Performances Improvement of photovoltaic thermal air collector by planer reflector

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***Abstract*— in this paper, simple mathematical model is presented for hybrid photovoltaic thermal collector with externals reflectors. Numerical calculations have been carried out for different tilts angle of the outer reflector on typical days in south Algeria, then we presented the influence of the input parameter on the collation electrical and thermal performance parameters. The parameters that affect the performance of PVT thermal collector such as; the geometrical of planer reflector, mass flow, the number of fins and the height of canal.**

***Keywords*— solar energy, PVT collector, Reflector**

I. INTRODUCTION

Solar energy is one of the most important sources of renewable energy. The main applications of solar energy can be classified into two categories, thermal system (T) and photovoltaic (PV) [1]. Several factors to improve the electrical efficiency of the photovoltaic module , the temperature rise due to the solar radiation is devoid electrical efficiency of the cell , using a water cooling system or air , the system PV / T air and PV / T in water was studied extensively in various types of configurations developed to test the overall performance of the combined system, The numerical simulation of PV / T systems has also provided more detailed information on system performance information, a solar PVT air pass with only a open channel has been studied by earlier researchers [1-2]. Another collector type a double pass was made by other researchers [3], the comparison between the two configuration has been done and shows that the double passage has a better performance [4] . Other research has been carried out by combining conductive heat in the solar collector such as fins [5-6]. The purpose of adding heat conducting in the solar collector is the extraction of heat from the manifold and thereby increases the thermal efficiency of the collector.

Another approach to reduce thermal losses to access high temperatures and at the same time increase photovoltaic efficiency is to combine PVT technology with an optical Concentrator that focuses the sun light on to a comparably smaller receiver[8]. Several System concentrations apply to hybrid solar thermal and photovoltaic's, planer reflectors, parabolic trough concentrator, compound parabolic Concentrators. Many studies have been done the investigate to increase solar irradiation on PVT thermal collector by concentrator system, Garg et al**.** [9] presented a study of a PVT air hybrid system comprised a plane booster and a flat plat collector mounted with photovoltaic cells It was concluded that the electrical efficiency of photovoltaic cell will linearly decrease with increase of the absorber temperature. The results also indicated that the minimum area of photovoltaic cell needed to operate a pump at a given flow rate is a function of time. The plane boosters were utilized to reflect the extra incident rays to the photovoltaic cell in order to increase the intensity of sunlight on the photovoltaic module ,SUN Jian, Li Guiqiang and [10-11] have a thermal/photovoltaic hybrid system with a parabolic solar concentrator composed building integrated. They studied the effect of the concentration ratio of the CPC on the electrical and thermal efficiency of the system. They have shown that increasing the ratio of concentration, an increase in thermal efficiency and a reduction in the electric efficiency of the system.

II. BASIC FORMULAS OF SOLAR RADIATION

Solar declination

$$\delta = 23.45\sin[\frac{284+n}{365} \times N] \quad (1)$$

N: the number of days in the year counted from1 January

Solar height

$$sinh = \sin(\Phi)\sin(\delta) + \cos(\Phi)\cos(\delta)\cos(\omega) \quad (2)$$

Hour angle

$$\omega = 15 * (tsv - 12) \quad (3)$$

Tsv*:* solar time

Solar incidence angle for a south-facing tilted surface in the Northern Hemisphere,

$$\cos\theta = \sin\Phi\sin\delta\cos\beta - \cos alt\sin\delta\sin\beta + \cos\Phi\cos\delta\cos h\cos\beta + \sin\Phi\cos\delta\cos h\sin\beta \quad (4)$$

Solar radiation outside atmosphere

$$I_c = I_0 \times [1 + 0.0034 \times \cos\left(\frac{360\times N}{365}\right)] \quad (5)$$

I_0; Solar constants equal to 1367W/m2

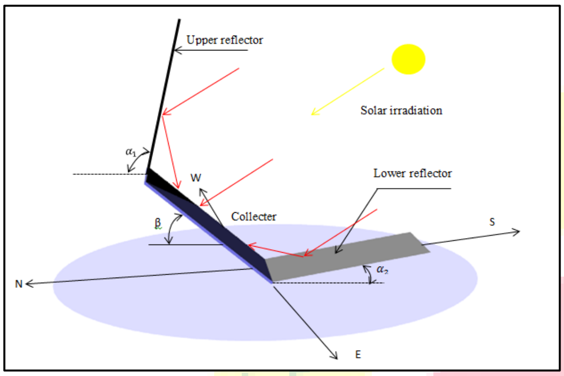

Fig. 1 schematic representation the angles of PVT collector with planer reflector

