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| **RESEARCH ARTICLE**

Solar Energy in IOT Integrated Thermal Distillation System (Sunitds) as an Alternative for Clean Water in Nunukan Regency

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| **ABSTRACT**
The water crisis issue has consistently been a concern for the residents of Nunukan Island in the Nunukan Regency, North Kalimantan, particularly during the dry season. In this study, experiments were conducted to develop a device capable of transforming the abundant seawater around Nunukan Island into clean water that can be utilized during the dry season. The research comprised several stages, including 1) planning, 2) design, 3) construction, and 4) testing, resulting in the creation of two devices: the SUNitds (Solar Energy in IoT Integrated Thermal Distillation System). This device utilizes thermal distillation to convert seawater into clean water and is integrated with Internet of Things (IoT) technology. Based on the conducted tests, the SUNitds device demonstrated the capability to produce water vapor, subsequently undergoing condensation.

| **KEYWORDS**

Thermal Distillation, the Internet of Things; and the Water Crisis

| **ARTICLE INFORMATION**

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1. Introduction
1.1 Background of Study
Indonesia, as the world's largest archipelagic nation with a land area of 5,193,252 km2, of which approximately 2/3 comprises oceans covering around 3,288,683 km2, possesses a vast wealth of marine resources. Despite this abundance of seawater resources, paradoxically, certain island regions surrounded by seawater, such as Nunukan Regency in North Kalimantan, still grapple with issues of inadequate freshwater supply, particularly during prolonged dry seasons. According to the obtained data, the freshwater crisis experienced in Nunukan in December 2022 was identified as the most severe crisis to date (Darmawan, 2022). This freshwater crisis has also resulted in an increased economic burden on the local populace, as they face challenges in acquiring scarce freshwater or relying on rainwater harvesting to meet their daily needs.

Emerging as a crucial issue that requires addressing to enhance the well-being of the community in the Nunukan Regency, the researcher proposes a solution based on the region's geographical potential—converting abundant seawater into clean water through thermal distillation, optimizing the use of environmentally friendly solar energy. Thermal distillation has long been employed as a method to produce clean water from seawater by heating seawater and condensing its vapor into fresh water. One such study by Mulyanef et al. (2014) investigated the treatment of seawater into clean water using thermal distillation.

This research introduces the concept of SUNitds (Solar Energy in IoT Integrated Thermal Distillation System), ultimately resulting in the production of the SUNitds device. SUNitds serves as a tool for converting seawater into clean water. In this device, the researchers provide advancements over previous studies by incorporating Internet of Things (IoT) technology for monitoring water volume, temperature, salinity levels, valve opening and closing, and utilizing energy from solar panels to make the device more effective, efficient, and environmentally friendly. The thermal distillation concept in this device involves storing seawater in a container and heating it using heating elements powered by solar energy to evaporate the seawater. Subsequently, the water vapor is condensed into clean water and collected for immediate use.

2. Literature Review

2.1 Solar Energy

Over the years, solar energy, or solar power, has been recognized as one of the renewable energy sources that is inexhaustible and environmentally friendly due to its non-polluting nature. The book titled "Cosmos" (Carl Sagan, 1980) asserts that the sun formed approximately 4.6 billion years ago from cosmic gas and dust clouds undergoing gravitational contraction. Once formed, the sun steadily initiated nuclear fusion reactions in its core, releasing radiation (radiance) into space. According to John Perlin (2013), the radiation reaching the Earth's surface consists of energy particles called photons. Upon striking the surface of an object, electrons on that object can be liberated, engaging in chemical reactions that produce energy. This energy is then converted into electrical energy using photovoltaic technology.

Photovoltaic is a component that transforms sunlight into electricity through the use of solar cells. Solar cells are composed of semiconductor materials such as silicon and a metal box collector. When photons hit the solar cell, they generate free electrons within the semiconductor material. These electrons are propelled by the electric field generated by the potential difference between the semiconductor material and the metal box collector, subsequently generating an electric current. Solar cells are arranged into modules and connected in a series to produce more electrical energy, as seen in solar panels (Andrei et al., 2007). The advantage of solar panels lies in the fact that the energy produced does not require fuel and does not emit environmentally harmful emissions. Additionally, solar panels can be deployed anywhere, be it in urban or rural areas, extending to islands.

