Development and Research of a Two-Contour Solar System in the Lorawan Network

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Abstract: - This article examines the mechanism for researching and improving the energy efficiency of a solar water heating system (SWH) in a building located in Kazakhstan. In this paper, we use data collected from LoRaWAN to obtain information about various environmental and operational aspects of the system under consideration, which determine the possibilities for improving the efficiency of various SWH subsystems and develop management strategies for the effective operation of the entire system. With the help of data collected by IoT, such as water consumption, the schedule of the heat pump and water pump, the availability of solar energy and electricity consumption, we conduct a comprehensive energy audit to analyze the efficiency of subsystems, as well as the performance of the system as a whole. Based on the findings obtained from the data analysis, appropriate management strategies are developed for various subsystems in order to increase the efficiency of the entire system and reduce the operating costs of SWH.

Key-Words: - Flat solar collector, two-contour solar installation, IoT, LoRaWAN, MQTT

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1 Introduction

Traditional fuels and nuclear energy for the sustainable development of energy resources should now be replaced by renewable energy sources. Renewable energy sources are sustainable and have the potential to meet current and future projected global environmental needs. Renewable energy sources such as solar energy, wind, hydropower and biogas are potential candidates to sustainably meet global energy needs. The best alternative to meet the growing demand for energy is solar energy. The conversion of solar radiation into heat is one of the simplest and most direct applications of this energy. A flat plate solar collector is a device used to convert solar energy into thermal energy. Flat plate solar collectors are the most commonly used solar energy collectors worldwide today in commercial and domestic water heating systems. Therefore, the way the domestic sector can reduce its environmental impact is by installing flat plate solar collectors to heat water. Flat plates, evacuated tubes or concentration collectors are solar collectors for hot water supply. The most commonly used type for low-temperature applications is the single-layer, flat plate type. The main component of a solar water heater is a flat plate collector. The absorber plate serves as the central component of the collector. The thermal characteristics of the solar collector depend on the optical and thermal properties, as well as on the design of the absorber plate. A typical flat collector consists of an absorber in an insulated box together with transparent covers (glazing). The absorber is usually made of a sheet metal with high thermal conductivity, such as copper or aluminum, with embedded or attached pipes. Its surface is coated with a special selective material to maximize the absorption of solar energy while minimizing solar energy radiation. In, [1], an insulated box was created that reduces heat loss in a flat solar collector from the back and sides. The simplest and most widely used devices for collecting and using solar energy are thermosiphon or natural circulation solar water supply systems (SWHS). They consist of a flat collector, a storage tank and connecting pipes. The collector consists of an absorber plate, a riser and collector tubes, a glass cover, a casing and insulation. The water in the riser pipes heats up and flows into the storage tank due to the difference in density. This flow depends on the thermosiphon head due to the buoyancy force, which is associated with a change in water density caused by an increase in water temperature in the solar collector. Solar energy is used in different types of fields for many applications. In, [2], [3], [4], [5] we have conducted a sufficient number of experiments on the conversion of solar energy into thermal energy. A lot of work has been done using single-phase heat transfer technology. In studies, [6], [7], [8], [9], [10], experiments were performed in a solar collector with flat plates using a single-phase heat exchange process using an uninsulated water tank and an uninsulated connecting pipe, as well as an insulated water tank and an insulated connecting pipe. For this purpose, a flat plate solar collector acts as a heater, and a water tank stores hot water. It is possible to reduce a huge amount of heat loss from the tank, as well as from the connecting pipe. The end result is the amount of increased water temperature and the efficiency of the flat plate collector will be increased.