III. MATHEMATICAL MODELING

The photovoltaic-thermal reflector assembly as shown in Fig.1This assembly consists of photovoltaic thermal collector having two reflectors, both above and below the collector unit. The reflectors are connected edge to edge with the collector. The collector unit is basically an air heater with an air flow passage between two metallic plates. In the hybrid system, the bare cells are pasted on the absorber surface. The air must not come in contact with the cells, otherwise the cells would be damaged. This requirement restricts the choice of air heater designs. Out of all the available designs, the one with two metallic plates with the air flow channel between the metallic plates would be the ideal design for hybrid systems. The upper metallic plate with fin is painted black, and the solar cells are pasted over it. The system shown in Fig. 1 has three different parts; PVT collector, upper reflector and Lower reflector.

The total irradiation falling is solar collector is described by the following relation ship

$$I_T = (I_{bh} + I_{dh}A_i)R_b + I_{dh}(1-A)F_{c-s} + (I_{bh} + I_{dh})\rho F_{c-g} + I_{Lor}\rho_r F_{c-Lr} + I_{upr}\rho_r F_{c-upr} \quad (6)$$

Where F_{c-s} is again [1] $(1+\cos(\beta))/2$ (7)

$$R_b = \frac{\cos(\Phi-\beta)\cos(\delta)\cos(\omega)+\sin(\Phi-\beta)\sin(\delta)}{\cos(\Phi)\cos(\delta)\cos(\omega)+\sin(\Phi)\sin(\delta)} \quad (8)$$

A_i: Anisotropy index

$$A_i = \frac{I_{bn}}{IC} \quad (9)$$

I_{bn}: beam solar radiation

F_{c-Lr},F_{c-upr} and obtained from reciprocity relation chip

$$\sum F_{c-i} = 1 \quad (10)$$

The view factor F_{lr-c} and F_{upr-c}can be optimized from the ratio geometry of the collector and the lower and upper reflector, There is method of Hotel's "crossed-string" method to gives the view factor as[13]

III. ENERGY BALANCE EQUATION

The transient energy balance equation for this configuration can be written as follows

- For the absorber plate

$$M_p c_p \frac{dT_p}{dt} = q_p(t) - \mathrm{h_{rps}}(\mathrm{T_p} - \mathrm{T_s}) - \mathrm{h_{cpa}}(\mathrm{T_p} - \mathrm{T_a}) - \mathrm{h_{rpb}}\frac{\mathrm{A_{cb}}}{\mathrm{A_c}}(\mathrm{T_p} - \mathrm{T_b}) - \mathrm{h_{cpf}}\frac{\mathrm{A_{cb}}}{\mathrm{A_c}}\eta_\mathrm{p}(\mathrm{T_p} - \mathrm{T_f}) \quad (11)$$

$$q_p(t) = \tau_g(I_T\alpha_P(1-R) + I_T * \alpha_{PV}(1-\eta_{\mathrm{PV}})) \quad (12)$$

- For the air stream in channel

$$M_f c_f \frac{dT_f}{dt} = -\dot{m}\mathrm{C_f}\frac{\mathrm{dT_f}}{\mathrm{wdx}} + \mathrm{h_{cpf}}\frac{\mathrm{A_{cb}}}{\mathrm{A_c}}\eta_\mathrm{p}(\mathrm{T_p} - \mathrm{T_f}) + \mathrm{h_{cpf}}(\mathrm{T_p} - \mathrm{T_f}) \quad (13)$$

- For the back plate

$$M_b c_b \frac{dT_b}{dt} = \mathrm{h_{rpb}}\frac{\mathrm{A_{cb}}}{\mathrm{A_c}}(\mathrm{T_p} - \mathrm{T_b}) + \mathrm{h_{cpf}}(\mathrm{T_b} - \mathrm{T_f}) - \mathrm{U_b}(\mathrm{T_b} - \mathrm{T_a}) \quad (14)$$

