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Examination of flat plate collector solar hot water system for Ankara province in Türkiye with TRNSYS software

Türkiye'de Ankara ili için düz plaka kollektör güneş sıcak su sisteminin TRNSYS yazılımı ile incelenmesi

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Highlights

- *A domestic solar water heating system using a flat plate collector is modeled.*
- *TRNSYS simulation program is used.*
- *The designed system was able to meet the hot water need in summer and winter months by using solar energy through auxiliary heaters.*
- *Collector efficiency reached its highest value with 40% in September.*

Graphical Abstract

Collector efficiency reached its highest value of 40% in September. The lowest efficiency value was determined as 5% in December.

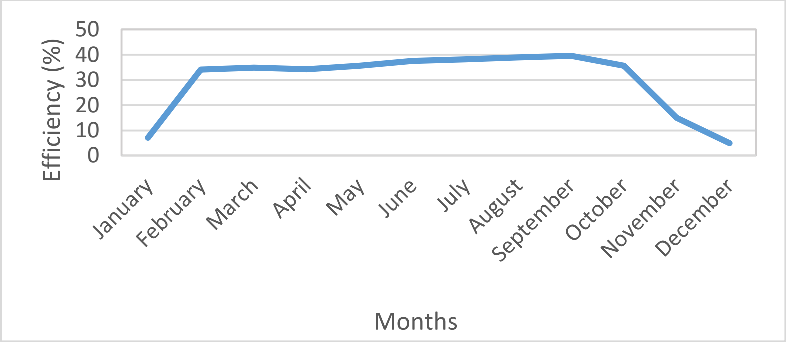

Figure. Efficiency graph

Aim

The aim of this study is to analyze the solar water system for the province of Ankara.

Design & Methodology

The solar data used for Ankara province were used for the collector. In the current study, the domestic water tank was divided into 20 layers and temperature measurements were taken from 5 different points of the tank. Two of these points are the bottom and top of the tank.

Originality

The TRNSYS model of the domestic water system was prepared in a unique way. In addition, hot water consumption hours have been determined by taking into account the hours when hot water is used the most, due to the entrance and exit times of the house in Turkey.

Findings

The top point temperature of the tank reached its highest value in summer. In the months when the solar radiation intensity is lower, the water temperature in the tank drops below the set value.

Conclusion

Collector efficiency reached its highest value with 40% in September and its lowest value with 8% efficiency in December.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Examination of flat plate collector solar hot water system for Ankara province in Türkiye with TRNSYS software

Araştırma Makalesi / Research Article

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ABSTRACT

A domestic solar water heating system using a flat plate collector is modeled for the domestic hot water requirement of a residential unit in Ankara, Turkey. The necessary design parameters were determined and the analysis was carried out using the TRNSYS simulation program. In the modeled system, the domestic water temperature was determined as 55 °C and water withdrawals were carried out at different flow rates during the day according to the usage intensity. The water withdrawal rates were determined as 80 kg/h between 07.00-09.00, 100 kg/h between 12.00-13.00 and 50 kg/h between 17.00-22.00. According to the results obtained, the designed system was able to meet the hot water need in summer and winter months by using solar energy through auxiliary heaters. While the collector efficiency reached its highest value with 40% in September, it reached the lowest efficiency value with 8% in December.

Keywords: SDHW, solar energy, TRNSYS.

Türkiye'de Ankara ili için düz plaka kollektör güneş sıcak su sisteminin TRNSYS yazılımı ile incelenmesi

ÖZ

Düz plaka kollektör kullanan bir güneş enerjili su ısıtma sistemi, Türkiye'deki Ankara ili için, bir konut biriminin kullanım sıcak suyu ihtiyacı için modellenmiştir. Gerekli tasarım parametreleri belirlenmiş ve analizler TRNSYS simülasyon programı kullanılarak gerçekleştirilmiştir. Modellenen sistemde kullanım suyu sıcaklığı 55 °C olarak belirlenmiş ve kullanım yoğunluğuna göre gün içerisinde farklı debilerde su çekimleri gerçekleştirilmiştir. Su çekim hızları 07.00-09.00 saatleri arasında 80 kg/saat, 12.00-13.00 saatleri arasında 100 kg/saat ve 17.00-22.00 saatleri arasında 50 kg/saat olarak belirlenmiştir. Elde edilen sonuçlara göre tasarlanan sistem, yardımcı ısıtıcılar vasıtasıyla güneş enerjisi kullanılarak yaz ve kış aylarındaki sıcak su ihtiyacını karşılayabilmiştir. Kolektör verimi Eylül ayında %40 ile en yüksek değerine ulaşırken, Aralık ayında %8 ile en düşük verim değerine ulaşmıştır.

