A review on development of solar thermal flat plate collector

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Abstract
Solar thermal collectors are most frequent type of solar energy applications. Solar collector is a type of heat exchanger where heat exchanges take place between a distance source and a moving heat transfer fluid in the collector. Solar collectors can be categorized as concentrated and non-concentrating according to their design. In this present work, the most important studies that dealt with the development in the manufacture of collectors were reviewed. Studies differed according to the type of improvement discussed, such as use of obstacles, type of fin, absorber plate design, nanofluid as heat transfer fluid and use of enhancement devices. Researchers can take advantage of simulation programs to get the best experiences at the lowest cost and time.

1 Introduction
One of the most serious matters in the world, is Energy. As we know, there are multiple sources of energy. The most important of which is the most common Fossil fuel, but, because of the many problem caused by fossil fuel, the attention
has been given to search for renewable energy. Solar energy is considered more renewable energy using. Solar thermal collectors are most frequent type of solar energy applications. Solar collector defined as a type of heat exchanger where heat exchanges take place between a source distance and a heat transfer fluid moving in the collector. Solar irradiance enters the absorber plate of collector and then the thermal energy is passed to the working fluid[1].

Can be solar collectors categorized as concentrated and non-concentrating according to their design. Flat plate solar collectors are the most frequent type of non-concentrating collectors. Work of Woertz and Hottel in 1942 and by Hottel and Whiller in 1958 can be seen as the first work on flat plate collectors.[2]

Solar energy has been used as a source of limitless energy because of increasing energy problems. Solar collectors have been the subject of detailed research. After 1990 several of the latest designs were produced. Several research work is under way around the world to boost the thermal efficiency of flat plate collectors[3]. The thermal efficiency of solar heaters is comparatively poor because of the low density [4]. To enhance efficiency, reducing the collector's heat loss is very necessary. Most experiments are focused in this direction, with increased honey comb maze, glazing dependent absorber layer, considering wind speed in collector research etc. It is equally important to evaluate collector efficiency, as it helps to further refine and enhance the design. The CFD simulation have been a considerable benefit to researchers. CFD's potential to shorten lead times, test device under unsafe conditions and research regulated device tests that are difficult or impractical to carry out in practice are some of the main advantages. [2]

In this present work, Authors provided a description of the different development and analysis methods used by investigators to boost the total collector efficiency. Studies include developing and analysing innovative designs of absorber plates, studying the effect of nanofluids, as a heat transfer fluid, on collector performance, Ways of reducing heat loss to nearby areas is discussed in this paper.

2 Analysis techniques and methods

Sun et al. [5] work to find best thermal performance for flat plate solar air collector by analysis of system consist of two air passage channels and glass cover.
The authors studied the effect of the flow rate on the efficiency of the collector under different conditions and forced convection. Mathematical analysis included air ducts, absorption plate, glass cover, thermal insulation board, and fan energy. They found that when the mass flow rate increases the hydraulic thermal efficiency will increase until it reaches a certain rate then it starts decreasing, but the outlet air temperature decreases as the mass flow rate increases; however, the effect of the ambient temperature on the efficiency will increase as the flow rate increases.

Daliran and Ajabshirchi [6] published an experimental and theoretical study to compare the efficiency of the rectangular-finned air collectors and the fin-free air collectors. While keeping the mass flow rate fixed at 0.033 kg/s, they proved that including the fins reduced the Nusselt number from 19.67 to 16.23, reduced the hydraulic diameter, increased the heat transfer coefficient between the absorber plate and the air, reduced the thermal losses, and increased the outlet temperature.