With

$$\eta_p = \frac{A_c + A_{fin}\eta_f}{A_{cb}} \quad (15)$$

$$\eta_f = \frac{\tanh(mH_f)}{\lambda_f\delta_f}, m = \left(\frac{2h_f}{\lambda_f\delta_f}\right)^{1/2} \quad (16)$$

$$\eta_{pv} = \eta_{ref}[1 - 0.0054(T_P - 298.15)] \quad (17)$$

Equations (10) (12) (13) are combined to yield a first differential equation for the air temperature

$$T_f(x) = \frac{q}{p} + \left(T_i - \frac{q}{p}\right) e^{-px} \quad (18)$$

With p and q are function of known constants occurring in equation (10) (12) (13)

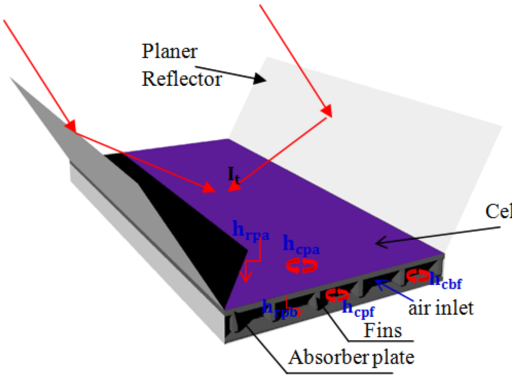

Fig. 2 Photovoltaic thermal collectors With planer Reflector

- Collector thermal performance

The thermal performance of the photovoltaic thermal collector with planer reflectors is easy as follow

$$\eta_t = \frac{Q_u}{A_c I_t} = \frac{\dot{m}Cp\int(T_o - T_i)dt}{A_c \int I_t dt} \quad (19)$$

The performance of the photovoltaic thermal collector is defined as the sum of the total thermal energy and electrical energy divided by the total radiation absorbed surface collector.

The performance of the photovoltaic thermal collector Is [9]

$$\eta_{pvt} = \eta_{pv} + \eta_t \quad (20)$$

The following table summarizes the different heat exchange coefficient used in our problem and thermo physical parameter.

Table 1 Heat exchange coefficient and thermo physical parameter of air

$$h_{rps} = (1 + \frac{\cos(\beta)}{2})\varepsilon_p\delta[(T_g + T_s)(T_p{}^2 + T_s{}^2)(T_p - T_s)] / (T_p - T_a)$$

$$h_{rpb} = \delta(T_p + T_b)(T_p^2 + T_b^2)/((1/\varepsilon_b) + (1/\varepsilon_p) - 1)$$

$$h_{cgw} = 2.8 + 3v$$

$$h_{cpf} = h_{cpf} = \left(\frac{\lambda}{D}\right)[0.0158Re^{0.8} + (0.00181Re + 2.92)\exp^{\left(-\frac{0.03795X}{D}\right)}$$

$$Re = \frac{2 \times \dot{m}}{\mu_a \times (W + H)}$$

$$D = (2 \times H \times W)/(H + W)$$

$$T_s = 0.0552(T_a)^{1.5}$$

$$\mu_{air} = 10^{-5} \times (0.0046 \times T + 1.7176), \quad T\ in°C$$

$$\rho_{air} = 1.1774 - 0.00359 \times (T - 27), \quad T\ in°C$$

$$\lambda_{air} = 0.02624 + 0.0000758 \times (T - 27), T\ in°C$$

$$C_{pair} = [1.0057 + 0.000066 \times (T - 27)] \times 1009, T in°C$$

IV. RESULTS AND DISCUSSION

In these results we try to present the amount of solar radiation incident on the surface of the PVT collector that come directly or the amount of solar radiation reflector ,we chose these entropic model HDM, to calculate the total solar radiation on an inclined plane, two aluminum reflector dimension using low and high solar collector withα_1PVTcorners and α_2 relative to the horizontal. Then A numerical modeling simulation has been done to show the effect of the reflector on solar-thermal and electrical performance of collector we chose the method of Ran Kuta to solve this system of equations using a Fortran 90 program. The system of equations and the coefficients of heat transfer are solved with initial temperatures. The thermo-physical parameters used in the calculation are shown in Table. System dimensions are 1m x 0. 5 m (W × L) The dimensions of the fins are 0, 0015m × 0.025 m × 1m ($e_f \times h_f \times l$) and we came the following results.

