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Design, construction and performance testing of a new system for energy saving in rural buildings

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ABSTRACT

Drying fruit, heating residential buildings and providing a hot water supply in villages all consume energy. Using fossil fuel for these purposes creates pollution and costs too much. In contrast, the use of solar energy in these applications leads to a noticeable decrease both in pollution and investment costs. In this study, a new solar system was designed and tested in order to reduce energy usage in rural residential buildings and the food drying industry. As the peaks of energy consumption in the proposed system are not simultaneous, this new system is very effective in reducing energy consumption, controlling energy peaks and reducing environmental pollution. This system has the ability to provide the required energy in both summer and winter modes. In the summer mode, the energy supply is used for providing hot water and drying agricultural products, while in winter mode it is used for rural residences heating and hot water supply. Drying time has been varied between 51.23 and 42.45 h according to type of application, and average temperature difference between room and ambient is almost nearly 10 °C with different air heaters. The system includes energy supply and storage equipment, solar dryers, water collectors and rectangular, triangular, trapezoidal and double-pass with longitudinal fins air heaters. The system was tested in Iran for drying apricots, heating rural residential buildings and supplying hot water for domestic use, meanwhile, the energetic and exergetic efficiency of the system was calculated 37.3–61.3 and 3.2–9.7 respectively for different types of installations.

1. Introduction

As a process in food industries, fruit drying requires a high level of energy. Since there is a high cost to heating houses and providing hot water, the new solar system was designed to decrease the use of energy in houses and the food industries. Since the energy peak is not synchronized in the system, the new system is very effective in reducing energy consumption and controlling energy peaks. It can help to decrease the energy consumption in rural food industries and in house heating applications. It also lowers the system cost by the synchronization of energy peaks, which is an advantage that comes from the unified design of this system. Economizing on fossil fuels; reducing environmental pollution as well as sanitary drying of agricultural products are among other useful applications of this system. In developed countries, energy consumption in the building sector represents a major part of the total energy budget. Most of the amount is spent for hot water production and space heating.

Hot water is required for bathing and washing clothes, utensils and other domestic purposes not only in the rural areas under discussion but also in urban areas. Water is generally heated by burning noncommercial fuels, namely, firewood in the case of the rural areas and commercial fuels such as kerosene oil, liquefied petroleum gas (LPG), coal and electricity in urban areas. In this regard, utilization of solar energy through solar water heating (SWH) systems can play a big role in the amount of energy required. Solar energy is a well-proven and readily available technology which can directly substitutes renewable energy for conventional water heating methodologies. Various systems are available which are suitable for different applications. Small systems are used for domestic hot water applications while larger systems can be used in industrial process heat applications. There are two types of water heating systems defined by the type of the water circulation involved: natural circulation and forced circulation. Natural circulation solar water heaters are simple in design and low in cost. Forced circulation water heaters are used in colder climates and for providing heat in commercial and industrial processes.

Karatasou et al. [1] designed a method to calculate the mean radiation in collectors inclined towards the south (that is, the method is useful in the northern hemisphere). Safaripur and Mehrabian [2] using another method, in Iran, predicted the amount

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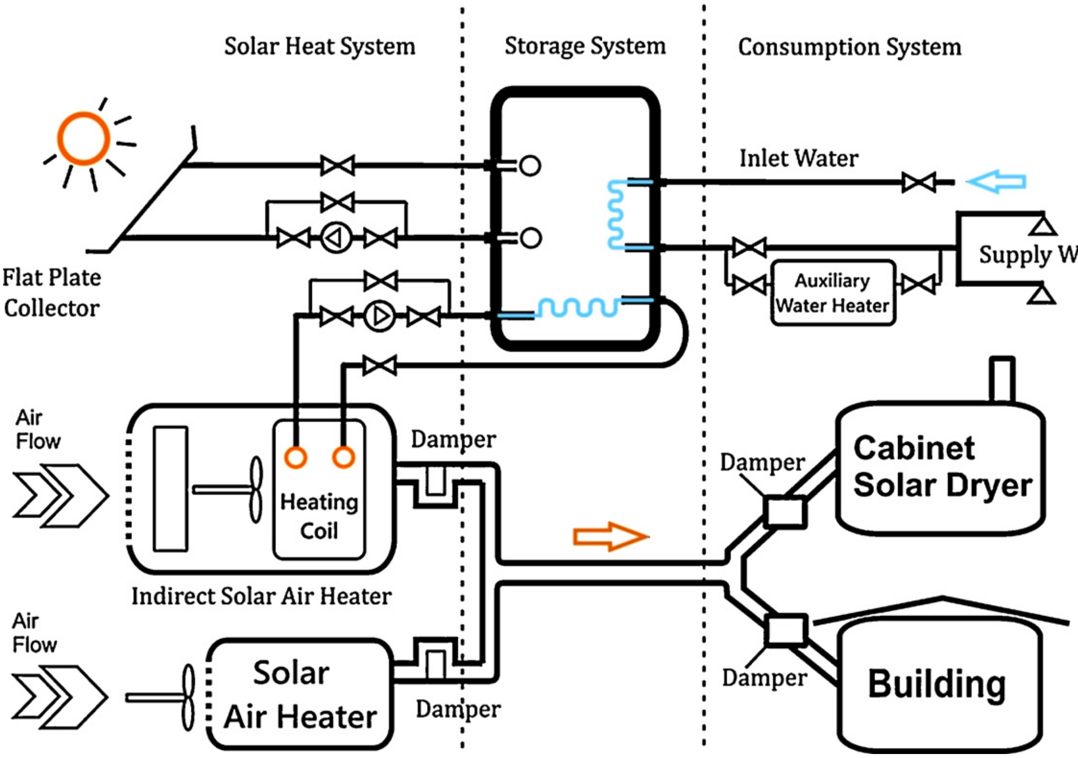

