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Development Of A Mathematical Model For A Photovoltaic/Thermal (PV/T) System Operating Under Different Environmental And Operational Conditions.

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Abstract
There is an increasing demand towards sources of clean energy due to increasing concerns about the environment as well as the rising prices of traditional power supplies. A recently developed type of solar conversion technique called hybrid photovoltaic/thermal (PV/T) converts incoming solar radiation onto both useable thermal and electrical power at the same time. This technology's fundamental result is a decrease in installed solar energy system performance with elevated irradiation levels due to the crystallized PV cells' negative thermal coefficient of power conversion efficiency. Furthermore, at least eighty percent of the sunlight that enters the system is lost and converted to heat by readily available solar PV panels, which raises the module's working temperature. These modules had relatively poor effectiveness of just more above 20%. The PV unit's heat exchanger connects to an external low-temperature fluids, such as either air or water, which is pumped through system to remove excess heat and cool the solar panel. The recovered heat could be utilized to low-temperature tasks such as drying for the agricultural and industrial industries or interior for air conditioning and heating within buildings. This investigation employed the steady-state thermal simulation of a PV/T airflow collector for solar energy to examine how different factors affected the system's efficiency. The mathematical model was constructed and verified using data from experiments. The findings show that whilst the design's parameters perform at their best, raising the air mass circulation rate would significantly improve the system's general efficiency.
Keywords: *Heat exchanger, power efficiency, thermal approach, PV panels, and PV/T collectors*

INTRODUCTION

Wherever humans reside and perform their jobs, energy is a vital component. An rise in energy consumption is strongly correlated with changes in a country's prosperity and level of living. The world's energy needs are rising quickly as a result of population expansion, industrialization, and the widespread and expanding usage of electrical devices. Human requirements are limitless, which is why the majority of countries in the world are now dealing with electricity shortages. This is especially important for emerging nations trying to catch up to industrialized nations' level of economic growth. Furthermore, the usage of traditional energy resources has resulted in the generation of Green House Gases (GHGs), which is the primary driver of climate change [1]. The energy industry must undergo significant changes in order to meet the increasing need for electrical power in an environmentally friendly manner. The ideal course of action in this respect, as well as for reducing inequality in countries that are developing wherein the bulk of people lack access to contemporary power sources, involves a massive shift to alternative sources of energy like solar energy. These resources may contribute more to this objective because of their intrinsic decentralized character. among the greatest solutions in this area being a hybrid photovoltaic/thermal (PV/T) systems, which transforms incoming solar energy throughout both thermal and electrical electricity. Approximately 5 to 20% for direct sunlight is turned into energy in a standard photovoltaic panel; the remaining 80% is transformed to heat as well as wasted [2]. By installing an exchanger for heat using alternatively water or ambient air to function as transfer of heat fluid within the photovoltaic (PV) module, that energy may be efficiently collected and utilized through a PV/T unit. This will lessen the issue of photovoltaic cells degrading from overheating and enable the PV element to function at its maximum electrical output. As a result, the system uses one surface region to produce both heat and electrical energy. This is very desired because it addresses the issue with "competing sky space," which arises when ordinary solar modules occupy an entire roof, providing not enough room available for additional solar energy sources. Since the start of the last century, investigation into PV/T systems had been conducted, and several system designs were created and examined by mathematical, computational, and practical means [3–9]. The goal of the majority of recent research on these kinds of systems is to identify the operating parameters and system layouts that would lead to higher thermally or electrical effectiveness [10–13]. The promise of hybrid technology throughout a range of different uses has been demonstrated by research to far [14]. In the present study, a steady state thermally model involving a PV/T the air collector with solar energy operating in its normal flow state has been developed, verified using data from experiments, and utilized to investigate how different parameters affected the system's efficiency.

Theoretical methodology

Figure 1 illustrates the components that make up the PVT/Air technology under investigation, which include a PV material, an annular air channel, an exterior absorber surface, as well as back insulating.

