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Review Article

A Review on Potential Opportunities to Preheat the Batteries Using a Finned Solar Air Energizer to Enhance Power Quality and Thermal Management in Low-Temperature Surroundings

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This research study's objective is to provide a comprehensive analysis of the efforts that have been made to improve the power quality and thermal management of batteries that are operating at low temperatures. These improvements have been made by combining the utilization of conventional solar air energizer (SAE) ducts with the application of a variety of different configurations of longitudinal fins. These expanded surfaces can be found on the absorber or bottom plate surface, and they are placed in a variety of positions along the airflow channel. It does this by increasing the surface area of the typical SAH and making the flow more turbulent, both of which contribute to the improvement in performance. Several studies have been carried out to enhance the thermal efficiency of clear SAE ducts by making use of experimental fins. An effort has been made to establish the Nusselt number and the friction factor by making use of the correlations that the researchers have provided. This was performed so that the performance of various configurations of finned SAEs could be compared to one another.

1. Introduction

The global expansion of industry raises the demand for thermal energy and depletes fossil resources. Solar energy has been identified by experts as a viable option for creating energy from an unlimited resource. Flat plate solar air energizers (SAEs) are utilized for the drying of agricultural (pepper, coffee, tea, grapes, Chilies, etc.) and industrial items (curing of concrete blocks, drying of paints, etc.). They are also utilized to improve the efficiency of desalination and heat pump systems. In addition, they are utilized for space heating applications and hot air requirements up to 120°C at low temperatures [1–4]. SAEs have a basic structure, less manufacturing, and maintenance complexity, and lower initial investment and maintenance expenses [5]. Even though SAEs have their own merits, the thermal performance of the flat plate SAE is low (40 to 45 percent) due to the low heat transfer coefficient produced by the thermo-physical properties of air.

To boost the thermal performance of conventional SAEs, researchers have utilized a variety of methods to increase the heat transfer coefficient between the air and absorber plate. The formulation of the laminar sublayer is one of the major primary factors that decrease the convection heat transfer rate. In previous research [6, 7], artificially rough wires are added to the absorber plate to disrupt the laminar sublayer formulation. In addition, the rate of heat transmission is increased by affixing V-grooves [8, 9], corrugations [10, 11], turbulators, and baffles [12, 13] to the absorber plate and generating local turbulence. In addition, the packed bed, wire meshes, and energy storage materials are attached to the absorber plate to increase its efficiency during periods of low sunlight [14–18]. The CFD-based analysis of SAEs is performed to analyze and gain a deeper understanding of heat transfer phenomena. Pashchenko conducted a CFD-based analysis for SAE using ANSYS-FLUENT and concluded that the optimal efficiency occurs at an inclination angle of 60 degrees between the absorption surface and the Earth [19]. Moreover, he discovered that using an L-shaped fin on SAE with a pitch of 30 mm and Re of 1500 improves its thermodynamic performance [20]. Using MATLAB tools, the finned and roughened SAE designs are examined, and the design configurations are optimized based on energy and exergy efficiency [21, 22].

There are numerous published reviews on the implications of various roughness design settings on the performance of SAEs [23, 24]. Singh and Dhiman [25] analyzed the various design configurations of double-pass SAEs and concluded that hot air recycling improves thermal performance. Alam et al [26] conducted a comprehensive analysis of the application of turbulators and evaluated the performance of SAE ducts with various forms of baffles, ribs, and barriers. From a review of the relevant literature, it can be determined that the attachment of fins increases the heat transfer surface area, local turbulence, and the convective heat transfer rate. As far as the author is aware, no systematic studies have been conducted on this design configuration, and additional improvisation techniques are not mentioned to heat the batteries under low-temperature operating conditions. The thermal performance of finned SAEs is compared on the basis of the Nusselt number and friction factor [27–30] in this study, which reviews the various configurations and designs of finned SAEs. From the aforementioned literature survey, it can be inferred that various review articles have been presented about SAH thermal enhancement strategies. As far as the authors know, no one has reviewed extended surface (fin) SAHs put longitudinally in the duct.

1.1. Thermal Efficiency.

1.1. Thermal Efficiency. The real usefulness of SAH can be determined by taking into account the amount of energy that enters the collector in the form of radiation as well as the pace at which energy is lost to the surrounding environment. It is determined by making use of the Duffie and Beckman relation and taking into account the fact that the entire absorber plate is kept at an average fluid temperature of T_f and an ambient temperature of T_a.

$$Qu = F_R A_C \left[I(\tau\alpha) - U_L \left(T_f - T_a \right) \right]. \tag{1}$$

The answer to the previous equation, T_f, is given by

$$T_f = \frac{T_i + T_o}{2}. \tag{2}$$

The amount of useable energy that is gathered by the SAH can be calculated by taking into account the enthalpy difference that exists between the air that enters and leaves the device.

$$Qu = mC_p \left(T_o - T_i \right). \tag{3}$$

From equations (1) and (3), the heat removal factor FR is expressed as

$$F_R = \frac{mC_p \left(T_o - T_i \right)}{A_C \left[I(\tau\alpha) - U_L \left(T_f - T_a \right) \right]}. \tag{4}$$

Using the Hottel-Whillier-Bliss equation and taking into account the overall loss coefficient UL and the heat removal factor FR, one may determine the level of thermal efficiency that solar collectors possess. It is represented by

$$\eta_{\text{th}} = \frac{Q_u}{IA_C} = F_R \left[I(\tau\alpha) - U_L \left(\frac{T_f - T_a}{I} \right) \right]. \tag{5}$$

