FUPRE Journal of Scientific and Industrial Research
Vol.6, (1), 2022
ISSN: 2579-1184 (Print) ISSN: 2578-1129 (Online)

Performance Analysis of a Flat Plate Solar Collector in a Multi-Panel Configuration System

Abhulimen F.O[1], Anaidhuno U. P[1], Maduike F.[1]
[1,]Department of Mechanical Engineering, Federal University of Petroleum Resources, Effurun, Nigeria.
okoigun.abhulimen@fupre.edu.ng, anaidhuno.ufuoma@fupre.edu.ng,maduike.francis@fupre.edu.ng

Abstract
Energy usage world- wide has been on the increase to the extent that fossil fuel resources are depleting. In Nigeria, price increase of this fossil fuel (oil and gas) has made the populace turning to the use of wood as fuel thereby causing desert encroachment. With these trends in energy usage, solar is conceived as alternative to these fuels.In this study a double glazed collector and single glazed collector was designed and using existing model (theoretical and experimental) was used to determine the effects of glazing cover arrangement on the performance of solar collector. Tests showed that the double glazed single panel collector, was able to heat water to an average maximum temperature of 98^0C and for the single glazed double panel collector, it was 84^0C in a clear weather condition for the same amount of water of 120 litres.

Keywords: Glazed, flat plate, solar, collector, panel.

1. Introduction
The heating of water for domestic use (bathing, cooking, cleaning, etc.) presently accounts for an appreciable proportion of energy needs. The enormous demand is currently being met primary through burning of fossil fuels like coal, gas, oil etc. or use of electricity; the use of fossil fuel like kerosene and cooking gas is very expensive nowadays in countries that are not endowed with such natural resources. In the countries that are endowed with it problem of distribution such as bad roads, lack of technological knowhow and excess profiteering by marketers deny most people access to it.

In Nigeria, for example, the hoarding and diversion of petroleum products to the neighbouring countries which resulted in an uneven distribution coupled with bad roads has further compounded the problem of supply and use of kerosene and cooking gas by both rural and urban dwellers. As a result of non-availability of some of these petroleum products, the use of firewood has been on the increase; the increase in demand of firewood is causing lot of deforestation which is leading to destruction of vegetation and animals. If the trend is not checked presently, Nigeria will continually be depleted of wood to the peril of national ecological setting or green environment and consequently will face global warming.

Besides the high procurement cost and scarcity of fossil fuels, their burning is associated with environmental pollutions. In order to circumvent these problems, alternative sources are sought; solar energy has been found to be one of the best alternatives, because of its inherent advantages such as its abundance, availability, inexhaustibility and environmental friendliness. At present the most successful utilization of solar energy is in area of domestic hot water, space heating and cooking as well as generating electricity, etc. Among these many uses of solar energy, heating process is one which has been exploited the most. It is now being accepted as a practical way of providing domestic hot water system in Japan, Israel, U.S.A, Indian, France, and some Latin America (Chandra and Oguntuase, 1986).

The most common solar collector types are; unglazed flat plate collectors, glazed flat plate collectors and evacuated tube solar collectors. In this study a double glazed and single glazed collectors was designed to compared the temperature output of the two and this study was carried out in Auchi in Edo State Nigeria where a single glazed has be used by past researchers with the followingresults from their study, highest output temperature of 60^0C and water temperature 48^0C, to compared the result of the double glazed with the single glazed result, Auchi is with high radiation intensity of up to 810W/m^2 and average ambient of 32^0C (Data from metrological observation by civil Department, Auchi polytechnic, Edo state).

The flat plate collectors use either air or liquid to transfer the collected heat to whatever it is needed but whatever heat transfer medium is used, the principle of operation involved is the same. The vast majority of the flat plate collectors therefore, have the following basic components in common:the absorber surface, the heat transfer interface/fluid passage, the glazing and the storage tank.

The flat plate collectors used are the single glazed where large area are used that is, multi collectors in order to raise the temperature to a higher degree and by doing this increase the cost and space, heat is loss along the way to the storage tank. But the double glazed has not be visited by many researcher, the double glazed is to make the system compact and increase the temperature output, using the same materials and reduced the heat loss in the system. Against this back drop on a single glazed, is this research – Performance analysis of a flat plate solar collector in a multi-panel configuration system.

