

A Comparative Study of Solar Heater Technologies for Domestic Water Heating

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ABSTRACT

The present research investigates solar water heater technologies in depth to find environmentally friendly methods of heating water for the home. The research analyses the efficacy, economic viability, and environmental effect of many collector technologies via the use of qualitative analysis, practical design, and the review of secondary data. A detailed analysis of the differences between evacuated tube and flat-plate collectors reveals the advantages of each type in certain environments. The culmination of this study is a prototype of a cutting-edge evacuated-tube solar water heater that aims to maximize the use of solar energy. Integrating a 58/1800-sized vacuum tube into a thoughtfully crafted water tank is a perfect example of how far in-depth research and creative thinking can take solar water heating systems. Finally, this investigation provides not only a more thorough comprehension of solar water heater technologies, but also a practical answer that exemplifies the revolutionary potential of research-led design in resolving energy efficiency issues.

Key Words: Evacuated Tube Collector, Efficiency, Flat-Plate Collector, Practical Design, Solar Water Heater, Sustainable Energy.

1. INTRODUCTION

1.1 Background analysis

In response to the rising need for clean and sustainable energy solutions, solar water heater technologies have undergone tremendous improvement over the years. Solar water heaters have emerged as a promising technology with the ability to solve environmental issues and energy security as the globe struggles with the problems of climate change and depleting fossil fuel supplies (A. Greco et al 2020) [1]. This contextual study examines the development, current problems, demand, and relevance of solar water heater technology [2].



Figure 1.1 Solar water heater for domestic purposes

The practice of using the sun's rays to heat water dates back to prehistoric times when crude devices were developed for this purpose. It wasn't until the middle of the twentieth century, however, that current solar water heater technology really took off [3]. Flat-plate collectors, typically made of metal and painted black, have been in use since the 1950s [4]. The groundwork for future innovations was set by these early systems. There was a resurgence of interest in solar water heaters in the 1970s in response to the oil crisis. This prompted fresh studies and developments in the field. Efficiency was further increased when, in the 1980s, evacuated tube collectors were widely used. Since then, solar water heating has evolved to include several solutions to fulfill the requirements of a wide variety of consumers thanks to advancements in technology, materials, and design [5].

There has been a lot of progress made, but there are still issues with solar water heaters. Efficiency is a major consideration. While today's systems are unquestionably more effective than their forebears, it is still difficult to achieve peak efficiency over a wide range of environmental circumstances. Although broad adoption would benefit from the long-term operating advantages, high up-front investment costs may prevent this [6]. To maintain the dependability and lifespan of these systems, it is also necessary to solve technical challenges relating to maintenance and system durability. The installation process might be complicated by the need to work around preexisting plumbing and heating infrastructure [7]. In addition, as solar water heater technologies advance, it becomes more important to get the services of trained personnel for set up and upkeep.

Solar water heater demand is being pushed by a number of different forces. First and foremost, people are beginning to understand the need to make the switch from fossil fuels to renewable energy in order to slow global warming [8]. Traditional water heating techniques contribute significantly to global warming pollution, but solar water heaters are a viable alternative. In addition, since the price of energy keeps going up, more and more people are looking for less expensive options. Using a solar water heater allows you to tap into a free and plentiful energy source, which may significantly reduce your energy costs over time [9].

The value of solar-powered methods of heating water isn't limited to private residences. There is growing consensus among international governments and policymakers that these systems may help them meet their renewable energy and carbon reduction ambitions [10]. A solar water heater may greatly lessen the demand for power during peak hours and relieve strain on the grid in areas with plenty of sunshine. Adopting solar water heaters also helps to expand the green technology industry, which in turn generates new opportunities for employment and technological advancement [11].

From basic collectors to complex systems, the development of solar water heating technology is a fascinating tale of growth and invention. The need for continuous research and development cannot be overstated in view of current concerns including efficiency optimization, cost-effectiveness, and technological issues [12]. Environmental concerns, energy savings, and government incentives all contribute to the growing demand for solar water heaters. Their importance stems from the fact that they have the ability to cut down on carbon emissions, provide energy security, and encourage long-term economic expansion [13]. Technology improvements in solar water heaters point to a greener and more eco-friendly future for home water heating.