The researcher bases the positive impact of harnessing solar energy through the use of solar panels and incorporates it as the energy source for SUNitds. A study by Nine Primastita Arif et al. (2020) designed a thermal seawater distillation device using solar panels with the MPPT P&O method. The MPPT P&O method enabled the researchers to develop a more innovative approach to designing a thermal seawater distillation device by incorporating Internet of Things (IoT) technology.

2.2 Some Pertinent Ideas

2.2.1 Internet of Things (IoT)

The Internet of Things (IoT) is a concept in which physical objects such as electronic devices, vehicles, buildings, and other items can be interconnected through the internet. This concept enables the continuous collection and exchange of data, allowing for the optimization of performance and improved efficiency across various systems. According to Gubbi et al. (2013), the IoT concept encompasses three main elements: devices that include various types of sensors, actuators connected in a network, connectivity involving network technologies such as Wi-Fi, Bluetooth, and NFC, and platforms comprising various applications and services used to manage data and perform various functions within the network.

Another characteristic of IoT is its ability to automate processes, as indicated in the study by Suhendar & Fatullah (2020). This means that by leveraging IoT technology, various processes that are traditionally performed manually can be automated, leading to increased efficiency and productivity. This capability can be applied to thermal seawater distillation devices utilizing solar energy. IoT can monitor seawater volume and regulate the water level inside the thermal distillation device to maintain the quality of the produced clean water and prevent damage to the equipment. Furthermore, IoT can control the temperature and seawater quality to ensure that the processed seawater meets the standards for conversion into clean water. With IoT automation, the opening and closing of valves in the thermal distillation device can be scheduled and executed based on predetermined conditions. This enhances the operational efficiency of the thermal distillation device and reduces the time required for its operation.

2.2.2 Thermal Distillation

Thermal distillation is a separation process that utilizes heating to separate two or more components in a mixture by exploiting their differences in boiling points. This technique has been widely applied in various applications, such as in oil and gas processing, pharmaceuticals, and water treatment. In the context of SUNitds, thermal distillation is employed in water treatment applications, specifically in the desalination of seawater to obtain clean water. Seawater thermal distillation involves heating seawater in a closed container, generating vapor that is subsequently condensed into clean water (Al-Sahali & Ettouney, 2007). In the initial stage, seawater is heated to boiling, producing vapor, while saltwater and other minerals remain in the container. The vapor is then condensed into clean water by transferring it to a lower-temperature location. This process is repeated to produce progressively cleaner water with reduced salt content.

The most efficient form of seawater thermal distillation apparatus is one that utilizes renewable energy sources, such as solar energy, as it can reduce operational costs and environmental impact. Research conducted by Ketut Astawa et al. (2011) and Mulyanef et al. (2014) has explored the use of solar energy in thermal seawater distillation. Based on these foundations, the researcher has developed a thermal distillation device that incorporates IoT technology and harnesses solar energy, aiming to provide a more efficient and environmentally friendly solution for obtaining clean water from seawater.

3. Methodology

3.1 Research Time and Setting

This research will be conducted from August to October 2023 at the State Polytechnic of Nunukan. The planned activities are outlined as follows:

No.	Activities	Month to		
		1	2	3
1.	Planning Stage	■		
2.	Designing Stage	■		
3.	Construction Stage		■	
4.	Try Out Stage			■

Table 3.1 Time Schedule

3.2 Data Sources, Tools, and Materials

The data source for this research includes secondary data obtained from various supporting sources such as journals, the internet, and other available references, contributing to a deeper understanding for the researcher in designing a product with improved, effective, and efficient innovation. Primary data will be acquired from the testing process of the device to obtain research trial results, which will undergo an evaluation phase to generate a product in line with the initial planning. Several key tools and materials for the SUNitds device include the frame, solar panels, iron container, pyramid glass roof, water volume sensor, salinity sensor, seawater, and other components.

3.3 Data Collection Method

The data collection method in this research involves a literature review of various information related to the SUNitds concept. The collected data will be analyzed to design a more advanced, effective, and efficient SUNitds innovation. Field observations will also be conducted to gather data on design development and the results of the research product trials. During these field observations, the researcher will be actively involved in the design and testing of the SUNitds device.

