IOP Conf. Series: Earth and Environmental Science **268** (2019) 012071 doi:10.1088/1755-1315/268/1/012071

Performance of Solar Air Collector-Thermoelectric Hybrid System

W E Ewe, A Fudholi, C H Yen, N Asim and K Sopian

Solar Energy Research Institute, National University of Malaysia, Malaysia
E-mail: P97455@siswa.ukm.edu.my, ksopian@ukm.edu.my, a.fudholi@ukm.edu.my, nilofarasim@ukm.edu.my, hoyyen.chan@ukm.edu.my

Abstract. Solar collectors are technologies which using sunlight to collect heat energy. In this study, solar air collector-thermoelectric hybrid systemis designed and constructed. Performance testing is conducted in the lab. The size of this hybrid system is 97.5 × 59 × 12 cm. The manipulating factor is the mass flow rate which is fixed at 0.033, 0.0385, 0.044, 0.0495 and0.055 kg/s. The intensity of solar radiation is set at 700 W/m^2. Maximum temperature change (T_o -T_i) reaches 7.5 ºC while maximum temperature change (T_{back} - T_{hollow}) reaches 16.7 ºC. Maximum thermal efficiency of this hybrid system reaches 79.0% at the highest mass flow rate of 0.055 kg/s. The maximum electrical efficiency reaches 5.3% at the lowest mass flow rate of 0.033 kg/s. Maximum overall efficiency reaches 79% at the highest mass flow rate. The hybrid system has better thermal efficiency than a stand-alone solar air collector.Due to the increased overall efficiency, the proposed hybrid system is anticipated to promote wider application of thermoelectric hybrid system.

1. Introduction

Limitation of fossil fuels is a main issue for generation of energy in the era of development[1]. Therefore, solar energy which is an essential, last-longing and clean energy holds an important role to replace the fossil fuels to generate energy. One of the application of solar energy is solar collector which traps heat energy for heating and drying purpose[2]. The most popular type of solar collector is flat plate due to easy built and installation. Thermoelectric (TE)is a device that converts heat to electric by using Seebeck and Peltier effect[3]. In order to collect heat and electrical energy in the same time, solar air collector-thermoelectric hybrid system is built. TE is introduced in the hybrid system as it can operate under low heat energy source such as waste heat and increase the heat transfer rate of the solar air collector in order to improve the energy yields per unit surface.Based on knowledge, less research is done on this hybrid system, so the objective of this research is to promote wider application of thermoelectric hybrid system by investigating the effects of thermoelectric on the thermal efficiency of a flat plate solar air collector.

2. Materials & Methods

2.1 List of components & apparatus

TEC (Thermoelectric cooler) is attached at the bottom of Al absorber plate as shown in figure 1 & 2 below with different sides of view. Table 1 below shows the components and apparatus used and their specifications.

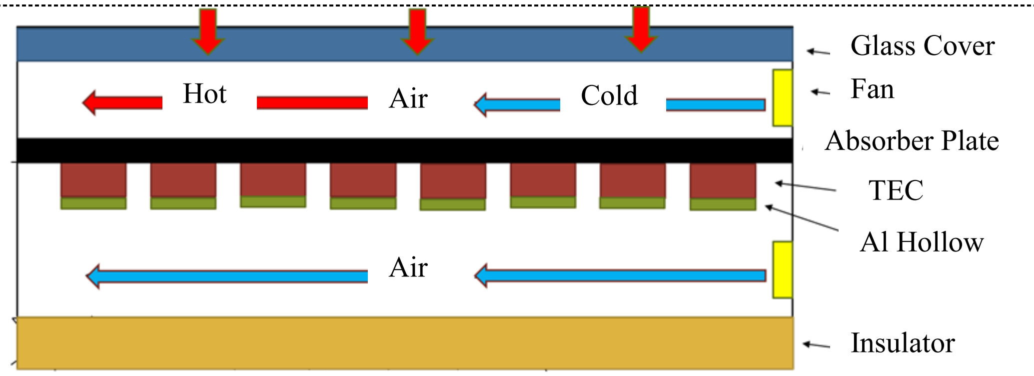

Figure 1. Cross-sectional view of the hybrid system.

