Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 8, No.1, August : 2024

DESIGN AND ANALYSIS OF SOLAR AIR HEATER

Mr. R. Tamilselvan, Department of Mechanical Engineering, Sri Ramakrishna Institute of Technology, Coimbatore,
Dr. S. Periyasamy, Department of Mechanical Engineering, Government College of Technology, Coimbatore,

ABSTRACT
This paper presents the perpetration, and experimental evaluation of a solar air heater (SAH) constructed utilizing simple and cost- operative accouterments. The SAH utilizes a rustic box as the frame, with an aluminum distance acting as an absorber, and aluminum barrels arranged in resembling to enhance heat immersion. The project incorporates multitudinous temperature detectors and amulet-level crackers for effective tailwind and temperature control. Experimental effects demonstrate the forcefulness of the SAH in employing solar dynamism for hitting air, making it able for colorful drying operations.
Keywords: Solar air heater, Experimental evaluation, Heat absorption improvement.

Introduction
Solar air heaters are an integral component of the ever-evolving world of renewable energy sources. By harnessing the vast and untapped power of the sun, these innovative devices provide sustainable heating solutions crucial for meeting growing energy demands while minimizing our impact on the environment. This introduction delves into the realm of solar air heaters, exploring their fundamental principles, practical applications, and significance in today's energy landscape. At its core, the solar air heater operates on the principle of converting sunlight into thermal energy, utilized for heating, ventilation, or industrial processes. This process involves the absorption of sunlight by a Collector, typically consisting of an absorber plate and a transparent cover. As absorbed energy transforms into heat, airflow through the collector transfers this thermal energy to spaces or systems requiring heating. Despite its simplicity, this process holds profound implications for sustainable energy solutions, offering a clean and renewable alternative to conventional heating methods.
Solar air heaters find diverse applications, from residential heating to industrial processes and agricultural drying. They offer a sustainable alternative to traditional heating methods, reducing carbon emissions and maintaining comfortable indoor temperatures. In industry, they support high-temperature processes and environmentally friendly production practices. Additionally, in agriculture, they play a vital role in solar drying systems, preserving crop quality and minimizing post-harvest losses.
As the world increasingly embraces sustainable energy solutions, the importance of solar air heaters continues to grow. Integrating them into our built environment not only conserves energy but also aligns with broader environmental objectives. Their undeniable benefits, including reducing greenhouse gas emissions, decreasing reliance on finite energy sources, and promoting energy autonomy, underscore their revolutionary potential. With ongoing advancements in technology, design, and efficiency, solar air heaters are poised to become central to the renewable energy movement. Join us on a journey through the world of solar air heaters, where we'll unravel the complexities of their design, explore their versatile applications, and highlight the impact they can have on a sustainable energy landscape. Our aim is to gain a deeper understanding of the current state and future innovations of solar air heater technology, shaping a greener, more sustainable future. Solar air heaters have gained attention as sustainable alternatives for heating applications. Previous studies have explored various designs and materials to optimize performance. Aluminum has been widely used due to its high thermal conductivity and affordability. The use of aluminum cans arranged in parallel has shown to improve heat absorption. However, there is a lack of research focusing on simple and cost-effective designs utilizing readily available materials. This paper addresses this gap

byproposing a SAH design using a wooden box, aluminum sheet, and cans, aimed at achieving high performance with minimal resources.

Literature

Sharma and Buddhi (2009) conducted a comprehensive review of current literature on solar energy and thermal energy. Their review covers colorful advances, styles, and findings in the field and provides insight into the current state of exploration and development in solar energy technology. Tiwari and Sodha (2011) conducted a comprehensive analysis of solar thermal absorbers by comparing designs with and without fins onthe plate absorber. Their analysis demonstrates the significance of fin arrangement in perfecting the thermal and overall performance of the system and helps understand the design of high-performing solar panels.

Choudhury and Goswami (2018) handed an overview of the rearmost developments in solar thermal heating, pressing new developments and trends. By combining data, they describe progress in perfecting the effectiveness and effectiveness of solar thermal heating to suggest unborn directions. Bansal and Mathur (2012) concentrated on perfecting the effectiveness of solar thermal heating through twisted caricatures connected to absorber panels. Their review discusses the impact of caricature figures on heat transfer and provides insight into how to maximize solar heat products. Tiwari and Sodha (2006) delved into the benefits and challenges associated with the integration of thermal energy storehouses by examining solar thermal systems with and without thermal energy storehouses. Their analysis highlights the significance of technology in prostrating these challenges and perfecting the overall performance of solar heating systems.