2. Methodology

The methodology of this research study involves three stages:

(i) The theoretical Analysis /Design
(ii) Construction of the Solar water heating system
(iii) Experimental/Performance Test

The double glazed solar flat plate collector and the single glazed flat plate collectors were connected in series, were stationed outside for effective solar radiation into the system. Mercury - in - glass thermometers were mounted in the following points in the solar collectors.

1. The water inlet pipe of the first collector, the thermometer measures the inlet water temperature,
2. The water inlet pipe of the second collector, the thermometer measures the outlet water temperature of the first collector and water inlet temperature of the second collector,
3. The water outlet pipe of the second collector to the hot water storage tank,the thermometer measures the outlet water temperature of the second collector,
4. The top water level and the bottom of the hot water storage tank, the two thermometers measure the temperatures of the hot water at the top and bottom of the hot water storage tank respectively. The average of the temperature readings atthe top water level and the bottom gives the bulk water temperature of the tank.

Eppley-pyranometer was used to measure the solar radiation intensity.

After the setting up of the experiment and carried out the orientation of the panel usingthe geographical latitude of Auchi of 7^0 with the convectional angle of 10^0, it was inclined at angle of 17^0 using the protractor to locate the direction.

The collector was made to face due south as the convectional rule for the best all year round performance, with this the sun ray can caught across the panel at any time of the day.

After all the above had be done the first test began by 8am and the first record was done after one hour by reading the thermometers that have been fixed in the various points in the setup and the test records is done every one hour, from 8am- 6pm each day for ten days. Also the solar radiation intensityusing the eppley-pyranometer recorded every one hour, the useful heat gain by the collector, the collector hourly efficiency and the performance coefficient were calculated using the following equations

For useful heat gain by the collector equation

$$Q_u = A_c F_R \lfloor H\tau\alpha - U_L(T_{in} - T_a) \rfloor \quad (1)$$

For the collector hourly efficiency equation $\eta_H = \frac{Q_U/A_C}{H}$, (2)

For the collector daily efficiency equation $\eta_D = \frac{\Sigma Q_U/A_C}{\Sigma H}$ **(3)**

For performance coefficient $(T_{fi} - T_a)/H$ (4)

All the above equations were repeated throughout the period of the test for each day based on the temperature and the solar radiation intensity for each day and the results are presented in the Tables.

3. Results and Discussion

3.1 Results

TABLE1:April 9th, 2019. Evaluated Parameters of Double-Glazed Single Panel Collector Unit.

Period Hour	Ambient Temperature Ta (^{0}C)	Fluid inlet temperature, T_{fi} (^{0}C)	Fluid outlet temperature, T_{fo} (°C)	Bulk water temperature, of the tank T_b, (^{0}C)	Solar radiation intensity on the Collector Tilted Surface H (W/m^2)	Useful heat gain by the collector, $Q_u = A_c F_R[H\tau\alpha - U_L(T_{in} - T_a)]$ (W/m^2)	Collector hourly efficiency $\eta_H = \frac{Qu}{H}$	Performance Coefficient $\frac{T_{fi}-T_a}{H}$ (°Cm^2/W)
8-9	31	38	64	50	295.71	134.08	0.45	0.01
9-10	35	39	70	57	306.10	150.14	0.49	0.01
10-	35	43	74	61	651.82	402.36	0.49	0.05
11	37	45	78	68	854.64	412.99	0.48	0.05
11-	37	54	79	73	868.08	376.13	0.43	0.05
12	38	62	90	77	871.04	367.92	0.42	0.06
12-1	39	65	96	81	871.95	358.51	0.41	0.07
1-2	37	60	91	79	858.76	340.80	0.40	0.06
2-3	35	56	88	75	641.97	213.33	0.33	0.08
3-4	34	55	86	71	291.72	12.37	0.042	0.12
4-5								
5-6								

The Daily Efficiency of the collector (η_D)

