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DESIGNING, MANUFACTURING AND PERFORMANCE EXPERIMENTS OF CORRUGATED-DUCT AND AIR HEATING-PURPOSE SOLAR ENERGY COLLECTORS

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Abstract: The solar-powered systems are mostly thought and used for the purpose of preparing sanitary hot water. The air heating collectors have recently started to come up with use areas. In this study, performances of the sanitary hot water preparation have been explored according to the experiment result data, on the subject of drying and domestic heating, with the purpose of increase efficiency, by designing and manufacturing solar radiation collectors in two different configurations as corrugated-duct and airflow-duct. One of the collectors has been taken into consideration as natural-flow and 1 meter; and since other one has been taken into consideration as forced-flow and circulation-duct, its airflow duct length has been 2 meters. As a result of the experiments; it has been obtained that the natural-flow and corrugated-duct collector’s efficiency is 25%, and corrugated-duct and forced-flow collector’s efficiency is 66%.
Keywords: Solar energy, Corrugated-duct collector, Air heating.

DALGALI KANALLI VE HAVA ISITMA AMAÇLI GÜNEŞ ENERJİSİ KOLLEKTÖRLERİNİN TASARIMI İMALATI VE PERFORMANS DENEYLERİ

Özet: Güneş enerjili sistemler daha çok, kullanma sıcak suyu hazırlama amaçlı olarak düşünülmekte ve kullanılmaktadırlar. Hava ısıtma kollektörleri (kolektörleri) yeni yeni kullanım alanları bulmaya başlamıştır. Bu çalışmada; kullanma sıcak suyu hazırlama, kurutma ve konut ısıtma konularında, verimi arttırmak amacıyla, dalgalı hava akma kanallı iki farklı yapıda güneş ışınımı kollektörleri (toplaçları) tasarlanıp yapılarak, deney sonuç verilerine göre, performansları araştırılmıştır. Kollektörlerden birisi tabii akım ve 1 m kanal düşünülmüş, diğeri de cebri akımlı ve dolaşım kanallı olarak düşünüldüğünden hava akım kanal boyu 2 m olmuştur. Deneyler sonucunda tabii akımlı ve dalgalı kanallı toplacın verimi % 25, yine dalgalı akımlı cebri dolaşımlı toplacın verimi de % 66 olarak bulunmuştur.
Anahtar Kelimeler: Güneş enerjisi, Dalgalı kanallı kollektör, Hava ısıtma.

SYMBOLS

A	Surface area [m^2]
$\dot{Q}$	Heat power [kJ/h]
$\dot{V}$	Air volume [m^3/h]
t	Temperature [$^{\circ}C$]
t_g	Inlet air temperature [$^{\circ}C$]
$t_ç$	Outlet air temperature [$^{\circ}C$]
c	Specific heat [kJ/kgK]
ρ	Intensity [kg/m^3]
$\dot{m}$	Mass flow [kg/h]
η	Efficiency [%]
I	Solar radiation [W/m^2]
X_M	Arithmetic average of observations
X_i	Observations carried out
N	Observation number
S	Standard deviation
a	Accuracy
V	Variance
U	Uncertainty

INTRODUCTION

In this regard; development of the nations is evaluated according to energy amount and range that they generate and consume. As the energy generation of Turkey is not covered its energy consumption as of today, it makes energy intake from the neighboring countries. Those energies of which importation are made, are different. Most known energy resources; such as petrol, natural gas, electric energy and coal, constitute the major ones of those mentioned.

Turkey, by its Gross National Product (GNP), ranks number 47 (Wikipedia, 2011) among the world countries, with approximately 12 thousand USD Dollars (with the year of 2007 data). Turkish people pay a large part of their incomes to outside in order to provide the energy intake. As the national resources remain incapable to cover increasing energy consumption; the energy dependence, of which importation is made at a high rate such as 73% in the year of 2008, shall increase further. In 2008, 48.2 billion dollars had spent for the energy importation;

however; the energy demand and energy cost of which importation is made, have decreased to 29.8 billion dollars level, together with the constriction in economy (Keskin and Ünlü, 2010). By the year of 2007, the petrol has had the biggest share with 33% in total energy consumption of Turkey; and natural gas with 29%, coal with 28% and renewable energy resources including hydraulic with 10% the remaining, have followed it (Enrgy, 2006).

