The Effect of Fin Placement on the Efficiency of Solar Air Collectors

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تأثير توضع الزعانف على مردود المجمعات الشمسية الهوائية

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Received: 23-04-2025; Accepted: 17-06-2025; Published: 26-06-2025

Abstract:
This work presents the results of an experimental investigation of the performance for a solar flat plate air collectors with several absorber plate orders (flat absorber plate, with rectangular fins, with consecutive fins, with staggered fins) in order to increase the convection coefficient between the absorber plate and the air which is used as a fluid of heat transfer in solar air collectors. Results show an appreciable improvement of the thermal heat performance of solar air collectors with staggered fins in comparison to those with flat absorber plate. The thermal efficiency increased for η = 22 % at a solar intensity of and mass flow rate of˙ for the solar air collector with staggered fins.

Keywords: Solar air collectors, Convection coefficient, Thermal efficiency, Fins.

الملخص:
يقدم هذا البحث دراسة تجريبية لأداء المجمع الشمسي الهوائي وفق نماذج مختلفة للصفيحة الماصة (صفيحة ماصة مسطحة – ذات زعانف مستطيلة - ذات زعانف ترادفيه - ذات زعانف انزياحيه) بهدف زيادة معامل الحمل الحراري بين سطح الصفيحة الماصة والهواء المستخدم كوسيط عامل في المجمعات الشمسية الهوائية. أظهرت النتائج تحسناً ملموساً في الأداء الحراري للمجمع الهوائي الشمسي ذي الصفيحة الماصة بزعانف انزياحيه مقارنة بالمجمع ذي الصفيحة الماصة المسطحة، حيث ازدادت الكفاءة الحرارية إلى $\eta = 22$ % عند معدل إشعاع شمسي ومعدل تدفق للمجمع الهوائي الشمسي ذي الصفيحة الماصة بزعانف انزياحيه.

الكلمات المفتاحية: المجمعات الهوائية الشمسية، معامل الحمل الحراري، الكفاءة الحرارية، الزعانف.

1. INTRODUCTION

Solar energy is considered one of the most important alternative and renewable energy sources in the world. There are several ways to harness this energy, including solar-air collectors. These are among the solar thermal systems widely used for heating purposes, such as drying agricultural crops, heating homes in the winter, and industrial processes requiring hot air. However, using them for water heating requires an external heat exchanger. The beginnings of solar air heating systems date back to the solar house built by engineer George Löf in Denver, Colorado, in 1958. This project covered an area of 300 m², incorporating 50 m² of solar collectors that used air instead of water as the heat transfer medium. The system successfully supplied approximately 25% of the annual thermal load for space heating and domestic hot water in the house [1]. In improve the thermal efficiency of these collectors, several studies and experiments were conducted to increase the thermal load coefficient of the absorber plate. Researcher [2] found that integrating ribs with the absorber plate in a flat-plate solar air heater improves the thermal efficiency by more than 9%. Researcher [3] concluded that the solar collector with fins is more cost-effective than the solar collector without fins, particularly at mass flow rates between 0.01-0.07 kg/s. The results also showed that the double-pass solar collector with fins is more cost-effective compared to the single-pass solar collector. Researcher [4] explained that increasing the fins leads to an increase in the heat transfer rate, but taking into account whether the metal from which the absorber plate is made is selective or non-selective, as the heat losses by radiation increase compared to the plate with non-selective metal. When comparing the performance of flat solar air collectors with absorber plates with fins and without fins, it was shown that adding fins leads to an increase in the thermal efficiency of the solar collector up to 60% in the case of adding triangular fins along the flow path, but on the condition of ensuring an air flow of no less than 0.0055 kg/s for this type of fins [5]. By examining the heat transfer characteristics through a rectangular channel with W-shaped ribs for both upstream and downstream flow, it was found that the W-shaped ribs showed better performance in downstream flow rather than lateral flow [6]. When studying the effect of a finned absorber plate and latent heat storage materials simultaneously in a forced convection solar air heater, compared to a flat absorber plate, it was found that the paraffin wax-filled nano-finned absorber plate showed an additional heat storage of 3 hours [7]. Adding cuts to the vertically mounted rectangular fins can significantly enhance thermal performance, as cutting the fins increases the heat transfer coefficient of the cut rectangular fins compared to long rectangular fins [8]. Due to the high prices of petroleum derivatives and the decline in fossil fuel production in our country, the need for a more economical alternative to secure hot air for heating and drying operations has emerged. Therefore, we made modifications to the structure of the absorber plate of the solar air collectors according to different models with the aim of increasing the yield of the solar air collectors and increasing their efficiency and suitability for heating and air conditioning purposes, testing these models and studying the thermal convective coefficient of the absorber plate in the implemented cases, and conducted the necessary comparisons in preparation for selecting the best model.