The heat removal factor FR can be evaluated using the relation as follows:

$$F_R = \frac{mC_p}{U_L A_c} \left[1 - \exp\left(\frac{U_L A_p F'}{mC_p} \right) \right]. \tag{6}$$

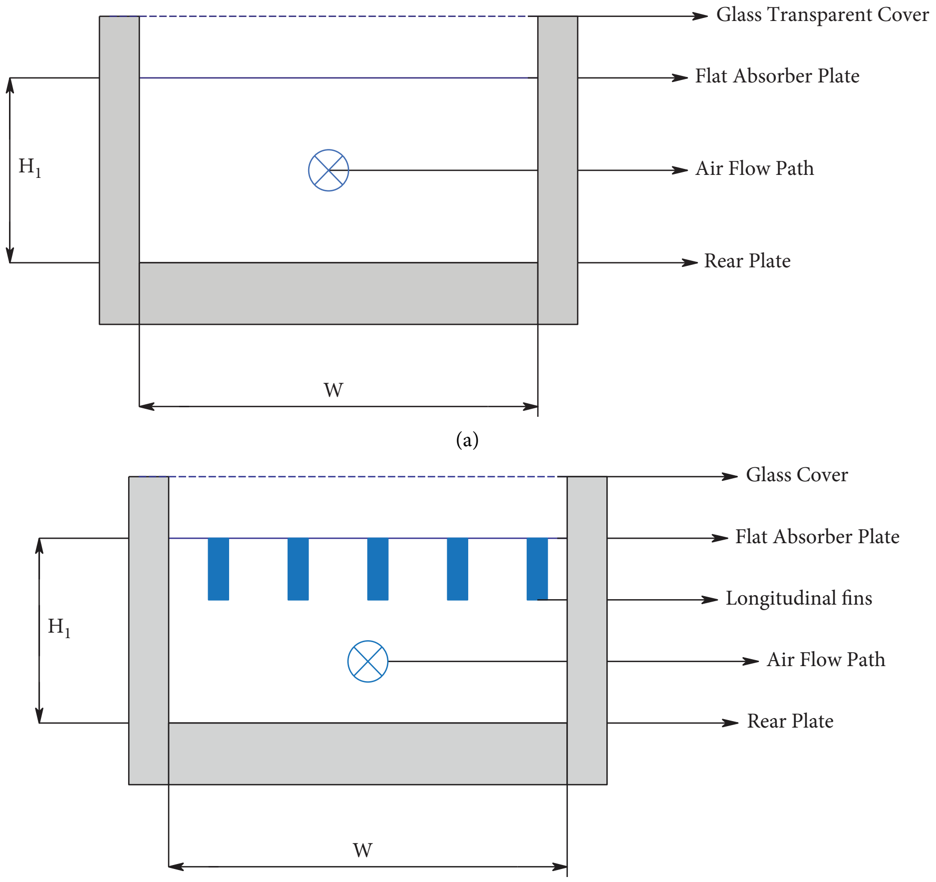
1.2. Effective Thermal Efficiency. The actual performance of the system can be determined by looking at the effective thermal efficiency of the SAH. It evaluated everything by taking into account the pumping power consumption that was used to propel the air inside the channel, the efficiency of the blower, the efficiency of the motor, the efficiency of the transmission, and the efficiency of the power plant.

Calculating the effective thermal efficiency is possible by applying the relation that is as follows:

$$\eta_{\text{ETE}} = \frac{Q_u}{IA_C} - \frac{P_m}{IA_C \left(\eta_B \eta_m \eta_T \eta_P \right)}. \tag{7}$$

2. Solar Air Energizer with Smooth and Fin Absorber Plates

The rate of heat transfer and SAE pipeline pressure drop are critical factors to be considered for the selection of the system for heating applications. Figure 1(a) shows a basic



(a)

(b)