1.2 Problem Statement

With rising global environmental concerns and a need for more sustainable energy sources, solar water heater technology has emerged as a potentially useful method for incorporating renewable energy sources into residential settings. Investigating the most effective solar water heater technology to meet the needs of economical and efficient home water heating is the focus of this study's in-depth investigation of a pressing problem [14]. There is still a lack of a thorough review despite the availability of several technologies, such as flat-plate collectors, evacuated tube collectors, concentrating solar collectors, and combined photovoltaic-thermal (PVT) systems. Performance, economic viability, environmental ramifications, and practical practicality are just a few of the many factors taken into account in this research to choose the best technology [15]. The study's overarching goal is to help people, businesses, and governments make more responsible decisions about adopting solar water heater technology for residential use.

1.3 Aim and Objectives

Aim

The main aim of this study is to determine which solar water heater technology is best for heating home water while taking into account practical practicality, cost-effectiveness, environmental impact, and efficiency by designing a CAD model of solar water heater in SolidWorks software.

Objectives

- To thoroughly evaluate the effectiveness and performance of several solar water heater systems under varied climatic situations and consumption patterns.
- To evaluate the initial investment costs, operating savings, and maintenance costs in order to assess the economic feasibility of various solar heating systems.
- To evaluate the life cycle, including embodied energy and carbon emissions, of each solar water heater technology in order to determine its environmental effect.
- To look at the viability of using various solar heater technologies in residential settings, taking installation challenges and upkeep needs into account.
- To promote sustainable energy practices by offering suggestions based on evidence for choosing the best solar water heater technology for certain residential applications.

1.4 Research Question

Question 1: What are the most prominent solar water heater technologies, and how do they vary in terms of design and functionality for home water heating?

Question 2: Under what environmental and operational circumstances do various solar water heating methods achieve their stated efficiencies?

Question 3: How do the upfront prices, ongoing costs, and long-term cost reductions of different technologies stack up against one another?

Question 4: How does each solar water heater technology affect the environment in terms of embodied energy and carbon emissions?

Question 5: How do the costs and complexities of implementing and maintaining these technologies in private homes compare?

1.5 Rationale

What are the issues?

Solar water heater efficiency varies by setup and circumstance. Solar water heater performance might vary owing to solar radiation levels, temperature, and design, even if efficiency has increased dramatically. This makes it essential to analyze efficiency under diverse conditions to guarantee consistent and dependable performance. Climate-sensitive solar water heaters are common. Systems that work well in sunny settings may struggle in cloudy or less sunny environments [16]. This climate dependency limits the usability of certain technologies and requires a detailed study of their appropriateness for a given place. Energy transmission and storage heat loss remain a problem. Energy retention and waste reduction need good insulation and heat transmission. Insulation and heat exchange innovations are needed to decrease thermal losses and boost system efficiency. Key problems include system lifespan and maintenance. Due to environmental variables, absorber plates, pipelines, and heat exchangers may degrade. Durable components and user-friendly maintenance are vital to enhancing solar water heater lifetime and efficiency [17]. Solar water heaters may be difficult to integrate with plumbing and heating systems. Installation must take into account compatibility, retrofitting, and solar backup heating source synchronization. Simplifying integration may improve user experience and technology adoption. Awareness and comprehension of solar water heater technology limit their adoption. Users may not know the pros, cons, and operations of various systems. Education and outreach are essential to demystify and promote the technology [18].

Table 1.1 Issues in solar water heater

Issue	Description
Efficiency Variability	Different technologies exhibit varying efficiency levels.
Initial Investment Costs	High upfront expenses can discourage adoption.
Maintenance and Durability	Varied maintenance needs and lifespans affect usage.
Geographic Suitability	Performance depends on regional solar radiation levels.
Integration Challenges	Integration complexities with existing systems.
Environmental Impact	Hidden environmental costs may arise.
Consumer Awareness	Limited public knowledge about available technologies.

Why are the issues now?

Solar water heater difficulties are caused by technological advances and environmental concerns. Solar water heater technologies have raised efficiency, dependability, and adaptability expectations. This effort for improved performance has raised awareness of efficiency fluctuation and climate sensitivity. As renewable energy solutions gain popularity, demand for solar water heaters has surged, emphasizing the need to tackle major concerns. Rapid advances in material science and design have raised efficiency requirements, boosting performance expectations [19]. However, the intricate interaction of factors including sun exposure, ambient temperature, and system design causes efficiency heterogeneity between systems. Consumers seeking optimum investment performance have seen this diversity.