Anahtar Kelimeler: SDHW, güneş enerjisi, TRNSYS.

1. INTRODUCTION

Due to the increasing energy need, the demand for renewable energy has increased in Turkey as well as in the whole world. Due to Turkey's high solar energy potential, various improvements are made in solar-heat systems in order to benefit from this energy with maximum efficiency. While analyzing solar thermal systems, simulation programs such as TRNSYS are used. There are many studies [1]–[8] on solar heating systems and different applications of these systems. In a study presenting a new TRNSYS model of a solar domestic water heater (SDWH) [9], a water heater with horizontal storage and covered heat exchanger is defined.

The fluid inlet is located at the top of the ring and this new TRNSYS "Type" is enhanced from the standard Type 45 and 38 with some new features.

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The results of the new strain were compared with two sets of experimental data and as a result, the new model was found to be compatible with the experimental data and daily energy data.

Lamrani and others, they investigated the performance of a hybrid solar dryer with the TRNSYS software [1]. A solar compound parabolic concentrator (CPC) was used to generate thermal energy. According to results, the integration of the solar collector will reduce energy consumption and approximately 34% of CO_2 emissions per year would be prevented. In another work [10], solar water heating systems using flat plate collectors are modeled for the SDHW requirements for Canada. By examining all necessary design parameters, optimum values were determined by using TRNSYS software. According to the results obtained, the system designed using solar energy can meet 83-97% and hot water need in summer and winter months 30-62%, respectively.

The researchers, who conducted the performance review of the simulation-based solar absorption cooling system with TRNSYS [11], analyzed a building to provide the peak cooling demand of 298 kW. According to the simulation results, evacuated tube solar collectors or flat plate collectors provided higher primary energy savings for the whole summer season. However, the difference between collectors is estimated to be marginal, mainly in terms of solar fraction and monthly collector efficiency.

In the study of Coşkun et al., a vertical type heat pump (ground source) was used to heat a restaurant and regulate the domestic water temperature in İstanbul [12]. The designed system was simulated with the help of TRNSYS software and the performance of the system was examined in terms of energy consumption.

In a study optimizing the solar energy system integrated into the building with seasonal storage, TRNSYS software was used to calculate the changing integration states of solar energy [13].The thermal load was determined by the contribution of the solar system and the auxiliary conventional system, and analysis was made for both space heating and domestic hot water, taking into account the relevant simulation periods. A parametric analysis of the effect of different types and solar collector areas, building integration type and seasonal storage tank volume is also provided to optimize system and presented a seasonal combined solar fraction of at least 39%.

In a research that determines the thermal performance of the solar collector under dynamic operating conditions for the weather conditions in Turkey, the thermal equation of the collector was created and the experimental setup was established [14]. Experiments were performed for different temperatures, and as a result the experimental work and thermal equation results were largely similar.

TRNSYS simulation program does not only simulate domestic hot water, for example in a photovoltaic system modeled with TRNSYS program, battery, inverter, regulator and panel connections were made and simulation was made. It has been concluded that a realistic mathematical battery and panel model can be modeled by TRNSYS [15]. In another study comparing the energy performance for heating applications in 39 cities in China, the TRNSYS model was used. At the end of the study, they concluded that the parallel system using the heat pump as an auxiliary source is more effective than the serial system [16].

The aim of this study is to analyze the solar water system for the province of Ankara. According to the Turkish Solar Energy Potential Atlas (GEPA) [17], the average annual total radiation value is calculated as 1.527.46 kWh/m^2. Considering the 81 provinces in Turkey, the annual average solar radiation values vary between 1300 kWh/m^2 and 1660 kWh/m^2. Ankara's solar radiation value is in the middle with an annual average value of 1473 kWh/m^2. These analyzes were made for all months and the collector efficiency was examined. In addition, temperature changes at the determined nodes of the domestic water tank used in the modeled system were examined. The TRNSYS software was used to make these analyzes. The most important feature that distinguishes the present study from other studies is that the TRNSYS model of the domestic water system was prepared in a unique way. In addition, hot water consumption hours have been determined by taking into account the hours when hot water is used the most, due to the entrance and exit times of the house in Turkey.