2.RESEARCH HYPOTHESES:

1. Is there an alternative for heating homes that is more economical than currently available methods and less polluting to the environment?
2. Can air-cooled solar collectors be used to heat a home with an efficiency comparable to that of water-cooled collectors?
3. Is the offset placement of fins the optimal method for increasing the thermal convection coefficient of the absorber plate of an air-cooled solar collector?

3. THE RESEARCH METHODS and RESOURCES:

- To measure the external air temperature entering the collector and the temperature exiting the collector, we use an electronic thermostat and an anemometer to measure the air velocity exiting the collector and the wind speed outside the collector.
- To design a model of the solar air collector, we used **Autodesk Inventor 16** before beginning the practical application. **Microsoft Excel** was used to process the data, draw graphs, and compare the results we obtained.

The solar collector components were assembled, and a 3.5 cm thick layer of thermal insulation Styrofoam was added under the absorber plate to reduce heat loss. A fan was installed at the collector outlet to maintain a constant airflow velocity (V_{out} = 0.5 m/s), while the airflow rate within the collector was (m_{out} = 0.0044 kg/s), and the air velocity touching the plate surface was (V_{in} = 0.157 m/s). Fig (1) illustrates the assembly of the solar collector parts.

a. Installing the absorber plate　　　　b. Installing the transparent cover

Fig 1: assembly of the solar collector parts.

- The collector was positioned facing south at a tilt angle of Φ = 30 to receive the maximum amount of incoming solar radiation.

Testing Conditions for the Surrounding Environment:

- Tests were conducted and measured variables recorded at intervals of 30 minutes from 9 AM to 7 PM in the city of Tartus in two phases:
    1. Phase 1 (Partly Cloudy Weather): Conducted from April 13–16, 2020, with an average total solar irradiance of Ic1 = 533 W/m² and a nearly constant wind speed of 4 m/s.

2. Phase 2 (Sunny Weather): Conducted from July 26–29, 2020, with an average total solar irradiance of Ic2 = 693 W/m² and a nearly constant wind speed of 2 m/s.

- Since external and absorber plate temperatures were consistent across each phase, the arithmetic means of t_i (inlet air temperature) and t_s (plate temperature) was used for analysis.

4. SOLAR AIR COLLECTOR DESIGN:

The research relies on increasing the yield of the air solar collector by adding fins to the absorbing surface, arranged in a specific configuration to enhance the heat transfer coefficient. To avoid building multiple solar air collectors for various shapes of the absorbing plate, a detachable solar air collector was developed, allowing the absorbing plate to be swapped with its four shapes: (1- Flat absorbing plate, 2- Rectangular fins, 3- Tandem fins, 4- Offset fins). Fig (2) illustrates the four tested absorber plate models (dimensions in mm).

