Simulation model to the study of an hybrid photovoltaic / thermal air collector

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***Abstract*— The electrical and thermal energy produced by the HPV / T collector depends on the different input and output parameters: solar radiation, wind speed, ambient temperature. If retrospectively TIWARI has made in relief in his paper, an experimental and analytical study, we suggest a study by numerical simulation, by establishing an energy balance on one of the four collectors, proposed in his study, which represent the best performance. In the present work we have developed a computer simulation program of the glazed hybrid PV/T without tedlar. It has been validated with Tiwari's experimental results carried out by his work. Simulation results show that the thermal efficiency increases with the increase of air flow mass rate but when the wind speed and the depth air increase, the outlet air temperature, solar cell temperature and electrical efficiency will decrease.**

Keywords- photovoltaic cell, thermal collector, thermal efficiency, electrical efficiency.

I. INTRODUCTION

In the world of tomorrow, it will be significant changes mainly due to the growing demand for all forms of energy: wind, water, oil etc. After the 1973 crisis experienced by the world about the casting or strategic position occupied by nation energy in its broadest sense, knowing that much of it, is finite in time and space. All states in the developing world have established strategic study groups to develop other types of renewable energy in order to provide clean energy in sufficient quantities and at low costs. The effect is double: it will satisfy the growing demand and promote the development of an environment saint for all humanity.

Besides the construction industry and public works have received the benefit of the conceptual coupling of photovoltaic panels with thermal collectors after that there was an increase in the electrical efficiency of the cell, which decreases when the temperature of the cell increases.

Photovoltaic solar panels have an electrical efficiency which varies between 5% and 25%, 80-85% of the energy absorbed by the solar cells are in the form of heat or thermal energy. [1] This allowed for get the idea to combine these signs another system in which a fluid which extracts heat from the photovoltaic cells. Many studies have been reported for hybrid systems among which are:

Hegazy[2] has compared the thermal, electrical, hydraulic and overall performances of four types of flat plate PVT/ collectors. The comparison indicated that the model 3 in which the air flow on both sides of the absorber, is the most suitable one, for converting solar energy into low quality heat and high quality electrical.

Tiwari et al [3] have evaluated the performance of the photovoltaic module integrated with air duct for composite climate of India.

Experimental validation has been carried out with an analytical expression for overall efficiency (electrical and thermal). They concluded that an overall thermal efficiency of PV/T system is significantly increased due to utilization of thermal energy in PV module.

Tonui et al [4] have presented the use of a suspended thin metallic sheet at the middle or fins at the back wall of an air duct as heat transfer in a cooled PV/T solar collector to improve its overall performances. Their paper focused on the experimental study and such they have presented experimental results regarding the relative performance improvement achieved by the modified systems with respect to the topical system.

Tonui et al [5], have investigated low cost techniques that can reduce the operating temperature of the PV modules integrated PV systems, to improve the electrical power output and increase the heat production. This work has focused on the performance of PV/T air collector, without and with additional glazing. They concluded that this last improves the heat production but lowers the electrical efficiency of a PV/T collector.

Niccolo et al [6] have described the research and development program carried out at the politecnico di Milano on the design, development and performance monitoring of a hybrid PV/T air collector.

To investigate the thermal and electrical performance of a solar PV/T air collector, Sarhaddi et al [7] have made an attempt and detailed thermal and electrical parameters of typical PV/T air collector. The thermal and electrical parameters of this collector include solar cell temperature, back surface temperature, outlet temperature, open-circuit voltage; short-circuit current, maximum power point voltage, maximum power point current, etc.

Two different types of commercially available PVT modules have been installed and tested by Swapnil et al [8]. In type A, the PV module was encapsulated with mono-crystalline Si solar cells and was integrated with a tube and sheet type thermal collector. In type B, the PV module was encapsulated with multi-crystalline Si solar cells and integrated with a parallel-plate type thermal collector. The performance of PV/T modules has been evaluated based on thermal and PV efficiencies.

A.Tiwari et al [9] have made an attempt to evaluate the overall performance of hybrid PV/Thermalair collector. The different configurations of hybrid air collectors which are considered as unglazed and glazed air heaters, with and without tedlar. Analytical expressions for the temperature of solar cells, back surface of the module, outlet air and the rate of extraction of useful thermal energy from hybrid PV/Tair collectors have been derived. It was observed that glazed hybrid PV/T without tedlar gives the best performance.