Fig. 1. Schematic diagram of a combined solar air handling unit and solar dryer.

of solar radiation using geometrical and astrological features along with geographical and meteorological data. Gunerhan and Hepbasli examined parts of the solar water-heating system for energy consumption and exergy and studied water-heaters in daily hours, in Izmir, and reported the results [3]. Badescu figured out the optimum current in flat-plate solar collectors [4]. Mittal et al. [5] Signal suggested some relationships for air-heater, and some formulas between roughness and their heat transfer. Hatami and Bahadorinezhad [6] conducted research on the application of vertical flat-plate solar air-heaters, suggesting a formula for heat transfer and thereby calculating Nuselt number. Bales and Persson [7] analyzed and compared eight water-heating systems, cross-comparing against a reference system. Chua and Chou [8] investigated low-cost rural dryers, pointing out the advantages and disadvantages for each, and mentioned some points on their application in developing areas as well as Asian countries. Montero et al. [9] designed and tested a solar dryer in Spain. In 2008, Amer et al. [10] designed a solar hybrid dryer for banana. In addition, the equations of heat and mass transfer for tropical fruit dryers were solved by Karim and Hawlader [11] the dynamic behavior of dryers was studied. Furthermore, the models of Newton, Page, Modified page Wang and Shung were investigated by Ceylan et al. in order to find out the degree of moisture in a solar dryer [12]. Abu-Hamdeh [13] proposed a model for the air-heater behavior, comparing gas and solar energy required for such a dryer. Moyls [14] studied the solar dryer with air heater and a rock tank for heat storage. Khollive et al. [15] investigated the use of dryers to dry apricots, grapes and apples. Kholliev et al. [16] showed that the solar dryer has other applications such as planting vegetables as well as the drying usage. Fadhel et al. [17] compared the simulation results in natural and forced convection systems. Golneshan et al. [18] Shiraz University, used the newly design solar collectors for pre-heating large spaces. Also, in a computer program Lund [19] analyzed the effect of various factors for calculating required heat load in order to decrease costs through dimensional optimizing of system parts. Concerning the use of solar energy for heating spaces, Kara et al. [20] used solar system for heating the administrative section of the solar institute in Turkey. Tchinda reviewed and classified various mathematical models of solar air heaters based on the shape, the number of cover and model of absorber [21]. Ho et al. investigated about efficiency of double-pass flat plate solar air heaters with fin attached and proposed a mathematical model for this solar air heater [22]. Hans et al. investigated the effect of artificial roughness in different forms, shapes and sizes for improving heat transfer in solar air heaters [23]. Hartnett and Minkowyez studied the heat transfer characteristics and the performance of flat plate solar air heaters by numerical methods [24]. The entropy generation in solar air heater with rib-grooves roughness was studied numerically by Layek et al. [25] Kumar and Saini has analyzed the performance of a solar air heater duct that provided with artificial roughness by using Computational Fluid Dynamics [26]. Pottler et al. has optimized finned absorber geometries for different solar air collectors [27]. The double pass-finned plate solar air heater was investigated theoretically and experimentally by El-Sebaii et al. [28]. Tronchin et al. has developed three different numerical models that calculate energy performance of rural buildings for single-family house in Italy [29]. Zhuang et al. has studied a thermal and airflow model for a Kang (special rural buildings used widely in China) with a simply consideration of heat transfer in building [30].