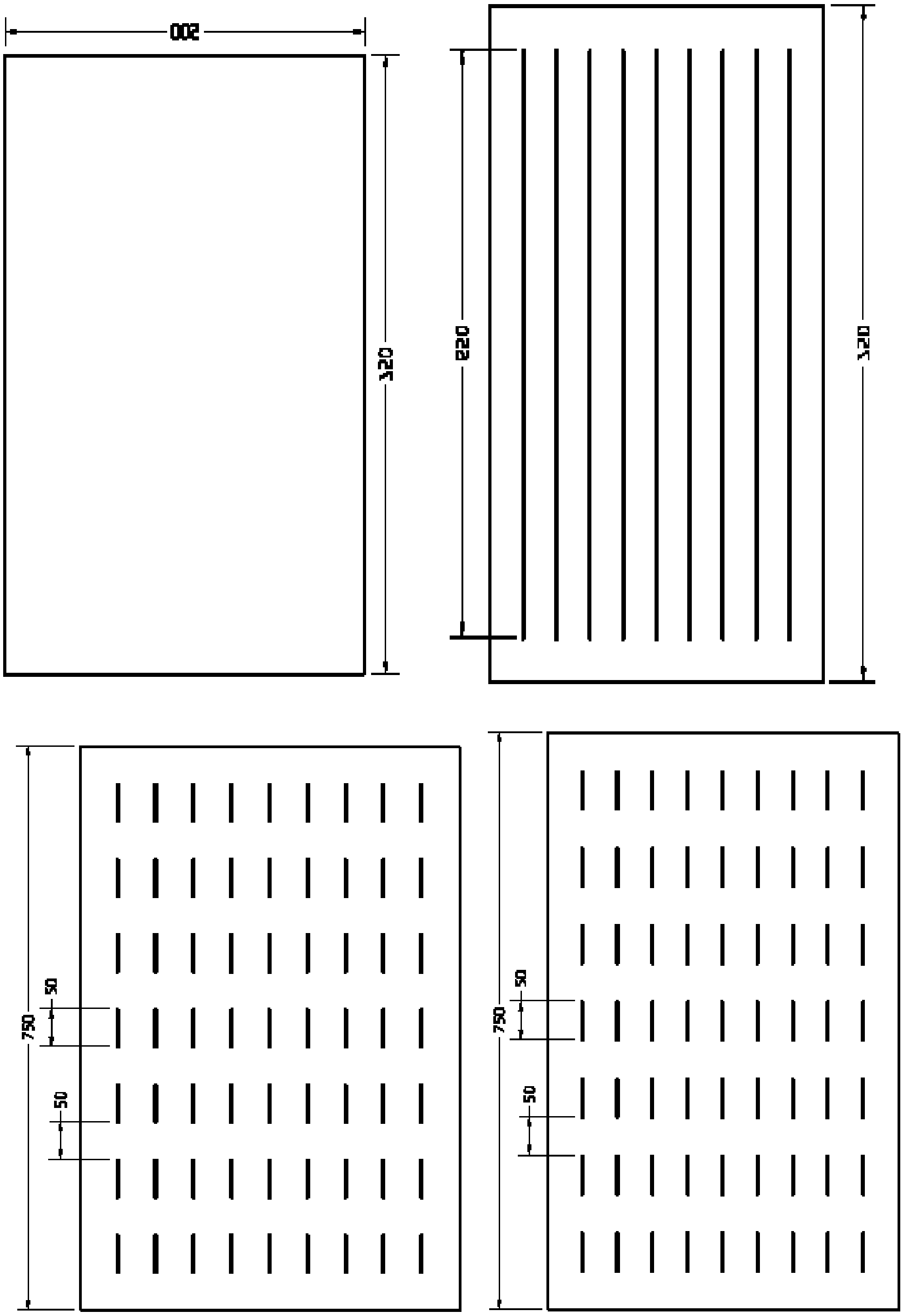

Fig 2: The four tested absorber plate models.

5. YIELD OF THE SOLAR COLLECTOR:

The yield of the solar collector is the ratio of the useful energy produced by it to the solar energy incident on it, expressed as [5, 9]:

$$\eta = \frac{Q_u}{I_c . A_c} \quad (1)$$

Where:
Q_u: Useful thermal energy produced by the solar collector [W].
I_c: Total incident solar radiation [W/m²]
A_c: Collector surface area [m²]
Q_u is calculated as:

$$Q_u = \dot{m}.cp.(t_o - t_i) = q_u.A_s \quad (2)$$

Where:
$\dot{m}$: Mass flow rate of air within the collector [kg/s], given by the following equation:

$$\dot{m} = \rho.v.A \quad (3)$$

ρ: Air density [kg/m3] (from tables)
v: Air velocity within the collector [m/s]
A: Flow cross-sectional area [m²]
cp: Specific heat capacity of air [kJ/kg·°C] (from tables)
t_i, t_o Inlet and outlet air temperatures [°C]
q_u: heat flux [W/m²]
A_s: Surface area of the absorbing plate [m²]
q_u is given by:

$$q_u = h.A_s.(t_s - t_a) \quad (4)$$

Where:
h: Convective heat transfer coefficient [W/m²·°C]
t_s: Absorber plate temperature [°C]
t_a: Air temperature above the absorber plate [°C]

6. RESULTS:

The first phase of experiments was conducted in April 2020 under cloudy weather conditions. Fig (3) presents the results of the first phase (cloudy weather) for the four models of the solar air collector.