In this work, a simulation program was been developed about a glazed PV/T solar air collector, which was concepted and studied analytically by Tiwari et al [9]. First, an experimental validation has been done, then it was useful to study the effect of many parameters like wind speed, depth of air duct and the mass flow rate, on the outlet air temperature, the electrical and thermal efficiencies.

II. HYBRID PV / THERMAL AIR COLLECTOR

a. The description of PV and thermal air collector

The photovoltaic / thermal air hybrid system includes a photovoltaic panel which produces electricity, to a thermal collector disposed behind the panel. The residual heat coming from the photovoltaic cell is transferred by conduction and convection inside the channel thermal collector so that a ventilation of the photovoltaic system improves its electrical productivity. The use of this hybrid collector is not limited as heating, but it can be used as ventilating. Note also, the high adaptability of these systems with different configurations in buildings.

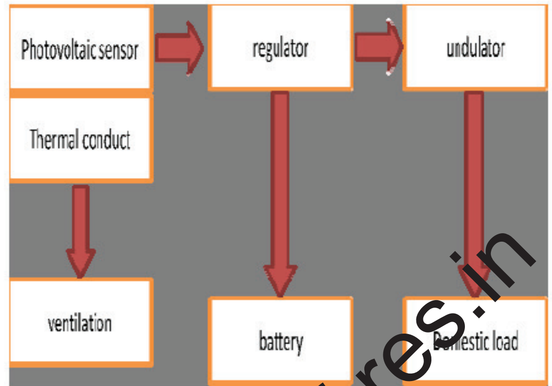

Figure 1. Hybrid photovoltaic/thermal air collector.

b. Equivalent diagram of a hybrid / PV air temperature collector

On the cover, the incident radiation is transmitted, a smaller proportion is reflected, or absorbed and re-emitted from both sides in the form of heat, either by convection or by radiation. The radiation reaching the absorber is re-emitted as heat by radiation or convection. Concerning the solar cell, the radiation is mostly absorbed and re-emitted from both sides in the form of heat, a small proportion is converted into electricity.

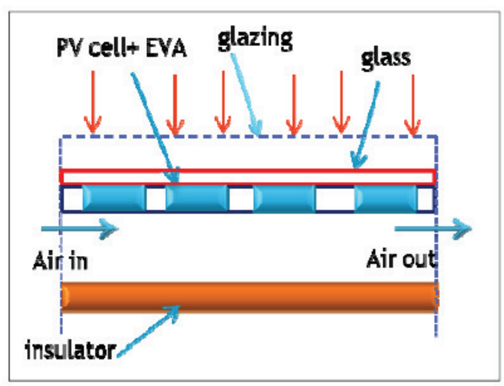

Figure 2. Cross-sectional view of glazed PV/T air collector without tedlar [9].

III. THE ENERGY BALANCE

By using the law of OHM at each node at time t, we obtained:

$$\frac{M_I}{S_i} Cp_i \frac{\partial T_I}{\partial t} = \sum_{j=1}^{N} h_{ij}(T_j - T_i) + P_i \quad (1)$$

where:

M_I: is the mass of the component i (kg).

Cp_i : is the specific heat (J / kg. K)
S_i : is the section (m^2).
N : is the set of nodes j for which Tj is a connected to Ti potential.
P_i : factor of well or source (W/m^2).

a. Schematic of the thermal resistance of the hybrid sensor

To determine the energy balance between the nodes it would be convenient to use the analogy between heat transfer and electricity.

Figure 3 represents the thermal resistance circuit diagram for glazed PV/T air collector without tadlar, in order to calculate the different temperatures such as the temperature of the cell, the air outlet temperature and the heat exchange coefficients to calculate the thermal and electrical performances.