In, [11], [12] developed a solar collector that is able to capture solar energy by absorbing liquid, and then stored in a tank used for a specific purpose. The thermal efficiency of photovoltaic air heating using fins attached to the collector was also investigated. The article, [13] presents many examples of electronic monitoring used in hospitals and medical centers with the Arduino platform as a cheap and simple control system. In the article, [14], an efficiency control system was developed to control a photovoltaic solar power plant

For automated systems, real-time monitoring is a necessary and important stage of work, which is carried out through constant data exchange and communication between IoT devices and a server for data processing and visualization. Systems that are used for the industrial sector are often expensive and complex. There are studies that show that the problems of high cost, compatibility, complexity can be solved by using inexpensive materials, as well as written open source code. To date, the market offers inexpensive materials and solutions that have characteristics compatible with many systems. At the same time, there is a great interest in systems using solar energy as the main one, since the receipt and consumption has an environmental advantage over other types of energy production. The prototype is a digital control and monitoring system for the functioning of the solar heat supply system. The basis of this system is a solar collector, a device that collects thermal energy, which is used to heat water. The key and promising aspect of the proposed system is the Internet of Things (IoT). The use of IoT was initially focused on the wireless transmission of data received from sensors with low power consumption, as evidenced by the development of technologies such as Bluetooth Low Energy, ZigBee, NB-IoT, LoRaWAN, etc.. The LoRa communication protocol was used in the work because of its features, such as transmission distance, low power consumption, low cost. The Internet of Things is a combination of different technologies to present solutions in different industries. The LoRaWAN (Long Range wide-area networks) specification is a low-power, wide-area Network (LPWA) protocol designed to wirelessly connect battery-powered "things" to the Internet and targets the key requirements of the Internet of Things (IoT). The LoRaWAN network architecture is based on the "star" topology, in which gateways relay messages between end devices and a central network server. The gateways connect to the network server via standard IP connections and act as a transparent bridge, simply converting RF packets into IP packets and vice versa. In the article, [15], communication between gateways was developed, which is carried out using wireless solutions using broadband LoRa or FSK modulation. Security is an integral part of LoRaWAN, there are two layers of security: one for the network and one for the application. Network security ensures the authenticity of the node in the network, while the application security layer ensures that the network operator does not have access to the end user application data. In, [15], AES encryption was developed, which is used for key exchange using the IEEE EUI 64 identifier. In, [16], a comparative study of LPWAN technologies for large-scale IoT deployment was conducted, technologies such as LoRa, Sigfox, NB-IoT were compared. This article summarizes the technical differences between Sigfox, LoRa and NB-IoT, as well as discusses their advantages in terms of IoT factors and main problems. LoRa technology, compared to other technologies, is a cheaper option for network deployment, with a very long range and with a long battery life. The article, [17] provides a comprehensive overview of LoRa networks, including the technical problems of deploying LoRa networks and the latest solutions, which will allow us to consider the issue from a broader overview and allow for a more practical deployment. In, [18], the mechanism of research and improvement of the energy efficiency of the solar water heating system (SWH) in a hospital building located in Singapore is studied. With the help of data collected by IoT, such as water consumption, the schedule of the heat pump and water pump, the availability of solar energy and electricity consumption, we conduct a comprehensive energy audit to analyze the efficiency of subsystems, as well as the performance of the system as a whole. The article considered data transmission using LoRa technology.

The control controller system described in this article includes temperature sensors and a real-time sensor assembled on the STM32 microcontroller. To improve the existing IoT solution for system monitoring, the LoRa communication protocol is used as a communication channel for data transmission. The controller allows you to connect several sensors, has good functional compatibility, data transmission can also be carried out over long distances, has low cost and power consumption.

2 Research Methodology

Flat solar collectors with thermosiphon circulation are used to convert incident solar radiation into thermal energy. This energy accumulates in the form of tangible heat in the liquid storage tank and is used as needed to power the premises and heat the water. Figure 1 shows a two-circuit solar installation with thermosiphon circulation, [15], [17].

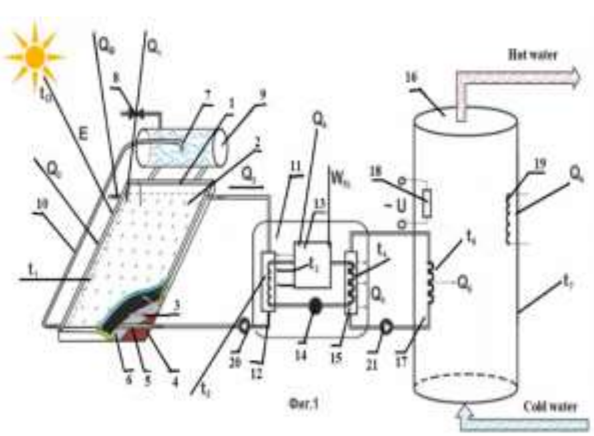

Fig. 1: Schematic diagram of a two-circuit solar installation with thermosiphon circulation, [15], [17].