How does the research help to resolve the issues?

The study addresses solar water heater technology challenges via theoretical analysis and actual execution. The research compares solar water heater technologies, including efficiency evaluations, economic assessments, and environmental impact analyses, to address efficiency variability, climate dependence, and economic viability issues. The project will also use SolidWorks, a strong 3D modeling program, to develop a solar water heater system to address integration and practical feasibility issues [20]. This hands-on approach will allow the development of creative design aspects to minimize heat loss, optimize energy collection, and ensure plumbing system compatibility. The design approach will examine real-world restrictions and practical concerns to improve solar water heater dependability and performance.

2. LITERATURE REVIEW

2.1 Introduction

A variety of academic sources, including journal articles and research papers, are critically analyzed in the literature review chapter in order to provide the groundwork for the next comparative study. This section tries to clarify the historical development, scientific developments, efficiency aspects, economic considerations, and environmental effects of different solar water heater systems by synthesizing the known information. The collection of secondary data offers a thorough overview of the status of solar water heater technologies today, allowing a methodical and knowledgeable evaluation of their advantages, disadvantages, and consequences for home water heating applications. The studies from [51-63] for solar air and water heater, [64, 65] for heat exchanger [66, 67] for solar cooker analyze thermal performance by varying the design of solar collector component which can be leveraged for current comparative study of solar heater technologies for domestic water heating.

2.2 Solar Heating Technologies

As the world moves towards more sustainable energy practices, the use of solar heating systems has become more important. These developments make it possible to use solar energy to heat buildings, water, and power factories, among other things. Several important solar heating systems are discussed in length in this section, including their underlying mechanisms, benefits, and possible uses [21].

Unglazed Solar Collectors

Unglazed solar collectors are a low-tech and inexpensive way to capture solar energy for use as heat. These collectors consist of a heat-conducting substance, often a dark metal or plastic, which soaks up sunlight and then transfers that heat to a fluid that flows through or below the surface. Without the protective layer of glass, heat is lost more easily from unglazed collectors. Since unglazed collectors can only reach lower temperatures, they are best used for supplemental systems in addition to more conventional heating techniques, or for less demanding heating applications

[22]. One common kind of unglazed technology is solar pool heating collectors. These collectors use tubular panels made of black plastic and installed on rooftops to preheat pool water before it is returned to the pool. The energy needed to heat pools is greatly reduced by using unglazed collectors, which also have uses in commercial and industrial water heating.

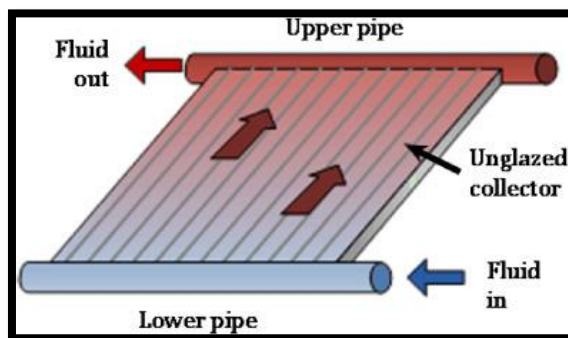


Figure 2.1. Unglazed Solar Collectors

Transpired Solar Air Collectors

An innovative method of sun heating is shown using expired solar air collectors. These collectors made out of dark-colored, perforated metal cladding, are attached to the exterior walls of an existing structure and employ a fan to suck fresh air through the openings [23]. The warmed air is sucked into the ventilation system after circulating behind the metal coating [24]. Indoor space heating is the technology's primary emphasis, although it also has industrial and agricultural benefits, including as crop drying. By harnessing the sun's rays to warm air directly, transpired solar air collectors provide a cost-effective alternative to traditional heating methods.