Table2 input parameter

Paramètre	Value
Day/year	/
Zénith angle	0°
Latitude	32.39° Nord
Longitude	3.78 ° Est
Collector inclination	32.39°
Collector surface	0. 5×1m
Canal height	0.1,0.09,0.08m
Upper reflector surface	0. 5×1m
Lower reflector surface	/
Fin dimension	0.001×0.04×1m
Number of fins	5,10,20
mirror Reflectivity	0.95
Glass transmissivity	0.90
Cell absorptivity	0.95
back plate absorptivity	0.95
Wind speed	2 m/s
Mass flow	0.03 Kg/s
Thermal conductivity fin	203.6 w/M K
Specific heat absorber plate	896 J/kg K
Density absorber plate	2707/kg /M^3

The performance of the system is evaluated for typical day of April ,mail, join ,the solar the total solar radiation falling on the collector is function reflector length, the angle between the collector and reflector and the tilt of collector ,so the collector is at fixed orientation of 32.48° facing south, whereas the angle of reflectors can be changed .in order to study the effect of tilt angle of the reflectors as function of time the day of April ,mail ,join is chosen, the upper reflector angle is changed from 70 to 150 °, while angle of the lower reflector is changed from 0 to 50 °. We optimize the angles of the reflectors of the ways that we are maximal insulation falls onto the collector. We presented in Figure 1.2 The variation in the total intensity falling on the solar collector and reflected respectively different number of day, we note the solar intensity increases as the length of the reflector increases. Figure 5 shows the change of the ambient temperature during the day in April 2013, for a polynomial approximation of the experimental results, the approximation curve

Is expressed by the equation, under the following conditions

$6 \leq TL \leq 17$ and $292\ K \leq Ta \leq 304k$

$Ta=39.483910.48073TL+1.67969TL^2 0.09325TL^3 +0.00171TL^4+273$

The sky temperature varies depending on the ambient temperature by empirical relationship we have shown previously, so they follow the same pace. The outlet air temperature as a function of time for some system parameters is plotted in Fig.6. It is seen that Tfo is more with the planer reflectors. And when we the length of planer reflector augment the outlet temperature of air increase The difference in Tfo without reflectors and with reflector is more pronounced at low flow rates,