Tyagi et al. [7] conducted an experimental study to analyses energy and exergy of flat plate collector with thermal storage material; paraffin wax and hytherm oil. They calculated first and second laws of efficiency with and without the thermal storage material. The Authors concluded that the efficiency; without thermal storage material; increases with time until maximum value at noon then it reduces and with this material, the efficiency will increases until 4:30 pm. Zhao et al. [8] published an experimental and theoretical study to analysis the effect of the maximum daily heat energy collected and flow rate on the daily heat energy under conjunction the solar collector and tank. This study also proposed a simplified formula for computing the daily heat energy collected. Gunjo et al. [9] work an experimental and theoretical study. This study investigate the effect of inlet water temperature, ambient temperature, solar radiation, and mass flow rate on the outlet temperature and thermal efficiency. The numerical analysis based on (CFD) with single riser tube and absorber plate at steady state. Thermal efficiency increases
with increases water flow rate, solar radiation, ambient temperature, while, reduces with inlet water temperature. Assari et al. [10] studied an experimental and theoretical investigation performance of dual purpose solar collector (DPSC). Two fluids are flow in this collector simultaneously to product hot air and hot water. Experimental data show that the high performance and high temperature can be getting on it by using this collectors compared to single solar collectors. Effectiveness method used to investigate thermal performance of DPSC mathematically. Three different type of air duct used to improve collector performance, such as: rectangular fin, triangular fin and non-fin. The results indicate that the rectangular fin has better performance compared to other fines and heat delivery reduces as water inlet temperature increases. AK and Arun [11] Conducted a numerical simulation study to improving the performance of a dual purpose solar thermal collector integrated with porous matrix. The simulation is carry out by ANSYS 13 software program. The suggestion system is compared with dual solar collector designed by M.R. Assari, et al [10]. The simulation results show that significantly higher temperature rises for air and water streams are obtained under different operating conditions as compared to the original system without the porous media.

3 Development of collectors

As discussed earlier, new methods and methodologies have to be applied to efficiently capture the heat from the sun. Those techniques aim to increase the collector's thermal efficiency and overall performance. Various researchers have performed several studies to boost the efficiency of collectors. The techniques include using various materials to render collectors, changes in the structure of the absorber layer, use of multiple heat transfer fluids to absorb heat.
2.1 Arrangement of pipes and channels

González et al. [12] Carried out an experimental and theoretical study of the behavior and efficiency of solar flat plate air heater. To enhancement thermal efficiency of the collector, the authors using counter-flow double pass air heater. The prototype is tested during four sunny winter days with a maximum solar irradiance of 1100 W/m² and dry temperatures ranging from 8° C to 23° C. Outlet air temperature during the test reached 80° C at noon by using a resistor and 75° C without it. The average difference between the inlet and outlet temperatures was 40° C where the air flow was fixed at 0.02 kg/s. The average efficiency was 42% and peaking at 50%. Hossain et al. [13] conducted an experimental study to enhance the efficiency of the flat plate solar water collector by rearrange pipes. The new arrangement is two parallel rows. It has a higher convective heat transfer between absorber and water, and more surface area exposed to solar radiation. The new suggestion design advantages are that easy to instillation, less cost and high thermal efficiency. The results show that the average of 75.50% for two months and the outlet temperature of 98° C. Balaji et al. [14] Published a theoretical study to analysis thermal efficiency of expanded surface of flat-plate solar water collector absorber tubing by passive technique. This technique based on changes the geometry of flow path of fluid. The objective of this study is increases effective of the heat transfer coefficient with minimum pressure drop. Two type of velocity enhancer were used in this study, then compared work at rod and tube. The authors concluded that the rod velocity enhancer greater than the tube velocity enhancer and the increase in efficiency are 15% and 10% for rod and tube respectively. Anto Joseph Deeyoko et al. [15] Published an experimental and theoretical study to enhancement the coefficient of convective heat transfer by increasing the effective area between the heat transfer liquid and the contact surface. Rectangular and square fins were used to enhancement the thermal performance of the collector.
The results show that the rectangular fin gives high exergy and energy efficiency. The rectangular fin efficiency is higher than plain tube by 18-20% at different mass flow rates. The square fin efficiency less than rectangular fin by 3-5%. Verma et al. [16] work on enhancement thermal performance of solar water collector by modification arrangement water pipes. The new model include a spiral pipes instead of parallel inline pipes in conventional collectors. This system investigated theoretically and experimentally. The theoretical results show good agreement with experimental results. Enhancement of thermal efficiency 21.45 percent compared to traditional collector configuration at mass flow rate 0.026kg/s and 1011 W/m².

2.2 Use of obstacles

Aoucs et al. [17] Published an experimental and theoretical study of a solar air flat plate collector with obstacle rows in the dynamic air vein to enhance thermal efficiency. They made a comparison between the theoretical and experimental results, and found that the theoretical approach reflects in a satisfactory way the thermal performance of the tested prototype and the effects of its components, primarily the absorber, on the results achieved. Akpınar and Koçyıgit [18] Published an experimental study of fourth types of flat plate solar air collector; three types with different obstacle and one type without obstacle. The first and second laws of efficiency was studded. The study showed that the two efficiency depend on solar radiation, geometry of absorber plate, and air flow line. Tests were held at two air mass flow, 0.0052 and 0.0074 kg/s. The values of first and second laws were 20-82% and 8.32-44% respectively. Esen [19] Carried out an experimental study analysis of energy and exergy of the double-pass flat plate collector with obstacle. The air flow through two passes, top and down absorber plate. The study show that the double-pass increasing the heat transfer area, therefore, increasing of efficiency.
2.3 Type of fin

