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DESIGN, DEVELOPMENT AND IMPLEMENTATION OF AN ELECTRICAL CONTROLLER FOR A SOLAR-ELECTRICAL COLLECTOR

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تصميم وتطوير وتنفيذ وحدة تحكم كهربائية لجامع الطاقة الشمسية

ملخص

تعد المحافظة على صحة الغلاف الجوي اليوم أحد أهم المتطلبات الأساسية للتنمية الاقتصادية العالمية المستدامة ، وليس أمام المجتمع الدولي خيار سوى التحول إلى الطاقات المتجددة ، بما في ذلك الطاقة الشمسية. كان الهدف من هذه الدراسة هو توفير درجة حرارة 60 درجة مئوية لتجفيف فواكه الصيف مثل المشمش وبالتالي قمنا بدراسة تأثير أنظمة التحكم في درجة الحرارة على أداء المجمع الشمسي الكهربائي. تم وضع ثلاثة مستشعرات درجة حرارة LM35 في 3 نقاط من المجمع (قبل مدخل الهواء إلى المجمع ، وبعد مخرج الهواء من المجمع وبعد عناصر التسخين) التي تم ربطها ببرنامج MATLAB وأرسلت درجة الحرارة إلى البرنامج عبر الإنترنت وتخزينها هناك. كما تم تضمين ثلاثة عناصر تسخين بعد مخرج الهواء من المجمع لتوفير الهواء الساخن عندما لا تكفي الطاقة الشمسية لتسخين الهواء اللازم. تم فحص أداء وحدة التحكم في ثلاث حالات وهي بالتحديد تم تنشيط جميع عناصر التسخين في وقت واحد ، وتم تنشيط العنصرين في وقت واحد وعندما تم تنشيط عنصر واحد فقط. أظهرت مقارنات الفروق أنه عندما يكون العنصران نشيطين ، كان لنظام التحكم استجابة في الوقت المناسب وتجاوز مثالي بدلاً من وضع العناصر الثلاثة وحيدة العنصر ، بسبب الانحراف المعياري المنخفض. وأظهرت النتائج أيضًا أنه باستخدام عناصر التسخين في مجمع الطاقة الشمسية ، يمكن تعويض الهواء الساخن في الأيام الممطرة أو في مناطق مثل أردبيل التي ليست عالية في ضوء الشمس. وفقًا للحسابات ، وجد أنه خلال ساعات تسجيل البيانات ، كانت مساهمة الطاقة الشمسية في تزويد الهواء الساخن 44.44٪ في يوم مشمس تمامًا و 23.66٪ في يوم مشمس جزئيًا.

Abstract

Todays, maintaining atmospheric health is one of the most important prerequisites for sustainable global economic development, and the international community has no choice but to switch to renewable energies, including solar energy. The goal of the study was to provide a temperature of 60 ° C for drying summer fruits such as apricots therefore we investigated the effect of temperature control systems on the solar-electrical collector performance. Three LM35 temperature sensors were placed at 3 points of the collector (before the air inlet to the collector, after the air outlet from the collector and after heating elements) that were linked to the MATLAB software and sent the temperature to the software online and stored there. Also three heating elements were embedded after the air outlet from the collector to provide hot air when the solar energy is not enough to heat the air needed. The performance of the controller was investigated in three cases namely all heating elements were simultaneously activated, the two elements were simultaneously activated and when only one element was activated. Comparisons of variances showed that when the two elements were active, the control system had a timely response and optimal overshoot rather than the three-element and single-element mode, due to the low standard deviation. The results also showed that using the heating elements in the solar collector, hot air can be compensated in rainy days or in areas such as Ardabil that is not high in sunlight. According to the calculations, it was found that during the data logging hours, the contribution of solar energy in the supply of hot air was 44.44 % on a completely sunny day and 23.66% on partly sunny day.

Keywords: Collector, Electric Controller, Heater and Solar energy.

1. INTRODUCTION

Renewable energies are considered as clean energy sources. The optimal use of these resources minimizes environmental impacts, produces the least secondary waste and sustains production. Considering the end of fossil and underground resources and the strong dependence of communities on energy resources, especially oil fuels, it is necessary to consider renewable natural energies more seriously than before [1].

