# PVT

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**Submission date:** 11-Jan-2023 09:44AM (UTC+0800)
**Submission ID:** 1991003574
**File name:** l_and_Sustainability_Index_of_Photovoltaic_Thermal_Solar_Air.pdf (1.25M)
**Word count:** 3875
**Character count:** 20954

International Journal of Heat and Technology
Vol. 40, No. 3, June, 2022, pp. 743-748
Journal homepage: http://iieta.org/journals/ijht

# Improvement Potential and Sustainability Index of Photovoltaic Thermal Solar Air Collector

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https://doi.org/10.18280/ijht.400312

**Received:** 13 May 2022
**Accepted:** 18 June 2022

***Keywords:***
*improvement potential, sustainability index, photovoltaic thermal, indoor, outdoor*

**ABSTRACT**

Photovoltaic thermal (PVT) system is the future technology that will help in decreasing carbon emissions because this PVT technology generates electricity and thermal simultaneously. The advantage of PVT technology is that it is clean, saves space and cost, et cetera. This research applies an experimental approach in the laboratory and outdoors. The objective of this comparison is to generate real and controlled data and parameters. The analysis conducted is the improvement potential and sustainability index analysis. Both analyses are rarely conducted in PVT technology studies. Mass flow rate used was 0.01 kg/s-0.05 kg/s and sun intensity used was 800 W/m$^2$. The result indicated the impact of mass flow rate on improvement potential and sustainability index. The higher the mass flow rate, the lower the improvement potential decreased; the higher the mass flow rate used, the higher the sustainability index increased.

## 1. INTRODUCTION

The awareness of utilizing clean and green energy has risen and taken very seriously in recent years. In order to achieve a better future and living standard, the United Nations has declared that 2030 is the year of clean and affordable energy [1, 2]. The issue of global warming keeps on being discussed by all developing and developed nations. It is estimated that the Earth's temperature will increase by an average of 1.5°C until 2030 and will continue to rise; in 2050, it will rise to 2°C [3]. Therefore, to reduce the rate of global warming, it is proposed to increase in implementation of renewable energy. The most abundant source of energy is solar energy. Because solar energy can be obtained anywhere and anytime as long as the sun still shines. Only about 51% of the available solar energy on Earth can be utilized [4, 5].

First, solar panel technology or photovoltaics can generate electricity, and solar collector technology produces thermal energy widely used in society. Second, the two technologies can be combined into photovoltaic thermal or PVT systems. The solar collector installed on the PVT system can be used to absorb or cool down solar panels (PV) through the air, water, or other mediums [6, 7]. Installing a solar collector can increase power efficiency and decrease solar panel temperature when the solar panel hits its maximum temperature. If the solar panel temperature is constantly at the maximum temperature, it will damage the solar panel [8, 9]. Additionally, solar panels (PV) alone need much space; in contrast to a system that combines PV and solar collector technology, it will reduce installation space and is easy to install on the roof or other places [10]. Likewise, in terms of cost, installing this technology is very cost-effective. Installing a PVT system is cheaper than installing it separately. Moreover, we get maximum energy efficiency [11]. Therefore, PVT technology has become very useful in increasing the efficiency of electricity, thermal, and overall PVT systems.

Flat plate collectors are collectors that are widely used in heat transfer applications. A flat plate collector has its own advantages and excellent performance. Implementing a flat plate collector in the PVT system can predict long-term heat efficiency, as conducted by Klein and Duffie [12]. The measured heat capacity temperature influences the efficiency of the flat plate solar collector. A study of glassless and flat plate PVT collectors was carried out by Calise et al. [13] by applying an experimental and numeric approach. They also consider the incoming fluid or liquid temperature because it affects thermal and electrical efficiency [14-16]. Accordingly, a flat plate collector can increase thermal and electrical performance in a PVT system. The most apparent function of a flat plate collector is that it can increase the speed of heat transfer rate in solar panels and reduce thermal resistance in PVT systems.