Chang et al. [20] Conducted an experimental and theoretical study of the finned solar air collectors in regards to the tilt angle, and the flow and the inlet mode of the air. The study showed that the efficiency difference resulted is only 3% when changing the installation angle of the collector, which means that the angle has a little effect on the efficiency; while the flow showed to have a positive impact on the efficiency of the collector, especially when the flow is small and increases gradually. Nematollahi et al. [21] Published an experimental investigation to study the performance of single and dual purpose solar collectors. To enhancement the efficiency of collector, it was used a triangular fin in air channels. The study included testing dual purpose solar collector at two different speeds of air, 2.8 and 3.2 m/s respectively. Using dual purpose solar collector decreases costs and required space. This study show that the efficiency of dual purpose higher than single purpose by 3 to 5%.

2.4 Absorber plate design

Rajaseenivasan and Srithar [22] Studied dual solar collector experimentally investigation on humidification dehumidification system. The system consist of dual solar collector with semicircular convex and concave shape integrated with absorber plate to create the turbulence, and packed bed humidification dehumidification unit. The system is tested with the mass flow rate of air varies (0.84 kg/min to 1.08 kg/min) and water (1 kg/min to 3 kg/min). The dual purpose collector provides the hot water and hot air needed for desalination system. In this collector, Air flows through the top of the absorber plate and water flows through the riser tubes, attached to the bottom of the absorber plate. The hot air and water from the collector are supplied to the humidifier, where the air is moistened and the condenser is dehumidified. The system distillation capacity enhances with the air
and water temperature and flow rate of air, hot water and cold water. The authors concluded that the highest distillate of 15.23, 14.14, and 12.36 kg/m² is collected for the concave, convex and conventional system respectively. The overall efficiency of the system with the presence of turbulators in the collector is about 68%. Wenjing He [23] using in his study the ceramic heat collection plate is a growing matrix with the hollow solar heat collector V-Ti black ceramic-coated. This has a solar radiation absorption ratio of 0.95, and over time it does not degrade. This also has excellent thermal efficiency, oxidation resistance, resistance to corrosion and scale-insensitivity. The amount of water absorption is less than 0.3%, for the same longevity and low quality. The ceramic heat collection board built by the researcher uses air and water simultaneously, with two forms of refrigerants in the solar collector, to achieve double heat collection in compliance with the seasonal heat requirement, making it possible to work in single mode or duplex composite joint heating mode, while increasing the efficiency of collector usage. Pathak et al. [24] carry out an experimental study to enhancement performance of dual purpose solar flat plate collector. In this study, the authors using corrugated absorber plate to increase heat transfer effectiveness. Two working mode thermal performance including water heating and water-air compound heating is investigated and analyzed. Seven different case of the system were tested at different mass flow rate and a comparison was made among them. The results show that, using corrugated absorber plate increasing thermal efficiency and reduce cost and space requirement. More and Pote [25] published an mathematical and experimental study to improve thermal performance of dual purpose solar collector by changes the made in the design developed by Assari et al. the development include using zig-zag water pipes instead of parallel pipe in Previous study. The experiment is designed to research the performance of the system. This parameter is calculated during experimentation: Ambient
temperature, inlet water temperature, outlet air temperature, absorber plate temperature, storage tank temperature, air & water flow rate, solar radiation. The mathematical analyses based on $\epsilon$-NTU method. The average efficiency achieved by this system about 72.4%. Pathak et al. [26] carry out an experimental and CFD analyses to improvement performance of solar collector by using water pipes in absorber plate. The flat plate solar collector system is a force convection system. The commercial coding for ANSYS Fluent 17.2 was used in the present analysis. The 3D CFD model was used to evaluate the outlet water and plate temperatures for a single straight elevator tube (including indoor fluid flow) at the bottom of an absorber plate. The average efficiency was 73.41 and 80.95 experimentally and numerically respectively. K. Anirudh and S. Dhinakaran [27] conducted an Numerical study of the thermal efficiency of a flat plate solar water collector (FPSC). To improvement the efficiency and facilitate thermal mixing the FPSC is intermittently filled with porous metal foam sheets. Four separate configurations are used depending on the presence of blocks at the inlet and exit, including NN, NP, PN and PP, where N means are missing and P means present. Study show that this modification increase heat transfer rate. Sakhaei and Valipour [28] The present of their research aims to compare the thermal efficiency of three flat-plate collectors which vary in the form of coatings used in the absorber plate. The collector's thermal efficiency was studied with three types of absorber plate: black coated, black chromium coating and carbon coating. Because of good optical properties and good thermal conductivity, black chrome, carbon and matt black paint were selected. The black paint optical absorptivity, the black chrome coating, and the carbon coating are measured, which is roughly 0.85, 0.93, and 0.95, respectively. The findings suggest that the use of black chromium and carbon coatings on FPC's absorber plates is possible due to their high capacity to improve the collectors 'thermal efficiency.
2.5 Nanofluid as heat transfer fluid

