Enhancing the Thermal Efficiency and Optimum Temperature of a Modified Evacuated Tube Solar Air Collector by using the Reflector

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https://doi.org/10.5109/7160902

出版情報：Evergreen. 10 (4), pp.2265-2276, 2023-12. 九州大学グリーンテクノロジー研究教育センター
バージョン：

Enhancing the Thermal Efficiency and Optimum Temperature of a Modified Evacuated Tube Solar Air Collector by using the Reflector

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(Received September 22, 2023; Revised December 13, 2023; accepted December 14, 2023).

Abstract: The experimental investigation of the thermal efficiency of a retrofitted evacuated tube solar collector employing air as the working fluid, with and without a rectangular aluminum sheet reflector during the winter, considering both sunny day and hazed day climatic conditions occurred at Glocal University in Saharanpur, India, between 30 17' (latitude) North and 77 38' (longitude) East. The solar collector comprises vacuum tubes with directed inner tubes that are 22 mm in diameter and are put in a single-ended steel cuboid-shaped manifold. The inner steel tubes supply the input air into the vacuum tube. The heated air is generated in vacuum tubes, collected in the central header cylindrical manifold, and expelled through the exit pipe. With an aluminum sheet reflector fixed, the flow velocity, mass flow rate, and irradiance affect thermal efficiency and exit air temperature. In the case of a stainless-steel tube with a 22 mm diameter and a length of 1.27 meters, the maximum temperature difference between the outside air and the input air is 71.9 C, and the maximum temperature recorded is 96.9 C. A higher efficiency of 36.69% is attained with a suitable aluminum sheet reflector at an increased flow rate of 20.14 kg/h. In ETSCs that have been updated, there is an average rise in exit air temperature of 37.5%.
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Keywords: thermal efficiency; reflector; vacuum tubes; solar irradiance; collector

1. Introduction

The world is increasingly shifting away from fossil fuels and adopting renewable energy sources for various objectives; this change will help protect our environment and stop the challenges brought on by climate change[1]. Many residents in rural areas still need to be made aware that meeting the energy requirement for sustainability is a big challenge, or they have never heard of the different ways to capture solar energy for daily activities[2]. Sustainability can be achieved through the proper use of solar energy. According to Akinwale et al.[3], many people must know solar energy's potential benefits, particularly in southern Nigeria. For more people to be better informed about the opportunities that abound in renewables, additional awareness efforts are required[4]. To avoid the primary source of energy loss, a solar-powered heat-driven cooling device uses radiation from the sun[5].

Lowering dependence on conventional energy sources necessitates the use of sources of clean energy, notably solar energy. Using vacuum-sealed tubes, evacuated tube solar collectors (ETSCs) convert solar energy into heat that can be utilized for various purposes, including space heating and water heating. One way to increase the performance of ETSCs is to use reflectors to concentrate and direct more sunlight onto the tubes, increasing the amount of energy they can absorb. There have been several studies on the performance of ETSCs with reflectors. The reflectivity of a material depends on factors such as wavelength, the material, the surface's quality, and the radiation's incident angle[6]. Apart from black bodies, all objects reflect a part of the incident radiation. The reflected fraction of the incident radiation is called reflectivity[7-9].

Many researchers have made some findings to predict the relationship between temperature and solar radiation. Daut et al.,[10] used a statistical model to predict this relationship in Perlis, Northern Malaysia 2006. The result showed that temperature depends on solar radiation. For example, a study by H. Singh and R. Saini[11] explored the effect of different types of reflectors on the performance of a solar water heating system with an ETSC. They found that a parabolic trough reflector was the most effective, increasing the daily average collector efficiency by 47.6%.

Another study by S. Arun Kumar et al.[12] analyzed the performance of a solar air heater with an ETSC and a flat plate reflector. The system's thermal efficiency rose by 23.78% when the reflector was used. In a study by P. C. Ekechukwu and N. Nwankwo, the efficiency of an ETSC compared to a conventional flat plate solar collector[13]. They found that the ETSC with the reflector heated the water more effectively and had a higher collector efficiency. Overall, reflectors can improve ETSC performance and increase the heat sunlight can produce. Hybridizing solar systems is one way to increase their efficiency[14].

Further research is needed to optimize reflectors' design and placement to achieve the highest possible performance gains. Using a reflector to increase the amount of solar radiation caught by the tubes is one technique to enhance the efficiency of ETSCs. A reflector is typically made of a highly reflective material, such as aluminum, and is placed behind the tubes to reflect sunlight onto the tubes. Numerous investigations have been carried out to evaluate the effectiveness of ETSCs with reflectors. For example, Li et al. [15] studied the effectiveness of a solar collector with a parabolic trough reflector and an ETSC. According to the study, using a reflector enhanced the collector's thermal efficiency by 31.2%. Another study by Kline et al.[16] analyzed the performance of an ETSC with a flat plate reflector. The study found that using the reflector increased the thermal efficiency of the collector by 27.3%. A third study by Abdallah et al.[17] investigated the performance of an ETSC with a cylindrical reflector. According to the study, using a reflector enhanced the collector's thermal efficiency by 19%.