Ghritlahre and Agrawal (2015) conducted an in- depth study on effectiveness enhancement strategies for forced convection solar thermal heating using artificial accouterments. Their analysis provides important guidelines for optimizing the design of solar thermal systems by assessing the effectiveness of colorful roughness shapes in perfecting heat transfer. Saini and Singh (2016) exhaustively reviewed colorful configurations of solar thermal systems and bandied their advantages, limitations, and effectiveness. By assaying different designs and installation styles, they give sapience into choosing the most suitable bone for a particular operation. Chandra and Kachhwaha (2014) concentrated on strategies to ameliorate the effectiveness of solar heating using turbulators. Their review explores the part of turbulators in perfecting heat and energy effectiveness and provides useful guidelines for optimizing solar thermal systems.

Baral and Bhagoria (2014) estimated the performance of a solar thermal system with external recovery and thermal energy storehouse, demonstrating the benefits of intertwined thermal storehouse to ameliorate performance and tractability. Their commentary punctuates the significance of integrating thermal storehouses in Gupta and Tiwari (2012) estimated the performance of binary-channel solar heating systems with thermal energy storehouse, demonstrating the advantages of binary-channel configurations combined with thermal storehouse to ameliorate energy effectiveness and performance. Their analysis provides insight into the eventuality of these systems for sustainable heat use.

Khan and Mufti (2014) conducted an in- depth study on the performance evaluation of finned double-channel solar heating system and thermal energy storehouse system. Their work delved the effectiveness of this invention in perfecting energy conversion and energy effectiveness. By assessing performance, they give good information about the eventuality of new installations for solar heating operations, paving the way for more effective and sustainable heating results.

A.K.S. and Singh (2012) give a comprehensive review fastening on perfecting the effectiveness of solar thermal systems. Their analysis includes colorful styles and ways to ameliorate the energy effectiveness and energy conversion of solar thermal systems. By combining available data, they give important guidelines for optimization and contribute to the advancement of renewable energy.

De and Bhattacharjee(2018) conducted the performance analysis of a solar water heater with different inflow channel shapes. Their work estimated the impact of inflow channel figures on heat transfer and