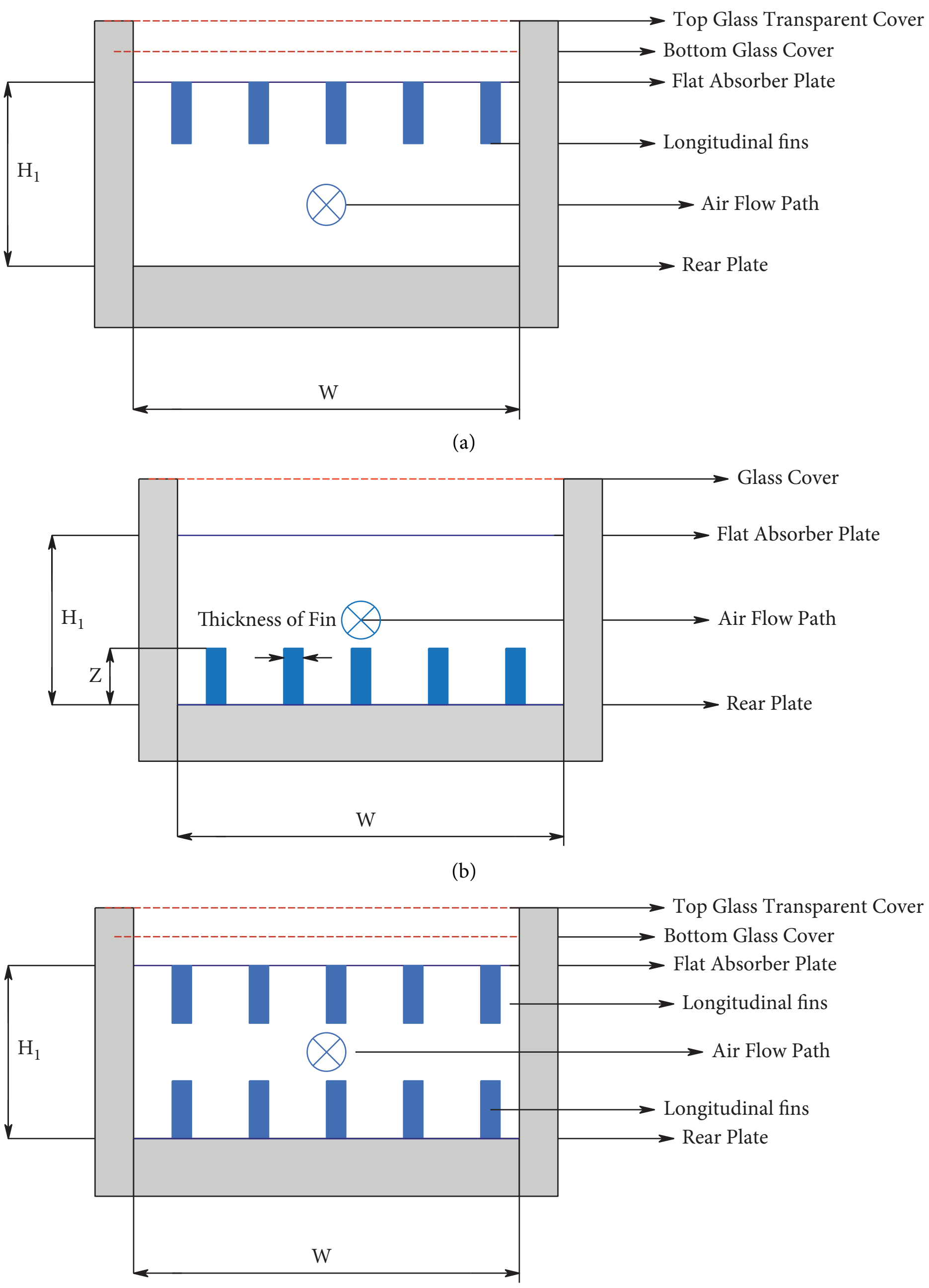
Figure 1: (a) Conventional smooth absorber plate solar air energizer. (b) Solar air energizer with a longitudinal fin plate absorber.

smooth plate SAE consisting of thin-walled bottom and glass-covered blackened absorber plates. There are longitudinal fins attached to the absorber surface of the heater shown in Figure 1(b).

3. Configurations of Fins and Flow Path Arrangements Utilized for the Heating Process

3.1. Longitudinal Fin-Integrated Solitary Pass Rectangular Solar Air Energizer. Garg et al. [31], who placed longitudinal fins on an absorber plate, were the first to observe the effect of rectangular fins on SAE. Using their mathematical model of steady state, they investigated the effect of fins on the efficiency of SAE. They evaluated three distinct types of SAE, including the Type-I conventional solar duct with an absorber plate as depicted in Figure 1(a). In Type-II SAEs with expanded surfaces, Figure 1(b)shows that Type-II SAEs are positioned across the absorber surface. The Type-III SAE was equipped with a V-grooved absorber plate. All SAE outputs and performance were analyzed using a single glass cover. The effect of the number of fins (n) on the outlet air temperature and thermal performance of a finned SAE was investigated by using three different rates of flows (m) in three different configurations. Garg et al. [32] analyzed three different designs of SAEs. They configured the Type-I SAE as illustrated in Figure 2(a). This comprises a double glass cover, and fins are put on the absorber plate to increase the turbulence of the flow. In addition, they adjusted the design by repositioning the fins on the backplate and assessed the resulting effect ((Figure 2(b)). As seen in Figures, Type-III SAE is created by combining both designs and incorporating fins into both SAE plates (Figure 2(c)). Following analytical and experimental processes, a comparison is performed between SAEs. Then, the effects of the fin density (n), mass flow rate (m), fin length (L), and height of the SAE duct (H) on the SAE performance were examined and compared to the performance of a conventional SAE under identical operating conditions.

The researchers Garg et al. and Karim and Hawaladar [33, 34] investigated the configuration of the expanded surface on the solar air energizer duct, which can be seen in Figure 3. They designed an SAE in which the height of the fin is proportional to the depth of the cavity. As a direct consequence of this, the absorber plates and back plates are connected by fins, which results in the formation of individual flow cells. The efficiency of the SAE and the temperature at its exit are investigated by making adjustments to the mass flow rate and the number of fins. Additionally, the impact that the SAE depth has on the organization's overall performance is investigated. After that, the researchers



(c)

Figure 2: (a) Fin solar air energizer with twin transparent sheets and the fin-integrated absorber surface [32]. (b) Fin solar air energizer with solitary glass sheets (fins at both the sheets) [32]. (c) Fin solar air energizer with finned bottom and glass sheet covered finned absorber plates [32].

investigated how a smooth plate and a V-groove SAE performed in single-pass and double-pass operation modes, respectively.

Bahrehmand et al. [35] developed an analytical model to evaluate the thermal performance of rectangular and triangular SAE fins. The SAE configurations are depicted in Figures 4 and 5. During the analysis, the effect of a suspended thin metal sheet on the airflow channel, the design configuration of the fins, the Reynolds number, the depth, and the length of the duct are examined.

