Original Article

Design and development of a sustainable and affordable water and electricity monitoring system through internet of things technology

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ABSTRACT

Unmonitored water and electricity consumption and leaks in households and establishments are considered safety hazards, can cause potential damage to properties, and incur high incidental costs. Current interventions are costly to maintain, manually operated, difficult to monitor, inconsistent in performance, and are not integrated into a single system. To overcome these gaps, this paper presents the design, development, and testing of an Internet of Things-based monitoring system that can accurately detect water and electricity consumption and leaks in a real-time manner. The proposed solution features the use of Arduino Mega 2560 and ESP8266 microcontroller units, non-invasive current sensors, YF-S201C water flow sensors, and an alternative transfer switch, and is implemented through a scaled prototyping approach. Hypotheses and technical testing results proved that there were no significant differences in the functional correctness of detecting electricity consumption in sampled lecture and laboratory rooms and the water consumption in sampled comfort rooms. Additionally, the system features a real-time mobile application that alerts users of detected water and electricity leaks in the lecture, laboratory, men's, and women's comfort rooms, thereby providing an extra layer of safety and reliability. The system is perceived to be beneficial to households, businesses, and public and private entities as a cost-effective and reliable solution in managing their water and electricity consumption and leaks. Furthermore, the outcomes are expected to contribute to the United Nations' Sustainable Development Goals (SDG) on affordable and clean energy (SDG 7); and responsible consumption and production (SDG 12).

Keywords: electricity monitoring, energy management system, internet of things, water monitoring

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INTRODUCTION

Water and electricity leaks are common problems for many households and establishments. These are considered safety hazards and, when undetected, may result in structural damage and significant costs (Hassan and Jasim 2021; Padillo et al. 2022). These issues can be attributed to various root causes, such as, aging or corroded distribution systems (Hussein et al. 2023), limited and unskilled manpower to do the monitoring (Magwilang et al. 2023), faulty tools and equipment (Che et al. 2021) inefficient monitoring systems (Wasoontarajaroen et al. 2017) manually-operated machines and protocols (Hassan and Jassim 2021; Che et al. 2021; Marathe et al. 2021) limited data storage (Shi et al. 2019); among others.

Several technological solutions have been developed to monitor water consumption and leakage. For instance, Che et al. (2021) implemented an Arduino microcontroller-based turbidity, water flow, and water sensor system. Despite the robustness of the three-sensor approach, they encountered issues with stable internet connection and power sources, and the sensitivity of the turbidity sensor. In another study by Marathe et al. (2021), they built an internet-connected system consisting of a node microcontroller unit (MCU), a water flow sensor, and the ThingSpeak app. While their system can detect water leakage in pipes, approximate the location, and send an alert message to the user, the dependence on proprietary software, such as Google Maps, remains unreliable within the premises of a house or establishment. In another study by Gautam et al. (2020), they used IoT through Arduino Uno, an ultrasonic sensor, and an Espressif Systems (ESP) module. Overall, their system features accurate and real-time monitoring. While their use of support vector machine for a 25-day dataset is somewhat interesting, it would have been more accurate if they utilized more datasets using artificial neural networks.

Meanwhile, Hassan and Jassim (2021) developed an internet-driven electrical energy consumption monitoring system and implemented it through a node MCU, wireless sensor network, and a free-global domain-based webpage. While their system features the detection of electrical shocks, lightning, and monitoring of electrical energy consumption, the use of an excessively high sampling rate significantly affects data storage and processing performance. Likewise, the use of free website hosting services poses potential data privacy risks. In another study by Wasoontaajoen et al. (2017), they developed an internet-driven system to manage the electrical consumption in a building through PZEM-004T electrical energy sensors, Arduino Nano Mini, and ESP8266 WiFi modules. While their system can collect electrical energy consumption for a maximum of one week, the app has no proactive feature of alerting the user to take specific actions to save electrical energy consumption in a particular time of the day, e.g., lunch time, as shown on their analytics.

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Moreover, there are several technologies that were patented with the main intent of monitoring water and electricity consumption and leaks. For example, an AI-based smart meter for water utilization and quality monitoring using IoT by Nataraj et al. (2022), a water leakage and detection device and method for the joint of cable tunnel and basement by Zheng et al. (2022), a highly flexible electrical distribution grid energy manager and router by Eckhardt and Watts (2025), and an electrical power distribution monitoring system and method by Kanoi et al. (1995). Overall, these patented technologies are functional, unique, and efficient. However, there are still areas for further improvement, such as consistency of measurements, cost-effective development and maintenance, reliability of sensing devices, and simplification of monitoring systems.

