International Conference on Mechanical, Industrial and Materials Engineering 2015 (ICMIME2015)
11-13 December, 2015, RUET, Rajshahi, Bangladesh.

Paper ID: ET-47

Maximum Utilization of Solar Radiation in a Solar Air Heater Combined with Solar Cells by Concave Lens

Md. Sazan Rahman*, Md. Saiful Islam, Najmul Hoque, Mohd. Rafiqul Alam Beg
Department of Mechanical Engineering, Rajshahi University of Engineering & Technology
E-mail: sazan.ruet@gmail.com

Abstract

A solar hybrid energy system having photovoltaic and thermal (PV/T) devices, which produces both thermal and electrical energies simultaneously is considered for this study. A double pass hybrid solar air (PV/T) heater with concave lens is designed and fabricated to observe its thermal and electrical performance. The collector is designed in such a way so that it contains concave lens which diverse sun light from collector plate to solar panel. The raise in temperature of the solar cell is liable to decrease its electrical performance and that is why the temperature above the solar panel is maintained around 25^0C by diverging light through concave lens to obtain maximum electrical power. Less space required for lens compared to normal systems also yield a better thermal power. The system produces overall efficiency 52.66% at mass flow rate 0.02816 kg/sec whereas the maximum thermal and electrical efficiency was 52.5% and 3.85% accordingly. Around 9.24% efficiency improvement has been achieved due to the design improvement for this study.

Keywords: Solar radiation, air heater, solar cell, concave lens.

1. Introduction

Solar energy is one of the most important sources of clean energy. Solar thermal energy systems convert solar energy into heat whereas solar photovoltaic systems produce electrical energy. Besides, in solar thermal energy systems electrical energy is one of the inputs for extracting the useful energy. A hybrid PV/T collector, however, provides both thermal and electrical energy simultaneously. This concept increases the electrical efficiency of photovoltaic systems by decreasing cell surface temperature and increasing overall efficiency of the hybrid unit.

A number of theoretical, numerical and experimental studies have been reported on the solar Hybrid PV/T air collector using air or water as the working fluid. Integrated PV/T collector based energy system produce both thermal energy and electrical energy, Kern and Russel [1]. Thermal efficiency and other performances of different types of collectors and unglazed transpired collector have been analyzed by M.Augustus Leon and S. Kumar[2]. But the transpired collector is not available everywhere. The flat plate heaters can absorb both direct and diffuse solar radiation while The concentrating heaters in the main can absorb only direct solar radiation The flat plat solar collector, its heat flow paths, way of losses have been reported, Fabio Struckmann[3].In which the reflection(10%) and absorption (5%) loss of glass cover and the collector plate reflection(5%) loss etc are shown. So heat absorbed by the collector is 80% .But most of which i.e about 45% heat is lost to surrounding due to poor insulation. So most solar collectors have maximum thermal efficiency 35% . By proper designing if any of these factors can be minimized then higher thermal efficiency can be obtained. The efficiencies for varying mass flow rate have been reported by Omjara and Aldabbagh and they observe the efficiency increases with increasing mass flow rate where external electrical source is needed [4]. The thermal efficiency increases with increase in height and number of fins of a double pass flat plate solar air heater with longitudinal fins, whereas the entropy generation was inversely proportional to the height and number of fins, Naphon [5].

Heating of both air and water simultaneously with electricity have been offered a complicated design but gives maximum efficiency 65% which required expensive transparent cell, Musallam Ahmed Tabook *et* all [6]. The combined PV/T system have been designed where the solar panels are placed above the collector surface. Panel is cooled by air flow above the collector surface which also act as air heating system but a large fraction of collector exposed area is covered by solar panel that have been found as major limitation, Maruful Haque and Md.Sharif Ahsan[7]. From those above study, in order to overcome maximum limitations, difficulties, and complexities and by considering maximum efficiency with lowest cost, a new design of PV/T collector is installed in this project and its performances are analyzed and compared with previous set up.