From equation (3.34) $\dot{\eta}_D = \frac{\sum Q_U}{\sum_H}$ where $\sum Q_U$ is the summation of hourly useful heat gain and $\sum_H$ is the summation of hourly solar radiation intensity.

$$\dot{\eta}_D = \frac{26888}{651179} = 0.41$$

TABLE 2: April 9th, 2019.Evaluated Parametersof Single Glazed Double Panel Collector Unit

Period Hour	Ambient Temperature Ta (°C)	First collector fluid inlet temperature, T_{fi} (°C)	First collector fluid outlet temperature, T_{fo}(°C)	Second collector fluid outlet temperature, T_{fo}(°C)	Bulk water temperature, of the tank T_t(°C)	Solar radiation intensity on the Collector Tilted Surface H (W/m²)	Useful heat gain by the collector, $Q_u = A_c F_R [H$	Collector hourly efficiency $\eta_H = \frac{Qu}{H}$	Performance Coefficient $\frac{T_{fi}-T_a}{H}$ (°Cm²/W)
7-8	31	38	39	44	41	295.71	132.18	0.45	0.03
9-10	35	39	44	49	46	306.10	147.14	0.48	0.03
10-11	35	43	49	58	50	651.82	315.63	0.48	0.02
11-2	37	45	59	66	57	854.64	410.29	0.48	0.03
12-1	37	54	67	71	66	868.08	375.33	0.43	0.04
1-2	38	62	70	74	71	871.04	365.72	0.41	0.04
2-3	39	65	73	80	72	871.95	347.51	0.40	0.04
3-4	37	60	69	74	68	858.76	337.83	0.40	0.04
4-5	35	56	66	69	64	641.97	209.53	0.32	0.05
5-6	34	55	62	66	63	291.72	11.27	0.039	0.10

$$\dot{\eta}_D = \frac{\sum Q_U}{\sum_H} \dot{\eta}_D = \frac{2653.42}{6511.79} = 0.40$$

The experimental hourly efficiencies ($\dot{\eta}_D$) of the collectors are plotted as a function of the period (hour) to obtained the hourly efficiency curve of the collector for the first test carried out on 9th April 2019 as shown in figure 1.

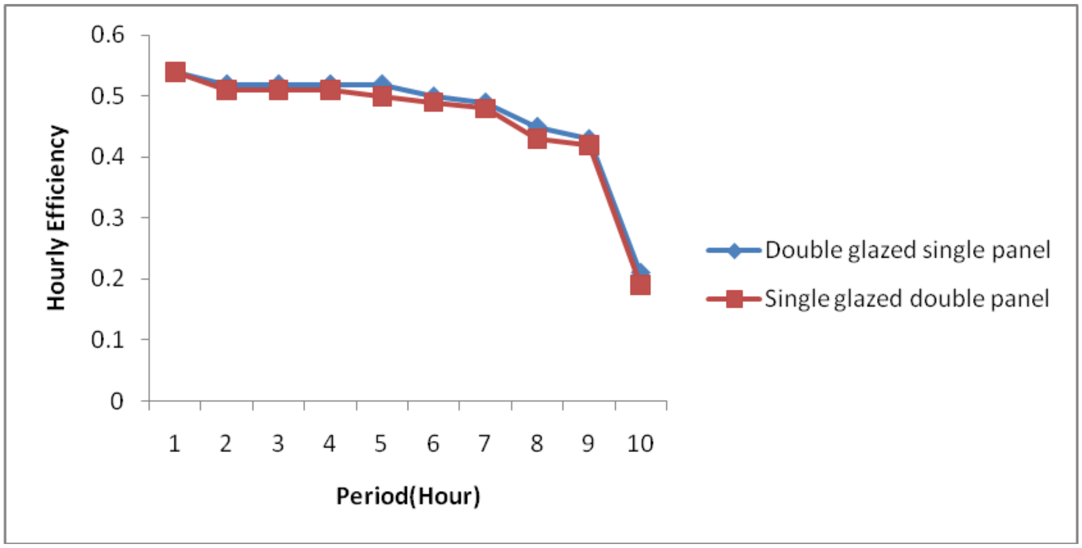

Fig.1: Experimental Hourly Efficiency Curve of the Collectors for the First Test

Table 3. April 13th, 2019. Evaluated Parameters ofsingle Glazed Double Panels Collector Unit

