# EVALUATION OF FIN CONFIGURATIONS FOR AN AIR-COOLED HYBRID PHOTOVOLTAIC-THERMAL SOLAR COLLECTOR

by

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*In this work, the examination of an experimental air-cooled photovoltaic-thermal (PV/T) module is introduced. Two different shapes of fin fixed to the copper absorber plate are examined for the classical unit of an air-cooled PV/T collector. Vertical and louver-shaped fins (with the same surface area) are investigated and thermally evaluated in this study. The experiments aimed to increase the temperature difference between inlet and outlet air to reach high thermal performance. The enhancement result showed that the thermal efficiency of the louver fin unit increased by 48% and 54% compared to the vertical fin and unfinned units, respectively. Thus, louver fins are better than vertical fins with the same surface area.*

Key words*: air-cooled PV/T, louver fins, thermal performance, absorber*

## Introduction

Renewable energy sources and their efficiency have been highly highlighted in the literature in recent decades. The most significant factor in using renewable energy sources is the development of energy efficiency [1]. One of the well-known obstacles to increasing the efficiency of the solar electrical system is that the efficiency is strongly dependent on temperature and decreases as the temperature increases. In the case of a hybrid solar panel/solar collector, the electrical efficiency can be increased by cooling the collector surface while heat energy is also obtained from the system [2, 3]. According to various studies, PV cells have the potential to last for upwards of 50 years if the appropriate cooling mechanisms are used [4]. Overheating is the most crucial factor that affects the productivity of PV modules [5]. It is the starting point for the researchers to focus on developing new methods to cool solar cells (such as air cooling with a fan or natural, water cooling [6], jet impingement [7], imersion [8], micro-channels [9], thermoelectric [10], *etc.*) using a hybrid PV/T collector that uses an air or water collector attached beneath the PV module [11], thus removing the heat and employing this heat from the PV module through further applications [12].

Several configuration changes have been proposed on the PV/T (air-cooled) to enhance the heat transfer from the back side of the PV module to the air, especially using fins and

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multiple-channel air-flow configurations [13]. Ranganathan *et al*. [14] developed and simulated a numerical model of the forced air-cooled PV/T and compared it with experimental results in Chennai, India. Their model agreed with the experimentation, and based on their model, they recommended several ways for heat transfer enhancement, such as the fin configuration. Jin *et al*. [15] investigated and discussed how having multiple *V*-shaped fins affects how well the solar air heater keeps heat. The use of these numerous *V*-shaped ribs on the heater absorber allowed for the maximum thermohydraulic performance of 2.35.

Zahran *et al.* [16] utilised turbulence to improve heat transfer in a rectangular channel with one corrugated wall within a solar air collector. Their work proved the valuable contribution of the corrugated surface to heat transfer enhancement.

Promvonge *et al.* [17] examined four configurations of the wing as fins within a vortex generator to improve the heat exchanger performance using a louvered winglet. The streamwise vortices that their new design made grew up the thermal boundary-layers, which increased the heat transfer rate greatly.

Slimani *et al.* [18] analysed the proficiency of three different air-cooled PV/T structures. Back-cooled (Case 1), back-cooled with additional glass cover (Case 2), and back-and-front cooled (Case 3). For each arrangement, they found that the thermal and electrical efficiencies were 21.19% and 10.73%, 41% and 10.33%, 44.4% and 10.65%, respectively. Yang and Athienitis [19] fabricated an air-cooled system with single and double inlets to cool the integrated PV panels to configure an integrated air-PV/T system and analysed its performance. A 5% improvement in thermal efficiency was achieved with the two-inlet air cooling arrangement, but there was an insignificant change in electrical efficiency. Kim *et al.* [20] flowed a constant air-flow utilising a fan into the pipe-lines fixed at the rear of the monocrystal PV module. The results of their experiments showed that the air heated by the air-based PV/T collector was, on average, about 5 °C warmer than the air around it.