In a recent analysis, the enviroeconomic and exergoeconomic have been analyzed by Tripathi et al. [17] for PVT system with concentrator collector. The same examinations of the PVT system were completed by Tiwari and Shyam [18] with a semi-transparent module photovoltaic. Shyam et al. [19] evaluated an environmental evaluation with energy and exergy approach analysis for cooling PVT by water collector. And Tiwari [20] designed a mixed-mode greenhouse PVT system with environmental and exergoeconomic analysis. The use of aluminum plate for cooling PVT with conventional and spiral stations has been conducted by Salem et al. [21]. Energy and exergy efficiency obtained 59.3-92% and 11.1-13.5% correspondingly. The electrical and thermal performances are 17.7-38.4% and 31.6-57.9% correspondingly. In a water-cooled PVT system, Kazanjari et al. [22] evaluated the energy, exergy, and thermal efficiency of PVT with nanofluid. The energy efficiency of the solar panels is 10-13.7%. and energy thermal and exergy efficiency of PVT system are 55% and 15% respectively. Photovoltaic thermal with based nanofluid has been designed by Lari and Sahin [23]. Energy efficiency informed 13.2% of PV energy.

This study implements exergy analysis to calculate and measure PVT systems' effective and efficient energy rate. Using Exergy helps us design and determine the location, material, and PVT system accessories that are about to be developed. Exergy analysis can be interpreted as the maximum amount of performance generated in the PVT system when it reaches the equilibrium point in the environment [24]. The ratio between the outgoing Exergy and the incoming Exergy represents the exergy efficiency in the PVT system, as shown in Table 1 [25]. The relationship between the concept of exergy efficiency and exergy destruction makes an Improvement Potential (IP) concept. This IP concept is very important to analyze the systems and processes efficiently system [26-28].

Many researchers in their research have carried out energy and exergy analyses in PVT systems. Nonetheless, improvement potential and sustainability index analysis have rarely been conducted. Therefore, this article aims to fill the scientific literature gap. Improvement potential is the approach to applying exergy efficiency in PVT systems and is expected to identify potential improvements in PVT systems heading to how to save sustainable energy.

## 2. METHOD

An air collector system (PVT) using a flat plate collector was designed and installed at the National University of Malaysia (UKM) by installing monocrystalline solar panels 100 Watt with outdoor and indoor investigation. The indoor evaluation was created with the solar simulator of 45 halogen lamps. The circuit connection diagram with indoor evaluation is shown in Figure 1. The solar panel size is 0.52 $m^2$. The simple design of this PVT system is that the solar panel is positioned above, below the solar panel (PV) is an air duct with a 0.04 m size, and the flat plate is made of aluminum to absorb residual heat from the solar panels. The function of the air duct is to cool down the solar panels, as shown in Figure 2 below.

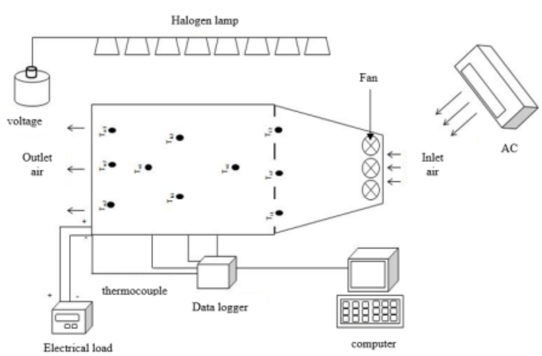


**Figure 1.** The circuit connection diagram of PVT system air collector with indoor evaluation

The experiment was conducted within four weeks at the National University of Malaysia in Bangi. The outdoor evaluation as shown in Figure 3. The climatic conditions at that time were selected as sunny. The sun intensity selected was 800 W/$m^2$. The mass flow rate or the wind speed is from 0.01 kg/s to 0.05 kg/s. the measurement tool for wind speed is anemometer as shown in Figure 5. The measuring equipment selected to obtain the appropriate and the selected data should be in good condition and calibrated. The measurement tool for sunlight radiation was a pyranometer as shown in Figure 4. Subsequently, the data logger with thermocouple K-type sensors was used for measuring solar panel temperature and flat plate collector temperature as shown in Figure 6.

The most important data in this experiment is the sunlight intensity and the inlet and outlet air temperature from the PVT system. We can calculate the PVT system's electricity and thermal collector efficiency by obtaining the above data. Afterwards, we can calculate exergy efficiency input, output, and destruction. In this research, the subject is the PVT system's improvement potential and sustainability index value, as shown in the following Table 1.