At lower Reynolds numbers (4000), it is established that the SAE without fins integrated with thin metal sheets operates better. In addition, for higher Reynolds numbers (>4000), the thin metal sheet solar air energizer with triangle fins is more efficient. For practicing engineers to design the SAE, they also report the critical values of design and operating circumstances, such as Re of 13500, depth of 0.095 m, and length of 2 m.

3.2. Semicircular Fin-Integrated Solitary Pass Rectangular Solar Air Energizer.

Chabane et al [36] conducted an experiment to determine the effect of semicylindrical fins distributed longitudinally across the absorber plate, as depicted in Figure 6. The analysis was conducted under

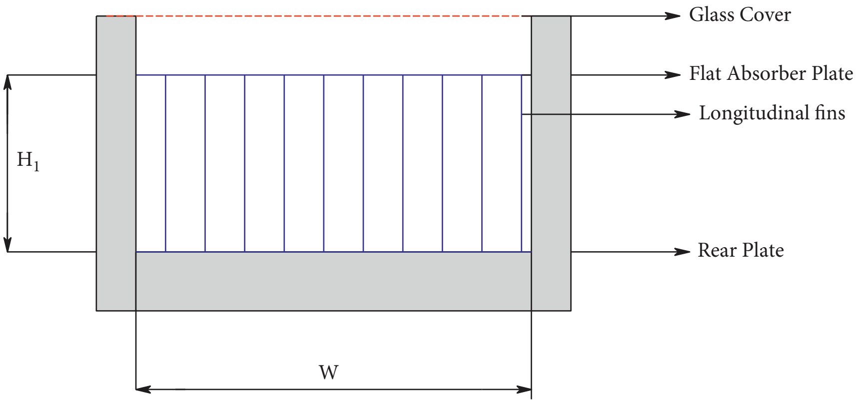


Figure 3: Fin solar air energizer with single glass cover investigated by the authors in [33, 34].

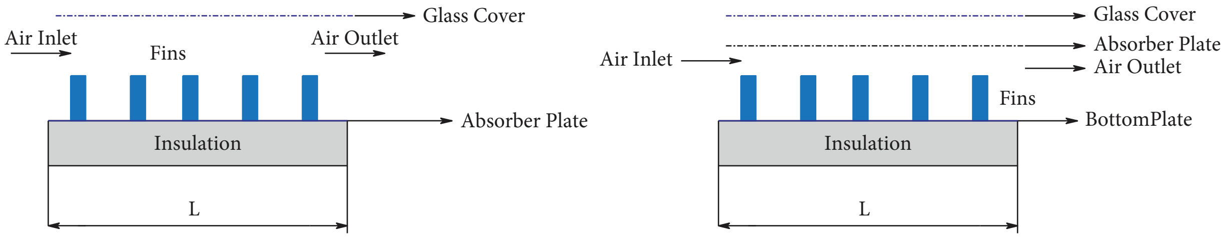


Figure 4: Solar air energizer with the extended surface (Type-I with only absorber plates and Type-II with absorbers and finned bottom plates) [35].

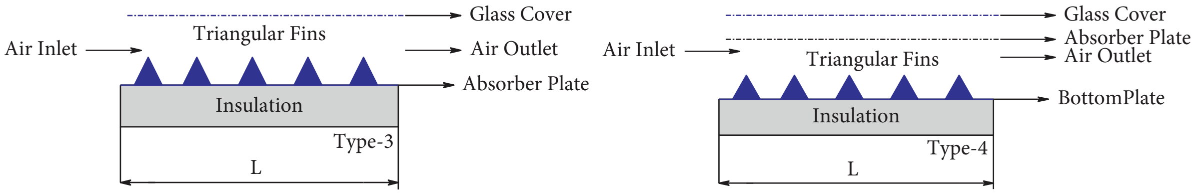


Figure 5: Solar air energizer with triangular fins (Type-III without bottom plates and Type-IV with absorbers and bottom plates) investigated by the authors in [35].

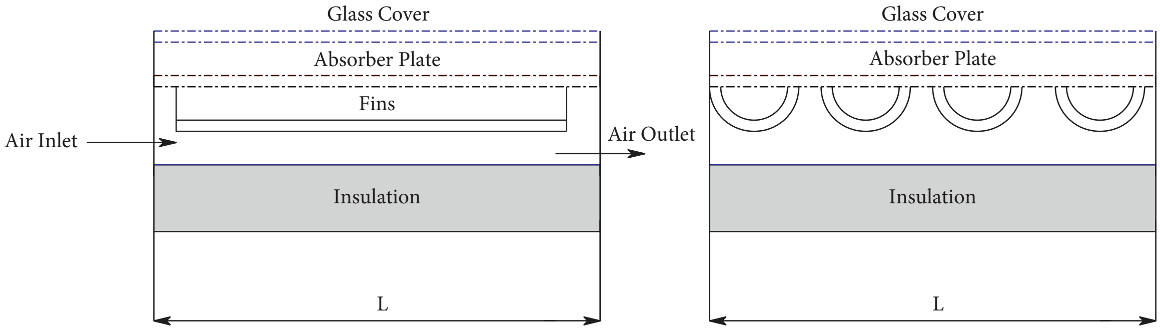


Figure 6: Semicircular fin-integrated solitary pass rectangular solar air energizer [36].

actual ambient circumstances with a mass flow rate between 0.012 and 0.016 kg/s. During the experiment, the impact of design and operating circumstances on the output air temperature, Nusselt number, Prandtl number, and heat removal rate is examined. In addition, the scientists determined that the highest increase in the Nusselt number was 99.03 at a mass flow rate of 0.016 kg/s and created a correlation for forecasting the Nusselt number as a function of design and operating parameters.

