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A REVIEW PAPER ON THE SOLAR WATER HEATING SYSTEMS WITH THERMAL STORAGE

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ABSTRACT

This abstract summarizes the importance of advanced simulation tools such as MATLAB and ANSYS in enhancing our understanding of Solar Water Heating Systems with Thermal Storage (SWHSTS). Through a comprehensive review of research papers, it is evident that these platforms have been instrumental in modeling complex thermal dynamics, optimizing system efficiency, and validating experimental setups. Future directions in this field suggest the exploration of advanced modeling techniques like machine learning algorithms and multi-physics simulations, alongside the integration of emerging materials such as advanced phase change materials (PCMs). Furthermore, there is a growing emphasis on considering environmental and economic factors, highlighting the need for real-world validation through experimental setups and field trials to ensure practical applicability and sustainability of proposed advancements. Ultimately, a holistic approach encompassing technical, economic, and environmental considerations is essential for the development of more efficient and viable SWHSTS.

1. INTRODUCTION

Renewable energy systems are currently being installed in rural communities around the developing world by a variety of international, national, and local institutions, Non-Governmental Organisations (NGOs), and private businesses when access to healthcare in rural regions is a national priority [1, 2, 3]. The World Health Organization's (WHO/EPI) expanded vaccination programme has taken the lead in assessing the viability of employing several energy sources to meet the vaccines' cold chain, electricity, and hot water demands. Solar energy was quickly shown to be a technology that would be essential to supplying rural health clinics with safe vaccinations, hot water, and high-quality power [4].

In emerging nations such as India, there is even. The implementation of solar water heating is more urgently needed. This isn't only because a lot of these nations don't own natural supplies of conventional fuel; yet, this is because the majority of people in these nations reside in rural locations without the extension of traditional electrical networks. Under such conditions, solar water heaters would be the only viable means of meeting the hot water needs, for instance, in cottage industries and rural health facilities [5, 6].

Solar Water Heating Systems with Thermal Storage represent a pivotal advancement in renewable energy technology, offering an efficient and sustainable alternative to conventional water heating methods. At its core, this innovative system comprises solar collectors, heat exchangers, and a sophisticated thermal storage unit, working in tandem to harness and store solar energy for heating water. The solar collectors, typically mounted on rooftops or open areas with optimal sun exposure, consist of absorptive surfaces that capture sunlight and convert it into heat energy. These collectors may take various forms, such as flat-plate collectors or concentrating collectors, each designed to maximize energy absorption and transfer.

The heat generated by the solar collectors is then transferred to a fluid medium, commonly a heat-transfer fluid like antifreeze, circulating through the system. This heated fluid flows through a heat exchanger, transferring its thermal energy to the water in a storage tank. What distinguishes Solar Water Heating Systems with Thermal Storage is the inclusion of a specialized storage unit that retains excess heat for later use.

This thermal storage component is crucial for overcoming the intermittency of solar radiation. During periods of abundant sunlight, the excess heat is stored in well-insulated tanks, often equipped with phase-change materials or other advanced thermal storage technologies. These materials allow for the efficient storage and release of heat, ensuring a continuous supply of hot water even when solar input is limited.

The advantages of this integrated approach are manifold. Firstly, the system provides a consistent and reliable source of hot water, addressing the inherent variability of solar energy. This reliability extends beyond daylight hours, making it a practical solution for both day and night use. Additionally, by storing excess energy, these systems can meet hot water demands during cloudy days or periods of increased consumption, reducing dependence on supplementary heating sources.From an economic standpoint, Solar Water Heating Systems with Thermal Storage offer substantial savings on energy bills over their lifespan. They contribute to a reduction in greenhouse gas emissions and promote sustainability by displacing the need for conventional water heating methods that rely on fossil fuels.

As we delve deeper into the workings and applications of these systems, it becomes evident that they represent a pivotal step towards a more sustainable and environmentally conscious future. This exploration will unravel the technical intricacies, environmental benefits, and diverse applications of Solar Water Heating Systems with Thermal Storage, shedding light on their potential to reshape the landscape of energy consumption worldwide.

