The Chitransh Academic & Research
An International Journal of Multidisciplinary Research

An Online Peer Reviewed / Refereed Journal
Volume1 | Issue 1 | January 2025
ISSN: 3049-303X (Online)
Website: www.thechitranshacadmic.in

IMPACT OF SOLAR IRRADIANCE AND AIR MASS FLOW RATE ON THE THERMAL PERFORMANCE OF A DOUBLE-PASS SOLAR AIR HEATER WITH FINS

Khoob Singh

Research Scholar, Department Arni School of Technology, Arni University, Himachal Pradesh, India

Dr. Sanjay Yadav

Professor, Department Arni School of Technology, Arni University, Himachal Pradesh, India

ARTICLE DETAILS

Research Paper

Received: **12/01/2025**

Accepted: **22/01/2025**

Published: **30/01/2025**

Keywords: Solar, Irradiance, glass, Thermal, Fins.

.

ABSTRACT

The impacts of sun irradiation and air mass flow rate are investigated in this study, along with the thermal performance of an aluminum fin double-pass solar air heater. A 35-lamp tungsten halogen artificial sun simulator, which can produce irradiance levels between 600 and 1000 W/m², is used in the experimental setting.After passing through the bottom channel, air is allowed to depart the system after absorbing heat from the glass and absorber plate that has been reinforced with fins. The collector is intended to improve convective heat transmission and has an insulated body, a 4 mm glass top, and a finned aluminum absorber plate. By means of a regulated blower system, mass flow rates ranging from 0.014 to 0.0261 kg/s are evaluated. The glass, absorber, fins, and air inlet/outlet temperatures are monitored using a multi-channel data logger. Heat uptake, airflow behavior, and overall thermal efficiency are all regulated by changes in mass flow rate and irradiance, which are also examined in depth in the inquiry.

I. INTRODUCTION

Solar thermal technologies are leading the charge toward a more sustainable energy future on a global scale. One kind of solar thermal system that has become more popular as of late is the solar air heater (SAH), which converts solar radiation into thermal energy in an efficient and environmentally friendly manner. Indoor heating, crop drying, industrial process preheating, and even ventilation are all possible uses for this energy. However, air has a naturally low thermal conductivity and conventional absorber panels have a little heat transfer surface, therefore they often provide inadequate thermal performance. To get around these limitations, you may try using longer surfaces, turbulators, phase-change materials, or multiple-pass topologies in your designs. The DPSAH with fins has been the center of attention among these improvements because of its better thermal stratification, longer contact length between the air and absorber surface, and enhanced heat transfer qualities. The quantity of sunlight that reaches a solar air heater is a major component in how well the heater conducts heat. Most importantly, how the system's overall efficiency, air temperature rise, and absorber plate temperature are affected by the daily, seasonal, and geographical fluctuations of the incoming radiation must be carefully considered. Because the absorber plate may become hotter under intense sunlight, the temperature differential between it and the circulating air becomes bigger. Because convective heat transfer rates are enhanced, thermal efficiency is improved. In contrast, system performance degrades due to a precipitous fall in useful heat gain during low irradiance periods. Therefore, knowing how solar radiation affects the thermal behavior of a fin-equipped DPSAH is critical for optimal design, operation, and control methods.

Another crucial feature that affects the efficiency of DPSAH systems is the air mass flow rate. The convective heat transfer coefficient, the amount of time the air spends in contact with heated surfaces and the mass flow rate are all influenced by how quickly the air stream's temperature rises. However, since less heat is removed per unit time at lower flow rates, the air remains in contact with the surface for longer, resulting in a higher departure temperature. Although bigger flow rates enhance the forced convection heat transfer coefficient and rate of heat removal, a shorter exposure period may lead to a lower outlet temperature rise. Discovering the optimal balance between output air temperature and significant heat gain requires an understanding of how various flow rates impact thermal performance indicators. Integrating the fins onto the absorber surface alters the heat transfer environment of the DPSAH in a big way. The addition of fins improves air turbulence levels inside the duct, increases the effective surface area accessible for heat exchange, and makes the temperature distribution throughout the absorber more uniform. There is a great need for them when the air velocity is high, as the presence of more turbulence compensates for less thermal contact time. Thermodynamic interactions inside the heater may be altered by fins in conjunction with variations in solar radiation. Exploring the interplay between solar irradiance and mass flow rate on the performance of fin-based DPSAH is essential for producing reliable design guidelines and foreseeing the system's behavior under different operating situations.