Saffarian et al. [29] using nanofluid and change flow direction in flat plate solar collector to enhancement the heat transfer rate and increase thermal efficiency of the collector. In this study, U-shaped and spiral pipes are used. Also, nanofluids of Al₂O₃/water and CuO/water are used in volume fractions of 1% to 4%. The numerical simulation is carried out using the finite volume method and the commercial program Fluent. The geometry is created with the help of software Space Claim. The Mesh is created using ANSYS Meshing. Simulation in three dimensions and the steady state is done. The results show that using of nanoparticles and U-shaped increases the heat transfer coefficient. Farshad et al. [30] carry out an numerical study to investigated thermal performance of flat plate solar water collector. To improvement heat transfer rate, Al₂O₃ nanoparticles are used as nanofluid in this study. Simulations with FVM capture thermal efficiency behavior with variance of the Reynolds number, diameter ratio and revolution number. Verification test shows that the present larger pressure loss and higher Nusselt number due to intensification of the turbulent strength was obtained with increase. Verma et al. [31] Conducted an experimental study for testing performance of flat plate solar water collector with Mgo/water working fluid with particle size ~40 nm. The study included effect of mass flow rate and particle volume fraction on the efficiency of the collector. The results show that used Mgo/water Nano fluid increases the efficiency comparison with water as working fluid by 9.34%.

2.6 Use of enhancement devices

Eleiwi and Shallal [32] carry out an experimental study to investigate thermal performance of solar air collector. In this study, worked in their study to Find the solution to sun absence problem (before sunrise, after sunset and cloudy
days) by using the heat exchanger to make up for the loss of sun, corrugated absorber plate and reflectors. The findings presented indicate that the average thermal efficiency of solar air heaters with reflectors is greater than without reflectors; the HE has high energy and can be used before sunrise, after cloudy days and sunset. However, on the cost of used fuel and environmental emissions, and the findings do demonstrate that solar air heaters have a strong reduction in fuel consumption over the sun's existence. The results show that Average thermal efficiency of SAH with reflectors at the same air mass flow rate is better than without reflectors. The average daily thermal efficiency with and without reflectors was 63.49 per cent and 59.49 per cent respectively. Badiei et al. [33] conduct an numerical study to investigate thermal performance of solar water flat plate collector. To increase the time of heating water, thermal storage material (Phase Change Material) is added to the system. On two summer and winter day’s four forms of PCM with different melting temperatures will be studied. The resultant distribution of temperature and velocity is used to measure the instantaneous and cumulative output in different incidents over the average days under investigation. The results show that the application of PCM usually reduces the temperature of the outlet water when charging in the morning. In summer day, with PCM the mean outlet water temperature is around 4 ºC cooler on the summer day than case without PCM. In winter day, hot water delivered until 1:00 AM. Martin et al. [34] studying solar flat plate to improvement heat transfer and thermal performance. For this goal, tube-on-sheet solar panel with wire-coil inserts. Using TRNSYS as tool for simulating. The computational simulation technique predicts the behavior of improved and normal tube-on-sheet solar collectors in thermohydraulic flow, Evaluation of the local losses, friction coefficients and Nusselt numbers as working parameter functions. Within the same ambient, radiant, and working conditions the normal and the improved collectors were simulated. The improved collector
improves by 4.5 percent the thermal efficiency values. Chabane and Sekseff [35] carried out an experimental study on flat plate solar air collector to reduce the thermal losses by adding double glass. The collector consists of a black-coated steel absorption plate, and double layers of glass. Testing of study included changing the distance between glass layers. The inclination angle of the collector is $37^\circ$. The results of adding the second glass layer and changing the distances between the two glass layers at 1, 2 and 3 cm were compared with the results of having single glass layer, and it was found that adding the second glass layer was effective in reducing the thermal losses.