In this study, the authors ultimately aimed to achieve the following specific objectives:

1. Design a system with the following features:
    a. A cyber-physical system based on the Internet of Things (IoT) architecture.
    b. Accurate and real-time monitoring of water and electricity consumption and detection of leakage data with a proactive notification system through a mobile application.
2. Develop a miniature model of the system using locally available materials through a scaled, prototyping approach.
3. Test the functional correctness and timeliness performance of the system based on the following null hypotheses (H_0):
    a. H_{01} = There is no significant difference in the functional correctness of the system in detecting electricity consumption in lecture and laboratory rooms.
    b. H_{02} = There is no significant difference in the functional correctness of the system in detecting water consumption in men's and women's comfort rooms.
    c. H_{03} = There is no significant difference in the timeliness of the system in notifying the user of detected water and electricity leaks in the lecture, laboratory, men's, and women's comfort rooms.

METHODS

System Designs

Figure 1 shows the block diagram of the proposed system. It is composed of various input, control, and output modules. The input modules (sensing layer) are composed of 4 pieces of YF-S201C water flow sensors, connected to 4 sets of 2-wire probes to detect water leakage, and 2 pieces of non-invasive current sensors to detect energy flow. These inputs are connected to the Arduino Mega 2560, the main microcontroller unit (data processing layer), which controls all system processes. The MCU receives and transmits data to the output module, i.e.,

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mobile application (application layer), through the ESP866 WiFi module and TP-Link router (network layer). All data is maintained through a Blynk cloud database (data processing layer), and the overall operation of the system is managed through an IoT architecture, which facilitates seamless integration of various sensing, processing, network, and application layers via the internet. Lastly, to ensure an optimal power source, the system is controlled by an automatic transfer switch, which shifts between the mainline electricity and battery sources in case of power failure.

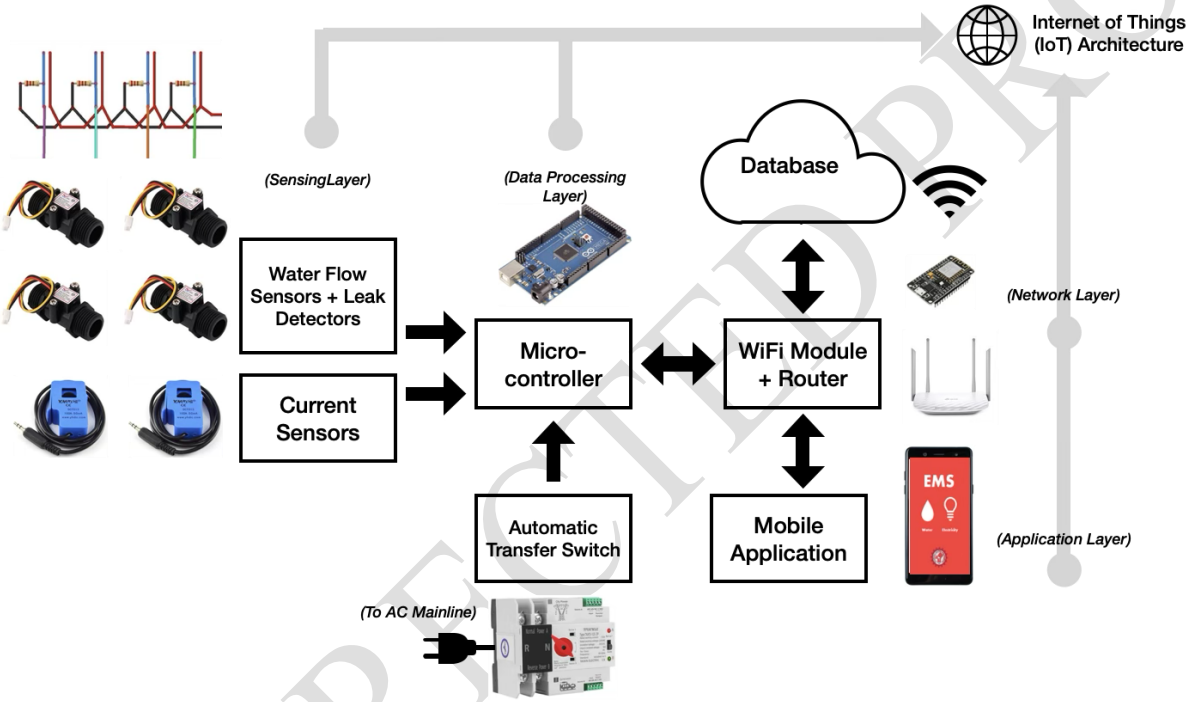


Figure 1. The system's conceptual model is composed of various inputs, controls, and output modules, which are further clustered into sensing, data processing, network, and application layers of the IoT architecture.