Given the dynamic nature of solar energy availability and the wide range of operational requirements for drying and heating applications, it is essential to conduct outside real-world testing of fin-equipped DPSAHs. Since they provide more heat absorption and reduced thermal losses, double-pass configurations outperform single-pass systems in terms of efficiency, as stated in the existing literature. However, the effects of fins, changes in irradiance, and variations in mass flow have not been investigated in any comprehensive theoretical or experimental context. The rapid change in irradiance, which impacts airflow, absorber temperature, and heat extraction rates, makes the system's thermal response more complex in cases of unpredictability in the weather. This study aims to analyze the thermal performance of a fin-equipped DPSAH under various situations of solar irradiation, taking into consideration heat transfer characteristics, thermal efficiency, temperature rise, useable heat gain, and air mass flow rate. The main purpose of the research is to provide light on how fins and other design modifications affect system performance by systematically investigating the connection between irradiance, an environmental input, and mass flow rate, an operational input. The findings might pave the way for more adaptable and effective solar air heating systems, which could find practical applications in a wider range of climates.

II. LITERATURE REVIEW

Dutta, Ajoy & Rabha, Deva (2024). The experimental investigation of an outdoor solar air heater was conducted using a finned absorber in the form of a perforated C, accounting for mass fluxes of 0.041, 0.045, and 0.049 kg/s. The architecture of the heater is double-pass and counter-flow. Results from experiments reveal that solar irradiation, ambient temperature, and mass flow of air have a substantial impact on the thermal effectiveness, efficiency, and air temperature rise of the solar air heater. As the air mass flow decreases, the heater's efficiency clearly declines.

Hussein, Nassr et al., (2022) Here, we examined the effects of pulsing flow, an active technique, on the thermal efficiency of a two-pass solar air heater coupled with a tubular solar absorber. In the downstream flow of the solar air heater, there is a pulse generator that is mounted on a ball valve. The experiments were carried out in an indoor environment with a constant heat flux of 1000 W/m2 and varied air mass flow rates from 0.01 to 0.03 kg/s. Three distinct pulsation frequencies, from 1 to 3 Hz, were also included of the study. In this case, the output temperature rises by around 25.6-27% compared to the constant flow condition, proving that pulsing flow enhances the heat transfer rate. At the maximum air mass flow rate, pulsing flow improves effective thermal performance by 15.2% compared to constant flow.

Hussein, Nassr et al., (2022) to find out how a new solar absorber might affect the thermal performance of a double-pass solar air heater, researchers used both theoretical and experimental methods. A flat plate solar absorber configuration (DPSAHWFP), a tubular absorber configuration (DPSAHWT-1), and a configuration (DPSAHWT-2) that utilizes a set of tubes fitted in parallel to the airflow direction are the three configurations that have been introduced for the purpose of comparison. The experiments were carried out indoors with a fixed heat flux of 1000 W/m2 and variable air mass flow rates between 0.01 and 0.03 kg/s. The results show that there is a clear association between the thermal performance of the solar air heater and increasing the mass flow rate of air because this variable has more obvious impacts than raising the air temperature. This was also shown experimentally and quantitatively for all air flow rates.

Rajendran, Vijayakumar et al., (2022) Experiments on solar air heaters (SAHs) are made possible by placing absorber plates with designs that employ several geometries. This investigation makes use of an absorber plate with a rectangular rib, slit, and cylinder layout. This proposed system makes use of a variety of shapes to create a fake roughness. In order to gauge the improvement, the results of this study are contrasted with those of a conventional SAH. The proposed system outperforms the conventional SAH in terms of thermal efficiency, energy gain, and top loss. At a mass flow rate of 0.04 kg/s, both thermal efficiency and energy gain reach their maximum. Raising the mass flow rate to its maximum potential improves the system's performance. Among the investigated flow rates, the average thermal efficiency of a SAH with a multi-geometry baffle was 58.2%, followed by 68.2%, and finally 77.4%. There is a improvement over a conventional SAH when using the same flow rates. The suggested air heater achieves a 31.9%, 21%, 19.2%, and 20.8% improvement in energy gain compared to conventional SAH when tested with the same air flow rates.