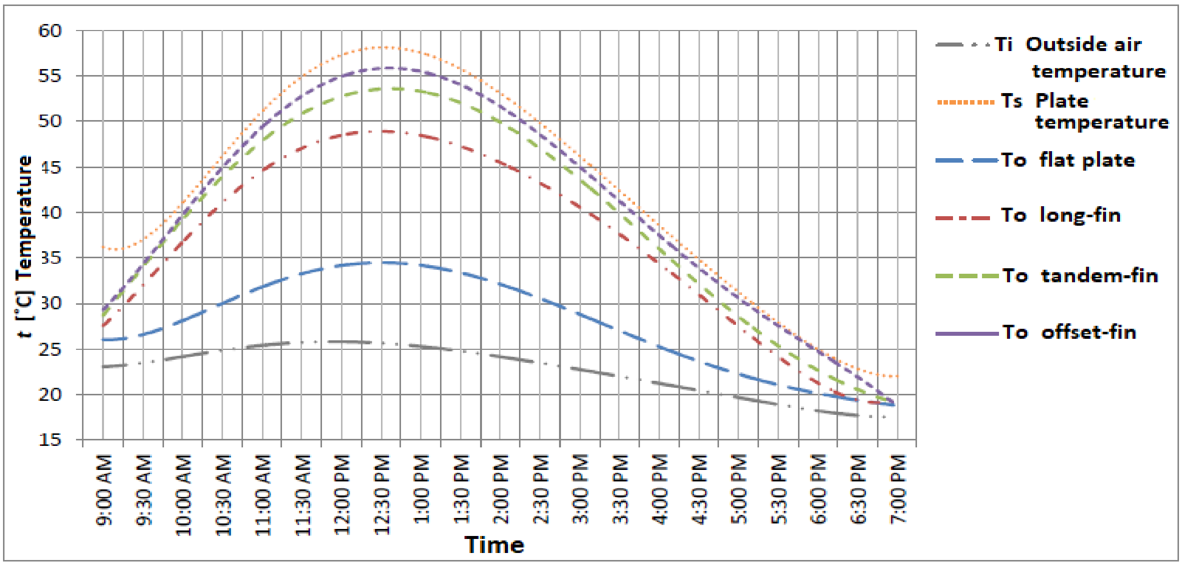

Fig 3: Results of the first phase (cloudy weather) for the four models of the solar air collector.

The experiments revealed that the highest temperature was achieved using the absorber plate with offset fins, reaching (t_o = 58°C), followed by the tandem-fin absorber plate (t_o = 54°C), and the long-fin absorber plate (t_o = 49°C). In contrast, the flat absorber plate recorded a maximum temperature of (t_o = 35°C). All measurements were taken at 12:30 PM under an ambient temperature of (t = 26°C).
Comparing these values, it was found that when testing the plate with offset fins, the ΔT_{max} increased by 3.5 times compared to the ΔT_{max} of the flat plate, while the plate with tandem-fins showed an increase of three times. In contrast, the addition of long-fins resulted in a ΔT_{max} approximately 2.5 times higher than that of the flat plate.
The second phase of testing was conducted in July 2020 under sunny weather conditions. Fig (4) illustrates the results of the second phase (sunny weather) for the four models of the solar air collector.

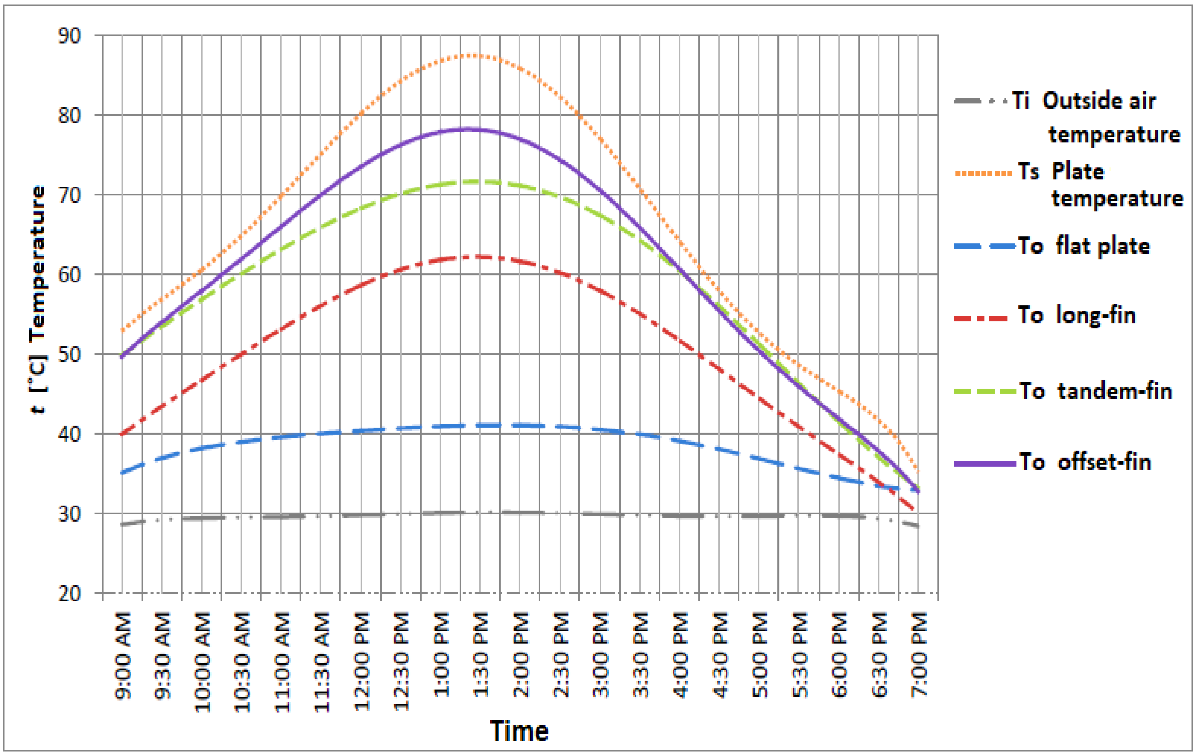

Fig 4: Results of the second phase (sunny weather) for the four models of the solar air collector.