The use of renewable energy and environmentally friendly methods for generating electricity is one of the priorities of today's developed countries; today, solar power has the greatest potential to meet the future needs of the world as one of the most renewable sources. More than 220,000 megawatts of world-class electricity are supplied by solar technology in two parts of photovoltaic technology and solar thermal technology [11].Fortunately, in Iran, due to the intensity of solar radiation in most parts of the country (300 sunny days in two thirds of the country with a mean of 4.5-5.5 Kwh/m^2 per day), the implementation of solar plans and the use of solar energy in cities and scattered villages in the country can bring significant savings in oil and gas consumption [2]. Solar collectors will have their highest efficiency when installed at their optimum slope, depending on various parameters, including geographical location [3]. Uncertainty in the parameters affecting production and development costs, as well as the productivity and efficiency of renewable energy technologies, has become a serious challenge for investors. Particularly for countries such as Iran, which have vast oil and gas resources and the potential of all types of renewable energies, there are plenty of options available to policy makers to determine the energy supply basket as well as supportive packages. Among renewable technologies, solar technologies have more uncertainties. The photovoltaic power plant in Iran has a comparative advantage over the CSP. These results are consistent with the reality in the world, but the characteristics of Iran are more justifiable than the CSP for the economics of PV plants. The combined technology of both PV and CSP technology is more economical, with its focus on R & D, making it more risky and more responsive [5, 4, 8].

According to a study by the United Nations Intergovernmental Panel on Climate Change (IPCC), if the Earth's climatic conditions continue as it is now, the Earth's heat will increase from 3.7 to 8.8 degrees by 2100. Most renewable energy sources and used technology have the lowest carbon footprint. Most renewable energy sources have the lowest carbon emissions. We can never be completely neutral in terms of carbon because it is used as a source for solar panel, barrier, etc., but in most cases it has a significant reduction in carbon production [13].

In the last half century, new methods have been developed for the use of solar energy in industrial applications. Solar-thermal conversion is one of the most commonly used methods, including designs such as flat collectors, concave collectors, desalination products and solar furnaces. Hot air is used extensively in industry, agriculture, animal husbandry and home affairs. One of the ways to produce hot air is in solar collectors. Unlike Solar water heating, much attention has not been paid to solar air heating [11].Moavenian and Naeemi[10] used a fuzzy controller to investigate the changes of control variables and a controller for fuzzy factorization of the gain coefficients. The proposed controller was implemented in a Simulink on a state-space model of an air conditioning system and its performance was examined.

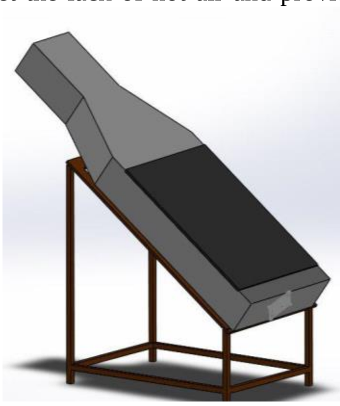
Barakat and Sinno [7] proposed renewable energy controller system. The proposed controller has an appropriate response to nonlinear characteristics and variations in variables. A DC converter is connected to the aero generator, it will be charging a group of batteries in order to store and produce electrical energy. Combining the two sources of renewable energy will lead to a maximum efficiency in electrical energy production. The system consists of a controller that will switch between the solar panel or wind turbine. The one that produce the maximum power needed will be switched on. Azeri [6] investigated the effect of physical parameters on the efficiency of the thermoelectric solar air heater system. The results showed that with increasing fluid velocity of the air heater, the amount of generated power would be reduced. Also as the flow rate increased, the amount of temperature rise in the air-heater plates decreased. Khosh'hal[9] conducted several experiments on a drying process with different moisture content using a laboratory dryer and presented a regression model for changes in moisture content, temperature and humidity of the output air. By measuring the temperature and relative humidity of the air outlet from the dryer, they estimated the moisture content of the product at any time, without the need for frequent sampling of the rice hulls. The results of this study showed that with the application of automatic control systems and also the optimization of the dryer, it can be significantly improved in rice hulls processing through reduction of waste, reduction of energy consumption and increase of efficiency. Wilcke[14] developed a control system for corn driers for solar air heating. They showed that using this system can reduce energy consumption by about 27%. Zaheeruddin[15] developed the Microgrid Central Controller (MGCC) that would use an embedded energy management algorithm to take decisions, which are then transmitted to the controllable RE systems to manage the utilization of their power outputs as per the load-supply power balance. A control strategy is adopted to regulate the power output from the battery in case of supply shortage, which results in a floating battery scheme in steady state. In order to get a satisfactory performance from the MGCC, a provision for the utility grid insertion has been made in the embedded algorithm in case all other energy options of proposed micro-grid are exhausted. This increases the reliability of the micro-grid as a whole.