2. MATERYAL VE METOD

Turkey, with a surface area of 783,562 km², is located in a sunny belt between 36°-42° north parallels and geographically good position in terms of solar energy potential is in the location. Although our country is located in the solar belt, the use of solar energy is not at the desired amount [17]. Despite this, solar energy installed power in Turkey is increasing over time. Ankara is one of the cities that benefit the most from solar radiation in Turkey. The annual average solar radiation map of Ankara is given in Figure 1.

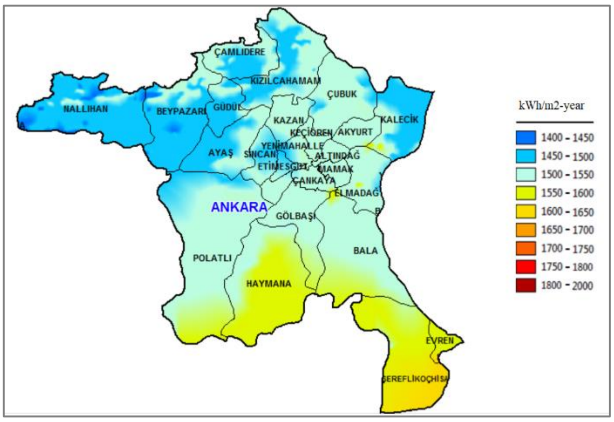

Figure 1. Average solar radiation map of Ankara

In this study, the solar data of the city of Ankara gains importance, since the study will be conducted for the city of Ankara, the capital of Turkey. The duration of sunshine in Ankara is approximately 2611 hours/year, radiation value is 1473 kWh/m^{2}year [18].

With a temperature of 23.4 °C, August is the hottest month of the year in Ankara provience and the average temperature in January is 0.2 °C, the lowest average of the year [19]. And these temperature distribution values are shown in Figure 2.

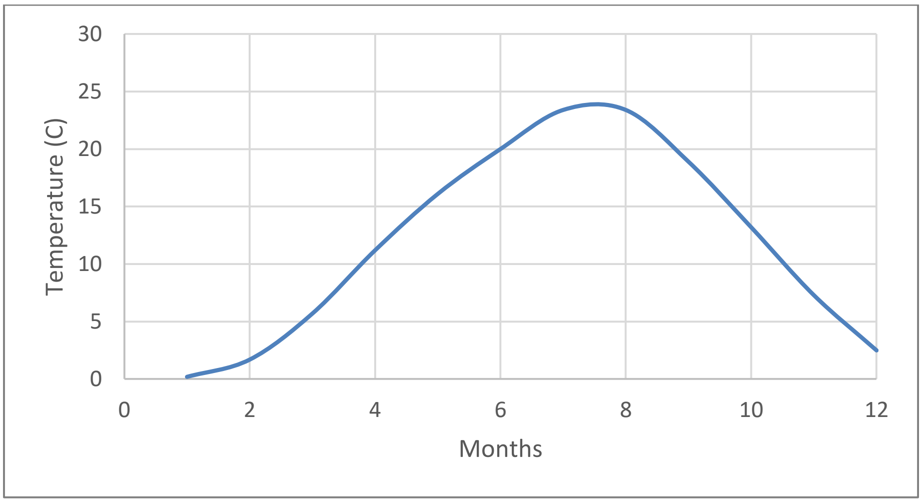

Figure 2. Temperature distribution according to months in Ankara

Solar thermal installations use the main and auxiliary components of the solar installation. These components are; solar collectors that allow the use of solar energy, pumps that enable the movement of liquids in the pipes, domestic tank and energy conversion systems.

The TRNSYS software provides a complete and extensible simulation environment for simulating systems. This program is used by many researchers from SDHW systems to design and simulation of buildings and equipment, user behavior, alternative energy systems. To create a model, the user has to select and connect the graphical components available in the TRNSYS library. Each component type is defined by a mathematical model in the TRNSYS simulation [20]. The flow chart of the modeled system is shown in Figure 3.

