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EPI - 60
THE PERFORMANCE OF HYBRID SOLAR COLLECTOR FOR WATER AND AIR HEATING

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Abstract: This paper presents the performance of a hybrid solar collector for water and air heating. The effect of solar irradiation, ambient temperature and air inlet temperature on the useful energy collected by air and water has been investigated. Absorber plate temperature variation, water and air outlet temperatures and collector efficiency effects are presented. Moreover, the triangular fins in the used air channel increase the heat transfer area and then increase the useful heat gain.

Keywords: solar water heater; solar air heater, hybrid solar collector.

1. INTRODUCTION

Solar energy has become one of the best potentials for clean energy in the world. Solar water heating and air heating are widely used in most of the countries. Therefore, there are many studies about the hot water and air heated by solar radiation. Among these, we remind the analysis of the increase in heat delivery of thermosyphon systems and the performance of solar systems variation with the design variables [1]. The performance and cost benefit analysis of solar air collectors with and without fins have been conducted in [2]. Here, the authors concluded that the energy efficiency of collectors increases with the increase of Nusselt number. Energy and exergy analysis was performed on a dual-purpose system using the effectiveness-NTU method [3].
In this work we study the thermal performance of the hybrid solar collector for water and air heating, taking into consideration the physics of the whole process.

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2. COLLECTOR CONFIGURATION

The studied collector is a hybrid solar air-water collector (HSC). An advantage of this configuration is that the heat which would normally be lost through the bottom side in a single water flat-plate collector, is absorbed by air, thereby increasing the efficiency. Detailed description of HSC design and construction details are presented in Figure 1.

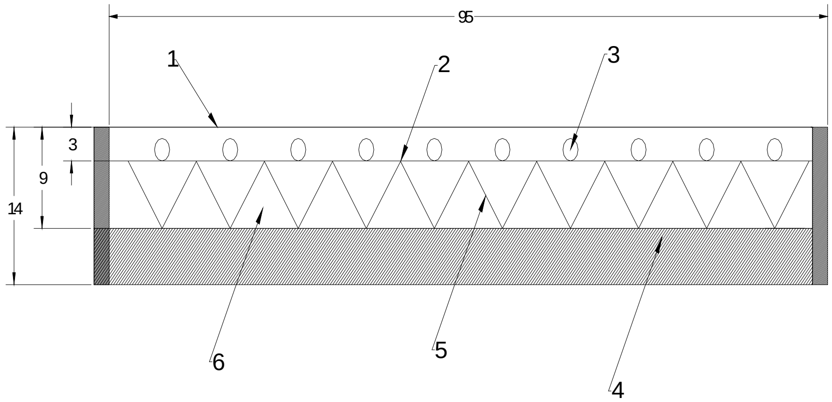

Fig. 1. Configuration of the HSC: 1 – glass cover; 2 – absorber plate; 3 – water pipes; 4 - Insulation; 5- triangular fins; 6- air channel. (All dimensions in cm).

The absorber plate covers the full aperture area of the collector, absorbs incident solar irradiance and conducts this heat to the working fluids. It can be observed that the absorber plate transfers heat both to the water through pipes located in the top, and to the air that flows through the bottom side. To enhance the heat transfer to the air, triangular fins were used. Due to the glass wool insulation, the amount of heat lost back to the surroundings is reduced to minimum. Table 1 illustrates the characteristics of the collector.

Tab.1. Characteristics of the HSC

HSC characteristics		
Water pipes	Number	10
	Diameter	7 mm
Absorber plate	Material	Aluminium
	Absorptivity	0.93
	Thickness	2 mm
Glass cover	Thickness	4 mm
Air side fins	Height	60 mm
	Angle	60 degrees
	Material	galvanized steel
	Thickness	1 mm
	Total air heat transfer area	8.16 m^2

3. THEORETICAL ANALYSIS

3.1. Thermal losses

When describing the actual heat loss at a certain temperature of the heat transfer media and at a certain ambient temperature, the overall top heat loss coefficient is [6]:

$$U_t = \left[\frac{N}{\left(\frac{c}{T_{pm}}\right)\left[\frac{T_{pm}-T_{amb}}{(N+f)}\right]^{0.33}} + \frac{1}{h_\infty} \right]^{-1} + \frac{\pm\left(T_{pm}+T_{amb}\right)\left(T^2{}_{pm}+T^2{}_{amb}\right)}{\left[\pounds_p + 0.05\,N\,h_\infty\left(1-\pounds_p\right)\right]^{-1} + \left[\frac{2N+f-1}{\pounds_c}\right] - N} \quad (1)$$