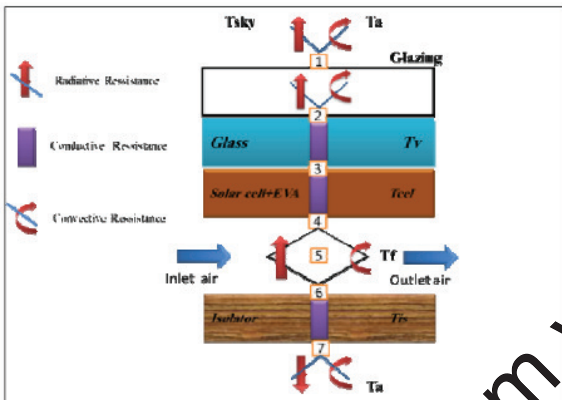

Figure 3. Thermal resistance circuit diagram for glazed PV/T air without tedlar.

It is necessary to make some assumptions in order to have an approximate simulation of the system:
- The sky can be assimilated to a black body with equivalent temperature calculated.
- The temperature of the soil is taken equal to the temperature of the atmosphere.
- The physical properties of materials are assumed to be constant.
- The wind is supposed blowing parallel to the faces of the system.
- Atmospheric diffuse radiation is isotropic.
- The system is in a transient state .
- The transmittivity of EVA is nearly 100%.

For the fluid balance, we can write:

$$\frac{G_f Cp_f}{S_f}(dT_f) = H_{vfce}(T_{ce} - T_f) - H_{vfisi}(T_f - T_{isi}) \qquad (2)$$

b. Expression of the different coefficients of heat exchange

All heat exchange coefficients depend on the temperature, for example, we have:
The coefficients that characterize the different types of heat transfer by convection and can be evaluated using the Nusselt, Reynolds and Prandtl equations.

$H_{vfisi}(W/m^2K)$: Is the convective heat transfer coefficient between the insulation and the air, which is calculated by:

$$Nu = \frac{H_{vfisi} L_c}{\lambda} \qquad (3)$$

with :
λ : Thermal conductivity (W/m. K).
L_c : The characteristic length (m).
Pr : Prandtl number, which is calculated by the following equation:

$$Pr = \frac{\mu\, c_p}{\lambda_f} \qquad (4)$$

As :
μ : The dynamic viscosity of the air (Kg/m. s).
C_p : The specific heat capacity (J/Kg. K).
λ_f : The thermal conductivity of the fluid (W/m. K).

Reynold's number is calculated as :

$$Re = \frac{V\, D_h}{\nu} \qquad (5)$$

With :
V : The average fluid velocity (m/s).
ν : The kinematic viscosity (m²/s).
D_h : The hydraulic diameter of the duct (m).

The Nusselt number is calculated as [10]:
- In the case of a laminar flow (R_e < 2300) :

$$Nu = N_\infty + \frac{a\left[P_r R_e \frac{D_h}{L}\right]^m}{1 + b\left[P_r R_e \frac{D_h}{L}\right]^n} \text{(Heaton)} \qquad (6)$$

With : a= 0.00190 b= 0.00563 N_∞= 5.4 Pr = 0.7 n=1.17 m=1.71
- In the case of a turbulent flow (Re> 6000)

$$Nu = 0.036 + R_e^{0.8} P_r^{\frac{1}{3}}\left(\frac{D_h}{L}\right)^{0.055} \quad \text{(Heaton)} \qquad (7)$$

c. Expression of different heat flux

c. 1 The rate of the energy absorbed by the glass

This quantity is calculated by the following expression:

$$P_{V1} = P_{dir}.\alpha_{V1-dir} + P_{dif}.\alpha_{V1-dif} \quad (W/m^2) \qquad (8)$$

Such as: P_{dir} et P_{dif} represent respectively the intensity of the direct and diffuse incident radiation. The absorption coefficients of glazing α_{V1-dir} et α_{V1-dif} are calculated from [11]

c. 2 The rate of solar energy received by solar cell after transmission

It is calculated by the following expression [12] :

$$P_{ce} = \tau_{V1} \times \tau_{V2} \times \alpha_{ce} \times B_{ce} \times G \quad (W/m^2) \quad (9)$$

where :

τ_{V1} , τ_{V2} : The transmission coefficients of the glazing and the glass cover.

α_{ce} : The absorption coefficient of the cell.