The experiments demonstrated that the highest temperature was achieved using the absorber plate with offset fins, reaching (t_o = 78°C), the tandem-fin absorber plate (t_o = 71°C), and the long-fin absorber plate (t_o = 62°C). For the flat absorber plate, the highest temperature recorded was (t_o = 41°C). All measurements were taken at 1:30 PM, under an ambient temperature of (t = 30°C).
Comparing these values, it was found that when testing the plate with offset fins, the ΔT_{max} increased by 4.5 times compared to the ΔT_{max} of the flat plate, while the plate with tandem-fins showed an increase of four times. In contrast, the addition of long-fins resulted in a ΔT_{max} approximately three times higher than that of the flat plate.

7. DISCUSSION:

To calculate the heat transfer rate and efficiency of the solar air collector for each measurement, an Excel-based program was developed using Equations (1), (2), and (4). Based on the program's results, graphs were plotted to illustrate variations in the basic parameters of the four solar air collector models.

7.1. CONVECTIVE COEFFICIENT *(h)*:

The Convective coefficient significantly increased in both testing phases for collectors with tandem-fin and offset fins, by approximately double its value for the long-fin plate and flat plate collectors. Fig (5) illustrates the change in the average convection coefficient relative to the change in the shape of the absorber plate

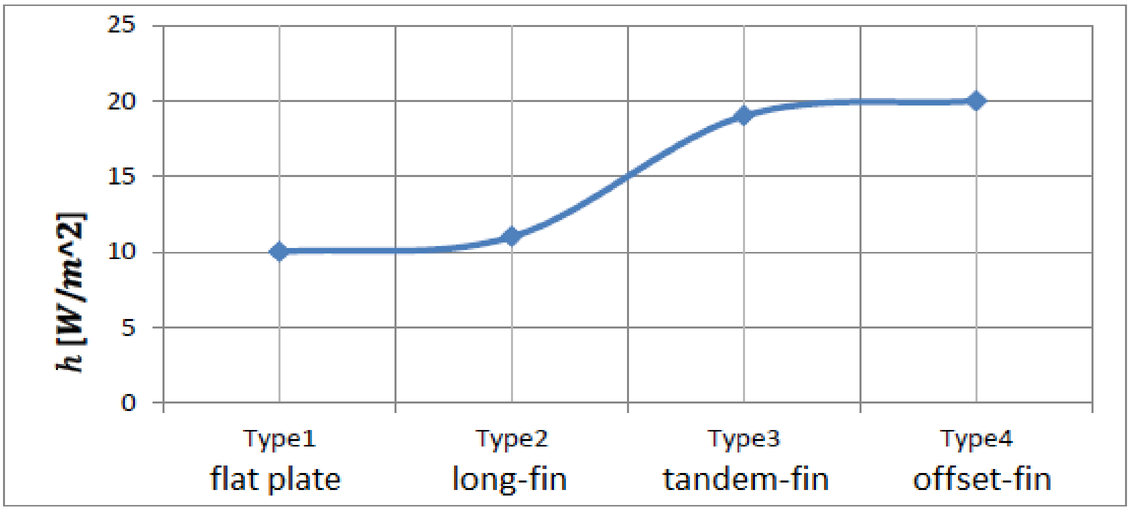

Fig 5: The change in the average convection coefficient relative to the change in the shape of the absorber plate.

7.2. HEAT FLUX (q_u):

The heat flux increases with the increase in solar radiation and in line with the increase in the thermal convection coefficient. Fig (6) shows the change in the average heat flux in relation to the change in the shape of the absorbing plate.