Overall, these studies suggest that using a reflector can significantly improve the performance of ETSCs. However, the optimal type of reflector may depend on various factors, such as the size and orientation of the collector, the location and intensity of solar radiation, and the desired operating temperature range. Zambolin & del Col [18]. The performance comparisons with and without the reflector effect showed that the optical efficiency with compound parabolic concentrators was increased by 66%. When the performance of solar evacuated air heaters with and without the reflector was compared, an efficiency improvement of more than 60% greater than the optical efficiency without compound parabolic reflectors was observed[19].

Lazzarin[20] studied that ETSCs are far more effective and efficient at catching solar intensity than traditional absorber field collectors. Vacuum tube solar collectors are frequently used to generate heat for various applications, including water heating. But there is still much to discover about heating the air in many applications, like space heaters and dryers. According to a review of published work on ETSCs, considerable effort has been previously put into experimental study. Minimizing the spaces between vacuum tubes, minimizing the heat loss to the surrounding[21]. Testing was done on the thermal investigation of ETSCs by Kumar et al.[22]. The collector had an aluminum tube inserted inside. Applying the various tube lengths, it can be determined that as tube length grows, the temperature difference at low airflow rates increases.

Yadav & Bajpai[23] compared the thermal efficiency of the ETSCs and FPCs at various flow conditions. The findings indicate that an ETSC's maximum temperature difference is higher. S. Kumar et al.[24] have studied data collected from an ETSC, revealing that the outlet temperature is exceptionally high and that the device can better conserve energy. Zubriski & Dick[25] investigated the effectiveness of ETSCs under various operating circumstances, which included the inclination angle. According to the findings, raising mass flow rates will increase collector effectiveness, and vertical installation is a more practical alternative design. The experimental research's findings show that the geometry of the absorber surface, mass flow rate, and solar radiation intensity are the key factors affecting the effectiveness of solar air heaters[26]. Performance analysis will be more appropriate with a measure of system effectiveness. Mehla & Yadav[27] explored PCM scientifically and demonstrated that the apparatus performs best at night. A mathematical simulation of an ETSAH with a parabolic trough collector was created by Pandey et al.[28]. They discovered that a flowing fluid receives the maximum radiation from the sun. Comparisons were made between an ETSC's thermal performance with and without a heat pipe system by Chopra et al.[29]. They concluded that the heat pipe's condenser area's short segment results in less valuable heat transmission, so there is room for improvement by lengthening the condenser area. In their economic research of employing greenhouse dryers in conjunction with evacuated tube solar collectors, Singh et al.[30] discovered 39% electrical energy savings with a short payback period. Evacuated tube solar collector thermal performance was examined using numerical and experimental methods, showing that the absorber area affects both the temperature and efficiency of the collector. Haze Climate change mitigation strategies include solar photovoltaics (PVs). Although solar power benefits air quality, pollutants in the lower atmosphere reduce the amount of light reaching the solar installation and reduce the solar intensity, ultimately reducing the optical and thermal efficiency of the solar collector[43]. Many scientists specializing in using an intermediary fluid to heat water and air have been investigating evacuated tubes experimentally[31]. The temperature and efficiency of evacuated tube solar collectors were calculated and experimentally demonstrated to depend upon absorber areas[32]. Three different types of reflectors were employed to increase the collecting area of evacuated tube solar collectors, and the performance of 21 various configurations of the devices was examined to assess the performance of some material reflectors. Three different reflective materials were employed in the study: mirror, white paint, and Aluminium foil. Five different Aluminum foil shapes were used: a flat surface, a parabola, a V-shape, a vertical zigzag, and a horizontal zigzag. The mirror and white paintings were also used, but only in a flat shape. Those reflectors were set up either 0.22, 0.17, or 0.12 meters behind the center of the evacuated tube solar collectors. A reference set without a reflector was used to compare each system. According to the calculations for thermal efficiency, the flat mirror at a distance of 0.17 m was the best. Additionally, the zigzag surface's orientation has a significant impact on effectiveness.

The current experiment's goal is to compare the thermal performance of retrofitted ETSC, one with a reflector and the second one without a reflector, in winter, the importance is to obtain informed knowledge about what to do to get hot air as quickly as possible during the winter season when there is a higher demand for hot air. The cold air was pumped into the stainless-steel tubes to conduct the investigation, and differences in exit temperature with thermal efficiency were monitored throughout the day.

1.1 The aim of the present research work

This research aims to produce heated air at different flow rates employing 22mm diameter directing inner steel tubes that are uniformly 1.27 meters long with and without a reflector attached and to track the day's maximum temperatures, output temperature variation, and thermal efficiency. Finally, depending on the earlier data collected, analyze the numerical outcomes. The setup for the experiment is located at Glocal University in Saharanpur, Uttar Pradesh, India, at latitudes of 300 17' and 770 38'. Data were gathered between November 11 and November 20, 2022.