The purpose of this study is to control the temperature of the solar electric air heater. The controlled hot air can be used for industrial and agricultural purposes. Due to the fact that during the night or in the clouds, the solar air heater is almost inactive, the use of an electric element is a good option to offset the lack of hot air and provide the desired amount of warm air. In processes that require a controlled and optimized temperature, we can use the temperature control circuit and maintain and control the temperature in an optimal amount.

2. DEGSINE METHODOLOGY

2.1. General specifications of the used collector

In this study, a flat plate collector was used which had a cross section of 1 cm2 and an absorbent plate with dimensions of 125 × 80 cm made of aluminum sheet with a thickness of 1 mm and covered with black matte cover (See Figure 1a). The body of this collector was made of MDF with a thickness of 160 mm, in order to reduce the heavy damage. To reduce the amount of heat dissipation, glass wool of 3 cm thickness was placed on this plate. A 4-mm thick dual-layer coating was used. The distance between glass covers varied from 2 to 6 cm. Also, the distance of absorbent plate from the second coat was 2 to 6 cm. In the upper part of the collector, a tin funnel was constructed and embedded in order to embed heating elements and temperature sensors (See Figure 1b).



a

b

Figure1. a: General schematic of solar air heater designed at SalidWork; b: Funnel for electrical

The bottom of the funnel, with dimensions 25 × 25, was as large that 3 elements can be placed 10 cm apart. The frame of this collector was designed angularly and was longitudinally smaller than the collector. By placing the collector at a suitable angle, it can easily be placed in the desired position. With respect to the moving rod, the collector could be in the range of 25 to 60 degrees. In order to create a space for uniform flow of air within the collector, as well as to neutralize the effect of the wind on the values of temperature and velocity of air from the collector, the inlet channel and air outlet are embedded at the beginning and end of the collector, respectively. The fan was placed at the beginning of the air inlet to inflate the air inside the collector. In order to prevent heat dissipation and insulate the device, all the side and bottom surfaces of the collector were covered with leather.

2.2. Stages of developing needed parts

2.2.1. Funnel

In order to place heating elements at the end of the collector, a tin-shaped funnel was designed and constructed. This template is attached to the collector as a slider. The bottom part of this formwork is so large that the three elements can easily be placed there.

2.2.2. Heating Elements

Heating elements were used to provide hot air when the sun was not available for reasons such as night or cloudy weather, and the collector was not able to supply the desired amount. Three of these elements were developed in 25 × 25 (See figure 2) and placed at the end of the funnel.

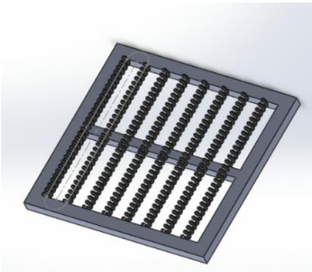


Figure2. Schematic design of Electric Element using SolidWork

2.3. Control system

In order to control the temperature, a control system was designed and developed. The purpose of this system is to control the temperature and send the temperature data to the computer for storage online.

2.3.1. Hardware of Automatic Control System

In this collector, three LM35 temperature sensors were considered (Figure 3). Due to temperature, this sensor generates a voltage at its output base. The output voltage variation is 10 mV per ^{0}c. All sensors were connected to a programmed Mega2560 R3 microcontroller board. For the turning on and off of elements, 3 SSR-40DA Solid State Relays - 2480 W to 40 A were used. Also a 12-volt DC 12V fan was used to supply the air to the collector.

Figure3. LM35 temperature sensor

2.3.2. Software of Automatic Control System

The R3 Mega2560 microcontroller board was developed using Arduino software (Figure 4). By connecting the boards to the computer and then executing the MATLAB software, the collector sensor data was recorded at a specified time. The program was sent to the microcontroller board via a computer connection to be implemented. Under this program, all sensors measured the temperature every 3 seconds at the same time and recorded on the computer. As seen in Figure 2, the system is a kind of feedback that can greatly reduce not only the output to the desired value but also external noise.