Composite materials represent a revolutionary class of materials that have transformed the landscape of engineering and manufacturing. Unlike traditional materials such as metals, ceramics, or polymers, composites are engineered by combining two or more distinct constituents with different physical or chemical properties to create a material with enhanced performance characteristics. The resulting composite material exhibits synergistic properties that surpass those of its individual components, making it an attractive choice across various industries.Composites typically consist of a matrix material, which surrounds and binds a reinforcement material. The matrix serves as a support structure, while the reinforcement provides strength and other desired properties. The combination of these elements results in a material that can be tailored to meet specific performance requirements, including high strength, low weight, corrosion resistance, and durability.

2. LITERATURE REVIEW

In this section previous research work in this sector has been discussed

I.ZEGHIB et al. [11], in their research work has mentioned that the modelling of a residential solar water heating system is presented in this work. The outcomes of the simulations that were run Design for a solar system that heats water for heating in Constantine, Algeria. The system consists of a 200-liter storage tank and a 2-meter-square collector. The setup includes a water tank, a solar flat collector, and radiators, a storage tank, and an auxiliary energy source.

Schematic of the model is shown below

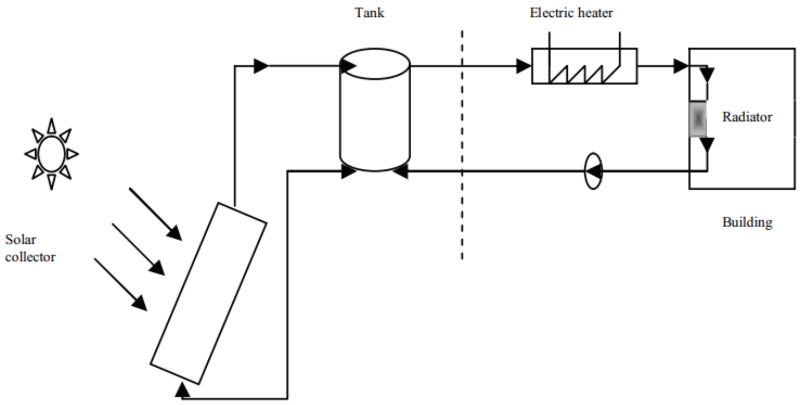

Figure 1 Schematic of model used in [11] research work

It is made up of an extra energy source, a water storage tank, and a flat plate solar collector. Water circulated from the collector transfers its heat to the water in the storage tank before returning to the collector to receive further solar energy heating. When the water in the storage tank is below 55ºC, an electric resistance heater is utilised as an auxiliary heater before the heated water is distributed via a radiator throughout the structure.To comprehensively analyze the entire system and investigate the functioning and behavior of the water heating system, a detailed simulation was executed. The simulation aimed to replicate the diurnal temperature variations of the storage fluid and quantify the energy fluxes exchanged within each component of the solar heating system—namely, the collection, storage, and distribution units.For this particular study, the simulation was conducted to calculate various parameters during the month of February, chosen due to its designation as the coldest month based on Constantine's weather data. The University of Constantine developed a simulation program written in the Fortran programming language to model the system's performance. This program systematically computes the solar gain for the specified system, taking into account factors such as radiation, ambient temperature, latitude, solar collector system parameters, storage tank volume, total energy demand for heating water, and daily load profiles. The time step employed for these calculations is set at two seconds, ensuring a detailed and accurate representation of the system's dynamics.

Duvuna et al. [12], in their research work has mentioned that the study endeavors to forecast the weekly performance of an active solar water heating system operating in the climatic conditions of Mubi, Nigeria, situated at a latitude of 10.26° and an altitude of 582 meters. Utilizing TRNSYS 16 software, the simulated system comprises several key components, including an integrated flat plate solar collector with a surface area of 2.10 m2, tilted at an angle of 10.26° from the horizontal. Additionally, the system incorporates a 100-liter thermally insulated vertical storage tank, a 20-Watt solar panel, and 4.8-Watt solar direct current (DC) pumps with a discharge rate of 240 liters per hour at a maximum head of 3 meters.