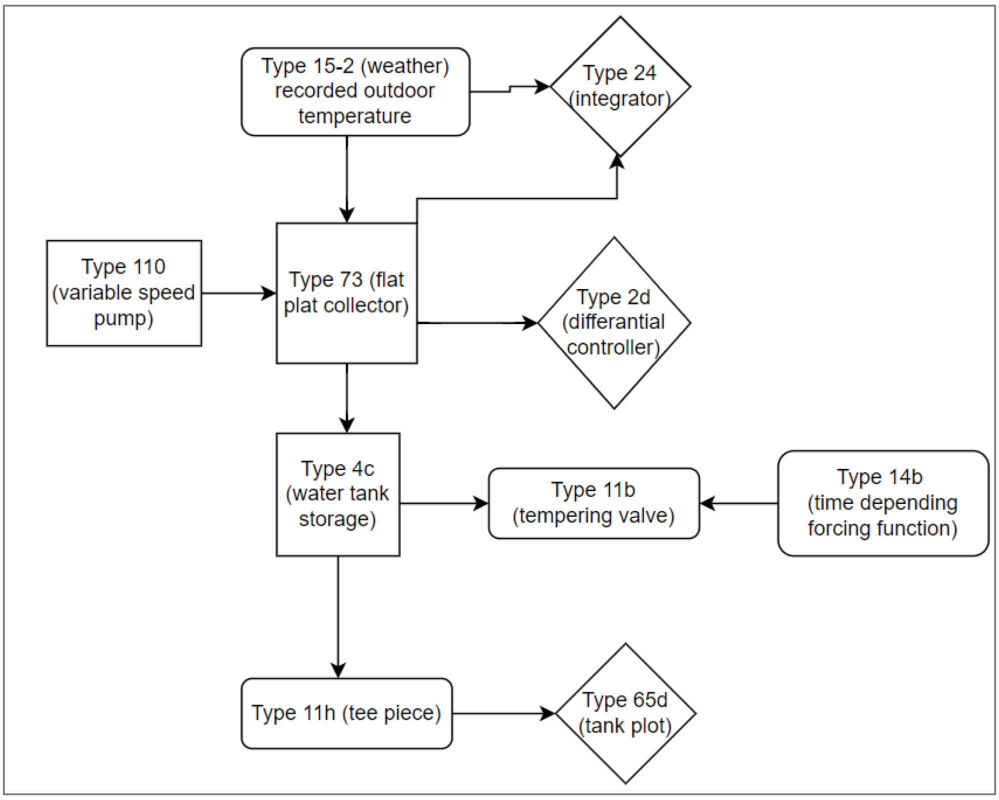

Figure 3. TRNSYS information flow chart

The schematic representation of the solar hot water system used in this study is given in Figure 4. In the defined system; inputs and outputs are user-defined and fixed volume water storage tank is used. Cold water enters the storage tank from the bottom of the tank. It is sent to the place of use from the top of the tank to meet the hot water load by being heated in the storage tank. The hot fluid coming from the collector enters the storage tank from the top and returns to the collector from the bottom of the tank.

In Figure 4, Type 4c indicates the water storage tank, Type 24 is integrator, Type 25 is printer, Type 110 is variable speed pump, Type 11b is tempering valve, Type 11h is tee piece, Type 2d is differential controller and Type 14 b is time dependent forcing function.

