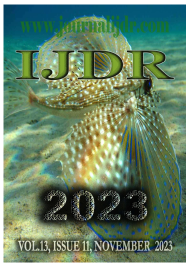
Available online at http://www.journalijdr.com

IJDR

ISSN: 2230-9926

International Journal of Development Research
Vol. 13, Issue, 11, pp. 64061-64069, November, 2023
https://doi.org/10.37118/ijdr.27172.11.2023



RESEARCH ARTICLE

OPEN ACCESS

ANALYZING HEAT TRANSFER FLUIDS FOR IMPROVED SOLAR WATER HEATER PERFORMANCE

***Anand Patel**

Mechanical Engineer, Mechanical Engineering Department, LDRP- Institute of Technology & Research, Gandhinagar, Gujarat, India

ARTICLE INFO

Article History:
Received 27th August, 2023
Received in revised form
06th September, 2023
Accepted 17th October, 2023
Published online 27th November, 2023

KeyWords:

Solar Applications, Solar panel, Temperatures, Hot water tank. Cold water tank, Insulators, Fluid, Simulink.

****Corresponding author: Anand Patel***

ABSTRACT

The First Chapter, discussed the Research background in the first section due to its potential to lower carbon emissions and energy costs, the use of solar water heaters for an environmentally friendly power alternative has increased. Also, it explained Current issues in that section Although rooftop water heater technology has advanced, choosing and optimizing heat transfer fluids (HTFs) continues to be a difficult task. The Second Chapterexplained first section is Passive solar water heating system in a passive solar water heating system uses the concept of radiation from the sun to heat water for domestic, commercial, or industrial usage without the use of active mechanical equipment like pumps or fans. It has also discussed Active solar water heating system as well as aspects affecting the performance of a solar water heater. Effective implementation of the Simulink model of the solar water heater has been adequately structured and interpreted. Additionally, proper implication over the entire work has been structured within this paper.

Citation*: *Anand Patel. 2023. *"*Analyzing heat transfer fluids for improved solar water heater performance". *International Journal of Development Research*, 13, (11), 64061-64069.

INTRODUCTION

The proper of solar technology, notably solar water heaters, has been spurred by the growing emphasis on renewable sources of energy on a global scale. Throughutilize of solar energy for both home and commercial uses, these systems provide a green substitute for conventional water heating techniques. The "*heat transfer fluid (HTF)***"** used in the system has a major effect on the effectiveness and performance of the solar water heaters. The purpose of this study is to analyze and assess various HTFs inside order to the grout the effectiveness of solar water heaters. The study aims to provide helpful understanding into how HTF features relate to system design elements to affect overall efficiency by utilizing computational tools like MATLAB.

Research background: Due to its potential to lower carbon emissions and energy costs, the use of "*solar water heaters"* for an environmentally friendly power alternative has increased. These systems' effectiveness and dependability are impacted by heat-transferring fluids (HTFs), which are a crucial component. Understanding the interaction between HTF characteristics and system behavior is essential in the context of Enhance the performregard "*solar water heaters*". This study extends previous research by using MATLAB for in-depth numerical analysis. In line of the global push for eco-friendly energy options, research into HTF features and their effect on solar water heater efficiency promotes sustainable energy solutions (Sheikholeslami *et al*., 2021).

Research aim and objectives

Aim: The main aim of the paper is to evaluate the "*efficiency of the heat transfer fluid"* of a designed "*solar water heater system*".

Objectives: Attainment of this significant aim is comprised of different objectives that are necessary to obtain significant outcomes for the system. The objectives are as follows:

- To evaluate all the basic principles of a "*solar heater*" and the factors that impact such a system.
- To optimize the ***"****solar water heater*" factors and effectiveness in terms consider the heat transfer medium.
- To signify the advanced implementation process of such implementation.
- To design an effective system using simulink software, MATLAB which is adequate for the aim.

Research questions: The research questions have been constructed based on the structured objectives of the model. These are responsible for providing adequate optimization of the determined outcomes. The Finding questions are structured as follows:

- What are the most common factors of a solar heater and what is the basic principle of such a system?
- How to optimize the effectiveness of the solar water heater and the heat transfer medium?
- What is the most advanced implementation process of solar water heater system design?
- How to utilize the simulink software, MATLAB for implementing the solar water heater system?

Current issues: Although rooftop water heater technology has advanced, choosing and optimizing heat transfer fluids (HTFs) continues to be a difficult task. The overall efficacy and efficiency of the system are substantially impacted by the HTF selection. Comprehensive studies on the impacts of various HTF features on the operation of solar water heaters under diverse circumstances are, however, lacking. This lack of information makes it difficult to choose an HTF with confidence, which may result in less-than-ideal system performance and slow acceptance of solar water heaters as a workable renewable energy alternative (Vengadesan and Senthil, 2020).

LITERATURE REVIEW

The studies from (Patel, 2023; Patel, 2013; Patel, Anand, 2023; 2023f) Patel Anand *et al*. for Solar Air and Water Heater (Anand Patel, 2023 and Patel, Anand, 2023) Patel Anand *et al*. for Solar Cooker (Patel, Anand, 2023). Anand Patel *et al*. for Heat Exchange studies include thermal performance analysis to increase heat transfer byvarying the dimensions of solar collector or adding different materials to it which is similar to the current study in this article where heat transfer fluids are reviewed for improvement in solar water heater performance.

Passive solar water heating system: A passive solar water heating system uses the concept of radiation from the sun to heat water for domestic, commercial, or industrial usage without the use of active mechanical equipment like pumps or fans. It is an environmentally friendly and energy-efficient means of heating water. This technology uses natural heat transfer processes, which makes it an economical and cost-effective replacement for traditional water heating techniques (Zheng, 2020). A solar collector, a storage tank, and a distribution system make up the fundamental parts of a passive solar hot water system. Turbulence and the effect of greenhouses are used by the system to move and circulate heat.

Working Principle:

- A vital component that absorbs sunlight and transforms it into thermal energy is the solar collector. It typically has a hollow tube or flat-plate construction with a clear cover over a dark absorbent surface (Wang, 2021). As the absorber surface warms up from solar radiation absorption, heat is transmitted to the water flowing through the collector.
- ***Storage Tank:*** A storage tank serves as a thermal reservoir by receiving the hot water from the collector. The tank is adequately insulated to reduce heat loss, ensuring that the heated water is maintained for a long time, even at night or under overcast conditions.
- ***Distribution System:*** The system of distribution enables the heated water to be utilizeconsider a variety regard application, including space heating and household hot water supply (Verma, 2020). Due to the difference inside temperature between the warm water in the tank where it is stored and the less warm water in the distribution tubes, circulation happens spontaneously. Pumps are not necessary thanks to this convection technique (Abdelsalam, 2020).

Advantages

- ***Energy Efficiency:*** In comparison to traditional systems, passive solar-powered water heaters require little to no electrical power input, which results in cheaper operating costs and a smaller environmental effect (Gudeta, 2022).
- Passive systems are more reliable and long-lasting because they don't have any moving parts or electronic gadgets to cause mechanical problems.
- ***Low Maintenance:*** Because passive systems are devoid of pumps along with other mechanical elements, maintenance is simplified and cost-effectively decreased (Pugsley, 2019).
- **Environmental Benefits:** Active systems help reduce the release of greenhouse gases and carbon footprint by utilizing solar energy (Elarem, 2021).