The simulation, conducted for the months of June to October, employs TRNSYS components (TYPE 109) to replicate the physical attributes of each real system component. These components, selected from the simulation studio's library, are intricately interconnected to emulate the operational dynamics of the entire system. Parameters characterizing each component (TYPE 109) were adjusted to align with the specific characteristics of the system under investigation. The simulation results unveil the system's capability to fulfill the daily hot water requirements, reaching temperatures of 68°C, 67.5°C, 53°C, 62.1°C, and 65.2°C for the respective months from June to October. These temperatures are achieved over an average duration of 15 hours per day. The findings suggest that the active solar flat plate water heater, with a surface area of 2.10 m2 and tilted at an angle of 10.26°, can consistently produce 100 liters of daily domestic hot water for the majority of the months.

However, it is noteworthy that in August, the tank temperature dropped to 53.5°C, indicating a potential need for auxiliary energy supplementation during this month. This insight suggests that the system may require additional support to meet hot water demands in specific scenarios, such as those encountered in industrial, hospital, and community-based organizational settings.

Amirull Danial et al. [13], in their research work has mentioned that a tangible solar water heater system was conceptualized, designed, and physically constructed alongside a MATLAB/SIMULINK model to facilitate mathematical simulation. The pre-designed system underwent simulation, focusing on two primary components: the flat plate solar collector and the thermal storage unit. The pivotal metrics assessed during this simulation were the efficiency levels of both the solar collector and thermal storage.A critical aspect considered in the evaluation was the total cost incurred each month, factoring in electricity consumption during the heating process necessitated by the electric heater. This holistic approach allowed for a comprehensive analysis, taking into account not only the performance metrics but also the economic implications associated with system operation.

In particular, the efficiency measurements for the solar collector and thermal storage components served as key indicators of the system's effectiveness in harnessing and retaining solar energy. Simultaneously, the evaluation of monthly costs provided valuable insights into the economic feasibility and sustainability of the solar water heater system. It is worth emphasizing that the MATLAB/SIMULINK model served as a versatile tool not only for the specific solar water heater system under consideration but also as a platform for future extensions to similar applications in the realm of solar energy systems. The adaptability of the simulation opens avenues for exploring diverse uses and potential benefits, thereby contributing to the ongoing advancement and optimization of solar technologies for various applications in the future. The proposed mode of prototype of solar thermal storage is shown in the figure below.

Figure 2 Prototype of solar thermal storage

The proposed prototype of flat plate solar collector is shown in the figure below

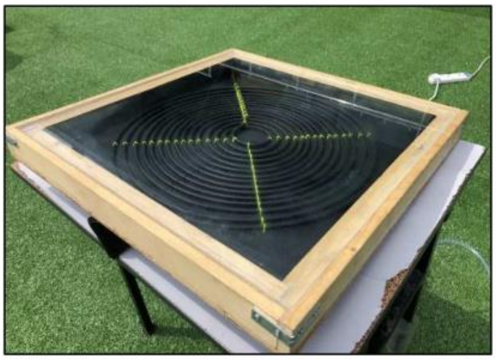

Figure 3 Flat plate solar collector

Ahmed Aisa et al [14], in their research work has mentioned that this paper introduces a solar thermal energy storage system designed for domestic water heating in a detached house environment. The focus lies on solar heating systems integrated with seasonal energy storage, a subject that has gained increasing attention in recent decades. Given the intermittent nature of solar energy availability, effective heat storage becomes an essential component in solar energy-based thermal systems within buildings.The primary goal of the modeling efforts is to ascertain the temperature of the storage tank and assess the heat loss characteristics of the entire system. The system design relies on specific equations and laboratory-derived data, incorporating parameters such as temperature, time, and flow rate. The modeling process employs a combination of BEopt and Matlab/Simulink tools to determine both the storage water temperature in the tank and the temperature within the house.