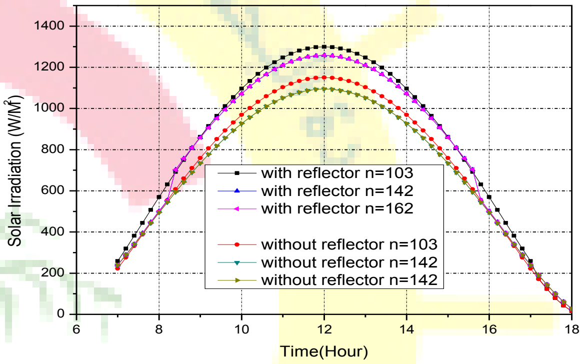

Fig. 3 hourly solar radiation in PVT collector with and without reflectors

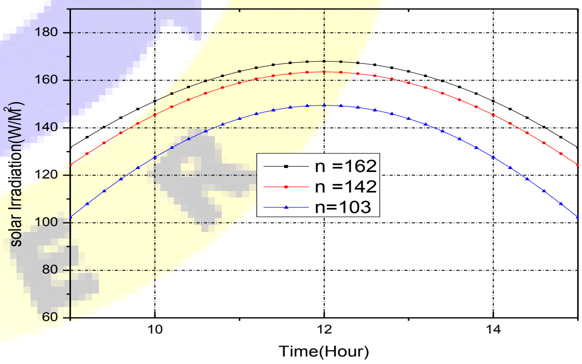

Fig. 4 hourly solar radiation in PVT collector prevent by reflectors

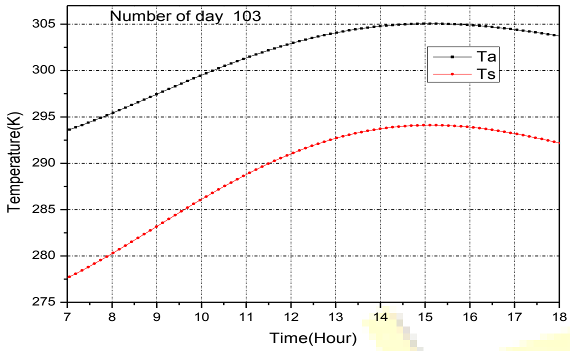

Fig. 5 daily variation of the ambient and sky temperature

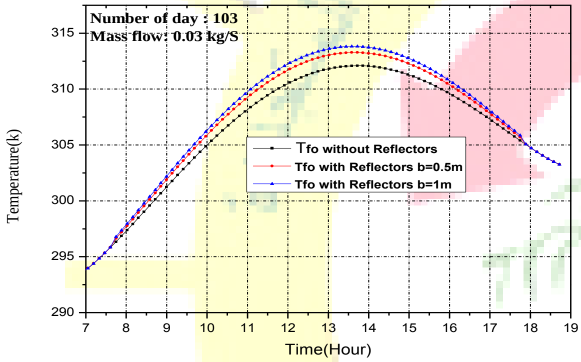

Fig. 6 daily variation of air temperature outlet of air with and without reflectors

In Figure 7 , we have shown the daily variation of the efficiency of thermal , electric and total efficiency of PVT system with an air flow of 0.03 kg / s , the efficiency is slightly higher with reflectors because of increasing of solar intensity exposure , since the PVT with reflector operates at a higher temperature losses also increase . The amount of energy carried by the air is such that the return is the same . The total radiation reaching the absorber is less than that in the absence of solar cells are present. The average temperature of the absorber is less , which is the cause of cause of the slightly higher of efficiency, the efficiency electric of collector with reflector less than the efficiency with reflector , has Cause increasing the temperature of the cell , in all cases , the efficiency is at least between 12 hours and 14 hours , total efficiency without reflector also slightly higher.

Figure 8 illustrate the effect of flow velocity of air on the performance of system. we can observed that the temperature of the fluid decreases as fluid velocity increases, the temperature evolution of the fluid in the two curves cases (with and without reflectors) takes the same shape but their temperature of the fluid when the PVT collector with reflector more elevated than the other, the increase of the velocity of the fluid reduces the heat loss from the system which can increase the efficiency of the system as provided in Figure 9

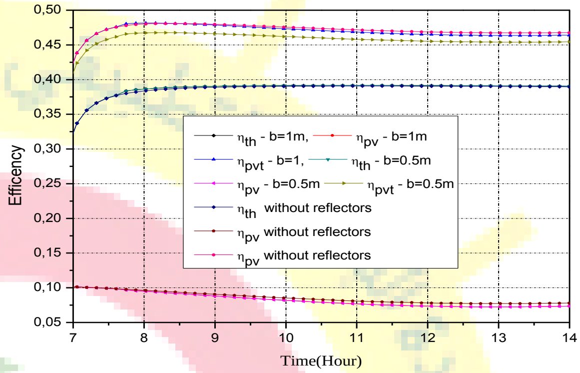

Fig. 7 daily variation of efficiency of PVT with and without reflectors

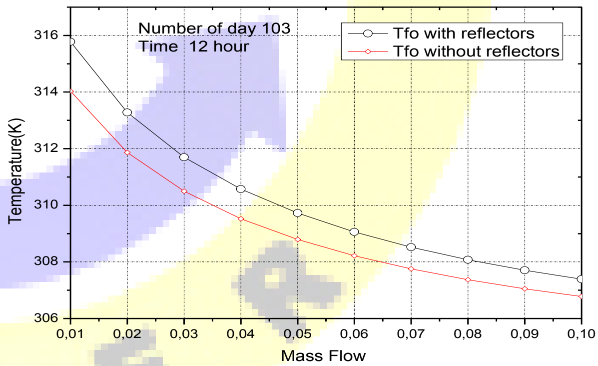

Fig. 8 Effect of mass flow on temperature outlet of air with and without reflectors