Jalil, Jalal et al., (2021) as part of the remodeling process; the absorber's wavy fin structure was rearranged. Because of their wavy shape, the fins of a double passes collector block flow in both directions. Thermal efficiency rose to 84% when the configurations were changed. This paper details the findings of an experimental study on a two-pass solar air heater that makes use of a wavy-fin absorber. These fins were secured to the upper and lower sides of the absorber. Two wavy fin configurations (3 and 7 fins) and a range of air mass flow rates were investigated with a plan absorber at different solar radiation intensities.

Murali, G. et al., (2019) solar air heaters with a double pass design and absorber plates with rectangular longitudinal fins on one side were the subjects of experimental investigation. The air heater's performance parameters were shown, including the absorber plate temperature, output power, and fin placement in the bottom and upper channels, respectively. Another aspect that was investigated was the impact of mass flow rate on the efficiency of an air heater that included fins in both the lower and upper channels. Air heaters that have their fins placed lower in the channel really perform better than those that have them positioned higher.

III. EXPERIMENTAL SETUP

Understanding the relationship between solar irradiation and air mass flow rates is the primary goal of this part, which tries to ascertain the impact of thermal performance on DPSAHWF. For the inflow section, the air will first pass through a channel containing a glass absorber plate and fins. After absorbing heat from the heat flux, it will go into the second channel and out the other end. The results of the experiment are detailed below.

A DPSAHWF test rig and an artificial sun simulator are the two most critical parts of the project. The experiment made use of 35 tungsten halogen lights, with a power of 500W each bulb. You may change the height of the solar simulator up to 1.5 m, and it is perpendicular to the top cover of DPSAHWF. The solar simulator can simulate real-time solar irradiance by adjusting light intensity to match varying amounts of solar irradiance. Conducting studies inside allows for the consideration of environmental factors like cloudiness, temperature, and humidity, which might impact the measurement instrument and the material's behavior under varying solar irradiance circumstances. Each dimension of the solar collector—its length, width, and depth—is 1 meter. The experimental glass has a thickness of 4 mm. To facilitate airflow along the intended route, the top channel is 0.3 m high and the bottom channel is 0.1 m low. To make the most of the heat that the halogen bulbs, which simulate sunlight, emit, the solar collector is coated in a completely black color. The solar collector has been covered with 25 mm thick insulation to minimize heat loss. With an aluminium material composition, the absorber plate had width of 0.295 m and length of 0.9 m. The purpose of this is to facilitate airflow between the top and lower channels. Using Tungsten Inert Gas welding (TIG), diamond-shaped fins made of aluminum are affixed to the absorber plate's top.

From 0.014 to 0.0261 kg/s of mass flow rate and 600 to 1000 W/m2 of solar radiation were used in the experiment. By optimizing convective heat transfer inside the solar collector, which moves heat away from the absorber plate and fins, the mass flow rates are selected to minimize heat losses. Mounted on the top channel's intake is the fan blower, which draws power from 0.75 kW. The velocity is measured using a digital anemometer, which is then translated to mass flow rate using a formula. With a precision of 5%, the anemometer is capable of measuring air velocities up to 30 m/s.

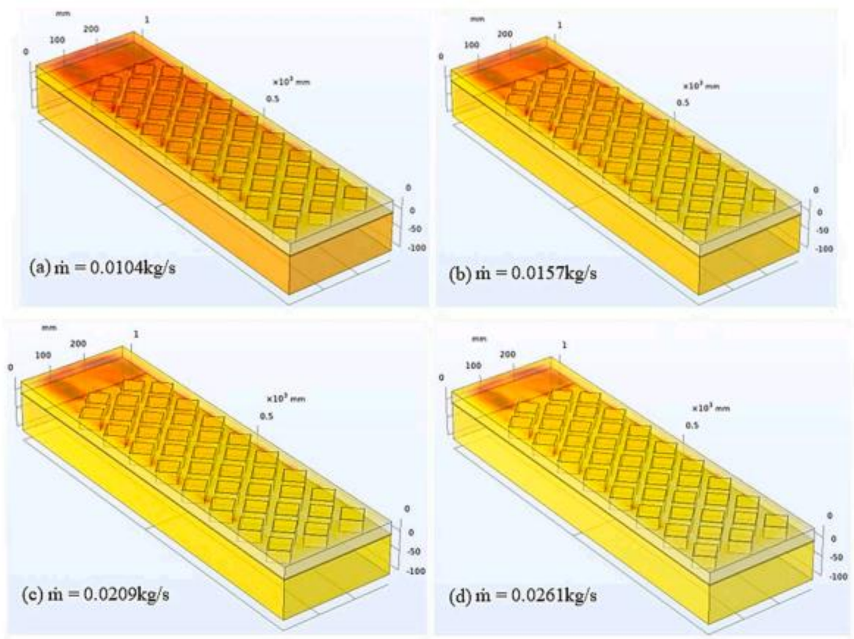

Figure 1: Temperature Distribution in Double-Pass Solar Air Heater at Different Air Mass Flow Rates

