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IMPROVING SOLAR THERMAL ENERGY UTILIZATION WITH OPTIMIZED AIRFLOW AND ANGLES

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ABSTRACT

Solar thermal energy is key to renewable energy technological breakthroughs. This research analyzes how optimal airflow and variable angles effect solar thermal system performance to improve energy collection and conversion. This study presents a solar air-collection technology to boost energy efficiency. The system's alloy steel inlet and exit ducts optimize heat transfer and air velocity. The system includes a durable stainless steel collecting box, a transparent glass insulator, and a high-performance aluminum absorber plate with V-shaped pins on both sides for optimal heat absorption. The experimental setup included air quality meters, digital anemometers, angle finders, solar power meters, and temperature sensors for precision data collecting. Solar radiation, air velocities, temperatures, and humidity were measured to assess the system's heat transfer efficiency, air circulation, and performance in various climates. A blower and double-pass air flow mechanism boost the examined solar air heating system (SAH)'s efficiency, notably during peak hours (12:00–3:00 PM).

Keywords: Solar thermal energy, airflow optimization, heat transfer efficiency, renewable energy, environmental.

I. INTRODUCTION

Advanced sustainable energy technology requires improved solar thermal energy usage. Increasing airflow and panel angles is essential for solar thermal system efficiency. Modifying these two parameters, which considerably enhance solar collector heat absorption and retention, may make solar thermal energy systems more effective and reliable in many conditions. Due to rising demand for renewable energy, solar collector location and airflow route engineering are crucial. Controlling airflow in and out of solar thermal collectors optimizes heat transmission and reduces losses. Forced and natural convection are utilized depending on solar system size and application. Improved air channel form in natural convection systems helps hot air ascend smoothly and efficiently, eliminating heat with less turbulence and loss. Forced convection systems employ precisely controlled blowers or fans to create airflow patterns for heat absorption and extraction. With these airflow approaches, collector surface temperatures may be optimized, overheating minimized, and efficient and continuous operation ensured. Airflow management reduces thermal resistance, improving heat transfer from the collector surface to the working fluid or storage medium.

Airflow optimization and solar collector angle adjustment to maximize sunlight absorption are crucial. The angle of incidence—the angle at which sunlight hits a collector—is crucial to its effectiveness. To maximize solar radiation, place the collector perpendicular to the sun.

Fixed-angle systems don't always get the most from the sun since its location changes throughout the day and seasons. Therefore, automated tracking systems or collectors with variable tilt angles may considerably increase system efficiency. This permits continual sun-path modification. To align collectors with the sun in winter and summer, seasonal changes are made. So, energy collecting rates may be high year-round. Clean airflow and precise angling boost solar thermal performance. Well-placed collectors and airflow reduce conduction, convection, and radiation heat losses. This increases energy transfer to the working fluid and stabilizes and raises output temperatures. Keeping operating temperatures within permissible limits extends optimum system lifespan and reduces maintenance needs while decreasing thermal cycling and material degrading stresses.

Advanced modeling and simulation are needed to create systems with appropriate airflow and angles. Engineers may use CFD models to visualize and predict airflow in and around collector assemblies to find hotspots, stagnation points, and excessive heat loss. Solar path analysis may also be used to discover the best fixed angles for locations or construct real-time collection tracking systems. These modelling tools may be used to build highly efficient solar thermal systems for specific areas. These methods employ local weather and sunlight. Novel materials and surface treatments improve airflow and angling. Combining airflow methods that cool the surface without compromising absorption with selective coatings that absorb a lot of solar light while restricting heat emission is one option. Textured surfaces and tapered air channels may increase airflow homogeneity, reduce dust accumulation, and reduce shadowing effects, which can lower system performance. These advancements increase short-term energy outputs, prolong solar thermal system life, and save money.

In large-scale applications like solar farms and industrial process heat systems, airflow and collector angling optimization multiplies. Standardizing modules using these optimization methods may improve average efficiency across collector fields. This decreases land use and makes solar thermal systems more economically viable. Additionally, hybrid systems with solar thermal collectors and photovoltaic panels may use airflow optimization. This method strategically channels air to cool both kinds of collectors at once, increasing thermal output and photovoltaic production. Strategic airflow and angle optimization in solar thermal energy systems is crucial to efficient, sustainable, and scalable renewable energy solutions. By focusing on these design factors, researchers and engineers may unlock greater potential from present solar resources to make solar thermal energy a more viable choice for meeting the world's energy demands. As technology advances, advanced control systems, real-time monitoring, and adaptive design will boost solar thermal system efficiency. This will make energy cleaner and more robust.