1.2 Research Methodology:

This paper relies upon the existing experimental work of ETSCs for air heating applications. Optimizing the ETSC performance based on the literature survey design of ETSC takes place using a reflector for air heating application because significantly less work is identified in the field of air heating application. Based on the design parameters, the experimental setup has been fabricated, and the experiments were conducted in November 2023 by changing the air flow rate. The discussion on results takes place, and the comparative analysis is done based on previously available data and the scope of future work identified. It must be financially feasible for household and industrial use for a newly created system [33]. Precise sizing and operating conditions are crucial factors to ensure cost-effectiveness[34]. The heat capture rate increased using a diffuse flat reflector at the back of the ETSC tube setup[39]. Performance comparisons with and without the reflector affect the optical efficiency[40-41].

2. Experimental Setup

In the present investigation, directed inner steel tubes are used to investigate the thermal performance of an ETSC. A glimpse of the setup used for the experiment is shown in Fig's 1 and 2. Nine 1.5-meter-long evacuated tubes, each measuring 0.037 and 0.047 meters in diameter, respectively.

Components of the experimental setup

1. Frame
2. Evacuated Tube
3. Aluminium sheet reflector
4. Inner Cuboid Channel with main header manifold

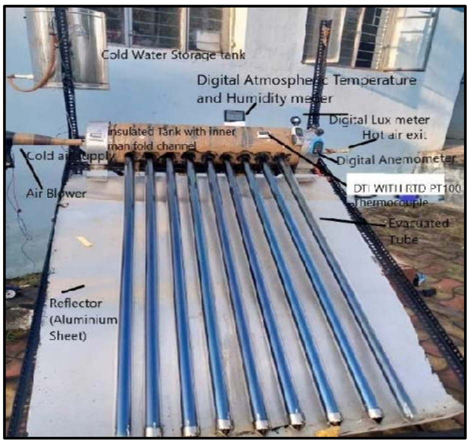

Fig.1: Show the Experimental Set up of ETSC with a reflector

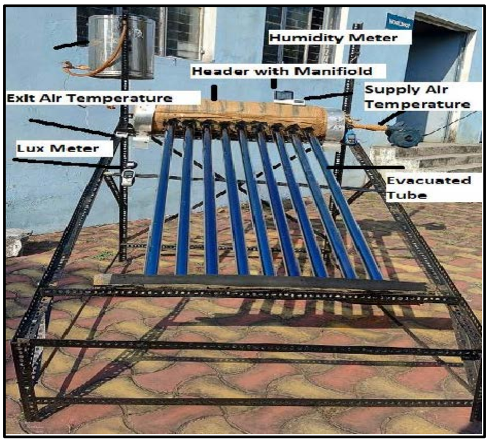

Fig.2: Show the Experimental Set up of ETSC without a reflector

Table 1: Thermo-physical properties of the evacuated tube[35]

Material	Parameters	Value
Glass tube outside	Outside Diameter	47mm
	Thickness	2mm
	Transmissivity	0.92
	Emissivity	0.9
Glass tube inside	Inside Diameter	37mm
	Thickness	2mm
	Inward Emissivity	0.35
	Absorption coefficient	0.9
	Outward Emissivity	0.08

The forced air through the air blower is supplied to the inner manifold channel via a steel tube to the main evacuated tube. The air inside the evacuated tube gets heated due to the accumulation of heat energy inside the surface of the evacuated tube. Then, the heated air returns and is collected in the central insulated header manifold. Air is the working fluid for this given ETSAC setup. Light rays can pass through a transparent outer tube with minimal refraction.

2.1 Frame

The frame was made of slotted angular mild steel and was inclined at an angle of 30° to the horizontal facing the south [1,21]. The frame was made from perforated angle mild steel of $50 \times 50 \times 4mm$.

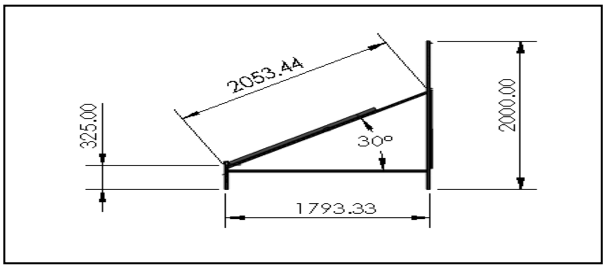

Fig.3: Frame design of frame structure

The perforation helps easy assembly and disassembly of the project and facilitates mobility. The stand members are fastened together by $M12 \times 1.0mm$ bolts and nuts. The stand was painted black. Depending on the reflector size, a rectangular aluminum glazed sheet is put in a frame with the appropriate grooved stainless-steel tube. The framework is also designed to allow the vacuum tube to be safely secured in the bottom supporter and the header.

2.2 Evacuated Tube

Fig. 5 depicts the evacuated tubes utilized in this system. Each evacuated tube consists of two borosilicate glass tubes that are concentric and separated by vacuum. The inside tube is coated (Al-N/Al) for improved radiation from the sun absorption, while the outside of the tube is translucent to prevent reflections. The evacuated tubes are thought to be heat absorbers, which absorb solar energy and convert it to heat air.