Within this designed system, the house incorporates two distinct heat sources: the hot water from the storage tank and solar energy utilized for heating. The outcomes of the modeling efforts reveal that the maximum temperature achieved in the storage tank is 82.4℃, while the interior temperature of the house ranges between 18℃ and 25.11℃. The heating demands for the house are quantified at 12,268 kWh/yr, contributing to the overall energy use of 19,537 kWh/yr. This research underscores the efficacy of the solar thermal energy storage system in meeting domestic water heating needs while providing insights into the temperature dynamics within the house. The findings contribute valuable information for future advancements in solar thermal energy applications, particularly those focused on enhancing energy efficiency and sustainability in residential settings.

Vikram M. et al [15], in their research work has mentioned that The primary objective of this project is to enhance the thermal efficiency of a flat plate collector in a solar water heater. To achieve this, a phase change material (PCM) is integrated into the flat plate collector, directly improving the heating rate of the solar water heater. The design of the solar water heater is meticulously crafted using SOLIDWORKS. The performance of the flat plate collector is further evaluated through ANSYS analysis, both with and without the use of PCM.The integration of PCM results in a notable increase in the efficiency of the solar collector, ranging from 7% to 20% when compared to scenarios where PCM is not utilized. This enhancement underscores the significant impact of incorporating PCM technology into solar water heating systems. Specifically, myristic acid and paraffin wax PCM exhibit exceptional thermal capacity and heat discharge properties.

The study emphasizes the versatility of PCM integration into solar collectors, showcasing it as an efficient means of storing and harnessing solar energy. By employing different types of systems integrated with phase change materials, the efficiency of the overall setup is markedly improved. The application of phase change materials in both cooling and heating systems serves a dual purpose: it enhances overall efficiency while simultaneously reducing electrical power consumption and greenhouse gas emissions. In particular, the heat storage unit, incorporating phase change materials, plays a pivotal role in optimizing the solar water heating system's performance. The findings from the ANSYS analysis indicate a noteworthy increase in efficiency, ranging from 6% to 12%, when transitioning from a solar collector to a solar water heater configuration. This study not only contributes to the development of an innovative experimental setup for solar water heating systems but also underscores the potential of PCM integration as a transformative approach for advancing solar energy utilization.

L Raji et al. [16], in their research work has mentioned that a comprehensive numerical experimental investigation was undertaken to formulate a model for an active solar water heating system designed to generate domestic hot water at a target temperature of 90°C. The study utilized Typical Meteorological Year (TMY 2) solar weather data specific to Maiduguri. Simulation was conducted using TRNSYS 16 software to assess the hourly thermal performance of the model. The TRNSYS deck file constructed for this purpose prominently features Type 109 as the main component, complemented by other necessary components.TMY 2 weather data for Maiduguri underwent processing to derive monthly average daily hot water values, with a focus on the recommended average day for each month. The design considerations were based on the weather conditions in the month of August. Simulation results indicate that an active solar system with a collector area of 2.04m², an inlet flow rate of 120kg/hour for hot water application, and tilted at an angle of 12° to the horizontal, can reliably produce a daily domestic hot water volume of 0.1m³, reaching the desired temperature of 90°C.

Validation of the model was conducted using statistical tools such as the Nash-Sutcliffe Coefficient Efficiency (NSE) and Root Mean Square Error (RMSE). The results revealed a high degree of accuracy, with NSE values of 82% and 96% for ambient temperature and storage tank temperature, respectively. This demonstrates the model's robust capability in predicting system performance during the conducted experiment.

Comparisons between different collector types indicated that the serpentine solar collector exhibited superior thermal performance during the early hours of each month. However, after 15:00 hours, the riser-header flat plate collector demonstrated better performance. This implies that the riser-header solar collector has an overall higher thermal efficiency than the serpentine solar collector, showcasing the nuanced performance characteristics of these collector types throughout the day.