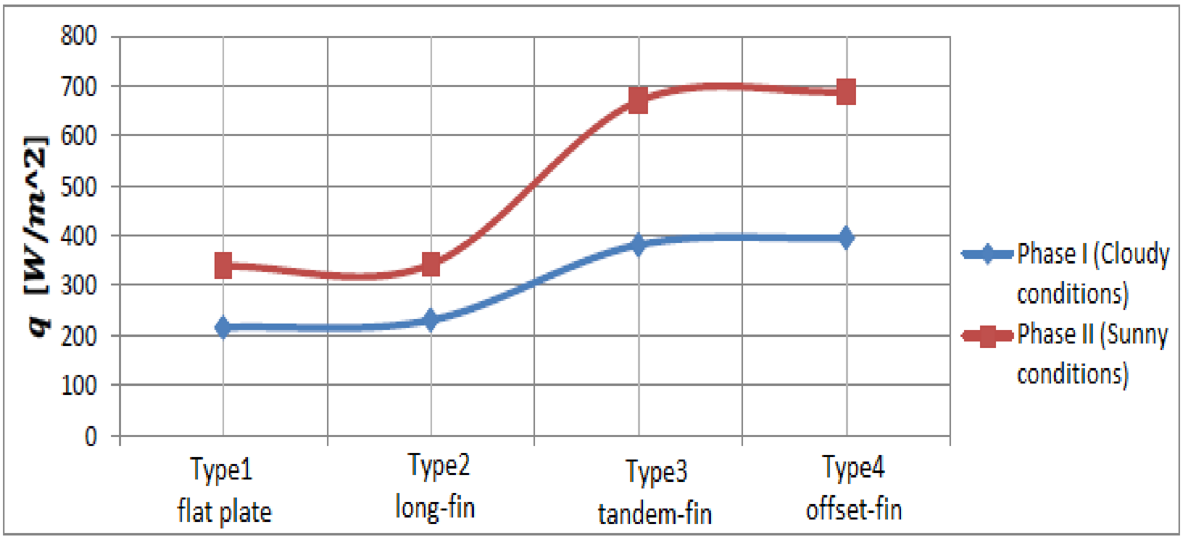

Fig 6: The change in the average heat flux in relation to the change in the shape of the absorbing plate.

Comparison of Heat Flux Between Flat-Plate and Offset-Fin Solar Collectors: Fig (6) demonstrates that the heat flux (q) of the offset-fin absorber plate increased from q = 216 W/m² to q = 395.42 W/m² in the first phase (cloudy weather) and from q = 339 W/m² to q = 688 W/m² in the second phase (sunny weather). The heat flux values for both the tandem-fin and offset-fin collectors increased by approximately twofold compared to the flat-plate and long-fin collectors. This increase is considered
logical due to the increase in the heat transfer coefficient of the offset-fin and flat-plate collectors, as shown in Fig (5). Consequently, this results in an increased temperature difference (ΔT) between the collector's inlet and outlet. Fig (7) illustrates the average temperature variation (ΔT) relative to the heat flux changes for all four absorber plates.

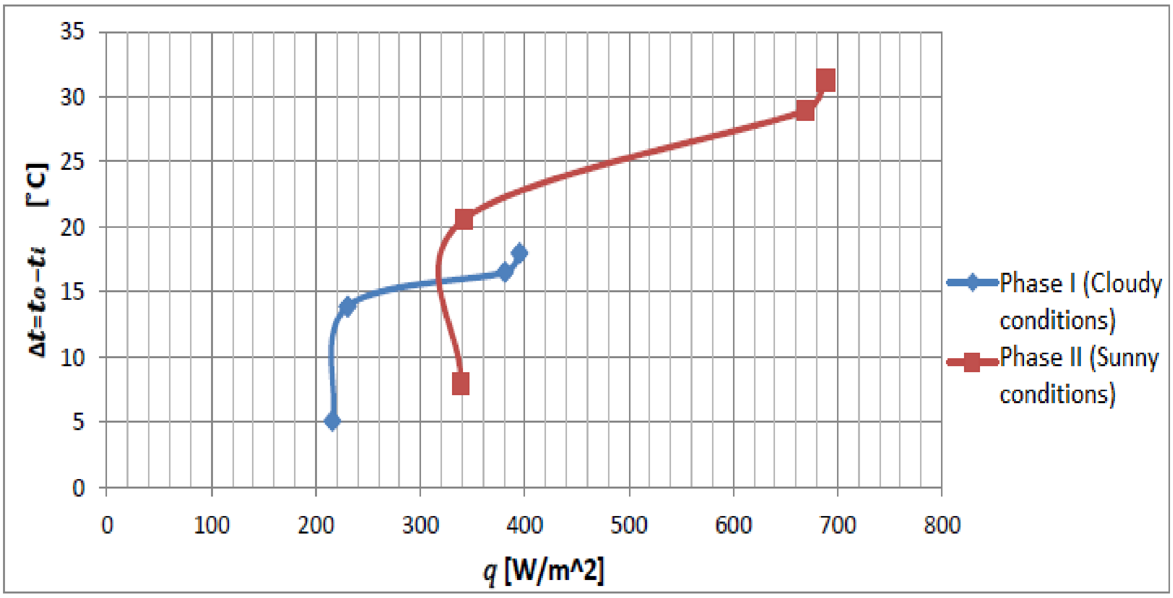

Fig 7: The average temperature variation (ΔT) relative to the heat flux changes for all four absorber plates.

