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Original Article

A Review of Glass Material Properties Effects on PV/T Systems

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Abstract: Energy has become an indispensable part of our lives today and our energy needs are increasing day by day with technological developments. In addition, the rapid depletion of natural resources and the deterioration of the ecological balance forced humanity to find and use new and clean energy resources. Renewable energy sources gained importance rapidly and dozens of studies were conducted on them. Photovoltaic panels are the basis of these studies, which started with the production of electricity from solar energy. Photovoltaic panels consist of many solar cells. The energy coming from the sun with photons is directly converted into electrical energy in these cells. The studies that started with the aim of generating electricity with photovoltaic panels were later developed to gain thermal efficiency in the same system and hybrid systems called Photovoltaic-Thermal were created. Photovoltaic-Thermal Systems (PV / T) transfers the thermal energy generated in photovoltaic panels to one or more fluids and aims to increase system efficiency by using the thermal energy generated during electricity generation.
In this study, it will be investigated how the properties of glass, which is the first part of solar energy, affect the thermal and electrical efficiency of a PV / T system working with air and water fluids. Three glasses were selected in the system and experiments were conducted under similar outdoor conditions. The experiment data were transferred to the computer environment by means of a program specially written for the system and daily. The electrical and thermal efficiency of the transferred data was calculated by mathematical formulation, and it was investigated how glasses affect the efficiency of the system. This system can be further developed and used in daily use in hotels and dormitories. The study will also trigger the use of alternative glasses with different properties in the system and will take a step towards increasing efficiency.

Cam Malzeme Özelliklerinin PV/T Sistemleri Üzerindeki Etkilerinin Araştırılması

Anahtar Kelimeler:
Cam Malzeme Özellikleri
PV/T Sistemleri
Yenilenebilir Enerji
Güneş Enerjisi
Verim Araştırması

Özet: Enerji bugün hayatımızın vazgeçilmez bir parçası haline gelmiştir ve teknolojik gelişmelerle birlikte enerji ihtiyaçlarımız her geçen gün artmaktadır. Buna ek olarak, doğal kaynakların hızla tükenmesi ve ekolojik dengenin bozulması insanlığı yeni ve temiz enerji kaynakları bulmaya ve kullanmaya zorlamıştır. Yenilenebilir enerji kaynakları hızla önem kazanıp üzerinde onlarca çalışma yapılmıştır. Güneş enerjisinden elektrik üretimi ile başlayan bu çalışmaların temelinde fotovoltaik paneller yer almaktadır. Fotovoltaik paneller birçok güneş hücresinden oluşur. Güneşten fotonlarla gelen enerji doğrudan bu hücrelerde elektrik enerjisine dönüştürülür. Fotovoltaik panellerle elektrik üretme amacı ile başlayan çalışmalar, daha sonra aynı sistemde termal verim de kazanmak amacıyla geliştirilmiş ve Fotovoltaik-Termal adı verilen hibrit sistemler oluşturulmuştur. Fotovoltaik-Termal Sistemler (PV/T), fotovoltaik panellerde üretilen termal enerjiyi bir ya da daha fazla akışkana aktarır ve elektrik üretimi sırasında oluşan ısıl enerjiyi de kullanarak, sistem verimini artırmayı amaçlar.
Bu çalışmada, hava ve su akışkanları ile çalışan bir PV/T sisteminde, güneş enerjisini karşılayan ilk kısım olan cam özelliklerinin, sistemin termal ve elektrik verimliliğini nasıl etkilediği araştırılacaktır. Sistemde üç adet cam seçilmiş ve benzer açık hava koşullarında deneyler yapılmıştır. Deney verileri günlük ve sistem için özel yazılmış olan program aracılığıyla bilgisayar ortamına aktarılmıştır. Aktarılan veriler matematiksel formülizasyon ile elektriksel ve termal verim hesaplanıp camların sistemdeki verime nasıl etki ettiği araştırılmıştır. Bu sistem daha da geliştirilerek otellerde ve yurtlarda günlük kullanımda kullanılabilir. Çalışma aynı zamanda farklı özelliklerde olan alternatif camların sistemde kullanılmasını da tetikleyebilecektir ve verimi artırmaya yönelik bir adım atacaktır.

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1. INTRODUCTION

Solar energy is used in two different ways. These are thermal solar systems where the incoming solar radiation is converted to heat and photovoltaic (PV) systems where solar energy is converted to electrical energy. Thermal solar systems are used in applications such as water heating, space heating and power generation. Photovoltaic systems are used in clocks, calculators and large-scale power generation applications. Hybrid systems in which these two systems are used together are called photovoltaic/thermal (PV/T) systems. The aim of these systems is to obtain both heat and electrical energy from a single system. (Abu Bakar M.N. et al., 2013)

In recent years, PV/T technology has attracted worldwide attention. Many researches conduted by researchers such as Xondag H.A. (2008), Tyagi et al. (2012), Hasan et al. (2010), Chaar et al. (2011).

In the reported PV/T systems, both air and water were used in the thermal part of the system. A number of design principles and solar cells have been developed that capture light and effectively convert it into electrical current. Overall progress in this area has been studied by many researchers.

N.A. Manaf et al. (2013), studied the air and water based PV / T system. In their studies, they determined the effects of single-pass and two-fluid solar collectors on total thermal equivalent efficiency performance and electrical efficiency using MATLAB simulation program. In the simulation results, it was observed that the system works more efficiently with water fluid compared to only air fluid.

Kalogirou and Tripanahnostopoulos (2006), in their studies, hybrid photovoltaic/ thermal (PV/T) systems consisting of polycrystalline-silicon (pc-Si) and amorphous-silicon (aSi) coupled to the thermal collector, installed and tested at the University of Patras, TRNSYS It has been modeled and simulated with the program. As a result of the study, they reported that the PV system produced 38% more electricity than the PV/T system, but the PV/T system met the hot water need of the building to which it is connected.

There’s also many research articles about PV/T systems in Turkey. Ahmet Kabul and Fatih Duran (2014) aimed to increase the efficiency, which decreases as a result of the increase in panel temperature during electricity generation from solar energy, by cooling the panel with water. With this goal, they cooled the panel by placing pipes on the back surface of the photovoltaic panel and passing water through the pipes installed. They circulated the water whose temperature increased by taking the heat in the panel in a water tank and transferred it to the water in the tank. Thus, they both increased the efficiency of the system and managed to provide hot water. As a result of their experiments, they obtained approximately 35% power and 7% efficiency increase in electricity generation.

Mert Gürtürk et al. (2011), investigated the effects of temperature changes on glasses used in photovoltaic modules in their study. They chose 2 glass types with 4 mm thickness and different transmittance values, first cooling and then heating. As a result, they observed that the energy efficiency varied between 1.24% and 2.06% with the measurements made on the reference solar glass placed on the solar cell.

However, no detailed and comprehensive study on two-fluid PV/T systems was obtained by comparing experimental results with numerical results and investigating the effect of the type of glass used on these systems to efficiency. This study aims to fill the gap on this subject.

2. MATERIAL AND METHOD

Konya Province was chosen for the study. Konya has a latitude of 37˚N and a longitude of 32˚E. For this reason, the inclination angle of the system was chosen as 33° throughout the year. Irradiation map of Konya is as follows:

Fig.1. Konya Province Solar Irradiation Map

Three types of glass were selected for the experiment. The first glass is 4 mm transparent flat glass. Three experiments were performed with this glass. The second glass is 4 mm low-e coated glass. This glass is coated with metal oxide and keeps the thermal gain inside. The third and last glass is double transparent glass cut in thickness of 4+12+4 mm. One day experiment was carried out with this glass. There is an air gap between them. All windows are the same size and 808 * 1630 mm. After the experiments were completed with one glass, the glass was disassembled and the other glass was installed. The same weather conditions were tried to be provided.