Heavy increase of the world petrol prices and limitation of the national resources, have alternatively made usage of the renewable energy resources a current issue, and whilst the solar energy is at the head of these renewable energy resources, its usage had become a current issue in every field of life. The natural origin resources, such as the solar energy, wind energy, wave energy and geothermal energy, create the major renewable energy resources for Turkey. The biggest problem in the usage of these kinds of resources is difficulties in non-storability of aforementioned energies. In view of the nation wide; the solar, wind and geothermal energy and also wave energies, especially in Black Sea and Aegean shores among the renewable energy resources, come to the forefront. Notwithstanding that the solar energy has the most extensive usage among them, even if it is limited; while the wind fields have started being conspicuous in Western Regions of Turkey, making usage of the wind energy has not become a current issue yet. Another advantage of making usage of the renewable energy resources is to be environmentally friendly. Although petrol, coal, plant and animal wastes, which are carbon-based classic energy resources, are the major energy resources; the damages of their productions and usages given to the environment are known by everyone. Because of these pollutions, the scientists are seriously worried with regards to future of the world.

In this study; because of the reasons we have specified; in order to take advantage of the solar energy, the solar radiation collectors have been designed, manufactured, and their performances have been specified, instead of the classic energy resources that are used in the hot air production for different purposes.

SOLAR ENERGY COLLECTORS

The collectors, in taking advantage of the solar energy, are the most important component of a system in various configurations and features for convection as heat to a heater by accumulating the solar energy. These solar-powered systems; which might increase the temperature of a coolant that is used as the heat conveyor to quite high temperatures; are especially used for the purpose of heating the sanitary water in Turkey as they are in the world, depending upon the manufacturing material and system statute of the collector. The solar-powered systems are manufactured as the natural-flow or pumped. Additionally, the heat convection to the system coolant is carried out directly or indirectly, by using the heat exchangers. Chen and et al (1982) from these researchers have manufactured a solar dehumidifier fully closed kiln equipped with a 1.5-BG heat pump. Çomaklı and et al (1990) has built up a solar-collector and energy-storage heat pump system for the purpose of drying and air conditioning for Black Sea Region and told that its energy efficiency has increased up to 70%. Tezcan (2002) has studied on the planar solar. The technical and economical examinations of a flat-plate solar collector, which are used in the hot water production in Turkey, have been made by Koyuncu and Ültanır (1987). Alkoç (1996) has made comparisons of the natural-circulation solar water heaters and their thermal efficiencies, by applying the heat pipe principle to the solar water heaters. Deniz (2003) has made comparisons of the solar collector systems, of which ethanol is used as the working liquid in the two-phase system and water is used as the working liquid in the indirect-circulation system. Yenice (1998) has made examination of the heat-pipe solar collectors, of which alcohol is used as the working liquid and selective-surface natural-circulation solar collectors in order to prepare the heat water. Doğan (2001) has seen that the system air has got warm faster than the other collectors, when its moisture has taken by passing through an evaporator in the air collector inlet, in the collectors designed as the air pre-drying. Sugözü and Sarsılmaz (2006) have ascertained that the air solar radiation collector has increased the indoor temperature between 5°C and 25°C, depending upon the solar radiation intensity. Bulut and Durmaz (2006) have calculated the average thermal efficiency of the solar air-collector systems as 53%, with different solar radiation collectors they have made, and as a result of the measurements they have carried out in 8 different days. The planar solar radiation collectors are the most commonly used solar radiation collector systems, as their manufacturing and systems are easy. In Figure 1, detail drawing of a commonly used planar solar collector is seen.

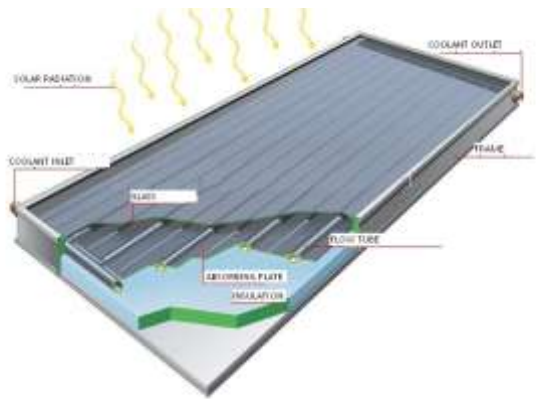


Figure 1. The classic flat plate collector (http://www.bildwoerterbuch.com).