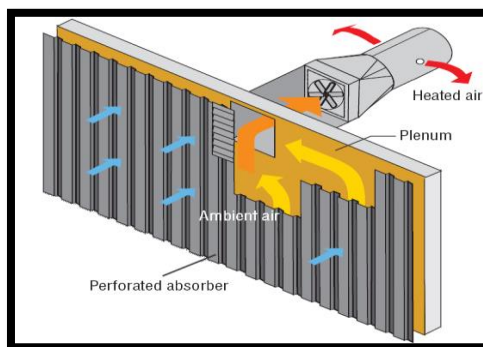


Figure 2.2 Transpired Solar Air Collectors

Flat-Plate Solar Collectors

Using a copper tubing system and heat-absorbing materials within an insulated frame or enclosure, flat-plate solar collectors are a popular solar heating method. These glazed collectors outperform their unglazed counterparts in absorbing solar energy across a broader temperature range [24]. Special coatings might be applied to the heat-absorbing materials to increase their effectiveness [25]. To save money on fuel, conventional water boilers often employ preheated water from collectors made of glazed flat plates. The production of hot air for bigger buildings through a heat exchange system is yet another area of use. This technology is adaptable and efficient since it can be easily integrated with preexisting heating systems.

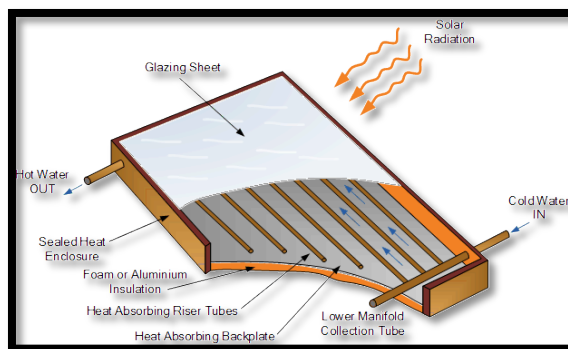


Figure 2.3 Flat-Plate Solar Collectors

Evacuated Tube Solar Collectors

This technique, known as an evacuated tube solar collector, is designed to absorb and store as much solar energy as possible without losing any of the heat. Thin copper tubes filled with a heat-transfer fluid are housed within larger vacuum-sealed glass or plastic tubes to create these collectors [25]. Due to the greater surface area exposed to the sun, the design allows for effective heat absorption from the sun at a variety of angles. The vacuum-sealed housing drastically reduces heat loss to the atmosphere [26]. Since evacuated tube systems can reach greater temperatures than flat-plate collectors, they are more flexible in their use. They are used for both batch and on-demand hot water production. Since these collectors reliably produce high-temperature fluids, they also find use in industrial operations and space heating.

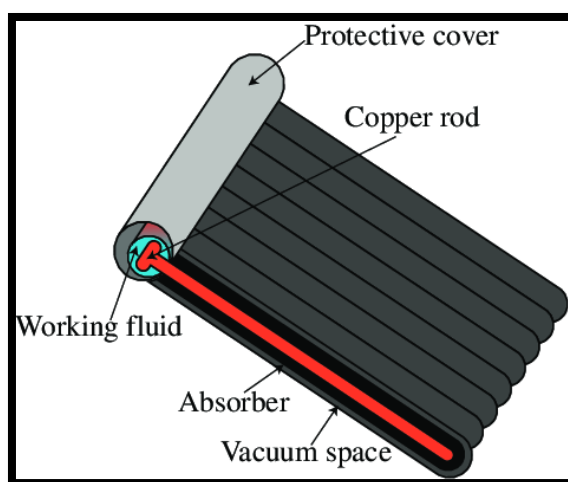


Figure 2.4 Evacuated Tube Solar Collectors

Concentrating Solar Systems

Solar concentrators use mirrors or lenses to concentrate sunlight into a smaller area, heating it to a higher temperature. A variety of configurations are available for these systems, such as bowl-shaped arrays of mirrors or parabolic troughs that focus sunlight onto pipes filled with a heat transfer fluid [27]. In larger arrays, mirror fields focus sunlight on a central tower, where it heats water to high temperatures to produce steam or other superheated fluids. Applications that benefit from higher temperatures, such as heat-intensive chemical processes, and electric power production, are ideal for concentrating solar systems. Large-scale solar thermal collectors are more difficult and expensive to build than other solar collectors, but their high energy production justifies their use in these situations [28].

2.3: KPI Factors for Solar Water Heater

The efficiency, efficacy, and overall performance of solar water heater systems are measured across a variety of KPIs and criteria. When determining which technologies are best suited to a given task, these measurements are crucial. In this article, we'll look at the key performance indicators (KPIs), parameters, and related equations that are used to assess solar water heater systems' efficacy [29].