II. REVIEW OF LITERATURE

Ibragimov, U.Kh et al., (2023) Modern research have concentrated on surface changes, multi-air flow organization, porous absorber utilization, impact-based air flow transfer, and surface integration with heat-accumulating materials to increase flat solar air collector thermal efficiency. A laminar viscous layer on an absorber reduces heat transfer to the air. To improve heat transmission, flat solar air collectors with fins, barriers, turbulizers, and baffles increase air residence time and heat transfer surface. The collector's thermal efficiency increases from 71.4% to 93% using various-shaped turbulizers on the absorber. With heat-accumulating materials and ribs on the absorber surface, collector daily thermal efficiency may reach 0.44–0.4%. This article reviews 10 years of research on making flat solar air collectors more thermally efficient.

Hasan, Husam et al., (2023) Heat rooms, dry produce, and season wood using a solar air heater. Finned plate solar air heaters were evaluated for thermal efficiency with different slant angles (30°, 45°, 60°) and mass flow rates (0.040, 0.045, 0.052 kg•s−1). Finned plates and solar air heaters (FPSAHs) with angled fins were used to build and test a thermal efficiency system. The absorber plate's back has angled fins to improve thermal efficiency and heat transfer. The results showed that thermal efficiency increased with decreasing slant angle, peaking at 30° slant angle and 0.052 kg•s−1 for 70% efficiency and 58.66 °C output. The FPSAH system uses angled fins to enhance solar energy absorption and create hot air at the exit. Its thermal performance exceeds flat-plate solar air heaters.

Utazi, Divine & Audu, Stephen & S., Umaru. (2021) Solar power has great potential to meet global energy demands. Solar air heaters transform sunlight into heat for drying crops, heating homes, and other industrial and agricultural applications. Thermal output and inefficiency make its thermal efficiency low. Latent heat storage, sensible heat storage, and chemical energy storage increase it. The ideal system domain and operating parameters are determined by optimizing the solar air heater to enhance system performance. Optimization is crucial to solar air heater design and development. An article about solar air heater performance improvement and designs is provided here.

Pakholiuk, Orest et al., (2020) Solar power might meet the world's energy demands. Solar air heaters transform sunlight into heat for drying crops, heating rooms, and other manufacturing and agricultural activities. Due to its low thermal output and efficiency, latent heat storage, sensible heat storage, and chemical energy storage are utilized to increase its thermal efficiency. To optimize system performance, the solar air heater's domain and operating parameters are optimized. Optimization is key to solar air heater design and development. This article discusses solar air heater ideas and performance enhancement.

Hu, Jianjun & Zhang, Guangqiu. (2019) Solar energy systems need a solar air collector to convert sunlight into heat and transfer it to a fluid. This research reviews literature-proposed strategies to increase solar air collector thermal performance. These methods include (1) changing the collector plate shape or using ribs, fins, or meshes to reorganize airflow in the laminar sublayer; (2) using an air impinging jet to reorganize airflow near the absorber plate to promote convection heat transfer; (3) switching from a single-duct collector to a double- or multi-pass duct to increase residence time; and (4) adding baffles to create secondary airflow. Find the commonalities among these improvement measures and call them airflow rearrangement. This review is unusual because it does that. This review compiles and analyzes significant publications to assist academics understand optimization strategy relationships.

III. Material and Methods

Experimental Set-up

Designed to enhance performance, the experimental setup includes a solar air collecting apparatus. These intake and exhaust air ducts are made of durable alloy steel. The intake duct, which is 20 cm wide and stretches to 57 cm, slows air entering the system, while the outflow duct, also made of alloy steel, speeds it up. The round openings in both ducts will provide smooth airflow throughout the experiment. Solar air collectors are rectangular boxes made of stainless steel that size 95 cm long, 57 cm wide, and 20 cm high. An insulating 4 mm transparent glass plate sits on top. Place a 45-by-90-centimeter aluminum absorber plate in the collector. The V-shaped pins on both sides of this absorber plate maximize heat absorption and transmission. Figures 1 and 2 depict the solar air collector experimental setup.

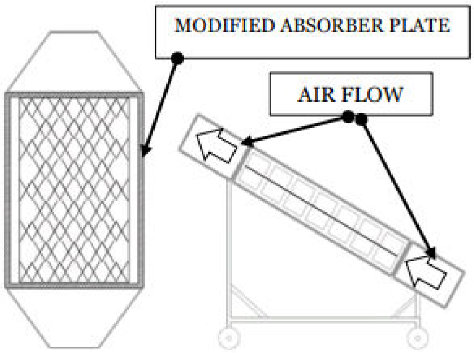

Figure 1 Front View of solar air collector

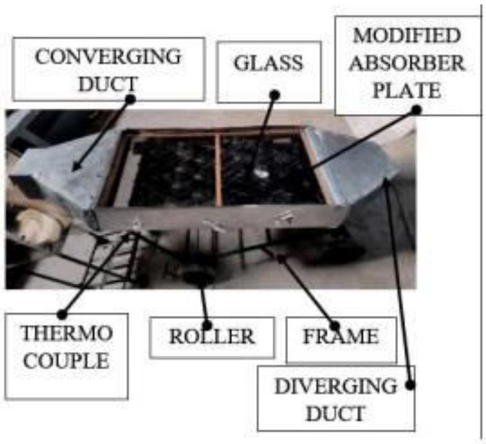

Figure 2 Side View of solar air collector

Instrumentation/Data Acquisition

The experimental system collects data with several high-precision sensors, ensuring accurate findings. These devices measure temperature swings using high-precision temperature sensors on the collector's surface and within the inflow and outflow ducts. A solar power

