Open Access Journal

Journal of Power Technologies 93 (1) (2013) 52–58

journal homepage:papers.itc.pw.edu.pl

Experimental analysis on thermal performance of a solar air collector with longitudinal fins in a region of Biskra, Algeria

Foued Chabane[*,a,b], Noureddine Moummi[a,b], Said Benramache[c]

[a] *Mechanical Department, Faculty of Technology*
University of Biskra 07000, Algeria
[b] *Mechanical Laboratory, Faculty of Technology*
University of Biskra 07000, Algeria
[c] *Material Sciences Laboratory, Faculty of Science*
University of Biskra 07000, Algeria

Abstract

This paper presents the experimentally investigated thermal performance of a single pass solar air heater with fins attached. Longitudinal fins were used inferior to the absorber plate to increase the heat exchange and render the flow fluid in the channel uniform. The effects of mass flow rate of air on the outlet temperature, the heat transfer in the thickness of the solar collector and thermal efficiency were studied. Experiments were performed for an air mass flow rate of 0.012 kg/s. Maximum efficiency was obtained by using five longitudinal fins and without using fins. The maximum efficiency levels obtained for the 0.012 kg/s with and without fins were 40.02% and 34.92% respectively. A comparison of the results of the solar collector with and without fins shows a substantial enhancement in thermal efficiency.

Keywords: Solar intensity, Solar air collector, Heat transfer, Design, Temperature

1. Introduction

The acceptance of solar energy technology depends on its efficiency, cost-effectiveness, durability and reliability, among other factors. Many solar thermal systems, such as solar water heaters, air heaters and distillation systems have improved in terms of efficiency and reliability.

In the study, a test of solar collector air was performed based on the heating of air by longitudinal fins (semi-cylindrical form) and the surface area for heat exchange. Our study seeks to increase the thermal efficiency of the solar collector, by using a single pass counter flow solar air collector with longitudinal fins. To this end a semi-cylindrical form is one of the important and attractive design improvements that has been proposed to improve thermal performance. This paper presents experimental analysis of a single pass solar air collector with and without fins.

A flat plate solar air heater differs from more conventional heat exchangers in several respects. The latter usually employ a fluid to exchange high heat transfer rates using conduction and convection. In solar air heaters, energy is transferred from a distant source of radiant energy directly into air [1, 2]. The heat may then be utilized by passing air through a conduit system located between the bottom and ab-

*Corresponding author

Email addresses: fouedmeca@hotmail.fr (Foued Chabane[*,a,]), nmoummi@lgm-ubiskra.net (Noureddine Moummi[a,]), benramache.said@gmail.com (Said Benramache)

sorbing plate. The heated air is subsequently used for space heating and drying [3, 4].

In addition to the essential effects of free and forced convection [5], there are many ways to achieve considerable improvement in collection efficiency by increasing the transfer area through attaching internal fins [6, 7], creating turbulence inside the flow channel using baffles [8, 9] or designing corrugated surfaces [10, 11], and enhancing the convective transfer rate [12].

On the other hand several configurations of absorber plates have been designed to improve the heat transfer coefficient. Artificial roughness, obstacles and baffles in various shapes and arrangements were employed to increase the area of the absorber plate. As a result the heat transfer coefficient between the absorber plate and the air pass is improved by [13]. Omojaro et al. [14] reported on experimental investigation of the thermal performance of a single and double pass solar air heater with fins attached and a steel wire mesh as absorber plate.

An experimental investigation carried out on the thermal performance of offset rectangular plate fin absorber plates with various glazing by [15]: in this work the offset rectangular plate fins, which are used in heat exchangers, were experimentally studied. The offset rectangular plate fins, mounted in a staggered pattern and oriented parallel to the fluid flow, high thermal performances were obtained with low-pressure losses.

