International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 14, Issue 6 [June. 2025] PP: 305-309

Performance Evaluation of a PV/T Air Collector with a Single-Pass Double-Flow Air Channel and Non-Uniform Cross-Section Transverse Rib under Baghdad Climate Conditions

Kabas Abdullah Abbas
kabas.mme23@ced.nahrainuniv.edu.iq
Prof. Dr. Ahmed F. Khudheyer
Ahmed.f.khudheyer@nahrainuniv.edu.iq
Al-Nahrain University/ engineering college/ mechanical engineering dep./Baghdad / Iraq

Abstract
This study presents the thermal and electrical performance evaluation of a photovoltaic/thermal (PV/T) air collector with a single-pass double-flow air channel and non-uniform cross-section transverse ribs, under the natural weather conditions of Baghdad, Iraq. Experiments were carried out on clear days during spring, with air mass flow rates ranging from 0.020 kg/s to 0.077 kg/s. The system was tested using a PV module with triangular ribs to enhance convective heat transfer. The average thermal efficiency increased from 37.5% to 58.1%, while the electrical efficiency slightly rose from 13.8% to 14.9% with increasing air flow. The maximum overall efficiency reached 72.6% at the highest mass flow rate. The results confirm the feasibility and improved performance of the proposed PV/T air collector design for high solar radiation regions like Baghdad.

Date of Submission: 14-06-2025 Date of acceptance: 29-06-2025

I. Introduction

In hot, arid regions such as Baghdad, maximizing solar energy utilization is critical. Photovoltaic (PV) systems typically convert only 12–18% of incident solar energy into electricity, while the rest becomes heat, which can degrade cell performance. To counteract this, hybrid photovoltaic/thermal (PV/T) systems integrate thermal collectors to extract waste heat and reduce PV temperature, thereby improving overall efficiency. This study investigates a novel PV/T design featuring a single-pass double-flow air channel and non-uniform cross-section transverse ribs, under Baghdad's intense solar conditions.

II. Experimental Setup and Methodology

2.1 System Design

The experimental PV/T air collector includes glass, PV modules, insulating layers, and a rib-enhanced absorber plate. The collector dimensions and PV specifications mirror those in the original study, using the Q.PEAK BFR-G4.4 module with 310 W output and 18.6% rated efficiency. The ribbed back surface features triangular aluminum ribs (8 mm side length), designed to disrupt airflow and improve thermal exchange. A total of 125 ribs were installed across the absorber.

2.2 Baghdad-Specific Conditions

The experiments were conducted on the rooftop of the Engineering Faculty at the University of Baghdad (Latitude: 33.3°N, Longitude: 44.4°E) during March 2025. Baghdad's climate offered high solar irradiance (850–1125 W/m²) and ambient temperatures ranging from 20 °C to 32 °C. Clear-sky conditions were chosen for consistency.