β_{ce} : Packing factor.

c.3 The rate of electrical energy generated by the PV cell

$$Q_{ele} = \eta_{éle} \times G \times B_c \times \tau_{V1} \times \tau_{V2} \quad (W) \quad (10)$$

C.4 The useful thermal energy

The useful thermal energy can be calculated as follows [9]:

$$Qu = \frac{\dot{m}_f Cp_f}{U_L}\left[h_{p1} h_{p2} (\alpha\tau)_{eff} P_g - U_L (T_{fe} - T_a)\right] \times (1 - \exp(-bU_L / \dot{m}_f Cp_f) L) \quad (11)$$

$(\alpha\tau)_{eff}$:The effective product of absorptivity and transmittivity.

U_L : The overall transfer coefficient from solar cell to ambient through glass cover.

h_{p1} : The penalty factor due to the presence of solar cell material.

h_{p2} : The penalty factor due to the presence of the interface between solar cell and fluid.

P_g , W et L : are respectively the incident solar intensity, the width and length of the hybrid PV / T collector air.

c.5 The thermal efficiency of the hybrid PV /T collector

The thermal efficiency of an hybrid PV/T collector is calculated by:

$$\eta_{the} = \frac{\dot{q}_u}{P_g b L} \quad (12)$$

c.6 The electrical efficiency of the HPV / T air collector [7]

The electrical performance of a hybrid PV / T collector is given by the following relationship:

$$\eta_{el} = \eta_{ref}[1 - 0.0045(T_c - T_{ref})] \quad (13)$$

Where:

T_{ref} : The reference cell temperature (K)

η_{ref} : The reference module efficiency.

c.7 The equivalent thermal efficiency to electrical efficiency of PV hybrid PV/T air collector [7]

The equivalent thermal efficiency of a hybrid PV / T is calculated with:

$$\eta_{el,the} = \frac{\eta_{el}}{C_f} \quad (14)$$

Where:

$\eta_{el,the}$: The equivalent thermal efficiency.

C_f : The conversion factor of the thermal energy.

c.8 the overall energy efficiency of hybrid PV/T air collector [7]

It can be simply calculated by adding the thermal efficiency (eq. (12)) and the thermal efficiency equivalent of electrical efficiency (eq. (14)):

$$\eta_g = \eta_{el,the} + \eta_{the} \quad (15)$$

IV. MATHEMATICAL RESOLUTION OF EQUATION SYSTEM

After developing the energy balance equations of glazed hybrid PV/T air collector which was based on the energy transfer phenomenon for each components. This equation system was discredited. The resolution of the system was performed by the iterative Gauss-Seidel method, which allowed us to evaluate the different heat exchange coefficients for each time and for each component, we obtained a system of equation whose resolution can calculate our unknowns.

V. RESULTS AND DISCUSSION

We elaborated a simulation program in Matlab language, for composite climate of Jijel. The results were obtained through the region specific meteorological data that is: Latitude = 36°48' N, Longitude = 5°53' E. We have chosen July 10 as a typical day.

Table I. DESIGN PARAMETERS OF GLAZED HYBRID PV/T AIR COLLECTOR WITHOUT TEDLAR.

Parameters	Glass	Solar cell	Insulator
Mass density ($kg.m^{-3}$)	2530	2330	450
Specific heat ($J.kg^{-1}.K^{-1}$)	836	903	1800
Emissivity	0.88	0.95	0.11
Thermal conductivity ($W.m^{-1}K^{-1}$)	0.93	270	0.039
Absorption Coefficient	0.066	0.9	0.11

a. Experimental validation

Variation of outlet air temperature of the air duct is shown in fig.4. from the simulation described in our study and Tiwari's experience validation of a glazed hybrid PV/T solar collector without tedlar has been performed. It has been noted a good agreement between simulation and experimental values.

b. Variation of wind speed

The figures 5, 6 and 7 show respectively the effect on outlet air temperature, solar cell temperature and electrical efficiency by varying speed wind.

It has been observed for the three curves that more the wind speed increase, the outputs decrease that returns to the losses of heat which vary proportionally with the wind speed.

c. Variation of the depth of air duct

Variation of the thermal efficiency is illustrated in fig.8. at different depth of air duct (5 cm, 7cm and 10cm).

It is noted that more the value of depth of air duct increase, the thermal efficiency decrease, this same result is also established by an experimental study carried out by KUMAR [13].

d. variation of the air mass flow rate

Is plotted on fig.9. The effect on thermal efficiency by varying air mass flow rate.