Efficiency (η)

Efficiency in converting solar energy into heat is a critical KPI for solar water heaters. It is the ratio of usable heat to solar energy utilized. The technology, layout, and operating criteria determine effectiveness [30].

$$\eta = \frac{Q_{\text{useful}}}{A \cdot G \cdot t} \times 100\%$$

- Q = Usable heat output
- A = Collector area
- G = Solar radiation incident on the surface of the collector
- t = Time interval of measurement

These key performance indicators and factors, together with the accompanying equations, provide the groundwork for evaluating the efficacy of solar water heater systems [31]. Researchers, engineers, and decision-makers may optimize the use of solar water heating systems by considering these aspects [32]. In order to do fair comparisons across various solar water heaters, it is crucial to use criteria that are relevant to each technology and use case.

2.4: Comparative study between flat-plate and evacuated plate collectors

Evacuated tube collectors and flat-plate collectors for solar water heating have been compared and contrasted for their unique features and benefits. Vacuum-sealed glass tubes with inner tubes of heat transfer fluid make up the cutting-edge design of evacuated tube collectors. This design reduces heat loss and maximizes heat absorption, especially in colder climates, making them a good option for areas with extremes of temperature. Because they are capable of producing hotter water, they are well suited for uses like industrial procedures that need high temperatures [33]. Flat-plate collectors, on the other hand, have a more straightforward construction, with a flat absorber plate covered by clear glass and housed inside an insulated box. Because of their durability and low price, these collectors are often used in commercial and domestic water heating systems. They are adaptable to a wide range of design aesthetics and work best in milder climates where insulation is less of an issue. Several variables influence the choice between these technological options [34].

In colder areas, the efficiency of evacuated tube collectors is maximized by the vacuum insulation they provide. Their potential greater initial expenses, though, may warrant some thought. Because of its low price and adaptability, flat-plate collectors are often used in places with moderate temperatures where high heat performance is not required [35]. Finally, it is important to consider your needs, budget, and location while deciding between flat-plate and evacuated-tube collectors. While evacuated tube collectors are ideal for high-temperature applications and low-temperature environments, flat-plate collectors are dependable and affordable. Consumers may tailor their heating solutions to their own needs and tastes with the help of this comparison, which offers a thorough knowledge of the benefits and applicability of each technology.

2.5 Literature Gap

There is a sizable literature gap that warrants more investigation despite the vast body of research on different solar water heating devices. Most prior research has isolated certain solar collector systems, such as evacuated tube collectors or flat-plate collectors, and compared their unique performance metrics, financial feasibility, and technical details [36]. However, an integrated evaluation that takes into account a wide range of characteristics has received very little focus. The comprehensive assessment of solar water heating systems in relation to local climates is an area where the literature is noticeably lacking [37]. A complete comparison taking into account larger climatic variables is unknown, while some studies emphasize the benefits of evacuated tube collectors in colder locations and flat-plate collectors in warmer ones. The dynamic interaction between collector efficiency, economic feasibility, and environmental effect is also understudied.

The investigation of novel hybrid systems that combine the benefits of evacuated tubes and flat-plate collectors is also under-researched. It is possible that a more flexible and adaptable solution for home water heating might be found by exploring how different technologies can complement each other to optimize efficiency across varied climatic circumstances [38]. While previous studies have provided the groundwork for understanding specific solar water heating systems, there is still a pressing need for a more holistic strategy that takes into account a variety of climates and hybrid solutions [39]. Closing this knowledge gap may provide useful information for developing solar water heating systems that provide the greatest possible savings in energy costs, money, and environmental impact.

3. METHODOLOGY

3.1 Research Methods

The research strategies include both theoretical and applied approaches. To better understand solar water heater technology, qualitative research necessitates an exhaustive reading of relevant publications and journals. As part of the study, researchers will create a 3D model of a solar water heater in SolidWorks, with special attention paid to developing novel structural components [40]. The efficacy, economic feasibility, and environmental effects of various solar water heater systems are assessed by analyzing secondary data sources.

3.2 Research Approach

The methodology combines theoretical frameworks with empirical design. The qualitative basis is an extensive literature study that sheds light on solar water heater technology. In addition, we use SolidWorks to model a solar water heater and investigate potential new approaches to design.