3.3.1 Data Processing and Analysis Method

Data processing in this research will occur in several stages, starting from planning, design, construction, testing, evaluation, and final production stages. The data obtained during the research will be qualitatively analyzed and presented in six stages as follows:

a) Planning Stage
   In this stage, with guidance from the mentor, the researchers will gather supporting information related to the SUNitds device concept. The aim is to deepen the understanding before progressing to the design stage. Specific details regarding various tools and materials needed, as well as the software used for integrating IoT technology and designing the 3D model of the device, will be determined in this stage.

b) Design Stage
   After the necessary elements have been prepared in the preceding stage, the next step is the design stage. In this phase, with guidance from the mentor, researchers will commence designing the device in a 3D model, utilizing various computer programs and electrical components to integrate technological aspects into the SUNitds device.

c) Construction Stage
   Following the design stage, with assistance from mentors, researchers will construct the SUNitds device based on the established design. This process will begin by preparing all components and designs in the field, initiating the manufacturing process, and eventually constructing both SUNitds devices by the designed model.

d) Testing Stage

Once the SUNitds devices have been completed, the testing stage will commence. Researchers will conduct tests on the functionality and performance of the devices following the planned procedures to obtain clean water from seawater conversion and generate electricity through batteries from saltwater waste. Throughout this stage, researchers will monitor and record the results of each test for subsequent evaluation.

e) Evaluation Stage (Improvement)
After the testing stage, an evaluation phase is necessary to identify issues with the device and examine shortcomings and achievements based on the recorded test results. Researchers, assisted by mentors, will seek solutions to the identified problems, and improvements will be made to enhance the effectiveness and efficiency of the device.

f) Final Production Stage
If the SUNitds device has successfully passed the evaluation and improvement stage, the device can then undergo final production or utilize the previously successful device that has demonstrated the intended functions, performance, effectiveness, and efficiency. Subsequently, researchers will create user guides to ensure proper and effective utilization of the device, as well as develop a maintenance plan to ensure the quality and reliability of the device for long-term use.

g) Final Production Stage
The last stage is the final production stage. After the SUNitds device has successfully undergone the evaluation and improvement stage, it can be produced in larger quantities for practical applications. Researchers will document the process and create user guides to facilitate proper and effective utilization. Additionally, researchers will develop a maintenance plan to ensure the quality and reliability of the device for long-term use.

4. Results and Discussion

4.1 Planning Stage

4.1.1 Planning Device of SUNitds (Solar Energy in IoT Integrated Thermal Distillation System).

SUNitds is an innovation developed by researchers, representing a device designed to convert seawater into clean water for community use in meeting hygiene and sanitation needs, especially during the dry season. Thermal distillation was chosen as the method for seawater conversion due to its lower energy requirement and environmental friendliness, utilizing solar energy for greater efficiency (Yogi Dewantara et al., 2018). This method involves heating seawater to evaporate dissolved salt, and then the vapor undergoes a phase change (condensation) from vapor to water. The distilled water produced through thermal distillation serves as a solution to the recurring problem of clean water crises during the dry season in island regions, such as Nunukan Island and North Kalimantan. By leveraging the abundant seawater surrounding the island and the high intensity of sunlight during the dry season, the SUNitds device proves to be a viable solution.

Based on the discussion results, the researchers agreed upon the required components (as seen in Table 1). It was also agreed that the SUNitds device consists of three parts: 1) seawater storage, 2) pyramid glass, and 3) distilled water storage. For part 1, used buckets serve as seawater storage containers and old chairs function as supports. An Ultrasonic Sensor HY-SRF05 is employed to monitor seawater volume in the buckets, and a buzzer serves as a reminder when seawater is running low. A ½-inch pipe is used to allow seawater to flow from the storage utilizing gravitational force to the Heater container inside the glass pyramid. To control the water flow, a stop valve and MG996R servo motor are used on the pipe. Transparent glass is chosen for the pyramid to allow easier penetration of solar heat, aiding in the seawater evaporation process. The pyramid shape with a 45-degree tilt on each side is selected to absorb sunlight from the east to the west.