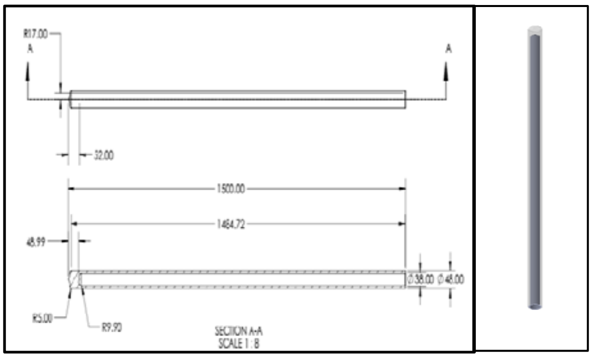

Fig.4: Evacuated Tube 2d and 3d view

2.3 Aluminium sheet reflector

Under the evacuated tubes, a reflector is placed to reflect sunlight onto the tubes. The reflector has a 5mm thickness. The reflector is 1.75 x 1.09 m^2. The Silver Rectangular Aluminium Grade 7075 Sheet is a non-alloy with good reflectivity. Due to the higher output temperature, it can swiftly reflect the solar energy directed toward the tubes.

Fig.5: Silver Rectangular Aluminum Grades 7075 Sheets

Table 2. Thermo-physical properties of aluminum sheet reflector [36,42]

S. No	Thermal Physical Properties	Dimension/Unit
1	Length	1600mm
2	Breadth	60mm
3	Thickness	2mm
4	Emissivity	0.09
5	Density	2700Kg/m3
6	Heat capacity	900kJ/KgK
7	Thermal conductivity	173W/mK
8	Coefficient of Thermal Expansion @ 20.0 - 100 °C Temp	23.4 µm/m-°C

2.4 Inner Cuboid manifold channel fitted in main manifold header

consists of a square bar of an SS-G304 grade with one end closed and fitted centrally aligned inside the circular header manifold, as shown in Fig. 6.

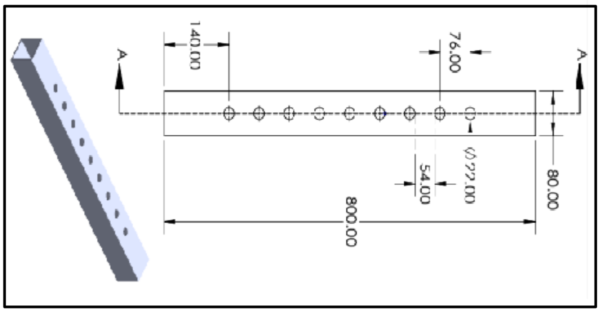

Fig.6: Shows View of square stainless steel bar inner manifold

Fig. 7 Inner cuboid manifold fitted with steel tube

The square bar is drilled with nine 22mm holes concentric with circular header manifold holes, as shown in Fig. 7. An internal thread in the bores is fastened to a 22 mm SS-G304 tube.

Mechanical equipment includes blowers. With the aid of these small blades, air can be directed precisely where needed by connecting them to a wheel and a casing. The typical blower has a 1-1.2 pressure ratio. The blower employed in the test had a running time of 10–12 hours. Cold air enters the SS-304 tubes with the help of a blower.

Fig.8: Air blower for air supply

2.5 Measuring Instruments

In this investigation, various parameters were measured, Such as

- Temperature measurement
- Irradiance measurement
- Air circulation rate
- Surrounding temperature
- Moisture present in the atmosphere

2.5.1 Temperature Indicator

Model: (AP-IS11A001) (Digital corded LCD Display)
Range: -50^0 C to 110^0 C
Accuracy: ± 1 ^{0}
Resolution:0.1

2.5.2 Solar Intensity Meter (Lux Meter)

Model**:** NAAFIE Meco-930P(Digital LCD Display)
Range: 0 ~ 200,000 lux
Accuracy level: ± 5%
Resolution: 0.1 lux
Powered by: Battery (9V) and Auto Power mode

2.5.3 Anemometer: To measure air velocity

Model**:** AVM-01 (Digital LCD Display)
Velocity range: 0m/sec to 30m/sec
Accuracy level: ± 5%
Resolution: 0.1m/s
Temperature range: -10°C to 50°C
Powered by: Battery (9V) and Auto Power mode

2.5.4 Digital LC hygrometer:

To measure the ambient temperature
Model**:** HTC-1 (Digital LCD Display)
Range: 0m/sec to 30m/sec
Accuracy level: ± 5%
Temperature accuracy: ± 1%
Temperature range: -50°C to 70°C
Humidity range: 20%RH to 90%RH
Powered by: Battery (9V)

3. Geometric Modelling of Experimental Setup

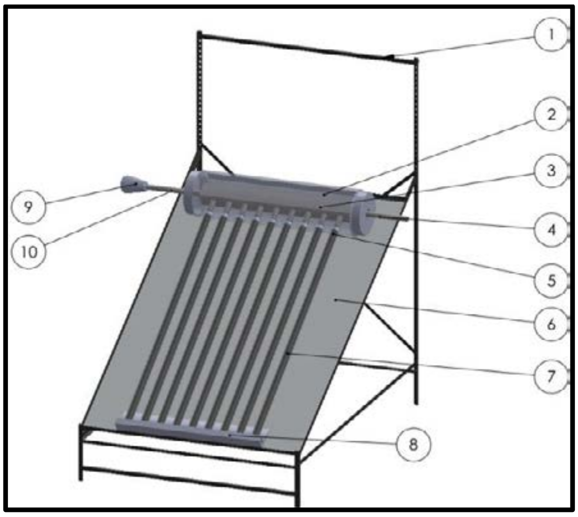

Fig. 9: Designed Model of ETSAC with reflector using Solid-Works (Based on the dimensions from Table 1)