Figure4. Microcontroller board (Model: Mega2560 R3)

According to the diagram (See Figure 5), at the beginning, the optimum temperature (R) is defined as input to the system; this value is related to the type of agricultural product, for example, apricot at 60 ° C [13] (Step 1). As known, the cool air enters into the solar collector and somewhat warmed up and leaves it. At the outlet, the temperature is measured and sent to the controller. The digital signal controller sends the signal transmitted by the sensor and registers it as variable C (step 2). In step 3, an error calculation is made, that is, the value of the difference between the optimum temperature R and the actual output of the heater C. In step 4, a decision is made regarding the error. If the error value is positive, then we still have not reached the optimum value, so the heater must be turned on so that it continues to heat the air and the air becomes hotter than before. If this is not the case (ie, $E \leq 0$), then the temperature of the output is increased from optimal temperature and hence the heater should be turned off. To continue this process, steps (2), (3) and (4) must be repeated. As seen in the figure, the feedback path (dashed line) should be pulled from the end point to the preceding step (2), which would allow the microcontroller to create loops or loops (See Figure 6).

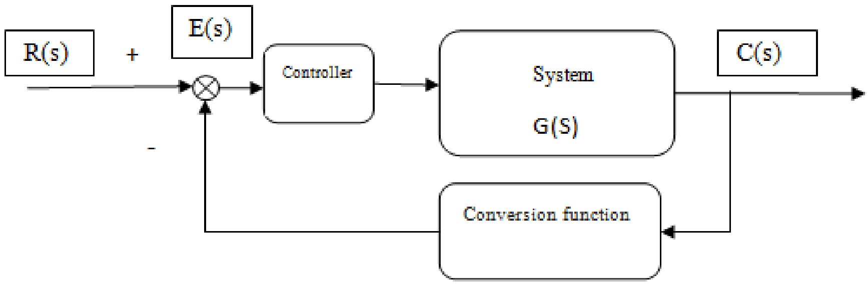


Figure5. Control system diagram

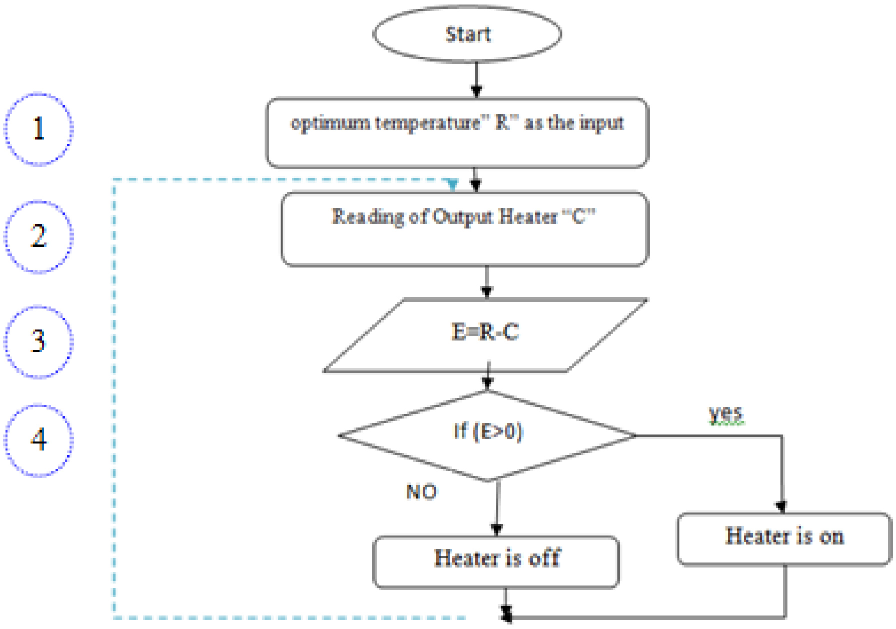


Figure6. Flowchart of algorithm implemented by the controller

3. RESULT AND DISCUSSION

3.1. Performance of the controller at a control point of 60 ° C and under sunny and partlysunny

Data was logged in different days and weather conditions. The data was stored in the MATLAB program, and then the charts related to each day were plotted by the MATLAB program. In Figure 4 shows the performance of the temperature controller at a control point of 60 ° C and under sunny day. If the collector's output temperature was less than 30 ° C, all three elements would be turned on to reach a temperature of 60 ^{0}c. If the sensor temperature was between 30 and 50 ° C, the two elements would be turned on, and if the sensor temperature was between 50 and 60 ° C, an element would be active. Finally, if the temperature of the outlet sensor was greater than 60 degrees, all three elements would turn off so that the temperature does not go up to the optimum level and remains at the selected limit (See Figure 7).