A data logger with 24 channels is used to record the temperatures of several components every 60 seconds during the tests. These components include the glass, fins, absorber plate, backplate, input, and outlet. All thermocouple readings must be in agreement with room temperature prior to experimentation. Physical parameters of DPSAHWF are shown in Table 3.

IV. RESULTS AND DISCUSSIONS

<u>Experimental analysis</u>

Comparative results of Outlet Temperature and Mass Flow Rate

The simulation result for DPSAHWF is shown in Figure 2. The maximum and minimum outlet temperatures for different mass flow rates are 40.86°C, 37.06°C, 34.79°C, and 33.27°C for 0.0104 kg/s, 0.0157 kg/s, 0.0209 kg/s, and 0.0261 kg/s, respectively, when the solar irradiation is 1000 W/m2. The temperature at which the four-mass flow rates were measured was 37.75°C, 34.69°C, 32.86°C, and 31.70°C, while the sun irradiation was 800 W/m2. When the mass flow rates are increased, the temperature is also shown by the falling outlet temperature and its eventual return to ambient temperature.

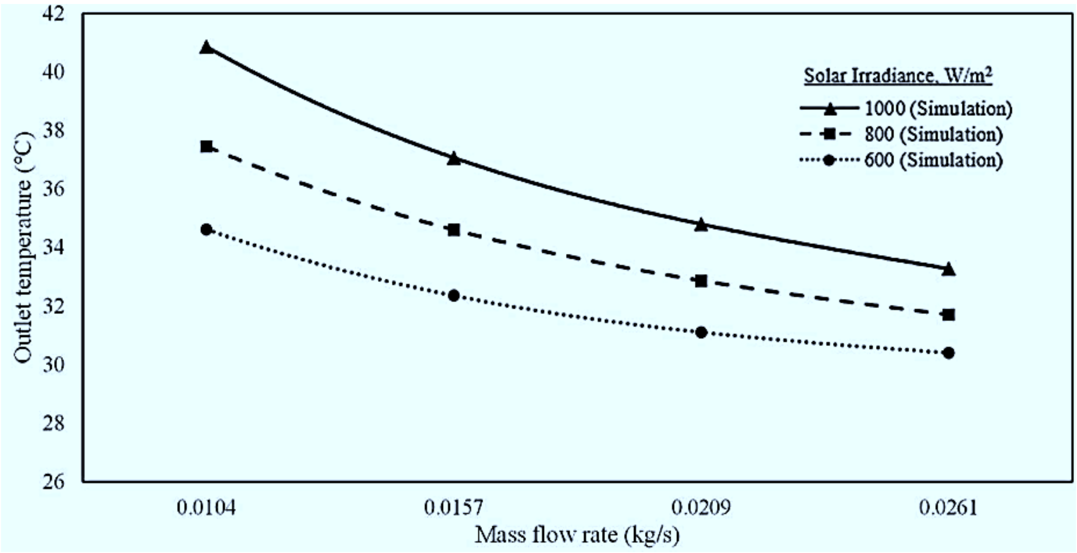

Figure 2: Variation of Outlet Air Temperature with Mass Flow Rate at Different Solar

Irradiance Levels between simulation

In Figure 3, we can see the experimental results of DPSAHWF plotted against the mas flow rate and output temperature.