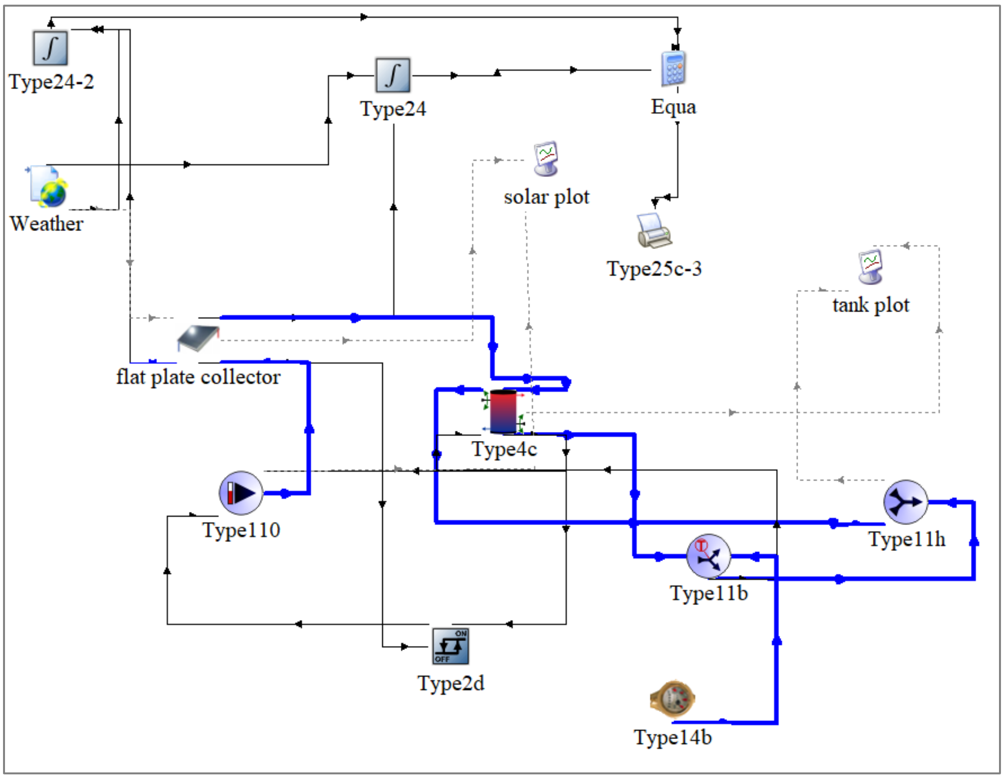

Figure 4. TRNSYS model

The solar data used for Ankara province were used for the collector. In this study, a flat plate solar collector (FPSC) with a collector area of 5 m^2, with an azimuth of 0° and incidence angle of 45° with positioned south, is chosen. The fluid circulating in the collector is a glycol-water mixture and its specific heat is 3.29 kJ/kgK. Collector parameters are given in Table 1.

Table 1. Collector parameters

Name	*Value*	*Unit*
Number in series	1	-
Inlet temperature	20	ºC
Inlet flowrate	100	kg/h
Collector area	5	m^2
Fluid specific heat	3.29	kJ/kgK
Tested flow rate	40	kg/h.m^2
Efficiency mode	1	-
Ground reflectance	0.2	-

The domestic tank parameters used in the current system are given in Table 2. These parameters are; tank volume, fluid specific heat, fluid density, tank loss coefficient, maximum heating capacity of each heater, set point and dead band temperatures for each heater. In the current study, the domestic water tank was divided into 20 layers and temperature measurements were taken from 5 different points of the tank. Two of these points are the bottom and top of the tank. Two heating elements, each with a power of 2.5 kW, were used in the tank. The water inlet temperature in the tank is taken as 15 ºC and flow rate value is 100 kg/h.

Table 2. Tank parameters

Name	*Value*	*Unit*
Variable inlet position	2	-
Tank volume	0.3	m^3
Tank loss coefficient	2.5	$kJ/h.m^2K$
Fluid specific heat	4.19	kJ/kgK
Fluid density	1000	kg/m^3
Maximum heating rate of element-1	2.5	kW
Maximum heating rate of element-2	2.5	kW
Set point temperature of elements	60	ºC
Deadband for heating of elements	5	ΔºC

A tempering valve is used so that the temperature of the water above the domestic water tank does not rise above the set point temperature during the water flow. When hot water flows from the upper layer of the tank, cold water is supplied from the mains water to the lower part of the tank.

The performance of the system modeled in Ankara weather conditions was analyzed throughout the year (8760 hours). The simulation time step was set to 0.125h (450 sec). In the system, it is aimed to obtain domestic water at a temperature of 55 °C from the domestic water tank by using a water flow control element and drawing water at different flow rates in three different time periods during the day.

As seen in Figure 5, the time periods are selected as 07.00-09.00 (80 kg/h) ; 12.00-13.00 (100 kg/h) and 17.00-22.00 (50 kg/h). A 0.75 kW pump was used in the modeled system and it is assumed that there is no thermal loss in the tank.