**Figure 2.** Schematic of photovoltaic thermal with flat plate air collector

**Figure 3.** Outdoor investigation of photovoltaic thermal air collector

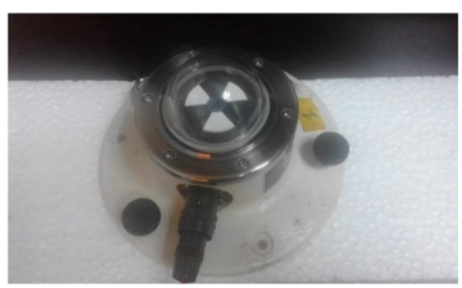

**Figure 4.** A pyranometer for sunlight radiation

**Figure 5.** Anemometer for wind speed

**Figure 6.** Data Logger ADAM-4019 for temperature data

**Table 1.** Parameters and equation of improvement potential and sustainability index [29, 30]

| Parameters | Equations |
|---|---|
| Improvement potential | $I\_Potential = (1 - \eta_{exergy}) Exergy_{destruction}$ |
| Sustainability Index (SI) | $S\_Index = \dfrac{1}{1 - \eta_{exergy}}$ |
| Exergy efficiency | $\eta\_exergy = \dfrac{Ex_{output}}{Ex_{input}}$ |
| Exergy of a PVT system | $Ex_{pvt} = Ex_{thermal} + Ex_{pv}$ |
| Exergy PV | $Ex_p = \eta_p AS$ |
| Exergy Thermal | $Ex_{th} = \dot{m}C(T_o - T_i)\left[1 - \dfrac{T_a + 273}{T_o + 273}\right]$ |
| Output exergy | $\sum(Ex_{th} - Ex_p) = \sum Ex_i - \sum Ex_d$ |
| Input exergy | $Ex_i = ANI\left[1 - \dfrac{4}{3}\left(\dfrac{T_a}{T_s}\right) + \dfrac{1}{3}\left(\dfrac{T_a}{T_s}\right)^4\right]$ |
| Exergy Destruction | $\sum Ex_{destruction} = \sum Ex_i - \sum(Ex_{th} - Ex_p)$ |

## 3. RESULTS AND DISCUSSIONS

Figure 7 displays the evaluation of improvement potential for photovoltaic thermal air collectors between indoor and outdoor experimental methods. The PVT solar air collector generated 356.60-368.08-Watt improvement potential with the indoor setup and 351.92-368.84-Watt improvement potential performance for the outdoor setup at 0.01-0.05 kg/s mass flow rate. After evaluation, the best improvement potential of photovoltaic thermal solar air collector is 368.08 Watt at 0.01 kg/s mass flow rate with an outdoor experimental investigation. The smallest improvement potential is 351.92 Watt at a 0.05 kg/s mass flow rate with an indoor experimental investigation.

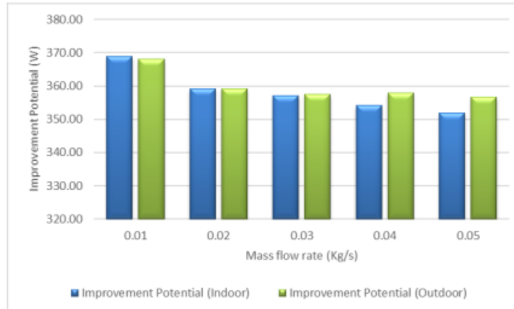


**Figure 7.** Improvement potential of photovoltaic thermal solar air collector indoor and outdoor investigation

Figure 8 displays the evaluation of the sustainability index between indoor and outdoor experimental investigation. These indoor and outdoor approaches used the 0.01 – 0.05 kg/s mass flow rate range by selecting 800 W/m$^2$ solar intensity. The performance of the sustainability index using the indoor experimental investigation is 1.147-1.174 and for the outdoor investigation is 1.148-1.166. the best performance of the sustainability index result is 1.174 using an indoor experimental investigation. Moreover, the lowest performance result is 1.147 using the indoor investigation.

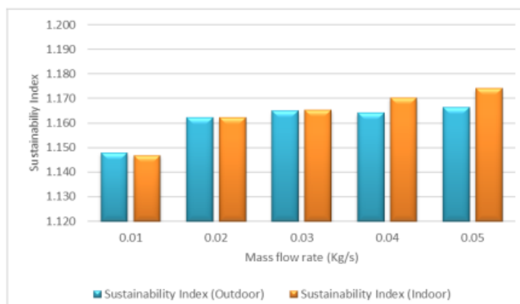


**Figure 8.** Sustainability index of photovoltaic thermal solar air collector with the indoor and outdoor investigation

Figure 9 shows the correlation between improvement potential and destruction exergy with mass flow rate using indoor and outdoor evaluation. The mass flow rate ranges from 0.01 kg/s to 0.05 kg/s, while the exergy destruction produced ranges from 415.90 Watt to 422.51 Watt. It implies that the higher the mass flow rate value, the lower the destruction exergy value. Otherwise, when the value of mass flow rate increases, it indicates that IP and destruction exergy strongly correlates with mass flow rate.