Chabane et al [37] conducted additional experimental research on the finned SAE (Figure 6). According to reports, the performance of SAE is dependent on solar intensity, inlet air temperature, and the distance between the absorber plate and the glass cover. At a mass flow rate of 0.016 kg/s, the maximum thermal efficiency of 43.94 percent is attained, according to the researchers.

4. Longitudinal Fin-Integrated Parallel Pass Rectangular Solar Air Energizer

To improve the convective heat transfer coefficient, researchers additionally implemented a double-pass configuration for SAE. Among these double pass flow systems, Yeh et al [38] affixed rectangular fins for additional augmentation, as depicted in Figure 7. Analytically and experimentally, the influence of solar radiation and the flow ratio on mass flow rates between 38 and 78 kg/h is examined. The analysis concludes that thermal efficiency has improved as solar radiation has increased, and it reaches its optimum value at a mass flow ratio (*r*) of 0.5.

Experimentally, Karim and Hawlader [39] examined the thermal performance of conventional, finned, and V-grooved SAEs working in both single-pass and double-pass modes. The comparison outcomes are depicted in Figure 8. The analysis is conducted in accordance with ASHRAE standards, and the flow rate ranges between 0.01 and 0.06 kg/s m^2. The results demonstrated that V-corrugated arrangement is more thermally efficient than finned SAE for the range of parameters studied.

Sebaii et al [40] conducted analytical and experimental research on double pass-double glass cover finned and V-corrugated SAEs. The performance evaluation was conducted under actual outdoor situations. Then, they compared the performance of the SAEs as depicted in Figures 9. As shown in Figure 10, throughout the analysis, the mass flow rate is kept between 0.01 and 0.06 kg/s.

Under comparable operational and climatic conditions, they concluded that the V-corrugated SAE and finned SAE achieve their maximum thermohydraulic performance at 0.0125 kg/s and 0.0225 kg/s, respectively. Moreover, the thermal performance of V-corrugated SAEs is 9.3 to 11.9%, which is greater than that of finned SAEs.

In addition, empirical work has been assessed, and reasonable agreement between experimental findings has been established. It has been determined that the V-corrugated SAE performs better than the finned and standard plate SAEs due to less pressure loss and the creation of more turbulence.

5. Longitudinal Fin-Integrated Counter Pass Rectangular Solar Air Energizer

Naphon [41] performed an analytical study on the SAE with fins parallel to the flow path on either side of the collection plate and a double-pass airflow arrangement as depicted in Figure 11. The mass flow rate, number of fins, and fin height are modified by 0.02 to 0.1 kg/s, 45 to 55, and 5 to 8 cm, respectively, during the analysis. Based on the findings, he concluded that an increase in the number of fins, flow rate, and fin height improves thermal efficiency and that these factors have an inverse relationship with entropy generation.

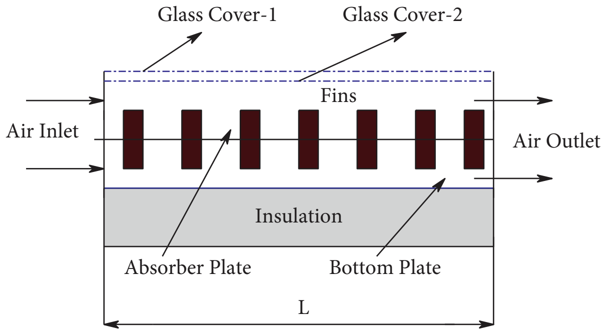


Figure 7: Double flow fin solar air energizer with multiple glass covers [38].

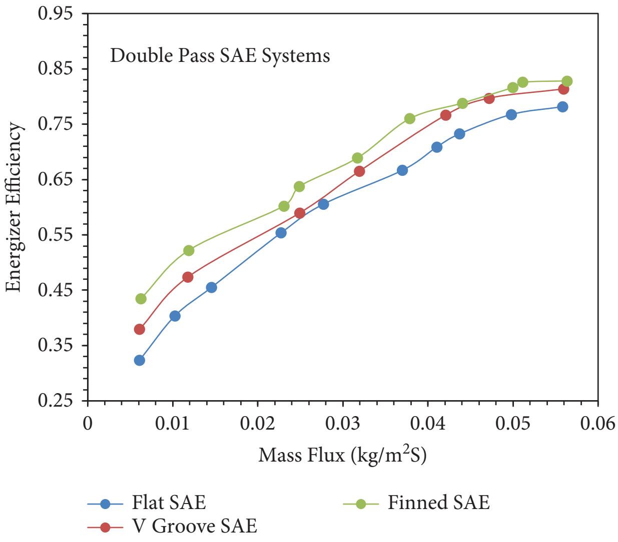


Figure 8: Performance assessment of finned SAEs with conventional and inline V-grooved SAEs for dual pass flow conditions [39].