An iron frame is constructed to support the pyramid glass and the heater container. Additionally, for part 2, a waterproof JSN-SR04T ultrasonic sensor is used to monitor the water volume inside the heater container. If the water volume in the heater container is low, the MG996R servo motor will open the stop valve to allow seawater to flow and fill the heater container. Recognizing the inefficiency of relying solely on direct sunlight, as it would take a long time to evaporate seawater (Iswari et al., 2017), the researchers innovatively introduced the use of solar energy to heat seawater. This involves utilizing resistive heating with an unused but functional HKT-PM75 car glow plug and a modified iron container as the heating container. Electrical energy is obtained from solar panels, and a 12 Volt 45 Ampere battery serves as an energy storage. The use of a Relay and DC Speed Controller is necessary to regulate the electrical current. This method is expected to expedite the seawater heating process compared to relying solely on direct sunlight.

The evaporated and condensed water on the pyramid glass is then directed through a ½-inch pipe to part 3, the distilled water storage. This section includes salinity sensors to monitor salt content, turbidity sensors to monitor cloudiness levels, pH sensors to monitor acidity levels, an Ultrasonic Sensor HC-SR04 for water volume monitoring, and a buzzer as a reminder when the distilled water container is nearly full. The distilled water quality monitored by these sensors will be validated against criteria set by the Ministry of Health Regulation No. 2/2023 on water quality requirements for hygiene and sanitation purposes. All monitoring and control on the SUNitds device can be conducted digitally via Android and desktop platforms, displayed on a web page named Smart SUNitds, utilizing Internet of Things (IoT) technology. The use of IoT is inevitable in the current era due to its numerous benefits in connecting the physical world with the digital world (Nahdi & Dhika, 2021). To integrate components, including sensors, servo motors, buzzers, and heaters into the IoT system, additional components such as ESP32 as a microcontroller, Step Down 12V to 5V DC as a voltage reducer from the energy source, and various applications and programming languages for designing the IoT system software on the SUNitds device are required. Further details will be discussed in the subsequent stages.

4.2 Designing Stage

To design the SUNitds and Wise devices, the digital application AutoCAD (Auto Computer-Aided Design) was utilized. The use of this application is part of the implementation of geometry in designing the device and proves to be highly beneficial for visualizing the shape and dimensions of the device before the construction (manufacturing) process. This application offers ease and advantages in designing models and sizes precisely and accurately (Yani et al., 2020). To use this application, the following steps were undertaken: 1) Download AutoCAD from www.autodesk.com following the provided guidelines and install it on the computer or laptop. 2) Open the AutoCAD application and click "new" to bring up the page for drawing the design. 3) Commence designing using the available tools, resulting in the digital depiction of the design. The design of the IoT hardware on the SUNitds device is also necessary to simplify the assembly process during the construction phase. The researchers employed the Fritzing application to design the electrical circuit schema of the IoT components on the SUNitds device. Additionally, software design is essential to integrate various components, collect and process data, and monitor and control the device through Android or desktop platforms on the Smart SUNitds website.

Designing of SUNitds device

Figure 1. The whole design of the SUNitds device

The design of part 1 (seawater reservoir) consists of a used plastic bucket as the seawater reservoir, a recycled chair as the supporting framework for the bucket, and an installation of pipes, elbows, and a ½-inch stopcock serving as the channel for seawater from the reservoir to the heater container in part 2 (pyramid glasshouse). Moving on to part 2 (pyramid glasshouse) includes a pyramid-shaped glass roof designed to trap water vapor, allowing it to condense back into water and flow into the distilled water reservoir in part 3 through a connecting pipe of ½ inch and 20 cm in length. The distilled water reservoir is a repurposed pot with a diameter of 24 cm and a height of 14 cm. The design of the IoT component installation will be further detailed in the subsection on hardware installation design.

4.3 The stage of hardware installation design

The design process of the SUNitds device progresses to the stage of hardware installation design. In this stage, the electrical circuitry for the electronic components of the SUNitds device is designed. The installation of the hardware for the IoT system is designed to integrate the components used so that they can be monitored and controlled automatically or manually through a website named Smart SUNitds. The workflow involves connecting the solar panel as the energy source to the Solar Charger Controller, which is then connected to a 12V 45 Ampere battery as the energy storage medium. The stored energy is distributed to two parts: the IoT component circuit and the heater. A 12V to 5V DC voltage regulator is used to connect to the IoT component circuit. A breadboard serves as the connecting medium for the entire IoT component circuit, including sensors for parameter measurement, a servo for water flow control, a buzzer for indicating water volume limits, and an ESP32 microcontroller to connect the IoT components to the internet network for data processing on the web server. Meanwhile, for the heater, the energy from the battery is first connected to a relay as the electricity flow regulator. For a clearer understanding, refer to Figure 2 below.