The system we used has 3 continents: cooling system, electrical system and data system. The test apparatus is shown in the figure 2, the system comprises these parts (Atmaca M., Pektemir İ.Z. (2018):

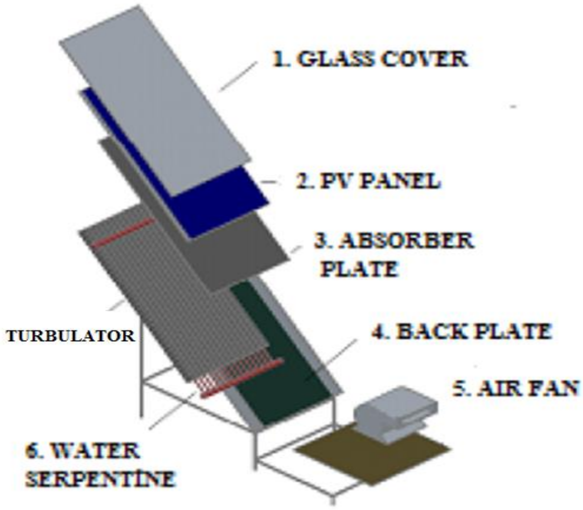

Fig.2. Parts of the System

1)Glass Cover: 4 mm transparent flat glass, 4 mm low-e coated glass, 4+12+4 mm double transparent glass, all three are has same size 808*1630 mm.

2) PV Panel: TPSM6U Monocrystal 200 W, 200 W, V_{oc}:45.4 V, I_{sc}:5.77 A.

3)Absorber Plate: 0.4 mm thickness, Aluminum alloy (200W/mK), painted to black.

4)Back Plate: Steel, 2 mm thickness.

5)Air fan: With electronic communication system.

6)Water Serpantine: Collector outer diameter: 32 mm, pipe outer diameter: 10 mm, material: copper (394 W/mK).

7)Turbulator: honeycomb, thickness 1.5 mm, length 1580 mm, material: aluminum (200W/mK).

Cooling system explained in figure 3 (Atmaca M., Pektemir İ.Z., 2019). The system can work with both air and water. In this review, system worked with only air cooling.

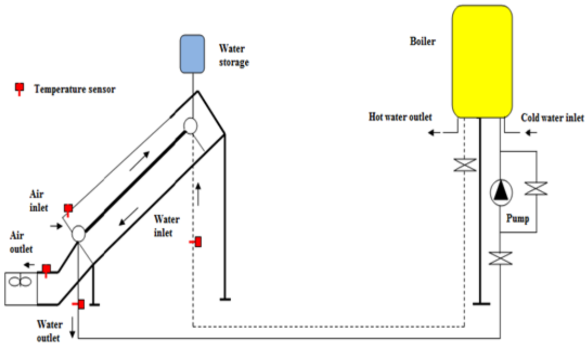

Fig.3. Air and Water Cycle

To receive and process data, PT-100 temperature sensors, air speed sensor for measuring air velocity, pyronometer for solar radiation, humidity and temperature sensors for comparing outdoor weather conditions, anemometer for measuring wind speed velocity values are used. And for electricity, current and voltage sensors are used. The data were transferred to the computer with a software specially prepared by İztekno Company and examined. This program shows all the data needed in the experiment such as outdoor temperature, irradiance values, wind speed and amper values produced in the system. Program also shows this values in a tables and allows us to track minute to minute changes. Figure 4 shows the interface of the program.

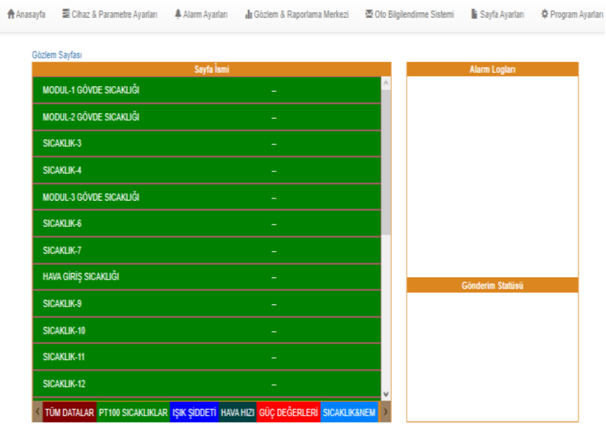

Fig. 4. Interface of the program to which data is transferred

The electrical circuit has a 1000 W full sine inverter, a 12/24 V 20 A charge controller, 6 12 V, 102 Ah batteries. Figure 5 show these devices. The electricity produced in the system is made usable in the connected devices and panels. Since the system is not connected to the grid, the energy requirement of the batteries has been eliminated even when the energy is insufficient. [11-12]

Fig. 5. Electrical Circuit of the System

The experimental results were calculated using the following three formulas and comparisons were made accordingly:

$Q = I_t \, . \, A_p$ (1)

Q = Gained energy from the solar power (W)

I_t = Average irradiance value calculated according to the figure (W/m^2)

A_p = Surface area of the panel: 1.2766 m²

$P_{th\text{-}a} = \dot{m}_{air} x C_{p(air)} x (T_o - T_i)$ (2)

$P_{th\text{-}a}$= Air circuit power of the system (W)

$\dot{m}_{air} = V_{air} . \, A_h \, .\rho$ (kg/s)

V_{air} = Air velocity (m/s)

A_h= Cross-sectional area of the air duct =0.6x0.35 = 0.21 m²

ρ = Air density (kg/m^3)

$C_{p(air)}$ = 0,24 kcal/kg.°C

T_o= Air out temperature (°C)

T_i= Air in temperature (°C)

η(%)=(Eq 2/Eq 1)x100 **(3)**

η: System Efficiency

3. RESULTS

The experiments and the results of the experiments are examined in this section. Experiments under similar weather conditions; outdoor temperature values were made close to each other, on windless and windy days, under open air conditions. Experimental data were examined separately for three glasses; The first of these three glasses is 4 mm flat glass. The second test glass was selected as 4 mm low-e coated glass. The third glass used was chosen as 4+12+4 mm ordinary double glazing and efficiency calculations were made for each glass separately. In the results section, the results of the experiments are examined comparatively. (Akıskalıoğlu E.)

Experiments with 4 mm flat glass

The first experiment was held in 25.08.2019. Data for this experiment are given below:

<u>*Outdoor Temperature:*</u> Outdoor temperature data has been added to indicate similar weather conditions. Figure 6 shows the air temperature on August 25, 2019 between 10.00 and 12.00. The maximum temperature was 28.2 ° C at 11.50 h and the minimum temperature was 25.8 °C at 10.04 h. According to the figure 6, the average temperature value was calculated as 27.4°C.