2. Experimental

2.1. Thermal analysis and uncertainty

2.1.1. Heat transfer coefficients

The convective heat transfer coefficient h_w for air flowing over the outside surface of the glass cover depends primarily on the wind velocity V_{wind}. McAdams [16] obtained the experimental result as:

$$h_w = 5.7 + 3.8V_{wind} \tag{1}$$

where the units of h_w and V_{wind} are $W/(m^2K)$ and m/s, respectively. An empirical equation for the loss coefficient from the top of the solar collector to the ambient was developed by Klein [17].The heat transfer coefficient between the absorber plate and the airstream is always low, resulting in low thermal efficiency of the solar air heater. Increasing the area of the absorber plate shape will increase the heat transferred to the flowing air.

2.1.2. Collector Thermal Efficiency

The efficiency of a solar collector is defined as the ratio of the amount of useful heat collected to the total amount of solar radiation striking the collector surface during any period of time. [18–20]:

$$\eta = \frac{Q_u}{I_0 \cdot A_C} \tag{2}$$

The equation for mass flow rate (m) is:

$$m = \rho \cdot Q \tag{3}$$

where ρ is the density of air which depends on the air temperature and Q is the volume flow rate which depends on the pressure difference at the orifice, which is measured from the inclined tube manometer and temperature.

Useful heat collected for an air-type solar collector can be expressed as:

$$Q_u = \dot{m}C_p\left(T_{out} - T_{in}\right) \tag{4}$$

where C_p is the specific heat of the air, A_c is the area of the collector. The fractional uncertainty for the efficiency from Eq. (6) is a function of ΔT, m, and I_0, considering C_p and A_c as constants.

So, collector thermal efficiency becomes,

$$\eta = \dot{m}C_p\frac{(T_{out} - T_{in})}{I_0 A_c} \tag{5}$$

2.1.3. Description of the solar air heater considered in this work

An experimental set-up was designed to study the effect of the new form of the fins on the back of the absorber plate on heat transfer to fluid flow characteristics in a solar panel channel, and to compare the results with and without fins; a calibrated orifice meter connected by manometer was used to measure the mass flow rate of air through the duct.

To measure temperatures type K thermocouples were connected at appropriate locations to a 0.1°C least count digital temperature indicator. The thermocouples were used to measure the temperature of

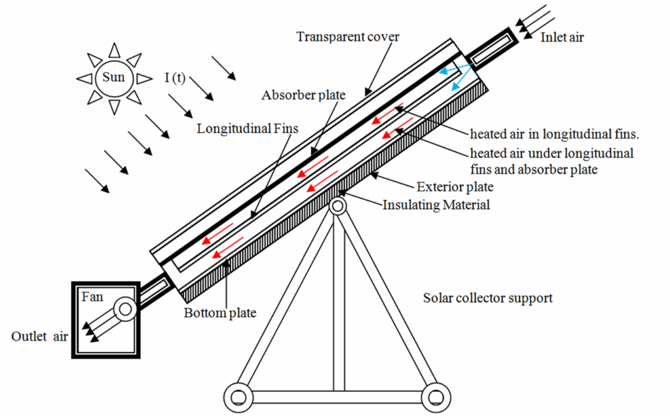

Figure 1: Schematic view of the solar air collector

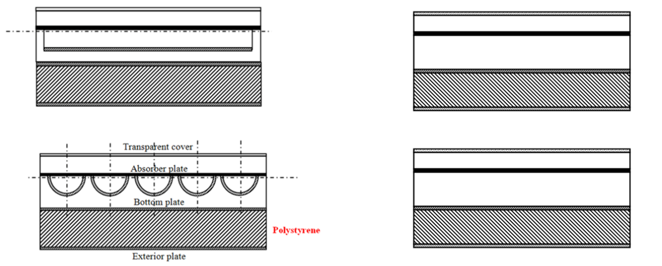

Figure 2: Composition of solar box with and without fins

the top surface of the transparent cover, absorber plate, bottom plate and exterior plate at various locations.