On a reflecting collector, which has been made in order to increase the system efficiency, a heat accumulation pipe has been mounted along the mirrors' focal points. In order that the parabola might follow the sun, necessary support configuration and bedding elements are available (Figure 2).

And, on the conical collectors (Figure 3) or combined parabolic collectors that have been made for the same purpose, the radiations coming from different ways have been thought to be transmitted to the heater (heating coolant = system coolant).

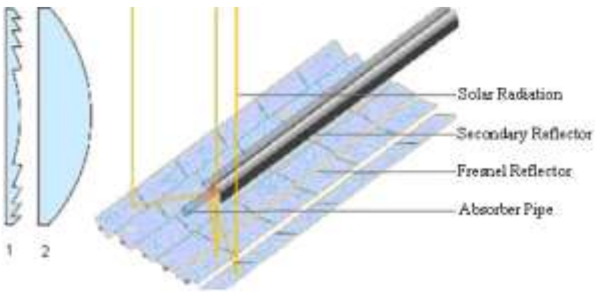


Figure 2. The vacuum-tube collector design (Ezen, 2010).

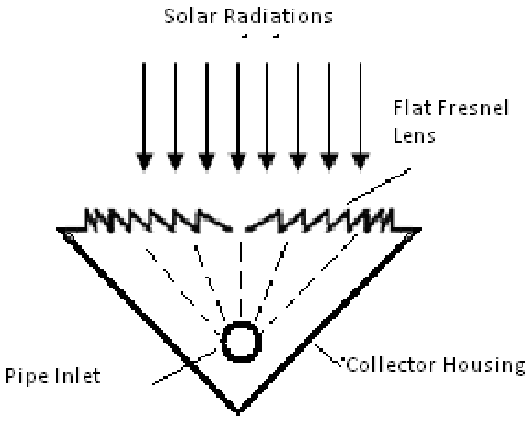


Figure 3. The radiation-focusing collector design (Eltez, 2003)

While some of the solar radiations coming to the opening field directly reach to the absorbing surface on the parabolic absorbers, the solar radiations coming to the edges come to the absorbing surface after they reflect a few times [Figure 4]. The parabolic collectors showed on Figure 4 have been made, taking into consideration that the reflecting radiations shall be taken again.

SYSTEM COMPONENTS AND PREPARATION OF THE SYSTEM

The collectors manufactured have 0.5 m^2 total surface area with the dimension of 1 m in length, 0.5 m in width and 0,1 m in depth. Frames of the collectors were built by galvanized sheet with 0.5 mm thickness, and insulated with 2 cm thickness of Styrofoam, and to prevent it from the outside air affect the outer surface of it was covered by commercial glass with 5 mm thickness. As seen in Fig 5, to enhance the heat convection surface area and enable air turbulence for heating the air more effectively, corrugated fins were installed at 6.25 cm intervals along the collector. One of the collectors whose photographs were given in Fig. 5a, was designed with natural flow (Fig. 5b), the other collector was designed with forced flow (Fig. 5c).

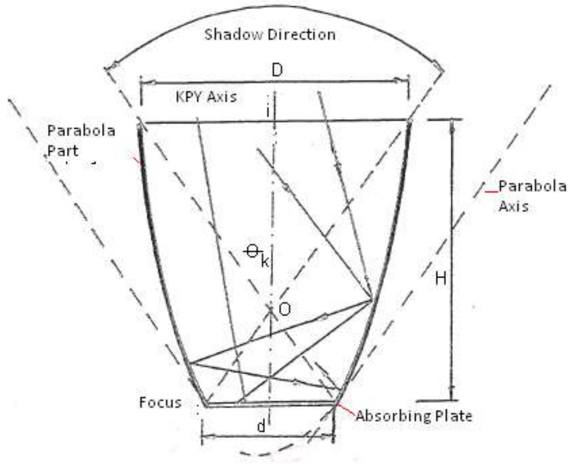


Figure 4. The parabolic collector design (Yılmaz, 1989)