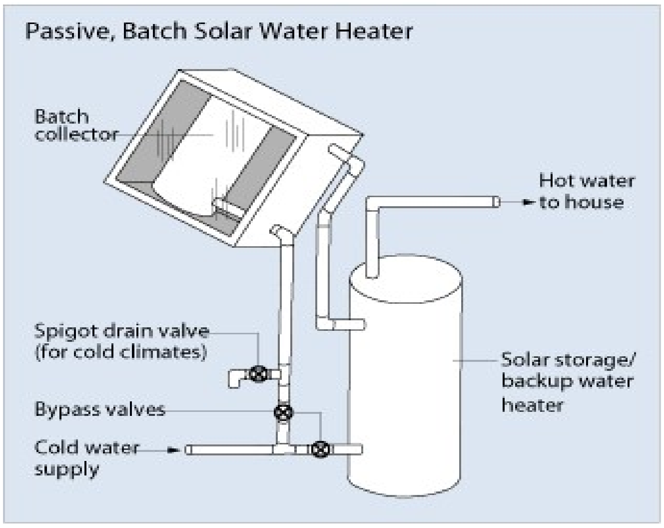


Figure 1. Solar Water Heaters

Active solar water heating system: A mechanical system, such as pump and controllers, is used in an active solar water heating system to improve the circulation and transmission of the energy from the solar collectors towards a storage tank. This device works even in less sunny situations because it uses external energy, usually electricity, to control the fluid circulation (Krishna, 2020). It offers a dependable and effective technique to use solar energy for heating water in homes, factories, and commercial settings.

Working Principle:

- ***Solar Collector:*** Active systems, like passive ones, have solar collectors that take in light and transform it into warmth. Active systems, on the other hand, use pumps to speed up the flow of heat transfer fluid (HTF) into the collector, improving the exchange of heat procedure (Ghenai, 2021).
- ***Heat Transfer Fluid (HTF):*** In an active system, HTF takes heat from the collection device and transports it to the heat exchangers in the storage tank. It is frequently a blend of water and antifreeze. The water in the storage tank will receive the heat from the fluid in an effective manner (Qi, 2019).
- ***Storage tank and Heat Exchanger:*** The water in the retention tank receives heat from the HTF through the heat converter. The hot water is then ready for usage in the home or for heating a room (Patel, 2023).

Advantages:

- ***Reliability:*** Because active systems have the potential to utilize external energy for fluid circulation, they are ideal for a wider range of climates and can deliver consistent hot water at all times, even on cloudy days.
- ***Efficiency:*** Compared to passive systems, pumps' managed circulation improves heat transfer effectiveness while which

may contribute to improved system efficiency overall (Verma, 2020).

- ***Flexibility:*** variable space requirements and consumption patterns can be accommodated by designing systems that operate with variable collector and storage tank layouts.

of the liquid that transfers heat, including temperature conductivity and heat capacity (Sheikholeslami, 2021).

System Sizing: For optimum performance, the capacity of the system must be properly matched with the hot water demand.

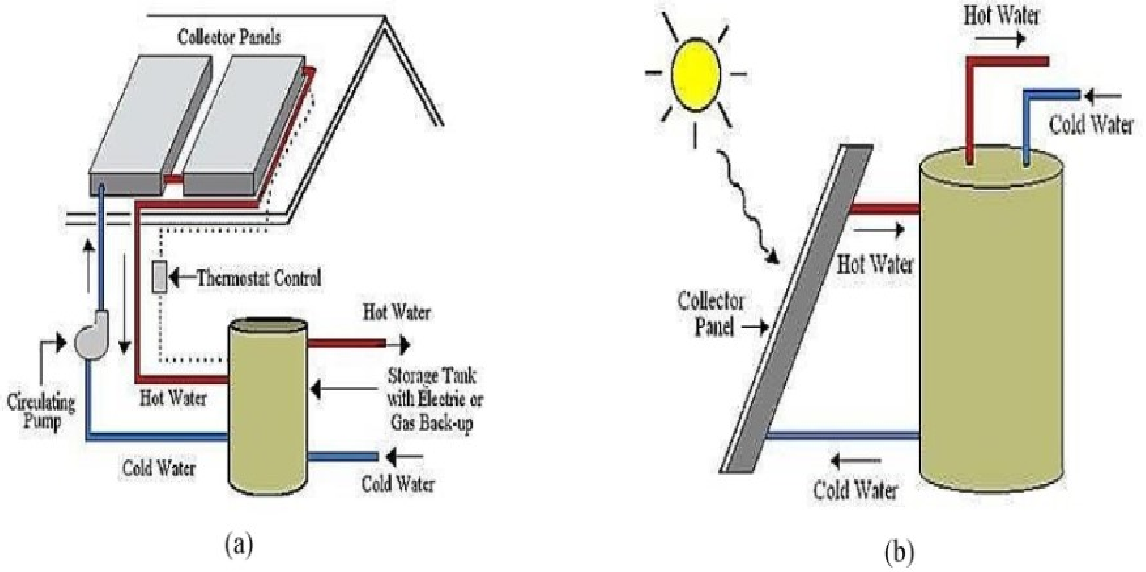


Figure 2.2.1. Active Type Solar Water Heater System

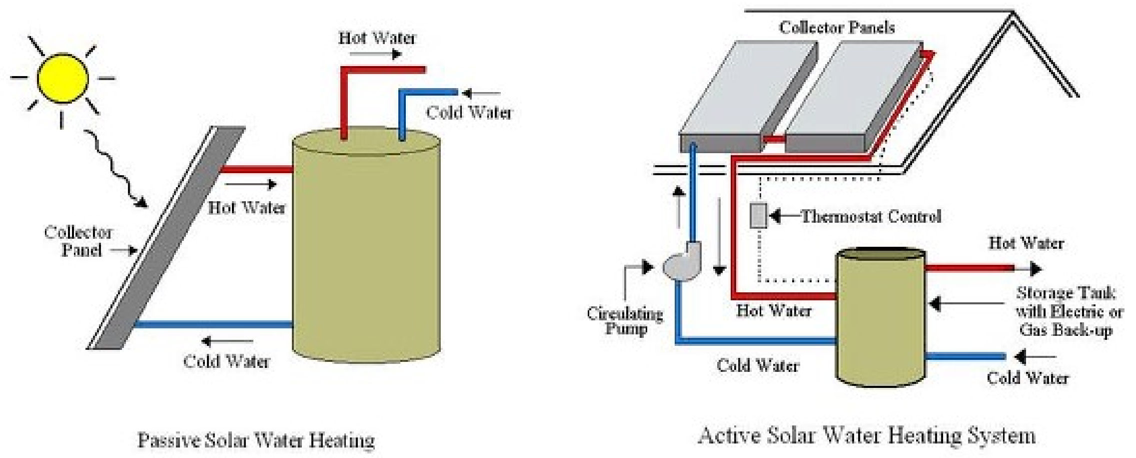


Figure 2.3.1. Residential Solar Water Heater

Aspects affecting the performance of a solar water heater: A solar water heater's performance is dependent on a number of important elements that together influence how effectively it can use the sunlight for water heating:

Solar Insolation: One of the key variables affecting system performance is the amount of solar radiation that is present in a certain area. Higher insolation rates often produce better results since they absorb more energy (Verma, 2020).

