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Research Article / Araştırma Makalesi

Thermal Control System Developed to Maximize the Use of Renewable Energy Space Heating Systems

Mahal Isıtma Sistemlerinde Yenilenebilir Enerjiden Maksimum Fayda Sağlamak İçin Geliştirilen Termal Kontrol Sistemi

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Abstract

In buildings and enclosed spaces, the majority of energy consumption is attributed to space heating systems. The integration of renewable energy sources into these systems plays a crucial role in reducing both energy costs and environmental impacts. In this study, a hybrid system was designed to enable the efficient utilization of solar energy in space heating systems. Data obtained from the system were processed using an Arduino board to develop a control mechanism. The system can be remotely controlled by users via the Arduino IoT Cloud platform. To demonstrate the effectiveness of the designed system, an experimental setup was established. The application results were obtained in Hakkari Province over several days and at three different operational levels. Transitions between levels occurred either automatically, based on ambient temperature, or manually by the user. At Stage 3, the highest temperature achieved was approximately 43°C, indicating that maximum benefit from solar energy was obtained. This system has the potential to significantly contribute to future energy management in buildings and provide sustainable solutions to energy challenges.

Keywords: *Hybrid System, Arduino, Solar collector, Remote Access, Renewable Energy*

Öz

Binalarda ve kapalı ortamlarda enerjinin çoğunluğu mahal ısıtma sistemleri tarafından sağlanmaktadır. Hem enerji maliyetleri hem de çevresel etkilerin azalmasında yenilenebilir enerji kaynaklarının sisteme entegrasyonu önem arz etmektedir. Bu çalışmada; mahal ısıtma sistemlerinde, güneş enerjisinin etkin bir şekilde kullanımını sağlayan hibrit bir sistem tasarlanmıştır. Sistemden alınan veriler Arduino kartında değerlendirilip kontrol mekanizması tasarlanmıştır. Arduino IoT Cloud platformu üzerinde; kullanıcı sistemi uzaktan kontrol edebilmektedir. Tasarlanan sistemin etkinliğini göstermek amacıyla bir deney düzeneği hazırlanmıştır. Uygulama sonuçları; Hakkari İlinde farklı günlerde ve üç kademede gerçekleştirilmiştir. Kademeler arasındaki geçişler ortam sıcaklığına bağlı olarak otomatik olarak ya da kullanıcı tarafından gerçekleşmektedir. Kademe 3'de en yüksek sıcaklık yaklaşık 43°C olarak ölçülmüş ve bu kademede güneş enerjisinden maksimum fayda sağlandığı sonucuna varılmıştır. Tasarlanan bu sistem; özellikleg gelecekte bina enerji yönetiminde yön verebilecek ve sürdürülebilir enerji problemlerinde çözüm olabilecek potansiyele sahiptir. olduğu ve daha doğru sonuçlar verdiği tespit edilmiştir

Anahtar Kelimeler: *Hibrit Sistem, Arduino, Güneş Kollektörü, Uzaktan Erişim, Yenilenebilir Enerji*

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1. Introduction

Energy has become the most fundamental problem and indispensable need due to the requirements of the age we live in. In the production phase of energy, the increase in fossil fuel consumption has brought about the problem of environmental pollution [1-2]. Greenhouse gases released into the atmosphere along with the increasing consumption of fossil fuels in the energy production phase have also triggered global warming [3-4]. Today; As a result of the increase in unnecessary energy consumption, energy and financial savings have been ignored. Due to the cost of energy, high bills have emerged. With the increase in energy prices day by day, users have to struggle to solve financial problems. As a result, problems have arisen regarding the efficient and economical use of energy. In order to minimize these problems, users have turned to search and developed many methods to use energy efficiently and maximize efficiency with smart systems. There are many projects and studies in the literature for the development of smart systems and efficient use of energy to minimize high energy costs. In addition, many countries offer solutions and incentives for the development of these systems. Because it is extremely important to take measures to improve the environmental conditions we live in and reduce fossil fuel consumption. In order to minimize the effects of global warming, intensive and efficient use of renewable energy resources is important. It is known that access to electricity is difficult and heating problems are experienced, especially in some rural areas. It has been observed that solar panels installed in these regions provide home heating, hot water and electricity [5]. It is important to implement such applications more frequently in regions where the sun is intense. Solar energy is one of the renewable energy production sources and does not leave any harmful waste. Therefore; various methods and designs have been developed to provide maximum efficiency in solar energy. Generally, solar panels are positioned at fixed angles and maximum efficiency is not obtained from the sun. In order to solve this problem, dual-axis solar photovoltaic (PV) panels are used to track the sun and improve system performance [6-7]. However; the controller designs developed for the designed solar-powered mechanisms to work with high performance are very important. Different programming cards are preferred for the control of the system. The Arduino card is frequently used to control the system and develop smart designs. For instance, this card is used in energy optimization and management [8]. Additionally, Arduino cards are preferred in various applications, including the control of IoT-based smart solar energy systems [9-10], the analysis phase of solar energy systems [11], the management of buildings that rely entirely on renewable energy for their energy consumption [12-13], the control of hybrid dryers powered by biomass and solar energy [14], and methods developed to enhance the performance of PV systems.

Apart from the use of renewable energy sources, monitoring them by remote access is also important. Energy consumption and monitoring are carried out using the IoT (Internet of Things) system [15]. Remote access to information about the system allows the development of appropriate control methods. Keeping energy savings at optimum values can be achieved by constantly monitoring these systems. Therefore; IoT technology is frequently used in industry and applications [16]. Examples include IoT-based smart campus applications developed using hybrid renewable energy [17], IoT-based cybersecurity frameworks proposed to ensure the security of designed renewable energy systems [18], agricultural applications [19], and IoT-based designs enabling the monitoring of the developed system [20].

This study consists of four main sections: Introduction, Materials and Methods, Results and Discussions and Conclusions. In the Introduction section; information about the importance of the system designed in the study and the scope of the study is given. In the Materials and Methods; information about the equipment used is provided and also the working principle of the systems designed using natural gas and renewable energy is mentioned. In the Results and Discussions section; the application results of the designed system are given. The data realized at different stages are evaluated. Finally, in the Conclusions section; a general evaluation is given in a summary form. In this section, suggestions are also made regarding future studies on the subject in the light of the knowledge and experiences gained throughout the this study.