There are various industrial drying systems as well as solar heating systems for houses, which have been designed and analyzed individually. However, simultaneous designing of the two systems has not taken place, because the drying in rural areas is generally done through traditional and unsanitary processes resulting in high cost of energy consumption, the simultaneous use of both systems is suggested in some rural applications. Since each family generally dries its individual products and fruits in the house, the system is designed in such a way as to both dry the products through solar energy and to supply heat for domestic use. Thus, the system uses

Table 1
Operation and load modes.

Load type	Operation mode	
	Summer	Winter
Hot water supply	*	*
Solar dryer load	*	–
Building load	–	*

*: available; –: not available.

solar energy to dry agricultural products in summer time, and supplying house heating in winter, while hot water for domestic use is provided all year round.

In this study, a new solar system was designed and tested in order to reduce energy usage in rural residential buildings and the food drying industry. As the peaks of energy consumption in the proposed system are not simultaneous, this new system is very effective in reducing energy consumption, controlling energy peaks and reducing environmental pollution. The system was tested in summer and winter and obtained the best efficiency by different collectors.

2. Methodology

There are various industrial drying systems as well as solar heating systems for houses, which have been designed and analyzed individually. However, a simultaneous design of the two systems has not taken place, because drying food products in rural areas is generally done through traditional and unsanitary processes which entail a high cost in energy consumption. In this article, the simultaneous use of both systems is suggested for rural applications. As each family generally dries its individual products and fruits in the house, the system is designed in such a way that it dries the products through solar energy and supplies heat. Thus, the system uses solar energy to dry agricultural products during summer, supply hot water yearly as well as heat building in winter. In other words, the system is bi-seasonal throughout the year.

To design and examine performance of system, the following steps were employed:

1. General design of system according to new idea explained in this section.
2. Calculation of heat load with software in different modes.
3. Calculation of solar energy incomes according to collectors type (more details in Section 4).
4. Selecting or designing system parts.
5. Testing of system.
6. Comparing different results and selecting best option.

The kind of collectors and the installation angles were found to be the effective parameters in utilizing solar energy. In this research, a computer program was employed to calculate the optimum installation angle for the periods of months, seasons, and year. In case the user intends to use the system at different times, the optimum installation angle would be determined by the software. The software can be adjusted to optimize the results, based on changing inputs including geographical conditions, the type of dryer product, moisture, collector installation angle, system heat load and so on.

The system can be set for both summer and winter modes. The heat load needed for both modes can be calculated as follows in Table 1.

Calculations were done to predict the heat load of hot water supply, based on the standards for a rural family of six members. The heat load for the fruit dryer based on the fruits' mass, primary and final moisture. The heat load of a sample house can be calculated through the software. (The traditional building of the laboratory belonging to Islamic Azad University, Semnan branch has been used in the experiment.) Necessary heat has supplied by solar water collectors or solar air-heaters in the two modes.

3. Implementation of the proposed system

The device (Fig. 1) is made up of four parts:

1. A system for collecting solar energy including water collectors and air heaters.
    a. A water collector with absorbent plate (200 cm × 100 cm), black chrome, water filled copper tubes, glass wool insulator and an anodized aluminum frame.
    b. Triangular, rectangular, trapezium and double pass with longitudinal fins shape air heaters with 4-mm glass and thermocouple PT100 and 370–550-W centrifugal fan.
2. A system for supplying sanitary hot water including:
    a. A 150-L hot water tank of 0.5-mm sheet and polyurethane insulator of 5-cm thickness and a 2-kW auxiliary electric heater.
    b. A 150-L auxiliary water-heater using liquid gas fuel.
    c. A centrifugal circulator pump of 3 L/min flow rate and a 5-m head.
3. A solar fruit dryer including:
    a. A cabin dryer of 1-m square cross section and 2-m height, consisting of six levels and a capacity of 12 kg of apricots.
    b. A compact heat exchanger with a 170-W axial fan.
4. Measurement instruments.

The instruments for measurement include thermometers, and thermocouples to record temperature; rotameter, to measure flow rate, Mannix C800DLAF model speedometer to measure air speed, and a humidistat, to measure moisture. A Kipp & Zonen digital Pyranometer with Solard digital data logger, which can be connected to a computer, is used to measure the intensity of the radiation of the sun.

4. Calculations and estimation of solar radiation energy

To design solar systems, the input of solar energy data relating to the situation is needed. As the accuracy of such data directly influences the accuracy of the device itself, the data for the trial were obtained from Iranian Meteorology organization compared with the additional data obtained through evaluating the amount of radiation by a Pyranometer device installed in site. Furthermore, the comparison was based on the data from various sources regarding the degree of radiation in different locations of Iran [31–34].