The layout of the solar air collector studied is shown in Figs. 1 and 2. The collector served as the baseline, with parameters as follows:

- The solar collecting area was 2 m (length) × 1 m (width);
- The installation angle of the collector was 45° from horizontal;
- The transparent cover was made of a Plexiglas panel, with a thickness of 3 mm;
- Height of the stagnant air layer was 0.02 m;
- The absorber plate was made of galvanized steel, 0.5 mm thick and black-painted;
- Thermal insulation board EPS (expanded polystyrene board), with thermal conductivity 0.037 W/(m·K), was put on the exterior surfaces of the back and side plates, with a thickness of 40 mm.

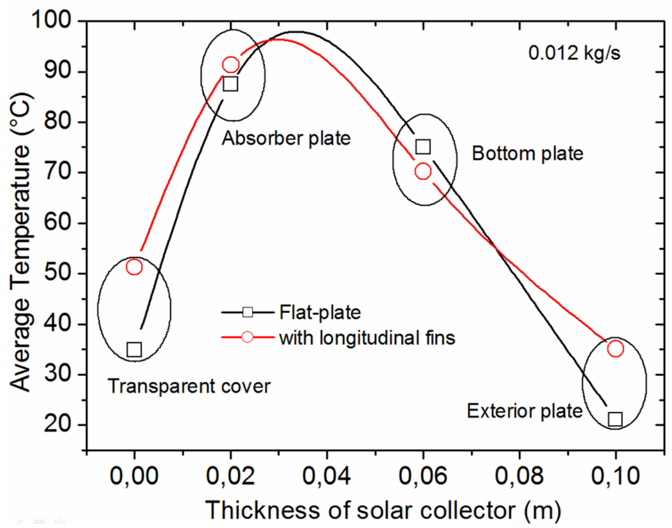

Figure 3: Average temperature in the thickness of a solar collector versus the whole area of the solar collector plates for a single pass solar air heater, with flow rates of 0.012 kg/s, for the solar collectors with and without fins

- A CMP 3 pyranometer was used to measure solar irradiance; a digital thermometer Model Number: DM6802B was also used;
- The absorber was of plate absorption coefficient $\alpha = 0.95$, the transparent cover transmittance $\tau = 0.9$ and absorption of the glass covers $\alpha_g = 0.05$;
- 16 positions of thermocouples connected to plates and two thermocouples to outlet and inlet flow;
- Five fins under the absorber plate, with a semi cylindrical longitudinal form, 1.84 m (length) × 0.03 m (Radian); the distance between the two adjacent fins and fins are 120 mm respectively and 5 mm thickness Fig. 2.

3. Discussion

Fig. 3 shows the average temperature distribution in the thickness of the solar collector, indicating the variation of the average temperature corresponding to the transparent cover, absorber plate, bottom plate and exterior plate. The difference can be seen in Fig. 3; at mass flow rates 0.012 kg/s the difference between the curves is remarkable; and the role of fins that allow a cooled absorber and ensure better

Table 1: Experimental data (average temperature, °C) for Flat-plate, and with fins corresponding to the mass flow rate 0.012 kg/s, on 24/01/2012, and 13/05/2012, for solar collector thickness from 0 to 0.1 m with tilt angle $\beta = 45°$

y, m	Flat-plate	Longitudinal fins (n = 5)	
0	34.80	51.28	T_{pl}
0.02	87.50	91.25	T_{ab}
0.06	75.02	70.25	T_{bp}
0.10	21.10	35.13	T_{ep}

Table 2: Experimental data for Flat-plate, and with fins corresponding to the mass flow rate 0.012 kg/s; on 24/01/2012 and 13/05/2012, for length of solar collector from 0.388 to 1.552 m