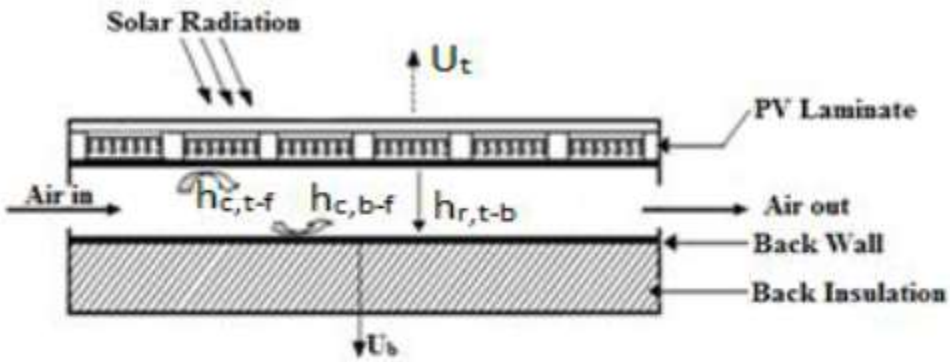

Fig. 1 PVT air collectors a cross-section view

Using ethylene vinyl acetate (EVA) as an adhesive, solar panel cells are additionally layered between a tedlar near the bottom with a covering of glass upon top to form the PV composite. The elements of the Photovoltaic lamination that transmit heat from the solar panels are depicted in Figure 2.

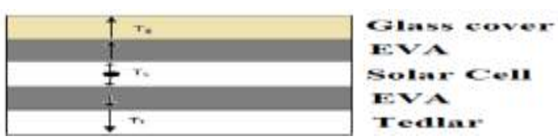

Figure 2: Heat transmission between the Photovoltaic laminate layers

The following are the energy equilibrium formulas for the different PV/T Air hybrid components:
glass cover

$$\propto_g G + P q_{up} = U_t (T_g - T_a) \qquad (1)$$

Ut : lose factor from the top surface
P : factor of packing
q_{up} : conducted heat transfer upwards
qup had been estimated as,

$$q_{up} = R_{up} (T_c - T_g) \qquad (2)$$

Where R_{up} is the upward thermal resistance and obtained as:

$$R_{up} = \frac{\left(L_{si}/_2\right)}{k_{si}} + \frac{L_{eva\,t}}{k_{eva\,t}} + \frac{L_g}{k_g} \quad (3)$$

Photovoltaic cell

The photovoltaic cells transform the energy they absorb into electrical power and heat. The generated heat is dispersed using the energy conservation formula below:

$$\tau_g \alpha_c G(1-\eta_{pv}) = q_{up} + q_{down} \quad (4)$$

q_{down} is the amount of heat conducted downwards f the solar cells and is given by:

$$q_{down} = R_{down}(T_c - T_t) \quad (5)$$

Where R_{down} is calculated as:

$$R_{down} = \frac{\left(L_{si}/_2\right)}{k_{si}} + \frac{L_{eva\,b}}{k_{eva\,b}} + \frac{L_t}{k_t} \quad (6)$$

Tedlar

$$\tau_g \alpha_t G(1-P) + Pq_{down} = h_{rt-b}(T_{tb} - T_b) + h_{ct-f}(T_{tb} - T_f) \quad (7)$$

Air Flow in the duct

$$\dot{m}C_p(T_o - T_i) = A_c[h_{c,t-f}(T_{tb} - T_f) + h_{c,b-f}(T_b - T_f)] \quad (8)$$

The back absorbing plate

Heat loss via the back insulating and heat acquired due to the duct's the flow of air distribute the heat obtained via the tedlar's bottom layer through the radiation heat transfer mechanism upon the bottom plates:

$$h_{r,t-b}(T_{tb} - T_b) = h_{c,b-f}(T_b - T_f) + U_b(T_b - T_a) \quad (9)$$

Where U_b is the back loss coefficient.

Each of the energy which is transferred to the behind surface of the conduit by radiation through its front side is thought to be well-insulated, making this surface its adiabatic and allowing convection to return the energy within the fluid.

$U_b = 0$ and $h_{c,t-f}$ can be considered equal to $h_{c,b-f}$ so that [14]

$$h_{c,t-f} = h_{c,b-f} = h_c \qquad (10)$$

The coefficient of convection heat transfer during laminar air flow across plates that are parallel within a duct may be found as [15].

thermal performance

The system's electrical as well as thermal efficiencies are used to describe its performance.