where:

$$f = (1 + 0.04h_\infty + 0.0005h_\infty{}^2)(1 + 0.091N) \quad (2)$$

$$C = 365\,(1 - 0.00883 \quad + 0.0001298 \quad {}^2) \quad (3)$$

N	Number of transparent covers.
T_{pm}	Mean absorber surface temperature (K).
T_{amb}	Temperature of ambient (K).
h_∞	Wind heat transfer coefficient (W/ m^2 K).
$\pounds_p$	Emissivity of absorber surface for long wavelength radiation.
$\pounds_c$	Emissivity of cover for long wavelength radiation.
	Slope or tilt angle.

The convection heat transfer coefficient from the glass cover to the ambient is calculated as a function of the wind speed and collector length [7]:

$$\mathrm{h}_\infty = 8.6\frac{V_\infty^{0.6}}{L_1^{0.4}} \quad (4)$$

where:

V_∞	Free stream wind speed (m/s).
L_1	Length of absorber plate (m).

The heat transfer coefficient for the heat loss from the bottom and edges of the collector can be obtained from [8]:

$$U_b = \frac{k_i}{¢_b} \quad (5)$$

$$U_e = \frac{(L_1 + L_2)L_3k_i}{L_1\,L_2\,L_3\,¢_e} \quad (6)$$

where:

L_2	Width of absorber plate (m).
L_3	Height of collector casing (m).
k_i	Insulation thermal conductivity (W/m K).
$¢_b, ¢_e$	Thickness of bottom and edge insulation (m).

3.2. Heat transfer coefficient

The heat transfer coefficient between water and the tubes is calculated depending on the Nusselt number [9], with the following formula:

$$h_w = \frac{k_w}{d}Nu_w \quad (7)$$

where

k_w Thermal conductivity (W/m K).

d Inner diameter of the tube (m).

Nu_w Nusselt number.

$$Nu_w = 3.66 + \frac{0.0668(\frac{d}{L_1}) \mathrm{Re}_w . \mathrm{Pr}}{1 + 0.04\left[(\frac{d}{L_1}) \mathrm{Re}_w . \mathrm{Pr}\right]^{\frac{2}{3}}} \tag{8}$$

Also, the heat transfer coefficient in the air channel with triangular fins is [10]:

$$Nu_a = Nu_o + \frac{b}{L_1} n, \left\{ \begin{array}{lll} Nu_o = 2.821 & = 0.126 \mathrm{Re}_a & \mathrm{Re}_a < 2800 \\ Nu_o = 1.9 * 10^{-6} \mathrm{Re}_a^{1.79} & = 225 & 2800 < \mathrm{Re}_a < 10^4 \\ Nu_a = 0.0302 \mathrm{Re}_a^{0.74} & = 0.242 \mathrm{Re}_a^{0.74} & 10^4 < \mathrm{Re}_a < 10^5 \end{array} \right\} \tag{9}$$

3.3. The useful heat gain

In steady state conditions, the performance of a hybrid flat-plate solar collector for water and air can be described by the useful heat gain from the collector, which is defined as the difference between the absorbed solar energy and the thermal loss of a collector. Finally the amount of useful heat gain (q_u) is calculated using the two following equations for water and air respectively [4]:

$$q_{u\_w} = F_{R\_w} A_p S - U_{L\_w} A_p (T_{w\_in} - T_{amb}) \tag{10}$$

$$q_{u\_a} = F_{R\_a} A_p S - U_{L\_a} A_p (T_{a\_in} - T_{amb}) \tag{11}$$

where:

q_{u_w} and q_{u_a} Rate of useful heat gain by water and air, respectively (W).

F_{R_w} and F_{R_a} Collector heat removal factor for water and air, respectively.

U_{L_w} and U_{L_a} Overall loss coefficient for water and air, respectively (W/ m^2K).

T_{w_in} and T_{a_in} Inlet water and air temperature, respectively (K).

The summation of the useful heat by air and water gives the total useful heat [11].

$$q_u = q_{u\_w} + q_{u\_a} \tag{12}$$

The prediction of collector performance requires knowledge of the absorbed solar energy by the collector absorber plate. The solar energy incident on a tilted collector consists of three different components: beam radiation, diffuse radiation, and ground-reflected radiation. The absorbed solar energy can be calculated from [7]:

$$S = I_T (\tau\alpha)_{av} \tag{13}$$

3.4. Collector efficiency

The thermal efficiency of the hybrid solar collector is defined as the ratio between the useful energy and the solar energy received by the collector. It can be obtained from the following equation [4]:

$$\eta = \frac{q_u}{A_p I_T} \tag{14}$$

4. Results and Discussions

In this study, the performance of HSC was investigated for the real conditions of operation in Timisoara, Romania (45° 44' 57" N / 21° 13' 38" E). The mathematical algorithm presented above was implemented and solved in MATLAB. Fig. 2 shows the incoming irradiance and ambient temperature, used in the equations, whereas the collector inclination has been fixed at 35^{o} in order to maximize the solar gain.