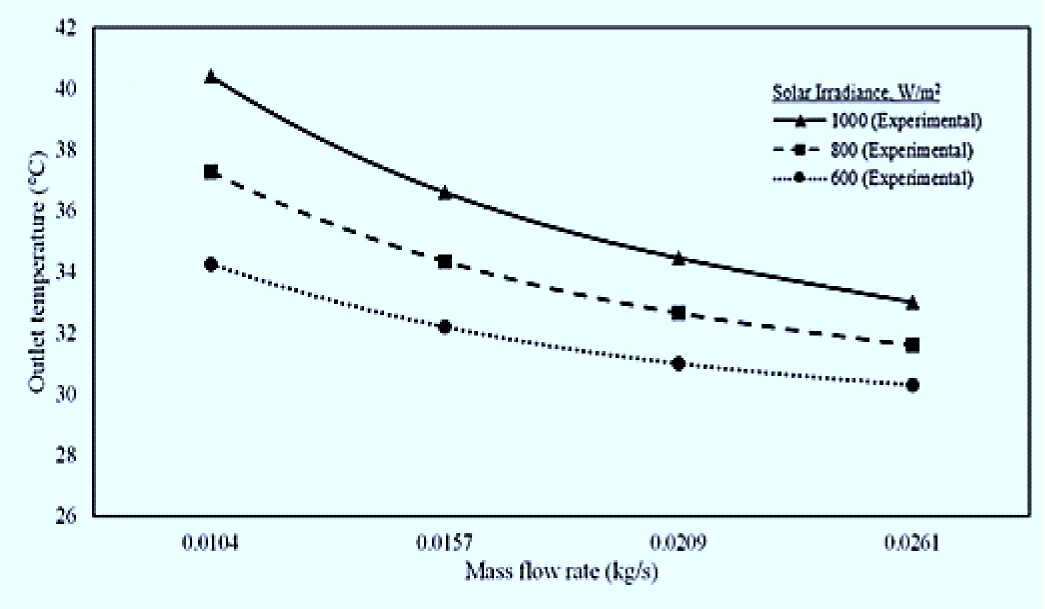

Figure 3: Variation of Outlet Air Temperature with Mass Flow Rate at Different Solar Irradiance Levels between experimental

In this experiment, three different types of solar irradiation were tested. According to the data shown in the graph, the air mass flow rate with the greatest outlet temperature for all three sun irradiances was 0.0104 kg/s, while the lowest was 0.0261 kg/s. Its temperature has almost reached the room's ambient temperature of 27°C. It shows that the output temperature drops as the mass flow rate rises. This is because the overall heat loss might have been minimized if the air flow rate hadn't been becoming stronger and quicker.

Comparative results of Thermal Efficiency and Mass Flow Rate

Figure 4 shows the difference in thermal efficiency between the computational and experimental results. The graph shows that thermal efficiency is directly proportional to the square of the product of solar irradiation and mass flow rate. Between 0.0104 and 0.0261 kg/s, the mass flow rates fall into a wide range. For 600 W/m2 solar irradiation calculations, the thermal efficiencies vary from 50.17% to 56.04%, whereas for experimental data, they range from 53.01% to 59.34%. In addition, the experimental findings ranged from 50.78% to

56.86%, whereas the modeling results varied from 51.56% to 58.10% for solar irradiation 800 W/m2. The findings obtained in the experiments ranged from 53.11% to 59.34% and in the simulations from 54.83% to 62.01% for the greatest solar irradiation of 1000 W/m2 that was employed in the tests. This demonstrates that the simulation results are marginally higher than the experimental results due to the assumptions made, such as the lack of simulation errors. The computational and experimental results show an improvement in energy efficiency of between 5% to 7%. It is crucial to get the maximum amount of sun irradiation in order to maximize heat transfer in solar collectors and achieve optimum performance.

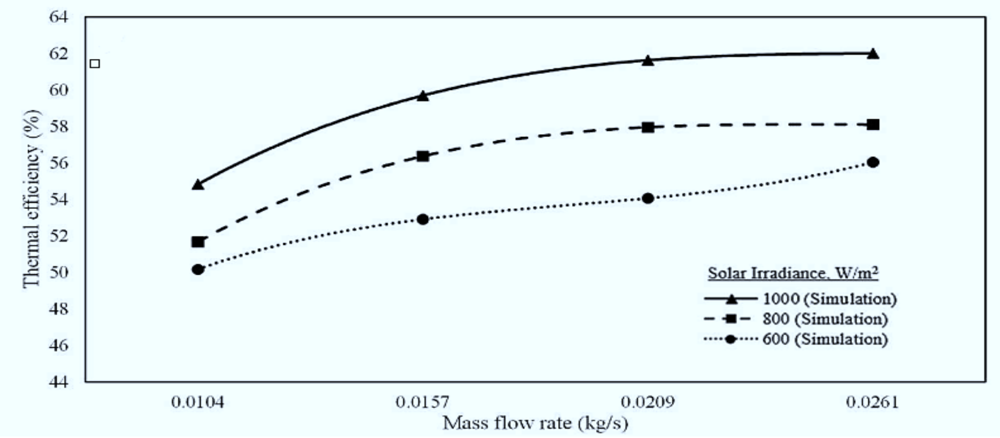

Figure 4: Variation of Thermal Efficiency with Mass Flow Rate at Different Solar Irradiance Levels at simulation level