Table 3: Evacuated tube setup parts description

S.No	Parts
1	Frame
2	Main Header
3	Inner Manifold
4	Exit air
5	Inner Steel tube
6	Aluminium Reflector
7	Evacuated Tube
8	Air Blower
9	Supply air pipe

3.1 System Operation

Fig. 9 depicts a three-dimensional geometric design model of reflector-equipped ETSCs. In this process, the other end of the inner square pipe closed, allowing the intake air to pass through it. Nine threaded holes in the inner square pipe with a diameter of 22mm for fitting steel tube. Through a cuboid-shaped steel pipe, the blower directs an external air supply to the evacuated tubes. The stainless-steel tube increases heat gain through the evacuated tubes because the thermosyphon effect separates the hot air from the cold air entering the system.

3.1.1 Thermodynamic performance analysis of ETSAC with reflector

While doing performance analysis following, are the input data taken from a weather station data book as per the location of the experimental model setup and the geographical location as per the Google map.

- Longitude and latitude
- Surrounding ambient dry bulb temperature
- Collector surface area (m^2)
- Solar collector altitude, azimuthal angle, and collector tilt angle

ETSACs' experimental setup with and without reflectors was set up at Glocal University, Saharanpur, India, to find out the thermal performance comparative study behind the mechanical engineering department workshop of Glocal University Saharanpur, India. Fig. 10 shows the satellite image snapshot captured by Google map; the precise coordinate is 30°17'34.5"N 77°38'32.2" E (30.292916N 77.642273E).

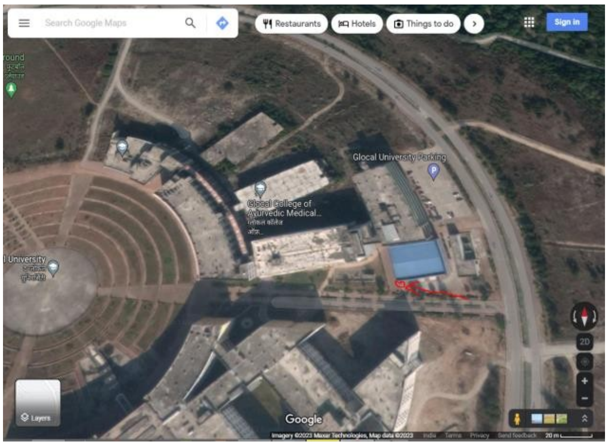

Fig.10: Google map location of the project showing red arrow [37]

Table4. Measuring value and measuring instruments detail

S. No	Measuring Value	Measuring Instruments	Unit
1	Irradiance	Lux meter	W/m^2
2	Wind Velocity	Anemometer	m/s
3	Dry Bulb Temperature	Hygrometer	^0C
4	Relative Humidity	Hygrometer	%rh
5	Inlet air temperature	Digital Temperature sensor	^0C
6	Outlet air temperature	Digital Temperature sensor	^0C
7	The mass flow rate of air	Anemometer	Kg/s

3.2 Governing Equations

Assumptions considered for a simplified collector analysis.

- SFEE process
- Adiabatic system design
- The system is a closed system.
- Assumed that the result obtained with no shading or abstraction with a clear sky.

$$\frac{G_{abs}}{G} + \frac{G_{ref}}{G} + \frac{G_{trs}}{G} = \frac{G}{G} \quad (1)$$

$$\propto + \rho + \tau = 1 \quad (2)$$

3.2.1 Reflectivity of Aluminium Yunus A. Cengel[38]

But the Aluminium plate is opaque, $\tau = 0$

$\alpha + \rho = 1$

$\rho = 1 - \alpha$,

3.2.2Collector efficiency[15]

$$\eta = \frac{Q_{out}}{Q_{in}} \quad (3)$$

$$I_{eff} = \alpha\tau \quad (4)$$

$$Q_{out} = mC_v(T_f - T_i) \quad (5)$$

$$Q_{in} = \alpha\tau IAc \quad (6)$$

$$\eta = \frac{mC_v(T_f - T_i)}{\alpha\tau IAc} \quad (7)$$

$$\eta = \frac{mC_v(T_d)}{\alpha\tau IAc} \quad (8)$$

$$T_d = T_f - T_{ini} \quad (9)$$

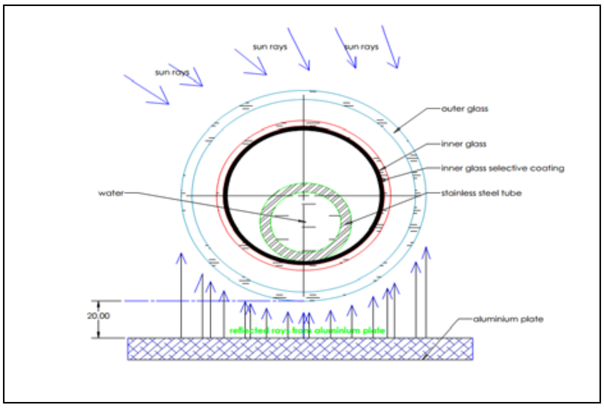

Fig. 11: Schematic diagram of the position of the stainless-steel tube in the evacuated tube.