2. Materials and Methods

This section provides information about the equipment used and the system design in the study. The Arduino IoT Cloud Platform used to enable internet access for the heating system, the structure of the Wemos D1 R2 ESP8266 board, the sensors employed for obtaining temperature and humidity data, and the hybrid heating systems are addressed sequentially.

2.1. Arduino IOT Cloud Platform

With the increasing focus on network technologies, the internet has become an integral and indispensable part of daily life. As is well known, the widespread adoption of network technologies has enabled communication between devices used in everyday life, leading to the concept of the Internet of Things (IoT). The Arduino IoT Cloud platform serves precisely this concept. It facilitates remote access to objects and allows users to obtain data from any system created in the web environment. In the heating automation system to be developed, the Arduino IoT Cloud platform enables access to data related to heating values and results derived from the designed system. The Arduino boards to be used in this setup must be ESP32- or ESP8266-based to ensure internet connectivity. In this study, the Wemos D1 R2 board was used to access the data generated by the system via the internet. This board is based on the ESP8266 microcontroller. As shown in the block diagram in Figure 1, users are required to have an account on the Arduino IoT Cloud platform to access the system's data via the internet. The Wemos D1 R2 board used in this study facilitated access to the data by connecting to the Arduino IoT Cloud platform via the internet. In the block diagram shown in Figure 1, energy was regulated using the data obtained from the sensors and control mechanisms, thereby achieving energy efficiency. Additionally, the results derived from this data were transmitted to the internet using the ESP8266-based Wemos D1 R2 board and accessed through the Arduino IoT Cloud platform.

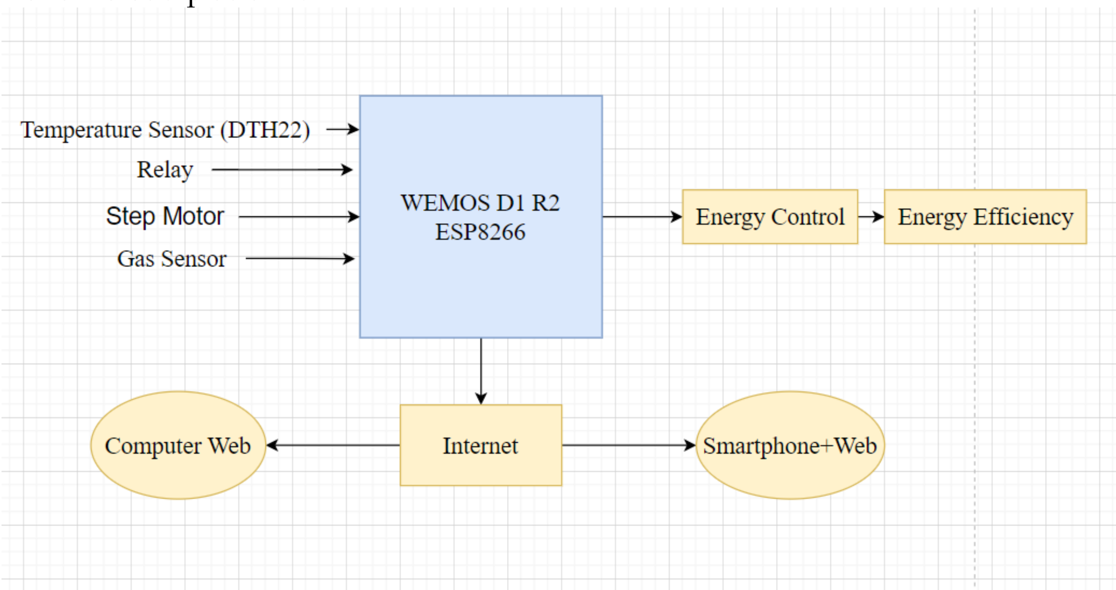

Figure 1. Block Diagram for Heating Automation Internet Access

As seen in the block diagram of the heating automation system, the data obtained from the sensors requires the use of the WEMOS D1 R2 ESP8266 board, and the user must access the data via the Arduino IoT Cloud through internet connectivity. By enabling this access, user control and energy efficiency will be achieved.

2.2. Wemos D1 R2 ESP8266 Board

The Wemos D1 R2 ESP8266 board is similar to an Arduino board but is Wi-Fi based. It operates with 3.3V power and may require an additional power source if the number of sensors connected to it increases.

Compared to Arduino, it has 11 digital input/output pins and 1 analog pin. Due to its Wi-Fi capability, the Wemos D1 R2 board allows data to be collected from various platforms, providing information about the system. In our application, the board, programmed on the Arduino IoT Cloud platform, enables the system data to be monitored at any time and location via internet connectivity. The Arduino IoT Cloud platform, which supports various Wi-Fi module-based boards, enables the visualization of the data obtained from this system. The structure of the Wemos D1 R2 ESP8266 board is shown in Figure 2.