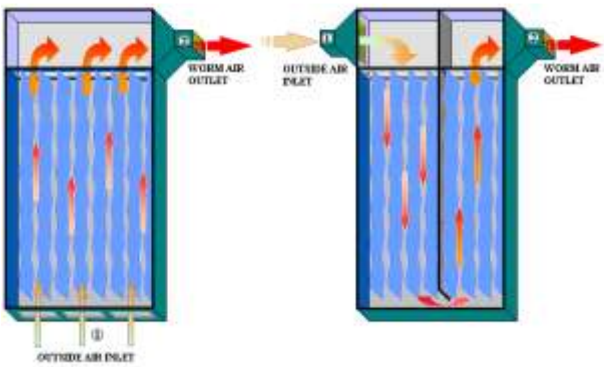
The natural-flow collector shall flow over the duct by going up, when the incoming air from the openings at the bottom (shown as 1 in Fig. 5b) gets warm, depending upon the "the air rises when it gets warm '' principle. On the other hand; in the forced-circulation collector, as the air inlets (shown as 1 in Fig. 5c) and outlets (shown as 2 in Fig. 5c) are mounted on the top, due to the fact that there shall not any air flows in the normal conditions, the air flow has been thought to be provided by placing a transmission fan, at very low capacity as seen on Figure 6, to the collector's inlet on the left. In order to adjust the air volume of the fan, which is used in the collector thought as the forced-flow and of which features are given on Figure 6, the transformer showed on Figure 6 has been used as the energy resource. This fan was installed in the system air inlet which is an external air inlet (shown as 1 in Fig. 5).As it is understood from the figure (Figure 5); these two collectors' radiation accumulation surfaces are the same, however; whilst the air duct length is 1.0 meter in the natural-flow collector, the flowing length of the air within the ducts is 2.0 meters in the forced-circulation collector.

A galvanized sheet in 0.35 mm thickness has been used in manufacturing of the corrugated-duct in the collectors. As the collector's housings have been made from known classic materials and simple transparent glass, it has not been needed to specify its details. The collector's interior surface has been painted with lusterless black color in order to reduce the heat loss arising from the reflection.There are holes in such a way that the air might flow through the wall between the radiation accumulation volume and duct. As it is understood from the figures; whilst there are air inlet openings (holes) under the natural-flow system, bottom part of the forced-flow system is fully closed.

EXPERIMENTATION

Owing to the fact that these kinds of researches have been started to be carried out hence the world's energy potential has been decreasing, in this study, it has been thought how the solar energy would be mostly able to be

a. The collectors experimented



b. The perspective drawings

Figure 5. The corrugated-duct air solar radiation collectors.

how many percent of the radiation energy coming onto the collector surface would be able to be converted into the utilizable energy, with less cost.

The system has been thought as 100% airborne and except for the solar radiation energy; not any energy has been used, except for the energy that the device having the features given on Figure 6 uses, in order that the air transmission fan might work. The energy to be come into existence from the air friction of the fan to be used in the forced-flow system has not been taken into consideration, as the energy shall be very low.

The energy gained by the system

The energy loads that the systems gain have been calculated over the temperature, intensity and flowing air volume of the air incoming to the system, and the temperature, intensity and flowing air volume of the air outgoing from the system. Therefore;

$$\dot{Q} = \dot{V} \cdot \rho \cdot c \cdot (\Delta t) \quad (1)$$

$$\dot{Q} = \dot{m} \cdot c \cdot (\Delta t) \quad (2)$$

$$\Delta t = t_g - t_ç$$

$$\dot{m} = \dot{V} \cdot \rho$$

equations have been used.

Whereas; “ $\dot{V}$ ”, on this equivalent, is volumetric flow rate of the system air,

$$\dot{V} = A \cdot v \quad (3)$$

it has designated with the above-stated equations.

Whereas; “A” is cross-sectional area of the duct and “v” is air flow of the air flowing from the duct, the air flow and temperature values have been measured with

Figure 6. The measurement devices used in the systems

Device Name	Features	Figures
The air transmission fan	A fan used in the computers for cooling Feature: DC 12 V. 0,15 A	
Transformer	Input: 220 V AC Output:0-14V DC, 1.1 A	
Solarmeter (measures the sun’s flux)	DAYSTAR Measurement Unit: Ws/m^2	
The temperature and airflow measurement device	TESTO 435 Temperature -20 … +70, Speed: 0 … 20 m Accuracy: Speed: ± 0,01 m/s, Temperature : ± 0,5°C	

‘‘Testo 435’’ temperature and air flow measurement device, as shown on Figure 6.