Both theoretical and practical aspects of the operation of an air-based PV/T collector have been investigated in a research project carried out in Kirkuk, Iraq, by Omer and Zala [21]. They conclude that the increase in fluid-flow rate from 0.024 $m^3$/s to 0.057 $m^3$/s has been found to result in a 20% increase in electrical efficiency and a 44% increase in thermal efficiency. Additionally, they highlighted the fact that the output air temperature and PV cell temperature perfectly matched the theoretical predictions.

When evaluating the effectiveness of a system for converting energy, exergy analysis is a crucial metric that relies on both the first and second laws of thermodynamics for its conceptual framework [22]. Energetics analysis has been investigated on the classic PV module and air-cooled PV/T unit by Joshi *et al.* [23]. They observed a 3% increase in the energetic efficiency of their system. In similar work, Saloux *et al.* [24] analysed the thermodynamics PV and PV/T systems across a wide range of ambient temperatures. They reported that the exergetic losses grew with the solar module surface temperature and that the exergetic efficiencies ranged from 8-10%. A comparative study conducted by Huang *et al.* [25] on the exergetic characteristics of air-amorphous silicon-based PV/T modules and classical air-cooled units. They expressed a 3.51% increment in the maximum exergetic efficiency of their module compared to the classical unit.

A novel type of solar cell, known as a *bifacial solar cell*, has been designed to optimise solar energy from both the front and rear of the panel surface. A bifacial solar cell has a metallic grating on its front and back, allowing it to generate about 30% more electricity than a standard solar cell. Four variations of the bifacial air-cooled PV/T were tested for their thermal and exergy efficiencies by Ooshaksaraei *et al.* [26]. One of the modules was without a glass cover. The air was circulated in parallel and opposite directions through the channels above and under the PV module. They concluded that the highest energetic efficiency was when the air-flowed through the back channel of the unit.

Despite the abundance of research on air-cooled PV/T systems, it has been noted that no study evaluates the finned metal absorber attached to the PV module.

Besides, as it was noted in the literature that used several shapes of fins in solar air collectors but did not focus on all fins types, there was a type widely used on heat exchangers it is so called louvred-fins type, which proved its thermal effectiveness in the air heat exchanger [27].

This study investigates this type for cooling the PV module via creating a new configuration of PV/T that investigates the louver fin within its copper absorber.

In addition the louver fins fixed to the absorber, this study compares the thermal behaviour of the presented absorber with another vertical fin absorber and an un-finned absorber.

The novel point this study focuses on in the configuration of the louvered-shaped fins is their ability to increase the air-flow length. Thus, it increases the heat transfer time from the absorber and fins to the air-flow. Furthermore, this fin is first used in configuring PV/T modules.

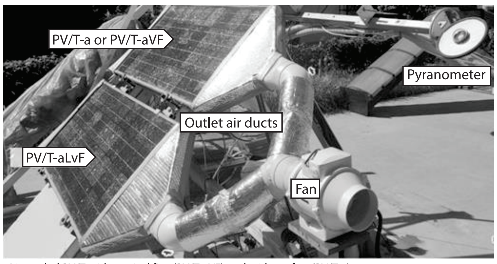
In this study, forced air was applied to the three absorbers, and the effect of fin configurations on the thermal performance of the PV/T module was investigated. This experiment aims to improve the thermal behaviour of classical air-cooled PV/T units by determining the impact of the applied cooling procedure on lowering the surface temperature of the solar cells through the use of fins during forced air cooling to enhance the heat transfer between the inlet and the outlet air-flow. The proposed modules also establish the thermodynamic characteristic curves of the PV/T performance. Evaluations are carried out for the effect of fin configuration on the electrical and thermal behaviour of the proposed modules.

## Experimental set-up

The actual image of experiments devices, including the PV/T modules and the measuring instruments, was constructed as a fixed frame, as shown in fig. 1. Clear-sky experiments were conducted in October 2022 in the Solar energy laboratory at the Hungarian University of Agriculture and Life Sciences, Hungary.