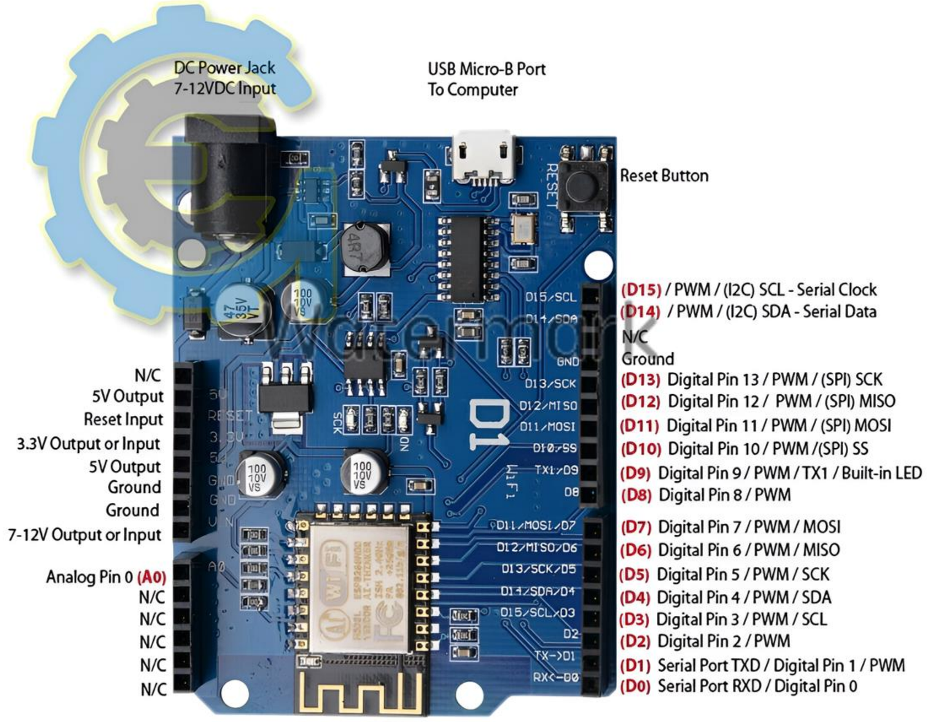

Figure 2. Wemos D1 R2 ES8266 Board

2.3. DTH11 Temperature and Humidity Sensors

The Arduino-compatible sensor is used for temperature and humidity measurement. After the Arduino circuit is connected, the microcontroller on the Arduino reads the values from the sensor, and components such as valves and motors operate accordingly. The system is controlled based on the data obtained from these measurements. In this study, the temperature and humidity sensor shown in Figure 3 has been used.

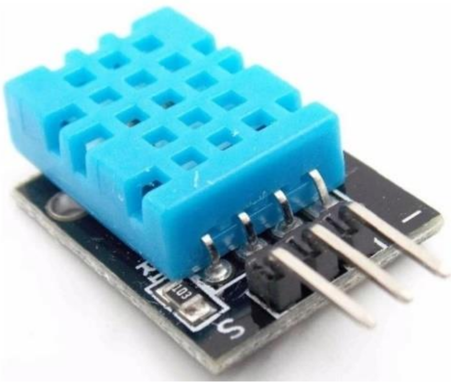

Figure 3. DHT11 Temperature and Humidity Sensor

The primary purpose of using the sensor is to accurately obtain both the internal temperature and humidity values of the environment, as well as the external temperature and humidity values. Based on these readings, a method and approach are designed to operate the system. The microcontroller processes the data obtained from the sensor using a specific algorithm, ensuring that the system operates in synchronization with the data.

2.4. Hybrid Heating Systems

Renewable energy sources are preferred as cheap, alternative and clean energy. The most commonly used energy types in this area are known as wind and solar energy. In order to keep energy efficiency at a maximum level, the Figure 4 modeling designed with the AutoCAD program is preferred. There are more than one different mechanism in the system. The control mechanism designed for the optimum operation of the system is important. In such studies; system control is possible with controllers designed using the Arduino microcontroller card. The hybrid mechanism given in Figure 4 includes natural gas energy and solar energy. One of the main purposes of this system design is to ensure that the user benefits from the solar energy system at the maximum level. Hybrid heating systems can be used in places such as homes, greenhouses and swimming pools.

When the working principle of the system is examined; firstly the water in the solar energy system is sufficiently heated, then the circulation pumps are activated. Finally; the heat energy is released to the exchangers. As seen in Figure 4; when the solar energy system is activated, the stages of the circulation pumps are adjusted and the average heat value in the house is determined by the user. There are two different types of energy in the system. Energy types are activated according to different situations. The operation of the system is completely controlled by the user.