Fig (7) reveals that during the first phase (cloudy conditions), the maximum average temperature difference (ΔT=18°C) between the collector outlet and ambient air was achieved by the offset-fin absorber plate at an average heat flux of q=395 W/m². In contrast, the flat-plate collector showed the minimum increase (ΔT=5°C) at q=216 W/m².
During the second phase (sunny conditions), the offset-fin absorber plate demonstrated the highest temperature difference (ΔT=31°C) at q=688 W/m², while the flat-plate collector exhibited the lowest increase (ΔT=8°C) at q=339 W/m².

7.3. USEFUL ENERGY (Q_u):

The addition of fins to the absorber plate significantly increased the useful energy output (Q_u) of the solar collector, primarily due to the increased surface area of the absorber plate. This improvement was more pronounced during the second phase (sunny conditions) as a result of higher solar irradiance. Fig (8) illustrates the variation in average useful energy output (Q_u) relative to the shape of the absorber plate.

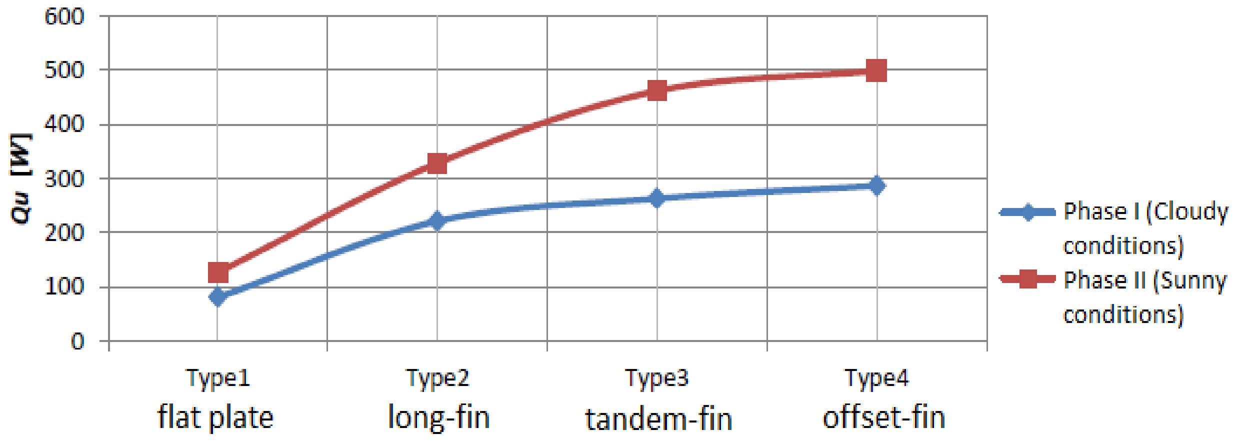

Fig 8: The variation in average useful energy output (Qu) relative to the shape of the absorber plate

As shown in Fig (8), the maximum useful energy output was achieved by the offset-fin absorber plate, reaching Q_u= 287 W during the first phase (cloudy conditions), and Q_u = 500 W during the second phase (sunny conditions) Fig (9) shows the average useful energy (Q_u) relative to the absorber plate surface area.

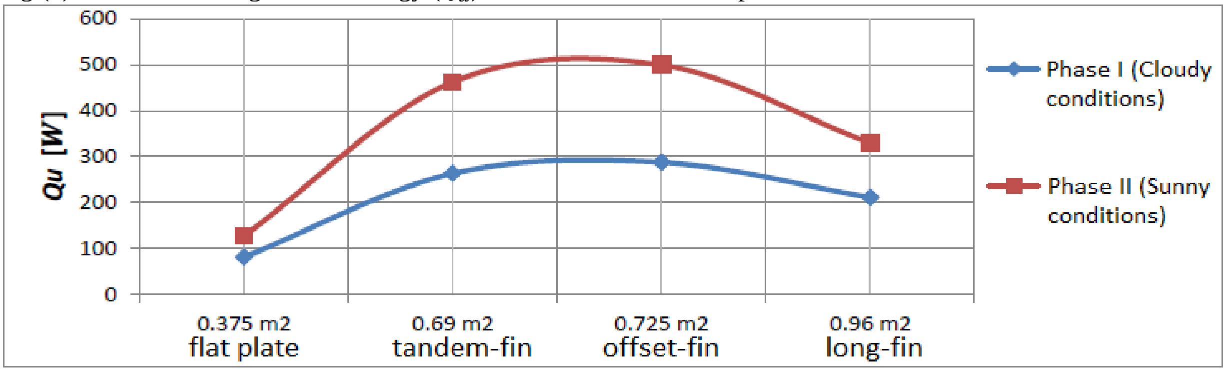

Fig 9: The average useful energy (Qu) relative to the absorber plate surface area.