The layers of the proposed modules in this study are illustrated in fig. 2. The copperplate absorber is fixed by a special Tedlar to the PV module. A single-pass air channel is structured next to the copperplate. Three different configurations of an absorber were investigated in this study. Figure 3 shows these three shapes of an absorber.

Two different configurations of fins were mounted to the absorber, vertical and louver-shaped fins, the height of the fins was 0.05 m, and the area was 0.2 $m^2$ with 1.5 mm thickness. Both shapes of fins have the same dimensions to reach scientific comparison among presented absorbers.




Air-cooled PV/T with vertical fins (PV/T-aVF) and without fins (PV/T-a)
Air-cooled PV/T with louver fins PV/T-aLvF

**Figure 1. The image of the proposed system of PV/T**

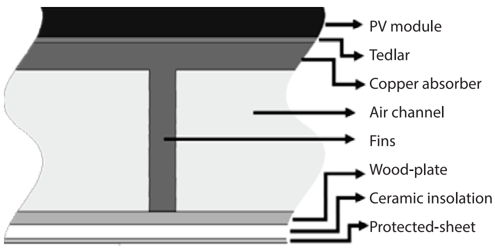



**Figure 2. Layers of proposed PV/T module**

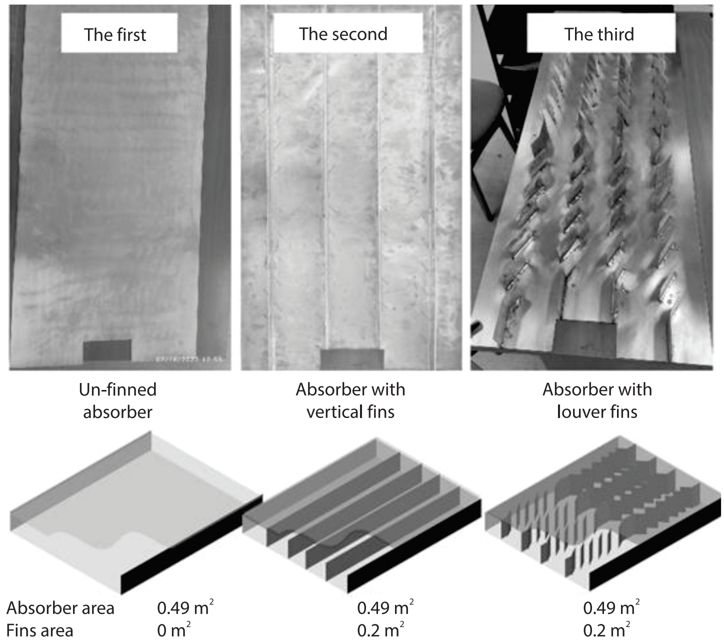



**Figure 3. Actual image of the proposed system of PV/T**

Thermodynamically, as reported by Cengel [28], the fins area represents all fin side surfaces in contact with air-flow within the air channel, which is added to the absorber area.

According to the literature, as the louvre angle gets bigger, the air-flow distance in the heat exchanger enlarges, and the heat transfer keeps increasing. The heat enhancement is lower in the case of a louvred fin with a low louvre angle [29]. Accordingly, this study chooses 28.5° as the slope angle of the louver-shaped fins used in several kinds of literature [27]. The other values of the parameters for creating louvered-shaped fins were consistent with the geometries stated by Atkinson *et al*. [30].

The tests were conducted in the empty, vertical, and louver fin configurations, and the outcomes were evaluated comparatively. An axial AC fan (Xpelair-XIM) is utilised to draw the air through single-pass channels under the modules. The airspeed was measured to be 0.915 m/s, 1.24 m/s, and 1.29 m/s for the third, second, and first modules using the ALMEMO-FVAD-35 sensor.