Due to the Ankara take place between 30^o-42^o north latitudes, the direction of the collectors were placed to the south and the angle was adjusted at 40° from the earth surface and the solar meter was put on the collector glass surface and measurement unit was taken as Ws/m^2 (J/m^2). As seen in Fig. 5, inlet air properties were measured in the inlet shown as 1 and exit air properties were measured in the outlet shown as 2.

The temperatures and air velocity were measured with Testo 435 measurement device with the units of °C and m/s respectively (Fig. 6). Channel section at the measurement points is square with 5x5 cm dimensions. Air flow rate ($\dot{V}$) was calculated by using channel section (A) and mean velocity (v) in Eq. 3. Since air velocity changes with the cross section, the mean velocity was used in the calculations.

The systems’ efficiencies

For the efficiency;

$$\eta = \frac{\dot{Q}}{I \cdot A} \qquad (4)$$

equation has been used.

On the equation; it has been taken into consideration that ‘‘ $\dot{Q}$ ’’, as the heat transmitted to the air in time unit, and ‘‘I.A’’, as the solar energy amount coming to the collector’s surface.

‘‘I’’, the solar radiation energy, has been measured as ‘‘Ws/m^2’’ with the ‘‘Solarmeter’’ shown on Figure 6.

The system’s uncertainty analysis

The uncertainty analysis ascertains accuracy limits of the data provided. The uncertainties of the measurement devices used in the system have been calculated b using the Equation (5) to (9), by taking their Standard Deviations into consideration, and given under the title of ‘‘Evaluation of the Experiment Results’’.

$$X_M = \frac{1}{N}\Sigma X_i \qquad (5)$$

$$V = \frac{1}{(N-1)}\Sigma(X_1^2 - X_M^2) \qquad (6)$$

$$S = \sqrt{V} \qquad (7)$$

$$a = \frac{1}{\sqrt{N}} \qquad (8)$$

$$U = \sqrt{\Sigma_{i-1}^{R} a_i^2 \cdot S_i^2} \qquad (9)$$

On the equations; it has been taken into consideration that ‘‘X_M’’, as the arithmetic average of observations, ‘‘X_i’’, as the observations carried out, ‘‘N’’, as the observation number, ‘‘a’’, as the accuracy, ‘‘S’’, as the standard deviation, ‘‘V’’, as the variance’’, and ‘‘U’’, as the un certainty (Aktaş and et al, 2010). The experiments were carried at Gazi University Technical Education Faculty between 24-28 May 2010. The data were collected for every fifteen minutes from 9:00 to 17:00.

Once every 15 minutes; the solar radiation coming to every two collectors, temperatures of the air incoming and outgoing and flows of the air outgoing, have been separately measured. The properties of the measurement devices are given in Fig. 6.

EVALUATION OF THE EXPERIMENT RESULTS

The systems’ efficiencies, as a result of the processes carried out by using the Equations (1) and (4), have been calculated as 25% for the natural-flow system and 66% for the forced-flow system.

Since daily recorded data about solar radiation and temperatures for five days between 9.00 and 17.00 o’clock were very close to each other, the calculations were carried out according to the data recorded on 28^{th} May. The variation of the solar radiation to time is given in Fig. 7 and variation of air temperatures versus time is given in Fig. 8.

As it is seen on the graphic (Figure 8); as the circulation way of the corrugated and forced-circulation-duct system is lengthier than the natural-flow system, the temperature values have been higher (≈ 45^oC) that the natural-flow system, as well.

Accordingly; as the airflow is higher (0.6 m/s) than the natural-flow system, the total air mass (m) induced heat has been bigger, as well. In addition, as the outside mean air velocity was measured as 0.4 m/s, and inner section mean air velocity of the system with the natural flow was measured as 0.64 m/s, with the forced flow mean air velocity was measured as 0.64 m/s.

Therefore heat stored total air mass (m) with the forced flow system was greater, (Eq. 2). Therefore; although they have the same radiation accumulation surface (0.5 m^2), the efficiency of the forced-flow system has been higher that the natural-flow system.