physical performance. By assaying the impact of the design process, they give better information regarding the optimization of solar heating systems, easing the design of better designs.
Tyagi and Buddhi(1996) studied the use of solar thermal heating in crop drying operations. Their analysis discusses thermal performance and considerations regarding the use of solar heat in the crop drying process. They estimate the felicity of solar thermal heating for husbandry, demonstrating the eventuality of using solar energy to increase drying of crops and reduce dependence on fossil energies. Lal and Varun (2017) conducted a comprehensive review of the design and construction of solar thermal systems. Their analysis includes colorful design considerations, advances in technology, and performance evaluations. By combining Exploration, they give important information on the current state of solar heating technology and suggest unborn exploration and development in this field. Sopian and Othman (2010) studied solar panels with thermal storehouse bias, fastening on the integration of these technologies to increase energy effectiveness. Their analysis discusses the principles of thermal storehouse and evaluates different storehouse unit designs. By demonstrating the advantages of integrating thermal factors, they give sapience into perfecting the performance and trustability of solar thermal systems.
Garg and Kachhwaha (1994) studied the thermal performance of colorful solar heater models. By assaying the differences between heating bias, they gained an understanding of the effectiveness and effectiveness of using solar energy for heating. Their analysis provides important information in opting for the stylish design to ameliorate the thermal performance of solar heating systems and therefore contributes to the advancement of technology.
Tiwari and Sodha (2002) conducted a comprehensive review on sun drying of agrarian products. They studied all processes of solar drying, including design, operation and operation. By combining exploration results, they gained sapience into the eventuality of solar drying as an effective and sustainable system of conserving agrarian products, with the end of promoting the use of renewable energy in husbandry. R.N. Saini (2006) conducted thermal performance evaluation of a binary- inflow solar creator. Their exploration concentrated on assessing the heat transfer and overall performance of two machines under different operating conditions. By assaying the experimental data, they attained a positive opinion on the effectiveness of the binary- inflow configuration in perfecting thermal performance and handed important information for perfecting the design and operation of the solar heating system.
Tiwari and Sodha (2001) conducted a review of solar thermal collectors and systems covering a wide range of collector factors, design considerations, and performance evaluations. Their review provides insight into the fundamentals of air- hotted solar collector technology and its operations in colorful fields. By collecting important exploration points, they contribute to a better understanding of solar heating solar collector systems and the development of more effective and effective results. K.R. and Velraj (2011) conducted a review fastening on the use of artificial accouterments to ameliorate heat transfer in solar thermal systems.Their studies anatomized the effectiveness of different rudiments in perfecting heat transfer and overall performance. By assessing colorful technological advances, they lead to the advancement of renewable energy by furnishing perceptivity to optimize the design of solar heating systems to ameliorate performance and energy effectiveness.
K. and Sharma (2008) conducted a study on the performance of solar thermal heating with different types of absorber plates. His exploration aims to estimate the impact of colorful structural problems on energy transfer and physical exertion. By assaying experimental data, they give perceptivity into the effectiveness of different styles in perfecting thermal performance, therefore leading to the optimization of solar wind heat setting to increase energy effectiveness. Tiwari and Sodha (2003) review the progress of solar thermal heating, covering colorful developments and inventions in this field. Their review discusses advances in design, accouterments, and integration and provides sapience into the rearmost trends and developments in solar heating technology. By combining exploration results, they lead to a better understanding of new technologies in solar thermal design and operation, encouraging further exploration and development in this field.

Tiwari and Sodha (2006) reviewed state- of- the- art solar energy products, fastening on new exploration results and technological advances. Their reviews cover all aspects of solar collector design, performance evaluation and integration. By recapitulating crucial exploration points, it provides information on the current state of solar- powered rainfall recording systems and makes recommendations on unborn exploration directions and ways in this field.

K. and Aharwal (2014) conducted a review on the use of unresistant systems to increase the effectiveness of solar thermal systems. Their exploration has determined the effectiveness of technologies similar to electronic outfit, electronic outfit, and the selection process in perfecting performance. By combining studies, they give a better understanding of the eventuality of unresistant systems to increase the effectiveness and effectiveness of solar thermal heating, therefore contributing to the development of stationary heat.

Kaushik and Tyagi (2011) conducted a review fastening on thermal energy storehouses using phase transition models (PCMs) and their operations. His exploration examines colorful aspects of PCM- grounded thermal storehouse systems, including accouterments, design, and operations in renewable energy operations. By combining exploration, they give sapience into the eventuality of PCM- grounded thermal storehouse to ameliorate energy effectiveness and trustability for colorful wind operations, heating and cooling, therefore paving the way for the advancement of sustainable energy use. A.K. Sharma (2013) studied the effectiveness of a binary- channel solar thermal system using phase shift control (PCM) for thermal energy storehouses. Their exploration concentrated on assessing the effectiveness of PCM- grounded thermal storehouse in perfecting performance and energy effectiveness. By assaying experimental data, they give insight into the eventuality of PCM- grounded thermal storehouse integration to ameliorate the effectiveness and trustability of solar thermal systems, therefore contributing to the development of stable heat.

Tiwari and Sodha (2006) conducted a comprehensive review of advances in energy wisdom and engineering, fastening on solar energy. Their review covers all aspects of solar energy, including solar thermal, photovoltaics and unresistant solar heating. By combining exploration results, it provides information on the current state of solar energy technology and provides scientific advice on the future and progress of studies in this field. A.K. and Gupta (2017) conducted an analysis fastening on the effectiveness of solar thermal systems. His exploration examines numerous ideas and technologies to ameliorate the effectiveness and effectiveness of solar heating systems. By combining data, they contribute to the development of sustainable and effective results by furnishing perceptivity into the eventuality of different advancements to ameliorate performance. Verma and Tiwari (2018) conducted a review fastening on the use of artificial roughness shapes on the heat Gomorrah plate to ameliorate the effectiveness of binary- channel solar heating systems. Their studies determined theeffectiveness of varying roughness in perfecting heat transfer and physical performance. By combining exploration results, they give insight into the eventuality of artificial accouterments to increase the effectiveness and effectiveness of two- channel solar heating, therefore contributing to the advancement of renewable energy.