Mode of solar collector	x, m	T_{pl}, °C	T_{ab}, °C	T_{bp}, °C	T_{ep}, °C
Longitudinal fins ($n = 5$)	0.388	47.75	83.00	53.00	35.50
	0.776	54.20	88.00	66.50	35.20
	1.164	58.35	94.50	74.00	35.00
	1.552	60.05	94.50	78.00	35.05
Flat-plate	0.388	34.05	95.00	67.50	22.05
	0.776	34.05	87.00	86.00	21.65
	1.164	35.55	88.00	79.00	20.55
	1.552	36.20	87.00	71.00	20.25

heat exchange can be seen in Table 1. The solar intensity increases its effect on the temperature bottom plate and the temperature of an absorber plate by rates of between 4 and 6°C, for the solar collector without and with fins; the temperatures of the bottom plate and the absorber plate for 0.012 kg/s were (T_{bp} = 75.02 and 70.25°C), (T_{ab} = 87.50 and 91.25°C) respectively in Table 1. The collectors were mounted on a galvanized steel frame. In the field the solar energy passing through the cover glass is absorbed by the absorber plate. The heat generated is then transferred to the collector fluid [21].

Fig. 4 shows the average temperature of a solar collector as a function of length, from 0.388 to 1.552 m, corresponding to the type without fins at mass flow rate of 0.012 kg/s. As can be seen, the curves of the bottom plate at lengths of $x_2 = 0.776$ m at $m = 0.012$ kg/s were (T_{bp} = 86°C) and (T_{ab} = 87°C) in Table 2, and more heat is taken from the absorber plate. The temperature of the absorber plate

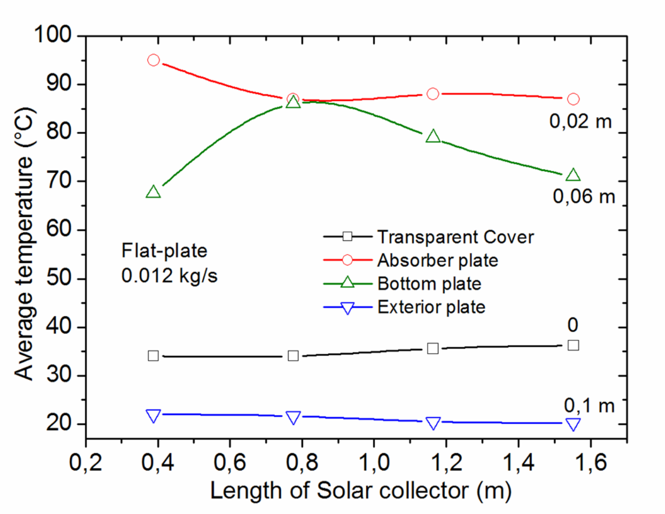

Figure 4: Average temperature along the length of solar collectors versus thickness of panel of between 0 and 0.1 m for single pass solar air heater, at flow rates of 0.012 kg/s, corresponding to the Flat-plate solar collector

at this point is decreased due to the air flow in the channel and becomes stable for all points.

Fig. 5 shows the average temperature of a solar collector as a function of length, from 0.388 to 1.552 m, corresponding to the type with longitudinal fins at mass flow rate 0.012 kg/s. As can be seen, the evolution of the curves takes a regular form; when the temperature of the absorber plate increases, the temperature of the bottom plate automatically increases in a regular fashion: (T_{bp} = 66.50°C) and (T_{ab} = 88°C) at $x_2 = 0.776$ m, see Table 2. Using fins with the absorber plate the values of temperature differences increase, because fins obtain more heat due to an increase in heating time through circulating the air inside; and a transparent cover helps to decrease convection heat losses. In the presence of fins, this exchange is effective along the entire length of the channel. Fins clearly play a very important role.

Figs. 6 and 7 show the variation of the thermal efficiency and solar intensity with and without fins at air mass flow rate 0.012 kg/s. The thermal efficiency used to evaluate the performance of the solar air heater is calculated; it is found from both figures that thermal efficiency increases with increasing solar intensity as a function of time, see Tables 3 and 4. The efficiencies of the finned collectors are higher than that of the collector without fins.