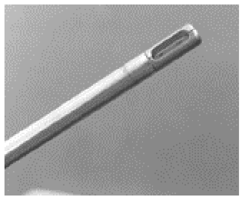
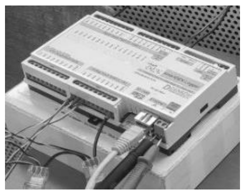
A polycrystalline photovoltaic module, which has technical specifications in tab. 1, produced by Solarex's Megamodule™ series, was utilised during the experiments.

**Table 1. Specifications of the PV module used in this study**

| Details | Value |
|---|---|
| Voltage at $P_{max}$ ($V_{mp}$) | 17.1 [V] |
| Current at $P_{max}$ ($I_{mp}$) | 3.5 [A] |
| Maximum power ($P_{max}$) | 60 [W] |
| Short-circuit current ($I_{sc}$) | 3.8 [A] |
| Open-circuit voltage ($V_{oc}$) | 21.1 [V] |
| Temperature coefficient of power | – (0.5 ±0.05) [ %°C$^{-1}$] |

This study utilised apparatuses and sensors to measure and collect the data during the experiment that was held in the solar energy laboratory, see tab. 2. The uncertainties of each instrument and the purpose of use are indicated in tab. 2.

**Table 2. Details of apparatus utilised in this study**

| Apparatus | Measurement accuracy | Used for | Photo of device |
|---|---|---|---|
| ALMEMO-Ahlborn-2890/9 | Depends on the digital ALMEMO-Ahlborn-2890/9 sensors used | Recording data |  |
| ALMEMO-ZA-9020-FS (K-type) | ±0.5 °C | Temperatures of:<br>– outlet air<br>– inlet air<br>– ambient<br>– cells<br>– fins |  |
| ALMEMO-FVAD-35 | 0.08 m/s | Air speed |  |
| MessKopF3.3 pyranometer | <±10 W/m$^2$ | Solar radiation |  |
| DENKOVE-SMART-32channel | ±0.5%<br><br>±0.5% | Modules voltage<br><br>Modules current |  |

### *Experimental error analysis*

Due to the labour conditions and experiment situation, the measurements obtained may be affected in addition the accuracy of the instruments. Thus, uncertainty analysis is essential to know how accurate the experience measurement is. Holman [31] presented the common equation calculate the experimental error:

$$Un_R = \left[\left(\frac{\partial R}{\partial x_1}\right)^2 Un_1^2 + \left(\frac{\partial R}{\partial x_2}\right)^2 Un_2^2 + \cdots + \left(\frac{\partial R}{\partial x_n}\right)^2 Un_n^2\right]^{1/2} \tag{1}$$

The thermal power, the electrical power, the thermal efficiency, and the electrical efficiency of the PV/T unit were evaluated using this method. Calculations of this equation for the previous parameters are listed in tab. 3.

**Table 3. Values of uncertainties**

| Parameters | Thermal power | Electrical power | Thermal efficiency | Electrical efficiency |
|---|---|---|---|---|
| Values | ±0.55% | ±0.63% | ±0.763% | ±0.96% |

## Thermodynamic analysis

The study system is a steady-state, known as control volume, and air channels were cooled using air-flowing via AC axial fan.

Thermodynamically, mass entering or leaving a control volume at a time interval equals the difference between the inlet and outlet of the system, which illustrates this mass balance:

$$\dot{m}_{\text{int}} - \dot{m}_{\text{out}} = \Delta\dot{m}_{CtV} \tag{2}$$

where $\dot{m}_{\text{int}}$ and $\dot{m}_{\text{out}}$ are the air mass-flow rate of the entering and leaving ducts, respectively, and $\Delta\dot{m}_{\text{CtV}}$ is the difference of air mass-flowrate between the inlet and outlet of the system.