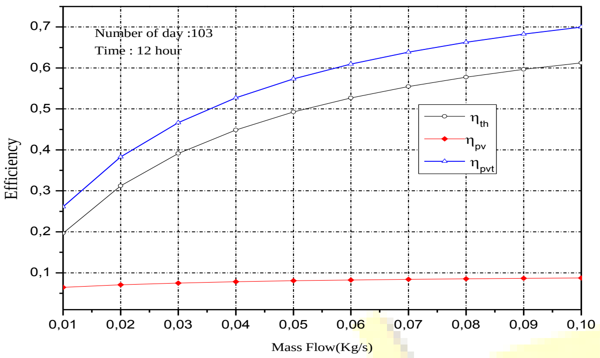

Fig. 9 Effect of mass flow on efficiency of PVT thermal collector with reflectors

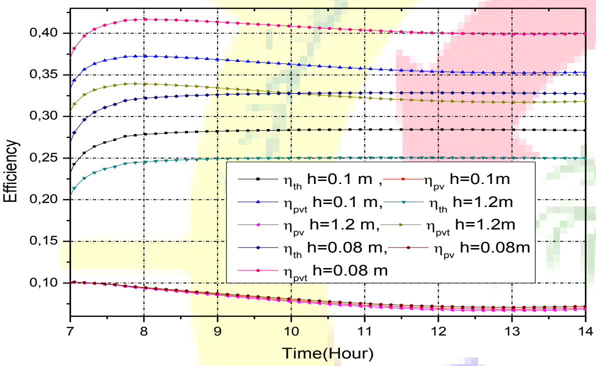

Fig. 10 Effect of height oh canal on efficiency of PVT thermal collector with reflectors

Figure 10 present the effect of the height of the fluid channel on the effectiveness of the system, it is considered that the constant flow system, that is to say the air flow at a constant rate throughout the operating time at a mass flow of 0.03 kg / S, However, because the exposure and the efficiency of solar cells are functions of time .the heat transfer coefficients hcbf and hcpf increase when the channel height decreases. The increased heat transfer coefficient removes more heat from the absorber. The thermal efficiency increases and so does the cell efficiency as provided in Figure

We show in the figure 11-12 the effect of number of fins added to the collector on the outlet temperature of air and the efficiency respectively. Here we can observe that, as we increase the number of fins, the plate temperature decreases as more heat is supposed to be transferred to the fluid because of more accessibility to the heat transfer area. Hence, we also observe an increase of outlet fluid temperature with addition of more and more fins, the increase of efficiency due to increase of number of fins added is represented. That is to say the air flow at a constant rate throughout the operating time at a mass flow 0.03 kg s^{-1}