Period Hour	Ambient Temperature T_a (^{0}C)	First collector fluid inlet temperature, T_{fi} (^{0}C)	First collector fluid outlet temperature, T_{fo} (^{0}C)	Second collector fluid outlet temperature, T_{fo}(°C)	Bulk water temperature, of the tank T_t(^{0}C)	Solar radiation intensity on the Collector Tilted Surface H (W/m^2)	Useful heat gain by the collector, $Q_u = A_c F_R$	Collector hourly efficiency $\eta_H = \frac{Q}{I}$	Performance Coefficient $\frac{T_{fi}-T_a}{H}$ (°Cm^2/W)
8.00—9.30	29	34	38	40	38	273.54	133.67	0.49	0.02
9.30-11.0011-12.30	30	34	38	40	38	307.35	158.53	0.52	0.01
12.30-2.00	32	35	38	41	39	635.04	355.58	0.56	0.01
2.00—3.30	33	38	45	48	49	781.57	417.47	0.53	0.01
3.30—5.00	34	40	47	50	49	778.39	414.50	0.53	0.01
5.00—6.30	31	35	39	41	40	298.30	153.53	0.51	0.01
	31	33	36	39	36	269.85	141.55	0.52	0.01

On the 13th April 2019 average temperature of hot water withdrawn from the tank, the double glazed single panel was 68^{0}C, the single glazed double panel was 49^{0}C and the double glazed double panel collector was 84^{0}C respectively.

The experimental hourly efficiencies ($\dot{\eta}_D$) of the collectors are plotted as a function of the period (hour) to obtain the hourly efficiency curve of the collector for the fifth test carried out on 13th April 2019 as shown in Fig. 2