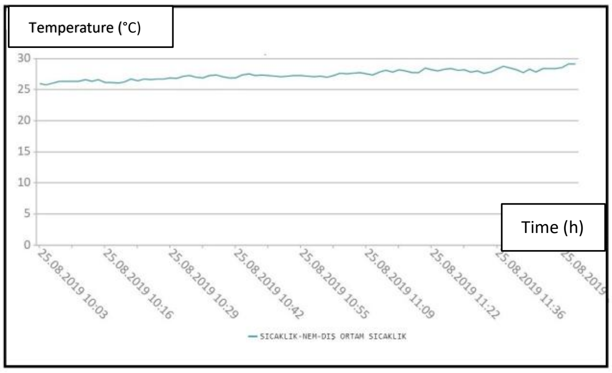

Fig. 6. Outdoor Temperature Values on 25.08.2019 (°C)

<u>*Irradiation Value:*</u> The values read from the pyranometer in the same time zone, between 10.00-12.00 pm are shown in Figure 7. The minimum irradiation value is 1003 W/m^2K at 10.00 and the maximum irradiation value is measured as 1247 W/m^2K at 11.49 when the sun goes upright. The average of all values was calculated as 1136 W/m^2K with Microsoft Excel.

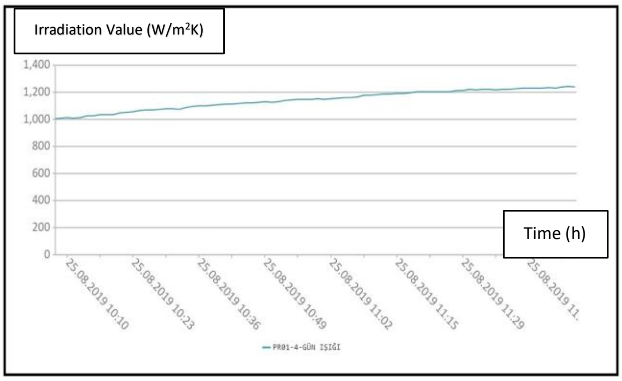

Fig.7. Irradiation Value on 25.08.2019 (W/m^2K)

<u>*Air Speed:*</u> The fan is operated at 15 watts. The differences are caused by outdoor wind. Outdoor wind speed was measured at 15 minute intervals. On August 25, 2019, the average wind speed in Konya was determined as 0.3 m/s. The average air velocity circulating in the system is calculated by using Microsoft Excel according to figure 8 and found to be 0.48 m/s.

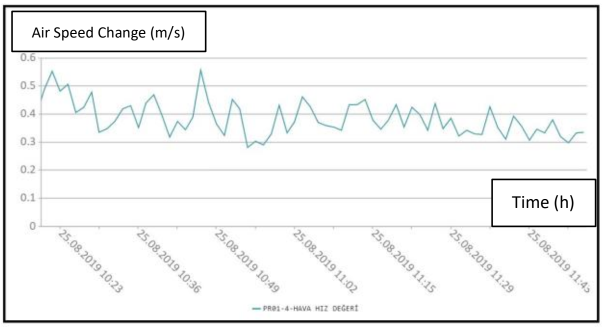

Fig. 8. Air Speed Change on 25.08.2019

<u>*Panel Current Value:*</u> The electrical current value formed on the panel with flat glass on August 25 is given in figure 9. These values are added to compare whether other glasses affect the current. The current value of the panel increased with the rising of the sun to the upright position. The maximum value was measured as

4.24 amps and the minimum value was 3.44 amps. The current comparison will be examined in the results section.

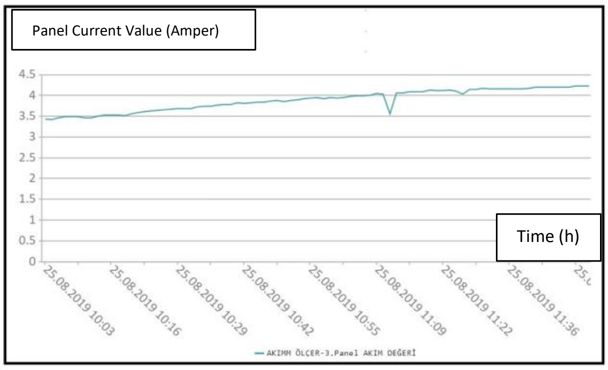

Fig.9. Ampere Change on 25.08.2019

Air Inlet-Outlet Temperature Values: Air inlet-outlet temperatures are shown in Figure 10. The fan lowered the air inlet temperature after switching on and transferred the incoming air temperature to the outlet air. The temperature difference 5.4°C was calculated as the Microsoft Excel program.

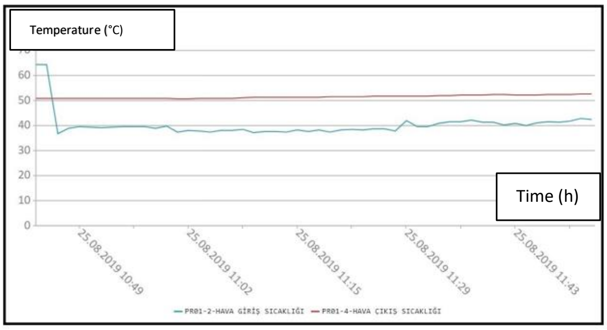

Fig. 10. Air Inlet and Outlet Temperature Values (°C)

System efficiency is calculated from the following formula according to the values read in the tables.

$$Q = 1136 * 1.27 = 1442.72 \text{ W} \quad \textbf{(1)}$$

$$P_{th\text{-}a}=0.21*0.48*0.24*4.18*1000*5.4=728.08 \text{ W} \quad \textbf{(2)}$$

$$\eta(\%)= 50.46. \quad \textbf{(3)}$$

The second experiment was held in 15.09.2019. Data for this experiment are given below:

Outdoor Temperature: In the experiment conducted on 15.09.2019, as a result of outdoor temperature measurements, the minimum temperature value was measured as 22.9°C and the maximum temperature value was measured as 24.9°C and shown in Figure 11. Average outdoor temperature was calculated as 23.6°C with Microsoft Excel.

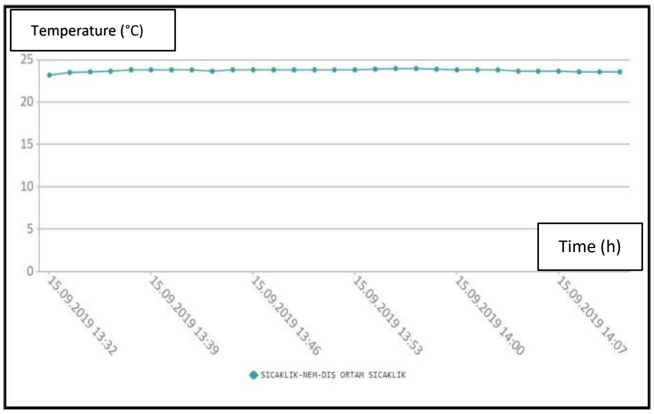

Fig.11. Outdoor Temperature Values on 15.09.2019

Irradiation Value: On 15 September 2019 the experiment was conducted between 13.30 and 14.30. Therefore, the graph produced a decreasing radiation values. The values read from the pyranometer are shown in figure 12. One hour average radiation value was calculated as 392 W/m^2K using excel program.

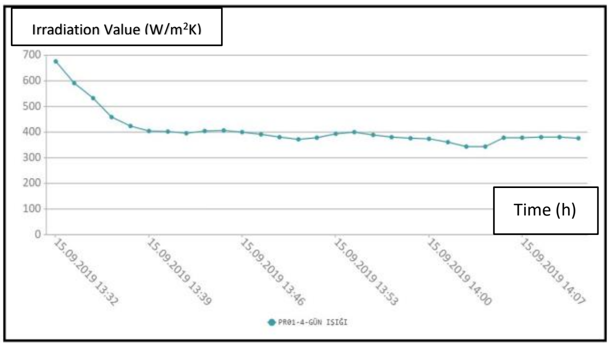

Fig.12. Irradiation Value on 15.09.2019 (W/m^2K)

Air Speed: The fan is operated at 15 watts. The speed change of the air circulating in the system on September 15, 2019 is shown in Figure 13. The average air velocity circulating in the system was calculated as 0.57 m/s with Microsoft Excel.