To calculate the percentage of savings in the use of the heating element by solar-based energy, the level below the figure was calculated; the contribution of solar energy at supplying hot air was 44.74% in a sunny day.

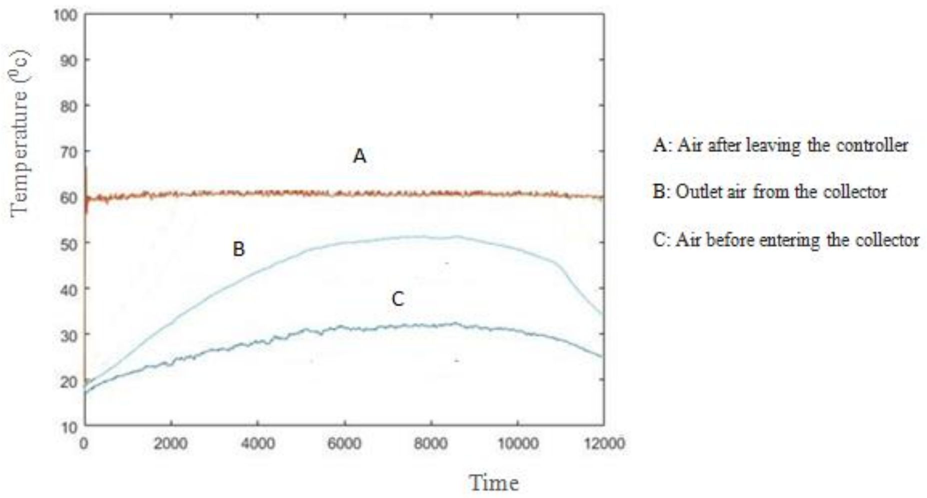


Figure7. Performance of temperature controller at 60 ° C in sunny day

The performance of the controller was checked at 60 ° C and in high wind conditions in semi-cloudy weather. As shown in Figure 8, the temperature of the input and output air is strongly fluctuating due to air instability and extreme temperature and wind variations. But the final temperature controlled with the controller was kept to a desirable level with very low volatility. This charts a good and acceptable performance of controller. The share of solar energy in supplying hot air for this day was 19.22%.

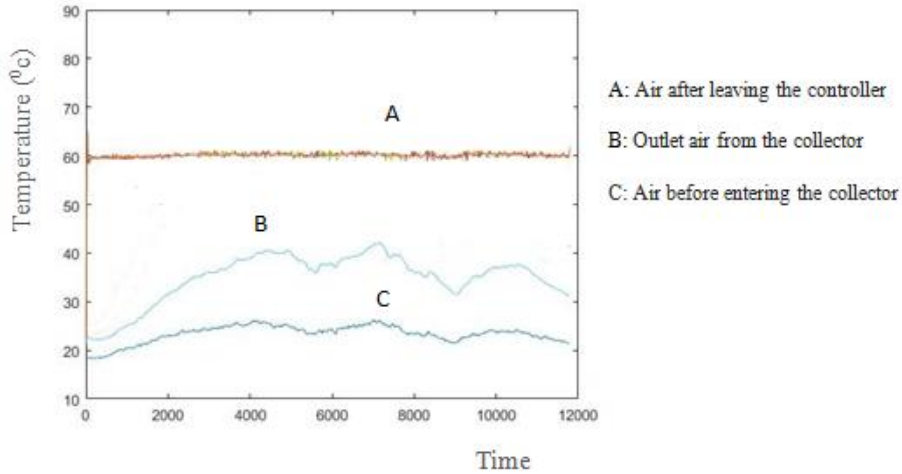


Figure8. Performance results of control at 60 ° C in semi-cloudy day with strong wind

3.2. Controller performance at 60°C for the solar-electric collector when all three elements are turned on and off

This time, the algorithm was executed so that all three elements simultaneously turned on and off.

For all temperatures of less than 60°C, all three elements were switched on, and off for all temperatures above 60 ° C. The share of solar energy for this day was 74.46% (See Figure 9). As you can see, the control temperature is high, because all three elements are simultaneously active or interrupted, and the controller has a maximum temperature of 68 degrees. At around noon and 1-3 o'clock, the collector alone could almost stand at a temperature of 60 degrees, and all elements were off, and in the diagram it was clearly seen that the temperature remained constant at that point.

