INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN BUSINESS & SOCIAL SCIENCES

Vol 14, Issue 12, (2024) E-ISSN: 2222-6990

Innovative Solar Ablution System: A Green Approach to Water Conservation

Muhammad Nizam Zainal Abidin[1], Khairul Azha A. Aziz[1]

[1]Faculty of Electronic and Computer Engineering and Technology, Universiti Teknikal Malaysia Melaka

Corresponding Author Email: khairulazha@utem.edu.my

To Link this Article: http://dx.doi.org/10.6007/IJARBSS/v14-i12/24410 DOI:10.6007/IJARBSS/v14-i12/24410

Published Date: 28 December 2024

Abstract

The increasing shortage of water, coupled with the need for sustainable solutions, necessitates innovative approaches to resource conservation. This paper presents the development of a portable solar ablution system, designed to reduce water wastage during ablution, a ritual performed five times daily by Muslims. On average, ablution consumes one to seven liters of water per person, contributing significantly to overall water use. Our proposed system integrates infrared sensors and a solenoid valve to control water flow, ensuring water is only dispensed when necessary. Powered by a solar panel and a battery storage system, the device is entirely self-sustaining. Through extensive analysis, the system demonstrated a reduction of water consumption by more than 50% compared to traditional manual taps, while maintaining the required standards for ritual purity. Furthermore, the solar power system successfully charges the battery between prayer times during day-time, ensuring reliable operation even at night. The innovative solar ablution system thus offers a practical, eco-friendly solution that not only preserves water but also promotes sustainability in religious practices. This technology aligns with global efforts to conserve water resources while leveraging renewable energy.

Keywords: Solar-Powered Ablution, Water Conservation, Infrared Sensor Control, Portable Ablution System, Sustainable Technology

Introduction

Water shortage has become a global concern, prompting the development of innovative solutions for water conservation, particularly in religious practices like ablution. One such solution is the use of solar-powered systems, which have proven to be efficient in conserving water. Solar-powered water evaporation systems, which harness solar energy for water desalination, have been widely researched, with studies showing significant improvements in water purification efficiency (Zhao et al., 2020). Biomass-derived materials have also been utilized in solar-driven water purification systems, offering cost-effective solutions for wastewater treatment (Guo et al., 2020). Similarly, smart irrigation systems powered by solar energy have been developed to minimize water wastage in agriculture by controlling water flow based on soil moisture levels (Dhole et al., 2021; Pujara, 2021; Kandhare, 2023; Ravindran et al., 2021).

In the context of ablution practices, rainwater harvesting and smart water taps have been explored to reduce water consumption. Kapli et al. (2023) examined the feasibility of using rainwater for ablution, showing promising results in terms of water savings. Furthermore, the implementation of smart taps for ablution in mosques has demonstrated significant reductions in water usage, with some studies highlighting an 8-fold decrease when following traditional practices (Al Alawi et al., 2023). The application of advanced technologies like automatic water taps and sensor-based systems for ablution also reduces water wastage by up to 50% (Zhang et al., 2022; Fidelis & Idim, 2020).

Research has further highlighted the role of cultural and religious practices in promoting water conservation. Al Alawi et al. (2023) stressed the importance of redesigning ablution facilities in mosques to address the overuse of water. Other studies have explored the potential of integrating sensor-based systems and smart technologies to optimize water distribution in ablution processes, demonstrating significant improvements in water management (Chen et al., 2021; Dao et al., 2020). Overall, these studies indicate that integrating solar-powered systems with innovative water-saving technologies can significantly contribute to sustainable water management in religious practices.

For this project, a portable solar ablution system is designed as an eco-friendly solution to conserve water during the ritual of ablution. The system integrates solar power and smart water-saving technologies, such as infrared sensors, to control water flow, ensuring water is only dispensed when necessary. This approach not only minimizes water wastage but also utilizes renewable energy for a sustainable and efficient ablution process. By promoting the use of solar power, this system aligns with global efforts to reduce water consumption and carbon footprints, contributing to both environmental preservation and energy conservation in religious practices.