Collector Efficiency: The solar collector's ability to gather and transmit solar energy to the fluid that transfers heat is significantly influenced by the workmanship and design of the collectors. Efficiency is greatly influenced by factors including absorber materials, coatings, and glazing characteristics (Panahi, 2019).

Orientation and Tilt: Optimal solar exposure is achieved by synchronizing the collector's direction and tilt distance with the path of the sun. This improves the capture of energy and system effectiveness.

Heat Transfer Fluid: The effectiveness of heat transfer from the collection vessel to the water is directly influenced by the properties Oversized equipment can result in energy waste, while underpowered systems may not be able to meet objectives.

Climate and weather: The local climate, which includes elements like the amount of sunlight and the surrounding temperatures, has a direct impact on the system's overall effectiveness.

Storage tank insulation: The storage tank's proper insulation reduces heat loss, ensuring that the hot water keeps its temperature for a longer period of time (Zayed *et al*., 2019).

Usage Patterns: By planning system maintenance strategically and scheduling system activities around peak water temperature usage times, system efficiency is increased (Sheikholeslami and Farshad, 2021).

Maintenance: To maintain the system's effectiveness and longevity, frequent maintenance procedures like cleaning collector surfaces and checking for leaks are essential.

Control systems: By integrating electronic control mechanisms, fluid distribution, and temperature, the the operation of pumps may be precisely controlled, which improves system performance (Zhou, 2020). The maximal performance efficiency of a solar hot water heater requires balancing and addressing these complex elements during design, installation, and continuous operation. Users can maximize the use of solar power that is renewable by carefully weighing these factors, reaping the rewards for cost savings and sustainability via water use for heating (Said, 2021).

METHODOLOGY

***Choice of method*:** A thoughtful and intelligent choice of study methodology becomes essential in the quest to understand the complex processes that affect the effectiveness of solar water heaters. For this reason, adopting an approach to research called interpretivism is in perfect harmony with the subject substance's complex and contextually dependent nature (Eisapour, 2020). The philosophy of interpretivism recognizes the importance of subjective feelings and aims to elucidate the fundamental significance and interpretations people give to things. Understanding stakeholders' viewpoints and opinions can be helpful in understanding how solar water heater effectiveness is affected by a variety of circumstances. The investigation of these numerous aspects is well suited by a descriptive study strategy, which enables a methodical and in-depth analysis of the phenomena without changing its natural environment. This design makes it easier to record and analyze existing conditions, which makes it the perfect choice for examining the complex interactions that determine the effectiveness of solar water heaters. The rigor of theinvestigation is further increased by a deductive approach, which is characterized by the investigation of assumptions and the confirmation of theories (Badiei, 2020). The investigation can identify assumptions and transferable patterns by developing hypotheses based on pre-existing theoretical frameworks and carefully testing those against empirical evidence. Additionally, by including MATLAB in the study technique, the analytical capabilities are improved. The computational capability of MATLAB enables complex modeling and simulations, enabling researchers to statistically assess many aspects affecting the performance of solar water heaters. These simulations can aid in a thorough knowledge of how the system operates in a variety of situations and provide predicative insights (Kumar, 2020).

Justification of chosen methods: The choice of research methodology plays a crucial role in determining the breadth, reliability, and applicability of the study. In light of the nature of the study purpose and the complexity of the subject matter, the chosen methodologies in this situation, interpretivism theory of research, descriptive research design, deductive approach, and the use of MATLAB—find solid justification. Because it recognizes the complex interplay of human viewpoints and experiences in the area of solar water heater efficiency, the approach to research known as interpretivism is ideally matched. Adopting an interpretive attitude enables a nuanced examination of these subjective elements because the performance of such devices is influenced by a variety of factors, including user perceptions (Evangelisti, 2019). The descriptive research design is in harmony with the phenomena being studied multidimensional nature. The robustness of the research is strengthened by the deductive methodology, which is based on theory and hypothesis testing. Testing hypotheses derived from known theories allows systematic examination and verification of anticipated correlations, which strengthens the reliability of the findings considering the complexity of the solar water heater systems (Abd-Elhady *et al*., 2020). The use of MATLAB improves the analytical capacity of the investigation. Researchers may simulate and model complex system behaviors using MATLAB's computing capabilities, enabling a quantitative assessment of the effects of various variables on effectiveness. This analytical accuracy improves the study's capacity to extract valuable insights from complicated data (Mao and Zhang, 2020).

Use of tools and technologies: In this research project, state-of-the-art equipment and methods are essential to improving the accuracy and breadth of the study. The incorporation of MATLAB, a potent computational tool, enables sophisticated modeling and computations and makes it possible to quantitatively analyze the complex dynamics of solar water heaters (Manoj Kumar, 2020). Researchers can forecast system behavior, improve variables, and find patterns that help them make decisions thanks to this technology-driven method. By utilizing these techniques, the research breaks through conventional barriers and provides a thorough and data-driven investigation of the variables influencing the effectiveness of solar water heaters, thus advancing the field of sustainable energy (Sharafeldin, 2019).

Ethical consideration: Thorough ethical considerations are of the utmost importance throughout this investigation. It is crucial to guarantee participant privacy, informed consent, and open data use (Zayed *et al*., 2019).

RESULTS AND DISCUSSION

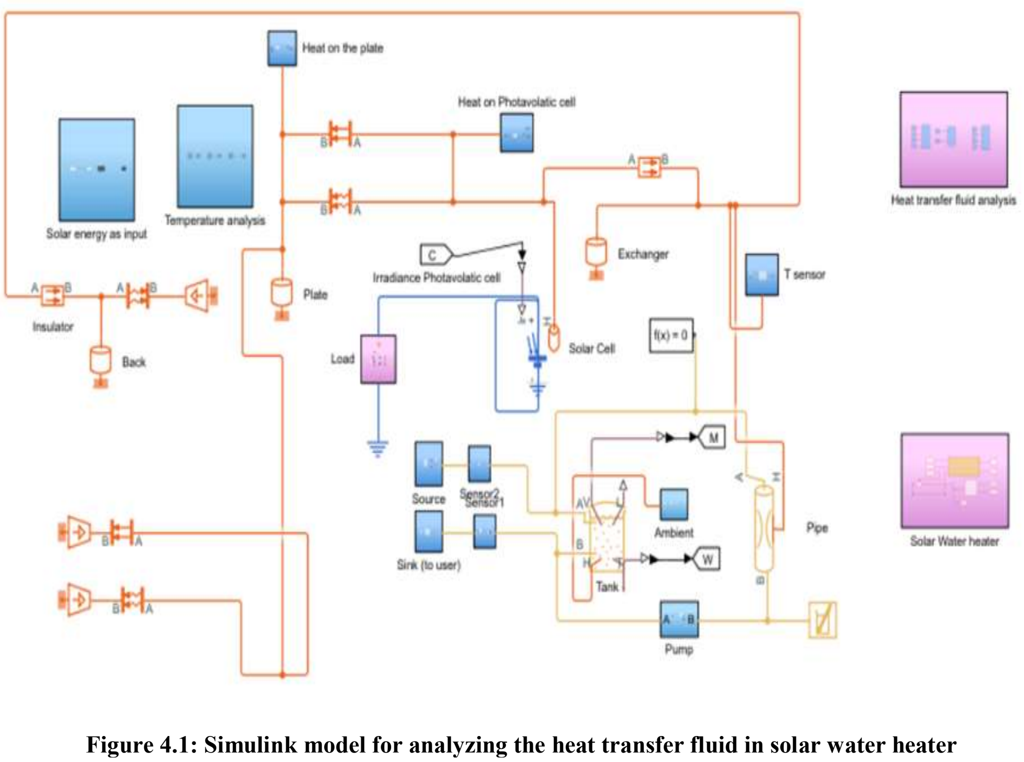


Figure 4.1: Simulink model for analyzing the heat transfer fluid in solar water heater