In this project, a simple flat plate collector is used to collect solar radiation because the concentrating heaters in the main can absorb only direct solar radiation while the flat plate heaters can absorb both direct and diffuse solar radiation. Black paint is used to make it a black body. Because black paint has reflectivity 0.02 & absorptivity 0.99.The collector contains 8 concave lenses where each 2 lens is used for one solar panel of 5 watt rated. In all previous set up, the solar panel is placed on the surface of the collector. So, a large area of black body is covered by solar panel & large amount of air is required to keep it's temp. at around 25°c at which it gives maximum efficiency. But by replacing solar panel by lens, a large advantage is obtained. When light is refracted through the lens and falls on the panel surfaces, due to small area of lens & more area of collector exposed to sun light & due to its diverging effect, the temp above the solar panel is lower than normal sun light temperature. The solar panel cooling is done by natural flow of atmospheric air.
Here, the light above the cell is not properly maintained that is why the cell gives lower output than it's rated value. But due to large area utilization, the collector gives maximum output or more efficiency than all previous set up. The latest set up gives 26.8% overall efficiency without fin [6].But this project gives more collector & overall efficiency than previous set up i.e about 52.5% and 52.66% respectively.

2. Methodology

The solar air heater of modified setup has been designed which is shown in figure 1. The materials used for the design are mainly: Wooden box :(1.5×1×.12) m^3 =1 piece, Glass: (1.46×.96×.005) m^3= 1 piece, Aluminum plate: (1.5×1×.001) m^3=1 piece, Concave lens : (0.075×0.0575) m^2=4 piece, Solar cell: (.30×.23)m^2= 4 piece, Black paint: 1.5 kg, Stand: Angle bar, Cork board: (0.5inch thick) = 2 piece. Area: 1m^2, Others: Wood, screw, brush, gum etc.