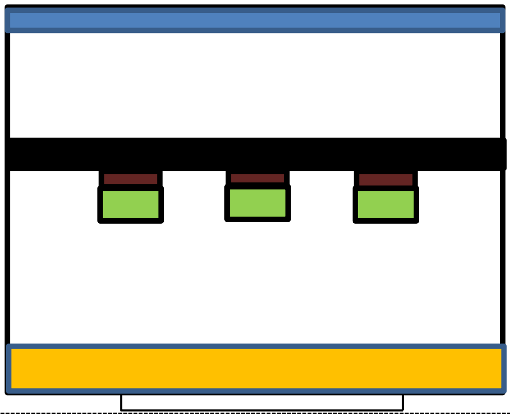

Figure 2. Front view of the hybrid system

Table 1: Specification of components and apparatus

Components & Apparatus	Specification
Glass Cover	97 cm × 55 cm × 0.6 cm
Solar Collector	97.5 cm × 59 cm × 12 cm
Al absorber plate	97.5 cm × 55 cm
Al hollow	76 cm × 5 cm
Distance bet. Al hollow	7 cm
No. of Al hollow	3 unit
Type of insulator	Silicon rubber sponge
Pyrometer	EPPLEY model 8-48
Thermocouple	Type K
Data Logger	ADAM (Automated Data Acquisition Module)
Anemometer	Pro'sKit MT-4015
Thermoelectric module	TEC1-12706

IOP Conf. Series: Earth and Environmental Science **268** (2019) 012071 doi:10.1088/1755-1315/268/1/012071

2.2 Steps of experiment

The experiment was run in a lab. 36 TECs is placed evenly in a row between the Al hollow and absorber plate. 16 thermocouples is placed around the hybrid system, which are connected to ADAM. First, the speed of fan was set to be 2.0 m/s, measured by using anemometer. Next, the solar simulator was set to 700 W/m^2, measured by using the ADAM data logger. The solar simulator and the fan were turned on for 30 minutes before the experiment began as for the stabilization of the system, to obtain more accurate and precise data. After 30 minutes, the temperature of each thermocouple, light intensity of solar simulator, voltage generated by the thermoelectric was recorded every 10 seconds automatically by using ADAM. After one hour run of the experiment, the system was left to rest for another one hour. The experiment was repeated twice to obtain the mean data before started changing the speed of fan with 1.8 m/s, 1.6 m/s, 1.4 m/s and 1.2 m/s.

3. Data Calculation

Air mass flow rate (kg/s) can be obtained from air velocity and calculated by:

$$\dot{m} = \rho A V_{av} \tag{1}$$

Where:

ρ = density of air (kg/m^3)

A = cross-section are of the output channel (m^2)

V_{av} = Average air velocity on the channel output

The thermal efficiency can be calculated by:

$$\text{Thermal efficiency}, \eta_t = \frac{Useful\ Heat}{Heat\ Absorbed}$$

$$= \frac{\dot{m} C_p (T_0 - T_{i)}}{I A_c} \tag{2}$$

Where:

C_p = specific heat capacity of air (J/kg K)

I = light intensity (W/m^2)

$T_0 - T_i$ = temperature out – temperature in (K)

A_c = area of absorber plate (m^2)

The efficiency of the thermoelectric cooler can be calculated by:

$$\eta_{tec} = \frac{Electricital\ energy\ generated}{Heat\ energy\ absorbed\ by\ hot\ surface\ of\ TEC}$$

$$\eta_{tec} = \frac{(T_h - T_c)}{Th} \frac{\sqrt{1+ZT_m - 1}}{\sqrt{1+ZT_m} + \frac{T_c}{T_h}}$$

(3)

Where:

T_m	=	average temperature TEG (T_h+T_c)/2 (°C)
Z	=	material quality factor
$T_h - T_c$	=	temperature of hot surface – temperature of cold surface (of TEC)