4 Conclusion

Flat plate collector is one of the most common types of collectors, and the easiest to install. Several studies were conducted to increase thermal performance and efficiency. Studies differed according to the type of improvement discussed, such as use of obstacles, type of fin, absorber plate design, nanofluid as heat transfer fluid and Use of enhancement devices. By looking at the studies above, we can say that the best improvement we can get by modification the absorber plate design. Researchers can take advantage of simulation programs to get the best experiences at the lowest cost and time.
References

[1] Soteris A. Kalogirou, “Copyright,” in *Solar Energy Engineering*, 2009, p. iv.

[2] K. M. Pandey and R. Chaurasiya, “A review on analysis and development of solar flat plate collector,” *Renewable and Sustainable Energy Reviews*, vol. 67. pp. 641–650, 2017.

[3] M. R. Assari, H. Basirat Tabrizi, and M. J. Movahedi, “Experimental study on destruction of thermal stratification tank in solar collector performance,” *Journal of Energy Storage*, vol. 15. pp. 124–132, 2018.

[4] J. Ma, W. Sun, J. Ji, Y. Zhang, A. Zhang, and W. Fan, “Experimental and theoretical study of the efficiency of a dual-function solar collector,” *Appl. Therm. Eng.*, vol. 31, no. 10, pp. 1751–1756, 2011.

[5] C. Sun, Y. Liu, C. Duan, Y. Zheng, H. Chang, and S. Shu, “A mathematical model to investigate on the thermal performance of a flat plate solar air collector and its experimental verification,” *Energy Convers. Manag.*, vol. 115, pp. 43–51, 2016.

[6] A. Daliran and Y. Ajabshirchi, “Theoretical and experimental research on effect of fins attachment on operating parameters and thermal efficiency of solar air collector,” *Inf. Process. Agric.*, vol. 5, no. 4, pp. 411–421, 2018.

[7] Tyagi et al., “Comparative study based on exergy analysis of solar air heater collector using thermal energy storage,” *Int. J. energy Res.*, vol. 31, no. August 2007, pp. 135–147, 2011.

[8] J. Zhao, Z. P. Wang, K. Z. Wang, and X. Lu, “Analysis of Thermal Performance of Solar Collector in Solar Water Heating System,” *Adv. Mater. Res.*, vol. 1055, pp. 193–198, 2014.
[9] D. G. Gunjo, P. Mahanta, and P. S. Robi, “CFD and experimental investigation of flat plate solar water heating system under steady state condition,” *Renewable Energy*, vol. 106. pp. 24–36, 2017.

[10] M. R. Assari, H. B. Tabrizi, and I. Jafari, “Experimental and theoretical investigation of dual purpose solar collector,” *Sol. Energy*, vol. 85, no. 3, pp. 601–608, 2011.

[11] A. V. AK and P. Arun, “Simulation studies on porous medium integrated dual purpose solar collector,” *Int. J. Renew. Energy Res.*, vol. 3, no. 1, pp. 114–120, 2013.

[12] S. M. González, S. F. Larsen, A. Hernández, and G. Lesino, “Thermal evaluation and modeling of a double-pass solar collector for air heating,” *Energy Procedia*, vol. 57, pp. 2275–2284, 2014.

[13] S. Hossain, A. W. Abbas, J. Selvaraj, F. Ahmed, and N. B. A. Rahim, “Experiment of a Flat Plate Solar Water Heater Collector with Modified Design and Thermal Performance Analysis,” *Appl. Mech. Mater.*, vol. 624, pp. 332–338, 2014.

[14] K. Balaji, S. Iniyan, and R. Goic, “Thermal performance of solar water heater using velocity enhancer.pdf.” 2017.

[15] L. Anto Joseph Deeyoko, K. Balaji, S. Iniyan, and C. Sharmeela, “Exergy, economics and pumping power analyses of flat plate solar water heater using thermal performance enhancer in absorber tube,” *Applied Thermal Engineering*. pp. 726–737, 2019.

[16] S. K. Verma, K. Sharma, N. K. Gupta, P. Soni, and N. Upadhyay, “Performance comparison of innovative spiral shaped solar collector design
with conventional flat plate solar collector,”” *Energy*, vol. 194, 2020.