The operation of the proposed installation is carried out as follows. Solar energy E with temperature t0 is absorbed by the solar collector 1, with temperature t1, heating the flow of solar energy passes through the translucent insulating glass 2. The heat received from the solar flow heats the liquid in the coils 3, which is removed from the collector, and in its place comes cold water from the pipeline with a valve for cold water 8, and from the siphon of the dispenser tank 7 there is a constant thermal siphon circulation using a circulation pipe 10. Next, the liquid enters the heat pump 11, which consists of an evaporator 12 of a condenser with a temperature of t2, in which the heat exchanger is made in the form of a spiral, absorbing the heat of the coolant, lowers its temperature below the ambient temperature (Q2) using a throttling valve 14, thereby contributing to additional absorption of heat from the atmospheric air. The diagram also shows solar radiation reflected from the translucent coating (Q0) and the surface of the absorbing panel (Q1). In the heat pump, the energy of the heat carrier, with a relatively low temperature, is transferred to the heat carrier of the condenser heat exchanger 15 in the form of a spiral with a higher temperature t2, which increases the area, as well as the intensity of heat exchange. To carry out such a cycle, a compressor 13 with a temperature of t3, with an electric drive 17 is used. Further, by means of the condenser heat exchanger 15 with temperature t4, heat from the heat pump (Q5) is transferred to the accumulator tank of the heat exchanger Q6 with temperature t6 of the heating system 18. Since the installation has two circuits, it is equipped with automatic circulation pumps 19 and 20 for the circulation of liquid between the solar collector and the evaporator, the condenser and the battery tank. The water temperature is brought to the required technological level and supplied to the consumer for the purpose of hot water supply and heating, [15], [17].

Fig. 2: Full-scale model of a flat solar collector, [15], [17].

Figure 2 shows a full-scale model of a flat solar collector. The solar collector is the main heat generating unit of the solar installation. To achieve this goal, we have developed a fundamentally new flat solar collector, on the basis of which a standard-sized range of solar installations for heating water and heating the building and room will be created.
The novelty of this research is the development of a two-circuit solar system with thermosiphon circulation, which has a flat solar collector, which is a heat-insulating transparent double-glazed window with reduced pressure, and the coolant is made of thin-walled corrugated stainless pipe. The heat received from the solar flux heats the liquid in the coils, which is removed from the collector, and in its place comes cold liquid from the siphon and there is a constant thermal circulation, which increases the efficiency of heat transfer, eliminating additional intermediate walls between the panel and thermal insulation. In the article, [15], a heat pump was developed, where the condenser and evaporator are made in the form of a "spiral in a spiral" heat exchanger, the heat exchanger pipelines are located one above the other, which increases the area, as well as the intensity of heat exchange.

3 Implementation of the IoT System

The controller combines six digital temperature sensors (Dallas DS18B20) (Figure 3) which register the temperature of a flat solar collector with a thermosiphone. Real-time Clock (RTC), records the date and time of temperature data measurements. The sensors are connected to the STM32 microcontroller, the power comes from the 5V pin, the digital contact is connected via a 4.7kOhm resistor. The microcontroller is connected to LoRa based on SX1276/SX1278 - it is a long-range transceiver operating at a frequency of 868 MHz. Connection to valves. Temperature data, date, time and valve states of the system are displayed on the display.