Methodology

The project of the solar air heater (SAH) is grounded on a rustic box with special confines of 81.1 mm in extent, 35.50 mm in range, and an inner gap of 11.5 mm. This box serves as the foundation for the heater, furnishing structural brace and casing for the factors within. To enhance heat immersion, five layers of aluminum wastes are strategically placed over the top face of the rustic box. These aluminum wastes portray the absorber, efficiently absorbing solar radiation and converting it into heat dynamism. In extension to the aluminum wastes, aluminum barrels with a capacity of 300 ml each are arranged in parallel over the aluminum distance. This arrangement maximizes the face area exposed to sun, further enhancing heat immersion and transfer. To capture and retain solar heat effectively, a glass cover is instated over the exclusive format. The glass cover acts as a hothouse sequel, enmeshing solar radiation and precluding heat loss to the girding terrain. To cover and control the temperature within the SAH, multitudinous K- type thermocouples are strategically placed at colorful overcritical points. These thermocouples measure temperatures at crucial locales, involving the bay and outlet anchorages of the air inflow, the face of the glass cover, inside the aluminum barrels, and on the face of the aluminum distance. This Multi-point temperature monitoring system provides precious data for laying the interpretation and effectiveness of the SAH project. Commonly, the project of the SAH incorporates colorful rudiments to maximize heat immersion, transfer, and retention, while also enforcing a complete temperature monitoring system for precise control and optimization of the heating process.

3.1 Rustic Box Construction: Start by building a rustic box with 81.1 mm long, 35.50 mm wide and 11.5 mm internal dimensions. Use strong wood to ensure integrity and ensure installation is done correctly. The box serves as the base of the solar thermal system (SAH) and must support the weight of the other components.

3.2 Aluminium Distance Absorber Application: Apply five layers of aluminum foil rustic box to the box surface. Cut the foil to fit the size of the box and place it securely in place, covering it completely with no gaps. These aluminum layers act as absorbers, capturing solar radiation and converting it into heat energy.

3.3 Preparation of aluminum cans: Take 300 ml capacity aluminum cans parallel to the aluminum plate. Place containers unevenly to reflect sunlight to increase heat absorption and change the results by increasing the solar absorption area. Attach a strong, clear glass lid over the jar to effectively capture and store solar heat throughout the installation. Make sure the glass product can withstand sunlight and rain. Securely attach the glass lid to the rustic box to reduce heat and ensure good insulation in the SAH.

3.4 Integrating a multi-stage crushing system: Incorporating a multi-stage breaking system into the SAH to provide a variety of airflow patterns for optimumair circulation. The pyrolysis process was designed to provide controlled air flow to various parts of the SAH, thus improving heating and temperature control. Such facilities can adjust air flow according to specific conditions and environmental factors.

3.5 Placement of Temperature Detectors: Multiple K-type thermocouple detectors are strategically placed around the SAH to measure the temperature of important points. Place the thermometer near the inlet to measure the temperature of the incoming air, and place the thermometer near the outlet to measure the temperature of the leaving air. Attach a thermometer to the glass lid to monitor its temperature and ensure proper protection. The gauges mounted on aluminum can directly measure the internal temperature, and the gauges are mounted on the surface of the aluminum sheet to monitor the temperature and suction temperature.

3.6 Testing and Evaluation: Before use, conduct a thorough inspection and evaluation of the SAH system to ensure operation and operation. Make sure all parts are assembled and connected correctly. Measuring accuracy and measurement accuracy are required. Perform a test run to measure potential heat, airflow dynamics and temperature control. Make any adjustments or adjustments to the operation of the SAH for efficient use of solar heating.

3.7 Using CAD software: Using CAD software such as SolidWorks, Fusion 360, CATIA or similar tools to digitally create SAH products. Start by creating a 3D model of a rustic box with dimensions. Build the layer of aluminum foil to fit directly onto the rustic box, creating a representation of the layoutof aluminum cans and glass lids. Use CAD capabilities to visualize the assembly of SAH components and optimize their planning for optimum performance. Integration of multi-stage cracker integration has the potential to enable the creation and deployment of air flow systems in the SAH.