Research Background and Motivation

Water scarcity is a growing global concern, particularly in regions where freshwater resources are limited. With the world's population continuing to rise, the demand for water is increasing at an unsustainable rate. According to the United Nations, by 2050, nearly half of the global population will be living in areas experiencing severe water stress. Religious practices, such as ablution performed by Muslims before prayers, contribute significantly to daily water consumption. In many Muslim-majority regions, ablution consumes several liters of water per person per day, exacerbating the pressure on already limited water resources. Traditional ablution practices often lead to water wastage due to the continuous flow of water throughout the ritual.

In response to this challenge, there is a growing need to develop water-efficient solutions that respect religious practices while promoting sustainability. Solar-powered technologies, which harness renewable energy, offer a promising avenue for reducing water consumption and carbon emissions. Current advancements in water-saving technologies, including sensor-based taps and automated systems, have demonstrated the potential to significantly reduce water wastage in ablution without compromising the ritual's requirements.

The portable solar ablution system was conceived with these concerns in mind. This innovative system integrates solar power and water-saving technologies to provide an eco-friendly and efficient solution for ablution, particularly in areas with limited access to water and electricity. By incorporating solar energy, the system not only conserves water but also promotes the use of renewable resources, aligning with global sustainability goals. The motivation behind this research is to address the pressing issue of water conservation while respecting cultural and religious practices, ultimately contributing to a more sustainable future.

Methodology

To successfully develop the portable solar ablution system, an interdisciplinary approach incorporating both hardware and software design is recommended, leveraging the methods and technologies outlined in prior studies. The system's core components should include solar panels for energy generation, a rechargeable battery for energy storage, infrared sensors to detect user presence, a solenoid valve to regulate water flow, and a microcontroller for overall system management (Dhole et al., 2021; Deogade et al., 2021).

The first step involves designing the photovoltaic (PV) system to harness solar energy. Solar panels are positioned optimally to capture sunlight, which is then converted into electrical energy. This setup powers the entire system during the day and stores energy in a rechargeable battery for nighttime or cloudy conditions. A charge controller regulates the flow of energy to the battery, ensuring consistent performance and preventing overcharging or depletion, as demonstrated in previous solar-powered systems (Yatnalli et al., 2022; Guo et al., 2020). The energy stored in the battery allows the system to operate continuously, ensuring reliable functionality even when solar power is not immediately available (Kathiresan et al., 2023).

Next, an infrared sensor system is installed to detect user presence. When a user approaches the system, the sensors trigger a 12V solenoid valve to release water for ablution. This automated water flow control ensures that water is dispensed only when necessary, reducing wastage, as noted in prior research on sensor-based irrigation and water-saving systems (Ramani et al., 2020; Naik, 2021). The integration of these sensors is crucial for achieving high water efficiency, a feature widely used in other sustainable water management systems (Dhole et al., 2021).

A microcontroller, such as an PIC microcontroller or Arduino, is programmed to manage the operation of the sensors, solenoid valve, and energy monitoring systems. The microcontroller ensures that the system operates efficiently by controlling water flow based on sensor input and managing energy use from the solar panels and battery. Additionally, the microcontroller is programmed to send real-time feedback to a user interface, allowing for remote monitoring and control via a mobile app or web interface (Lakshmi et al., 2023). The use of microcontrollers to manage sensor data and automate water systems is well-established in agricultural and environmental technologies (Sarwar & Iqbal, 2022).

Once the system is assembled, initial testing is conducted to ensure that all components function correctly, including the solar panels, battery, sensors, solenoid valve, and microcontroller. The sensors and system are tested to ensure accurate detection of user presence, and adjustments are made to the valve's response times to optimize water conservation. Previous studies have shown that sensor calibration and testing is essential for maintaining system efficiency and reliability (Chandel et al., 2022). The system also undergoes continuous testing to ensure it operates reliably under various conditions.

The whole system block diagram is shown in Figure 1. The hardware design is structured into three main sections: sensor selection, actuator selection, and solar system components, along with hardware construction. A digital infrared (IR) sensor is employed to detect the presence of the user’s hands. For the actuator, a 12V solenoid valve has been selected, and the control system is managed by a PIC microcontroller.

The solar system is comprised of three key components: the solar panel, charge controller, and battery. The solar panel used in this design is a 17V panel, paired with a 12V, 10A charge controller to regulate the charging process. For energy storage, a 12V lead-acid battery is utilized to ensure reliable power supply during periods when sunlight is unavailable.