Fudholi et al. [42] explored the performance of double-pass SAEs with fins at the lower path, as depicted in Figure 12. On the basis of the energy and exergy efficiency data, they conducted experimental and theoretical analysis and compared the performance with traditional double-pass SAEs. According to the findings of the investigation, the thermal efficiency of SAEs ranges from 54 to 79 percent, with an outlet temperature of 36.4 to 62.9 degree Celsius. It has been stated that the thermal efficiency improvement is in linear relation with the sun insolation (I) for a fixed quantity flow rate (*m*). Additionally, the yearly cost and yearly energy gain of the two SAEs have been evaluated and published.

6. Longitudinal Fin-Integrated Repeated Pass Rectangular Solar Air Energizer

Velmurugan and Kalaivanan [43] created mathematical models of the thermal performance of various SAEs. Figure 13(a) depicts a Type-I SAE with a single-pass, double-glass SAE and a smooth absorber plate. In addition, they analyzed the performance of longitudinal finned SAEs with

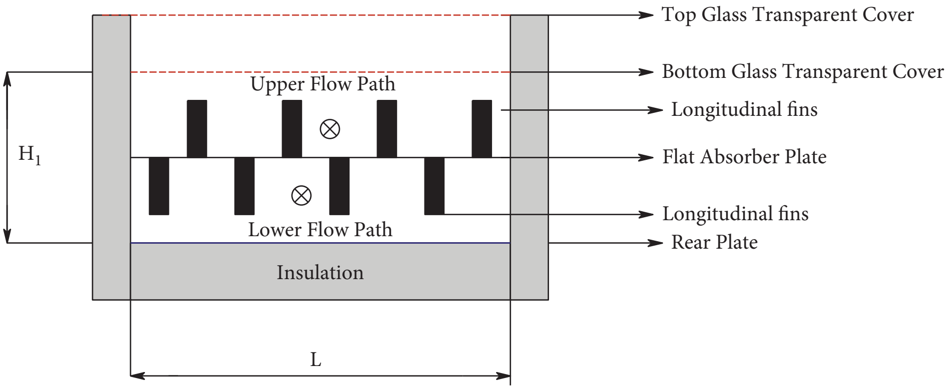


Figure 9: Double flow finned solar air energizer [40].

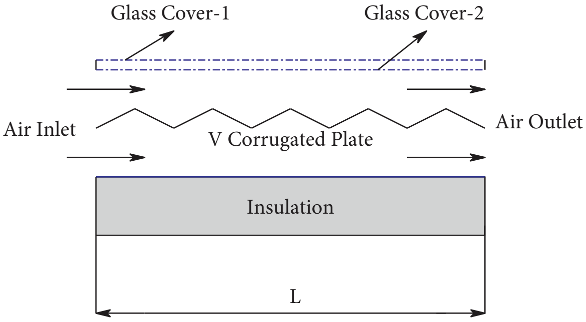


Figure 10: Double flow V-corrugated plate solar air energizer [40].

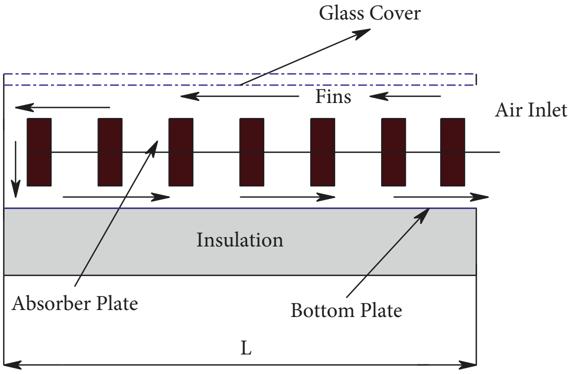


Figure 11: Double pass fin solar air energizer arrangement investigated by the authors in [41].

Type-II, double glass double pass and Type-III, double glass triple-pass operation, as depicted in Figures 13(b) and 13(c).

They created a mathematical model for SAEs and used the MATLAB code to solve it. They analyzed the impact of the mass flow rate, inlet air temperature, and solar radiation in the ranges of 0.01 to 0.04 kg/s, 294 to 306 K, and 800 to 1000 W/m^2. In addition, it is concluded that the triple-pass SAE with fins produces superior performance with a greater value of beneficial heat gain enhancement to a power consumption increment value of 0.1.

SAEs of four different varieties were tested in an indoor experiment by Velmurugan and Kalaivanan [44]. It is divided into four distinct types: Type-I: a single-pass flat plate; Type-II: two passes with roughness rib on the absorber plate; Type-III: double passes with fins on the glass cover; Type-IV: double passes with wire mesh. Each SAE configuration was examined to determine its first and second law efficiency (Figure 14).

7. Wavy Form Fin-Integrated Solitary Pass Rectangular Solar Air Energizer

A wavy finned absorber plate (SAE) has been studied by Priyam and Chand [45], and the results are displayed in Figure 15. The mass flow rate varied from 0.01 to 0.08 kg/s, while the fin spacing varied from 1 to 5 cm. From the analytical investigation, the influence of these parameters on the thermal efficiency, collector heat removal factor, collector efficiency factor, effective temperature rise, effective efficiency, and pressure drop of the SAE is reported. Additional research was carried out by the authors to examine the influence of the amplitude and wavelength of wavy fins (ranging from 3 cm to 20 cm) on energy and system efficiency [46]. Based on heat transfer correlations, the model was created [47]. Both the parameter and performance evaluation parameters such as energy transfer first law-based efficiency, heat removal factor at SAE, collector efficiency factor, effective rise, and effective rise in temperature have an inverse connection.