The solar radiation can be calculated using meteorological, geographical and weather parameters. To analyze the relationship between the total daily solar radiation, Semnan Geographical specifications through Google Earth have been used (longitude: east 53.26; latitude: north 35.36; height: 1118 m) and the total radiation value of daily solar energy was obtained through a Pyranometer installed on the site for eight months (January to August).

The intensity of outside-atmosphere solar radiation on a horizontal plate is calculated through Eq. (1) in which G_0 signifies the outside-atmosphere solar constant (1367 W/m^2) and φ is the latitude of the site and δ is the declination angle [35].

$$H_0 = \frac{24G_0}{\pi}\left(\cos\varphi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\varphi\sin\delta\right) \tag{1}$$

G_0 is defined as follows;

$$G_{0n} = G_{sc}\left(1 + 0.033\,\cos\frac{360n}{365}\right) \tag{2}$$

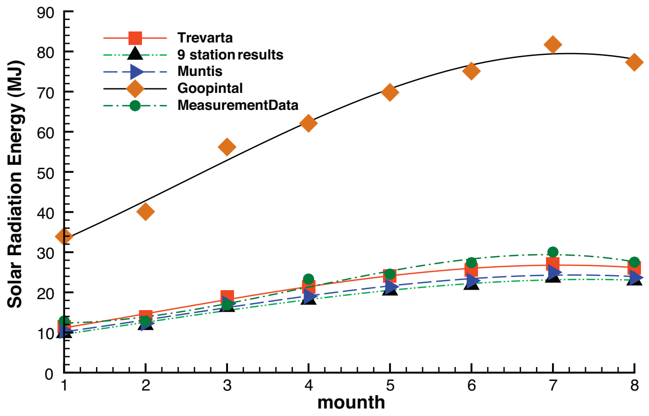

Fig. 2. Diagram showing the comparison between different Angesterom Priscat methods.

In which "n" shows the number of days passing from January 1. The sunrise and sunset hour angle can be calculated through Eq. (3).

$$\omega_s = \cos^{-1}(-\tan\varphi \tan\delta) \tag{3}$$

Declination angle can be calculated through Eq. (4):

$$\delta = 23.45 \sin\left(360 \frac{284+n}{365}\right) \tag{4}$$

The maximum number of sunlight hours from sunrise to sunset is calculated through Eq. (5).

$$N = \frac{2\omega_s}{15} \tag{5}$$

There are several models to calculate the mean daily radiation, including the Angesterom Priscat, Maximum probability, and Hybrid models. In this research the Angesterom Priscat model was used as shown in Eq. (6).

$$\frac{\bar{H}}{\bar{H}_0} = \left(a + b\frac{\bar{n}}{N}\right) \tag{6}$$

Here $\bar{n}/N$ is the ratio of measured hours to calculated hours.

The calculation methods for estimating the solar energy are different in how indexes a and b are treated. The suggested methods were considered for Semnan (Iran). Based on weather ranking of Trewartha the values of $a = 0.37$ and $b = 0.41$ were calculated through Eq. (7).

$$\begin{aligned} a &= 0.309 + 0.539\cos\varphi - 0.0693h + 0.290\left(\frac{n}{N}\right) \\ b &= 1.527 - 1.027\cos\varphi + 0.96h - 0.359\left(\frac{n}{N}\right) \end{aligned} \tag{7}$$

Here, φ signifies latitude and h height. Montis suggested $a = 0.25$ and $b = 0.5$ for the Angesterom Priscat model indexes. Using the data gathered from nine synoptic stations in Iran, a and b were calculated as 0.2551 and 0.4466 then comparing with different methods of Angesterom Priscat, it is concluded that all methods fairly match the radiation data except for Goopintal (Fig. 2).

Since there is a difference in absorbed radiation energy for collectors, first the solar radiation was calculated, then the system was tested in different modes and the results were compared.

5. Software designed for system heat load calculation

The kind of collectors and installation angle were effective parameters in calculating the absorption of the solar energy. In this research, a computer program was employed to calculate the optimum installation angle in the above location for the periods of months, seasons, half-years and a year. In a case where the user intends to use the system of different points in time, the optimum installation angle would be suggested by the software.

For this study, the optimum installation angle for the year has been considered; however, experiments led to different results for different modes because of limitations in installing the collector on the building exterior, horizontal and slanted roofs as well as regional architecture. These are important factors in determining the way the system is used.