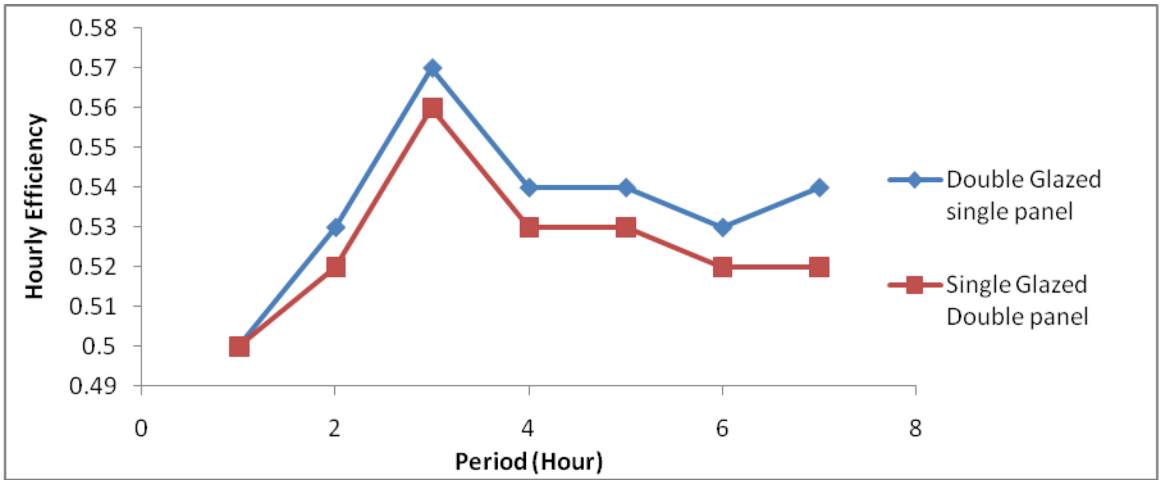

Fig. 2: Experimental Hourly Efficiency Curve of the Collector for the Fifth Test

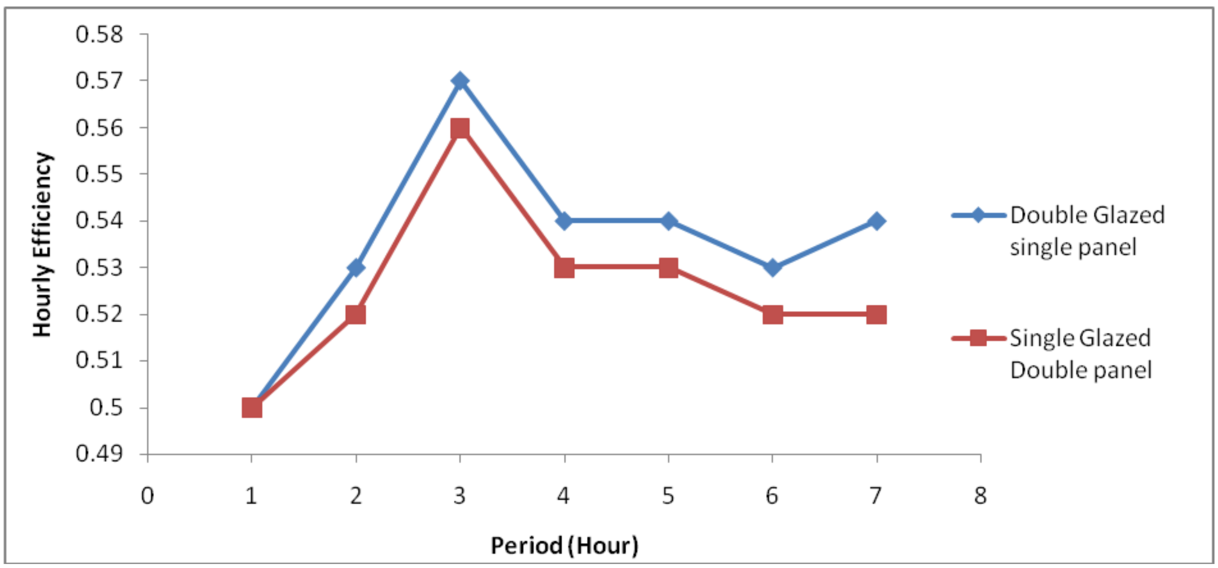

Fig.3: Experimental Hourly Efficiency Curve of the Collector for the Tenth Test

The table below showed the calculated daily efficiencies $\left(\dot{\eta}_D\right)$of the three set up experiments for the period of the study.

Table 3. The Calculated Daily Efficiencies ($\dot{\eta}_D$) of the Tests during the Period of Test

Period (Day)	Double Glazed single panel Daily efficiency($\dot{\eta}_D$)	Single Glazed Double Panel Daily Efficiency($\dot{\eta}_D$)
1.09/04/2019	0.42	0.40

2. 10/04/2019	0.43	0.42
3. 11/04/2019	0.48	0.47
4. 12/04/2019	0.52	0.51
5. 13/04/2019	0.54	0.53
6. 14/04/2019	0.41	0.40
7. 16/04/2019	0.43	0.42
8. 17/04/2019	0.48	0.47
9. 19/04/2019	0.52	0.52
10.20/04/2019	0.54	0.53

From the experimental calculateddaily efficiencies **($\dot{\eta}_D$)** of the collectors, are plotted as a function of the period (day) to obtain the daily efficiency curve of the collector as shown in Fig.4