The research procedure will follow ethical standards and look for institutional review boards' clearance. Additionally, the results shall be disseminated in a responsible manner while protecting participant privacy and intellectual property rights. This moral strategy upholds the values of responsible and objective inquiry, protects the rights of consumers, and upholds the integrity of the research (Said *et al*., 2022). The figure is representing the solar water heater with a fluid medium of heat transfer. The Simulink model is significantly comprised of different components including an insulator, photovoltaic cell, exchanges, load, water heater system, pump, and plate. These components can be integrated under three different groups such as the solar collector, hot water storage tank, and cold water tank and heat transfer fluid and components. This typical system of water heaters based on the solar energy involves in basic concept of absorbing solar radiation and using it as a heating source through a fluid medium. The collectors are responsible for the active absorption of solar radiation through the plate and photovoltaic cells. The higher-density cold water moves downward and the hot water which is less dense moves upward and is stored within the storage tank. A sufficient number of collectors are required to collect the desired amount of heat from the solar energy which can be arranged in series or parallel patterns and connections. This entire system can actively provide hot water of 60 to 80 degrees C.

Cold storage tank: The hot water storage tank is actively connected to two different sources and two sinking blocks as represented in the figure. Two different connections of ambient and pump also can be observed that are responsible for providing an adequate source of water and heating factors.

Hot water tank and principles: The cold water gets heated with the structured connections and principles by which the hot water passes to the storage tank through different insulated pipelines.

```
****** Efficiency Calculation *********

Total input energy from the sun in the period: 43.7853 kWh
Average input energy from the sun per day: 14.5951 kWh/day

Total absolute thermal energy in the water supplied to the user: 26.4739 kWh
Total absolute thermal energy in the water extracted from the source: 16.5049 kWh

Total used thermal energy (sink - source): 9.9689 kWh
Average used thermal energy per day (sink - source): 3.323 kWh/day

Thermal efficiency: 0.22768
Total efficiency: 0.39971

**************************************
```

Figure 4.2. Efficiency calculation of the model

The figure represents the efficiency of different factors related to the solar water heater that has been structured with the simulation software MATLAB. The total input energy obtained from the Sun in a significant period is about 43.785 kWh as measured by the model. The average input of solar energy per day has been measured as 14.59 kWh.

The expected source of the water is about 16.3504 kWh and the total thermal energy supplied to the water is about 26.479 kWh as represented in the outcome of the efficiency measurements. The total thermal energy between the sink and the source has been measured up to 9.9689 kWh and per day it is 3.323 kWh. Thus, in conclusion, the system is responsible for providing a thermal efficiency of 0.22768 and a total efficiency of 0.39971 as obtained from the simulation of the model.

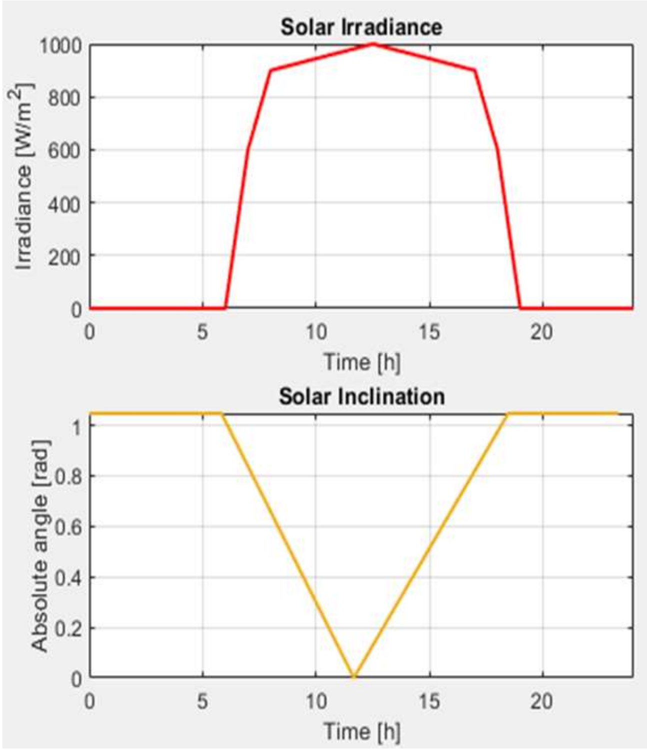


Figure 4.3. Solar radiation insertion reading

The graph has been obtained from the input of the solar variables which are solar irradiation and solar inclination received on the solar plates.

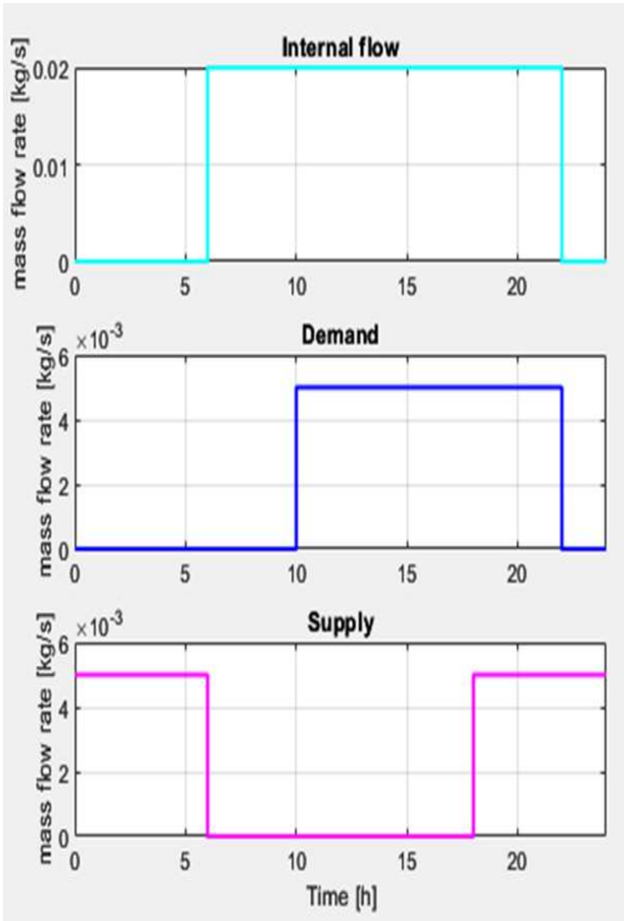


Figure 4.4. Pump flow insertion reading

The graph is representing the reading of three different variables of the scope including internal flow, demand, and supply.