Result

The thermal effectiveness effects indicate the forcefulness of the solar air heater in landing solar dynamism to heat the air passing through the system. The loftiest thermal effectiveness was observed at 1 pm, with an outlet temperature of 65 °C, indicating significant heat gain by the air. This can be attributed to the optimal solar radiation entered during this time interlude, performing in an advanced temperature differential across the system.

Again, lesser thermal edges were recorded during the morning and late autumn hours when solar radiation vehemence was lesser. Despite this, the solar air heater lasted to give conspicuous heating, establishing its capability to serve indeed under varying solar conditions. Commonly, the solar air heater exercising aluminum foils and drum barrels as the base proves to be an ultra-practical and effective result for room heating operations. Its interpretation highlights the eventuality for renewable dynamism technologies to contribute to dynamism effectiveness and sustainability, offering a feasible volition to traditional heating systems while reducing dependence on non-renewable dynamism sources. Upon as saying the data, several compliances can be made

Temperature Trends Throughout the day, the temperatures usually boost from morning to autumn and also drop towards the autumn, which is anticipated due to the solar heating sequel. There are oscillations in temperatures at nonidentical time intervals, likely told by procurators similar as solar radiation vehemence, ambient temperature, and tailwind variations.

Variation among Heater Units There's variation in temperature readings among the nonidentical solar air heater units at each time interlude. This variation could be attributed to differences in project, exposure, effectiveness, and environmental conditions girding each unit. Forcefulness for Crop Drying. To charge whether these solar air heater units can effectively be exercised for desiccating crops, several procurators need reflection, involving temperature range, thickness, and tailwind.

The temperatures achieved by the solar air heater units are within a able range for crop desiccating purposes, with temperatures ranging from around 35 °C to 50 °C during the day. still, to insure operative crop drying, it's essential to conserve harmonious and acceptable tailwind within the drying chamber, which may bear fresh outfit similar as suckers or boasters. farther inquiries or trials may be demanded to determine the effectiveness and forcefulness of these solar air heater units specially for crop drying operations. Recommendations Grounded on the handed temperature readings, it's presumptive that these solar air heater units can contribute to crop drying missions, especially when integrated with proper drying chambers and tailwind systems. still, it's judicious to guide farther experiments under real- world conditions and cover procurators similar as moisture situations, desiccating classes, and common dynamism effectiveness to optimize the drying process. also, esteeming the variability among the nonidentical solar air heater units, opting the most able unit or a combination of units grounded on interpretation and trustability would be salutary for scoring harmonious drying effects.