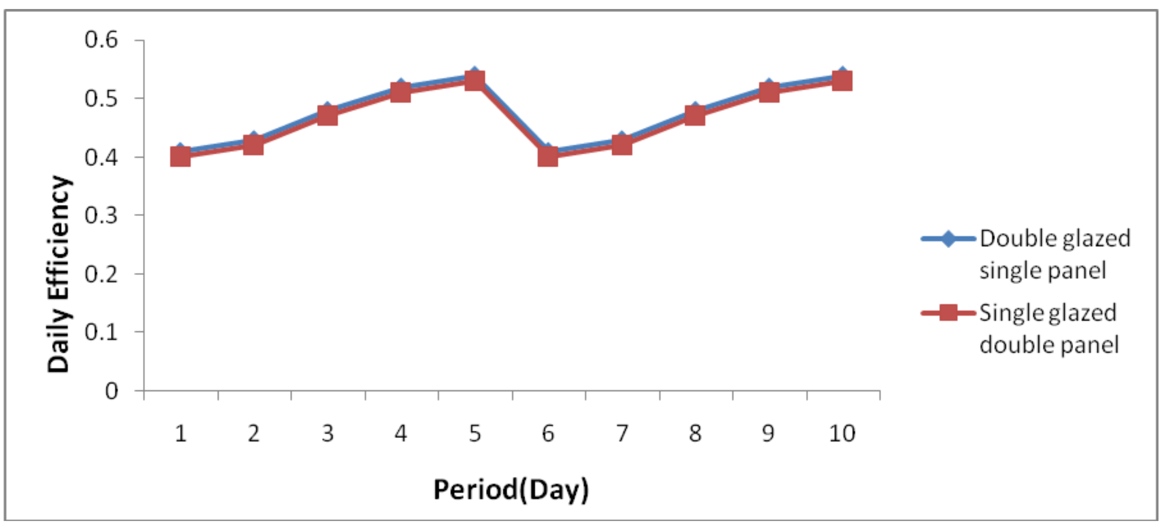

Figure 4. Experimental Daily Efficiencies Curve of the Collector for the periodof Test

3.2 Discussion

Analysis of the results of the tests are here discussed, 9 April 2019, it was a sunny day and looking at Tables 1&2,

shown that the ambient temperature rose from 31^0C at 9.00 hours to 39^0C at 15.00 hours and dropped gradually to 34^0C at 18.00 hours. The maximum water outlet temperature for the double glazed single panel collectorwas 96^0C, tank bulk hot water temperature was 81^0C and the hourly efficiency rose from 45% at 8.00 hours to 49% at 11.00 hours and dropped to 4.2% at 18.00 hours, the daily efficiency was determined to be 0.41, heat loss was reduced due to double glazed on the collector surface which acts as temperature booster.

The single glazed double panel collector was carried out at the same time with the double glazed, with the same ambient temperature as shown in Table 2. The maximum water outlet temperature for the water and tank bulk temperature was 80^0C and 72^0C. The hourly efficiency rose from 45% at 8.00hours to 48% at 12.00 hours and dropped to 3.9% at 18.00 hours. The daily efficiency was determined to be 40% the rate at which heat is loss to the environment through the surface of the collector is high and the large connection also affect the final outlet temperature of the water.

The graph of the hourly efficiency clearly shown in Figure1, the temperature output which reflect in the calculations of the useful energy gain with the solar radiation, which gives the hourly efficiency.

Tables 3 is the values measured on 13th April 2019.It was cloudy in the morning and the sky later became clear. The ambient temperature rose from 29^0C at 9.30 hours to 34^0C at 15.30 hours and dropped to 31^0C at 18.30 hours. The average temperature of hot water withdrawn from the tanks was 56^0C. It is interesting that under this extreme condition, that is low ambient temperature of between 29^0C and 34^0C the double grazed was able to heat the water to average temperature of about 56^0C suitable for bathing was obtained and also the single average temperature was 41^0C.of the water withdrawn from the tank.

The experimental collector hourly efficiency $\dot{\eta}_H$ was plotted against period (hours) to obtain the curve of the collector performance for the test carried out on 13th April 2019 for both thedouble-glazed single panel collector and single as shown in Fig.2 which clearly shown the hourly variation of the efficiency of the test.

On 19th of April 2019, it shown that the day was sunny looking at the ambient temperature which rose from 30^0C at 8.00- 9.30 hours to 40^0C at 14.00 -15.30 hours and dropped to 32^0C at 17.00-18.30 hours. The hourly efficiency of the double glazed single panel rose from 45% at 9.30 hours to 55% at 14.00 hours. The maximum hourly efficiency of 55% was obtained at 14.00 hours and the minimum hourly efficiency of 45% was obtained at 9.30 hours. Average temperature of hot water withdrawn from the tank was 67^0C.

Under the same ambient temperature on the test on 19th April, the single glazed double pane collector shown.The hourly efficiency of single glazed double panel rose from44% at 9.30 hours to 54% at 14.00 hours. The maximum hourly efficiency of 54% was obtained at 14.00 hours and the minimum hourly efficiency of 44% was obtained at 9.30 hours. Average temperature of hot water withdrawn from the tank was 57^0C.