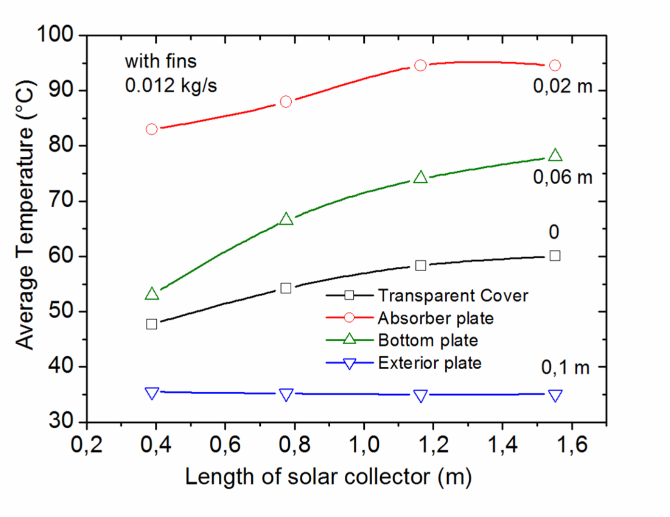

Figure 5: Average temperature along the length of a solar collector versus thickness of panel between 0 and 0.1 m for a single pass solar air heater, with flow rates at 0.012 kg/s, corresponding to solar collectors with longitudinal fins

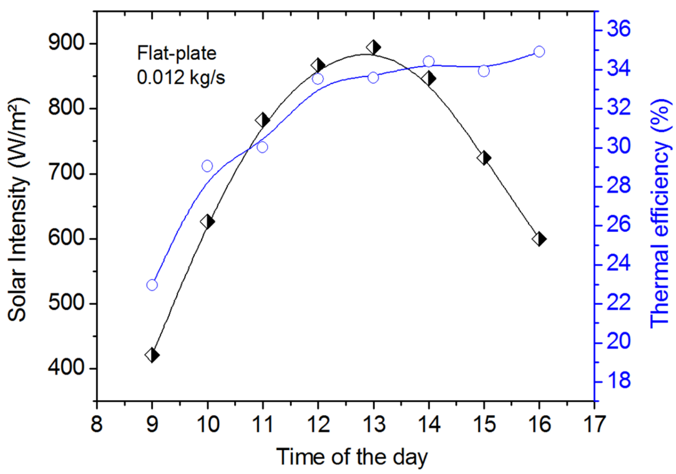

Figure 6: Solar intensity and thermal efficiency versus time of day for a single pass solar air heater, with flow rates at 0.012 kg/s, corresponding to solar collectors without fins

Table 3: Experimental data for Longitudinal fins, corresponding to the mass flow rate 0.012 kg/s on 13/05/2012, according to the time of day, between 9:00 and 16:00, with tilt angle β = 45°

Time, h	T_{in}, °C	T_{out}, °C	T_a, °C	I, W/s^2	η, %	ΔT, °C
9:00	30.20	43.10	25.00	417	27.47	12.90
10:00	33.10	53.70	29.40	570	32.09	20.60
11:00	35.00	63.70	30.50	675	37.75	28.70
12:00	37.00	67.50	32.50	740	36.60	30.50
13:00	38.50	70.10	30.60	753	37.26	31.60
14:00	39.20	69.20	34.50	684	38.94	30.00
15:00	39.10	66.70	31.80	617	39.72	27.60
16:00	38.50	64.70	30.80	580	40.02	26.20

Table 4: Experimental data for Flat-plate, corresponding to the mass flow rate 0.012 kg/s, on 24 /01/2012, according to the time of day, from 9:00 to 16:00, with tilt angle β = 45°