8. Performance Characteristic Comparison between Finned Solar Air Energizers

A comparison of heat transfer in terms of the Nusselt number and the friction factor for various types of longitudinal finned SAEs has been made, and the results of this comparison are shown in Figure 16, respectively. This comparison was Figure 17 made based on the correlations that different researchers found while reading the relevant literature. The values of the Nusselt number are shown to be directly proportional to the mass flow rate in Figure 17, and the SAE that was created by Garg et al. [33] has the greatest value of Nu. In addition, the data shown in Figure indicate that the friction factor has an inverse correlation with the mass flow rate (m). According to the findings of Fudholi

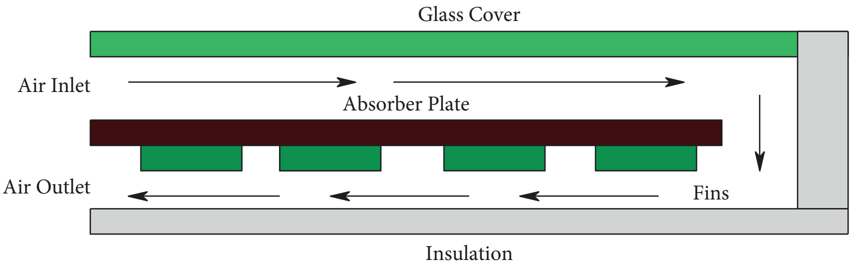


FIGURE 12: Layout of dual pass finned solar air energizer [42].

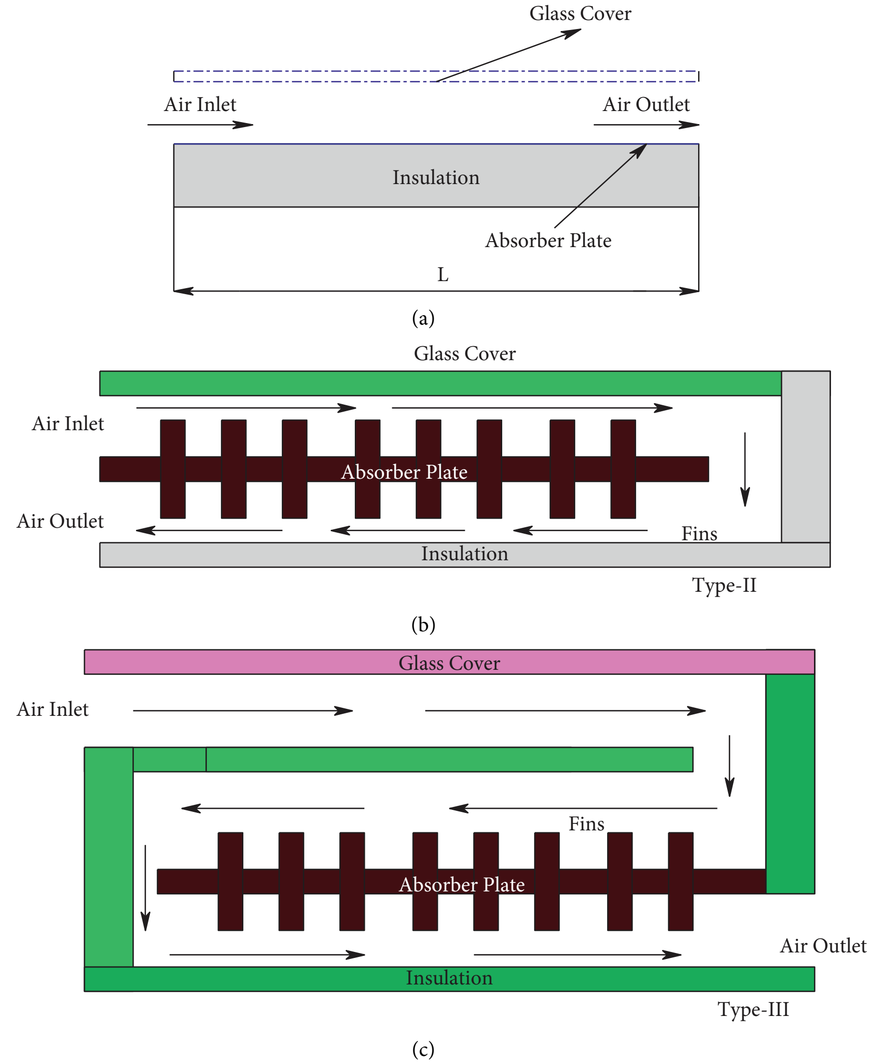


FIGURE 13: (a) Type-I: solitary pass twin glass smooth plate SAEs [43]. (b) Type-II: double pass, double glass [43]. (c) Type-III: multipass, twin glass SAEs with extended surfaces [43].

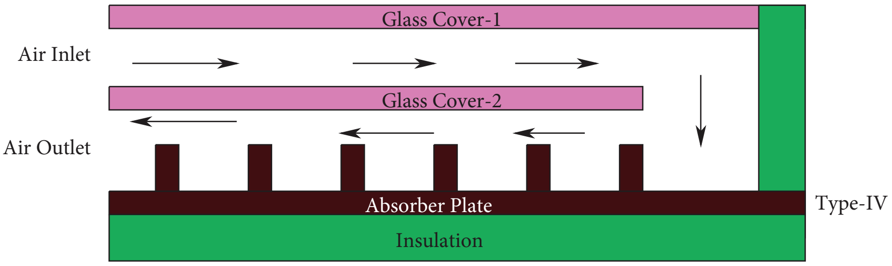


FIGURE 14: Twin pass, twin glass SAEs with extended surfaces (Type-IV) [44].