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meter (Tenmars TM-207) measures solar radiation to assess energy utilization. A magnetic base-mounted 4-1/8" angle finder is used to properly measure the collector's orientation and angle, helping choose the best location for the solar air collector to harvest solar energy. A digital anemometer (Btmeter BT-846A Pro HVAC Anemometer) records air velocities at intake and exit ducts to evaluate air circulation system efficiency. An indoor air quality meter (Extech EA80- EasyView) measures and records humidity at the collector's input and output to monitor humidity's effect on the system. Table 1 lists research measuring devices. This extensive sensor suite makes it possible to gather vital data to assess the solar air collector system's performance in different climates.

Experimental method

The experiment was conducted at Engineering College, India's outdoor laboratory from 9 AM to 3 PM on sunny days. The solar air collector, which included alloy steel intake and outflow pipes, was set to receive the most sunshine during the experiment a blower on the input duct kept the system's airflow between 3.21 and 4.10 m/s. The collector and ducts were dynamically changed throughout the experiment, thus sun radiation, air velocities, temperatures, and humidity were measured regularly. The temperature fluctuations caused by the see-through glass plate amplifying the sun's rays striking the collector's absorber plate were carefully examined. Temperature sensors, a solar power meter, an angle finder, a digital anemometer, and a hygrometer provided data on system performance in diverse settings. Systematic data collecting examined the system's heat transfer efficiency, air circulation dynamics, and solar radiation's effects on temperature changes and performance.

IV. RESULTS AND DISCUSSION

Daytime Intel and Outlet Temperature

Figure 3 demonstrates that a solar air heater (SAH)'s intake and output air temperatures climb from 9:00 AM to 3:00 PM throughout three days. Input temperature was 35.3–45.7 degrees Celsius, while output temperature was 44.7–59.5 degrees Celsius. The SAH heats water effectively, particularly around 3 p.m., when the sun is hottest.

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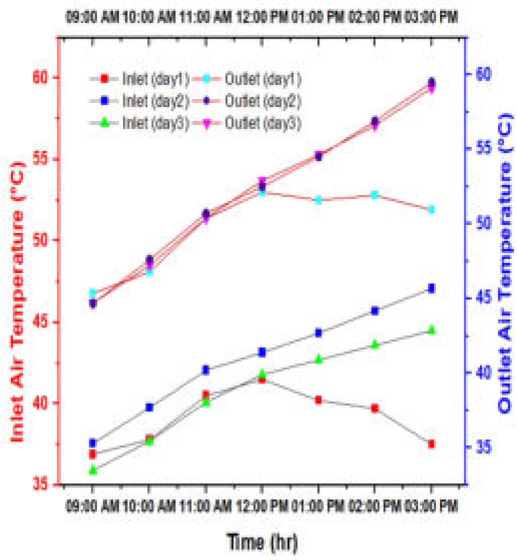

Figure 3 Shows time-varying inlet and outlet temperatures

The SAH absorbed solar energy between 9:00 AM to 10:00 AM, when temperatures rose. The temperature rose significantly between 11:00 AM and 12:00 PM, suggesting improved heat transport. The system worked best in the afternoon (1:00–3:00 PM), with steady intake temperatures and rising outflow temperatures to 59.5°C. Heat transfer is efficient when the collector temperature differential is consistent. These experiments indicate that the SAH may be used for sustainable and energy-efficient space heating and industrial activities at severe temperatures.

<u>Daytime Intel and Outlet Velocity</u>

Figure 4 displays the solar air heating system's input and output velocities in meters per second (m/s), which exhibit remarkable patterns throughout day, indicating its performance dynamics. From 3.21 m/s at 9:00 AM to 4.07 m/s at 3:00 PM, the Inlet Velocity has risen. This increasing trend implies the system is using solar energy well, improving airflow. The device gradually absorbs solar energy in the morning, which may improve air circulation.