### *Energy analysis*

The following equation calculates the gained heat amount of the PV/T modules during air-flowing through the channels, representing the module's thermal power:

$$Q_u = \dot{m}Cp\left(T_{\text{out}} - T_{\text{int}}\right) \tag{3}$$

where $\dot{m}$, $Cp$, $T_{\text{int}}$, and $T_{\text{out}}$ are the mass-flowrate of the flowing air, specific heat, inlet temperature and outlet temperature, respectively. The electrical energy that converts the solar radiation incident on the PV cells into DC voltage and current within the common formula is one of the PV/T outcomes [32]:

$$P_{\text{el}} = I_{\max}V_{\max} \tag{4}$$

The following balanced equation represents the energy gained from the hybrid solar collector:

$$P_{\text{out}} = Q_u + P_{\text{el}} = \dot{m}\,Cp\left(T_{\text{out}} - T_{\text{int}}\right) + I_{\max}V_{\max} \tag{5}$$

where $I_{\max}$ and $V_{\max}$ are DC current and voltage at the maximum PowerPoint, the input energy was investigated to achieve the outcomes:

$$P_{\text{in}} = GA_{\text{rig}} \tag{6}$$

where $G$ and $A_{\text{rig}}$ are the solar radiation and area of the experimental rig.

### *The PV/T modules efficiencies*

The electrical performance evaluation of the PV modules can be given by an electrical efficiency expression, which represents the ratio of the output power as electrical to the input power as solar radiation and can be calculated [33, 34]:

$$\eta_{\mathrm{el}} = \frac{P_{\mathrm{el}}}{P_{\mathrm{in}}} = \frac{I_{\max} V_{\max}}{G A_{\mathrm{PV}}} \tag{7}$$

Besides, Wu *et al.* [35] and described the thermal efficiency of the air-cooled PV/T modules in the equation as a ratio of the output power as a useful heat power to the input power as solar radiation:

$$\eta_{\mathrm{th}} = \frac{Q_u}{P_{\mathrm{in}}} = \frac{\dot{m} Cp \left(T_{\mathrm{out}} - T_{\mathrm{int}}\right)}{G A_{\mathrm{PV/T}}} \tag{8}$$

The comprehensive performance of the PV/T module can be calculated by eq. (9), which is the overall summation of the electrical and thermal performances [34]:

$$\eta_{\mathrm{th}} = \eta_{\mathrm{th}} + PF\,\eta_{\mathrm{el}} \tag{9}$$

## Results and discussions

This study compares the efficiency of the proposed solar air-cooled PV/T module with two different fin configurations and without fins under steady-state circumstances. This study was conducted under weather conditions in Godollo, Hungary, within latitude and longitude 47.5995007, 19.4356256. Figure 4 describes the ambient temperature distribution during the experiment period. The maximum and average ambient temperature values are 23 °C and 21 °C, respectively. The experiments were conducted on October 17, the sky was clear, and the solar radiation distribution is illustrated in fig. 5. The maximum and average solar radiation values are 906 W/m$^2$ and 821 W/m$^2$, respectively.

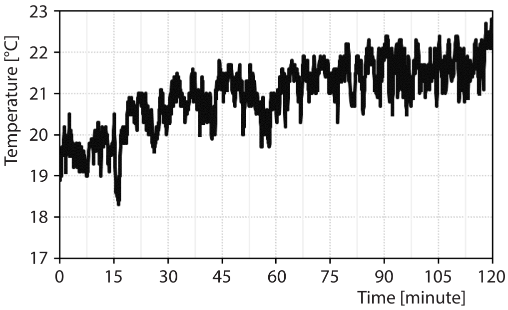



**Figure 4. Ambient temperature of the study site**

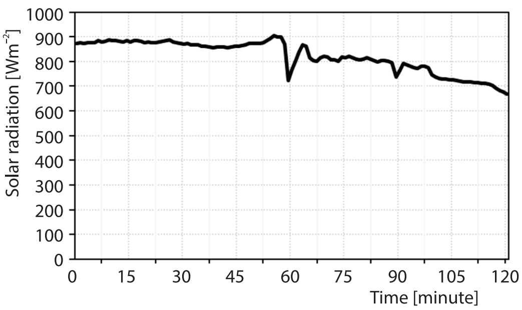



**Figure 5. Solar radiation distribution of the study site**

The temperature difference between the inlet and outlet of the forced air-flowing through the channels of the presented PV/T modules is shown in fig. 6. Instant, a significant increase in a temperature difference ($T_{\mathrm{out}} - T_{\mathrm{int}}$) for the third module (louver-fins) compared to the first (un-finned) and second (vertical-fins). The first module and the second module are close to each other. By more than 48% and 56%, the third module is superior to the first and second, respectively.