Time, h	T_{in}, °C	T_{out}, °C	T_a, °C	I, W/s^2	η, %	ΔT, °C
9:00	14.60	25.20	12.40	421	22.94	10.60
10:00	17.20	37.20	13.10	627	29.10	20.00
11:00	19.10	44.90	15.30	783	30.02	25.80
12:00	23.10	55.00	20.20	867	33,52	31.90
13:00	23.80	56.80	21.40	895	33.59	33.00
14:00	24.30	56.30	23.00	847	34.42	32.00
15:00	24.40	51.40	23.10	725	33.92	27.00
16:00	23.00	46.00	19.80	485	34.92	23.00

It can be seen that the lowest solar intensity conversely can produce highest thermal efficiency through adding fins to the back of the absorber plate, see Table 3. Solar air heaters heat the air much more at the lower air rates, because the air has more time to heat up inside the collector.

Figs. 8 and 9 show the variation of the ambient, outlet and inlet temperature affected by air mass flow rates, as a function of time during the day, and with the influence of a longitudinal fin on the back of the absorber plate, as shown in Tables 3 and 4. The temperature was measured experimentally. It can be seen from Figs. 8 and 9 that the curve of outlet temperature tends to increase with decreasing air mass flow rate. For a specific air mass flow rate at a constant ambient temperature, the outlet and inlet temperature increase with increasing solar intensity. Again, it clearly demonstrates that the longitudinal fins on the back of the absorber plate help increase the outlet-air temperature. In general, the inlet temperature (Figs. 8 and 9) was found to increase exponentially from the morning for mass flow rates m = 0.012 kg/s are T_{in} = 30.2°C, and for flat-plate 14.60°C at 9:00 h, respectively, about ambient temperature T_a = 25 and 12.40°C, respectively in Tables 3 and 4.

The thermal efficiency of the heater improves with increasing air flow rates due to enhanced heat transfer to the air flow, while the temperature difference

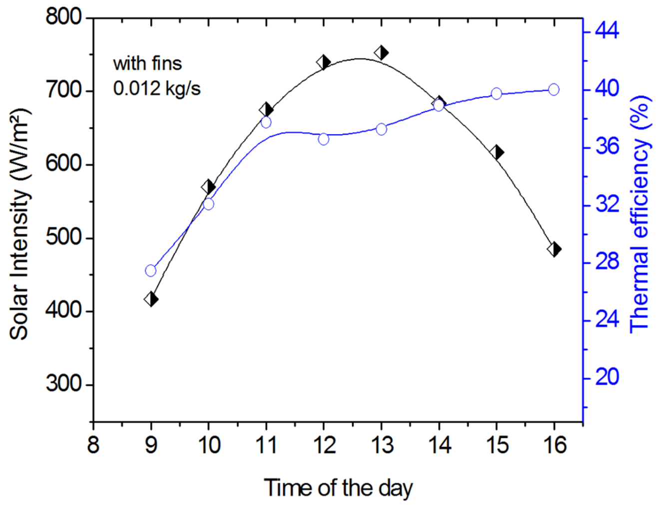

Figure 7: Solar intensity and thermal efficiency versus time of day for a single pass solar air heater, with flow rates at 0.012 kg/s, corresponding to solar collectors with fins

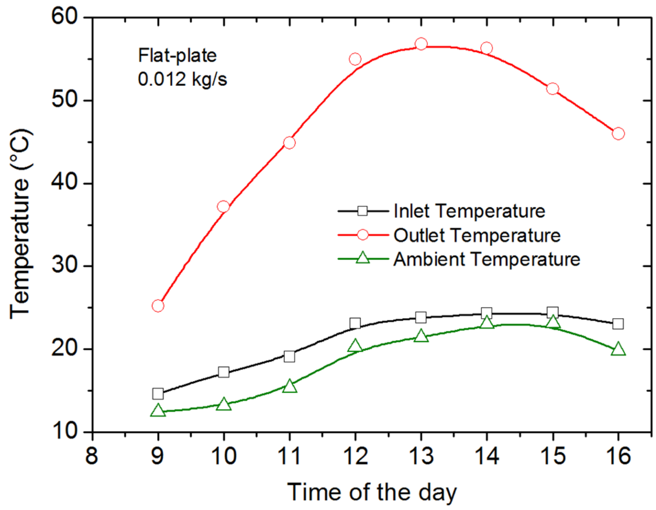

Figure 8: Temperature versus different standard local time during days for single pass solar air heater, of the flow rates at 0.012 kg/s, corresponding to the outlet, inlet and ambient temperature of a solar collector without fins