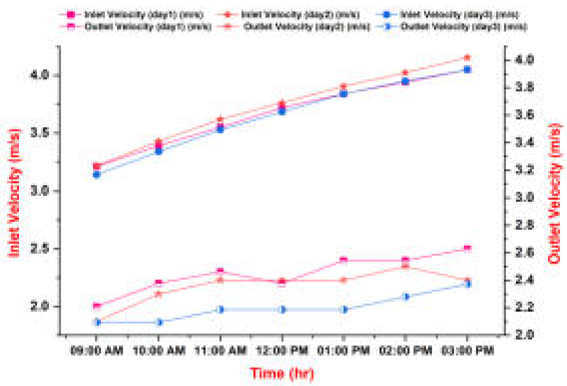

Figure 4 demonstrates time-varying inlet/outlet velocity

Outlet Velocity also ranges from 2 m/s from 9:00 AM to 2.4 m/s at 3:00 PM. Continuous outlet velocity rises throughout the day, indicating excellent heat transfer and energy conversion in the solar air heating system. The system works best in the afternoon (1:00–3:00 PM) when heat exchange and sun radiation are highest.

Daytime Heat Absorption

The graphic below shows how a solar air heater (SAH) worked over three days. The experiment measured the solar air heating system's heat absorption from 9 to 3. This shows that the apparatus can collect solar energy all day as heat absorption grows constantly.

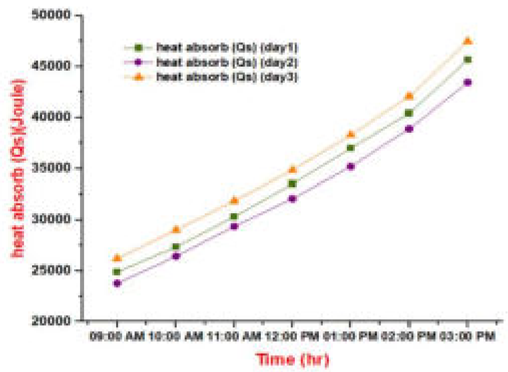

Figure 5 Variation in heat absorption over time

The system initially absorbed solar energy between 9:00 and 10:00 AM, absorbing 23,771 J to 26,431 J. From 11:00 AM to 12:00 PM, heat absorption increased from 29,348 J to 35,199 J, suggesting higher heat transfer efficiency. The system operated best between 1:00 and 3:00 PM, when the sun was at its strongest, absorbing 38,878 J to 47,479 J of heat. The solar air heating system's consistent rise in heat absorption over three days proves its ability to collect solar energy. These findings demonstrate the modified absorber plate's ability to improve collector heat transfer and promote energy-efficient heating.

Daytime solar radiation

Sunlight levels at different times of day over three days are displayed below. Solar radiation peaks at 950 W/m² at midday, starting at 824 W/m² at 9:00 AM and progressively rising. Around 2:00 PM, radiation decreases to 840 W/m³. These oscillations reflect changes in daytime solar intensity.

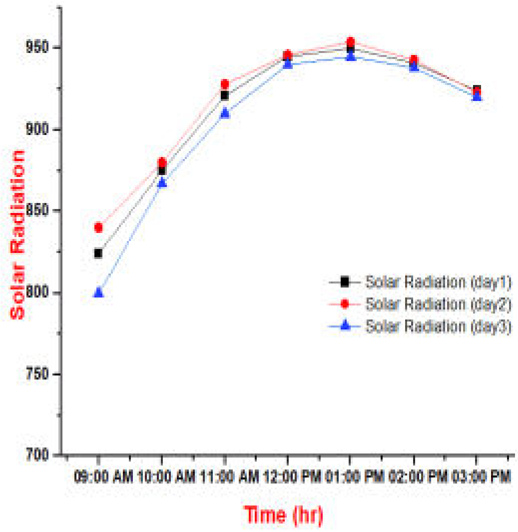

Figure 6 Time-varying solar radiation

Radiation increases with the sun in the morning, peaking at noon. The following decrease, affected by sun locations and air variables, is a typical daily radiation pattern. Sun radiation measurements impact the solar air heating system's heat absorption. Peak heat absorption around noon, when radiation is maximum, shows the system's solar energy efficiency.

V. CONCLUSION

Finally, optimising airflow and collecting angles boosts solar thermal energy system efficiency and reliability. Controlling collector airflow reduces heat losses, extends component life, and optimizes system temperatures. Similarly, adjusting collector angles to the sun's beams permits constant and seasonally optimum solar energy absorption. These strategies increase energy output and solar thermal technology adaptability to varied climates and areas. Advanced modeling tools, materials, and control mechanisms improve airflow and angling. Solar thermal R&D will lead to better, cheaper, and longer-lasting systems. Optimizing the whole process, from design to operation, maximizes solar resource consumption and accelerates the world's transition to renewable energy. Due to energy security and environmental concerns, solar thermal energy will remain essential to sustainable energy strategies. These methods' ongoing development and usage will enable this.

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