(i) Electrical Efficiency

The electrical efficiency was calculated as:

$$\eta_e = \eta_r(1 - \beta(T_c - T_r)) \qquad (13)$$

Where β is the temperature coefficient of the efficiency of a crystalline PV module and is equal to 0.0045, η_r is the reference efficiency of the PV cell at the reference temperature, T_r (usually 25 °C) [16].

(ii) Thermal Efficiency

The thermal efficiency of the system was calculated using the equation

$$\eta_{th} = \frac{Q_u}{G.A_c} \qquad (14)$$

Where Qu is the useful heat transferred to the air in the duct.

Results and discussion

1. Solar radiation effect

Figure 3 illustrates how irradiance affects the PVT/Air technique's thermal in addition to electrical efficiency. Three constant parameters included the temperature outside, wind speed, and air mass circulation rate: 27 C, 1.21 m/s, and 0.011 kg/m3/s. The findings show that while electrical efficiency falls with irradiance, thermal effectiveness rises. The higher temperature on the back surface and tedlar under high irradiance indicates that more energy will be transmitted to the airflow through the duct, thereby accounting for the rise in thermal performance. This rise in the photovoltaic cell temperature of operation with irradiation is the cause of the observed drop in efficiency of electricity.

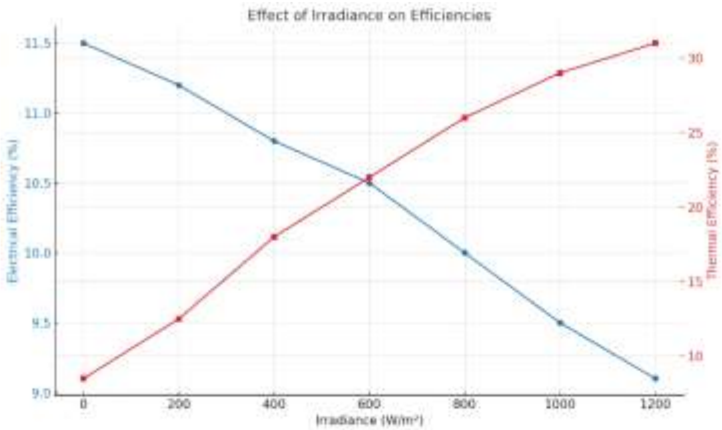

Figure 3: Effects of Irradiance on Electrical and Thermal Efficiencies

2. Effect of Tamb. On thermal performance

The influence of the surrounding temperature regarding the PV/T Air technique's efficiency are depicted in Figure 4. It has been shown that each of electrical as well as thermal efficiency decline with rising ambient temperature. This results from the fluid's entry temperature through the duct being extreme at ambient temperatures, which also leads to inadequate removal of heat from the solar photovoltaic cells.