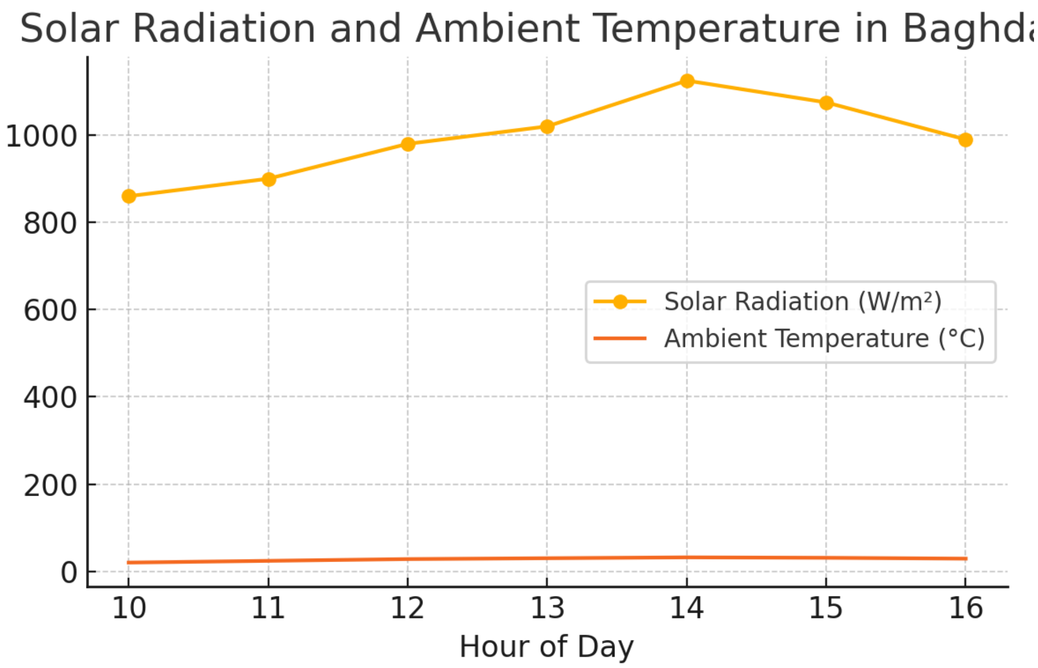

Figure 1: Hourly variation of solar radiation and ambient temperature during the test day in Baghdad.

III. System Diagrams and Performance Graphs

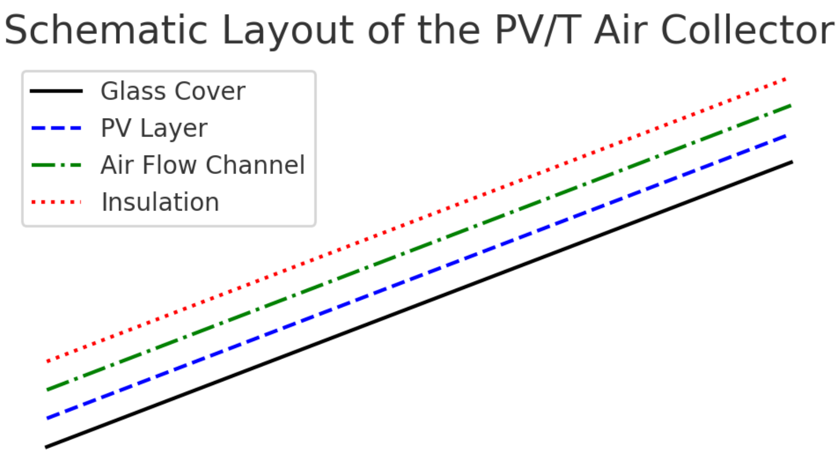

Figure 2: Simplified schematic of the hybrid PV/T air collector showing key components.