The heat load of hot water or that of the dryer was entered as input data into the software. The heat load of the building was calculated through establishing a link with Carrier software.

With regards to calculated heat load and other kinds of data – including geographical specifications of the region concerned, collector parameters, the kind of collector used and agent fluid – the type and number of collectors can be determined in order to supply the required heat load. The software can be adjusted to optimize the results for any change of input for geographical conditions, the type of dryer product, moisture, collector installation method, system heat load and so on.

6. Results and discussion

Since the kind of collector and the installation method are very effective factors in system performance, several tests were done using water collectors and air-heaters and results were compared. Thus, different collectors could be used according to the architecture principles and the limitations in various geographical locations. The system test results with water collectors are shown in Section 6.1 and the system test results with air heater are shown in Section 6.2. Since testing the dryer with various installation angles needs a lot of time and money, also, it is practically impossible to test all possible permutations, the air-heaters were tested in various installation angles to heat buildings.

6.1. System testing with water collector

This section has two parts. In Section 6.1.1 the summer test results are presented, that include fruit dryer test results and hot water supply preparation. In Section 6.1.2 the winter test results are presented, that include hot water supply preparation results and the quantity of temperature rising in residential building.

6.1.1. Summer mode test results

First, the water collectors were employed to evaluate the system. This test was performed in June in order to prepare hot water and dry apricots from an initial moisture level of approximately 85% to a final moisture of 15%.

Several factors have been effective in increasing the efficiency of the dryer, temperature was an important one. It was, in turn, a function of several other factors including the intensity of the sun's radiation, speed of the wind, mass flow rate of water in the hot-water generator and mass flow rate of the hot water passing through the dryer. Parameters such as the intensity of the sun's radiation and speed of wind are among the factors which cannot be controlled. However, through the mass flow rate of hot water and that of the air current passing through the dryer, timing, temperature and moisture in the drying process could be controlled in order to get the dryer functioning closer to optimum efficiency. So, in testing the water collector, a variable speed pump was used and it tested three water mass flow rates in the circuit. The revolution of the fan was adjusted by a potentiometer and this meant it could be tested in various mass flow rates of hot air currents.

To obtain the diagrams of moisture versus time, the pump was operated in each of the three modes, and the fan was adjusted in n1, n2 and n3 so that the speed of the air would be equal to V_1, V_2

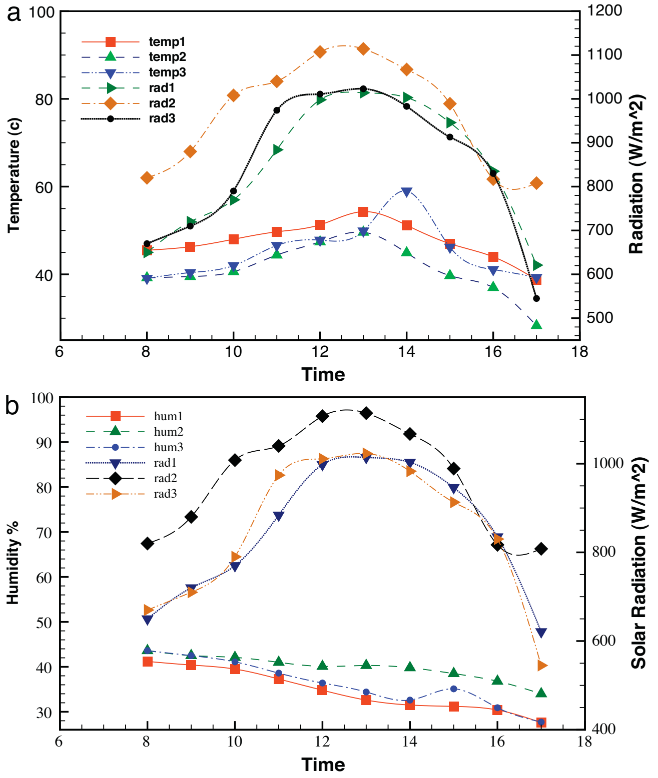

Fig. 3. (a) Variation of dryer temperature in different modes and (b) variation of dryer moisture in different modes.

and V_3. Then the dryer was tested. After changing the hot water flow rate, the test was repeated with different hot air flows and temperature and moisture were recorded (Fig. 3).

Results show that the speed and temperature of the input dryer air are effective parameters relating to the period of time items take to dry, and the drying process can be controlled by changes or adjustments to the fan revolution and selecting the correct proper mass flow rate of pump.