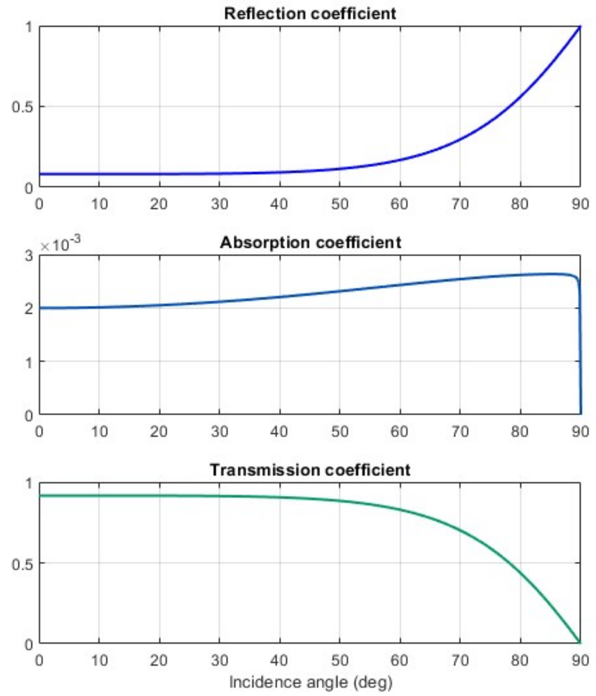


Figure 4.5. Solar water heater coefficient reading

This figure represents the obtained graph of the coefficients of the solar water heater system. It is significantly reflecting the rate of heat absorption, reflection, and transmission performed by the system. The discussion part goes into the learnings from this study on how to improve the performance of solar water heaters by using MATLAB simulations (Riahi, 2020). We can uncover the possibilities for improving solar water heater systems and promoting environmentally friendly energy sources by analyzing the results and considering their ramifications. This research has benefited greatly from the use of MATLAB, in a number of ways. The development of complex mathematical representations was made possible by the computational power of MATLAB, allowing for the simulation of intricate heat transfer behaviors within solar water heaters (Riahi, 2020). Researchers were able to objectively examine the effects of numerous parameters on the system's operation thanks to the aforementioned simulations, which were based on actual events data and assumptions. This level of analytical accuracy provided important discoveries that may not have been possible through solely testing by observation (Nidhul, 2020). The significance of heat transfer fluids (HTFs) in rooftop water heater efficiency was revealed using MATLAB simulations. The simulations made it possible to quantify the effects of changing HTF parameters, including electrical conductivity and heat capacity, on heat conveyance efficiency. As it offers a data-driven method for choosing and optimizing HTFs for particular conditions of operation, this finding has immediate applications for system architects and manufacturers (Farhana, 2019). The selection of fluids that produce the best performance is based on how various HTFs interact with collector designs, meteorological circumstances, and consumption patterns as shown by MATLAB simulations (Akram, 2020). The study also clarified collector design elements that have a big impact on overall system effectiveness. MATLAB simulations were used to examine different collector setups and highlight the effects of absorber coating and glazing materials. For system designers looking to maximize the harvesting of energy while taking into account practical limits, these insights are priceless (Patel, 2023). The forecasting powers of MATLAB simulations are an additional important contribution. Researchers can predict system behavior over a period of time by performing simulations under various conditions. Planning preventive maintenance is made much easier by this understanding (Sheikholeslami, 2020). By assisting in the early detection of possible bottlenecks, component failures, or suboptimal circumstances, predictive modeling can help to reduce operational disruptions and improve system reliability. Intricate elements like fluctuating fluid flow prices, pressure harm, and uneven solar radiation dispersion can be taken into account when heat transfer models in MATLAB are further refined (Qiu, 2019). The accuracy of simulators can be improved and more accurate predictions of system behavior can be made by calibrating them using real-world data (Kabeel *et al*., 2020). The use of MATLAB simulations to enhance the performance of solar water heaters is consistent with global initiatives to use sustainable energy sources (Jamshed *et al*., 2021). The study aids in the wider adoption of clean energy technologies by maximizing system design, element selection, as well as upkeep techniques. This has wide-ranging effects on cutting carbon emissions, bringing down energy prices, and promoting energy independence (Said, 2021). Dynamic mathematical models that take startup, shutdown, and transient behavior into consideration can be used to provide insights into everyday operations and prospective battery storage options (Li, 2019). Adaptive management and fault detection are made possible by combining machine learning techniques with MATLAB simulations to create predictive models based on historical data (Liu *et al*., 2020).

FUTURE WORK

This study opens the door to a wide range of potential future projects, all of which have the potential to further our knowledge of solar water heating efficiency and change the face of green technology (Xiong, 2021) Here are a few intriguing directions that beg for more investigation:

Innovative Modeling Methods: A major step towards moving beyond MATLAB is adopting cutting-edge CFD (computational fluid dynamics) software (Ahmadi, 2019). This would allow for complex simulations that accurately reflect real-world situations by digging into the nitty-gritty of fluid dynamics, thermal transfer, and system behavior (Awais, 2021).

Long-Term Quality Analysis: Including long-term field investigations in research perspectives gives an intriguing possibility. A lot of empirical insights on changing seasons and maintenance needs can be gained through monitoring solar-powered water heaters over an extended length of time under a variety of meteorological conditions and user practices (Shafieian, 2019).

IoT Integration and Data Analytics: The management of solar water heaters may be completely transformed by the integration of Internet of Things (IoT) devices and powerful data analytics (Yao, 2020). This route has the prospect of raising performance to previously unheard-of heights by enabling continuous evaluation, predictive maintenance ideas, and adaptable optimization (Eltaweel, 2019).

Studies of comparison: The canvas of comparison is open for research. It is hoped that comparing various solar water heater technologies, such as active and passive systems and heat transfer fluids, will reveal subtle realities that will help in system selection (Eltaweel, 2019).

Exploration of Novel Materials: Materials and coatings are also subject to innovation. By investigating unorthodox materials for solar energy harvesting and storage tank construction, materials with greater heat absorbing and retention properties might be discovered, increasing system efficiency (Ramesh, 2022).

Socioeconomic Impact Assessment: Looking at the bigger picture, it is important to assess the socioeconomic effects of the widespread use of solar water heaters (Sheikholeslami and Ebrahimpour, 2022). This research can highlight energy savings, smaller environmental footprints, and economic viability—all of which help us understand the effects of this technology more thoroughly (Wang, 2020). Understanding user behavior is the key to developing solar water heaters in a way that is more considerate of the needs of people. Researchers can create efficient interventions by looking into usage trends, adoption hurdles, and tactics for promoting sustainable energy behaviors (Sadeghi, 2020).