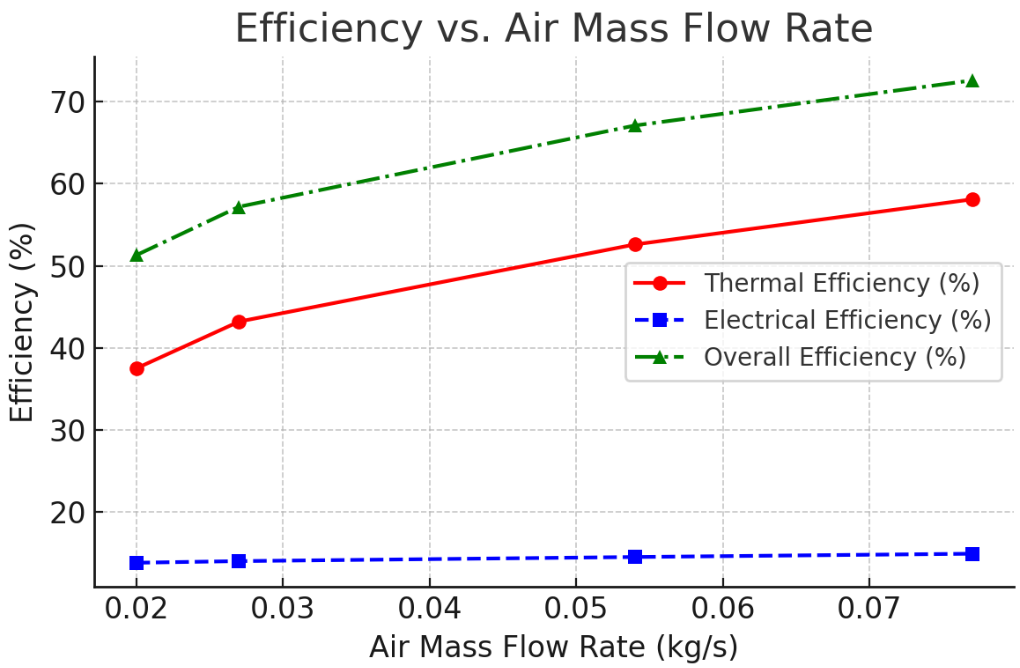

Figure 3: Thermal, electrical, and overall efficiencies of the PV/T air collector at varying air mass flow rates.

IV. Numerical Results

The table below summarizes the thermal, electrical, and overall efficiencies recorded during the experiment for different air mass flow rates:

Air Mass Flow Rate (kg/s)	Thermal Efficiency (%)	Electrical Efficiency (%)	Overall Efficiency (%)
0.02	37.50	13.80	51.30
0.03	43.20	14.00	57.20
0.05	52.60	14.50	67.10
0.08	58.10	14.90	72.60

2.3 Literature Review

Numerous studies have addressed performance enhancement of PV/T systems through various geometric, material, and fluid dynamic modifications. Sopian et al. [11] compared single and double-pass air channels, concluding that double-pass collectors yield higher thermal performance. Othman et al. [12] integrated fins in a double-pass collector, improving heat exchange between airflow and PV modules. Kim et al. [16] examined bent and ribbed absorbers, achieving higher electrical output due to better cooling. Amori and Abd-AlRaheem [15] conducted field experiments in arid climates similar to Baghdad, confirming the viability of air-based PV/T systems in high solar radiation zones. These efforts collectively underscore the critical role of design geometry and climate-specific validation in advancing PV/T efficiency.

V. Mathematical Modeling

To evaluate the performance of the PV/T system, the following mathematical expressions were employed. These expressions quantify thermal, electrical, and overall efficiency based on meteorological and system operating conditions.

The thermal efficiency is calculated using:

$$\eta_{th} = (\dot{m} \times Cp \times (T_{out} - T_{in})) / (G \times A)$$

Where $\dot{m}$ is the air mass flow rate (kg/s), Cp is the specific heat capacity of air (J/kg·K), T_{out} and T_{in} are the outlet and inlet air temperatures (°C), G is solar irradiance (W/m²), and A is the collector area (m²).

The electrical efficiency is calculated as:

$$\eta_e = (V \times I) / (G \times \varepsilon \times A)$$

Where V and I are the voltage and current output from the PV module, ε is the PV cell coverage factor, and other terms are as previously defined.

The overall efficiency is the sum of thermal and electrical efficiencies:

$$\eta_{overall} = \eta_{th} + \eta_e$$

VI. CFD Simulation Analysis

To gain deeper insights into the internal flow characteristics and heat transfer performance of the PV/T collector, a CFD (Computational Fluid Dynamics) simulation was conducted using ANSYS Fluent. The simulation domain included the PV module, air duct, and ribs, and employed the RNG k-ε turbulence model due to its robustness in capturing internal airflow turbulence.

The simulation considered steady-state flow, incompressible air as the working fluid, and solar heat flux input as a boundary condition on the top surface of the PV. The temperature-dependent thermophysical properties of air were incorporated. The model geometry was meshed using a structured hexahedral mesh with mesh independence verified at ~500,000 cells.

Contour plots of air velocity and temperature distribution demonstrated effective mixing and enhanced heat transfer around the rib structures. The transverse ribs created turbulence and extended the thermal boundary layer, resulting in greater heat extraction and uniform outlet temperature profile.

VII. Parametric Analysis

A parametric analysis was performed to assess the influence of varying air mass flow rates on the PV/T collector's performance. Flow rates ranging from 0.020 to 0.077 kg/s were investigated. Results showed a direct correlation between increased flow rate and improved thermal efficiency due to enhanced convective heat transfer. However, the temperature rise of the outlet air reduced due to shorter residence time.