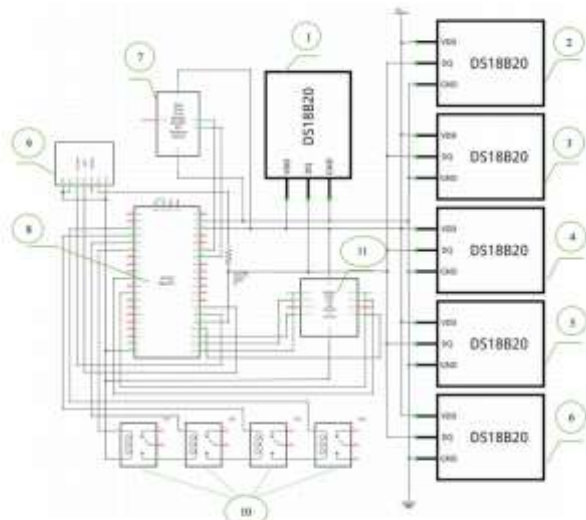

Fig. 3: Connection diagram of the system controller

To transfer data from end devices to the gateway, the LMIC library was selected and installed, it allows you to send uplink packets, encrypt and verify the integrity of messages, receive downlink packets, configure data parameters, activate over a wireless network. The architecture of the system is shown in Figure 4.

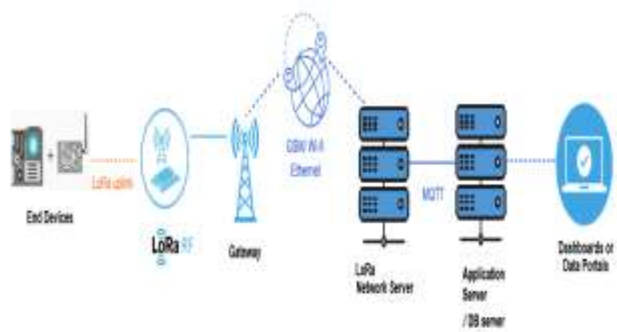

Fig. 4: System architecture: End devices in the LoRaWAN network deployment

LoRa is a broadband radio signal with linear frequency modulation CSS (Chirp Spread Spectrum). The frequency of the CSS radio signal can either increase (up-chirp) or decrease (down-chirp). It is possible to express the signal mathematically in the form:

$$x(t) = A_0 \cdot \cos\left(\omega_0 t + \frac{\mu}{2} \cdot t^2\right), where\ \frac{T_{sym}}{2} \leq t < \frac{T_{sym}}{2}$$

Also the parameters that describe the signal:
f_0; $\omega_0(2\pi f_0)$ - center (carrier) frequency of the radio signal;
$f_l\left(= f_0 - \frac{BW}{2}\right)$; $\omega_l(= 2\pi f_l)$ - lower radio frequency;
$f_{up}\left(= f_0 + \frac{BW}{2}\right)$; $\omega_{up}(= 2\pi f_{up})$ - upper radio frequency;
BW – radio spectrum width (bandwidth);
SF – spectrum spreading factor (varies in the range from 7 to 12);

$T_{sym} = \frac{2^{SF}}{BW}$ - radio signal duration;
$\mu = \frac{BW}{T_{sym}}$ - radio frequency change rate;
$B = BW \cdot T_{sym} = 2^{SF}$ – radio signal base.

The system allows monitoring using LoRa with characteristics such as 125 kHz spectrum width, spectrum expansion coefficient (SF) 7, encoding rate (CR) 4/5 of the operating frequency band. The choice of bandwidth also affects the length of the payload. For example, for the same 125 kHz bandwidth at 868 MHz, if SF = 7, then the bandwidth will be 5470 bits/s, and the payload will be 230 bytes. In, [19], [20], the transmission parameters for LoRa are presented.
The data from the end devices in the upstream message transmits the payload to the LoRa gateway. Next, the gateway transmits messages to the network server via Wi-Fi or GSM (the gateway board has a Wi-Fi module 802.11 b/g/n and an additional slot for a GSM SIM card). There are several options for network servers, in this case the choice was made on a third-party server The Things Network (TTN), [21]. Figure 5 shows a detailed connection diagram of the LORA radio module with further data transfer to the server.

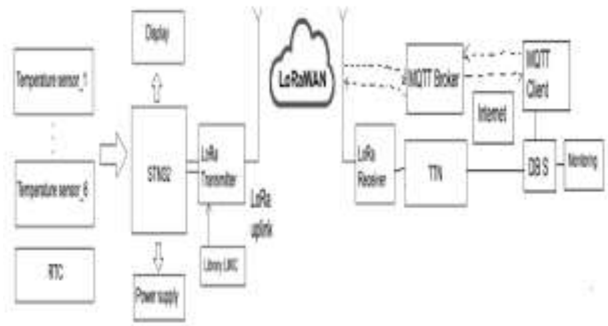

Fig. 5: Block diagram of the system

To work in the The Things Network system, we need to register devices, choose a frequency plan depending on the region (in this project, the frequency of 868 MHz was selected). To join the LoRa network, the terminal devices must go through the activation process (Figure 6).