Results & Discussion

Under various operational and geometrical conditions, this test setup aims to heat the air. The tests were performed in November 2022 during daylight hours with good weather. During the day, the temperature typically varied between 18 °C to 28 °C. Nevertheless, it sometimes approached 30 °C. From 10 am until 4 pm, an investigation was conducted. The test used the following circumstances, and the results were described utilizing a side-by-side graphic representation.

Case 1: ETSC with steel manifold channel fitted with directional inner SS-304 tube of 22mm diameter with rectangular aluminum sheet reflector

Case 2: ETSC with steel manifold channel fitted with directional inner SS-304 tube of 22 mm diameter without rectangular aluminum sheet reflector

4.1. Case 1: Vacuum tube with steel manifold channel fitted with directional inner SS-304 tube of 22mm diameter with silver color aluminium sheet reflector.

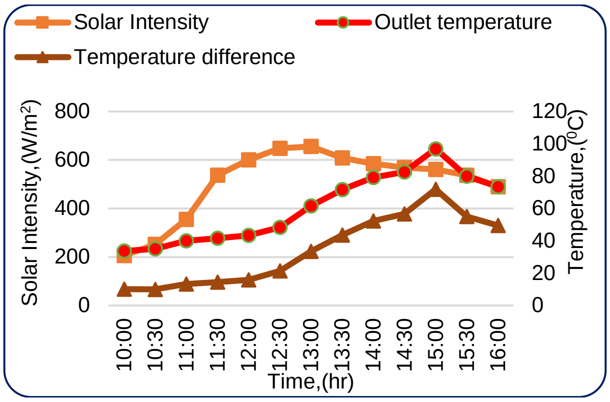

Fig. 12a Variation of solar radiation concerning time with Variation in final outlet temperature at a lower flow rate of 8.58 (kg/h)

4.1.1. At a lower flow rate of 8.58 (kg/h) with a reflector

Temperature and sun intensity variations throughout time are depicted in Fig. 12a. In the experimental setup, air acts as the working fluid and heats up over time at a lower flow rate of 8.58 kg/h. The ETSC with a reflector was discovered to have increased its maximum temperature to 96.9 °C, its maximum temperature difference to 71.9 °C at 3 pm, and its solar intensity of 560.9 W/m^2.

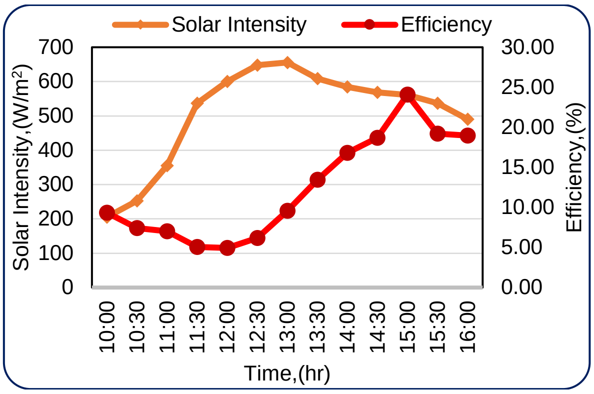

Fig. 12b of solar radiation concerning time with Variation in the collector efficiency at a lower flow rate of 8.58 (kg/h)

The change in efficiency and sun intensity over time is depicted in Fig. 12b. Air is the working fluid in the experimental setup, and it heats up over time at a low flow rate of 8.58 kg/h. At 3 pm, with the sun at 560.9 W/m2, it was visible that the ETSC with a reflector had achieved its maximum efficiency of 24.08% at 3 pm and solar intensity of 560.9 W/m^2.

4.1.2. At a higher flow rate of 20.14 (kg/h) with a reflector

Temperature and sun intensity variations throughout time are depicted in Fig. 13a. In the experimental setup, air acts as the working fluid and heats up with time at a high flow rate of 20.14 kg/h. At 2 pm, the ETSC with a reflector gained a maximum temperature of 82.6 °C and a maximum temperature difference of 55.6 °C, with a solar intensity of 660.3 W/m^2.