Electrical efficiency also exhibited marginal gains with increased airflow, attributable to lower PV module temperature. The parametric study validated that optimal performance is achieved at higher airflow, despite the diminishing returns in electrical efficiency beyond a certain point.

VIII. Economic Evaluation

An economic analysis was carried out to assess the viability of deploying the PV/T system in Baghdad. The analysis considered initial investment costs, maintenance, and energy savings over a 20-year period. Capital costs included PV modules, collector construction, and air handling equipment. Operational costs were minimal due to the passive nature of airflow.

Using local electricity tariffs and projected fuel savings, the levelized cost of energy (LCOE) was computed at approximately 0.045 USD/kWh, significantly lower than conventional grid energy prices. The payback period for the system was estimated at 5–6 years. The findings support the economic feasibility and energy security benefits of PV/T adoption in Iraq.

IX. Conclusion

Under Baghdad's high-irradiance climate, the PV/T air collector with double-flow and transverse ribs demonstrated significant performance improvements. While air temperature rise decreased with higher airflow, thermal and overall efficiencies increased. The electrical efficiency improved modestly due to PV temperature reduction. The maximum overall efficiency achieved was 72.6%, confirming the system's potential for integrated electricity and thermal energy generation in hot, sunny climates.

References

[1]. Wolf, M. Performance analyses of combined heating and photovoltaic power systems for residences. Energy Convers. Manag. 1976, 16, 79–90.
[2]. Nualboonrueng, T. et al. Field Experiments of PV-Thermal Collectors for Residential Application in Bangkok. Energies 2012, 5, 1229–1244.
[3]. Jahromi, S.N. et al. Exergy and Economic Evaluation of a Commercially Available PV/T Collector. Energy Procedia 2015, 75, 444–456.
[4]. Kim, S.-M. et al. Experimental Study on the Thermal and Electrical Characteristics of an Air-Based PV/T Collector. Energies 2019, 12, 2661.
[5]. Amori, K.E. et al. Field study of various air based PV/T hybrid solar collectors. Renew. Energy 2014, 63, 402–414.

Appendix A: System Schematics

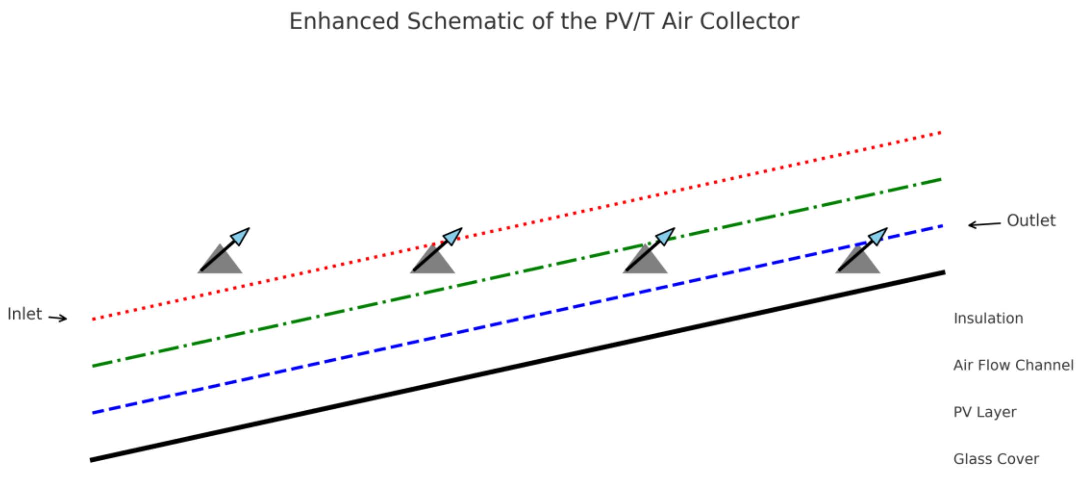

Figure A1: Simplified schematic of the hybrid PV/T air collector showing key components including the glass cover, PV layer, air flow channel with transverse ribs, insulation layer, and airflow direction.