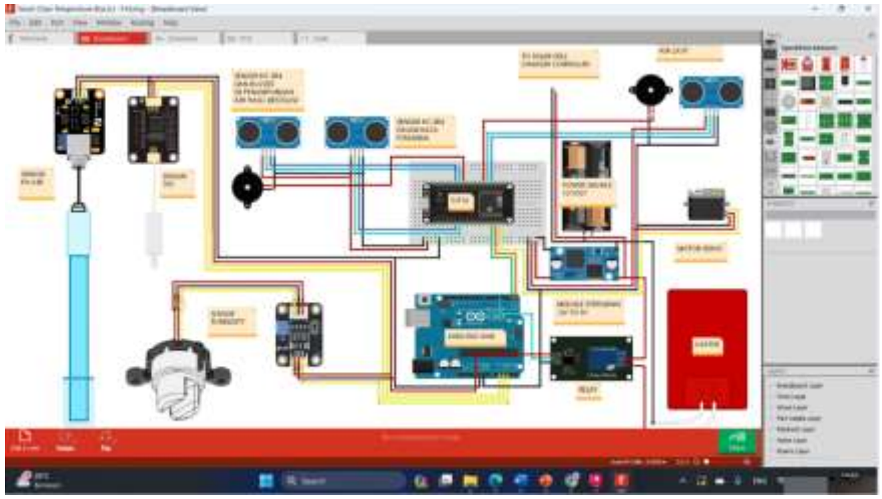

Figure 2. Electricity Scheme of SUNitds Device

4.4 Construction Stage

After the design of the SUNitds device, hardware, and IoT system software, the construction phase commenced. This process took place from September 6th to 22nd at the Researcher's Residence. The construction phase was executed based on the designs and dimensions established during the planning and design stages. The construction began with the assembly of the SUNitds device, followed by the assembly of IoT components and the installation of solar panels.

The first stage involved constructing the three parts of the SUNitds device: the pyramid glass, seawater reservoir, and distilled water container. Initially, the researcher fabricated an iron frame to serve as the base for the pyramid glass and the heating container. A 4-meter iron piece was cut using an angle grinder and welded together. Subsequently, the glass was cut to fit the planned dimensions. The glass was cut into equal-sized triangular pieces, forming a pyramid, with additional pieces made for the bottom base and side of the pyramid glass. The glass pieces were then joined using glass glue and allowed to dry.

Next, pipes were attached to the pyramid glass for freshwater collection. The subsequent step involved creating the heating container using a pot and two glow plugs. After completing the pyramid glass, the researcher prepared a place for the seawater reservoir using a used chair and a used plastic bucket. The chair served as a support for the seawater container, and the bucket was modified to attach a pipe for water flow to the heating container. A modified stop valve, controlled by an MG996R servo motor, was also installed. Once the seawater reservoir was completed, the researcher prepared the container for collecting distilled water, placing sensors for salinity, pH, and turbidity. Each component was positioned according to its designated part.

The assembly of IoT components followed, with the HY-SRF05 sensor mounted on top of the seawater container and directed towards the water inside. The JSN-SR04T sensor was placed on the pyramid glass with its bracket pointing toward the water in the heating container. The HC-SR04 sensor was positioned above the heating container with supporting pillars and a bracket directing towards the water in the distilled water container. A box was provided to house the breadboard, ESP32, and step-down, and it was placed on the side wall of the pyramid glass base. All IoT components were connected using male-to-male, female-to-male, and female-to-female jumper cables. Once the assembly of all electronic IoT components was completed, the process proceeded to assemble the heater circuit and the energy source as per the predetermined design.

Figure 3. Construction Process of SUNitds Device

4.5 Testing Phase

The testing of the SUNitds-Wise device involves two testing methods: performance testing and operational testing. These tests were conducted, and the results are presented in the following subsection:

a) Performance Testing

Performance testing aims to assess the performance of the sensors used in the SUNitds device. This is achieved by comparing the measurement results from the sensors with those obtained from conventional measuring instruments to determine the accuracy and errors of the sensors. To assess the accuracy and error levels of the water content measurement sensor, various samples were utilized, sourced from Perumda Tirta Taka, Kab. Nunukan. Each sample had its acidity level (pH), water turbidity level, and salinity level measured using conventional parameters such as a pH meter, turbidity meter, and refractometer, respectively. For the distance measurement sensor, a conventional measuring tool, a tape measure, was employed to compare the results obtained from the sensor.