The summary of the above mentioned literature review is given in the following table

Reference no.	Title	Research results	Software used	Future scope
11	Simulation of a solar domestic water heating system	This program systematically computes the solar gain for the specified system, taking into account factors such as radiation, ambient temperature, latitude, solar collector system parameters, storage tank volume, total energy demand for heating water, and daily load profiles	Simulation program written in the Fortran programming language	The presented results are theoretical and explanatory, one must in future work develop this system and verify all these simulation results.
12	Modelling and simulation of an active solar flat plate collector water heater	To forecast the weekly performance of an active solar water heating system operating in the climatic conditions of Mubi, Nigeria, situated at a latitude of 10.26° and an altitude of 582 meters	TRNSYS 16 software	Novel solar water heating configuration that uses three in-line fluid passages for hot water demand.
13	Modelling and Simulation of Solar Water Heating System (SWH) with Thermal Storage using Flat Plate Solar Collector	A tangible solar water heater system was conceptualized, designed, and physically constructed alongside a MATLAB/SIMULINK model to facilitate mathematical simulation	MATLAB/SIMULINK	A further extension to similar applications for solar energy systems can be used by the simulation for a various uses that could provide other significant benefits in future.
14	Modelling and simulation of a solar water heating system with thermal storage	The primary goal of the modeling efforts is to ascertain the temperature of the storage tank and assess the heat loss characteristics of the entire system. The system design relies on specific equations and laboratory-derived data, incorporating parameters such as temperature, time, and flow rate	combination of BEopt and Matlab/ Simulink tools	Not mentioned
15	Modelling and Simulation of Solar Water Heater Integrated with Phase Change Material in Solar Collector	Enhance the thermal efficiency of a flat plate collector in a solar water heater. To achieve this, a phase change material (PCM) is integrated into the flat plate collector, directly improving the heating rate of the solar water heater	SOLIDWORKS., ANSYS	Future research should focus on optimizing the design and configuration of PCM-based solar water heaters to further improve their performance and increase their adoption in residential and commercial applications.
16	Modeling and simulation of an active solar water	A comprehensive numerical experimental investigation was undertaken to formulate a model for	TRNSYS 16	Storage tank with higher capacity such as 200 or 300

	heating system for Maiduguri, Borno State, Nigeria	an active solar water heating system designed to generate domestic hot water at a target temperature of 90°C.		litres should be experimented.

3. RESULT

The comprehensive review of research papers on Solar Water Heating Systems with Thermal Storage highlights the pivotal role of advanced simulation tools like MATLAB and ANSYS. These platforms have consistently facilitated the modeling and simulation of complex thermal dynamics, enabling optimization of system efficiency and validation of experimental setups. Future prospects in this domain include the exploration of advanced modeling techniques such as machine learning algorithms and multi-physics simulations. Additionally, the integration of emerging materials like advanced phase change materials (PCMs) and a broader consideration of environmental and economic factors present promising avenues for further research. Real-world validation through experimental setups and field trials is essential to ensure the practical applicability and sustainability of proposed advancements. A holistic approach, which encompasses technical, economic, and environmental aspects, will contribute significantly to the development of more efficient and viable solar water heating systems with thermal storage.

4. CONCLUSION

In conclusion, the comprehensive review of research papers on Solar Water Heating Systems with Thermal Storage underscores the pivotal role played by advanced simulation tools like MATLAB and ANSYS in enhancing our understanding of these systems. Researchers have consistently utilized these platforms to model and simulate complex thermal dynamics, optimize system efficiency, and validate experimental setups. The future scope in this field holds exciting prospects, including the exploration of more advanced modeling techniques such as machine learning algorithms and multi-physics simulations. Additionally, the integration of emerging materials like advanced phase change materials (PCMs) and a broader consideration of environmental and economic factors present promising avenues for further research. Real-world validation through experimental setups and field trials will be crucial in ensuring the practical applicability and sustainability of proposed advancements. As the field progresses, a holistic approach that considers not only technical aspects but also economic and environmental implications will contribute to the development of more efficient and viable solar water heating systems with thermal storage.

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