The critical focus of the hardware design is the integration of the IR sensor as an input to the PIC microcontroller. This connection enables the system to regulate water flow through the solenoid valve by detecting hand presence via the IR sensor. When a user’s hands are detected, the valve opens, allowing water to flow. As for the controller, PIC16F877 was used with the integration with relay circuit to control the valve. The successful construction of this design is exemplified in the prototype of the portable ablution system, as illustrated in Figure 2. The AutoCAD design for the prototype can be seen in Figure 3 and the whole system circuit connection shown in Figure 4.

This design ensures efficient water usage and energy sustainability, aligning with the project’s goal of creating a portable, solar-powered ablution system.

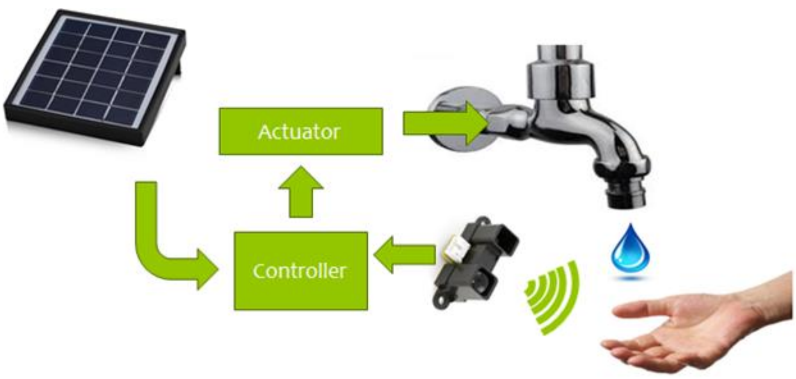

Figure 1: System Block Diagram

Figure 2: Portable Ablution System Prototype

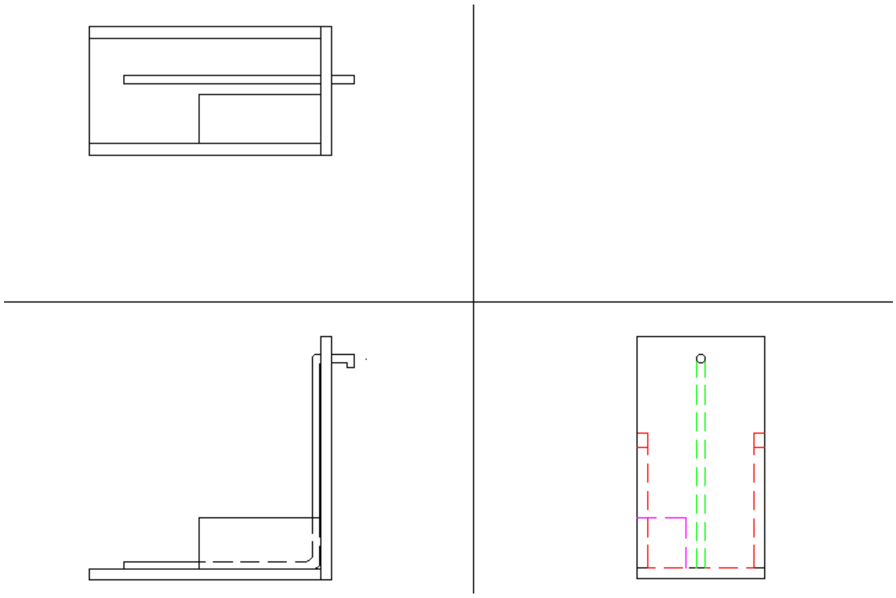

Figure 3: Prototype design using AutoCAD

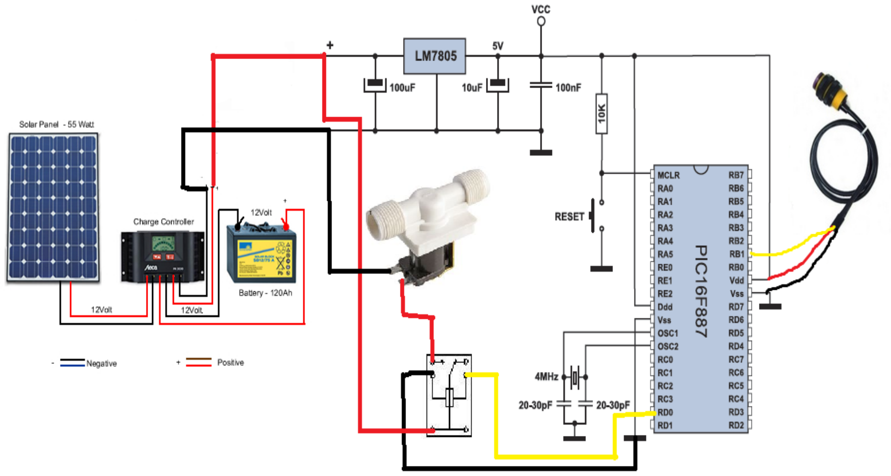

Figure 4: System Circuit Connection

Results and Discussions

Battery Charging Analysis

The Battery Charging Analysis was conducted to assess the efficiency of the solar-powered charging system for the portable ablution machine. The analysis focused on three time intervals during daylight: 8 AM to 11 AM, 11 AM to 1 PM, and 2:30 PM to 4 PM. The primary goal was to determine whether the solar system could recharge the battery fully between the daily prayer intervals, ensuring continuous availability for users.

The data collected revealed a progressive increase in charging voltage during each time slot, indicating that the battery charges effectively as solar radiation intensifies throughout the day. From 8 AM to 11 AM, the voltage steadily rose from 10.08V to 12.26V, showing a significant charge accumulation as in Figure 5. Similarly, during the 11 AM to 1 PM period, the voltage increased from 11.26V to 12.14V as shown in Figure 6, and in the final time slot of 2:30 PM to 4 PM, the voltage rose from 11.79V to 12.21V as can be seen in Figure 7. These results clearly demonstrate that the solar system efficiently harnesses sunlight during different parts of the day, with adequate voltage increases to ensure battery recharging.