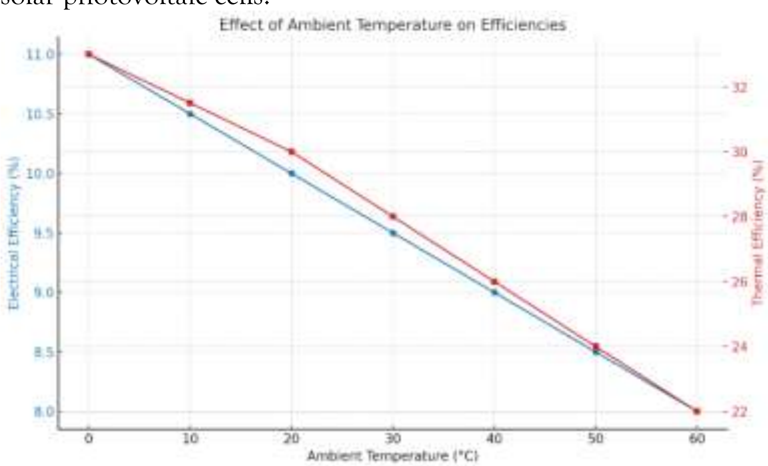

Figure 4: Effects of Ambient Temperature on Electrical and Thermal Efficiencies

3. Effect of length for collector

Variations were made to the Photovoltaic/T air collector's lengths while maintaining the same number of photovoltaic cells. Figure 5 illustrates that approach affects system performance. The thermal performance is found to grow when the collector's length grows, whereas the efficiency of the electricity is shown to decrease. The packing factor decreasing with length provides an explanation for this. Since a result, the total quantity of solar energy that the tedlar immediately absorbs through the intercellular gaps rises. As a result, there is a rise in heat transmission to the airflow but a decrease in the transfer of heat from the PV Cells to the tedlar. the tedlar which raises the amount of heat released into the atmosphere. However, because of the rise in lost heat at the upper cover, the fluctuations in the performances appear to be relatively small over high collector lengths.

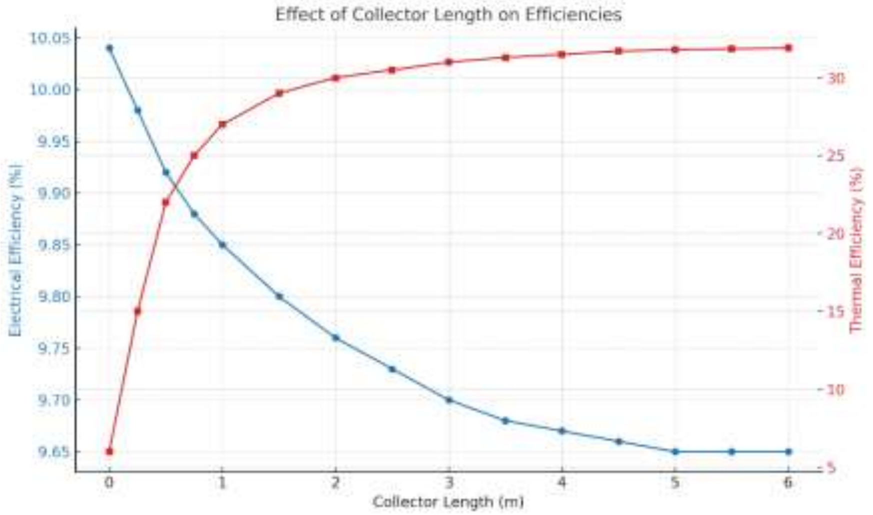

Figure 5: Effect of Collector Length on efficiencies

4. The impact of toddler's heat conductivity

To examine the impact on the collector's effectiveness, the heating capacity of tedlar was adjusted between 0.0005 and 0.1 W/mK. The observation (based on figure 6) indicates that a rise in the thermal conductivity of tedlar is associated with a simultaneous improvement in the equipment's electrical as well as thermal effectiveness. This is brought on by the fact that as toddler's thermal conductivity rises, more heat is transmitted to the airflow and the photovoltaic cell's temperature drops accordingly.