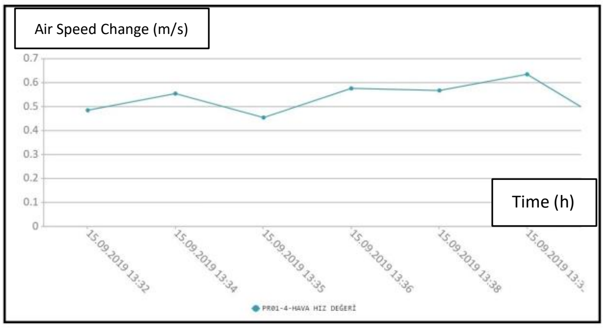

Fig. 13. Air Speed Change on 15.09.2019 (m/s)

Panel Current Value: The change in the current value of the panel on the date of 15 September is given in Figure 14. The maximum current value in the panel was 1.93 amps at 13.30 and then decreased.

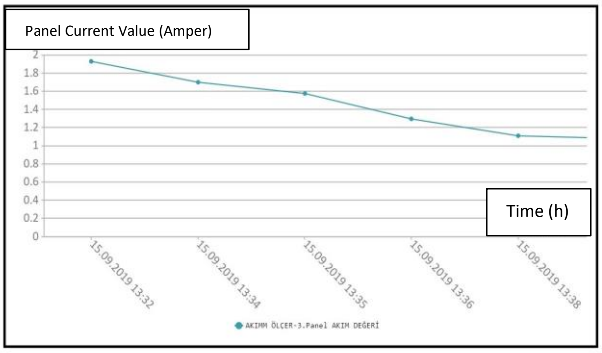

Fig.14. Ampere Change on 15.09.2019

Air Inlet-Outlet Temperature Values: Air inlet-outlet temperatures are shown in Figure 15. The temperature difference was calculated as 1.7°C using Microsoft Excel.

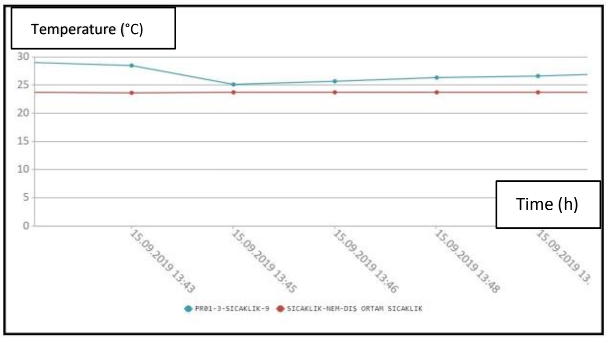

Fig. 15. Air Inlet and Outlet Temperature Values (°C)

Second the experiment conducted on September 15, 2019,the system efficiency was calculated as follows:

$$Q = 429*1.27 = 544.83 \text{ W} \quad \textbf{(1)}$$

$$P_{th\text{-}a}=0.21*0.57*0.24*4.18*1000*1.7=204.14 \text{ W} \quad \textbf{(2)}$$

$$\eta\ (\%)= 37.46 \quad \textbf{(3)}$$

The third experiment was held in 16.09.2019. Data for this experiment are given below:

Outdoor Temperature Value: The change of outdoor temperature according to hours on September 16 is shown in figure 16. The outdoor temperature is measured as minimum 18.3°C at 16.49 pm and maximum 24.1°C at 15.57 pm. The average outdoor temperature was calculated as 22.9°C.

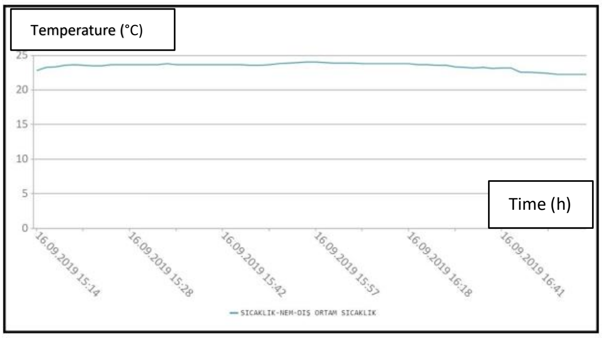

Fig.16. Outdoor Temperature Values on 16.09.2019

Irradiation Value: Values read from pyranometer are shown in figure 17. The average radiation value was calculated as 745 W/m^2K in excel program.

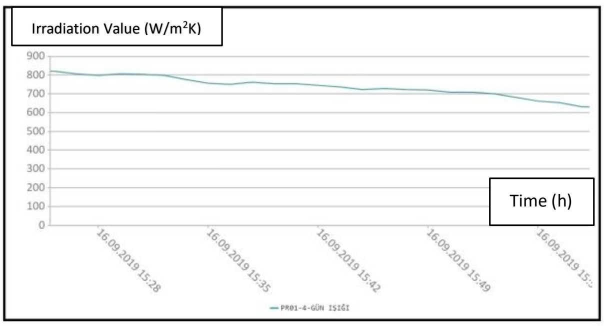

Fig.17. Irradiation Value on 16.09.2019 (W/m^2K)

Air Velocity: In this experiment, the fan is not operated due to the decrease in the power of the batteries and the charge. Outdoor wind speed measured by 15 minutes and calculated as 0.7 m/s.

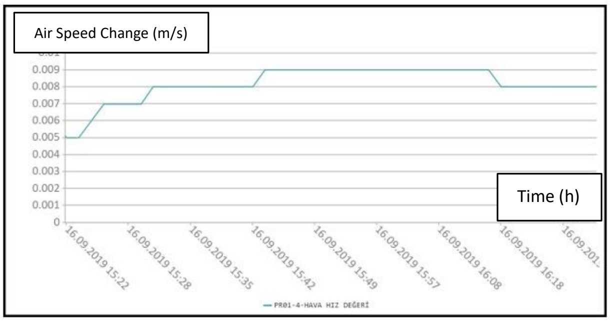

Fig. 18. Air Speed Change on 16.09.2019 (m/s)

Panel Current Value: The change of panel current measurement according to time is given in figure 19. The peaks in the table are due to the fact that the experiment was carried out on a cloudy day. The moments when the clouds were closing the sun reflected to the figure 19 as peak. The maximum ampere readings were calculated as 2.9 amps at 15.15 and the minimum amps as 0.39 amps at 16.12. In the conclusion section, comparisons will be made.

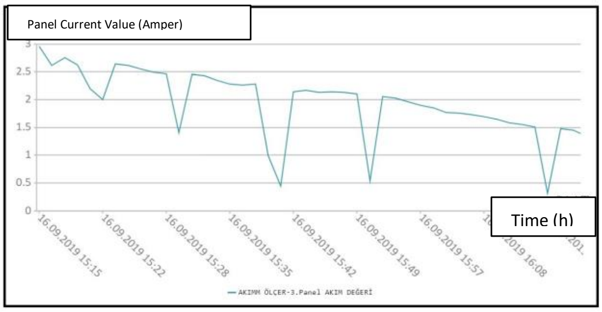

Fig.19. Ampere Change on 16.09.2019

Air Inlet - Outlet Temperature Values: Change of air inlet-outlet temperatures are shown in figure 20. The temperature difference was calculated as 3.6°C.