As the thermal power is a function of the temperature difference between the outlet air-flow rate temperature and the inlet flowrate temperature ($T_{\mathrm{out}} - T_{\mathrm{int}}$), based on the results specified in fig. 6, fig. 7 illustrates the thermal power of the three modules. It is clearly noted the enhancement of the thermal behaviour of the PV/T module that employed the louver-shaped fins compared to the other modules. The average daily value of the thermal power of the three modules is 139, 166, and 320 W for the first, second and third modules, respectively.

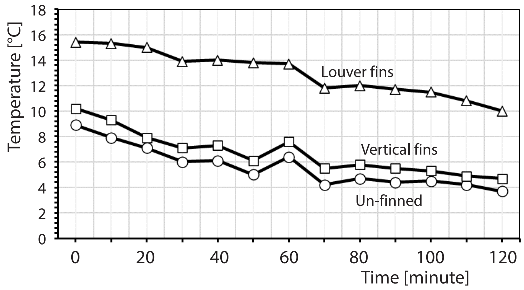



**Figure 6. The temperature difference of the presented modules**

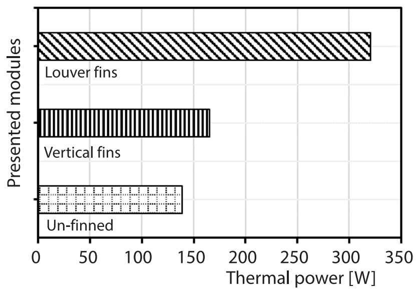



**Figure 7. Thermal power of the presented modules**

Figure 8 illustrates the thermodynamic characteristics curves of the three proposed PV/T systems for various copper absorber configurations. Thermal efficiency is obtained for the systems and plotted against the value of the $(T_{\text{int}} - T_{\text{a}})/G$. Maximum heat yield from an air-cooled PV/T collector is shown on these curves for various absorber designs, and the inlet air temperatures varied (18 °C, 19 °C, 20 °C, 21 °C, and 22 °C). The maximum thermal efficiency achieved from the PV/T module corresponds to the use of louver fins within an absorber. In addition, the system's efficiency is reduced when the air entering the system is at a higher temperature than when the air entering the system is at a lower temperature. As the temperature of the incoming air increases from 18-22 °C, the values of $(T_{\text{int}} - T_{\text{a}})/G$ rise from 0-0.007 °Cm$^2$/W.

The performance of the three systems used in this study is clarified by the electrical and thermal efficiencies, as illustrated in fig. 9. The PV/T module that employs the louver fins has the highest performance compared to the other investigated PV/T module. The average electrical and thermal efficiencies for the modules with louver fins, vertical fins and un-finned are 7.34%, 69%, 6.98%, 36.6%, and 6.53%,33.8%, respectively.