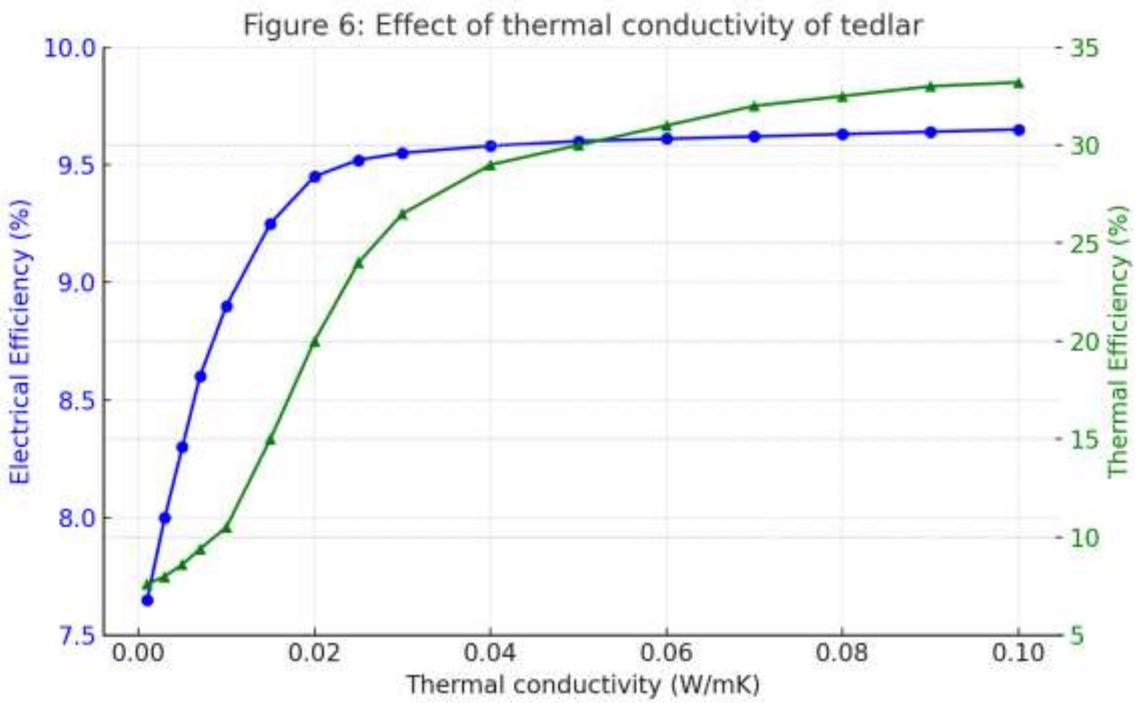

Figure 6 effect of thermal conductivity on efficiencies

5. Mass flow rate effect

Table 1 illustrates whether the air's flow rate of mass affects the PV/T The air collector's electrically and thermal performances. The picture illustrates how thermal and electrical efficiency rise with mass flow rate rises. This is because the quantity of heat removed because of the air through the duct grows as the mass rate of flow does. The smaller the operating temperature on the photovoltaic panel and consequently the greater electrical and thermal efficiency, which means more heat is absorbed using the air.

Table 1 effect of mass flow rate on the electrical and thermal efficiencies.

Mass flowrate (kg/s)	Electrical efficiency (%)	Thermal efficiency (%)
0.002	8.75	14.0
0.005	9.2	22.0
0.007	9.35	25.0
0.01	9.5	28.0
0.015	9.6	30.0
0.02	9.65	31.5
0.025	9.68	32.5
0.03	9.7	33.0
0.04	9.72	33.4
0.05	9.74	33.8
0.06	9.75	34.0

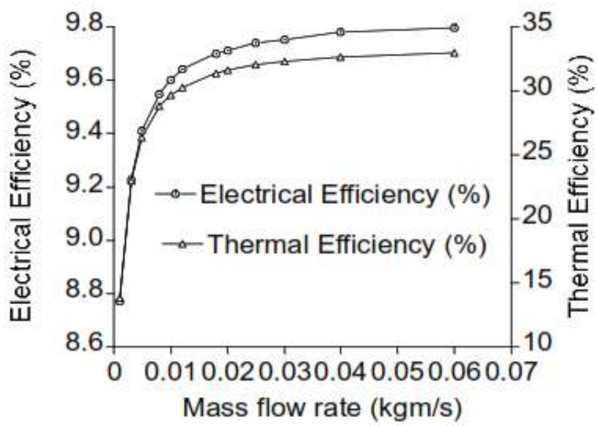

Figure 7: Effects of mass flow rate

CONCLUSIONS

Electrical and thermal efficiency were found to rise by around 20% and twenty-four percent, respectively, when the tedlar's thermal inefficiencies was reduced and its coefficient of thermal conductivity increased from 0.0005-0.025 W/mk. A large improvement in the system's general efficiency may be achieved by raising the rate of mass circulation while the thermal conductivity within the cells that produce electricity is extremely low.