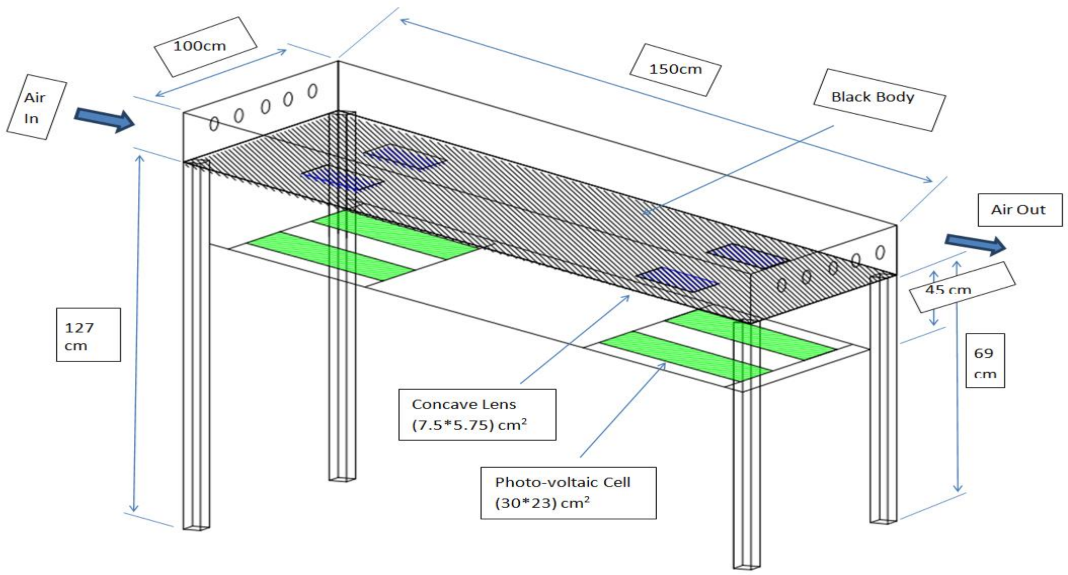

Fig. 1. Isometric view of solar air heater with PV panel

Construction procedure

At first a wooden box is made whose base is covered by partex of 1.5 m² .The box is sufficiently rigid to take the load of cover glass, collector sheet & other arrangements [8-9]. After making the box, the stand is made by angle bar according to the size of the box. In stand, there are two racks that are made to support air heater box & solar panel. Then the box is covered by insulator for which cork sheet of 3 in is used and four opening are cut to pass light through it from lens to the panel which is closed by transparent glass. Next, the G.P. sheet is coated by black paint in order to make it a good radiation absorber and 8 small holes are made to set lens at that opening. After drying the paint, the lens are placed on the sheet opening & adjusted by pudding. Then, this collector sheet with lens is set on the box and total arrangement is covered by transparent glass. After preparing the box, a convergent section is adjusted with the box which contains both the inlet & exit port for the flowing of air. The exit port also contains the arrangement to hold the blower.

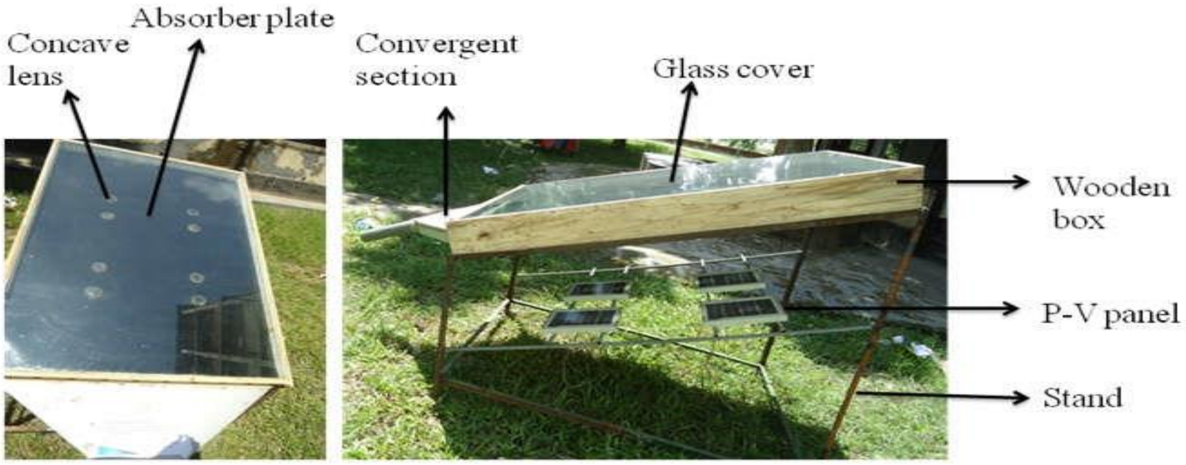

Fig. 2. Final assembly of solar air heater

Finally, the box with the convergent section is set on the frame and the solar panels are set on the lower rack according to the lens & the opening of the box. The total system is made incline 23^0 to receive solar radiation in perpendicular with the collector plate.

Experimental procedure

Air inlet and outlet temperatures were measured by using thermometer. From thermometer those data are directly noted to data table with the help of anemometer. The velocity of flow is measured directly from the outlet of the heater [10]. For measuring mass flow rate, the anemometer propeller was placed at the outlet of the blower. The velocity was measured for several times and finally the average velocity was fixed to take reading. The known outlet area was used to calculate mass flow rates according to the formula m= ρ Av (where,ρ =density of air, A= cross sectional area ,v= velocity of air). A rate of mass flow was fixed for a particular day. The velocity was adjusted to keep the mass flow rate constant, since the density of air changes with changes in temperature.

The current and voltage was measured by multi-meter directly. To get the voltage reading the multi-meter is calibrated to voltage part and circuit is connected to voltage knob. Similarly, to get current reading the multi-meter is calibrated to current part and circuit is connected to current knob. From multi-meter those data are directly used to calculate efficiencies. The current and voltage are also measured by changing the circuit in series and parallel. The readings were taken at various intervals (15min, 30min or 60min) and were recorded in a data sheet. The top of the heater was not always placed normal to the sun because the tilt angle of sun varies from time to time but our heater tilt angle is fixed. The day which gives intensity of irregular value was neglected from investigation [11].