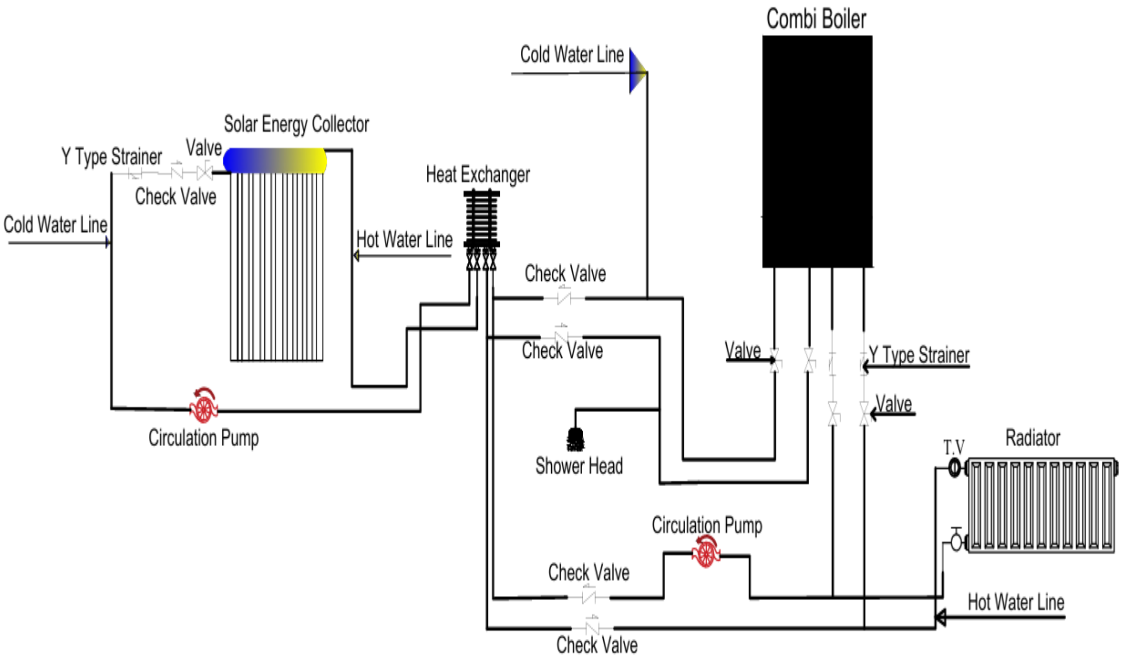

Figure 4. Hybrid Modeling in Heating System

In the heating system; the water heated by the solar collectors, passes through the exchanger plates and transfers its heat to the radiator line on the opposite side. The radiator line distributes the heat with the circulation pump that circulates its heat and then the heated water cools down again. Finally; the cooled water returns to the system and continues to work by heating up in the exchanger plates. This system continues to work in a cycle. The check valves and strainers used in the system are intermediate elements used entirely for the safety of the system and to extend its service life. Exchangers are the heat transfer elements of the system and the exchanger size changes completely according to the size of the system to be used. In fact, the size of the exchangers to be used in the systems changes in direct proportion to the size of the system. In the heated hybrid modeling given in the figure above; the heating energy obtained with natural gas or any other type of fuel is deactivated and when the weather is sunny, the heating energy obtained from the solar collector saves on fuel type, reduces fuel consumption against environmental pollution and also saves the user from the bill burden.

3. Results and Discussion

In this study; the system was designed with a solar energy collector and the maximum benefit was tried to be obtained from the heat energy obtained by heating the water. The system that was established is a hybrid system design that works with both natural gas and solar energy. In cases where there is no sun; a mechanism was designed that will automatically activate the natural gas system with the programming developed in the microcontroller card Arduino. At the same time; when the sun is effective, the solar energy system is activated; the system fed by natural gas or other energy sources is prevented from working. Therefore; in sunny weather, only solar energy is activated and the aim is to use only renewable energy sources effectively and efficiently in the system.

The experimental set modeling that provides the effectiveness of solar energy on heating systems and the high efficiency of the engine used is given in Figure 5. The application set includes 1 solar collector, 1 radiator, 2 circulation pumps and 1 heat exchanger. The main purpose of this experimental set is to ensure that the system works more efficiently by making transitions between the stages of the circulation pumps and also to produce solutions to problems that may occur in the automation system. Cold water circulating in solar collectors; heats up by passing through the collectors. Therefore; heat energy obtained from solar energy is released as heat in the exchanger system with the help of circulation pump. This heat passing through the exchanger plates provides the heating of cold water coming from radiators. Thanks to the circulation pump on the cold water on the radiator line, it ensures that the water heated in the exchanger is compressed in the radiators and distributes the heat energy on the radiator.

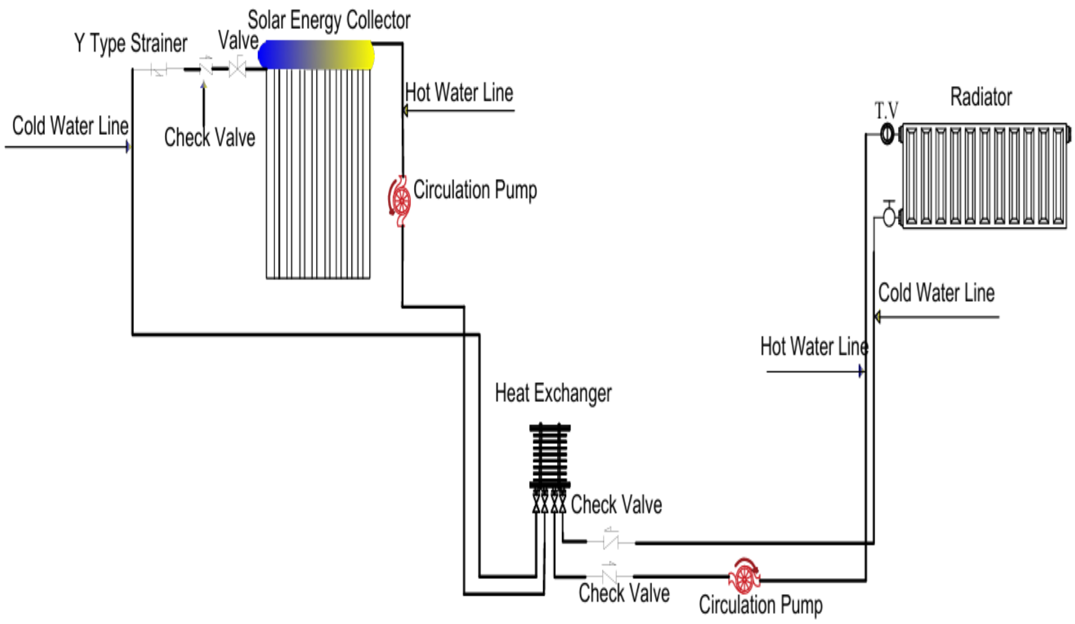

Figure 5. Modeling of the System Used in the Experiment

A solar collector consisting of 16 collectors is seen in Figure 6. The cold water passing through this solar collector is heated and converted into heat energy in the system. There is a cold inlet line and a hot water outlet line on the collector. In the experiment, the solar collector was set to the full south direction in order to provide maximum benefit. There are also more suitable situations to provide this maximum benefit. In Figure 7, the heat energy obtained in the solar heating system transfers heat energy to the radiator by releasing its heat to the exchanger. For the data planned to be obtained here, there are three different stages in the circulation motor on the solar collector. The effects of these motor stages on the system were analyzed. In order to analyze the effects of the circulation pump stages on the system, data was collected and the automation system was designed by taking this data as a reference.

Figure 6. Solar Collector Used in the Experiment

As seen in Figure 7; there is a circulation pump on the lines belonging to a radiator and a solar collector. The circulation pump on the hot water line that comes from the solar collector heats up and circulates the water and the heated water is converted into heat energy by means of the exchanger. The heated water is transferred to the radiator by the circulation of the water on the hot water line that comes from the exchanger plates heats up and heat energy is created.