CONCLUSION

This research has traveled a diverse landscape that weaves together technology, environment, and human behaviors in its quest to comprehend and improve the efficiency of solar water heating systems. The investigation produced informative results and set the stage for future developments in the use of sustainable energy. The adventure started by exploring the various elements affecting the performance of solar water heaters. Each component, from the amount of sunlight and collector effectiveness to heat fluid transfers including user behaviors, is crucial in determining the system's total efficiency. The detailed examination of these factors revealed the complex web of connections that must be carefully maintained in order to get the best performance. The chosen technique, which included a descriptive study design, a deductive approach, and Interpretivism as a theoretical philosophy, was crucial in helping to understand the intricacies of solar water heater systems. A holistic examination of multiple factors, incorporating both quantitative models and qualitative insights, was made possible by the methodological synergy. By enabling complex simulations and modeling, the inclusion of MATLAB as a computer program improved the research. These simulations gave us a quantitative lens through which to examine the constantly changing actions of solar water heaters in various environments. The outcomes of MATLAB-powered analysis not only supported theoretical presumptions but also opened the door to real-world insights that may be used to improve system functioning and design. As this investigation comes to a close, it is clear that the field of solar water heaters is characterized by both potential and difficulties. The future holds a variety of possibilities for investigation, including enhanced modeling methods, long-term performance assessments, IoT integration, and comparison research. These options promise to improve solar water heating' effectiveness, resiliency, and impact, strengthening their contribution to environmentally friendly energy sources. In the big picture, this research supports the appeal for appropriate energy use and environmentally friendly technologies that is being made throughout the world. The consequences of the discoveries made here go beyond the scope of the study, reverberating across families, businesses, and decision-making spheres.

REFERENCES

Abd-Elhady, M.S., Abd-Elkerim, A.N.A., Ahmed, S.A., Halim, M.A. and Abu-Oqual, A., 2020. Study the thermal performance of solar cookers by using metallic wires and nanographene. *Renewable Energy,* 153, pp.108-116.

Abdelsalam, M.Y., Teamah, H.M., Lightstone, M.F. and Cotton, J.S., 2020. Hybrid thermal energy storage with phase change materials for solar domestic hot water applications: Direct versus indirect heat exchange systems. *Renewable Energy,* 147, pp.77-88.

Ahmadi, M.H., Ghazvini, M., Sadeghzadeh, M., Nazari, M.A. and Ghalandari, M., 2019. Utilization of hybrid nanofluids in solar energy applications: a review. *Nano-Structures & Nano-Objects,* 20, p.100386.

Akram, N., Sadri, R., Kazi, S.N., Zubir, M.N.M., Ridha, M., Ahmed, W., Soudagar, M.E.M. and Arzpeyma, M., 2020. A comprehensive review on nanofluid operated solar flat plate collectors. *Journal of Thermal Analysis and Calorimetry,* 139, pp.1309-1343.

Anand Kishorbhai Patel, 2023. Technological Innovations in Solar Heater Materials and Manufacturing. *United International Journal for Research & Technology* (UIJRT), 4(11), pp13-24.

Anand Patel, "Comparative Thermal Performance Analysis of Circular and Triangular Embossed Trapezium Solar Cooker with and without Heat Storage Medium", *International Journal of Science and Research (IJSR)*, Volume 12 Issue 7, July 2023, pp. 376-380, https://www.ijsr.net/getabstract.php?paperid=SR23612004356

Anand Patel, 2023, Heat Exchangers in Industrial Applications: Efficiency and Optimization Strategies, *International Journal of Engineering Research & Technology (IJERT)* Volume 12, Issue 09 (September 2023), DOI: 10.17577/IJERTV12IS090003 (https://www.ijert.org/research/heat-exchangers-in-industrial-applications-efficiency-and-optimization-strategies-IJERTV12IS090003.pdf).

Awais, M., Ullah, N., Ahmad, J., Sikandar, F., Ehsan, M.M., Salehin, S. and Bhuiyan, A.A., 2021. Heat transfer and pressure drop performance of Nanofluid: A state-of-the-art review. *International Journal of Thermofluids,* 9, p.100065.

Badiei, Z., Eslami, M. and Jafarpur, K., 2020. Performance improvements in solar flat plate collectors by integrating with phase change materials and fins: A CFD modeling. Energy, 192, p.116719.

Eisapour, M., Eisapour, A.H., Hosseini, M.J. and Talebizadehsardari, P., 2020. Exergy and energy analysis of wavy tubes photovoltaic-thermal systems using microencapsulated PCM nano-slurry coolant fluid. *Applied Energy,* 266, p.114849.

Elarem, R., Alqahtani, T., Mellouli, S., Aich, W., Khedher, N.B., Kolsi, L. and Jemni, A., 2021. Numerical study of an Evacuated Tube Solar Collector incorporating a Nano-PCM as a latent heat storage system. *Case Studies in Thermal Engineering,* 24, p.100859.

Eltaweel, M. and Abdel-Rehim, A.A., 2019. Energy and exergy analysis of a thermosiphon and forced-circulation flat-plate solar collector using MWCNT/Water nanofluid. *Case Studies in Thermal Engineering,* 14, p.100416.

Eltaweel, M. and Abdel-Rehim, A.A., 2019. Energy and exergy analysis of a thermosiphon and forced-circulation flat-plate solar collector using MWCNT/Water nanofluid. *Case Studies in Thermal Engineering,* 14, p.100416.

Evangelisti, L., Vollaro, R.D.L. and Asdrubali, F., 2019. Latest advances on solar thermal collectors: A comprehensive review. *Renewable and Sustainable Energy Reviews*, 114, p.109318.

Farhana, K., Kadirgama, K., Rahman, M.M., Ramasamy, D., Noor, M.M., Najafi, G., Samykano, M. and Mahamude, A.S.F., 2019. Improvement in the performance of solar collectors with nanofluids—A state-of-the-art review. *Nano-Structures& Nano-Objects,* 18, p.100276.

Ghenai, C., Kabakebji, D., Douba, I. and Yassin, A., 2021. Performance analysis and optimization of hybrid multi-effect distillation adsorption desalination system powered with solar thermal energy for high salinity sea water. Energy, 215, p.119212.

Gudeta, M.S., Atnaw, S.M., Shibeshi, M. and Gardie, E., 2022. Performance analysis of solar water heater system with heat pipe evacuated tube collector on Moha soft drink industries in Ethiopia. *Case Studies in Thermal Engineering,* 36, p.102211.

Jamshed, W., Nisar, K.S., Ibrahim, R.W., Shahzad, F. and Eid, M.R., 2021. Thermal expansion optimization in solar aircraft using tangent hyperbolic hybrid nanofluid: A solar thermal application. Journal of Materials Research and Technology, 14, pp.985-1006.

Kabeel, A.E., Sathyamurthy, R., Manokar, A.M., Sharshir, S.W., Essa, F.A. and Elshiekh, A.H., 2020. Experimental study on tubular solar still using Graphene Oxide Nano particles in Phase Change Material (NPCM's) for fresh water production. *Journal of Energy Storage,* 28, p.101204.

Krishna, Y., Faizal, M., Saidur, R., Ng, K.C. and Aslfattahi, N., 2020. State-of-the-art heat transfer fluids for parabolic trough collector. *International Journal of Heat and Mass Transfer,* 152, p.119541.