The experimental collector hourly efficiency $\dot{\eta}_H$ was plotted against period (hours) to obtain the experimental hourly efficiency curve of the collector for the tests carried out for both the double glazed single panel, double glazed double panel and single glazed double panel collector.The calculated daily efficiency of the tests carried out during the period of test (day),from 9th April to 20th April 2019and these data are plotted in against the period (day).

Looking at the graph of the daily efficiency plotted against (day), it clearly seen that the daily performances of each of the collectors, the double glazed single panel daily efficiency is higher than that of the single glazed double panel when they are compared.

The higher daily efficiency during the period was on the 13th April, it was 58% for double glazed double panel, 54% for double glazed single panel and 53% for single glazed double panel at ambient temperature of between 29^0C and 34^0C. This shown that when the ambient temperature is low the rate heat loss from the system is low thereby increases the efficiency of the system.

Conclusion

The double-glazed single panel collector produced the maximum temperature at the fluid outlet of 113^oC and for the single glazed double panel, it was 87^0C for the period of testing. Conclusively, the double glazed single panel collector was found to be more effective for a heating process when compared with the single glazed, for the same number of glass covers.

References

Agbo, S.N. and Okorugwe, E.C. (2007).Analysis of Thermal Losses in the Flat Plate Collector of a Thermal-Syphon Solar Water Heater.*Research Journal of Physic,1(1) 35-41.*

Ahmed, M.S. (2012). Modelling of Flat Plate Collector Operation in TransientStates.Master Thesis at PurdueUniversity Fort Wayne, Indiana.http://opus.ipfw.edu/master-thesis/11. Assessed on 12th March 2013.

Anderson,T., Duke M., and Carson J.,(2010). The effect of color on the thermalperformance of building integrated solar collectors, *Solar Energy Materials &solar cells, 94, 350-354.*

Bhanadari, D. and Single, S. (2012). Performance Analysis of Flat Plate Solar Air Collectors with and without Fins.*International Journal of Engineering Research and Technology (IJERT) 1 (6)*

Bhatt, M.K; Gaderia, S.N. and Channiwela, S.A. (2011). Experimental investigations on top loss co-efficient of solar flat plate collect at different tilt angle. *World Academy of Science, Engineering and Technology, 55 .432-436.*

Bolaji, B.O (2006). Flow design and collector performance of a natural circulation solar water heater. *Journal of Engineering and Applied Science 1(1) 7-13.*

Chandra, M. and Oguntuase, O. (1986). A natural convention solar water Heater for an Application in Nigeria Buildings, *Nigeria Journal of Solar Energy, 5, 154-157*

Duffie, A. and Beckman, W.A. (2006). Solar Engineering of thermal processes*3rd Edition Wiley and Sons, New Jersey.pp. 236-288.*

Duffie, A. and Beckman, W.A. (1980). Solar Engineering of thermal processes. *Wiley and Sons, New Jersey.pp.121-180.*

Fabio, S. (2008).Analysis of a Flat Plate Solar Collector, Department of Energy Science, Faculty of Engineering, Lund University, Sweden.

Farahat, S; Sarhaddi, F. and Ajam, H. (2009).Exegetic Optimization of Flat Plate Solar Collectors.Department of Mechanical Engineering University of sistan and Baluchestan, Zahedon,Iran*Renewable Energy, 34. 1169-1174*

Fan J.; Shah, L. and Furbo, S.(2007). Flow distribution in a solar collector panelwith horizontally inclined absorber strips, *Solar Energy, 81, 1501-1511.*

Hilmer, F., Vajen, K.; Ratka, A.; Ackermann, H.; Fuhs, W. and Melsheimer, O.(1998). Numerical solution and validation of a dynamic model of solar collectorsworking with varying fluid flow rate, *Solar Energy Vol. 65, No. 5, pp. 305-321*

John, A.D. and William, A. B. (2003). Solar Engineering of Thermal Processes,*4th Ed.John Wiley and Sons, Inc. ; Hoboken, NewJersey. pp 254-263*

Kalogirou, S.A. (2004). Solar Thermal Collector and Applications Progression in Energyand Combustion Science. 30. 231-295

Karagiorgas, M.; Galatis, K.; Tsagouri, M.; Tsoutsos, T. and BotziosValaskakis, A. (2010).