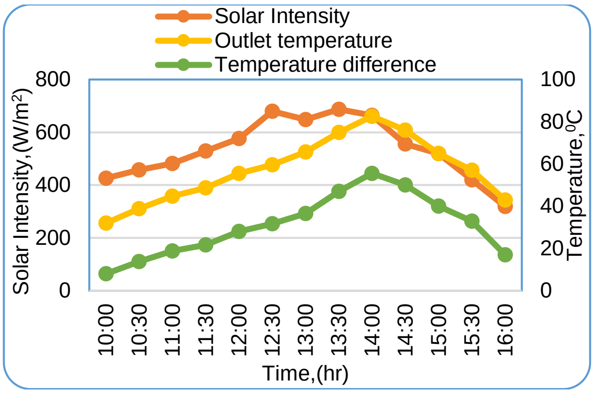

Fig. 13a Variation of solar radiation concerning time with Variation in final temperature and temperature difference at a higher flow rate of 20.14 (kg/h)

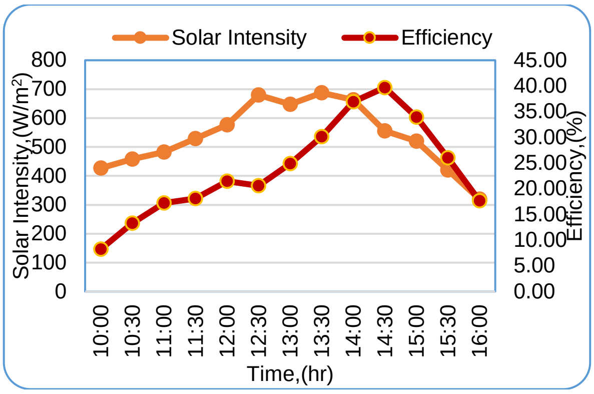

Fig.13b Variation of solar radiation concerning time with Variation in the collector efficiency at a higher flow rate of 20.14 (kg/h)

The efficiency and sun intensity variations over time are depicted in Fig. 13b. In the experimental setup, air is the working fluid and is heated over time at a high flow rate of 20.14 kg/h. As observed, the ETSC with a reflector benefited from a sun intensity of 687.3 W/m^2 and a maximum efficiency of 39.69% at 2:30 pm.

4.2 Case 2: Evacuated tube with steel manifold channel fitted with directional inner SS-304 tube of 22mm diameter without rectangular aluminum sheet reflector

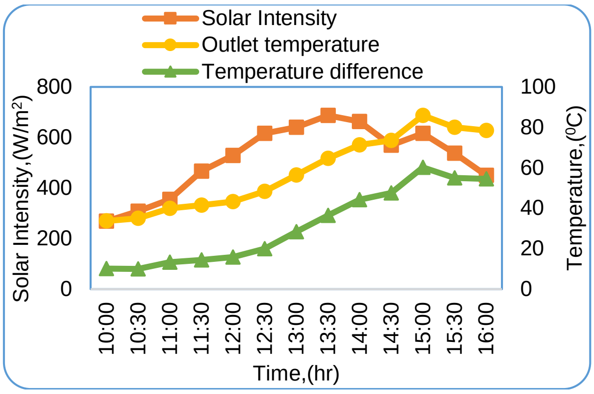

Fig.14a Variation of solar radiation concerning time with Variation in final temperature at a lower flow rate of 8.58 (kg/h)

4.2.1. At a low flow rate of 8.58 (kg/h) without a Reflector

Temperature and sun intensity variations throughout time are depicted in Fig. 14a. Air is the working fluid in the experiment setup, and it heats up over time at a low flow rate of 8.58 kg/h. The ETSC without a reflector gained a maximum temperature of 85.9 "°C" and a maximum temperature difference of 60.2 0C at 3 pm, along with a solar intensity of 687.3 W/m2.

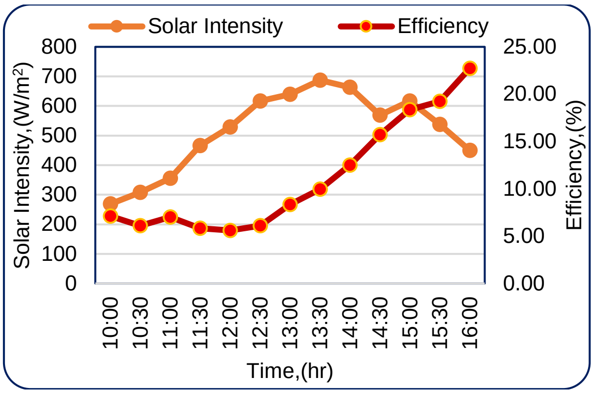

Fig. 14b Variation of solar radiation concerning time with Variation in the collector efficiency at a low flow rate of 8.58 (kg/h)

Efficiency and sun intensity variations throughout time are depicted in Fig. 15b. In the experimental setup, air is the working fluid, which heats up over time at a high flow rate of 20.14 kg/h. The ETSC attained a maximum efficiency of 22.73% at 4:00 pm and a solar intensity of 710.3 W/m2, as could be seen.

4.2.2At a high flow rate of 20.14 (kg/h) without a reflector

Temperature and sun intensity variations throughout time are depicted in Fig. 16a. In the experimental setup, air acts as the working fluid and heats up with time at a high flow rate of 20.14 kg/h. The ETSC gained a maximum temperature of 71"°C" and a maximum temperature difference of 41 0C at 2:30 pm, along with sun intensity of 532.6 W/m2, as could be seen.