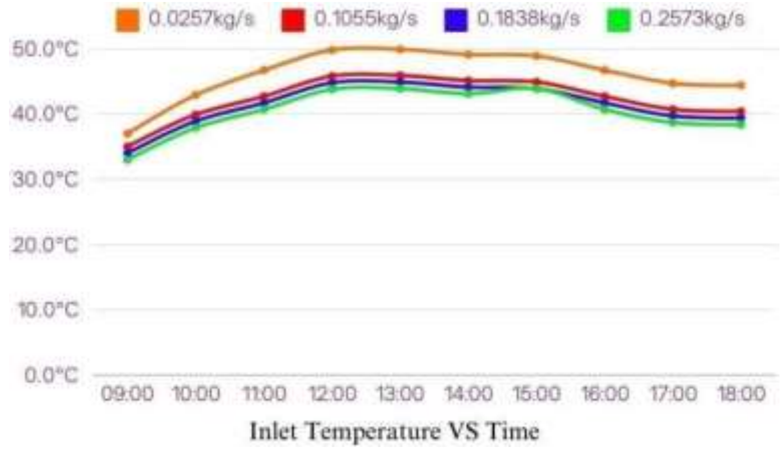

Figure 1: Inlet Temperature vs Time

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 8, No.1, August : 2024

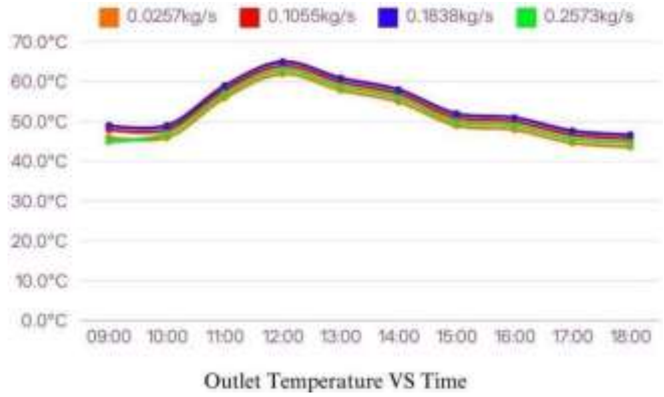

Figure 2: Outlet Temperature VS Time

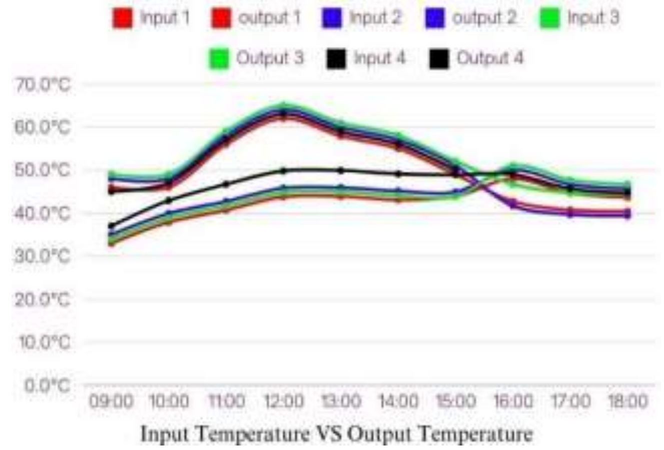

Figure 3: Input Temperature VS Outlet Temperature

Conclusion

The solar air heater constructed using aluminum foils and tin cans as the base represents a practical and cost-effective solution for harnessing solar energy to provide efficient space heating. Through its ingenious design and utilization of readily available materials, this solar air heater offers numerous advantages, including affordability, durability, high thermal conductivity, and scalability. Its applications span across residential, commercial, industrial, and agricultural sectors, addressing heating needs while promoting energy efficiency and sustainability. From supplementing conventional heating systems in homes to providing off-grid heating solutions in remote locations, this solar air heater demonstrates versatility and reliability. Additionally, its integration into solar drying systems enhances agricultural processes, contributing to food preservation and quality.

Furthermore, the simplicity of its design makes it an ideal educational tool for fostering understanding of solar energy principles and encouraging DIY projects. By harnessing the power of the sun to generate heat, this solar air heater embodies the spirit of renewable energy and underscores the importance of sustainable technologies in mitigating climate change and reducing dependency on fossil fuels. In essence, the solar air heater using aluminum foils and tin cans stands as a testament to innovation, efficiency, and environmental stewardship, offering a glimpse into a future powered by clean, renewable energy sources.

Reference

[1] Sharma, R. and Buddhi, D. (2009). Review of current literature on solar panels and thermal storage devices. Renewable and Sustainable Energy Reviews, 13(8), 1514- 1522.

[2] Tiwari, A. and Sodha, M.S. (2011). Analysis of solar air heaters with and without fins on plate absorbers. Renewable and Sustainable Energy Reviews, 15(1),313-332.

[3] Choudhury, C. and Goswami, D.Y. (2018). Recent advances in solar heating: a review. Renewable and Sustainable Energy Reviews, 81, 1906-1919. 4. Bansal,

[4] N.K. and Mathur, J. (2012). Analysis of solar thermal heating performance improvement with multiple curved fins connected to the heat sink plate. Renewable and Sustainable Energy Reviews, 16(8), 6238-6245.

[5] Tiwari, A. and Sodha, M.S. (2006). Analysis of solar thermal systems with and without thermal energy storage systems. International Journal of Energy Research, 30(8), 599-620.

[6] Ghritlahre, H.K. and Agrawal, G.D. (2015). Analysis of artificial roughness to improve the performance of forced convection solar heating: dimples, ribs and roughness elements. Renewable and SustainableEnergy Reviews, 49, 69-89.