According to the research[4]**,** type of Tec used in the experiment is TEC1-12706, where its z-value of 2119 K^{-1} is given for the calculation of the electrical efficiency. Referring to the research[5]**,** the overall efficiency of the hybrid system can be calculated using the following formula:

$$\eta_{\text{total}} = \frac{Qu + P_e}{SA} \times 100\%$$

(4)

Where:

Qu	=	Useful heat (W)
P_e	=	Electrical power generated (W)
S	=	Light intensity (W/m^2)
A	=	Surface area of solar collector (m^2)

4. Results & Discussion

Table 2: Mass flow rate versus thermal, electrical & overall efficiency

Mass flow rate, $\dot{m}$ (kg/s)	**Thermal Efficiency,** n_t (%)	T_{back} – T_{hollow}, (°C)	**Electrical Efficiency,** n_{tec} (%)	**Overall Efficiency,** n_{total} (%),
0.0330	66.4	16.7	5.3	66.4
0.0385	70.2	13.9	4.4	70.2
0.0440	72.5	12.4	3.9	72.5
0.0495	73.4	10.3	3.3	73.4
0.0550	79.0	9.2	2.9	79.0

The thermal efficiency increases from 66.4% to 79% when the mass flow rate increases from 0.033 kg/s to 0.055 kg/s. This is due to more heat transfer from the absorber plate to the fluid (moving air). $T_{back} - T_{hollow}$ value shows the temperature difference between the hot and cold surface of the TEC, where the hot surface attached to the back of absorber and the cold surface attached to the aluminium hollow. It reaches the lowest which is 9.2 ℃ when the mass flow rate reaches the highest. This is because high speed of flowing air will increase the rate of heat transfer from the absorber plate and Al hollow to the fluid. The electrical efficiency is directly proportional to the $T_{back} - T_{hollow}$ value while the overall efficiency is directly proportional to the mass flow rate. The electricity generated in this experiment is in the range of 10.383 mW to 13.434 mW. The difference between overall and thermal efficiency is very small, which is only approximately 0.003%. Generally, overall efficiency of hybrid system increases with increasing mass flow rate.

Comparison of overall efficiency between the hybrid system and previous studies is done. In previous research[6] which uses flat plate solar air collector with different shape of fins has obtained maximum thermal efficiency of 51.5%, which is 27.5% less than the hybrid system. Hence, the results above have shown that the thermal efficiency of solar collector can be enhanced by adding thermoelectric cooler.

5. Conclusion
A solar air collector-thermoelectric hybrid system is constructed and built. The higher the air mass flow rate, the higher the thermal efficiency of the hybrid system. The electrical efficiency is inversely proportional to the air mass flow rate. The overall efficiency of the system is 79% at 0.55 kg/s air mass flow rate. The highest electricity generated is 13.434 mW. TEC enhances the overall performance of a flat plate solar air collector

Acknowledgments
The authors would like to thank UKM for its funding (DPP-2018-002) and (GUP-2018-038).

References
[1] Sansaniwal SK, Sharma V, Mathur J. Energy and exergy analyses of various typical solar energy applications : A comprehensive review. *Renew Sustain Energy Rev*. 2017;(May):0-1. doi:10.1016/j.rser.2017.07.003
[2] Pandey KM, Chaurasiya R. A review on analysis and development of solar flat plate collector. *Renew Sustain Energy Rev*. 2017;67:641-650. doi:10.1016/j.rser.2016.09.078
[3] Ahiska R, Mamur H. A review: Thermoelectric generators in renewable energy. *Int J Renew Energy Res*. 2014;4(1):128-136.
[4] Shareef MH, Sajid A, Majeed AA, Abdul M, Adnan B. Efficiency Calculation of a Thermoelectric Generator. 2016;5(7):2015-2017.
[5] Al-Nimr MA, Tashtoush BM, Khasawneh MA, Al-Keyyam I. A hybrid concentrated solar thermal collector/thermo-electric generation system. *Energy*. 2017;134:1001-1012. doi:10.1016/j.energy.2017.06.093
[6] Chabane F, Moummi N, Benramache S. Experimental study of heat transfer and thermal performance with longitudinal fins of solar air heater. *J Adv Res*. 2014;5(2):183-192. doi:10.1016/j.jare.2013.03.001