It is noted that the thermal efficiency vary proportionally with the air flow. The increase in this efficiency returns to the quantity of heat recovered by the fluid, because the increase in air velocity in the duct raised the heat collected by the air.

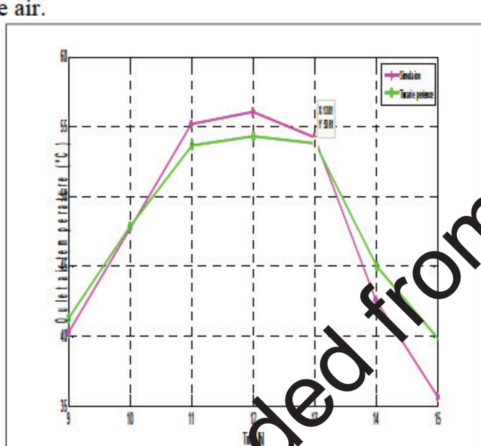

Figure 4. Experimental validation of hourly variation of the outlet air temperature of a glazed hybrid PV/T solar collector without tedlar.

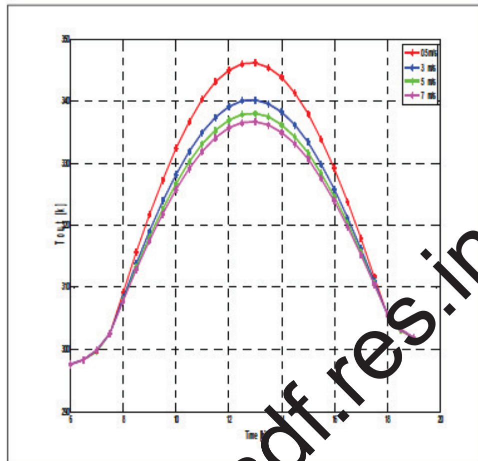

Figure 5. Effect on outlet air temperature by varying wind speed.

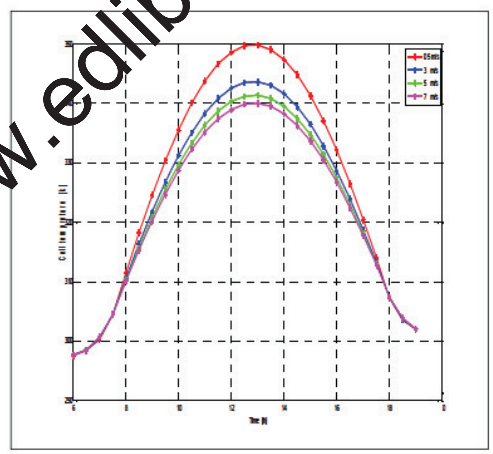

Figure 6. Effect on solar cell temperature by varying the wind speed.

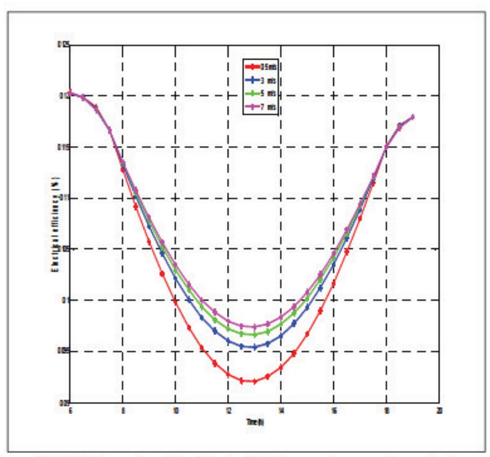

Figure 7. Effect on the electrical efficiency by varying wind speed.

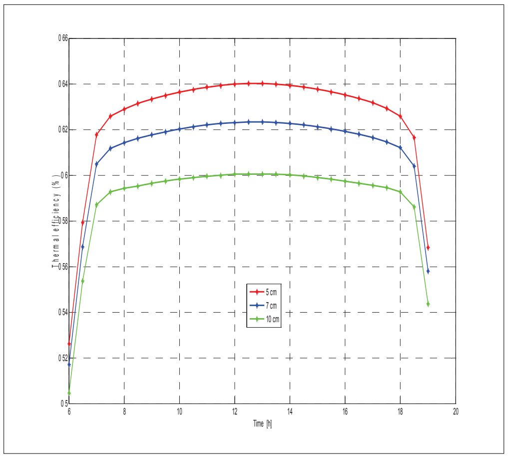

Figure 8. Effect on thermal efficiency by varying the depth of air duct.