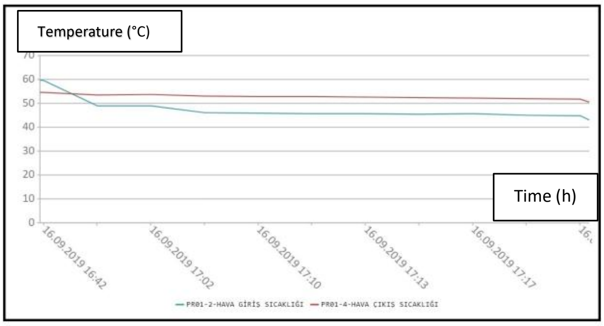

Fig.20. Air Inlet and Outlet Temperature Values (°C)

The efficiency of the system in the experiment conducted on 16 September 2019 was calculated as follows:

$$Q = 745 * 1.27 = 946.15 \text{ W} \quad \textbf{(1)}$$

$$P_{th-a} = 0.21*0.7*0.24*4.18*1000*3.6 = 505.6 \text{ W} \quad \textbf{(2)}$$

$$\eta (\%) = 53.44 \quad \textbf{(3)}$$

As a result of 3-day experiments with 4 mm flat glass, the minimum efficiency of the system was %37.46 and the maximum system efficiency was calculated as %53.44. Average system efficiency was calculated as %47.12. After these experiments, 4 mm flat glass was disassembled and replaced with mm low-e coated glass. Experimental data with this glass are given below.

Experiments with 4 mm low-e coated glass

The first experiment was held in 12.10.2019. Data for this experiment are given below:

Outdoor Temperature: The outdoor temperature was 28.4°C at 15.00 and 22.8°C at 17.24. The variation of the values is shown in Figure 21, with an average temperature of 26.2°C.

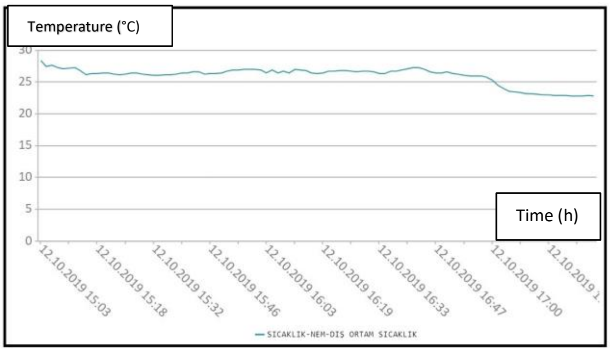

Fig.21. Outdoor Temperature Values on 12.10.2019

Irradiation Value: Values read from pyranometer are shown in figure 22. The maximum radiation value was 848 W/m^2K at 15.00 and the minimum radiation value was 594 W/m^2K at 16.03. The average radiation value was calculated as 770 W/m^2K in excel program.

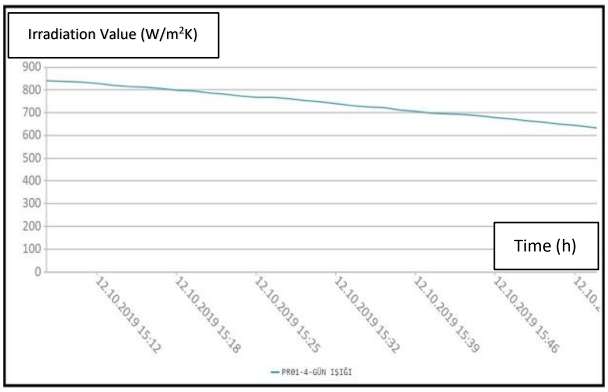

Fig.22. Irradiation Value on 12.10.2019 (W/m^2K)

Air Speed: The system fan is operated at 15 watts. The air velocity change is shown in Figure 23 and the average value is calculated as 0.741 m/s.

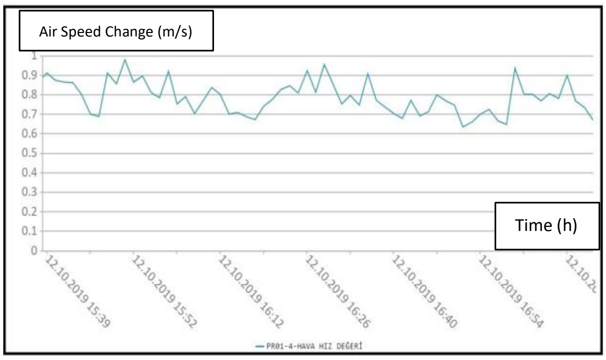

Fig. 23. Air Speed Change on 12.10.2019 (m/s)

Panel Current Value: Electricity production starts at 2.37 amp at 15.00 and reset at 17.09 with the sunset. Figure 24 shows the change of ampere values in the panel according to the hour.

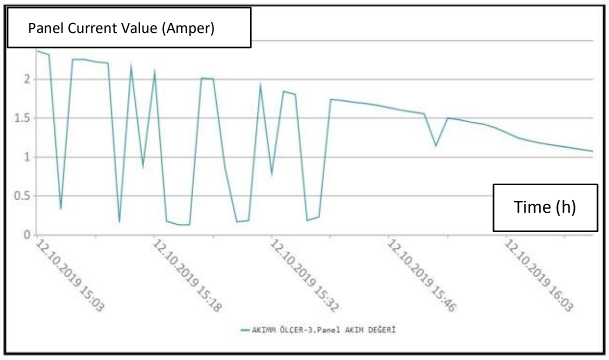

Fig.24. Ampere Change on 12.10.2019

Air Inlet-Outlet Values: The fan was operated at 15.30. The variation of the air inlet temperature values is shown in Figure 25 and the average difference is calculated as 3.9°C.

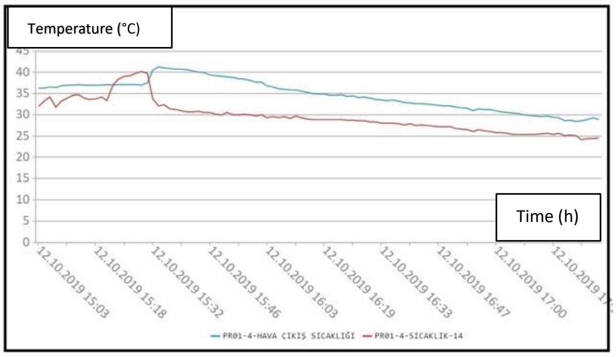

Fig.25. Air Inlet and Outlet Temperature Values (°C)

The efficiency calculation according to the values read from the tables was calculated from the same formula made with 4 mm flat glass. Accordingly, the air circuit efficiency of the system on October 12:

$$Q = 770 * 1.27 = 977.9 \text{ W} \quad \textbf{(1)}$$

$$P_{th\text{-}a} = 0.21 * 0.741 * 0.24 * 4.18 * 1000 * 3.9 = 608.82 \text{ W} \quad \textbf{(2)}$$

$$\eta\ (\%) = 62.25 \quad \textbf{(3)}$$

The second experiment was held in 13.10.2019. Data for this experiment are given below:

Outdoor Temperature: The outdoor temperature is measured as 16.4°C at 09.00 and 25.8°C at 11.48 and is shown in Figure 26. The average is calculated as 19.7°C.