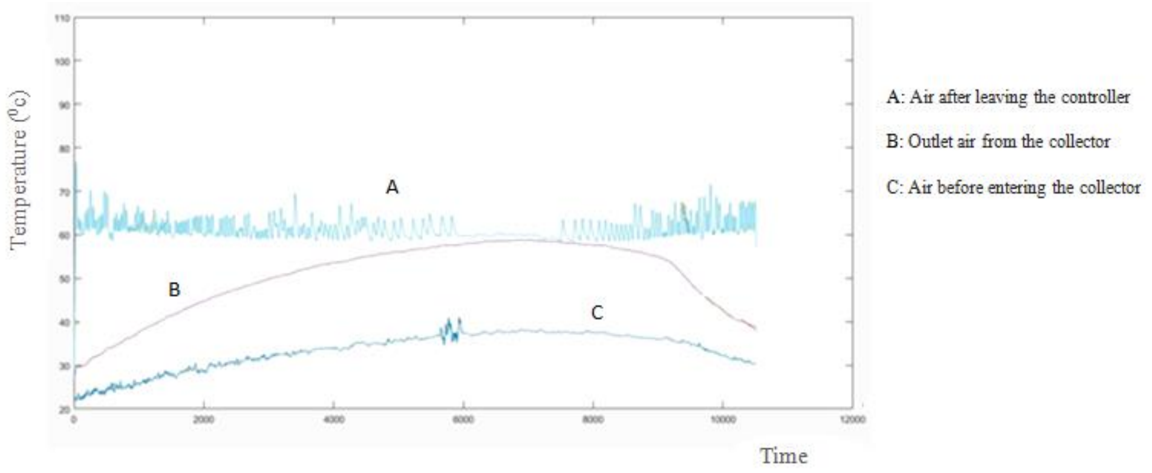


Figure9. Performance of the controller in the event that the three elements simultaneously turn on and off

3.3. Performance of controller at 60°C when two elements simultaneously turn on and off

Once again, the program was designed to activate two elements at temperatures below 60 ° C and turn off both elements at temperatures above 60 °C. In the case of simultaneous actuation or interruption of the two elements, it produces fewer fading than the condition that all elements are active or interrupted. The share of solar energy for this day was 22.9% (See Figure 10).

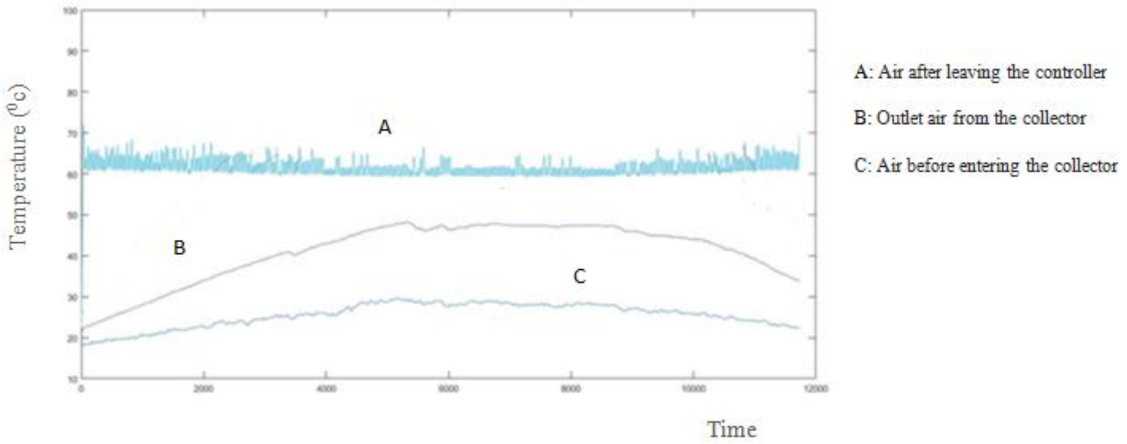


Figure10. Controller performance in the case of 2 actuators simultaneously activated

3.4. Controller performance at 60°C, when only one element is activated

At this stage, the program was designed to turn on only one element at temperature of less than 60°C and turn off it at temperatures above 60 ° C. The share of solar energy for this day was 30/18% (See Figure 11).