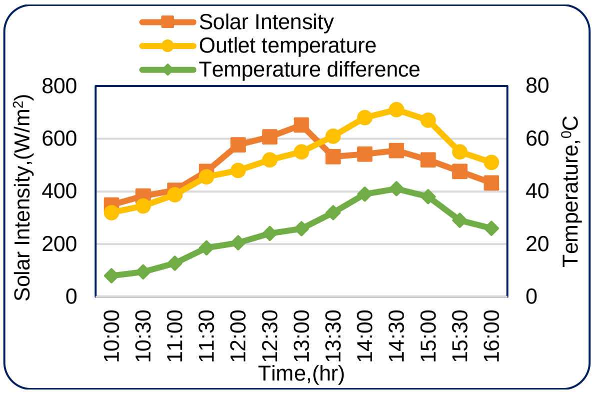

Fig. 15a Variation of solar radiation concerning time with Variation in final temperature and temperature difference at a high flow rate of 20.14 (kg/h)

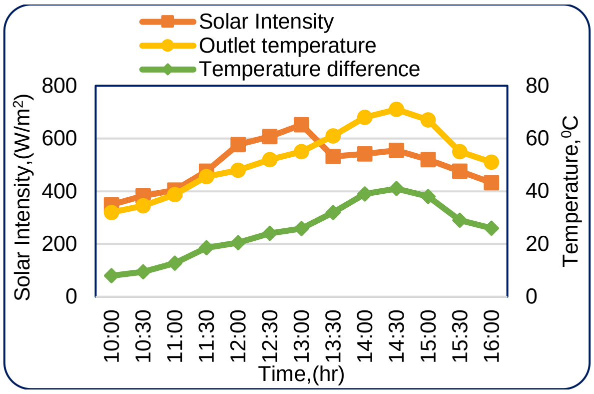

Fig. 15b Variation of solar radiation concerning time with Variation in the collector efficiency at a high flow rate of 20.14 (kg/h)

Fig. 15b shows the Variation of efficiency and solar intensity with time. The working fluid in the experimental setup is air, which gets heated over time at a high flow rate of 20.14 kg/h. It could be seen that the ETSC, without a reflector, gained a maximum efficiency of 32.55% at 2:30 pm and solar intensity of 651.3 W/m^2.

5. Conclusion

We found that when all of the results obtained from the graph were compared in both sunny day and hazed day climatic conditions, ETSC's steel manifold channel, with rectangular aluminum sheet reflector, produced the most significant temperature variation of 71.9 ^{0}C, and the maximum outlet temperature of 96.9 ^{0}C at a lower flow rate of 8.58 kg/h and solar intensity of 560.9 W/m^2.

This is because the air stay at a low flow rate is generally more extended than the residence time at the highest flow rate, enhancing the heat transfer rate.

As well as this result is obtained at 560.9 W/m^{2,} which is comparatively low. The result could be more optimized if the solar intensity exceeds this value.

Also, the aluminum sheet reflector offered a slight increase in temperature more than the evacuated tube without the reflector as per the irradiance. Also, as the solar intensity level increases, the output temperature and temperature difference increase, as shown in the graph.

All efficiency values have been compared for flow rates of 8.58 kg/h and 20.14 kg/h, and the results were obtained with and without a reflector. We conclude that the arrangement of fitting Aluminium sheet reflectors results in a higher efficiency of 36.69% at a high flow rate of 20.14 kg/h. The reflector, it was concluded, provides an additional benefit for maximizing the output temperature and efficiency of the ETSC. The efficiency of ETSC by using diffuse flat reflector improvement varies from 14.7% to 27%[39]. Because the thermal efficiency is directly proportional to the mass flow rate, the output efficiency rises as the mass flow rate does. It shows that with more solar irradiation, more light will be reflected by the aluminum sheet reflector on the evacuated tube, generating more heat. This accounted for the higher temperature in the air in the evacuated tube with a reflector.

For future advancement in this project, a more reflective reflector can be used to optimize the experiment's performance. The use of a different kind of effective reflector can enhance optical properties,

Acknowledgments

In collaboration with the "research and development center" at the Glocal University, Saharanpur, Uttar Pradesh, India, the "ETSAC with reflector" project is fabricated. The experimental setup is installed correctly and tested.

Abbreviation & Nomenclature

ETSCs	evacuated tube solar collectors
FPC	flat plate collector
ETSAC	evacuated tube solar air collector
PCM	phase change material

List of symbols

T_f	final temperature of outlet air(˚C)
T_i	Initial temperature of inlet air(˚C)
$\dot{m}$	mass flow rate of air(kg/h)
A_c	area of evacuated tube solar air collector (m^2)
C_v	specific heat capacity of water [J/kg K]
I	intensity of solar radiation [W/m^2]
G	total radiant incident energy
Q_{in}	heat supplied to the water [W]
Q_{out}	heat required by water [W]

Greek symbols

η	collector efficiency
$\propto$	absorptivity
β	tilt angle

γ	reflectivity
$\in$	emissivity
τ	Transmissivity
σ	Stefan Boltzmann constant [W/m^2]

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