The system’s uncertainty analysis

As a result of the experiments carried out; when evaluating according to the Equations (5) to (9), the uncertainty analysis data has been found that the temperature is ± $0{,}39^oC$ and airflow is ± 0,25 m/s for the natural-flow system, and the temperature is ± $0{,}37^oC$ and airflow is ± 0,609 m/s for the forced-flow system, as well.

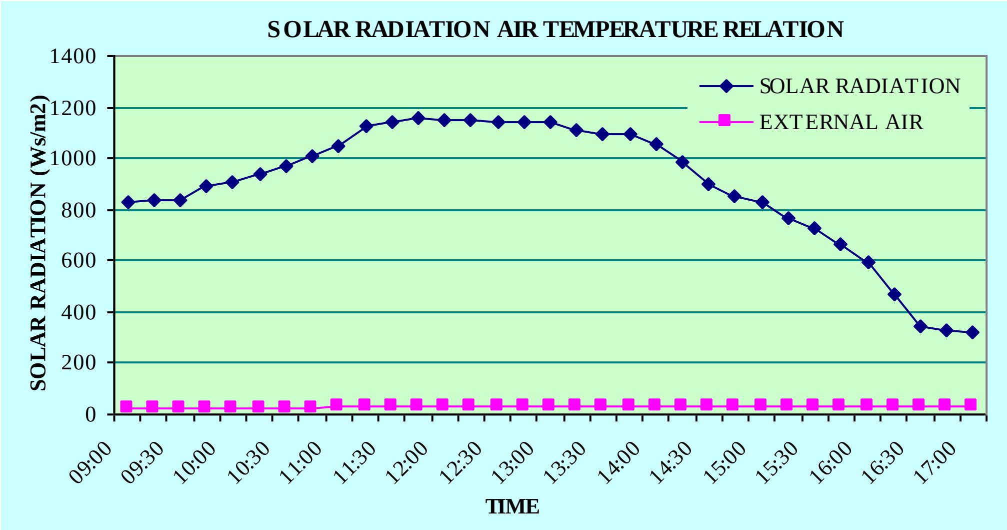


Figure 7. The solar radiation versus the time and outdoor temperature graphic.

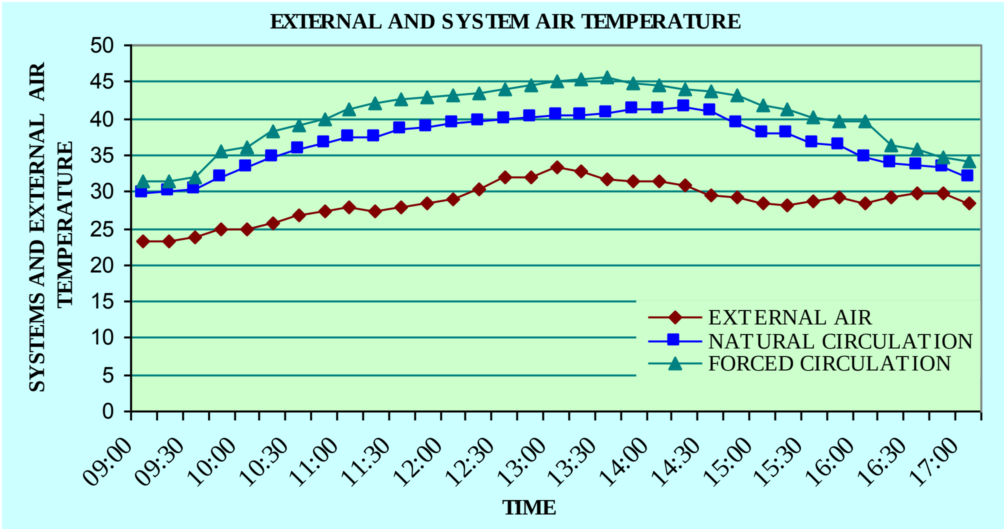


Figure 8. The time and temperature relationship graphic.