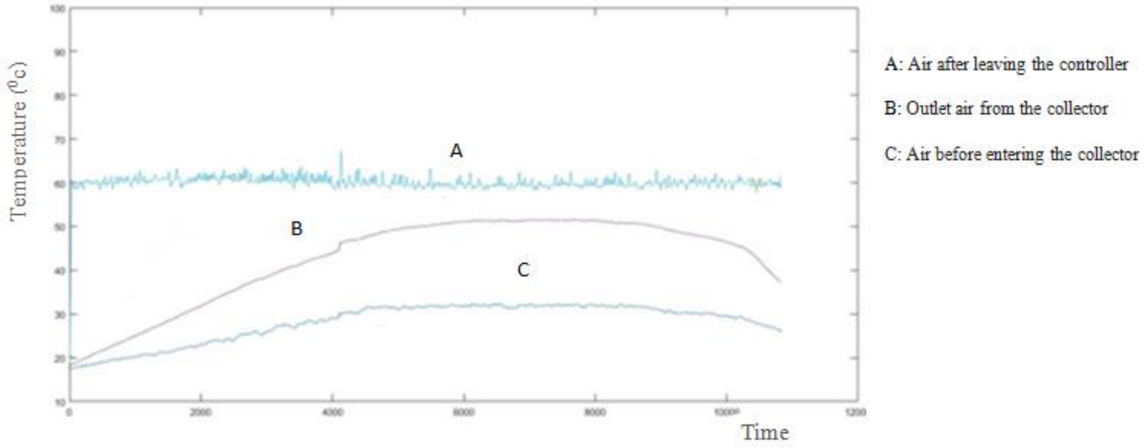


Figure11. Controller performance in the case of 1 element activated

Regarding the standard deviations given in Table 1, it can be concluded that simultaneous insertion of the 3 elements in the circuit is the worst possible because the control system is steeper and more efficient due to the simultaneous on and off of the heater at the same time (Figure 9). Also, the insertion of only one element in the circuit is not acceptable due to the system's slowness and the delay time when the heater is turned on and off (See Figure 11). In contrast, the simultaneous entry of two elements into the circuit has the lowest standard deviation (See Figure 10). It means that for Conditions in the study area, the presence of two heating elements is recommended to provide the desired temperature.

Table1. Statistical data on the number of active elements in the circuit

		Input temperature	**Element temperature**	**Output temperature**
Figure 11	Mean	25.4913	61.6719	41.0126
	Std. Deviation	2.92698	2.15405	7.10215
	Variance	8.567	4.640	50.441
	Std. Error of Mean	.02703	.01989	.06558
	Maximum	29.75	72.09	48.29
	Minimum	18.06	22.45	21.47
Figure 10	Mean	28.0952	60.1057	42.6183
	Std. Deviation	4.42180	1.66232	9.85143
	Variance	19.552	2.763	97.051
	Std. Error of Mean	.04251	0.01598	.09472
	Maximum	32.41	67.34	51.56
	Minimum	17.08	18.93	17.57
Figure 9	Mean	33.2987	61.4512	50.3008
	Std. Deviation	4.28370	2.41069	8.14715
	Variance	18.350	5.811	66.376
	Std. Error of Mean	.04178	0.02351	0.07946
	Maximum	41.19	76.77	58.91
	Minimum	21.75	26.84	26.35

4. CONCLUSIONS

The purpose of this study was to perform a controller operation for a solar-electric collector, which, can compensate for the lack of warm air and keep this temperature in a desirable manner. The following results were obtained:

1. According to datasets performed on a solar collector in Ardebil, without the installation of heating elements, the final air temperature of investigated collector was less than 60^{0c}, even during the warm days.
2. Using heating elements in solar air heaters, it is possible to reliably compensate for the shortage of hot air in rainy days or in areas such as Ardebil that is not high in solar radiation. Of course, solar energy contributed to the supply of hot air, and it was found that during the hours of operation, the contribution of solar energy to the supply of hot air was incontrovertible and it was 44.44% in a completely sunny day, and 23.66% in the sunshine day.
3. Data logging was performed with three elements, two elements and one element separately. The results showed that in July, using two elements, the control system had a timely and proper response rather than three-element and single-element mode due to the low standard deviation.

It is suggested that the present collector should be investigated in other cities, where the amount of solar radiation differs significantly from Ardabil, also should be tested and compared the results to determine what the energy savings in other areas are.

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