Meanwhile, Figure 2 shows the methodological framework of the system. Within this framework is the conceptual model (Figure 1) composed of various components that make up the sensing, processing, network, and application layers of the IoT architecture. Next is the design of the electronic circuit of the proposed system using Fritzing (Figure 3) and the miniature model using SketchUp. Figures 4, 5, 6, and 7 illustrate the isometric view, top view, bottom view, and control room view of the miniature model, respectively.

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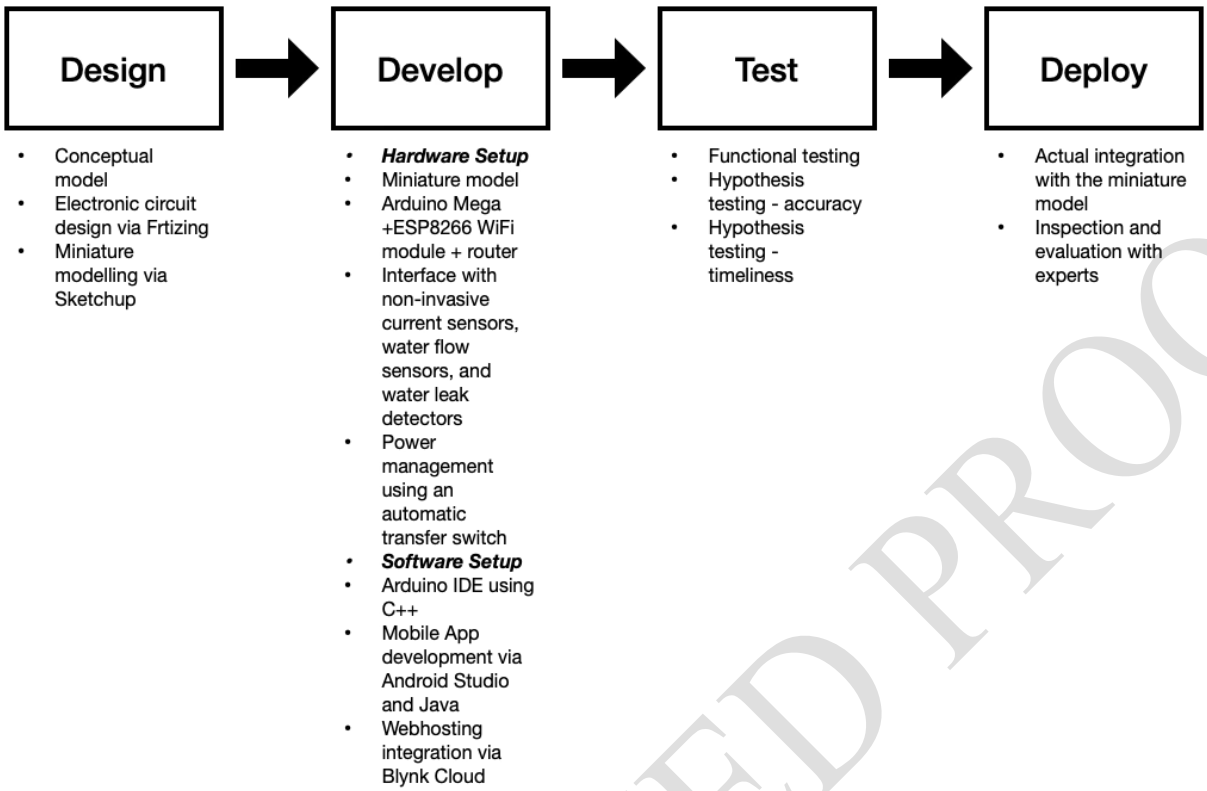


Figure 2. Methodological framework of the study.