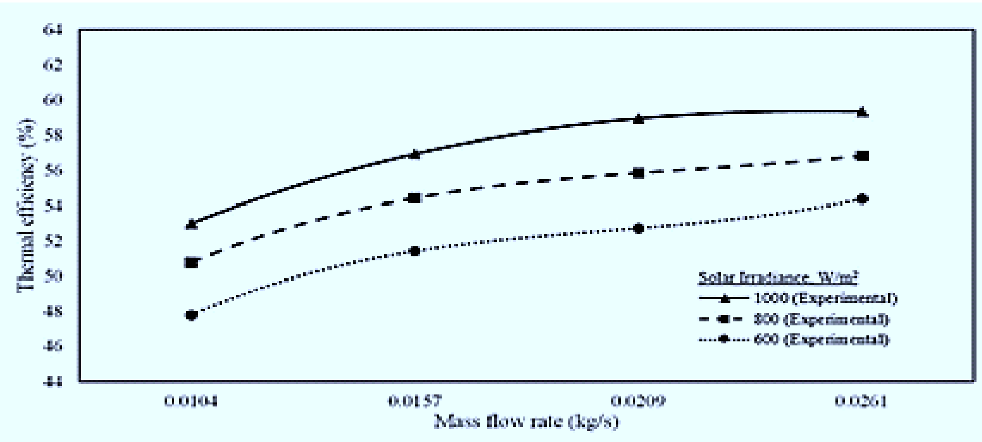

Figure 5: Variation of Thermal Efficiency with Mass Flow Rate at Different Solar Irradiance Levels at experimental level

They said that the thermal efficiency would keep going up until it's no longer noticeable. The thermal performance has also been improved because to the enhanced rate of heat transfer caused by the turbulent flow generated by the diamond-shaped fins. As a result of merging all sides into a diamond shape, the possible manufacturing complexity may have increased as a result of the thermal efficiency achieved in this experiment. The thermal performance benefits, nevertheless, make it worthwhile.

V. CONCLUSION

The investigation of solar irradiance and air mass flow rate on the thermal performance of a double-pass solar air heater with fins demonstrates that both parameters exert significant and interdependent influences on system behavior. Higher solar irradiance consistently enhances absorber plate temperatures and increases the useful heat gain, resulting in improved thermal efficiency. However, the extent of this enhancement depends on the air mass flow rate, which governs the rate of heat extraction and the convective heat transfer characteristics inside the heater. Lower flow rates lead to a higher temperature rise but reduced overall heat removal, whereas higher flow rates increase useful heat gain despite producing lower outlet temperatures. The inclusion of fins plays a critical role by improving turbulence, expanding heat transfer surface area, and compensating for reduced thermal contact time at higher flow rates. Overall, the finned DPSAH configuration proves effective across a wide range of irradiance and flow conditions. The results underscore the importance of optimizing both environmental and operational parameters to achieve maximum thermal efficiency. This study provides valuable guidelines for designing high-performance solar air heaters suitable for drying, space heating, and industrial thermal applications, particularly in regions with fluctuating solar radiation profiles.

REFERENCES:

1. A. Dutta and D. Rabha, “Experimental investigation on counter flow double-pass solar air heater with absorber attached with perforated C-shaped fins,” J. Phys.: Conf. Ser., vol. 2818, no. 1, pp. 12–21, 2024.

2. J. Chen et al., “Experiment and dynamic simulation of a solar tower collector system for power generation,” Renew. Energy, vol. 196, pp. 946–958, 2022.

3. H. Hussein, S. Ahmed, and A. Ekaid, “Thermal performance of a counter-flow double-pass solar air heater with steady and pulsating flow,” Eng. Technol. J., vol. 41, no. 1, pp. 176–184, 2022.

4. H. Hussein, S. Ahmed, and A. Ekaid, “Thermal performance of double-pass solar air heater with tubular solar absorber,” Int. J. Renew. Energy Dev., vol. 12, no. 2, pp. 11–21, 2022.

5. V. Rajendran et al., “Experimental study on the thermal performance of a solar air heater integrated with multi-geometry arrangements over the absorber plate,” Environ. Sci. Pollut. Res., vol. 29, pp. 1–9, 2022.