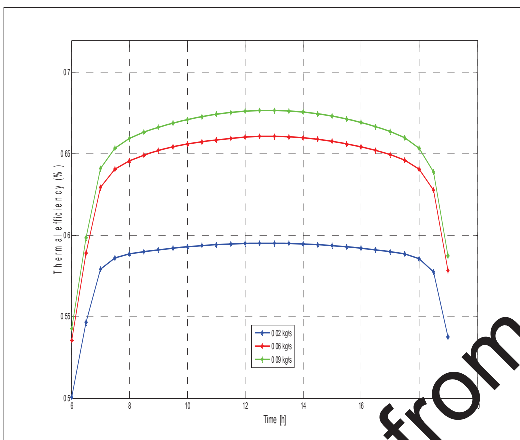

Figure 9. Effect on thermal efficiency by varying air mass flow rate.

VI. CONCLUSION

A numerical simulation of a glazed hybrid photovoltaic/ thermal air collector without tedlar was been elaborated in this work.

From the study, the following conclusions can be drawn:

- The numerical simulation results of our work are in good agreement with the experimental measurements of Tiwari et al [9].
- The increase in the wind speed or the depth of air duct decrease the outlet air temperature, temperature of solar cell and electrical efficiency of the glazed hybrid PV/T air collector without tedlar.
- When the air mass flow rate increase, the thermal efficiency increase.

REFERENCES

[1] K. Touafek , W. Bendaikha-Touafek, A. Malek , M. Haddadi et L. Serir, 'Etude d'un système de cogénération par les capteurs hybrides photovoltaïques thermiques destiné à l'habitat', Revue des Energies Renouvelables, CER'07 Oujda, 2007, pp177 – 180.

[2] A. Hegazy. 'Comparative study of the performances of four photovoltaic/thermal solar air collectors'. Energy Conversion & Management. Vol 41, 2000, p 861-881.

[3] Arvind Tiwari, M.S.Sodha, Avinash Chandra, J.C.Joshi, 'Performance evaluation of photovoltaique thermal solar air collector for composite climate in India', vol 90, 2006, pp 175-189.

[4]J.K.Tonui, Y.Tripanagnostopoulos, 'Improved PV/T solar collectors with heat extraction by forced or natural air circulation', Renewable energy, vol 32, 2007, pp623-637.

[5] J.K.Tonui, Y.Tripanagnostopoulos, 'performance improvement of PV/T solar collectors with natural airflow operation', Solar energy, vol 82,2008, pp1-12.

[6] Niccolo Aste, Giancarlo Chiesa, Francesco Verri,'Design, development and performance monitoring of a photovoltaic-thermal (PVT) air collector', Renewable energy, vol 33, 2008, pp 914-927.

[7] F.Sarhaddi, S.Farahat, H.Ajam, A.Behzadmehr, M.Mahdavi Adeli, ', Applied Energy, vol 87, 2010, pp 2328–2339.

[8] Swapnil Dubey, Andrew A.O.Tay, ' Testing of two different types of photovoltaic-thermal (PVT) modules with heat flow pattern tropical climatic conditions', Energy for sustainable development, vol 17, 2013, pp1-12 .

[9] Arwind Tiwari, M.S.Sodha,'Parametric study of various configurations of hybrid PV/thermal air collector: Experimental validation of theorical model', vol 91, 2007, pp 17-28.

[10] K. S. Ong. 'Thermal performance of solar air heaters experimental correlation'. Solar Energy Vol. 55, N 03,1995, p 209-220.

[11] J. A. Duffie, W. A. Beckman. 'Solar engineering of thermal processes' .3th edition. 2006, John Wiley and sons.

[12]A.S.Joshi, A.Tiwari, G.N.Tiwari, I.Dincer, B.V.Reddy, 'Performance evaluation of hybrid photovoltaic thermal (PV/T) (glass to glass) system' vol 48,2009, pp 154-164.

[13] R. KUMAR, M. A. ROSEN. 'Performance evaluation of a double pass PV/T solar air heater with and without fins'. Applied Thermal Engineering. Vol 31, 2011, p 1402-1410.

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