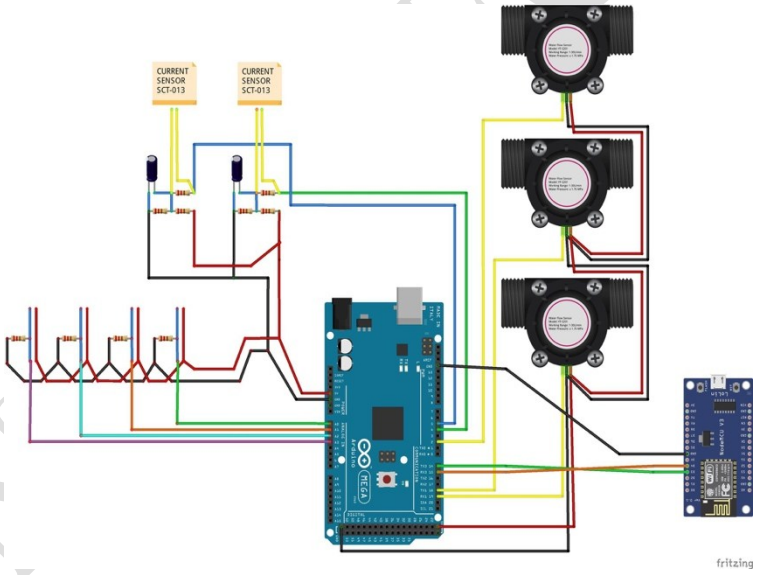


Figure 3. The system's component diagram showing the interface of the input and output modules.

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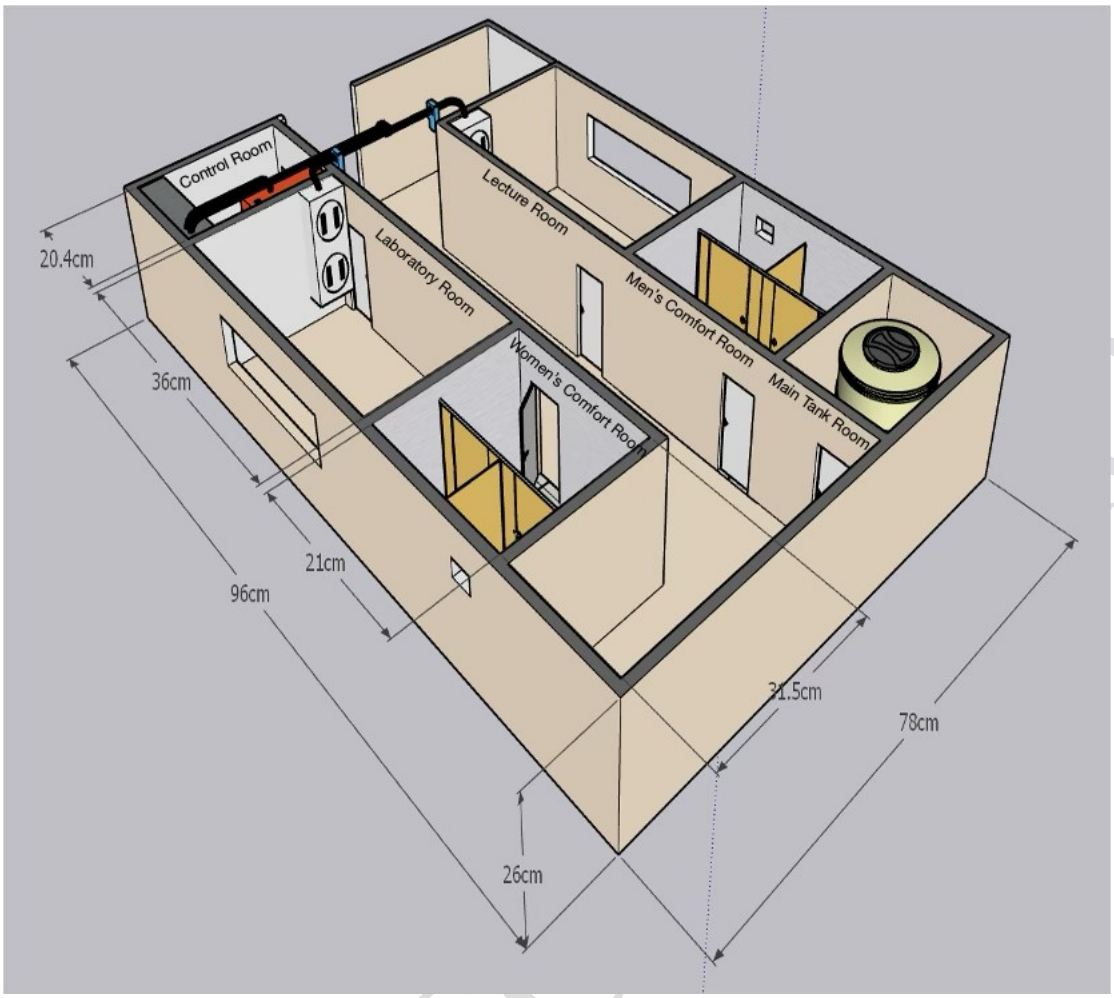