3. Results and Discussion

The double pass solar air heater combined with photovoltaic panel by concave lens is investigated experimentally between 08-12-2014 and 17-12-2014 under Rajshahi weather condition. The readings are taken at the bright sunshine day. The performance of double pass solar air heater is studied. The mass flow rate is varied from 0.0012 kg/s to 0.02816 kg/s. where the intermediate mass flow rates are 0.016 kg/s, 0.0181 kg/s, and 0.02112 kg/s. The various curves showing the performance of the solar air heater are given below:

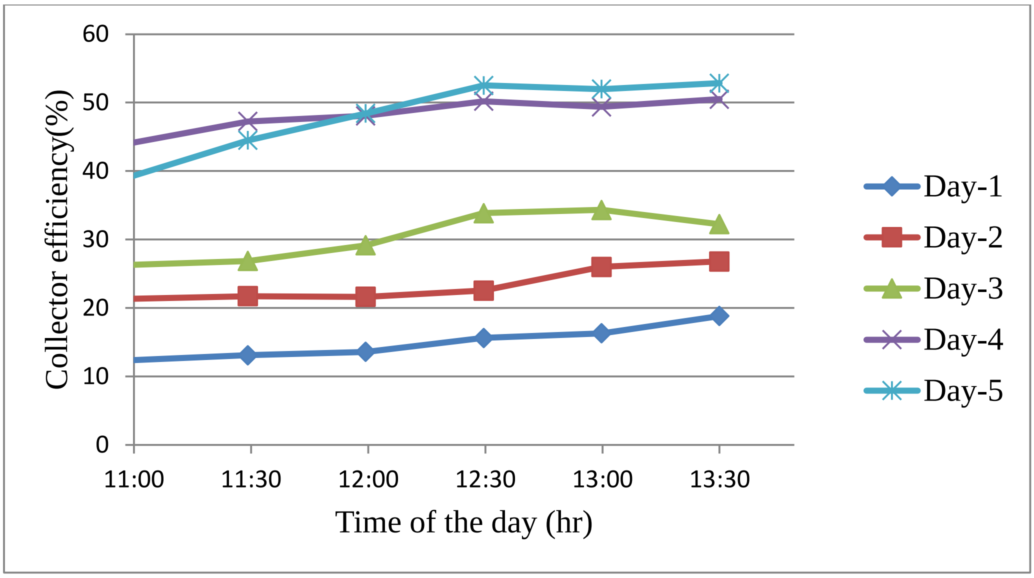

Fig. 3. Time of the day vs. collector efficiency curve.

From fig. 3, it is seen that the collector efficiency increases with the day time. In 1st & 2nd day, the collector gives lower efficiency due to low mass flow rate and leakage problem. By overcoming the leakage problem and by increasing the mass flow rate, the maximum efficiency of 52.3% is obtained at day-3.