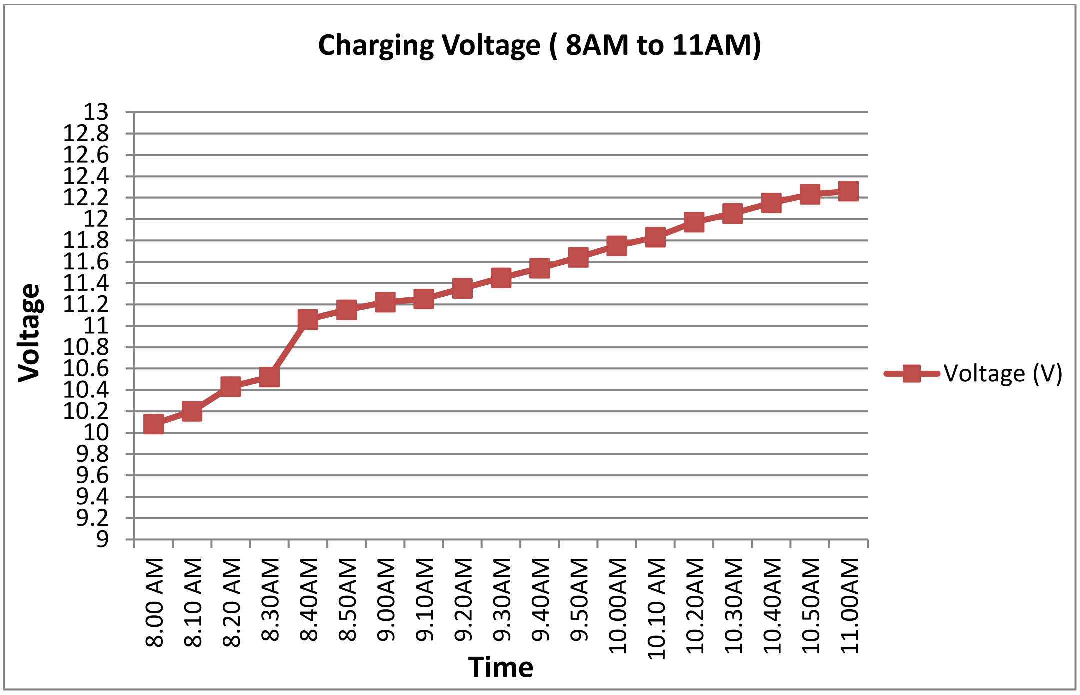

Figure 5: Charging voltage for 8AM to 11AM

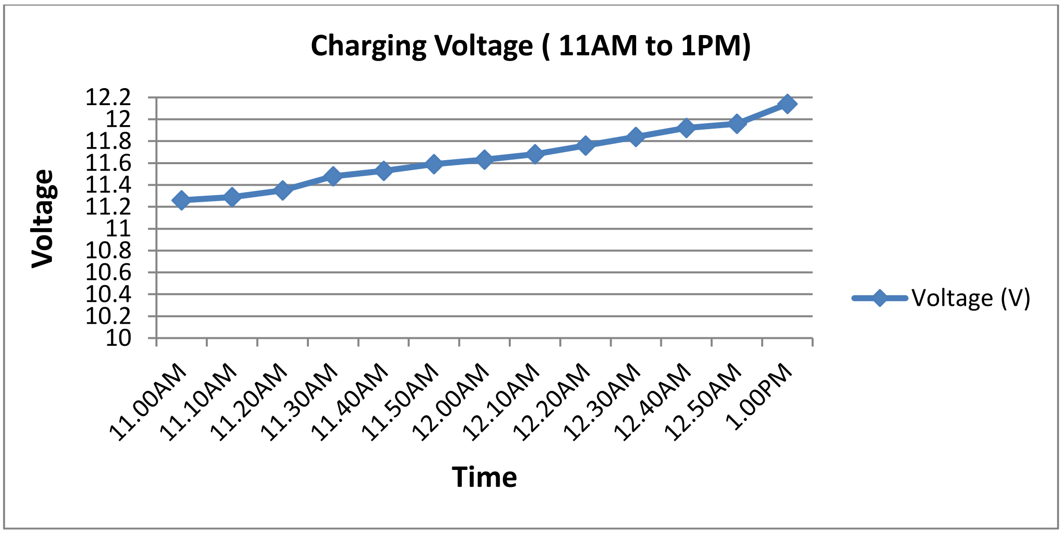

Figure 6: Charging voltage for 11AM to 1PM

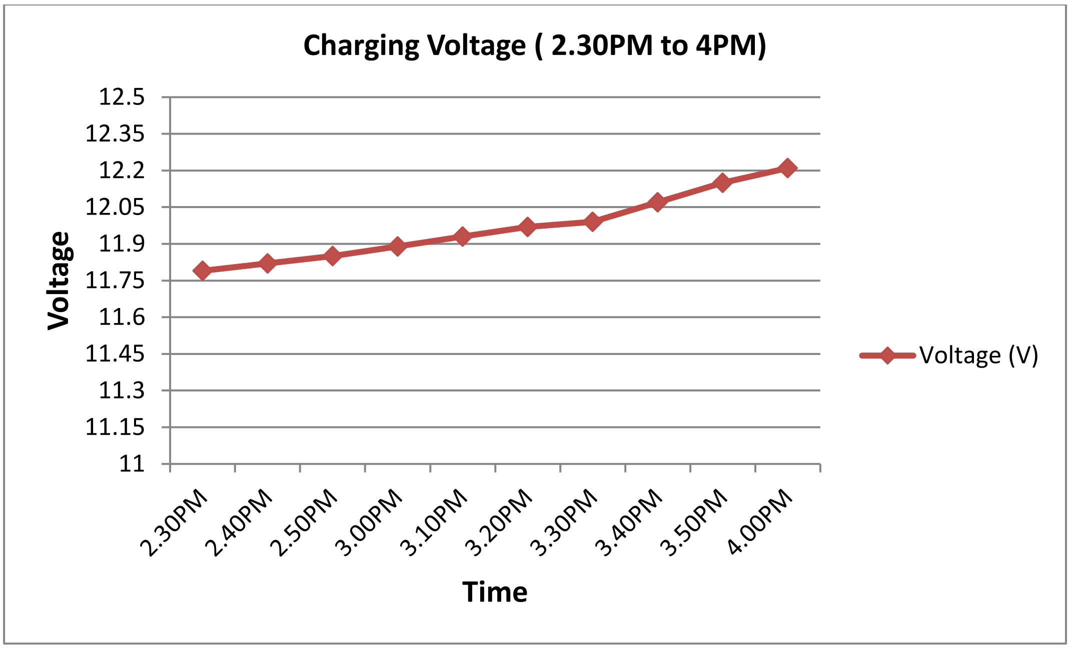

Figure 7: Charging voltage for 2.30PM to 4PM

It is notable that the system's charging capability was sufficient to replenish the battery between prayer times. This is critical for the system's operational sustainability, particularly during periods of high usage in the daytime. The results confirm that the solar panels are capable of generating enough power even in the shorter afternoon periods, such as 2:30 PM to 4 PM, which is essential for meeting energy demands at night when recharging is not possible.