Looking more closely at the changes in the dryer diagram, it can be seen that there is a high drying speed in the initial phase of the process, which gradually decreases. Also, increases in the temperature of input air causes an increase in the drying efficiency, thereby decreasing drying time. However, an excessive increase of temperature lowers the quality of the products. Thus, the maximum thermostat temperature was set at 65 °C, which prevents an excessive temperature rise. The maximum degree can be defined and then set for the various products.

An increase in the air temperature reduces drying time, but increasing the mass flow rate of hot water and air does not reduce it in all situations. Therefore we can obtain the best drying conditions as shown in Table 2 for the different modes. Factors such as changes in the intensity of solar radiation, environmental moisture levels and wind speed affect the results but they were not taken into account in this phase of research.

6.1.2. Winter mode test results

Since it is important to provide year round hot water and to heat the building in winter, the experiments were done again in March. Based on the standard, the per capita consumption of hot water supply is 60 L with a maximum of 360 L/day for a rural family of 6 members and the heat load for the input water is assumed at 10 °C and the output water temperature is set at 60 °C.

The following data and diagrams were obtained during the experiments (Fig. 4).

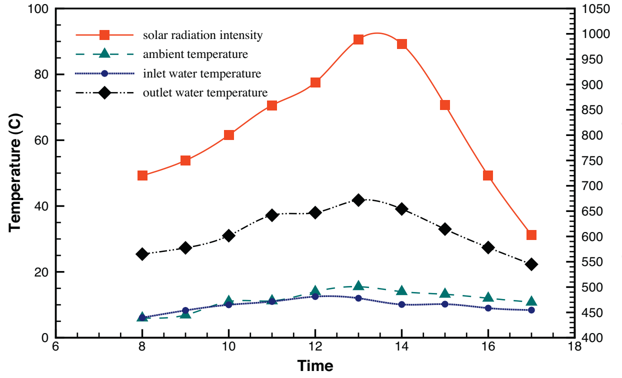

Fig. 4. Variation of temperature and radiation in solar water heater.

The water collector efficiency was evaluated according to the standard ASTME 1056-85 (reapproved, 2001). In a steady state condition, based on the continuity equation and energy conservation, there is...

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \tag{8}$$

$$\sum \dot{E}_{in} = \sum \dot{E}_{out} \tag{9}$$

The instant efficiency of the collector can be computed through the following formula and theoretical and practical efficiency values can be compared:

$$\eta = \frac{T\alpha I - U_L(T_c - T_a)}{I} \tag{10}$$

where T is the transparency coefficient of the glass, equal to 0.91, $\alpha = (0.95)$: absorbency of the absorbent plate, I is the solar radiation intensity, U_L is the total heat transfer coefficient of the collector, T_c is the collector temperature and T_a is the environmental temperature. The theoretical efficiency is calculated as 84%.

The instant practical efficiency of the collector is determined as the ratio of the useful energy absorbed in the collector divided by the input solar radiation energy on the collector's surface unit.

$$\eta_{col} = \frac{\dot{Q}_u}{IA_c} \tag{11}$$

And the absorbed useful solar energy is:

$$\dot{Q} = \dot{m}_w c_p (T_{out} - T_{in}) \tag{12}$$

Based on the mentioned standard, the overall equation for efficiency is;

$$\eta = \eta_0 + ax \tag{13-a}$$

$$x = \frac{T_m - T_a}{I} \tag{13-b}$$

Coefficients a and η_0 can be calculated in various mass flow rate by the duplication of the experiment as

$$\eta = 987.5x + 75 \tag{14}$$

By drawing efficiency diagram (Fig. 5) and comparing with the reference diagram [3], it can be observed that the efficiency of the system is higher than that of the mentioned reference because of the higher average solar radiation.

Moreover, the temperature of the experiment room, of 60 m^3, rises by 7 °C. Although this equipment cannot provide the heat load for the room by itself, it can economize energy to a great extent. The point is that the room was not completely insulated and allowed cool air to enter, which is the norm in rural houses.

Table 2
Drying time for different modes in the solar dryer.

Hot water flow rate in heating coil (L/min)	$Q_1 = 6$ L/min			$Q_2 = 8$ L/min			$Q_2 = 10$ L/min		
Air velocity in solar dryer (m/s)	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3
Drying time in solar dryer (h)	31	29	25	45	60	63	52	45	68
Average temperature in solar dryer (°C)	61.8	62.7	63.1	58.8	57.1	54	57.5	52.7	51.2
Maximum temperature record in solar dryer (°C)	64.8	65	65	62.7	65	63.1	64.5	61.1	63.2

$V_1 = 1$ m/s.
$V_2 = 2$ m/s.
$V_3 = 3$ m/s.