A control element is available for solar cycle automation. To avoid evaporation in the system, a limit for tripping is defined for this controller. This limit value is 100 ºC, which is the boiling temperature of water.

After the system modeling and input preparation are completed, the simulation program is run. One of the most important results to be obtained in this study is the change of collector efficiency according to months. In general, the efficiency of the solar collector is given in the form below by the Hottel-Whillier equation (Eq.1) [21].

$$\eta = \frac{Q_u}{AI_T} \qquad (1)$$

The A value given in the equation shows the collector area, the I_T value shows the total solar radiation and the Q_u value shows the useful energy.

3. ANALYSIS RESULTS

In this study, the analysis of the domestic water heating system for Ankara was made with the TRNSYS software using a FPSC. Ttop and Tbottom temperatures changes are given at Figure 6. The values on the horizontal axis in the figure correspond to the days of the year, and the axis values are adjusted to correspond to a month.

The control element monitors the temperature of the water in the upper part of the domestic water tank, ensuring that it does not overheat by using the high limit cut-off temperature. This temperature was determined as 100°C. Thus, when this temperature is reached during operation, the pumps stop and the water in the tank is prevented from boiling.

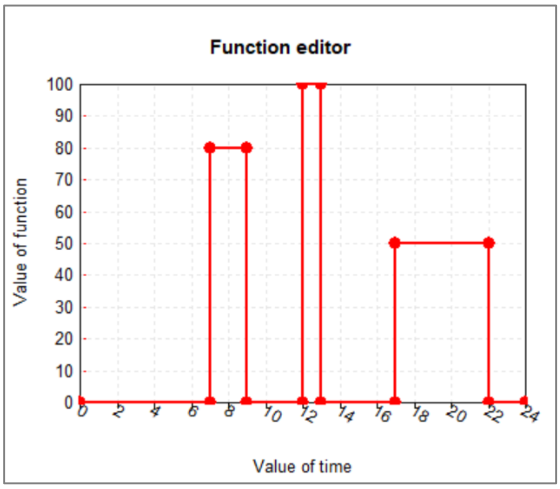

Figure 5. Daily hot water consumption

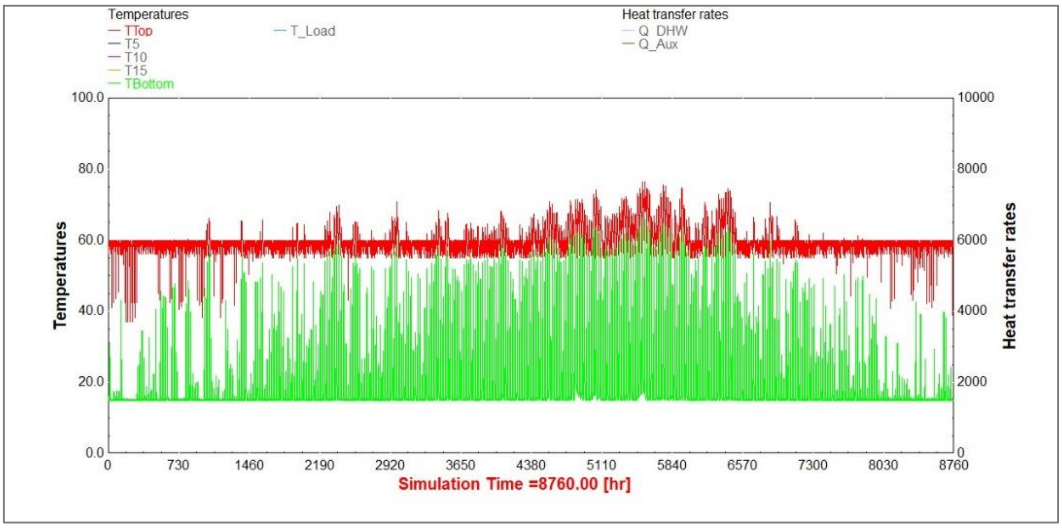

Figure 6. Ttop and Tbottom temperatures

As seen in Figure 6, the top point temperature of the tank reached its highest value in summer. In the months when the solar radiation intensity is lower, the water temperature in the tank drops below the set value (55 ºC). While the water temperature at the top of the tank reached approximately 78 °C in August, the temperature at the lowest point reached a maximum of approximately 66°C. The temperature change values at the upper and lower points of the tank are similar to the literature [22]- [23]. The temperature distribution at other points of the tank is similar (Figure 7). The temperature changes in the tank were generally in accordance with the literature [24].