Table 2 displays the performance of the sustainability index and improvement potential between indoor and outdoor approaches for the photovoltaic thermal solar air collector. The error average of the sustainability index is 1.89% between indoor and outdoor approaches, or a 98.11% accuracy. The error average of improvement potential for the PVT system solar air collector is 0.53% or a 99.47% accuracy between indoor and outdoor approaches. The sustainability index and improvement potential between an indoor and outdoor experiment make a good result, as shown in Table 2.

Table 3 shows the sustainability index and improvement potential evaluation using the previous studies. In previous studies or exposed literature, the sustainability index and improvement potential for the PVT system are very rare experiment studies. The sustainability index is just two datasets by Caliskan [31] and Fudholi et al. [32]. Caliskan [31] has analyzed the solar collector with a 1.0073 sustainability index. Furthermore, Fudholi et al. [32] has conducted the PVT system's experiment and theoretical evaluation by applying the 1.15-1.17 sustainability index. This recent study indicated that the improvement potential and sustainability index result are suitable to previous authors.

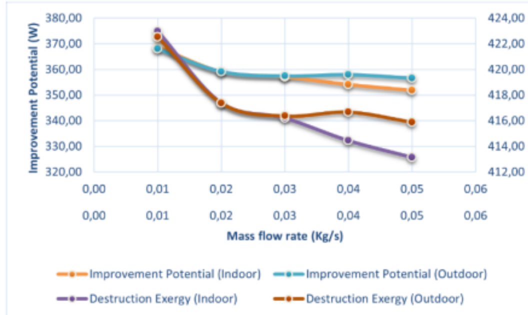


**Figure 9.** Improvement potential and destruction exergy of photovoltaic thermal solar air collector with the indoor and outdoor investigation

**Table 2.** Sustainability index and improvement potential

| Mass flow rate (Kg/s) | S (W/m²) | Improvement Potential (W) | | | Sustainability Index | | |
|---|---|---|---|---|---|---|---|
| | | Indoor | Outdoor | % Error | Indoor | Outdoor | % Error |
| 0.01 | 800 | 368.84 | 368.08 | 0.20 | 1.147 | 1.148 | 4.70 |
| 0.02 | 800 | 359.17 | 359.15 | 0.01 | 1.162 | 1.162 | 0.61 |
| 0.03 | 800 | 357.14 | 357.42 | 0.08 | 1.165 | 1.165 | 0.03 |
| 0.04 | 800 | 354.14 | 357.95 | 1.07 | 1.170 | 1.164 | 2.26 |
| 0.05 | 800 | 351.92 | 356.60 | 1.31 | 1.174 | 1.166 | 1.83 |
| Average | | | | 0.53 | | | 1.89 |

**Table 3.** The improvement potential and sustainability index compared to the previous studies

| Solar collector | Efficiency exergy (%) | Improvement potential (Watt) | Sustainability Index |
|---|---|---|---|
| Water collector [31] | 0.73 | NA | 1.0073 |
| Fin and without fins [32] | 15-28 | 740 – 1070 | NA |
| Solar drying [33] | NA | 0 – 17 | NA |
| Solar drying for seaweed [34] | 1-93 | 0.3 – 630 | NA |
| Solar drying for chili [35] | 43-97 | 0.135 – 47 | NA |
| Solar drying for palm [36] | 10-73 | 8 – 455 | NA |
| Water collector [37] | 12.0-14.0 | 98 – 404 | NA |
| ∇-collector [38] | 12.89-13.36 | NA | 1.15 – 1.17 |
| **Recent study** | 13-15 | 351.92-368.84 | 1.147 – 1.174 |

## 4. CONCLUSIONS

The air collector PVT system has been evaluated in indoor and outdoor settings. The evaluated analysis is the improvement potential and sustainability index. The mass flow rate value is from 0.01 kg/s to 0.05 kg/s and the sunlight intensity selected is 800 W/m$^2$. The result analysis of improvement potential in indoor and outdoor settings is 351.92-368.84 watt. Meanwhile, the sustainability index value in indoor and outdoor settings is 1.147-174. This research result has been compared to the previous research and indicated a close similarity. This research result is expected to be the reference and foundation for developing better PVT system technology.

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