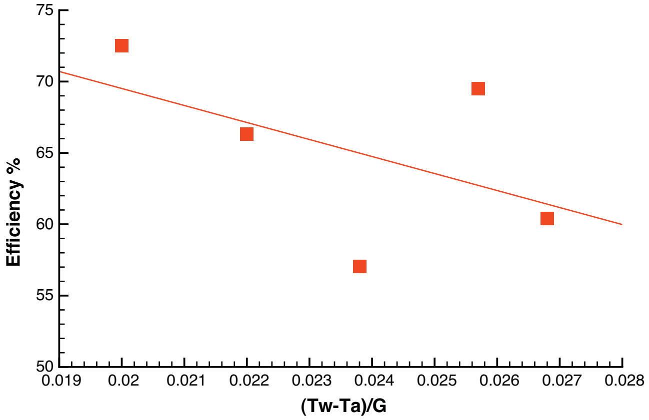

Fig. 5. Thermal efficiency curve for the solar collector tested.

6.2. System test results with different air heaters

In another mode, the system was tested by air-heaters, their effects investigated and the results compared. Air-heaters are usually less expensive and easier to operate, especially in rural areas where there are fewer facilities along with cleaner air. Thus, several of these air-heaters were tested and compared on the basis of their efficiency and the application of air-heaters in the system. These tests has been done with two objectives. The first aim was selecting the kind of the best air heater and second one was obtaining the best position of installation of air heater.

As the air heaters functioning depend on the kind of absorbent plate, coefficients of heat transfer and pressure drop in the air-heaters, collectors with the absorbent plate of triangular, rectangular, trapezium double-pass with longitudinal fins type were experimented according to following specifications (Fig. 6).

The air, directly heated by the air-heaters, installed at an angle that equated to the area's latitude, was sent to the dryer by closing the input dampers of residential space and opening the input damper of the dryer. On other occasions, the air was conducted to the building interior by closing the input damper of the dryer and opening the input damper of the room and it heated the space.

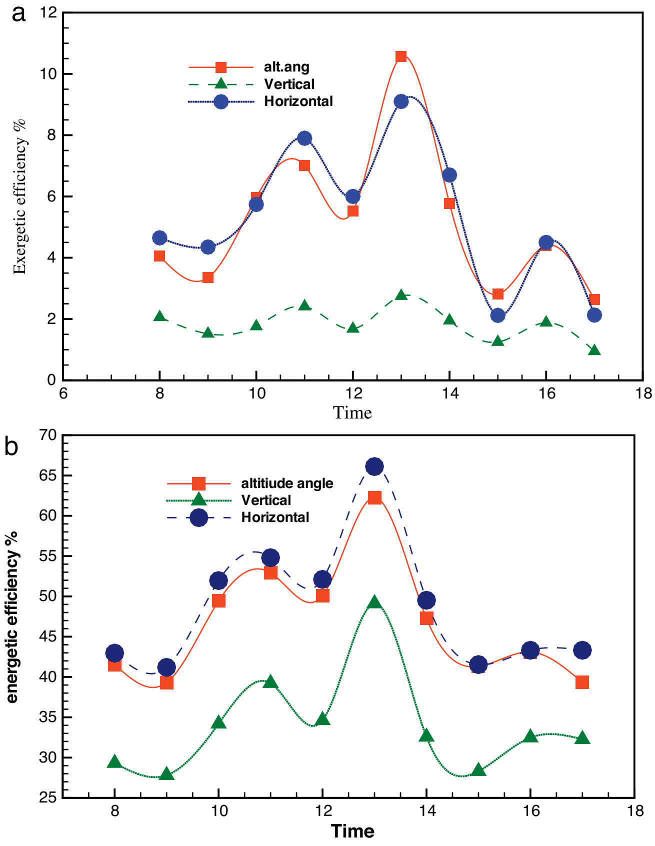

Fig. 7. (a) Exergetic efficiency for trapezium back plate in different installation type and (b) energetic efficiency for trapezium back plate air heater.

The time required for drying the products and achieving appropriate moisture for air-heaters can be seen in Table 3, based on the installation angle of collectors at an angle that equated to the region's latitude. As shown in this table, the trapezium type has minimum drying time.