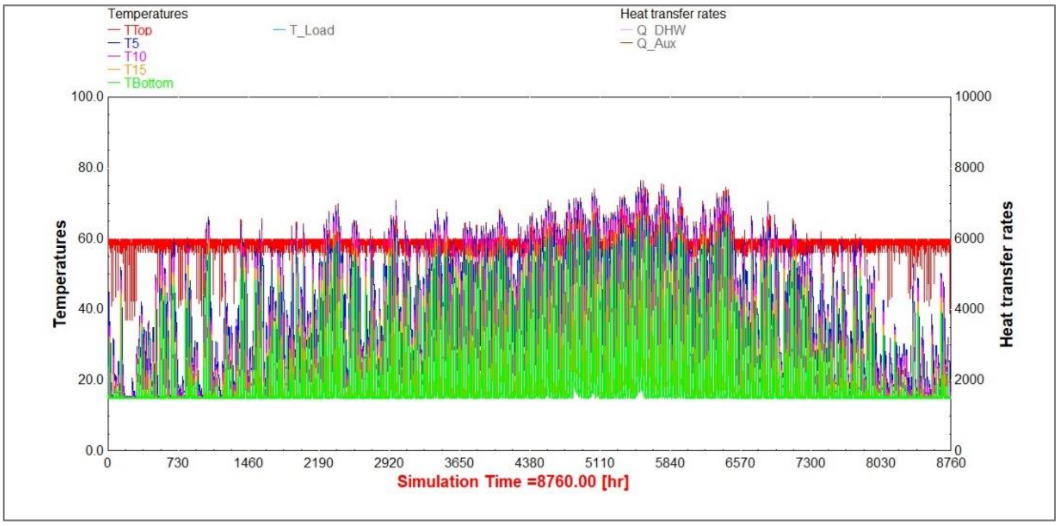

Figure 7. Temperature values for T5, T10 and T15 nodes

In the modeled system, two auxiliary heaters are used in the tank to meet the load requirements. The power of these heaters is determined as 2.5 kW. In some systems, although these heaters do not work, they are kept as backup to provide energy. As seen in Figure 8 in the designed system, only one heater operated throughout the year. The auxiliary heater started working towards the end of November and worked almost continuously until the end of January. From mid-May to the end of September, the auxiliary was partly less involved. The useful heat provided by the solar collector during these months met most of the hot water needs. During the rest of the year, the heater worked intermittently. The trend followed by the backup heater is consistent with the literature [20].