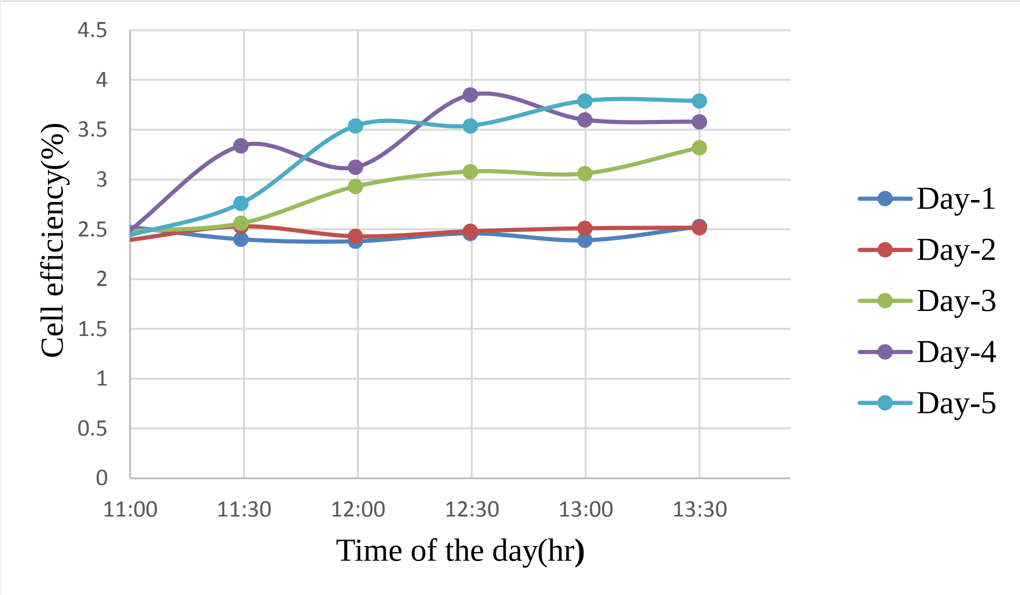

Fig. 4. Time of the day vs. cell efficiency curve.

From fig. 4, it can easily be told that, the cell efficiency is also independent of day time but the efficiency varies slightly due to light angle of the lens. The maximum efficiency is obtained when the solar ray is approached to perpendicular with the concave lens. The cell efficiency varies from 2.38% to 3.85%. The day time and mass flow rate have very little effect on cell efficiency but with increasing the total lighted surface of panel the efficiency will be increased.

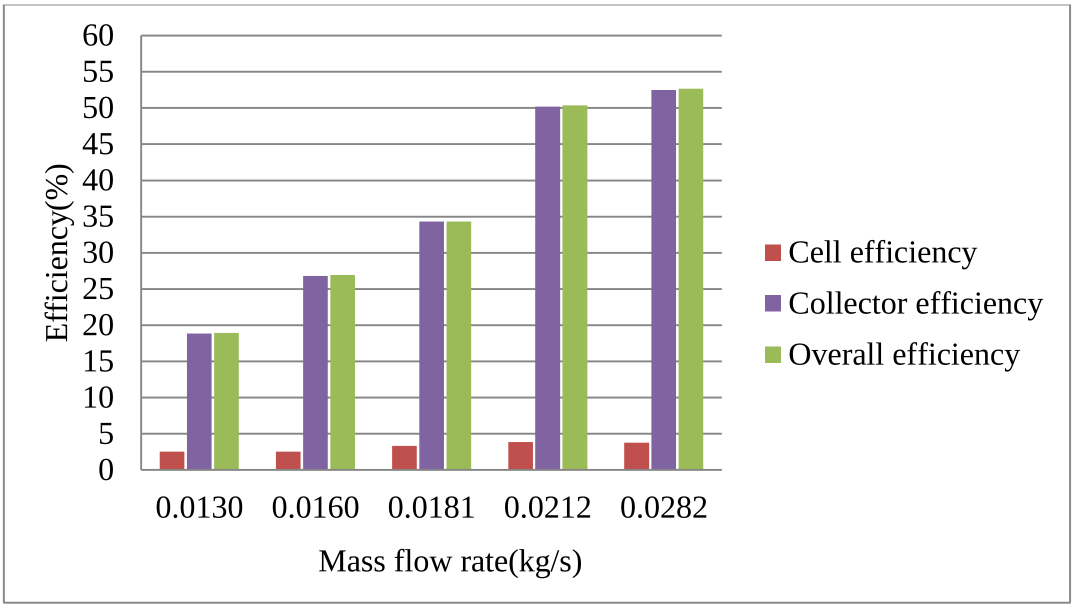

Fig. 5. Effect of cell efficiency on overall efficiency.