[17] K. Aoucs, N. Moummi, M. Zellouf, and A. Benchabane, “Thermal performance improvement of solar air flat plate collector: A theoretical analysis and an experimental study in Biskra, Algeria,” *Int. J. Ambient Energy*, vol. 32, no. 2, pp. 95–102, 2011.

[18] E. K. Akpinar and F. Koçyiğit, “Energy and exergy analysis of a new flat-plate solar air heater having different obstacles on absorber plates,” *Applied Energy*, vol. 87, no. 11. pp. 3438–3450, 2010.

[19] H. Esen, “Experimental energy and exergy analysis of a double-flow solar air heater having different obstacles on absorber plates,” *Building and Environment*, vol. 43, no. 6. pp. 1046–1054, 2008.

[20] Z. Wang, F. Qiu, W. Yang, and X. Zhao, “Applications of solar water heating system with phase change material,” *Renewable and Sustainable Energy Reviews*, vol. 52. pp. 645–652, 2015.

[21] O. Nematollahi, P. Alamdari, and M. R. Assari, “Experimental investigation of a dual purpose solar heating system,” *Energy Convers. Manag.*, vol. 78, pp. 359–366, 2014.

[22] T. Rajaseenivasan and K. Srithar, “Potential of a dual purpose solar collector on humidification dehumidification desalination system,” *Desalination*, vol. 404. pp. 35–40, 2017.

[23] W. He, “Design of a two-medium solar collector in residential buildings,” in *Energy Procedia*, 2018, vol. 152, pp. 456–461.

[24] P. K. Pathak, P. Chandra, and G. Raj, “Comparative analysis of single- and dual-purpose corrugated plate solar collector by force convection,” *Heat*
Transf. - Asian Res., vol. 48, no. 6, pp. 2387–2401, 2019.

[25] N. G. More and R. S. Pote, “Numerical and Experimental investigation of dual purpose solar collector,” Int. J. Eng. Res. Technol. ISSN, vol. 7, no. 08, 2018.

[26] P. K. Pathak, P. Chandra, and G. Raj, “Experimental and CFD analyses of corrugated-plate solar collector by force convection,” Energy Sources, Part A Recover. Util. Environ. Eff., vol. 42, no. 3, pp. 304–318, 2020.

[27] K. Anirudh and S. Dhinakaran, “Performance improvement of a flat-plate solar collector by inserting intermittent porous blocks,” Renew. Energy, vol. 145, pp. 428–441, 2020.

[28] S. A. Sakhaei and M. S. Valipour, “Investigation on the effect of different coated absorber plates on the thermal efficiency of the flat-plate solar collector,” J. Therm. Anal. Calorim., 2019.

[29] M. R. Saffarian, M. Moravej, and M. H. Doranehgard, “Heat transfer enhancement in a flat plate solar collector with different flow path shapes using nanofluid,” Renew. Energy, vol. 146, pp. 2316–2329, 2020.

[30] S. A. Farshad, M. Sheikholeslami, S. H. Hosseini, A. Shafee, and Z. Li, “Nanofluid turbulent forced convection through a solar flat plate collector with Al2O3 nanoparticles,” Microsyst. Technol., vol. 25, no. 11, pp. 4237–4247, 2019.

[31] S. K. Verma, A. K. Tiwari, and D. S. Chauhan, “Performance augmentation in flat plate solar collector using MgO/water nanofluid,” Energy Convers. Manag., vol. 124, pp. 607–617, 2016.

[32] M. A. Eleiwi and H. S. Shallal, “Thermal performance of solar air heater
integrated with air–water heat exchanger assigned for ambient conditions in Iraq,” *Int. J. Ambient Energy*, 2020.

[33] Z. Badiei, M. Eslami, and K. Jafarpur, “Performance improvements in solar flat plate collectors by integrating with phase change materials and fins: A CFD modeling,” *Energy*, vol. 192, 2020.

[34] R. H. Martín, J. Pérez-García, A. García, F. J. García-Soto, and E. López-Galiana, “Simulation of an enhanced flat-plate solar liquid collector with wire-coil insert devices,” *Solar Energy*, vol. 85, no. 3, pp. 455–469, 2011.

[35] F. Chabane and E. Sekseff, “Iranian Journal of Energy & Environment Experimental Study of a Double Glazed Solar Air Collector,” vol. 9, no. 3, pp. 163–167, 2018.