Kumar, P.M. and Mylsamy, K., 2020. A coPamprehensive study on thermal storage characteristics of nano-CeO2 embedded phase change material and its influence on the performance of evacuated tube solar water heater. *Renewable Energy,* 162, pp.662-676.

Li, Z., Ma, T., Zhao, J., Song, A. and Cheng, Y., 2019. Experimental study and performance analysis on solar photovoltaic panel integrated with phase change material. Energy, 178, pp.471-486.

Liu, M., Riahi, S., Jacob, R., Belusko, M. and Bruno, F., 2020. Design of sensible and latent heat thermal energy storage systems for concentrated solar power plants: Thermal performance analysis. *Renewable Energy*, 151, pp.1286-1297.

Manoj Kumar, P., Mylsamy, K., Alagar, K. and Sudhakar, K., 2020. Investigations on an evacuated tube solar water heater using hybrid-nano based organic phase change material. *International Journal of Green Energy,* 17(13), pp.872-883.

Mao, Q. and Zhang, Y., 2020. Thermal energy storage performance of a three-PCM cascade tank in a high-temperature packed bed system. *Renewable Energy,* 152, pp.110-119.

Nidhul, K., Kumar, S., Yadav, A.K. and Anish, S., 2020. Enhanced thermo-hydraulic performance in a V-ribbed triangular duct solar air heater: CFD and exergy analysis. Energy, 200, p.117448.

Panahi, R., Khanjanpour, M.H., Javadi, A.A., Akrami, M., Rahnama, M. and Ameri, M., 2019. Analysis of the thermal efficiency of a compound parabolic Integrated Collector Storage solar water heater in Kerman, Iran. *Sustainable Energy Technologies and Assessments,* 36, p.100564.

Patel, A (2023). ""Comparative analysis of solar heaters and heat exchangers in residential waterheating"". *International Journal of Science and Research Archive* (IJSRA),09(02), 830–843. https://doi.org/10.30574/ijsra.2023.9.2.0689."

Patel, A (2023). "Efficiency enhancement of solar water heaters through innovative design". *International Journal of Science and Research Archive* (IJSRA),10(01), 289–303. https://doi.org/ 10.30574/ijsra.2023.10.1.0724.

Patel, A. (2023f). Thermal Performance of Combine Solar Air Water Heater with Parabolic Absorber Plate. *International Journal of All Research Education and Scientific Methods* (IJARESM), 11(7), 2385–2391. http://www.ijaresm.com/uploaded_files/ document_file/Anand_Patel3pFZ.pdf

Patel, A. (2023k). Enhancing Heat Transfer Efficiency in Solar Thermal Systems Using Advanced Heat Exchangers. *Multidisciplinary International Journal of Research and Development (MIJRD),* 02(06), 31–51. https://www.mijrd.com/ papers/v2/i6/MIJRDV2I60003.pdf.

Patel, A., 2023. Comparative thermal performance investigation of the straight tube and square tube solar water heater. *World Journal of Advanced Research and Reviews,* 19, pp.727-735.

Patel, Anand "Optimizing the Efficiency of Solar Heater and Heat Exchanger Integration in Hybrid System", *TIJER - International Research Journal* (www.tijer.org), ISSN:2349-9249, Vol.10, Issue 8, page no.b270-b281, August-2023, Available: http://www.tijer.org/papers/TIJER2308157.pdf

Patel, Anand, *et al*. "Comparative Thermal Performance Evaluation of U Tube and Straight Tube Solar Water Heater." *International Journal of Research in Engineering and Science* (IJRES), vol. 11, no. 6, June 2023, pp. 346–352. www.ijres.org/index.html.

Patel, Anand. "Performance Evaluation of Square Emboss Absorber Solar Water Heaters." *International Journal For Multidisciplinary Research (IJFMR),* Volume 5, Issue 4, July-August 2023. https://doi.org/10.36948/ijfmr.2023.v05i04.4917

Patel, Anand. "A COMPARATIVE ANALYSIS OF SOLAR HEATER TECHNOLOGIES FOR RESIDENTIAL APPLICATIONS." JOURNAL OF AERONAUTICAL MATERIALS (ISSN: 1005-5053), vol. 43, no. 02, Oct. 2023, pp. 633–47. www.hkclxb.cn/article/view/2023/2-633.html.

Patel, Anand. "Advancements in Heat Exchanger Design for Waste Heat Recovery in Industrial Processes." *World Journal of Advanced Research and Reviews (WJARR)*, vol. 19, no. 03, Sept. 2023, pp. 137–52, doi:10.30574/wjarr.2023.19.3.1763.

Patel, Anand. "Effect of W Rib Absorber Plate on Thermal Performance Solar Air Heater." *International Journal of Research in Engineering and Science* (IJRES), vol. 11, no. 7, July 2023, pp. 407–412. Available: https://www.ijres.org/ papers/Volume-11/Issue-7/1107407412.pdf

Patel, Anand. "Heat Exchanger Materials and Coatings: Innovations for Improved Heat Transfer and Durability." *International Journal of Engineering Research and Applications (IJERA),* vol. 13, no. 9, Sept. 2023, pp. 131–42, doi:10.9790/9622-1309131142.

Patel, Anand. "HEAT STORAGE STRATEGIES IN SOLAR HEATER SYSTEMS FOR NIGHTTIME USE." NANOBIOTECHNOLOGY REPORTS (ISSN: 2635-1676) (E-ISSN: 2635-1684), vol. 18, no. 1, Oct. 2023, pp. 49–66. nanobiotechnologyreports.org/index.html.

Patel, Anand. "OPTIMIZING SOLAR HEATER EFFICIENCY FOR SUSTAINABLE RENEWABLE ENERGY." CORROSION AND PROTECTION, ISSN: 1005-748X, vol. 51, no. 2, 2023, pp. 244–258, www.fsyfh.cn/view/article/2023/02-244.php.

Patel, Anand. "Sizing and Optimization of Solar Water Heater Systems for Different Demands." *Tuijin Jishu/Journal of Propulsion Technology* (ISSN: 1001-4055), vol. 44, no. 4, Oct. 2023, pp. 279–91. https://doi.org/10.52783/tjjpt.v44.i4.836.

Patel, Anand.""Comparative Thermal Performance Analysis of Box Type and Hexagonal Solar Cooker"", *International Journal of Science & Engineering Development Research* (www.ijsdr.org), ISSN: 2455-2631, Vol.8, Issue 7, page no.610 - 615, July-2023, Available :http://www.ijsdr.org/papers/IJSDR2307089.pdf".

Pugsley, A., Zacharopoulos, A., Mondol, J.D. and Smyth, M., 2019. Theoretical and experimental analysis of a horizontal planar Liquid-Vapour Thermal Diode (PLVTD). *International Journal of Heat and Mass Transfer,* 144, p.118660.

Qi, C., Luo, T., Liu, M., Fan, F. and Yan, Y., 2019. Experimental study on the flow and heat transfer characteristics of nanofluids in double-tube heat exchangers based on thermal efficiency assessment. *Energy Conversion and Management,* 197, p.111877.

Qiu, L., Ouyang, Y., Feng, Y. and Zhang, X., 2019. Review on micro/nano phase change materials for solar thermal applications. *Renewable Energy*, 140, pp.513-538.