From fig. 5, it is obtained that the effect of cell efficiency is very low on overall efficiency because the cell produce maximum power 2.81 watt with 3.85% efficiency but the collector produce the maximum power 838.08 watt with 52.66% efficiency. So, in order to get maximum overall efficiency, more concentration is given to increase the collector area. By sacrificing small amount of cell power, a large collector power can be achieved for which the overall efficiency of this project is higher than all previous setup.

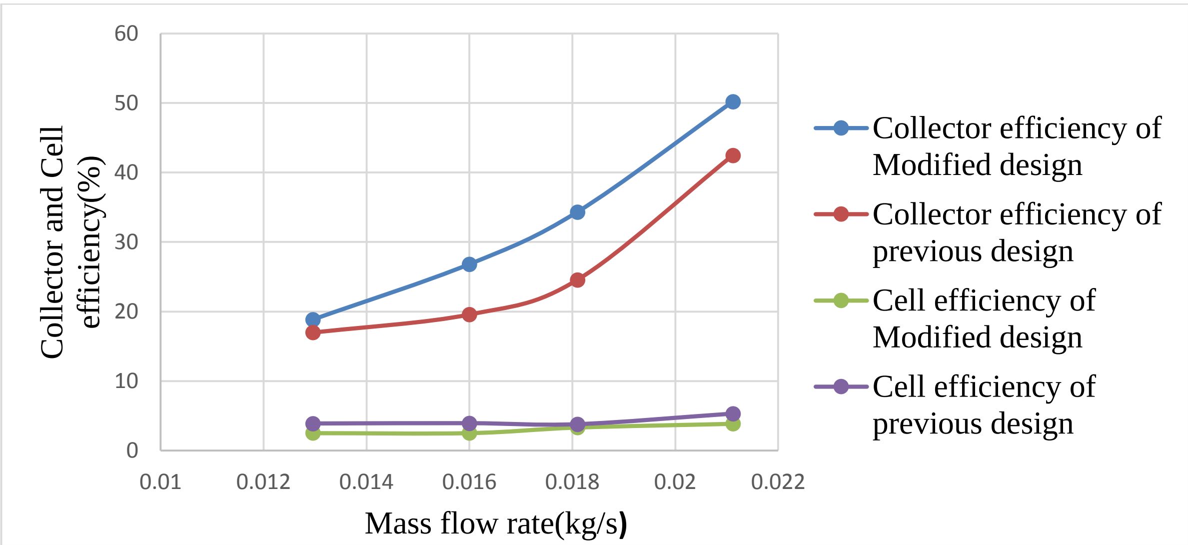

Fig. 6. Comparison curve of mass flow rate vs. collector and cell efficiency.

From fig. 6, it is shown that the cell efficiency of modified design is lower than the old design. It is due to poor lighting on panel surface, due to lens angle. If the lens is able to light the whole area of the panel, then the cell gives their rated power and those small power losses is eliminated. But the modified collector gives more efficiency than the old collector which is very much higher than the small lens.

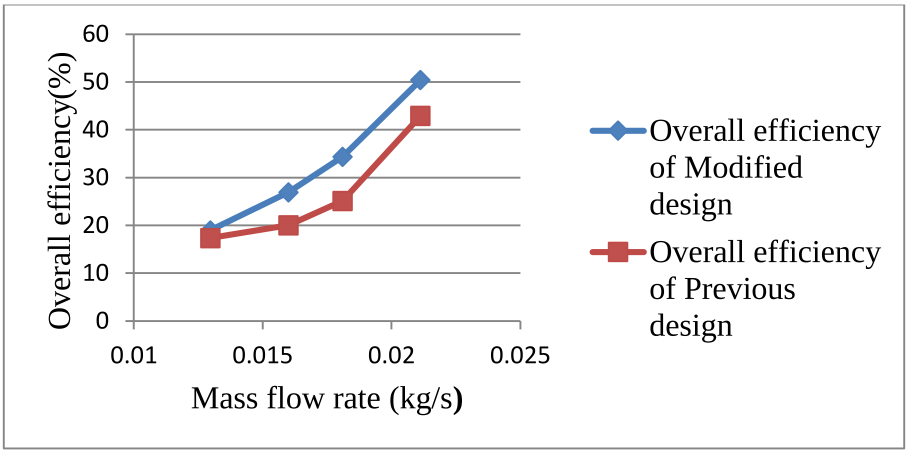

Fig. 7. Comparison curve of mass flow rate vs. overall efficiency.