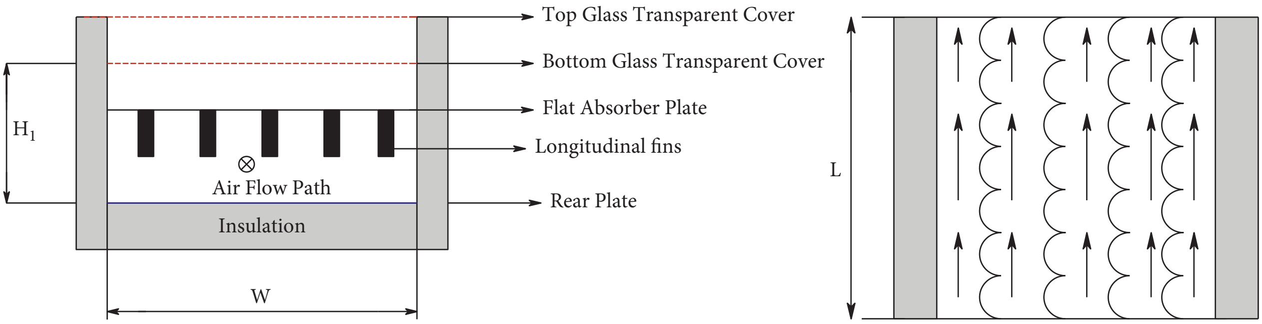


FIGURE 15: Solar air energizer with a wavy finned absorber [45, 46].

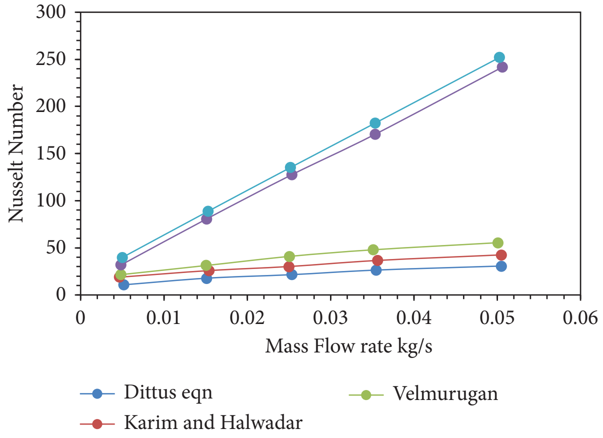


FIGURE 16: Comparison of the Nusselt number reported by various researchers for different types of longitudinal finned SAEs with the Dittus–Boelter equation as reported in [48].

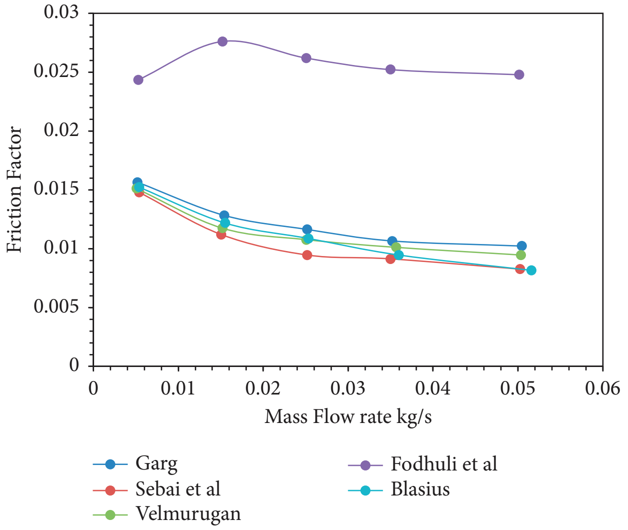


FIGURE 17: Comparison of the friction factor reported by various researchers for different types of longitudinal finned SAEs with the Blasius equation as reported in [48].

et al. [42], the friction factor had the greatest value out of all the factors that were considered.

The solar air heaters can maintain the battery at the required temperature while operating under low-temperature conditions. The low-cost technology is very useful for the commercialization process.

9. Conclusion

In this article, a thorough review and study of how longitudinal finned SAEs are used were performed. The researchers attached different shapes of fins to the SAE, such as rectangular, triangular, and semicylindrical profiles and then used analytical and experimental studies to figure out what effect these have. From this thorough look at the finned SAEs, the following conclusions have been drawn:

(i) When compared to the smooth plate solar air energizer, the addition of longitudinal fins increases the solar air energizer's thermal efficiency in functionally equivalent settings.

(ii) Fin factors such as the number of fins, fin length, and fin height, operating parameters such as mass flow, and geometrical parameters such as sun intensity and ambient air temperature all have a substantial impact on the performance of SAE.

(iii) SAE fin density and thermal efficiency are both improved, as is the pressure drop in the airflow channel, as the fin height is increased.

(iv) Increasing the depth of the ducts has a negative impact on SAE's thermal efficiency, and increasing the number of glass covers and air passes has a positive impact on SAE's thermal efficiency.

(v) The majority of the research studies that have been performed to increase the performance of SAEs have utilized rectangular fins as the primary method of investigation. In addition, there is not a lot of research that looks at how effective SAE fins that are triangular or semicylindrical. As a consequence of this, scientists need to direct their attention toward the development of innovative fin designs that will result in an increase in SAE's overall performance. It is possible to increase the electrical output quality of low-temperature situations by first heating the cabins and then using batteries in those environments.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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