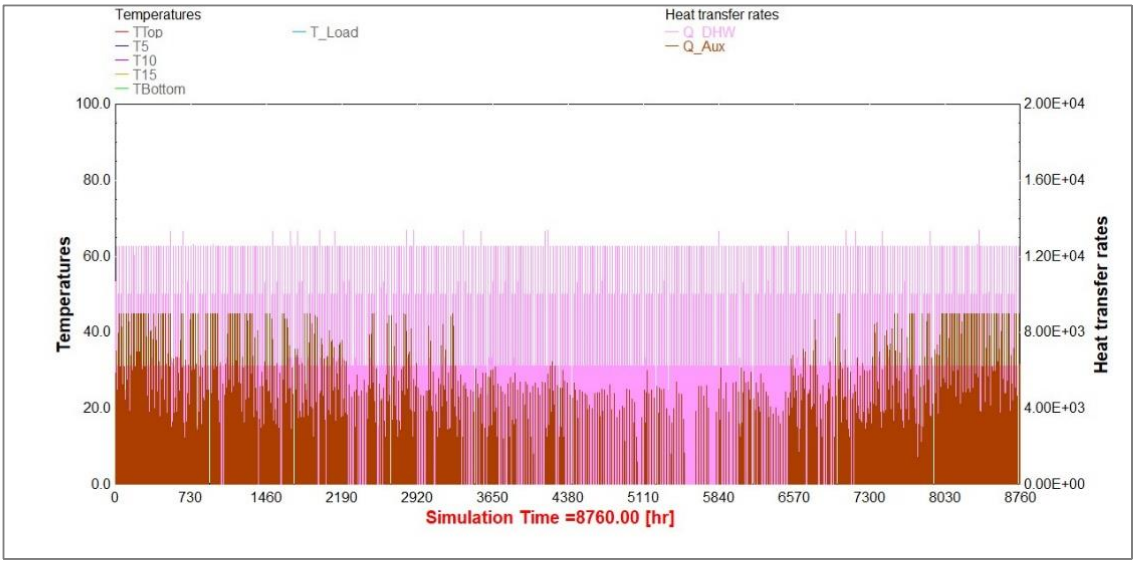

Figure 8. Use of auxiliary heater

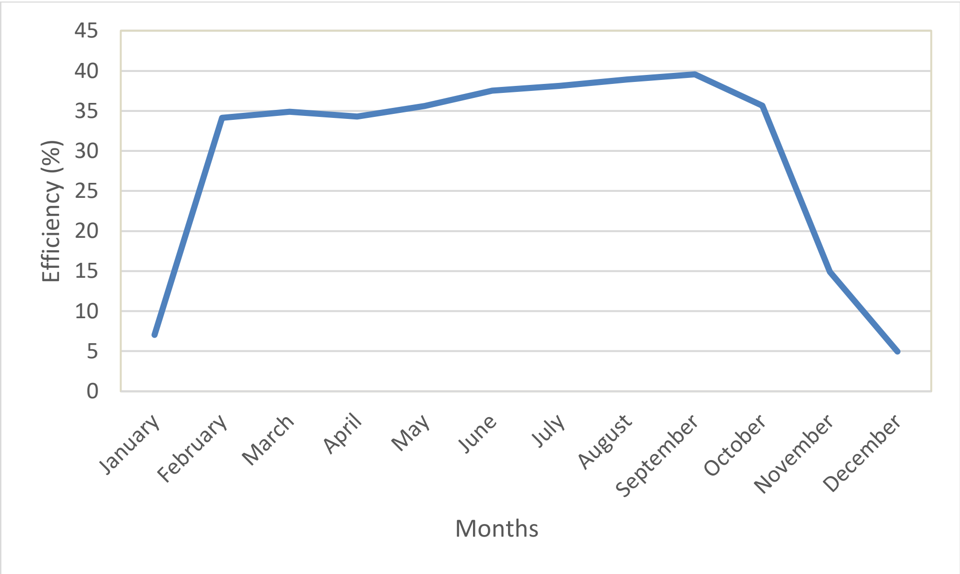

Figure 9. Efficiency graph

Figure 9 shows the change in collector efficiency throughout the year. Collector efficiency reached its highest value of 40% in September. The lowest efficiency value was determined as 5% in December. The variation of the collector efficiency according to the months was consistent with the literature [20].

4. CONCLUSION

The performance of a SDHW system for the whole year was investigated through modeling and simulation. SDHW system modeling for the province of Ankara was made with the TRNSYS program. Conclusions are described as follows:

- While the water temperature at the top of the tank reached approximately 78 °C in August, the temperature at the lowest point reached a maximum of approximately 66 °C.
- The auxiliary heater operated almost continuously from November to January. The auxiliary heater was activated less frequently from May to September. The useful heat provided by the solar collector during these months completely met the need for hot water.
- Collector efficiency reached its highest value with 40% in September and its lowest value with 8% efficiency in December.

The efficiency of the FPSC is sufficient to meet the thermal energy input required for the system during the hot months of the year. Meeting the need for hot water in buildings with SDHW systems will save on electricity or natural gas use. In Turkey, increasing the SDHWS in buildings by evaluating the solar energy potential will significantly reduce foreign dependency in energy. This modeling can be examined in later studies in terms of the economic feasibility of the system.

Nomenclature

SDHW	Solar Domestic Hot Water
TRNSYS	TRaNsient SYStem
PV	Photovoltaic
DHW	Domestic Hot Water
FPSC	Flat Plat Solar Collector
TTop	Top temperature (C)
Tbottom	Bottom temperature (C)

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Aslıhan KURNUÇ SEYHAN: Performed the analyses and interpreted the results.

Sinem UZUN: Performed the analyses and interpreted the results.

Salih COŞKUN: Provided technical information support to the article.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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