Ramesh, C., Vijayakumar, M., Alshahrani, S., Navaneethakrishnan, G., Palanisamy, R., Natrayan, L., Saleel, C.A., Afzal, A., Shaik, S. and Panchal, H., 2022. Performance enhancement of selective layer coated on solar absorber panel with reflector for water heater by response surface method: A case study. *Case Studies in Thermal Engineering,* 36, p.102093.

Riahi, A., Ali, A.B.H., Fadhel, A., Guizani, A. and Balghouthi, M., 2020. Performance investigation of a concentrating photovoltaic thermal hybrid solar system combined with thermoelectric generators. *Energy Conversion and Management,* 205, p.112377.

Riahi, A., Ali, A.B.H., Fadhel, A., Guizani, A. and Balghouthi, M., 2020. Performance investigation of a concentrating photovoltaic thermal hybrid solar system combined with thermoelectric generators. *Energy Conversion and Management,* 205, p.112377.

Sadeghi, G., Nazari, S., Ameri, M. and Shama, F., 2020. Energy and exergy evaluation of the evacuated tube solar collector using Cu2O/water nanofluid utilizing ANN methods. *Sustainable Energy Technologies and Assessments,* 37, p.100578.

Said, Z., Ghodbane, M., Boumeddane, B., Tiwari, A.K., Sundar, L.S., Li, C., Aslfattahi, N. and Bellos, E., 2022. Energy, exergy, economic and environmental (4E) analysis of a parabolic trough solar collector using MXene based silicone oil nanofluids. *Solar Energy Materials and Solar Cells,* 239, p.111633.

Said, Z., Ghodbane, M., Sundar, L.S., Tiwari, A.K., Sheikholeslami, M. and Boumeddane, B., 2021. Heat transfer, entropy generation, economic and environmental analyses of linear Fresnel reflector using novel rGO-Co3O4 hybrid nanofluids. *Renewable Energy*, 165, pp.420-437.

Said, Z., Hachicha, A.A., Aberoumand, S., Yousef, B.A., Sayed, E.T. and Bellos, E., 2021. Recent advances on nanofluids for low to medium temperature solar collectors: energy, exergy, economic analysis and environmental impact. *Progress in Energy and Combustion science,* 84, p.100898.

Shafieian, A., Khiadani, M. and Nosrati, A., 2019. Strategies to improve the thermal performance of heat pipe solar collectors in solar systems: A review. *Energy conversion and management,* 183, pp.307-331.

Sharafeldin, M.A., Gróf, G., Abu-Nada, E. and Mahian, O., 2019. Evacuated tube solar collector performance using copper nanofluid: Energy and environmental analysis. *Applied Thermal Engineering,* 162, p.114205.

Sheikholeslami, M. and Ebrahimpour, Z., 2022. Thermal improvement of linear Fresnel solar system utilizing Al2O3-water nanofluid and multi-way twisted tape. *International Journal of Thermal Sciences*, 176, p.107505.

Sheikholeslami, M. and Farshad, S.A., 2021. Investigation of solar collector system with turbulator considering hybrid nanoparticles. *Renewable Energy*, 171, pp.1128-1158.

Sheikholeslami, M., Farshad, S.A. and Said, Z., 2021. Analyzing entropy and thermal behavior of nanomaterial through solar collector involving new tapes. *International Communications in Heat and Mass Transfer,* 123, p.105190.

Sheikholeslami, M., Farshad, S.A., Ebrahimpour, Z. and Said, Z., 2021. Recent progress on flat plate solar collectors and photovoltaic systems in the presence of nanofluid: a review. *Journal of Cleaner Production*, 293, p.126119.

Sheikholeslami, M., Jafaryar, M., Abohamzeh, E., Shafee, A. and Babazadeh, H., 2020. Energy and entropy evaluation and two-phase simulation of nanoparticles within a solar unit with impose of new turbulator. *Sustainable Energy Technologies and Assessments,* 39, p.100727.

Vengadesan, E. and Senthil, R., 2020. A review on recent development of thermal performance enhancement methods of flat plate solar water heater. *Solar Energy,* 206, pp.935-961.

Verma, S.K., Gupta, N.K. and Rakshit, D., 2020. A comprehensive analysis on advances in application of solar collectors considering design, process and working fluid parameters for solar to thermal conversion. *Solar Energy,* 208, pp.1114-1150.

Verma, S.K., Sharma, K., Gupta, N.K., Soni, P. and Upadhyay, N., 2020. Performance comparison of innovative spiral shaped solar collector design with conventional flat plate solar collector. Energy, 194, p.116853.

Verma, S.K., Sharma, K., Gupta, N.K., Soni, P. and Upadhyay, N., 2020. Performance comparison of innovative spiral shaped solar collector design with conventional flat plate solar collector. Energy, 194, p.116853.

Wang, D., Liu, J., Liu, Y., Wang, Y., Li, B. and Liu, J., 2020. Evaluation of the performance of an improved solar air heater with "S" shaped ribs with gap. *Solar Energy,* 195, pp.89-101.

Wang, K., Zhang, Z.D., Li, M.J. and Min, C.H., 2021. A coupled optical-thermal-fluid-mechanical analysis of parabolic trough solar receivers using supercritical CO2 as heat transfer fluid. *Applied Thermal Engineering,* 183, p.116154.

Xiong, Q., Altnji, S., Tayebi, T., Izadi, M., Hajjar, A., Sundén, B. and Li, L.K., 2021. A comprehensive review on the application of hybrid nanofluids in solar energy collectors. *Sustainable Energy Technologies and Assessments*, 47, p.101341.

Yao, J., Xu, H., Dai, Y. and Huang, M., 2020. Performance analysis of solar assisted heat pump coupled with build-in PCM heat storage based on PV/T panel. *Solar Energy*, 197, pp.279-291.

Zayed, M.E., Zhao, J., Elsheikh, A.H., Hammad, F.A., Ma, L., Du, Y., Kabeel, A.E. and Shalaby, S.M., 2019. Applications of cascaded phase change materials in solar water collector storage tanks: A review. *Solar Energy Materials and Solar Cells,* 199, pp.24-49.

Zheng, D., Wang, J., Chen, Z., Baleta, J. and Sundén, B., 2020. Performance analysis of a plate heat exchanger using various nanofluids. *International Journal of Heat and Mass Transfer,* 158, p.119993.

Zhou, Y., Zheng, S., Liu, Z., Wen, T., Ding, Z., Yan, J. and Zhang, G., 2020. Passive and active phase change materials integrated building energy systems with advanced machine-learning based climate-adaptive designs, intelligent operations, uncertainty-based analysis and optimisations: A state-of-the-art review. *Renewable and Sustainable Energy Reviews,* 130, p.109889.

Zhou, Y., Zheng, S., Liu, Z., Wen, T., Ding, Z., Yan, J. and Zhang, G., 2020. Passive and active phase change materials integrated building energy systems with advanced machine-learning based climate-adaptive designs, intelligent operations, uncertainty-based analysis and optimisations: A state-of-the-art review. *Renewable and Sustainable Energy Reviews,* 130, p.109889.

****