From Fig (9), we observe an increase in useful energy transfer through both the offset-fin and tandem-fin absorber plates compared to the long-fin plate, despite the increase in its surface area. This is due to the interruption of the fins, as the absorber plate with the short, interrupted fins maintains a high thermal convection coefficient due to the separation of the boundary layer at the end of the fin and its reformation at the beginning of the fin.

7.4. COLLECTOR EFFICIENCY (η):

The thermal efficiency of the solar air collector is directly affected by its useful energy output. The collector's performance increases with the addition of fins to the absorber plate. Figure (10) illustrates the change in the average collector efficiency (η) relative to the shape of the absorber plate.

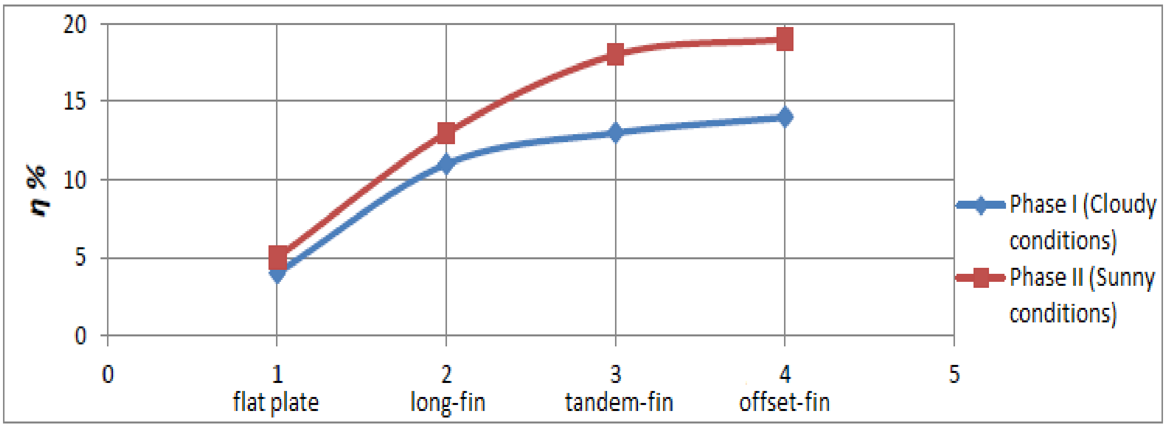

Fig 10: The change in the average collector efficiency (η) relative to the shape of the absorber plate.

From Fig (10), comparative with the flat-plate collector reveals that the maximum efficiency increase was achieved using the offset-fin absorber plate configuration. The efficiency improvement measured 10% increase during Phase I (cloudy conditions), and 14% increase during Phase II (sunny conditions).

8. CONCLUSIONS:

In this study, four absorber plates for solar collectors were tested in two distinct phases: Phase I (Cloudy conditions) total solar irradiance was 533 W/m², and in the Phase II (Sunny conditions) was 693 W/m². All tests were conducted with constant airflow rate through the collector. The experimental results demonstrated that:

The highest temperature of the solar air collector was achieved using the absorber plate with offset fins, reaching (t_o = 78°C), the tandem-fin absorber plate (t_o = 71°C), and the long-fin absorber plate (t_o = 62°C). For the flat absorber plate, the highest temperature recorded was (t_o = 41°C).

The highest average convective coefficient of the solar air collector was achieved using the absorber plate with offset fins, reaching (h =20 W/m^2), the tandem-fin absorber plate (h =19 W/m^2), and the long-fin absorber plate (h =11 W/m^2). For the flat absorber plate, the highest average convective coefficient recorded was (h =10 W/m^2).

The highest air collector efficiency was achieved using the absorber plate with offset fins, reaching (η =29 %), the tandem-fin absorber plate (η =25 %), and the long-fin absorber plate (η =20 %). For the flat absorber plate, the highest efficiency recorded was (η =7 %).

9. RECOMMENDATIONS WORK:

- Use this type of solar collector for heating and air conditioning purposes using an external heat exchanger.
- Use this type of solar collector for agricultural purposes in greenhouses and glass houses, with temperatures controlled using special regulators and controllers.

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