of fluid decreases at a constant tilt angle $\beta = 45°$. Solar intensity is at its highest values at about 13:00, as would be expected. The solar intensity decreases over the course of the afternoon. Figs. 6 and 7 show the overall results of the experiments, including the difference of air inlet and outlet temperature and daily instantaneous solar intensity levels. The ambient temperature was between 21.40 and 30.60°C. The inlet temperatures to the two types of solar air collectors were measured to ambient temperature. The temperature differences between the inlet and outlet temperatures can be compared directly when determining the performance of the collectors. The highest daily solar radiation is obtained as 895 W/m^2 for a Flat-plate and 753 W/m^2 at solar collector with fins. As expected, it increases during the morning to a peak value of 895 W/m^2 and 753 W/m^2 , respectively, for a flat-plate and with fins at the sun's zenith and starts to decrease in the afternoon on all the days of experiments.

4. Conclusions

In the present study, two types of solar air collectors were tested and their performance was compared. The efficiency of the solar air collectors depends significantly on the solar radiation and surface geometry of the collectors. The efficiency of the collector improves with increasing solar intensity at mass flow rate 0.012 kg/s, due to enhanced heat-transfer to the air flow. The efficiency of the solar air collector is proven to be higher. The highest collector efficiency and air temperature rise were achieved by the finned collector with an angle of 45°, whereas the lowest values were obtained from the collector without fins.

The efficiency of the solar air collectors depends significantly on the solar radiation and surface geometry of the collectors and the fins on the back of the absorber plate.

References

[1] H. P. Garg, R. S. Adhikari, Performance evaluation of a single solar air heater with n-subcollectors connected in different combinations, International Journal of Energy Research 23 (5) (1999) 403–414. doi:10.1002/(SICI)1099-114X(199904)23:5<403::AID-ER488>3.0.CO;2-F.

[2] M. Belusko, W. Saman, F. Bruno, Performance of jet impingement in unglazed air collectors, Solar Energy 82 (5) (2008) 389–398. doi:10.1016/j.solener.2007.10.005.

[3] J. Duffie, W. Beckman, Solar Engineering of Thermal Processes, Wiley, New York, 1991.

[4] T. Koyuncu, Performance of various design of solar air heaters for crop drying applications, Renewable Energy 31 (7) (2006) 1073–1088. doi:10.1016/j.renene.2005.05.017.

[5] H. ming Yeh, T.-T. Lin, The effect of collector aspect ratio on the collector efficiency of flat-plate solar air heaters,

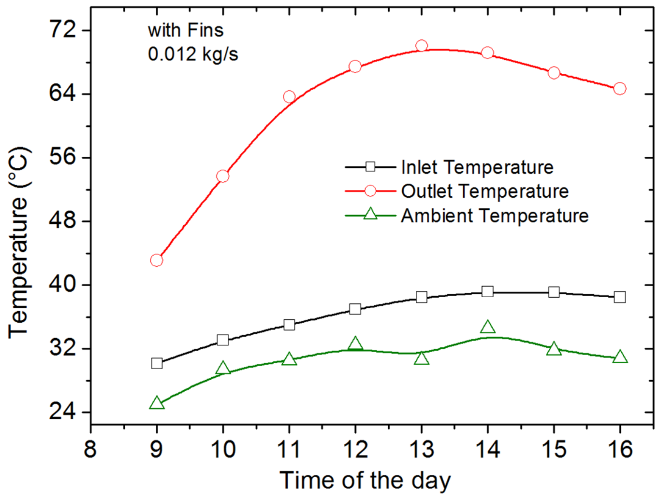

Figure 9: Temperature versus different standard local time during days for single pass solar air heater, at flow rates of 0.012 kg/s, corresponding to the outlet, inlet and ambient temperature of a solar collector with fins

Energy 20 (10) (1995) 1041–1047. doi:10.1016/0360-5442(95)00053-J.