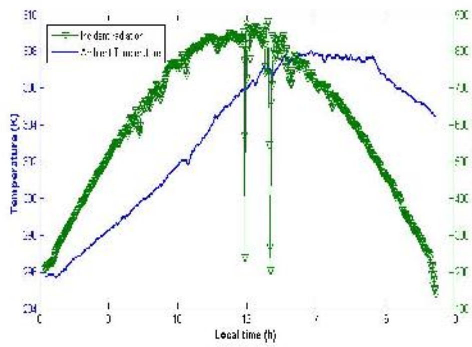

Fig. 2. Variation of ambient air temperature and solar radiation intensity on 01/July/ 2010.

The variation of water outlet, air outlet and plate mean temperatures, respectively, is shown in Fig. 3. The maximum water and air outlet temperature was 318 K and 311 K, respectively, results obtained for water inlet temperature fixed at 313 K.

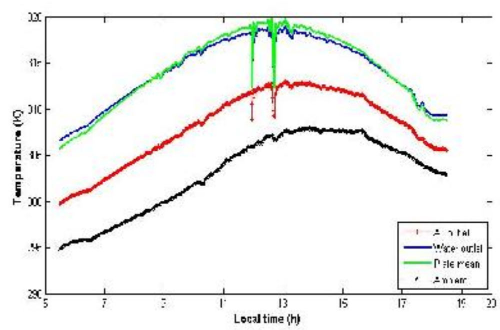

Fig. 3. Variation of working fluids outlet, plate mean and ambient air temperatures

Fig. 4 shows the useful heat gain for water and air during the day. It is noticeable that the heat gain for water is high when compared with the amount of heat gain in the air. Moreover, as the water heat delivery increases, heat delivery to the air decreases. The average value of the useful heat gain from sunrise to sunset is 420.3 W for water side and 110.4 W for air side.

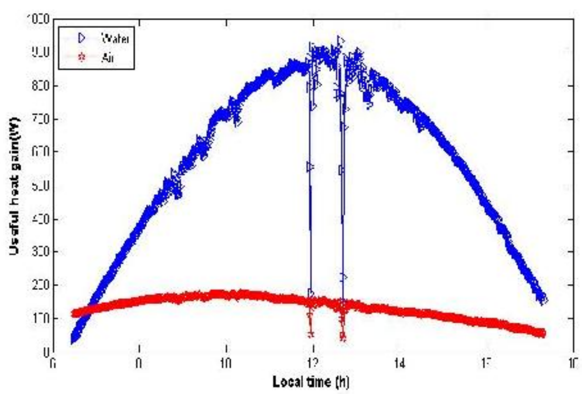

Fig.4. Useful heat gain for water and air

The collector efficiency follows the same trend as the useful heat flux. It increases until noon time and then decreases as shown in Fig. 5. The maximum efficiencies value equals 67.2 % and occurs at 12:48.

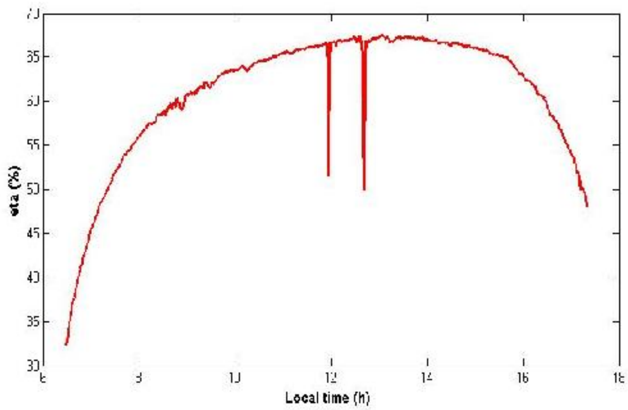

Fig.5. Collector efficiency variation with time.

5. CONCLUSION

Using hybrid solar collector for water and air heating increases system efficiency and decreases costs and required space. Average efficiency of the HSC is 57.4 %. It is more efficient than the single collector (single flow) mode due to the increased heat removal factor.

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