3.3 Research Philosophy

This study adheres to a pragmatic approach to research, one that integrates qualitative analysis and practical design to efficiently fulfill the study's aims. The pragmatist approach to science places an emphasis on real-world applications and meaningful results [41]. A positivist approach is acceptable for this kind of secondary research. The philosophy of positivism stresses the importance of empirical evidence in evaluating claims and theories. Thus, to objectively compare solar water heater systems, this concept works well with a systematic literature review technique, which involves identifying and synthesizing relevant secondary sources.

3.4 Research Design

The research method incorporates both qualitative analysis and practical design elements, using a mixed-methods approach. The qualitative part is a library-wide search for information on solar water heater technology. Developing a

Solar Water Heater model in SolidWorks is the practical design task at hand. A descriptive research strategy is appropriate for this secondary study [42]. The study goals are met via a design that does not include any modification or intervention, namely the collection and analysis of existing literature on the efficiency, economic feasibility, and environmental effects of different solar water heater technologies [43].

3.5 Data collection and analysis

A methodical strategy is used in the field of data collecting and analysis. Relevant secondary data was collected from a wide variety of scholarly publications and journals and serves as the study's backbone. These resources provide light on the effectiveness, viability, and ecological effects of various solar water heating methods [44]. The obtained data is carefully reviewed and synthesized using a systematic literature review approach, allowing for an in-depth comparison and assessment. This detailed examination is adapted to meet the goals of the study, and it will help researchers spot important patterns, connections, and trends among the many types of solar water heaters under investigation [45].

4. RESULT AND DISCUSSION

The investigation led to the development of an evacuated tube solar water heater in SolidWorks, including input from the in-depth study. The efficiency of this developed model is much better than that of its competitors. The design was improved upon by using the findings from the qualitative research to maximize the use of solar energy. The sophisticated design of the model follows current advancements in solar water heater technology by optimizing heat absorption and storage [46]. Its potential to considerably contribute to home water heating efficiency and sustainability is supported by the careful integration of analysis and design.

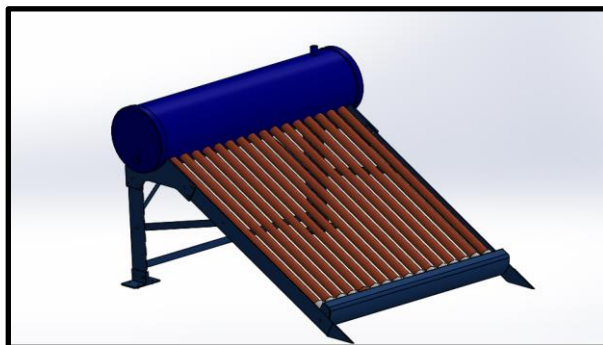


Figure 4.1. Evacuated solar water heater for domestic purposes

The attached figure shows the designed evacuated solar water heater where solar water heater uses a vacuum tube with the diameters of 58/1800 to improve the efficiency with which heat is collected. The hot water is stored in a tank with a diameter of 475mm, maximizing the system's efficiency and performance for household use.

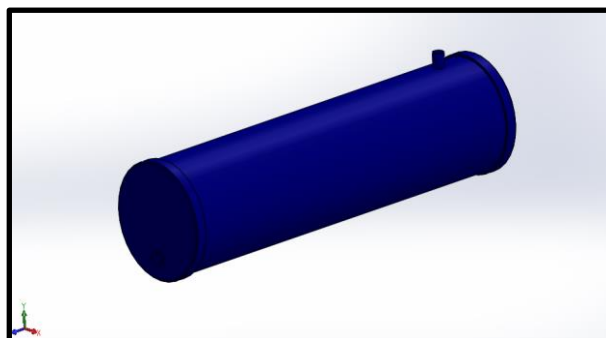


Figure 4.2. Water tank

The above figure as the reservoir for holding and dispensing hot water is the model's water tank, which has a diameter of 475mm. It complements the vacuum tube system and is built for maximum efficiency. As a result, solar energy is effectively transferred and used to heat household water.