[6] H.-M. Yeh, C.-D. Ho, J.-Z. Hou, Collector efficiency of double-flow solar air heaters with fins attached, Energy 27 (8) (2002) 715–727. doi:10.1016/S0360-5442(02)00010-5.

[7] M. Y. H. Othman, B. Yatim, K. Sopian, M. N. A. Bakar, Performance analysis of a double-pass photovoltaic/thermal (pv/t) solar collector with cpc and fins, Renewable Energy 30 (13) (2005) 2005–2017. doi:10.1016/j.renene.2004.10.007.

[8] A. Hachemi, Thermal performance enhancement of solar air heaters, by a fan-blown absorber plate with rectangular fins, International Journal of Energy Research 19 (1995) 567–578.

[9] H.-M. Yeh, C.-D. Ho, C.-Y. Lin, Effect of collector aspect ratio on the collector efficiency of upward type baffled solar air heaters, Energy Conversion and Management 41 (9) (2000) 971–981. doi:10.1016/S0196-8904(99)00148-X.

[10] L. GoldsteinJr., E. Sparrow, Experiments on the transfer characteristics of a corrugated fin and tube heat exchanger configuration, Journal of Heat Transfer 98 (1976) 26–34.

[11] W. Gao, W. Lin, T. Liu, C. Xia, Analytical and experimental studies on the thermal performance of cross-corrugated and flat-plate solar air heaters, Applied Energy 84 (4) (2007) 425–441. doi:10.1016/j.apenergy.2006.02.005.

[12] C. Ho, C. Yeh, S. Hsieh, Improvement in device performance of multi-pass flat-plate solar air heaters with external recycle, Renewable Energy 30 (10) (2005) 1601–1621. doi:10.1016/j.renene.2004.11.009.

[13] B. S. Romdhane, The air solar collectors: Comparative study, introduction of baffles to favor the heat transfer, Solar Energy 81 (1) (2007) 139–149. doi:10.1016/j.solener.2006.05.002.

[14] A. Omojaro, L. Aldabbagh, Experimental performance of single and double pass solar air heater with fins and steel wire mesh as absorber, Applied Energy 87 (12) (2010) 3759–3765. doi:10.1016/j.apenergy.2010.06.020.

[15] A. Hachemi, Experimental study of thermal performance of offset rectangular plate fin absorber-plates, Renewable Energy 17 (3) (1999) 371–384. doi:10.1016/S0960-1481(98)00115-3.

[16] W. McAdams, Heat Transmission, McGraw-Hill, New York, 1954.

[17] S. Klein, Calculation of flat-plate loss coefficients, Solar Energy 17 (1975) 79–80.

[18] S. Karsli, Performance analysis of new-design solar air collectors for drying applications, Renewable Energy 32 (10) (2007) 1645–1660. doi:10.1016/j.renene.2006.08.005.

[19] İrfan Kurtbas, A. Durmus, Efficiency and exergy analysis of a new solar air heater, Renewable Energy 29 (9) (2004) 1489–1501. doi:10.1016/j.renene.2004.01.006.

[20] H. Esen, Experimental energy and exergy analysis of a double-flow solar air heater having different obstacles on absorber plates, Building and Environment 43 (6) (2008) 1046–1054. doi:10.1016/j.buildenv.2007.02.016.

[21] E. Azad, Design, installation and operation of a solar thermal public bath in eastern iran, Energy for Sustainable Development 16 (1) (2012) 68–73. doi:10.1016/j.esd.2011.10.006.