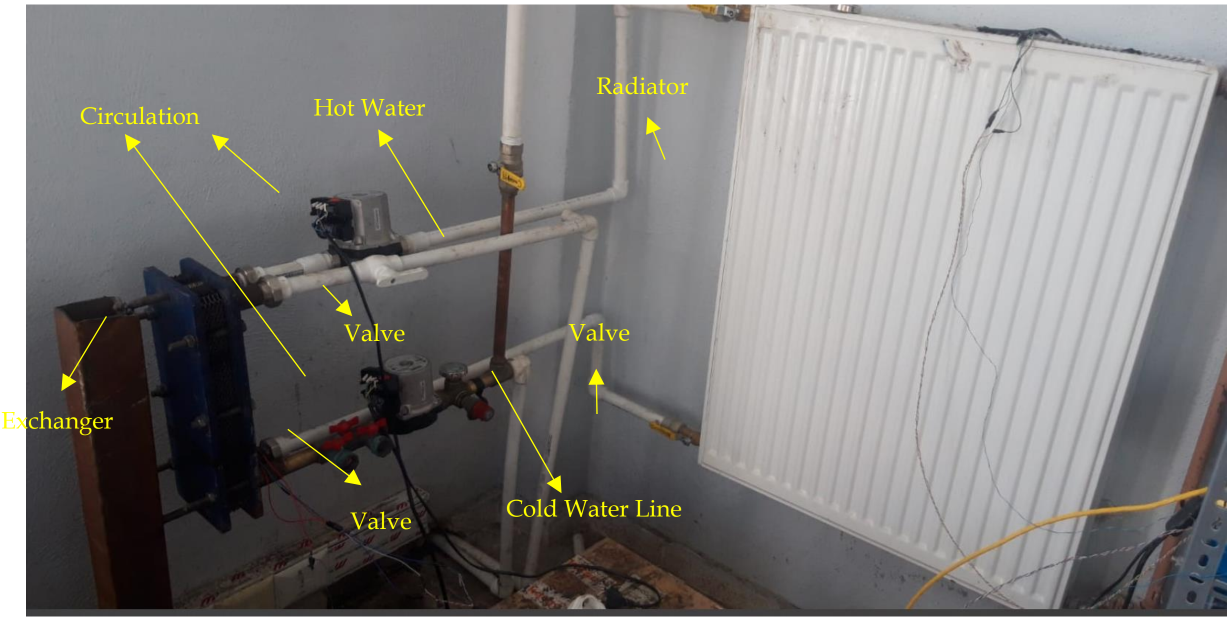

Figure 7. Heat Exchanger and Radiator Used in the Experiment

The cooled water is heated by passing through the solar collector. The main function of the circulation pump is to ensure that the water circulates. The application was carried out using 1 heat exchanger, 2 circulation engines and 1 radiator. Here, the engine was operated in three stages and the results were compared.

3.1. Circulation Pump Stage 1 Results

The solar heating system used in the experiment was operated in three different stages of circulation pumps on different days and times. As seen in the Figure 8; the circulation pump was operated in the first stage. The heat values left by this stage on the exchanger and radiator during the day are given. Figure 8 was obtained by operating the circulation pumps in the Stage 1 between 11:45 and 13:00 on April 19, 2024. The data was obtained from DTH22 humidity and temperature sensors compatible with the Arduino microcontroller. The temperature data obtained in 1 minute and 40 seconds with the microcontroller was taken from the system. While the pumps were operating in the Stage 1, a temperature difference of 1.5 Degrees Celsius was calculated between the average heat energy released to the exchanger and radiator.

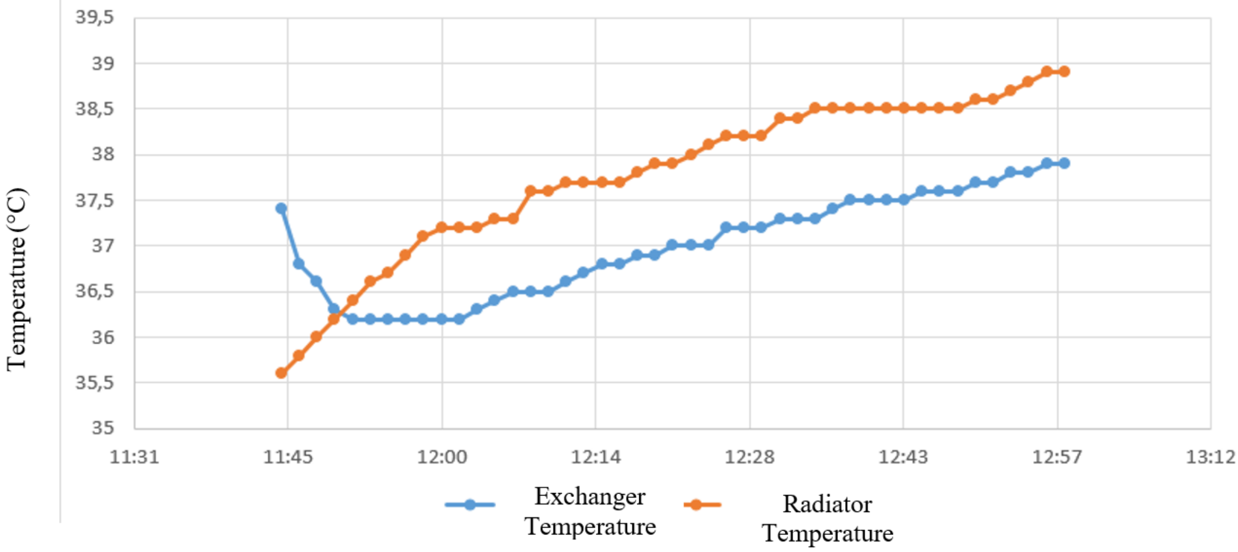

Figure 8. Stage 1 Results of the System (On April 19, 2024 between 11:45-13:00)