Fig. 6: Initialization process in TTN: selection of operating mode

After the gateway registration procedure is completed, the end node will be ready to transmit sensor readings at a specified interval. To analyze message latency, the timestamps of each sent packet are recorded on the LoRa server. After the connection is established, the data is converted to the payload format in the form of hexadecimal code (HEX) (Table 1).

Table 1. Example of the analysis of the data received from one temperature sensor

Parameter	HEX data	Decimal equivalent	Ratio	Data
Temperature	1C E8	7400	0.01 °C Signed MSB	74

The payload has a size, it is equal to 14 bytes (when adding new sensors or adjusting data, the size can be changed). Next, on the TTN server, you can see the process of decoding the payload to obtain a readable format (Figure 7).

```
function Decoder (bytes, port) {
  var result = {};
  var transformers = {};

  if (port==1) {
    transformers = {
      'temperature': function transform (bytes) {
          value=bytes[0]*256 + bytes[1];
          if (value>=32768) value=value-65536;
          return value/100.0;
      },
```

Fig. 7: Code snippet for the decoder

As shown in Figure 7, the code snippet is a decoder used to convert data from a given payload. In the console, the decoder function is programmed in JavaScript.

The main function of data transfer between server components is MQ Telemetry Transport (MQTT), [22]. The gateway connector protocol allows you to exchange messages over two network protocols, via rpc and MQTT (with TLS encryption).

TTN does not allow storing data, a database (DB) was created on MySQL for storing data with further displaying them in the browser. In this case, the SDK on Node was used.JS with npm (package manager). The MySQL data warehouse is used. To display the data in the browser, a MySQL web administration tool, phpMyAdmin, was used on the Apache web server.

4 System Testing and Results

Experimental studies were carried out using an automatic control controller, for stability and accuracy of operation for a two-circuit solar installation with thermosiphon circulation. Figure 8 shows the operation of a two-circuit solar installation with thermosiphon circulation on a clear day. The heat pump was running continuously from 10 a.m. to 7 p.m., so the collection of solar energy took place during this time period. When the heat pump was running, the water temperature at the outlet of the flat solar collectors gradually increased in the morning, and then gradually in the afternoon, the water temperature at the inlet constantly increased and decreased when the heat pump was turned off. When the temperature of the hot water in the accumulator tank increased, it led to an increase in the temperature of the water at the entrance to the flat collectors. Another reason is that the ambient temperature and solar radiation also increased in the morning and then gradually decreased in the afternoon. The water temperature at the outlet of the flat collectors reached its maximum value of 74.5 ° C at 14:05. When the heat pump was started, the variable mass flow in the circuit increased greatly, and then gradually decreased. This is due to the heat accumulated in the collector, which leads to a sudden increase in the outlet temperature, and then to a rapid decrease.

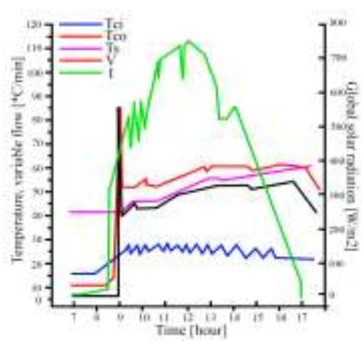

Fig. 8: Operation of a two-circuit solar installation with thermosiphon circulation on a clear day

Figure 8 shows the operation of a two-circuit solar installation with thermosiphon circulation on a cloudy day. The heat pump worked continuously from 10:00 to 17:00, and the collection of solar energy also took place between these times. During the operation of the heat pump, the water temperature at the outlet and inlet gradually increased until 15:15 pm, and then gradually decreased. The temperature of the hot water in the accumulator tank gradually increased, and the variable mass flow rate also increased. As can be seen in Figure 9, the variable flow rate fluctuated greatly between 11:22 and 3:58 pm, which is due to solar radiation, leading to a change in water temperature at the outlet of flat solar collectors.