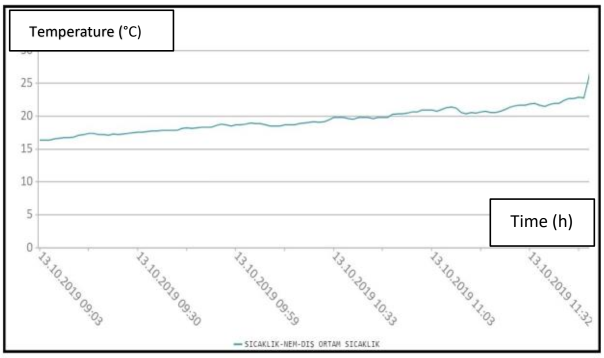

Fig.26. Outdoor Temperature Values on 13.10.2019

Irradiation Value: The values read from the pyranometer are shown in Figure 27. The average was calculated as 1117 W/m^{2}K.

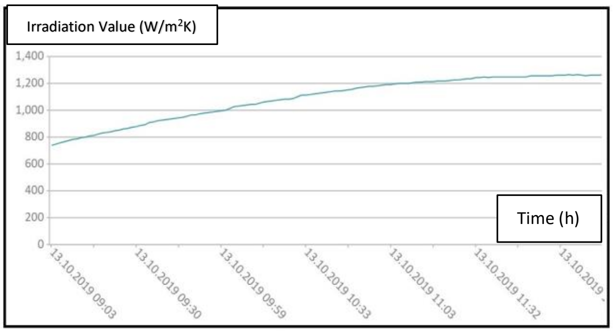

Fig.27. Irradiation Value on 13.10.2019 (W/m^{2}K)

Air Velocity: Outdoor wind has also increased the air velocity circulating in the system. Outdoor wind speed was measured in 15 minute intervals. With this effect, the circulating air velocity in the system was calculated as 1.13 m/s. Figure 28 shows the change of values.

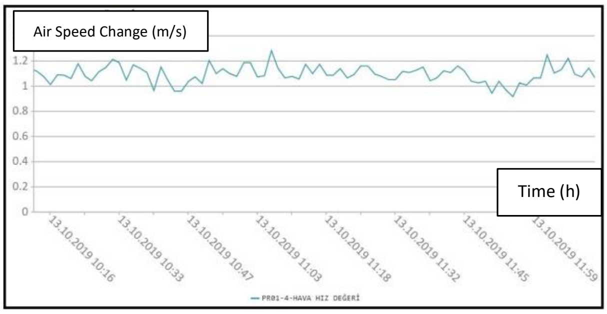

Fig. 28. Air Speed Change on 13.10.2019 (m/s)

Panel Current Value: The system started to produce 2.18 amps electricity at 09.00. This value reached 3.74 amps at 12.03. The variation of ampere values produced in the panel is shown in Figure 29.

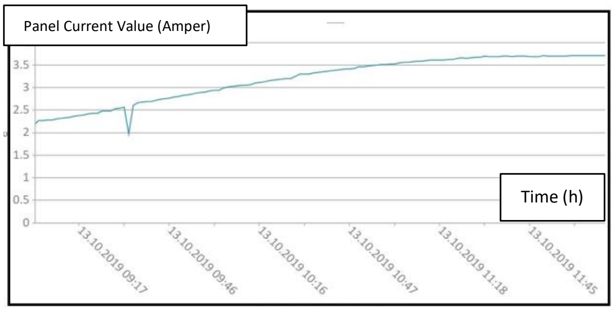

Fig.29. Ampere Change on 13.10.2019

Air Inlet-Outlet Temperature Values: The fan was operated at 10.00 am. The temperature difference at the air inlet and outlet after the fan is turned on is calculated as 4.7 ° C and is shown in Figure 30.

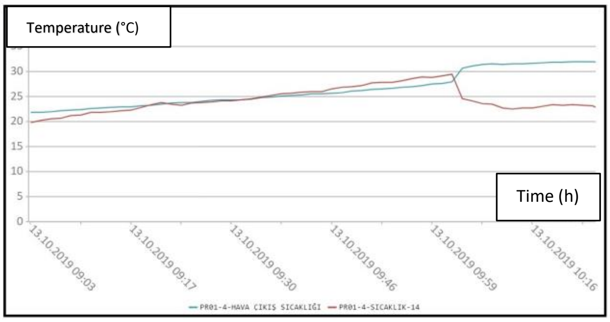

Fig.30. Air Inlet and Outlet Temperature Values (°C)

The efficiency of the system on October 13 was calculated as follows:

$Q = 1117 * 1.27 = 1418.6$ W **(1)**

$P_{th-a}=0.21*1.13*0.24*4.18*1000*4.7=938.4$ W **(2)**

Ƞ (%)= 65.72 **(3)**

The third experiment was held in 23.11.2019. Data for this experiment are given below:

Outdoor Temperature Value: The average outdoor temperature is measured as 17.3°C and the change in temperature values is given in Figure 31.

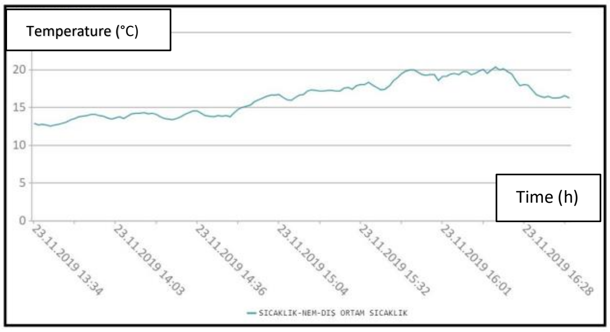

Fig.31. Outdoor Temperature Values on 23.11.2019

Irradiation Value: On November 23, there was a cloudy day in Konya. This is the reason for the peaks in the table. The average irradiation value is calculated as 765 W/m^{2}K in the light of the values in figure 32.

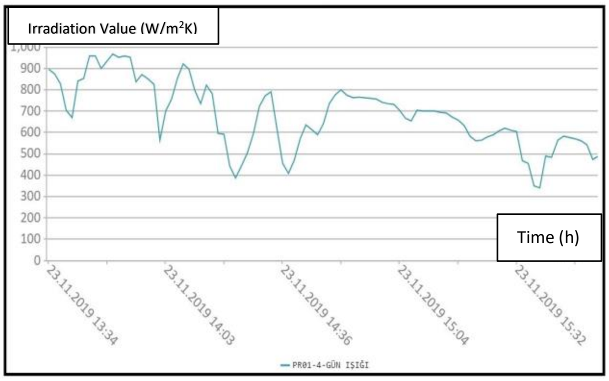

Fig.32. Irradiation Value on 23.11.2019 (W/m^{2}K)

Air Velocity: On November 23, measurements were made on a windless day. The fan was operated at 15 watts. The average air velocity circulating in the system is calculated as 0.42 m/s and its variation according to the hour is shown in Figure 33.

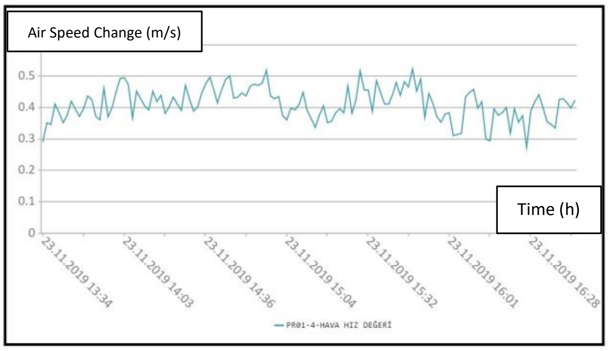

Fig. 33. Air Speed Change on 23.11.2019 (m/s)

Panel Current Value: The current value was seen as 2.69 amps at 13.45. At 16.43, this value has dropped to 0.51 amperes as the sun approaches sunset. Current variations are shown in Figure 34.