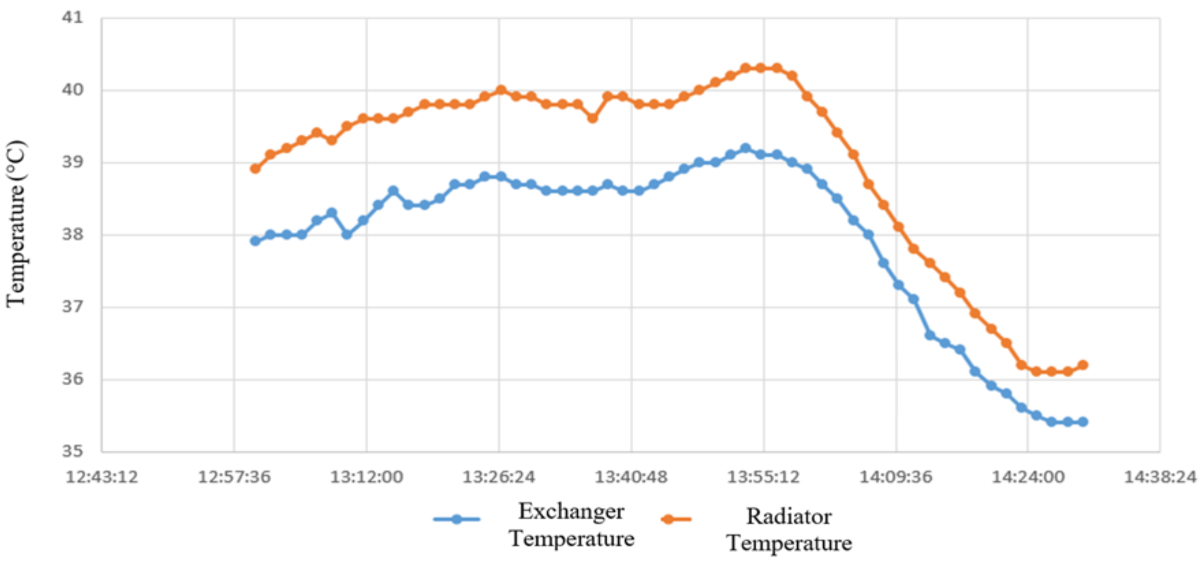

Figure 9. Stage 1 Results of the System (On April 19, 2024 between 13:00-14:30)

Table 1. The Weather Conditions for Hakkari on April 23, 2024

Hour	Temperature (°C)	Real Feel Temperature (°C)
03:00	5 °C	2 °C
06:00	5 °C	1 °C
09:00	16 °C	12 °C
12:00	19 °C	19 °C
15:00	20 °C	19 °C
18:00	17 °C	15 °C
21:00	11°C	7 °C
00:00	7 °C	3 °C

The results presented in Figure 9 were obtained by operating the circulation pumps at the Stage 1 between 13:00 and 14:30 on April 19, 2024. Data was collected using DTH22 temperature and humidity sensors, which are compatible with the Arduino microcontroller. While the circulation pumps were operating at the Stage 1, there was a temperature difference of 1 Degree Celsius between the average heating energy transferred to the heat exchanger and the radiator.

The weather conditions for the province of Hakkari on April 23, 2024, are presented in Table 1 As shown in the weather data, the highest temperatures of the day occurred between 12:00 and 15:00. The maximum temperature during the day reached 19 degrees Celsius.

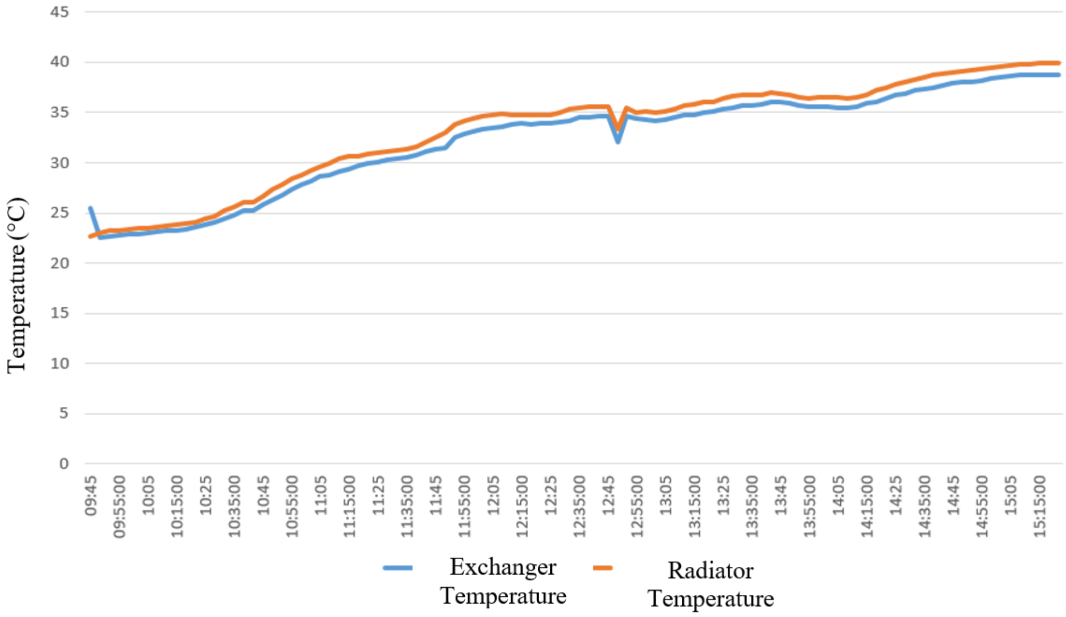

Figure 10. Stage 1 Results of the System (On April 23, 2024 between 09:45-15:15)

Figure 10 was obtained by operating the circulation pumps at the Stage 1 between 09:45 and 15:15 on April 23, 2024. Temperature data was collected from the system by the microcontroller for a duration of 3 minutes and 20 seconds. Upon examining Figure 10, it can be seen that maximum efficiency was achieved between 12:00 and 15:00.

3.2. Circulation Pump Stage 2 Results

In the designed system, the circulation pumps were operated at the Stage 2 during different time intervals. Here, an analysis of the heat energy values transferred to the heat exchanger and radiator was conducted.