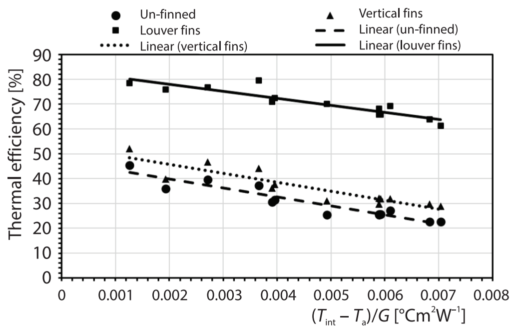



**Figure 8. Thermodynamics characteristic curves of the proposed PV/T systems**

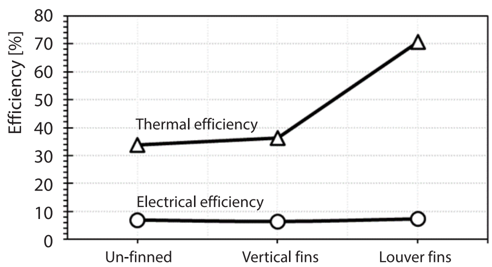



**Figure 9. Electrical and thermal efficiencies for presented solar PV/T systems**

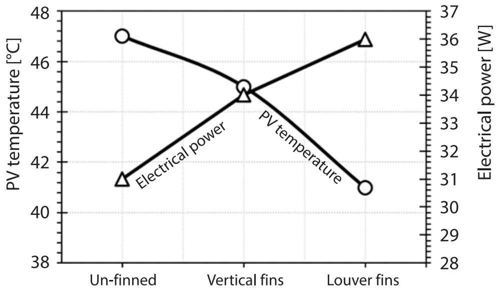



**Figure 10. Electrical generation *vs.* the PV temperature of the examined modules**

As a result of the heat extraction, the electrical power generation increases accordingly, with PV temperature decreasing. fig. 10 illustrates the imaging of the productivity behaviour among the study modules. The average electrical power and PV temperature values for the modules with louver fins, vertical fins and un-finned are 36.4 W, 40.6 °C, 34 W, 45 °C and 31 W, 47 °C, respectively.

Aside from copper's high heat capacity, the low airspeed of about 0.9 m/s combined with the unique shape of the louvre fins allows for significant heat transfer from the fins to the air-flow. Thus, this leads to dramatic temperature differences between the outlet and the inlet air-flow, and this difference represents the dependent value of the thermal efficiency.

## Conclusions

This study investigates three configurations of an air channel based on the fixing of two shapes of fins (vertical and louver) and the last without fins to the copper plate mounted under the polycrystalline PV module. The main objective of this study was to enhance the heat transfer between the inlet and outlet air in the channel under the PV. Additionally, the performance of the three configurations is performed. Based on the result of the enhancement conducted in this study, the main findings have been summarised as follows.

- The temperature difference between inlet and outlet air was enhanced in the system with lover fins by 6.29 °C compared to the vertical fins unit and by 7.4 °C compared to the un-finned unit.
- The thermal efficiency of the unit with lover fins was enhanced by 48% and 54% compared to the vertical fins and unfinned units.
- By 2.7% and 4.3%, the electrical efficiency of the unit with lover fins was increased compared to the vertical fins and unfinned units.
- The results between the two fin configurations examined in this study lead to the fact that the area needed by the copper vertical fins to reach the performance of the louver fins is higher by more than half. Thus, louver fins are better than vertical fins with the same surface area.

Overall, the presented PV/T module held the unique idea of this study, which confirms how the louvred fins can increase the air-flow length. Consequently, this mechanism holds a long time for heat to move from the fins and absorber to the air-flow. For further experiments, it is possible to use aluminum metal instead of copper to make a comparison study for their performance and economic parameters. Additionally, it is more significant to take into consideration the amount of rejected heat by the PV and PV/T modules and the percentage of the emissions to the surroundings.

## Acknowledgment

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## Nomenclature

$A$ – area, [m$^2$]
$G$ – global radiation [Wm$^{-2}$]
$I$ – current, [A]
$\dot{m}$ – air mass-flow rate, [kgs$^{-1}$]
$P$ – power [W]
$Q_u$ – useful thermal power, [W]
$R$ – parameter of uncertainty function
$T$ – temperature, [°C]
$Un$ – uncertainty
$V$ – voltage, [V]
$x$ – variables of uncertainty function

*Greek symbols*

$\partial$ – partial

$\eta$ – efficiency, [%]

*Subscripts*

a – ambient
CtV – control volume
el – electrical
int – inlet
max – maximum power point
out – outlet
th – thermal
Δ – change

*Acronyms*

PF – packing factor
PV/T – photovoltaic thermal module

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