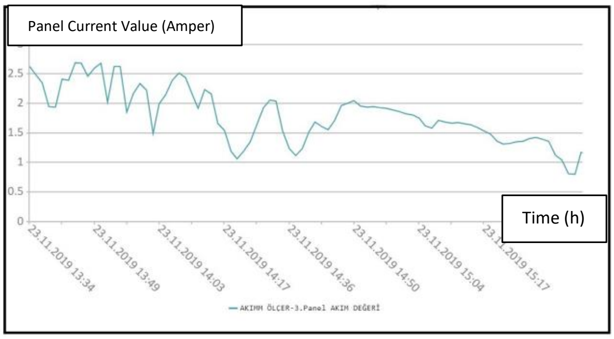

Fig.34. Ampere Change on 23.11.2019

Air Inlet-Outlet Temperature Values: The average temperature difference value is calculated as 4.2°C and the values are shown in figure 35.

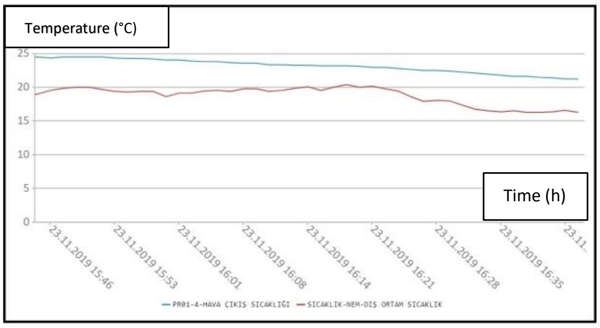

Fig.35. Air Inlet and Outlet Temperature Values (°C)

On 23 November the air circuit efficiency of the system was calculated as follows:

$$Q=586*1.27=744.22\ W \quad (1)$$

$$P_{th-a}=0.21*0.42*0.24*4.18*1000*4.2=371,62\ W \quad (2)$$

$$\eta\ (\%)= 49.9 \quad (3)$$

As a result of 3-day experiments with 4 mm low-e coated glass, the minimum efficiency of the system was %49.9 and the maximum system efficiency was calculated as %65.72. Average system efficiency was calculated as %59.29. After these experiments, 4 mm low-e coated glass was disassembled and replaced with 4+12+4 mm double glass. Experimental data with this glass are given below.

Experiments with 4+12+4 mm double transparent glass

The first experiment was held in 24.11.2019. Due to weather conditions, only one experiment applied with double glass. Data for this experiment are given below:

<u>*Outdoor Temperature Value:*</u> The average outdoor temperature is measured as 11.8°C and the change in temperature values is given in Figure 36.

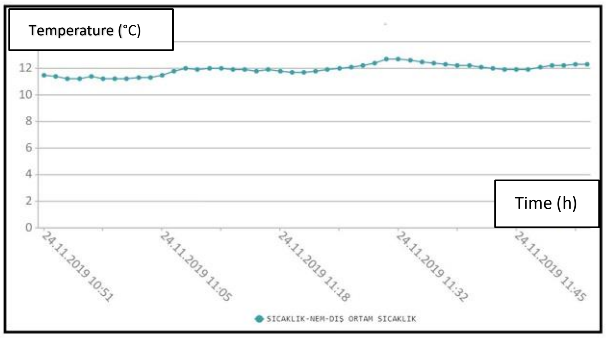

Fig.36. Outdoor Temperature Values on 24.11.2019

<u>*Irradiation value:*</u> Daylight values are low because of the measurement on a rainy and cloudy day. The minimum radiation value was 274 W/m^2K at 11.15 and the maximum radiation value was calculated as 856 W/m^2K at 11.29. The average radiation value was calculated as 420.375 W/m^2K. The variation of the values is shown in figure 37.

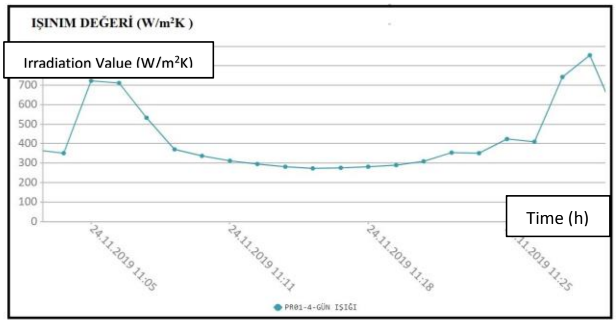

Fig.37. Irradiation Value on 24.11.2019 (W/m^2K)

<u>*Air Velocity:*</u> Since it is a windy and rainy day, the air velocity is high. The system fan is operated at 15 watts. The average air velocity circulating in the system is calculated as 0.7 m/s and the change of values is given in Figure 38.

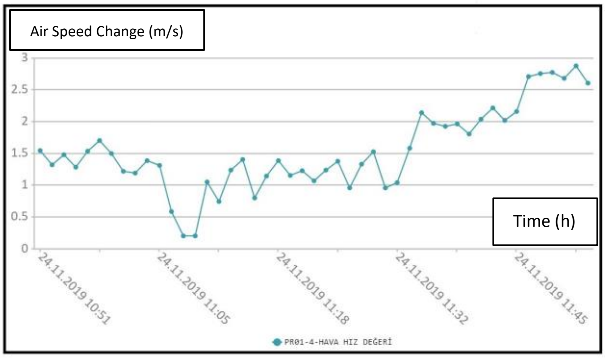

Fig. 38. Air Speed Change on 24.11.2019 (m/s)

<u>*Panel Current Value:*</u> The maximum current value of the panel is 2.58 amperes at 11.15. The time-dependent variation of panel current values is shown in Figure 39.

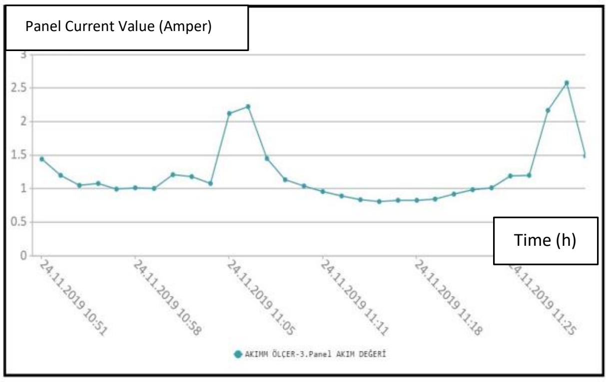

Fig.39. Ampere Change on 24.11.2019

Air Inlet-Outlet Temperature Values: Air inlet-outlet temperature difference is calculated as 2.2°C, is shown in Figure 40.

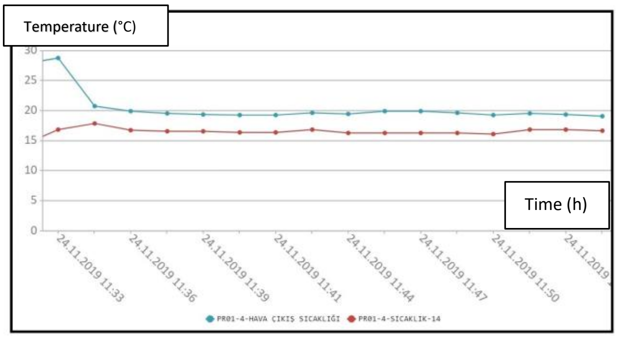

Fig.40. Air Inlet and Outlet Temperature Values (°C)

On 24 October 2019, the efficiency of the system was calculated as follows:

$$Q = 420.375 * 1.27 = 533.88 \text{ W} \quad \textbf{(1)}$$

$$P_{th\text{-}a} = 0.21 * 0.7 * 0.24 * 4.18 * 1000 * 2.2 = 324.43 \text{ W} \quad \textbf{(2)}$$

$$\eta\ (\%) = 60.76 \quad \textbf{(3)}$$

The second experiment was held in 07.03.2020. Data for this experiment are given below:

Outdoor Temperature Value: The outdoor temperature was measured as 17.2 ° C on average and the change of temperature values is given in figure 41.