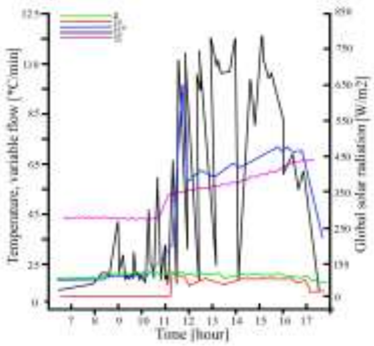

Fig. 9: Operation of a two-circuit solar installation with thermosiphon circulation on a cloudy day

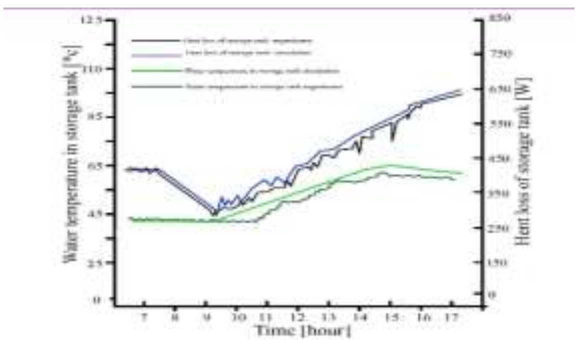

Fig. 10: Changes in heat loss and water temperature of the battery tank on a periodically cloudy day

Figure 10 shows the change in heat loss and temperature of hot water in the accumulator tank depending on the time on a periodically cloudy day. Heat losses through the walls of the battery tank gradually decreased between 7:00 and 9:20 a.m., and then gradually increased due to an increase in the temperature of hot water in the battery tank, changes in solar radiation and ambient temperature.

Criteria that were evaluated when testing the system:
Delay: The process of transmitting data from sensors to the server in real time was 5 seconds, which gives a clear picture when monitoring the system.
Transmission Distance: The system, in particular the LoRa protocol, provides a long data transmission distance. The data stated by the manufacturer indicates the provision of data transmission over a distance of up to 15 km, especially in remote areas without obstacles or with large obstacles.
Low Power Consumption: This is one of the main advantages of the system, as LoRaWAN technology allows you to achieve the low consumption required for data transmission from sensors to the server.
Interoperability and Scalability: System components are compatible, which makes it possible to use materials from different manufacturers to expand the system. If there is a need to connect new sensors, that is, to improve the systems, then the proposed system will allow this to be done.
Low Cost: The system is relatively inexpensive due to the use of inexpensive materials and devices, also meets the monitoring requirements.

5 Conclusion

In this work, we have developed a two-circuit solar system with thermosiphon circulation and a control controller of the solar system (Almaty, Kazakhstan). The developed two-circuit solar installation with thermosiphon circulation has a flat solar collector, which is a heat-insulating transparent double-glazed window with reduced pressure, and the coolant is made of thin-walled corrugated stainless pipe. The developed solar system control controller is able to control the current temperature of the solar thermal system. Experimental results showed that the contribution of the useful heat gain during the day for two cases was 35.1, 22.06 kWh, respectively. While the change in mass flow varies from 2.35 to 22.4 l/min, the amount of mass flow depends on direct and indirect parameters, such as the water temperature at the outlet of the flat solar collector, the temperature of hot water in the heat pump, solar radiation and the load of hot water for consumers.

References:

[1] Duffie, J.A., and Beckman, W.A. Solar Engineering of Thermal Processes. New York: John Wiley and Sons,1991.
[2] Samanci, A., and Berber, A, Experimental investigation of single-phase and two phase closed thermosyphon solar water heater systems. *Scientific Research and Essays*,Vol.6,No.4,2011,pp.688–693.
[3] Islam, M.A., Khan, M.A.R., and Sarkar, M.A.R, Performance of a Two-Phase Solar Collector in Water Heating, *Journal of Energy & Environment. Technical Note*, Vol. 4,2005, pp.117–123.
[4] Chuawittayawuth, K., and Kumar, S, Experimental investigation of temperature and flow distribution in a thermosiphon solar water heating system, *Renewable Energy*, Vol.26,2002,pp. 431–448.