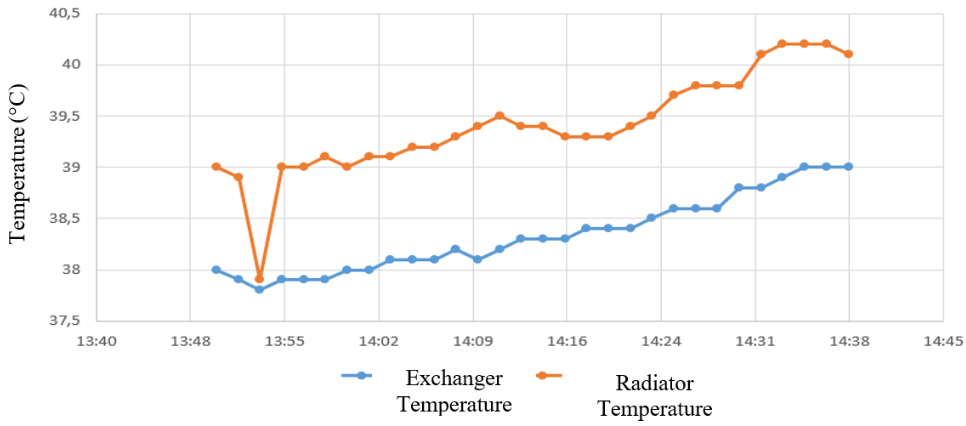

Figure 11. Stage 2 Results of the System (On April 20, 2024 between 13:50-14:38)

The heating values transferred by this stage to the heat exchanger and radiator are presented in the figure below. On April 20, 2024, between 13:50 and 14:38, the motor was operated while the circulation pumps were at the second stage, and the results obtained are shown in Figure 11. According to the obtained data, an average temperature difference of 1.07 degrees was observed over the 1 minute and 40 seconds of recorded temperature data.

Table 2. The Weather Conditions for Hakkari on April 26, 2024

Hour	Temperature (°C)	Real Feel Temperature (°C)
03:00	6 °C	2 °C
06:00	6 °C	2 °C
09:00	16 °C	12 °C
12:00	20 °C	18 °C
15:00	21 °C	19 °C
18:00	19 °C	16 °C
21:00	14°C	11 °C
00:00	9 °C	5 °C

In Table 2, the weather conditions for Hakkari on April 26, 2024, are presented. As shown in the weather data, the highest temperatures of the day occurred between 12:00 and 15:00. Therefore, the system's highest performance was achieved during this time interval. On April 24, 2024, the circulation pumps were operated at the second stage between 10:15 and 16:55, and Figure 12 was obtained.

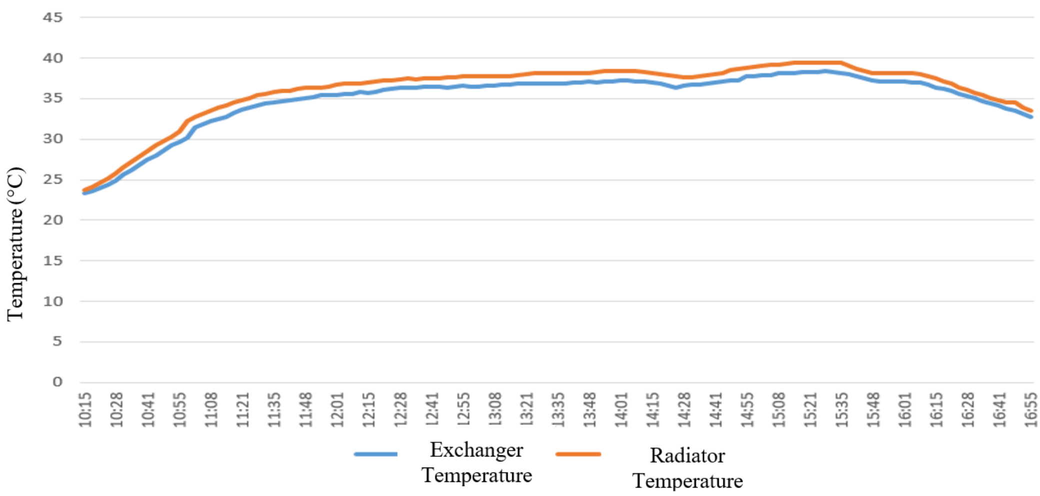

Figure 12. Stage 2 Results of the System (On April 26, 2024 between 12:00-15:00)

Data was periodically collected from the microcontroller every 3 minutes and 20 seconds. According to the results obtained at the first stage, the results from the Stage 2 were found to be better. Upon examining Figure 12, it is understood that the maximum efficiency was achieved between 12:00 and 15:30. Based on these data, an average temperature difference of 1.10 degrees was calculated between the temperature readings taken every 3 minutes and 20 seconds.

3.3. Circulation Pump Stage 3 Results

In this section, the circulation pumps were operated at the Stage 3 on different days and times. The aim here is to examine the heat energy values transferred to the heat exchanger and radiator by operating the circulation pumps at the third stage. The heating energy values transferred by this stage to the heat exchanger and radiator are presented in Figures 13 and 14 below.

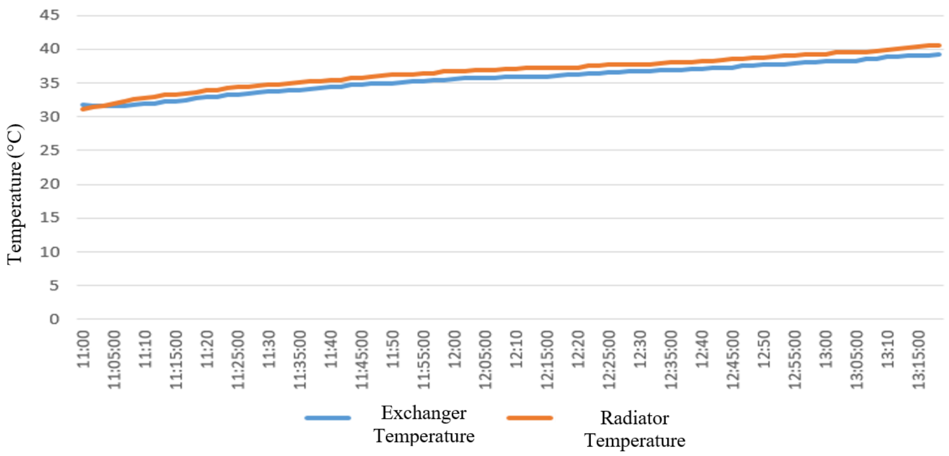

Figure 13. Stage 3 Results of the System (On April 19, 2024 between 11:00-13:15)

On April 16, 2024, the circulation pumps were operated at the third stage between 11:00 and 13:15, and Figure 13 was obtained. Data was periodically collected from the system via the microcontroller every 1 minute and 40 seconds. According to the obtained data, it was observed that the operation of the pumps at the third stage resulted in a smaller temperature difference between the heat exchanger and the radiator compared to other stages, with a difference of 0.51 degrees.