Since testing the dryer with various installation angles needs a lot of time and money also, it is practically impossible to test

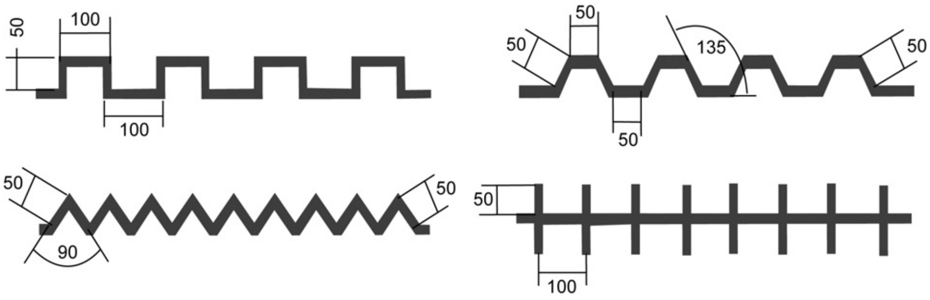

Fig. 6. Schematic diagram of different absorbent plates used.

Table 3
Drying time for solar dryer with different air heater's back plate.

Kind of air heater's back plate	Double pass with longitudinal fins	Trapezium	Triangle	Rectangular
Drying time (h)	42.45	35.30	46.12	51.23

Table 4
Temperature difference (°C) between room and ambient for different installation modes.

Installation angle	Kind of air heater			
	Double pass with longitudinal fins	Trapezium	Triangle	Rectangular
Altitude	9.5	10.1	9.2	8.9
Horizontal	10	10.3	9.5	9.1
Vertical	8.2	9.9	8.6	7.5

Table 5
Air heater energy efficiency in different installation modes.

Installation angle	Kind of air heater			
	Double pass with longitudinal fins	Trapezium	Triangle	Rectangular
Altitude	49.3	58.2	49.1	42.1
Horizontal	53.7	61.3	52.5	46.2
Vertical	41.5	51.7	37.3	39.1

Table 6
Air heater exergy efficiency in different installation modes.

Installation angle	Kind of air heater			
	Double pass with longitudinal fins	Trapezium	Triangle	Rectangular
Altitude	8.8	9.5	5.5	4.5
Horizontal	9.2	9.7	7.2	6.5
Vertical	7.3	8.7	4.3	3.2

Table 7
The priority of solar air heaters application.

Priority	Kind of air heater			
	Drying time	Temperature difference	Energy efficiency	Exergy efficiency
First priority	Trapezium	Trapezium	Trapezium	Trapezium
Second priority	Double pass with longitudinal fins	Double pass with longitudinal fins	Double pass with longitudinal fins	Double pass with longitudinal fins
Third priority	Triangle	Triangle	Triangle	Triangle
Fourth priority	Rectangular	Rectangular	Rectangular	Rectangular

all possible permutations, the air-heaters were tested in various installation angles to heat buildings (horizontal installation for flat roofs with optimized usage in summer, vertical installation for the exterior of buildings with optimum usage in winter, an installation at an angle that equated to the region's latitude for optimum usage throughout a year, and an installation at an angle appropriate to the slant of the roofs). Then, their energetic and exergetic efficiency were calculated and compared, which are shown in the diagrams for the collector's efficiency and air-heaters (Fig. 7). Based on the present theoretical data and the tests conducted, the output data of air-heaters and heating of the building were generalized to the dryer (Table 4).

The average energetic efficiency of the air heaters is calculated based on formula (16) and is presented in Table 5.

$$\eta = \frac{\dot{Q}_u}{IA_c} \tag{15}$$

$$\eta = \frac{m_a c_{pa}(T_2 - T_1)}{I \cdot A_c} \tag{16}$$

While the exergetic efficiency of the air heaters is calculated based on formula (17) and is presented for different installation modes in Table 6.

$$\eta_{ex} = \frac{Ex}{A \cdot I}\left[1 + \frac{1}{3}\left(\frac{T_0}{T_{sr}}\right)^4 - \frac{4}{3}\left(\frac{T_0}{T_{sr}}\right)\right] \tag{17}$$

Findings show that fluctuations of the parameters in rectangular air heaters are less than for that of all other kinds, but instant functioning and maximum parameters in other air heaters are better. Thus, the priority of air heaters are presented in Table 7 based on their applications.

7. Conclusion

In this study, a new hybrid solar system has been designed which can be used to provide hot water, heat rural houses and dry agricultural products. The system was tested in Semnan (Iran), with the longitude of east 53.26 and the latitude of north 35.36. The system helped analyze the functioning of flat water collectors and the air heaters of rectangular, trapezium and triangular shapes as well as double-pass types with longitudinal fins at different angles. The energetic and exergetic efficiency of the system were also investigated, compared with different modes and suggested appropriate kind of collectors based on their applications.

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