Overall, the analysis supports the conclusion that the solar-powered system can maintain continuous operation of the ablution machine throughout the day. It provides a reliable energy source without requiring grid electricity, aligning with the project's objective to promote sustainability through the use of renewable energy.

Water Consumption Analysis

The water consumption analysis was conducted to evaluate the efficiency of the portable ablution system in comparison to a conventional manual tap system. The study involved 10 participants performing ablution at three different speeds: fast (22 seconds), medium (44 seconds), and slow (90 seconds). The aim was to determine how much water could be saved using the automated system across five daily prayers.

The results reveal a significant reduction in water usage when using the automatic system compared to the manual taps as in Figure 8. In the fast-speed category, the automatic system consumed 4.02 liters on average, compared to 5.02 liters with the manual system by 1 liter saving. In the medium-speed category, the automatic system used 7.77 liters, compared to 13.56 liters for the manual system with 5.79 liters saving. The most pronounced difference was observed in the slow-speed category, where the automatic system consumed 8.88 liters, while the manual system consumed 16.89 liters with 8.01 liters saving.

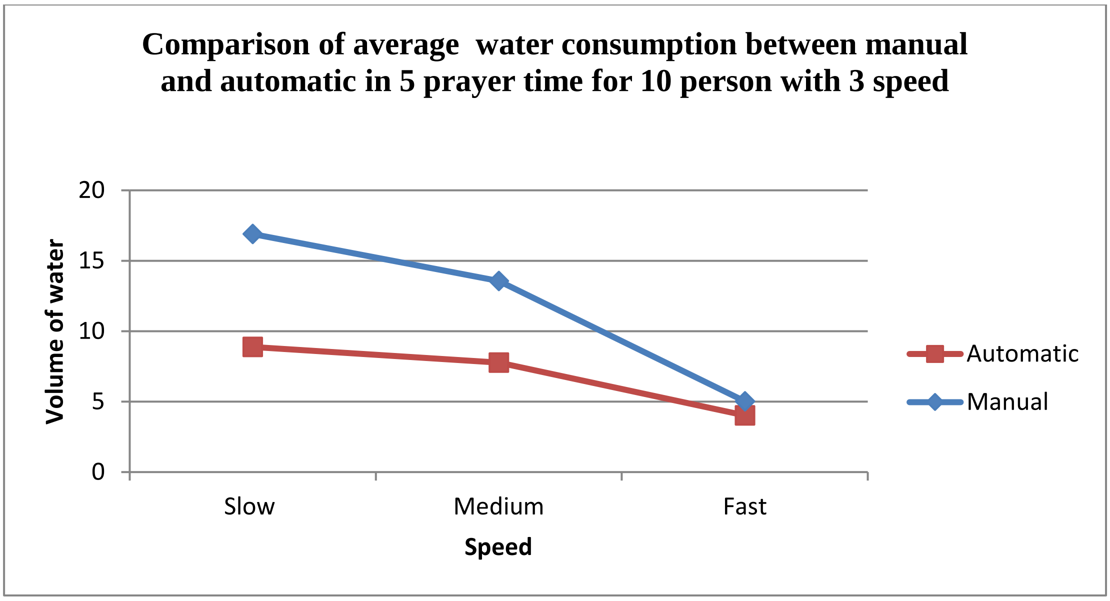

Figure 8: Comparison of average water consumption between manual and automatic in 5 prayer time for 10 persons with 3 speeds

The total water consumption for five prayer times across the 10 participants, shown in Figure 9. For slow speed ablution, the total water consumption with the manual system was 168.95 liters, while the automatic system only used 88.80 liters. Similarly, at medium speed, the manual system consumed 135.64 liters, compared to 77.8 liters for the automatic system. In the fast-speed category, the manual system consumed 50.3 liters, while the automatic system used only 40.24 liters. Total water saving were 80.15 liters for slow speed, 57.84 liters for medium speed and 10.06 liters for fast speed.