[7] Saini, R.P. and Singh,S. (2016). Review of research on various configurations of solar thermal systems. Renewable and Sustainable Energy Reviews, 55, 1-9.

[8] Chandra, A. and Kachhwaha, S.S. (2014). Improving the performance of solar thermal systems using turbulators: a review. Renewable and Sustainable Energy Reviews, 32, 490-504.

[9] Baral, S. and Bhagoria, J.L. (2014). Performance evaluation of solar wind water heater with external circulation thermal storage Renewable and Sustainable Energy Reviews, 30, 446-456.

[10] Gupta, A. and Tiwari, G.N. (2012). Performance evaluation of regenerative dual-channel solar air heater Renewable Energy, 39(1), 284-287.

[11] Khan, M.J. and Mufti, R.A. (2014). Performance evaluation of dual-channel solar heating system with fins and thermal energy storage system. Renewable Energy, 62, 243-252.

[12] AXLE. and Singh, S. N. (2012). A review of solar air heater efficiency Energy Research, 39(1), 134-

[13] De, S. and Bhattacharjee, A. (2018). Performance evaluation of solar water heaters with different geometries of water flow: a review. Renewable Energy, 123, 108-124.

[14] Tyagi, V.V. and Buddhi, D. (1996). Solar thermal heating for crop drying: a review. Electronics Engineering and Management, 37(8), 1247-1257.

[15] Lal, S. and Varun. (2017). Review of the design and construction of solar thermal heating Renewable and Sustainable Energy Reviews, 80, 447-474.

[16] Sopian, K. and Osman, M.Y.H. (2010). Analysis of solar wind collectors for thermal storage devices. Renewable and Sustainable Energy Reviews, 14(1), 314- 322.

[17] Garg, H.P. and Kachhwaha, S. S. (1994). Thermal Performance of Some Solar Air Heater Designs: Kev Ntsuam Xyuas. Renewable Energy, 5(1-4), 197- 207.

[18] Thiv, G. N. and Sodha, M.S. (2002). Research on the progress of solar drying of agricultural products, Renewable and Sustainable Energy Reviews, 6(5), 467- 492.

[19] R.N. and Saini, J.S. (2006). Thermal Performance index ntawm dual flow solar air heater. Solar Energy, 80(5), 512-520.

[20] Tiwari, A. and Sodha, M.S. (2001). Examination of air heated solar collectors and systems. Renewable and Sustainable Energy Reviews, 5(2), 91-112..K.R. and

[21] Velraj, R. (2011). Using artificial roughness to improve heat transfer in solar thermal systems: a review. Renewable and Sustainable Energy Reviews, 15(8), 3793-3805.

[22] K. and Sharma, V. (2008). A study on the performance of solar heating of solar panels with different types of radiation absorption, 82(11), 1004-1013.

[23] Tiwari, A. and Sodha, M.S. (2003). First in solar heat. Energy Transfer and Control, 44(8), 1547-1563.

[24] Tiwari, A. and Sodha, M.S. (2006). New equipment review of solar air collectors. International Journal of Energy Research, 30(5), 339-361.

[25] K. and Aharwal, K.R. (2014). A review of passive systems for improving the thermal efficiency of solar energy and Sustainable Energy Reviews, 37, 600- 616.

[26] Kaushik, S.C. and Tyagi, S.K. (2011). Analyzing phase transfer data for heat storage and utilization. Renewable and Sustainable Energy Reviews, 15(1), 318-345. 27. A.K. and Sharma, G. (2013).

[27] Improving the performance of dual-channel solar thermal systems using PCM thermal storage. Electronics Engineering and Management, 75, 517-526.

[28] Tiwari, G.N. and Sodha, M.S. (2006). Advances in Electrical Science and Engineering: Solar Energy Research. Energy, 31(14), 2321-2337.

[29] WHITE. and Gupta, R.P. (2017). Efficiency of Solar Air Heaters - Review. Renewable and Sustainable Energy Reviews, 70, 708-724.

[30] Verma, S.K. and Tiwari, G. N. (2018). Analysis of improving the efficiency of two-channel solar thermal heating using the roughness geometries of heat sink plates. Renewable and Sustainable Energy Revie