[5] Taherian, H., Rezania, A., Sadeghi, S., and Ganji, D.D, Experimental validation of dynamic simulation of the flat plate collector in a closed thermosyphon solar water heater, *Energy Conversion and Managements*, Vol.52,2011,pp. 301–307.

[6] Zerrouki, A., Boumedien, A., and Bouhadef, K, The natural circulation solar water heater model with linear temperature distribution, *Renewable Energy*, Vol.26,2002, pp. 549–559.

[7] Abreu, S., and Colle, S, An experimental study of two-phase closed thermosyphons for compact solar domestic hot-water system, *Solar Energy*, Vol.76,2004,pp. 141–145.

[8] Hobbi, A., and Siddiqui, K, Experimental study on the effect of heat transfer enhancement devices in flat-plate solar collectors, *International Journal of Heat and Mass Transfer*, Vol.52, 2009,pp. 4650–4658.

[9] Ogueke, N.V., Anyanwu, E.E., and Ekechukwu, O.V, A review of solar water heating systems, *Journal of Renewable and Sustainable Energy*, Vol. 1,2009, pp. 043106.

[10] Mohammed. A.A, Heat Transfer and Pressure Drop Characteristics of Turbulent Flow in a Tube Fitted With Conical Ring and Twisted Tape Inserts, *Engg. & Tech. Journal*, Vol.29,No. 2, 2011,pp.226-239.

[11] Duncombe, J.U, Infrared navigation – Part I. An assessment of feasibility (Periodical style), *IEEE Trans. Electron Devices*, Vol.11, 1959, pp.34–39.

[12] De Marchi Neto, I., and Padilha, A, 2008, Refrigerator COP with thermal storage, *Appl. Therm. Eng*, Vol.29, No.1, 2008, pp.2358–2364.

[13] Rosen, M.A., and Kuma, R, Performance of a photovoltaic/thermal solar air heater: effect of vertical fins on a double pass system, *Int. J. Energy Environ. Eng*, Vol.2,No.4,2011,pp.1–4.

[14] Sugathan, A., Kirthyvijay, G.J., and Thomson, J, Application of Arduino based platform for wearable health monitoring system, *In: Presented at the 1st International Conference on Condition Assessment Techniques in Electrical Systems*,2013.

[15] LoRa Semtech. https://lora-alliance.org/about-lorawan/ [Accessed October 1, 2021].

[16] Mekki, K., Bajic, E., Chaxel, F., and Meyer, F, A comparative study of LPWAN technologies for large-scale IoT deployment, *ICT Express*, Vol. 5, No.1,2019, pp. 1-7.

[17] Shanmuga Sundaram, J.P., Du, W., and Zhao, Z, A Survey on LoRa Networking: Research Problems, Current Solutions, and Open Issues, *IEEE Communications Surveys & Tutorials*, 22:1, 2019, pp.371-388.

[18] Li, W-T., Tushar, W., Yuen, C., Kai Kiat Ng, B., Tai, S., and Chew, K.T, Energy Efficiency Improvement of Solar Water Heating Systems - An IoT Based Commissioning Methodology, *Energy & Buildings*, Vol.224,2020,p.110231.

[19] Augustin, A., Yi, J., Clausen, T., and Townsley W.M, A Study of LoRa: Long Range & Low Power Networks for the Internet of Things, *Sensors*,Vol. 16,No.9,2016,p.1466.

[20] Chiani, M., and Elzanaty, A, On the LoRa Modulation for IoT: Waveform Properties and Spectral Analysis, *IEEE Internet of Things Journal*, Vol.6,No.5,2019, pp.8463-8470.

[21] Platform for IoT applications TheThingNetwork (TTN). https://www.thethingsnetwork.org [Accessed January 4 , 2022].

[22] The Standard for IoT Messaging MQTT. https://mqtt.org/. [Accessed January 4, 2022].

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

-Kunelbayev Murat, Imankulova Binara carried out the simulation and the optimization.
-Sundetov Talgat, Tyulepberdinova Gulnur has implemented the Algorithm.
-Issabayeva Sulu, Sagimbayev Lida has organized and executed the experiments of Section 4.

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Conflict of Interest

The authors have no conflict of interest to declare.

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