6. Z. Song, J. Liu, and H. Yang, “Air pollution and soiling implications for solar photovoltaic power generation: A comprehensive review,” Appl. Energy, vol. 298, p. 117247, 2021.

7. N. A. Habib, A. J. Ali, M. T. Chaichan, and M. Kareem, “Carbon nanotubes/paraffin wax nanocomposite for improving the performance of a solar air heating system,” Therm. Sci. Eng. Prog., vol. 23, pp. 1–11, 2021.

8. S. Khanmohammadi, H. A. Chaghakaboodi, and F. Musharavati, “A new design of solar tower system amplified with a thermoelectric unit to produce distilled water and power,” Appl. Therm. Eng., vol. 197, pp. 1–15, 2021.

9. A. Kumar, P. Bhandari, and K. S. Rawat, “Numerical simulation of solar air heater using paraffin wax–aluminum compound as phase changing material,” Aptisi Trans. Technopreneurship, vol. 3, pp. 164–170, 2021.

10. J. Jalil, R. Nothim, and M. Hameed, “Effect of wavy fins on thermal performance of double pass solar air heater,” Inf. Technol. J., vol. 39, no. 9, pp. 1362–1368, 2021.

11. B. Das, J. D. Mondol, S. Debnath, A. Pugsley, M. Smyth, and A. Zacharopoulos, “Effect of the absorber surface roughness on the performance of a solar air collector: An experimental investigation,” Renew. Energy, vol. 152, pp. 567–578, 2020.

12. Q. A. Jawad, A. M. J. Mahdy, A. H. Khuder, and M. T. Chaichan, “Improve the performance of a solar air heater by adding aluminum chip, paraffin wax, and nano-SiC,” Case Stud. Therm. Eng., vol. 19, pp. 1–9, 2020.

13. B. Madhu et al., “Investigation on heat transfer enhancement of conventional and staggered fin solar air heater coated with CNT-black paint—an experimental approach,” Environ. Sci. Pollut. Res., vol. 27, pp. 32251–32269, 2020.

14. P. G. Kumar et al., “Effect of using low-cost thermal insulation material in a solar air heating system with a shot blasted V-corrugated absorber plate,” Therm. Sci. Eng. Prog., vol. 14, pp. 1–10, 2019.

15. S. M. Salih, J. M. Jalil, and S. E. Najim, “Double-pass solar air heater utilizing latent thermal energy storage,” Mater. Sci. Eng., vol. 518, pp. 1–14, 2019.

16. M. G. Murali et al., “Experimental study on double pass solar air heater with fins at lower and upper channel,” Mater. Today Proc., vol. 21, 2019.

17. A. K. Raj, M. Srinivas, and S. Jayaraj, “A cost-effective method to improve the performance of solar air heaters using discrete macro-encapsulated PCM capsules for drying applications,” Appl. Therm. Eng., vol. 146, pp. 910–920, 2019.

18. J. M. Jalil and N. A. Abdulkadhim, “Vacuum effect on the performance of solar air collector with micro-channel absorber plate,” Eng. Technol. J., vol. 37, no. 8, pp. 348–353, 2019.

19. T. Josyula, S. Singh, and P. Dhiman, “Numerical investigation of a solar air heater comprising longitudinally finned absorber plate and thermal energy storage system,” J. Renew. Sustain. Energy, vol. 10, pp. 1–22, 2018.

20. D. Zhang, J. P. Li, Y. J. Cho, L. Wang, and J. Nan, “Thermal performance investigation of modified flat plate solar collector with dual-function,” Appl. Therm. Eng., vol. 108, pp. 1126–1135, 2016.

21. A. H. Abed, “Thermal storage efficiency enhancement for solar air heater using a combined SHSm and PCM cylindrical capsules system: Experimental investigation,” Eng. Technol. J., vol. 34, no. 5, pp. 999–1011, 2016.

22. H. M. Ali, A. I. Bhatti, and M. Ali, "An experimental investigation of performance of a double pass solar air heater with thermal storage medium," Therm. Sci., vol. 19, no. 5, pp. 1699–1708, 2015.

23. A. Mahmud, K. Sopian, M. A. Alghoul, and M. Sohif, "Using a paraffin wax–aluminum compound as a thermal storage material in a solar air heater," ARPN J. Eng. Appl. Sci., vol. 4, pp. 74–77, 2009