Table 3. The Weather Conditions for Hakkari on April 25, 2024

Hour	Temperature (°C)	Real Feel Temperature (°C)
03:00	7 °C	3 °C
06:00	7 °C	3 °C
09:00	17 °C	14 °C
12:00	21 °C	22 °C
15:00	22 °C	22 °C
18:00	19 °C	18 °C
21:00	15°C	13 °C
00:00	10 °C	7 °C

Table 3 presents the weather conditions for Hakkari province on April 25, 2024. As shown in the weather report, the highest temperatures of the day were recorded between 12:00 and 15:00. Consequently, it was observed that the hours during which the system achieved optimal efficiency were between 12:00 and 16:00. On April 25, 2024, the circulation pumps were operated in the Stage 3 between 08:00 and 16:40, as depicted in Figure 14. The microcontroller collected data from the system every 3 minutes and 20 seconds. Upon analyzing the results, it was found that the best outcomes for the system occurred in the Stage 3. Additionally, maximum efficiency was observed between 12:00 and 16:30.

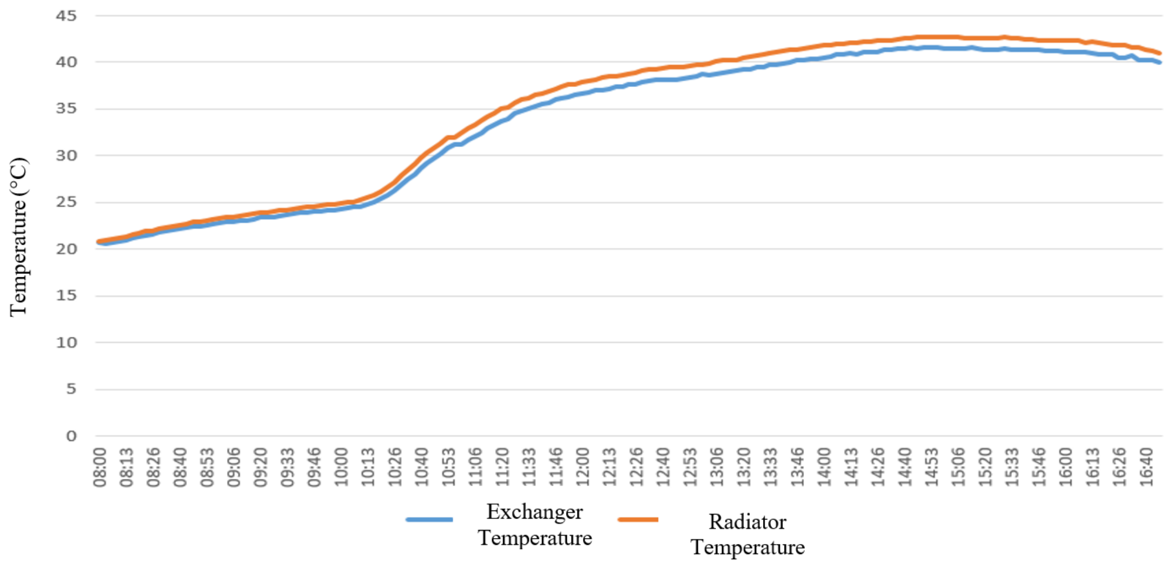

Figure 14. Stage 3 Results of the System (On April 25, 2024 between 08:00-16:40)

As a result of the increase in the motor stages within the system, it has been observed that the difference between the heat values released to the heat exchanger and the radiator is decreasing, and the amount of heat released is directly proportional to the increase in the motor stages.

4. Conclusions

In this study; an automation system design that provides maximum performance has been carried out in order to minimize the harmful effects of fossil fuels on the atmosphere. This smart system provides the opportunity to control mechanical parts and prevent unnecessary energy consumption of the system. Space heating systems are specifically used in indoor spaces and buildings to maintain a balanced indoor temperature. In this study, the aim is to reduce energy costs, utilize resources efficiently, and achieve energy independence by using both renewable energy and natural gas in the space heating system. The system is controlled by the microcontroller added to the system and the user is automatically able to intervene in the system via wireless network access. During the application phase; a hybrid heating system working with solar energy and natural gas has been designed. When there is solar energy, solar panels are actively working. However; when there is no solar energy, natural gas is activated. In our automation system, adjustments are made according to the comfort value determined by the user with motor stages. The energy to be obtained from solar energy is designed to be suitable for use in home heating and water heating. The engine was operated in different stages and the heat values released to the heat exchanger and radiator in the stages of the engine were measured and compared. The efficiency status of the engine was observed by comparing the temperature values between the engine stages. Since our work is an efficiency-based smart automation and the engine was operated according to the user comfort value. At the same time; the user was provided with access to the system status via the internet to the data obtained from the sensors in the system. When the results between the stages are analyzed, it is concluded that the best result was achieved by Stage 3. In Stage 1, the radiator temperature was approximately 39°C, in Stage 2 it was approximately 40°C, and in Stage 3 it was approximately 43°C. The differences between these stages vary according to the user's preferences. This method is particularly recommended for space heating systems. The smart automation system developed in our study can be developed with artificial neural networks and adaptive control mechanisms. An example can be given by training the weather data obtained in previous years of a region with artificial neural networks and making optimum system designs. This designed system can be realized with a 3-stage hybrid system on generating electrical energy.

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