CONCLUSION

It is possible to state like that in those years in which the energy prices increase as the day goes on and permanent effects and damages of the classic fossil fuels harming the environment come into question, as well; it is very important for the economy and future to make use of the solar energy, which is a renewable resource and does not under no circumstances harm the environment, with these simple mechanisms even if it is 66%. The systems' efficiencies 25% and 66% mean that the energy coming onto the collector surface from the sun is transmitted to the system at the rate of 25% in the natural-flow system and at the rate of 66% in the forced-flow system, respectively. Even in these simple systems; in cases where better insulation is made and the absorbing surface is a bit more extended, even if not being the collector which cost vacuum-tube and of which cost is pretty much, the system's efficiency certainly increase further. In case where the heat taken in these simple systems is transmitted to the water; it is possible to prepare the domestic sanitary hot water, as well as, it shall be possible to heat locations when becoming sunny. Moreover; as these kinds air heating systems do not have any water storage tanks, they are both light and easy to place.

REFERENCES

Alkaç, O., 1996, Application of Heat Pipe Principle to Solar Water Heaters, Zonguldak Kara Elmas University, Institute of Science and Technology, Post Graduate Thesis, 20-48.

Aktaş, M., Ceylan, İ., Doğan, H., Aktekeli, Z., 2010, Designing, Manufacturing and Performance Experiments Of Solar Energy-Assisted Heat-Pump Red Pepper Dryer, Journal of Thermal Science and Technology, 30, 1, 111-120.

Bulut, H., Durmaz, A. F., 2006, Designing, Manufacturing and Experimental Analysis of an Air SolarCollector, UGHEK'2006: I. National Solar and Hydrogen Energy Congress, Volume: 168, June 21-23.

Chen, P., Y. S., Helwer. W.A., Roen H.N., And Barton, D. J., 1982, Experimental Solar Dehumidifier Kiln for Lumber Drying, Forest Products J., Southern Illinois University, USA, 32(9): 35-41.

Çomakli, Ö., Ayhan, T., and Kaygusuz, K., 1990, Air Conditioning-Purpose Solar-Collector Energy-Storage Heat Pump System for Black Sea Region, Black Sea Technical University, Department of Mechanical Engineering, Trabzon, 1-4.

Deniz, E., 2003, Comparison of Two-Phase Protected-Zone Solar Water Heater and Indirect-Heated Solar Water Heater Efficiencies, Zonguldak Kara Elmas University, Institute of Science and Technology, Post Graduate Thesis, Zonguldak, 5-42.

Doğan, H., 2001, Experiential Comparison of Air Heating Collectors Used in Drying, Karabük University, Journal of Technology, and Volume: 4, Issue: 1-2, s.75.

Eltez, M., 2003, Thermal Focalization Technologies and Application Examples in Solar Energy Usage. TMMOB, Solar Energy Systems Symposium and Exhibition, Mersin, 1-13.

Energy Statistics of the World and Turkey, Turkey, 2006.

Ezen, H., H., 2010, Theoretical and Experimental Analysis of Vacuum-Tube Solar Collectors, Süleyman Demirel University, Institute of Science and Technology, Post Graduate Thesis, 32-42.

http://www.bildwoerterbuch.com/en/energy/solar-energy/flat-plate-solar-collector-2.php

Keskin, M. Tülin, Ünlü, H., 2010, Energy Efficiency Status and Role of Local Governments in Turkey, Topkapı, Istanbul, October 2010; Chamber of Mechanical Engineers: Energy Outlook of Turkey, Nisan.

Koyuncu, T., Ultanir, M. Ö., 1997, Interpretation of Flat-Plate Solar Collectors in Terms of Economy, Agricultural Mechanization 17th National Congress, Tokat, September 17-19,.

Sugözü, İ., Sarsilmaz, C., 2006, Experimentally Researching of Air Solar Collector and Indoor Heating'', Fırat University, Journal of Institute of Science and Engineering, Volume: 18(2), Issue: 257-265.

Tezcan, M., 2002, Planar Solar Collectors and Efficiency Calculations, Post Graduate Thesis, Istanbul University, Institute of Science and Technology.

Yenice, O. T., 1998, Development of Heat-Piped Water Heater Solar Collector, Ankara University, Institute of Science and Technology, Post Graduate Thesis.

Yilmaz, R., 1989, Manufacturing and Testing of Parabolic-Reflector Solar Collectors, Post Graduate Thesis, Gazi University, Institute of Science and Technology, Ankara, 33-66.

Wikipedia, Özgür Encyclopedia, 2011, List of Countries by GDP Per Capita, January 28.

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