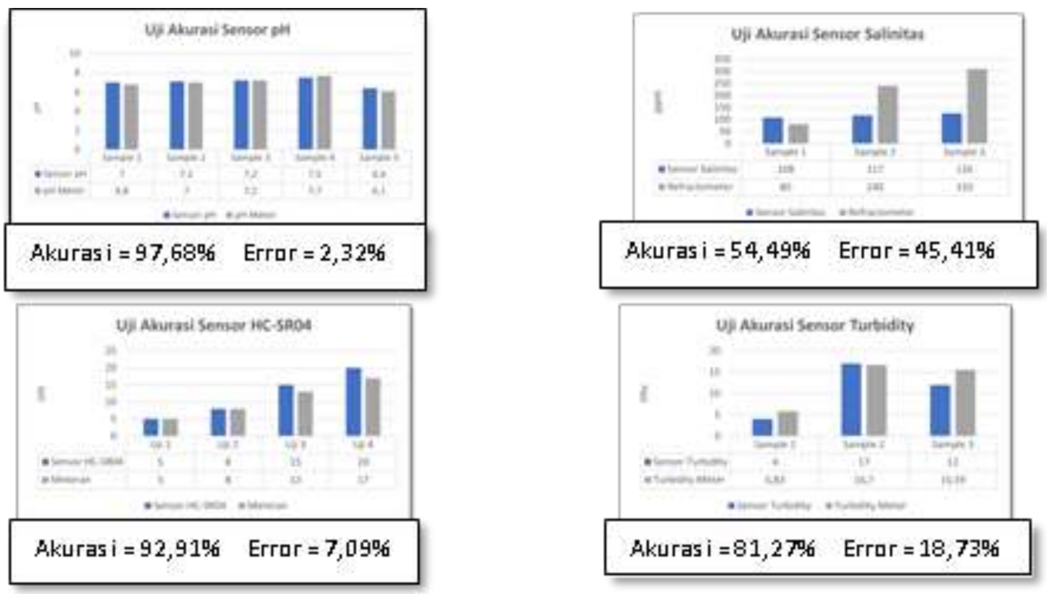

Figure 4. Accuracy and Error Chart of the Used Sensors

b) Operational Testing

Operational testing was conducted to determine whether the system of the device could function according to the plan. The testing of the SUNitds device took place on September 23, 2023. The testing commenced at 13:30 WITA with approximately 70% solar intensity, monitored directly, and energy obtained from the solar panel was recorded at 9.5V 2.99A. The incoming current was directed to the glow plug, regulated at 7.4A, and left for some time. At 14:00 WITA, as the solar intensity decreased to 60%, water began to evaporate, resulting in 9V 2.19A from the solar panel. After allowing time until 16:00, water vapor started to condense into droplets, but solar panel energy began to decline as it was late in the afternoon, registering at 8.4V 1.72A with a solar intensity of about 55%. The experiment was then halted due to the diminishing solar intensity and the depletion of energy from the battery. Observing this, it can be stated that solar intensity significantly influences the water evaporation process in this SUNitds device, necessitating further testing during high solar intensity. The water vapor and droplets produced can be observed in Figures 6 and 7 below.

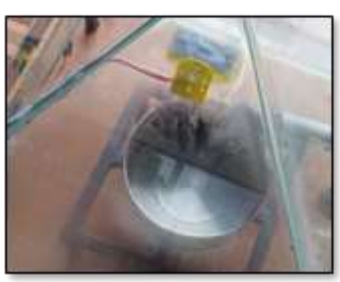

Figure 4.7 Evaporated Water

Figure 4.8 Water droplets produced.

5. Conclusion

Based on the data obtained through all stages of the SUNitds (Solar Energy in IoT Integrated Thermal Distillation System) device research conducted above, it can be concluded that the SUNitds device operates as planned. It can heat water using energy from solar panels, and the implementation of Internet of Things (IoT) technology allows for remote monitoring and control of the device, both automatically and manually. Consequently, it is highly feasible to apply this device as a solution to address the clean water crisis, leveraging technology and renewable energy.

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Conflicts of Interest: The authors declare no conflict of interest.

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