REFERENCES

[1] Sanchez B.A. and Poschen P. (2009) "The social and decent work dimensions of a new Agreement on Climate Change; A Technical Brief

[2] Chow T.T. "A review on photovoltaic/thermal hybrid solar technology." Applied Energy 87 (2010) 365–379 doi:10.1016/j.apenergy.2009.06.037

[3] Cox, C.H. and S.C. Raghuraman, 1985. Design considerations for flat-plate photovoltaic/thermal collectors. Solar Energy, 35: 237-242.
[4] Garg, H.P., R.K. Agarwal and A.K. Bhargava, 1991. Study of a hybrid solar system-solar air heater combined with solar cells. Energy Convers.Manage., 31: 471-479.
[5] Sopian, K., K.S. Yigit, H.T. Liu, S. Kakac and T.N. Veziroglu, 1996. Performance analysis of photovoltaic thermal air heaters. Energy Convers. Manage., 37: 1657-1670
[6] Hegazy, A.A., 1999. Comparative study of the performances of four photovoltaic/thermal solar air collectors. Energy Convers. Manage., 41:861-881
[7] Tonui J. K. and Tripanagnostopoulos Y., "Improved PV/T solar collectors with heat extraction by forced or natural air circulation," Renewable Energy, 32(4), 2007, pp. 623–637.
[8] Ibrahim A., Othman M.Y., Ruslan M.H., Alghoul M.A., M.Yahya, and A. Zaharim and K. Sopian "Performance of Photovoltaic Thermal Collector (PVT) With Different Absorbers Design", Issue 3, Volume 5, March 2009
[9] Jin G.L, Ibrahim A., Chean Y.K, Daghigh R., Ruslan H., Mat S. Othman M.Y and Sopian K. "Evaluation of Single-Pass Photovoltaic-Thermal Air Collector with Rectangle Tunnel Absorber", American Journal of Applied Sciences 7 (2): 277-
282, 2010 ISSN 1546-9239
[10]Tiwari A, Sodha M.S. "Parametric study of various configurations of hybrid PV/thermal air collector: Experimental validation of theoretical model", Solar Energy Materials & Solar Cells 91 (2007):17–28
[11]Joshi A.S, Tiwari A, Tiwari GN, Dincer I, Reddy BV. "Performance evaluation of a hybrid photovoltaic thermal (PV/T) (glass-to-glass) system." Int J. Therm Sci 2009; 48:154–64.

[12]Barnwal, P. and Tiwari, G.N. "Experimental Validation of Hybrid Photovoltaic-Thermal (PV/T) Greenhouse Dryer under Forced Mode," International Journal of Food Engineering 6(6),
2010, Article 17. DOI: 10.2202/1556-3758.1451
[13]Sarhaddi F., Farahat S., Ajam H., Behzadmehr A., Adeli M. M. "An improved thermal and electrical model for a solar photovoltaic thermal (PV/T) air collector", Applied Energy 87 (2010):2328–2339.
[14]Riffat S.B. and Cuce E. "A review on hybrid photovoltaic/thermal collectors and systems." Int. J. Low-Carbon Tech. (2011) doi: 10.1093/ijlct/ctr016
First published online: July 21, 2011
[15]Lee W.M., Infield D.G, Gottschalg R. "Thermal modeling of building integrated photovoltaic system," Proc. 17^{th}, European PV Solar Energy Conference, Germany 2001, vol.III pp.2754-2757.
[16]Zondag H.A,, De Vries D.W, Van Helden W.G.J., van Zolingen R.J.C., van Steenhoven A.A. The yield of different combined PV-thermal collector designs Solar Energy 74 (2003) 253–269

NOMENCLATURE
Ac Collector area (m2)
Cp Specific heat capacity of air (J kg-1 K-1) H Height of duct (m)
hc Convective heat transfer coefficient at heated surfaces ($W/m^2/K$)
ht-f Convective heat transfer coefficient at tedlar ($W/m^2/K$)
hr,t-b Radiative heat transfer coefficient from tedlar to back plate (Wm-2 K-1)
hb-f Convective heat transfer coefficient at tedlar ($W/m^2/K$)
k Thermal conductivity (W/m/k)
L Collector length (m)
W Collector width (m)
G Incident solar radiation (Wm-2) T Temperature (K)

Greek Symbols
mass flow rate
α Absorptivity
η Efficiency
β Temperature coefficient of the efficiency

Subscripts

a Ambient
b Back plate
c PV Cell
g Glass
f Fluid

i Inlet
o Outlet
r Reference
tb Tedlar back
t Top
si Silicon
EVA t Top EVA layer
EVA b bottom EVA layer