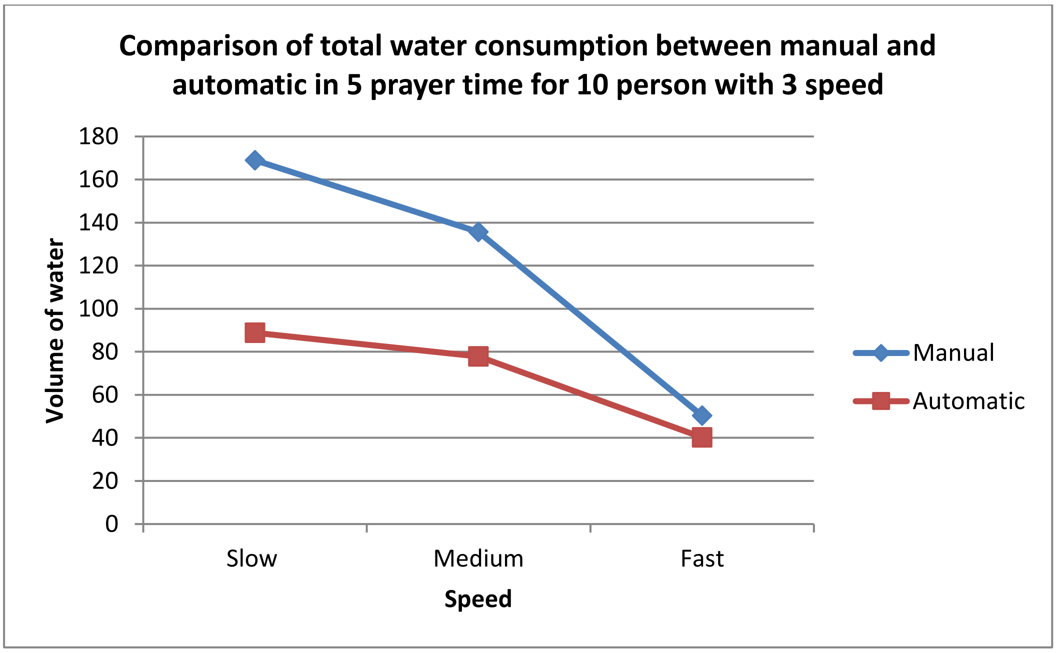

Figure 9: Comparison of total water consumption between manual and automatic in 5 prayer time for 10 persons with 3 speeds

These results clearly demonstrate the water-saving potential of the automatic ablution system, particularly at slower ablution speeds where the water savings are most significant.

The system reduces water consumption by nearly half compared to manual taps, with the most substantial savings observed during slower, more deliberate ablution practices. This aligns with the system's objective of promoting sustainability by minimizing water wastage in religious practices.

Conclusion and Future Work

In conclusion, the development of the portable solar ablution system has demonstrated significant improvements in water conservation and energy sustainability. The system effectively utilizes solar energy to recharge its battery between prayer times during day-time, ensuring continuous operation, even during night-time usage. The integration of an automatic water flow control mechanism, driven by infrared sensors and a solenoid valve, has proven to reduce water consumption by nearly half when compared to conventional manual taps. This system aligns with global sustainability efforts by promoting efficient water usage and leveraging renewable energy sources.

For future work, the system could be further enhanced by incorporating an IoT-based microcontroller such as Nodemcu and ESP32, which would allow for remote monitoring and control of the ablution system. This would enable real-time tracking of energy usage, water consumption, and system performance using PC or mobile based system. Additionally, the implementation of a user interface that provides real-time information on battery status, water flow, and system health would enhance user experience and system manageability. Such improvements would not only increase the system’s efficiency but also provide valuable data for optimizing performance and ensuring long-term sustainability. These advancements would further align the system with modern technological trends and elevate its utility in various contexts.

Acknowledgement

The authors would like to thank Fakulti Teknologi dan Kejuruteraan Elektronik dan Komputer, Universiti Teknikal Malaysia Melaka for providing the facilities to do the experimental analysis and work towards completing this research paper.

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