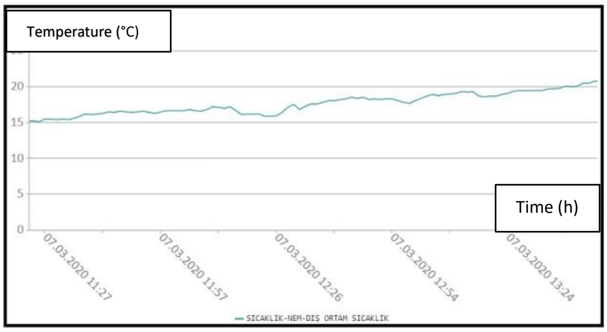

Fig. 41. Outdoor Temperature Value (°C)

Irradiance value: The average irradiance value is calculated as 1257 W/m^2. The change of values is shown in Figure 42.

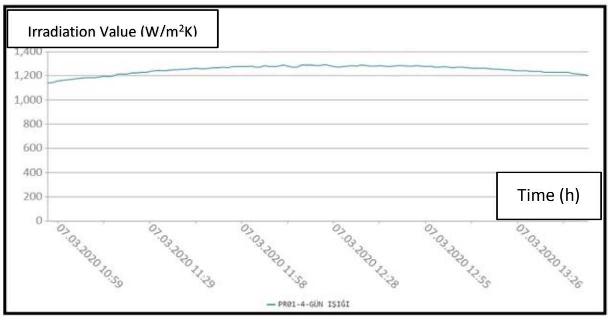

Fig. 42. Irradiance Value (W/m^2)

Air Velocity: System fan was operated at 15 watts. The average air velocity circulating in the system is calculated as 0.54 m/s, and the change of values is given in figure 43.

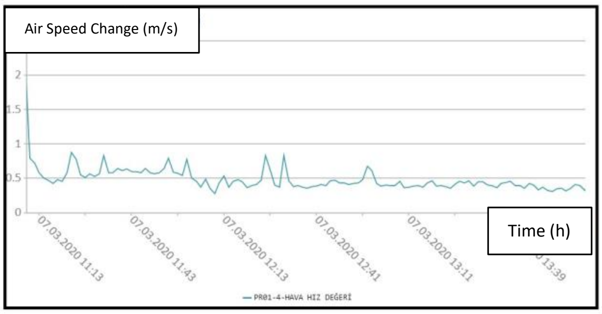

Fig. 43. Air Speed Change (m/s)

Panel Current Value: The maximum current value formed in the panel was measured as 3.9 amperes at 12.57. The change of panel current values depending on time is shown in Figure 44.

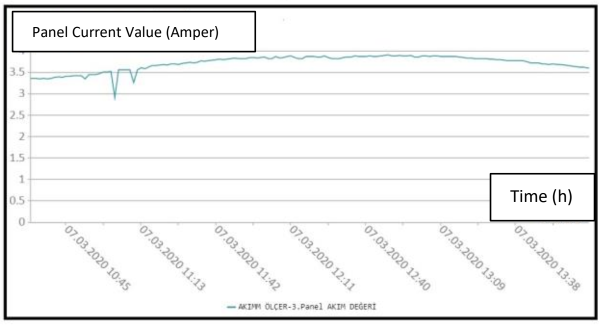

Fig.44. Ampere Change on 07.03.2020 (Amper)

Air Inlet-Outlet Temperature Values: The air inlet-outlet temperature difference has been calculated as 7.6 ° C and is shown in Figure 45.

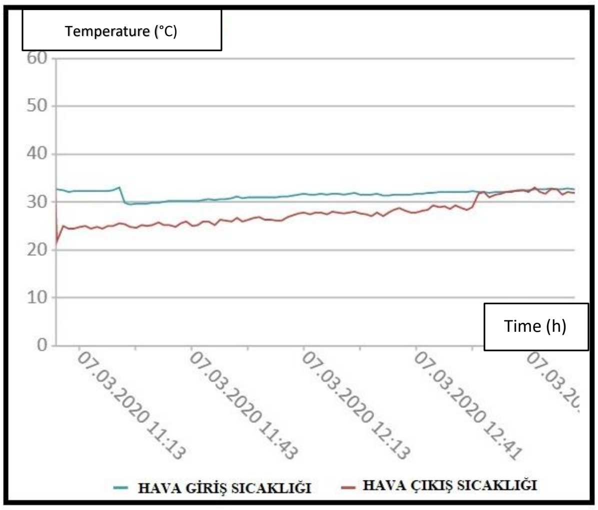

Fig. 45 Air Inlet and Outlet Temperature Values (°C)

$Q = 1257x1.27 = 1596.39$ W **(1)**

P_{th-a} = 0,54x0,21x0,24x4,18x1000x7,6 = 864,6 W **(2)**

Ƞ (%)= 54.16 **(3)**

4. DISCUSSION

As a result of 3-day experiments with 4 mm flat glass, the minimum efficiency of the system was %37.46 and the maximum system efficiency was calculated as %53.44. Average system efficiency was calculated as %47.12.

As a result of 3-day experiments with 4 mm low-e coated glass, the minimum efficiency of the system was %41.5 and the maximum system efficiency was calculated as %62.25. Average system efficiency was calculated as %59.29.

As a result of 2-day experiments with 4+12+4 mm double glass, overall system efficiency calculated as %57.46.

The above data is a comparison of the thermal efficiencies of the system. When the electrical efficiency of the system is compared, the measurements made with three glasses are based on the amperage production at the same radiation values. This value was selected as 700 W/m^2K.

At 700 W/m^2K radiation, the amperage of 4+12+4 mm double glass was read as 2.05 amps average. At the same radiation on 12.10.2019 at 15.13 amperage of 4 mm low-e glass was read as 2.02 amps. In the experiment conducted with 4 mm flat glass on 16.09.2019, when the pyranometer read the value of 700 W/m^2K at 15.53, the amps produced at the same hour were measured as 2.11. These values indicate that the thickness of the glass does not affect electricity production. Reduction in electrical current was calculated due to coating only on low-e glass. However, this decrease can be ignored due to the increase in thermal gain.

The thermal efficiency gain and the change in electrical efficiency are shown in Table 1 below:

Table 1. Thermal and electrical efficiency comparision

Glass Type	Avr. Thermal Efficiency (%)	Electrical Production at 700 W/m^2K Irradiation Value
4 mm flat glass	47.12	2.11 Ampere
4 mm low-e glass	59.29	2.02 Ampere
4+12+4 mm double glass	57.46	2.05 Ampere

As a result of the experiments, the use of solar low-e coated glass doesn't affect much the electrical efficiency and increases the thermal efficiency in the system. It has been found appropriate using of low-e glass. But the studies about material efficiency are still continuing. Energy sources and uses are a very large subject and important for our next generations. We tried with 3 different glasses but in the future, other researches can research of different materials and may increase whole system efficiency much more.

5. ACKNOWLEDGMENT

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