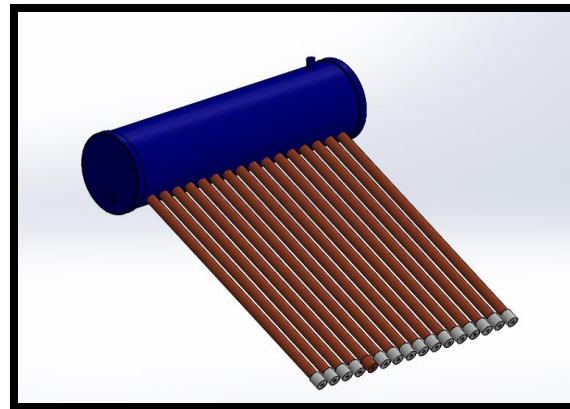


Figure 4.3 Tube connected to the tank

The attached figure shows the 58/1800-mm vacuum tube is well-fitted with the water tank. This connection makes it possible for solar heat to be efficiently transferred to the tank's contents. The tube and tank's complementary designs guarantee an efficient system for capturing and storing solar energy for home water heating applications.

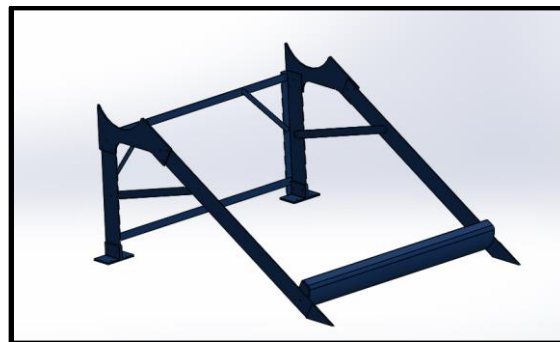


Figure 4.4 Skeleton

The solar water heater system is supported and maintained with strength and integrity by the model's structural skeleton. In order for the parts, such as the vacuum tubes and water tank, to perform efficiently and contribute to the effective solar energy utilization for water heating, this framework assures stability and durability.

The proposed evacuated tube solar water heater model improves efficiency, meeting the research goal of finding the best solar water heating technology. Its revolutionary design, inspired by extensive solar heater technology studies, makes the evacuated type more efficient. A 58/1800 vacuum tube improves heat absorption, enabling the device to gather more solar energy in different weather situations. This design option boosts system efficiency, improving water heating performance [47]. The model's efficiency is further improved by the 475mm-diameter seamless connection between the vacuum tube and the water tank. The direct transport of collected solar heat to the water tank minimizes energy loss and maximizes solar heating. The structural skeleton supports the system, guaranteeing stability and longevity and enabling components to perform efficiently and increase efficiency [48].

The evacuated tube solar water heater model results from research on higher-efficiency technologies. The model outperforms existing systems by synthesizing qualitative analysis and using SolidWorks. The planned evacuated type

might provide an effective and sustainable home water heating solution, meeting the rising need for energy-efficient technology [49]. Therefore, the evacuated tube solar water heater model is a potential residential water heater due to its revolutionary design characteristics and increased efficiency. This model illustrates the advantages of educated design choices based on thorough research, highlighting its potential contribution to solar water heating sustainability [50].

5. CONCLUSION AND RECOMMENDATION

In conclusion, this research examined solar water heater technologies to meet the growing need for sustainable and efficient home water heating. An improved evacuated tube solar water heater model was created by combining qualitative research, practical design, and secondary data analysis to understand different technologies. The comparison of the evacuated tube and flat-plate solar collectors revealed characteristics suitable for diverse regions and applications. The comparison of these technologies revealed their strengths and weaknesses, revealing their efficiency, economic viability, and environmental effect. A vital addition to the discipline, this comparative study helps consumers and practitioners make educated judgments that meet particular needs.

This project's greatest success was the evacuated tube solar water heater type, which harnessed and transferred solar energy more efficiently. The combination of a 58/1800 vacuum tube and a properly built water tank demonstrated heat absorption and retention optimization. The model's efficiency increase emphasizes the need for thorough study and creative design to enhance solar water heating solutions. These results suggest various further projects. For starters, comparing additional solar water heater technologies will help you comprehend the sector better. Real-world testing and data validation might also verify the model's theoretical efficiency. To ensure energy-efficient solution dissemination, researchers, producers, and policymakers must collaborate to bridge the gap between discovery and practical implementation. In conclusion, our qualitative analysis and advanced design research have shown a way to sustainable residential water heating. The evacuated tube solar water heater model, technology juxtaposition, and secondary data investigation have created a thorough framework for assessing solar water heater technologies. This study shows how research-led design may revolutionize renewable energy solutions. The model showcases the research's findings and offers hope for energy-efficient and ecologically friendly technology.

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