energy 2017,116.
https://doi.org/10.1016/j.renene.2017.10.013

[32] W. He; L. Xue; B. Gorczyca; J. Nan; Z. Shi. Comparative analysis on flocculation performance in unbaffled square stirred tanks with different height-to-width ratios: Experimental and CFD investigations. Chemical Engineering Research and Design 2018,132,518-535.
https://doi.org/10.1016/j.cherd.2018.01.055

[33] C. Garnire; T. Muneer; J. Currie. Numerical and empirical evaluation of a novel building integrated collector storage solar water heater. Renewable Energy 2018,126,281-295.
https://doi.org/10.1016/j.renene.2018.03.041

[34] K. Çomakl; U. Çakır; M. Kaya; K. Bakirci. The relation of collector and storage tank size in solar heating systems. Energy Conversion and Management 2012,63,112-117.
https://doi.org/10.1016/j.enconman.2012.01.031

[35] J. Ji; J. Han; T. Chow; H. Yi; J. Lu; W. He; W. Sun. Effect of fluid flow and packing factor on energy performance of a wall-mounted hybrid photovoltaic/water-heating collector system. Energy and Buildings 2006,38(12)1380-1387.
https://doi.org/10.1016/j.enbuild.2006.02.010

[36] S. Fertahi; A. Jamil; A. Benbassou. Review on solar thermal stratified storage tanks (STSST): Insight on stratification studies and efficiency indicators. Solar Energy 2018,176,126-145.
https://doi.org/10.1016/j.solener.2018.10.028

[37] Y. Han; R. Wang; Y. Dai. Thermal stratification within the water tank. Renewable and Sustainable Energy Reviews 2009,13(5),1014-1026.
https://doi.org/10.1016/j.rser.2008.03.001

[38] K. Kumar; S. Singh. Investigating thermal stratification in a vertical hot water storage tank under multiple transient operations. Energy Reports 2021,7,7186-7199.
https://doi.org/10.1016/j.egyr.2021.10.088

[39] K. Reddy; N. Kaushika. Comparative study of transparent insulation materials cover systems for integrated-collector-storage solar water heaters. Solar Energy Materials and Solar Cells 1999,58(4),431-446.
https://doi.org/10.1016/S0927-0248(99)00018-5

[40] T. Ferhatbegovic; G. Zucker; P. Palensky. An unscented Kalman filter approach for the plant-model mismatch reduction in HVAC system model-based control. IECON 2012 - 38th Annual Conference on IEEE Industrial Electronics Society.
https://doi.org/10.1109/IECON.2012.6388685

[41] M. Bilardo; G. Fraisse; M. Pailha; E. Fabrizio. Modelling and performance analysis of a new concept of integral collector storage (ICS) with phase change material. Solar Energy 2019,183, 425-440. https://doi.org/10.1016/j.solener.2019.03.032

[42] P. van Schalkwyk; J. Engelbrecht; M. Booysen. Thermal stratification and temperature variation in horizontal electric water heaters: A characterisation platform. Energies 2022,15(8),2840.
https://doi.org/10.3390/en15082840

[43] R. Singh; I. Lazarus; M. Soulioti. Recent developments in integrated collector storage (ICS) solar water heaters: A review. Renewable and Sustainable Energy Reviews 2016, 54, 270-298.
https://doi.org/10.1016/j.rser.2015.10.006

[44] L. Juanicó. A new design of roof-integrated water solar collector for domestic heating and cooling. Solar Energy 2008,82(6),481-492.
https://doi.org/10.1016/j.solener.2007.12.007

[45] Y. Kohol´e; F. Fohagui; G. Tchuen. Flat-plate solar collector thermal performance assessment via energy, exergy and irreversibility analysis. Energy Conversion and Management:X 2022,15, 100247. https://doi.org/10.1016/j.ecmx.2022.100247