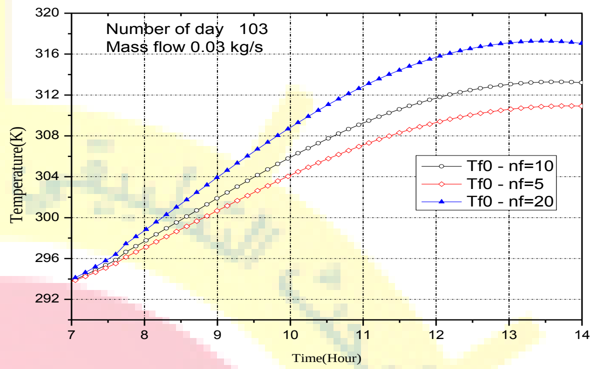

Fig. 11 Effect of number of fin on temperature Outlet of air of PVT collector

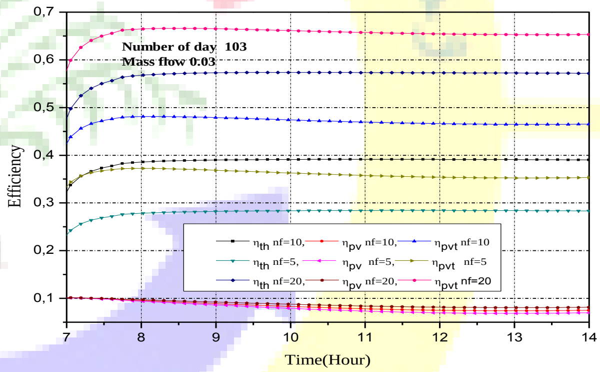

Fig. 12 Effect of number of fin on of efficiency of PVT collector

V. CONCLUSION

A photovoltaic cell generates more electricity when receiver more solar radiation efficiency but decreases when temperature of the solar cell increases. hybrid photovoltaic and the thermal collector with a concentration system is the solution to this problem. Simulation model for single pass, single duct solar collector with fins and planer reflector is developed, we presented a theoretical study of a solar photovoltaic-thermal system (hybrid) consists of a solar air collector solar mounted solar cells a with planer reflector. we tried to present the effect of adding solar reflector on the electrical and thermal performance in their thermal and electrical performance, and other parameter that improves the heat exchange in solar collector such as the height of the air channel of the numbers heating Coils and yielded that the presence of planer reflector, Due to the increased solar insulation , the temperature of the plate and the air outlet temperatures and increases the effectiveness of the collector is slightly increase with respect to without reflector due to increased losses. Decreasing the height of the channel increases the heat exchange coefficient; the heat transfer coefficient increased removes more heat from the absorber. An increase in thermal efficiency and the fact of cell performance

Another thing, when the fins are added to a collector, the temperature of the plate is reduced and, therefore, the coefficient of heat loss is also reduced. This also improves performance by reducing the total heat loss.

VI. References

[1]. EbrahimM. Ali Alfegi, Transient mathematical model of both side single pass photovoltaic thermal air collector, ARPN Journal of Engineering and Applied Sciences,vol. 2,no. 5,october2007.

[2]. F. Sarhaddi, An improved thermal and electrical model for a solar photovoltaic thermal (PV/T) air collector, Applied Energy 87 (2010) 2328–2339

[3]. Ashok kumar ,Bhargava, Study of a hybrid solar system--solar air heater combined with solar cells Energy Converts. Mgmt Vol. 31, No. 5, pp. 471--479, 1991.

[4]. Adel A. Hegazy, Comparative study of the performances of four photovoltaic/thermal solar air collectors, Energy Conversion & Management 41 (2000) 861±881.

[5]. M.Y.H. Othman, Development of advanced solar assisted drying systems, Renewable Energy 31 (2006) 703–709.

[6]. Ebrahim M. Ali Alfegi, Mathematical Model of Double Pass Photovoltaic Thermal Air Collector with Fins, American Journal of Environmental Sciences 5 (5): 592-598, 2009.

[7]. Goh Li Jin, Adnan Ibrahim, Evaluation of Single-Pass Photovoltaic-Thermal Air Collector with Rectangle Tunnel Absorber, American Journal of Applied Sciences 7 (2): 277-282, 2010.

[8]. Henning Helmers, Multi-linear performance model for hybrid (C)PVT solar collectors, Solar Energy 92 (2013) 313–322

[9]. H. P. GARG, The effect of plane booster reflectors on the performance of a solar air heater with solar cells suitable for a solar dryer, Energy Convers. Mgmt Vol. 32, No. 6, pp. 543-554, 1991.

[10]. Goh Li Jin, Adnan Ibrahim, Evaluation of Single-Pass Photovoltaic-Thermal Air Collector with Rectangle Tunnel Absorber, American Journal of Applied Sciences 7 (2): 277-282, 2010.

[11]. Li Guiqiangab, Preliminary study based on building-integrated compound parabolic concentrators (CPC) PV/thermal technology, Energy Procedia 14 (2012) 343 – 350

[12]. SUN Jian& SHI Ming Heng, Numerical study on optical and electric-thermal performance for solar concentrating PV/T air system, Sci China Ser E-Tech Sci, 2009,52(12): 3514—35.

[13]. Du • e, J. A. and Beckman, W. A., Solar Energy Thermal Processes. Wiley, New York, 1974, p. 83.

[14]. K.F. RILEY, M.P. HOBSON and S.J. BENCE, Mathematical Methods for Physics and Engineering, Third Edition,© K. F. Riley, M. P. Hobson and S. J. Bence 2006

[15]. J.I. Rosell, X, Design and simulation of a low concentrating photovoltaic/thermal system, Energy Conversion and Management 46 (2005) 3034–3046.

[16]. Masato Morimoto, Static solar concentrator with vertical flat plate photovoltaic cells and switchable white transparent bottom plate, Solar Energy Materials & Solar Cells 87 (2005) 299–309.