In fig. 7, it is clear that the overall efficiency of modified design is very higher than the previous. For same mass flow rate of 0.02112 kg/s, the old design efficiency is 42.89% where the new modified design efficiency is 50.38%. So, the improvement in efficiency is 7.49%. As a result, more solar radiation is utilized in modified setup.

4. Conclusion

Hybrid photovoltaic-thermal solar collector is experimentally studied with respect to its operating characteristics. All the data are collected in sunny weather. The thermal efficiency is increased with the increase of mass flow rate. In lower mass flow rate, the efficiency is lower. The mass flow rate varies from 0.01296 kg/s to 0.02816 kg/s. The maximum collector efficiency is 52.50% for the higher mass flow rate of air 0.02816 kg/s. The maximum overall efficiency is obtained 52.66% for the higher mass flow rate of air 0.02816 kg/s. The cell efficiency is also calculated. The maximum Efficiency of cell is 3.85 %.The maximum cell, collector and overall efficiency of previously designed double pass solar air heater are 6.65 %, 42.46% and 42.89% respectively. The maximum improvement of collector efficiency for modification of design is 9.24%. But the maximum humiliation of cell efficiency is 2.8%.

5. References

[1] Kern Jr, E. C. and Russell, M.C.(1978). “Combined photovoltaic and thermal hybrid collector systems”, in: *Proc.13th IEEE photovoltaic specialists*, Washington, USA, 1978, 1153–1157.

[2] Augustus, L. M. and Kumar,S.*(2007). “Mathematical modeling and thermal performance analysis of unglazed transpired solar collectors”. Received 1 September 2006,*Solar Energy* 81 (2007) 62–75.(Energy field of study , AIT, Thailand .)

[3] Stackmann, F.(2008). “Analysis of a Flat-plate Solar Collector.” Project Report, May 08, 2008, Lund, Sweden.

[4] Omjara, A.P.O. and Aldabbagh, L.B.Y.(2010). “Experimental performance of single and double pass solar air heater with fins and steel wire mesh as absorber”. *Applied energy* 87 (2010) 3759-3765.

[5] Naphon, P.(2005). “On the performance and entropy generation of double pass solar air heater with longitudinal fins”. *Renewable Energy*. 2005, 30, 1345–1357.

[6] Tabook1,M.A., Othman2,M.Y., Sopian3, and K. Ruslan4,M.H.(2014), “A Review Paper on PV/T Combination Flat Plate Collector System and Design” *World Essays Journal* / 1 (1): 1-5.

[7] Haque,M. and Ahsan, M.S.(2013), “Effect of mass flow rate on the performance of a double pass solar air heater with and without fin”. UG thesis, Rajshahi University of Engineering and Technology, Bangladesh.

[8] Ahmad M. S.(2012). “Modeling of flat plate solar collector operation in transient states”. PG thesis, May 2012 Purdue University Fort Wayne, Indiana.

[9] Ebrahim, M.A.A., Sopan, K., Othman, M.Y.H., and Bin, Y.(2009). “Mathematical model of double pass photovoltaic thermal air collector with fins”. *APRN Journal of Engineering and Applied Sciences*. Vol .2, no.5, October.

[10] Qenawy, A. M. and Mohamad, A. A.(2007). “Analysis of high efficiency solar air heater for cold climates”. *2nd Canadian Solar Buildings Conference Calgary*, June 10 – 14, 2007.

[11] Srinivas, M. and Jayaraj, S.(2013). “Energy and exergy analysis of a two pass photovoltaic -thermal (PV/T) air heater”. *International journal of Energy and Environment.* Volume 4, Issue 3, 2013 pp.467-480.