SolarAssistedHeatPump on Air Collectors: A Simulation Tool. *SolarEnergy. 84(1). 66-78.*

Khalecl, Z.; Amenallah, G.R.S.; Chalib, K. (2012). Solar thermal systems Performances Versus Flat Plate Solar CollectorsConnected in series, *Thermal Processes Laboratory (LPT) Research and Technology Centre of Energy (CRTEN) BoriCedria Tunisia*

Koo, J.M. (1999).Development of Flat Plate Solar Collector Design Program.Masters Thesis, University of Wisconsin, Madison, pp 1-173

Kreider, J.F. and Kreith, F. (1975).Solar Heating and Cooling Engineering Practical Design and Economics.*First Edition, McGraw-Hill Book Company, New York.Pp 45-63*

Landon, T.A. and Brain, W.R. (2012). An Empirically derived model regarding the performance of flat plate solar thermal collectors based on varying ratios of direct to diffuse solar radiation, Department of Technology and Environmental Design Appalachia state University Katherine Harper Hall Boone, NC 28608.

Odusote, O.O (1989). Performance Evaluation of Flat Plate Collators, Nigerian journal of Solar Energy, volume 8, pp364-367

Ojike, O. (2011). Characterization of a Flat Plate Double Glazed Solar Collector. *Continental Journal of Renewable Energy. 2(2) 10-18.*

Oliva, A.; Costa, M. and Perez, S, C. (1991). Numerical simulation of solarcollectors: the effect of non uniform and non steady state of boundary conditions,*Solar Energy, 47, 5, 359-373. (1983/84).*

Olusoji, O. (1983/84).The Design Construction and Evaluation of Solar Water Heater.*Nigerian journal of Solar Energy, volume 3, pp 18-25*

Owonuji, J.J. and Olorunju, S.A.S (1986).Solar Radiation Measurements and Energy Balance of Crops in the Nigeria Savanna.Nigerian journal of Solar Energy, volume 5, pp. 62.

Raja, S.Y; Shama, K.V and Basaveswara, R.M. (2009).Evaluation of Heat loss Coefficients in Solar Flat Plate Collectors.ARPN*Journal of Engineering and Applied Sciences.44 (5).*

Ramani, B.M.; Akhilesh, G. and Ravi, K. (2010). Performance of a Double Pass Solar Air Collector Solar Energy, *Science Direct. 84 (11).1929-1937*

RETScreen® International. (2012). Clean Energy Decision Support Centre. CleanEnergy Project Analysis: RETScreen®

Engineering & Cases Textbook.<*www.retscreen.net*>. *Assessed 10th October 2013*.

Sambo, A.S and Bello, M.B. (1990).An experimental Evaluation of Collector units for Thermo-Syphonic Solar Water Heater, *Nigeria Journal of Renewable energy*, *5.4-11*.

Shitzer, A; Lalmaoviz,, D; Zviriy, and Grossma, G. (1979). Experiments with a flat plate solar water heating system thermo-syphon flow. Solar Energy journal, volume 22, pp 25-30

Singh P, Sarviya, R. and Bhagoria, J. (2010). Heat loss study of trapezoidal cavity absorbers for linear solar concentrating collector, *Energy Convergence and Management, 51, 329-337.*

Tasdemirogulu, E. and Gursory, A. (1995).A Water Trickle Solar Collector, *Applied Energy Journal. 50. 163-183.*

Zhao, J., LU, J., Wang, X., HOU, N. and Zhou, W. (2013).Different Heating Systems of Flat Plate Solar Collector Efficiency in LHASA *in APEC Conference on LowCarbon Towns and Physical Energy Storage. Changsha, China, 152-157.*

Zheng, X. (2004).Thermal Performance Comparison of Three Integrated Thermal Solar Collectors.Faulty of the Virgina Polytechnic Institute and State University, Blacksberg Virginia.