[46] M. Ghamari. Solar wall technology and its impact on building performance. Energies 2024, 17,(5),1075. https://doi.org/10.3390/en17051075

[47] C. Ovalle; L. Nieves; H. Medrano; E. Paiva-Peredo. Intelligent photovoltaic system to maximize the capture of solar energy,"

Indonesian Journal of Electrical Engineering and Computer Science 2023,32(3),1557. https://doi.org/10.11591/ijeecs.v32.i3.pp1557-1568

[48] N. Mokhlif; M. Eleiwi; T. Yassen. Experimental investigation of a double glazing integrated solar water heater with corrugated absorber surface. Materials Today:Proceedings 2021,42,2742–2748. https://doi.org/10.1016/j.matpr.2020.12.714

[49] J. Fan; S. Furbo; H. Yue. Development of a hot water tank simulation program with improved prediction of thermal stratification in the tank. Energy Procedia 2015, 70,193 – 202. https://doi.org/10.1016/j.egypro.2015.02.115

[50] J. Dragsted; S. Furbo; M. Dannemand; F. Bava. Thermal stratification built up in hot water tank with different inlet stratifiers. Solar Energy 2017,147,414-425. https://doi.org/10.1016/j.solener.2017.03.008

[51] M. Abokersh; M. Osman; O. El-Baz; M. El-Morsi; O. Sharaf. Review of the phase change material (PCM) usage for solar domestic water heating systems (SDWHS). Wiley-Blackwell 2017,42(2),329-357. https://doi.org/10.1002/er.3765

[52] C. Ding; J. Pei; S. Wang; Y. Wang. Evaluation and comparison of thermal performance of latent heat storage units with shell-and-tube, rectangular, and cylindrical configurations. Applied Thermal Engineering 2023,218,119364. https://doi.org/10.1016/j.applthermaleng.2022.119364

أثر معايير التصميم في أنظمة خزانات المياه الحرارية: مراجعة

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المستخلص

يقدم هذا العمل نظرة تاريخية شاملة على خزانات تخزين المياه المستخدمة في جمع الطاقة الشمسية، مع التركيز على استكشاف تأثير الأشكال الهندسية المختلفة على الأداء الحراري وكفاءة تخزين الطاقة في الخزانات لجمع الطاقة الشمسية. تم استعراض تصاميم الخزانات الأسطوانية، والكروية، والمستطيلة، والمثلثة لتحليل تأثيرها على التدرجات الحرارية، والاحتفاظ بالحرارة، وسعة تخزين الطاقة. كما و ركزت الدراسة على تحديد العوامل التي تؤثر على اختيار شكل الخزان من حيث الحجم والسعة، ونسبة الأبعاد، مع أخذ ما يعزز تخزين الحرارة في الخزان بعين الاعتبار لتقييم الكفاءة الحرارية. أظهرت النتائج أن الخزانات ذات التصاميم الأسطوانية تفوقت على الأشكال الأخرى، مثل الكروية والمستطيلة والمثلثة ؛لأنها توفر حجماً مناسباً لمساحة محدودة وسعة عالية بفضل نسبة الطول إلى العرض كما أنها تمتاز بخسائر حرارية أقل من نظيراتها. من جانب آخر، فإن تقليل نسبة الأبعاد للخزانات يؤثر بشكل كبير على التدرج الحراري عندما تكون زاوية ميل الخزان مع الأفق تساوي صفر درجة. تمثل هذه النتائج لتخزين المياه للطاقة الحرارية النقاط الأساسية لتصميم أنظمة تسخين المياه بالطاقة الشمسية؛ لتعزيز كفاءتها الحرارية. تضع الدراسة أساسا للعمل المستقبلي على تقنيات تخزين الطاقة الشمسية ذات درجات الحرارة العالية ودمجها في أنظمة الطاقة المستدامة مع تقديم اقتراح أمثل لزيادة التقسيم الطبقي الحراري عن طريق إدخال الحواجز عند مدخل الخزان.