Figure 4. Isometric view of the miniature model showing the dimensions and different rooms.

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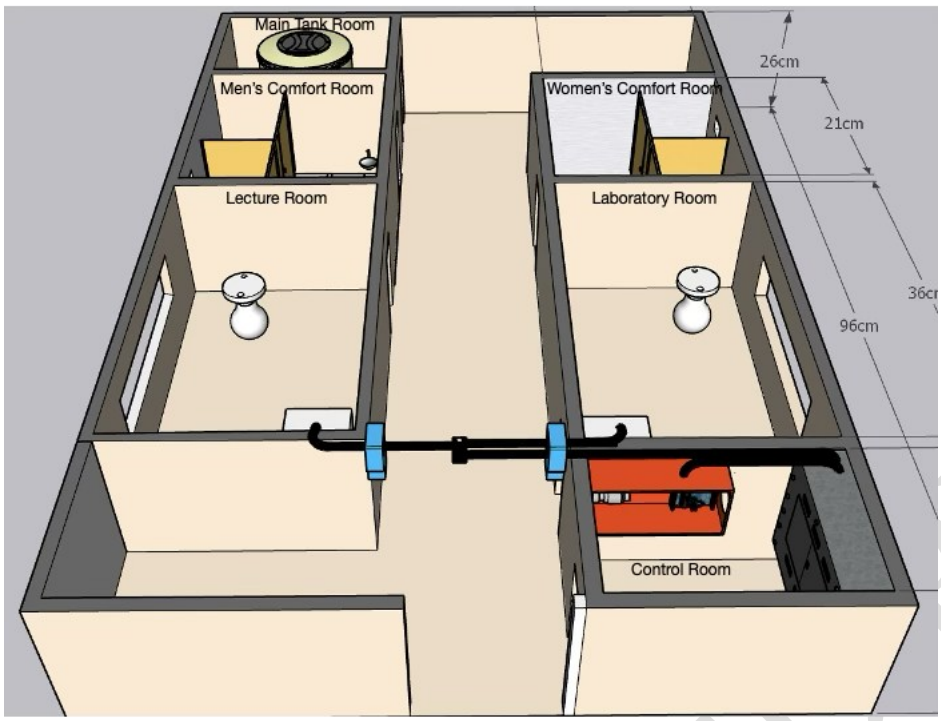


Figure 5. Top view of the miniature model showing the dimensions and different rooms.

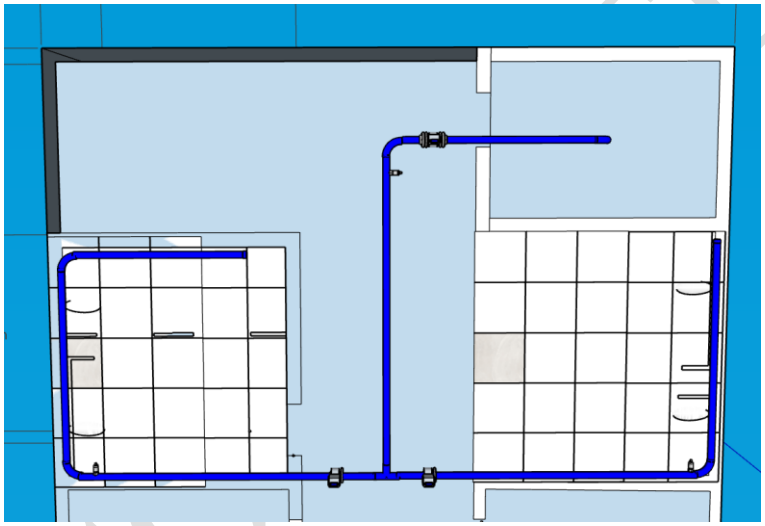


Figure 6. Bottom view of the miniature model showing the interconnection of water pipelines.

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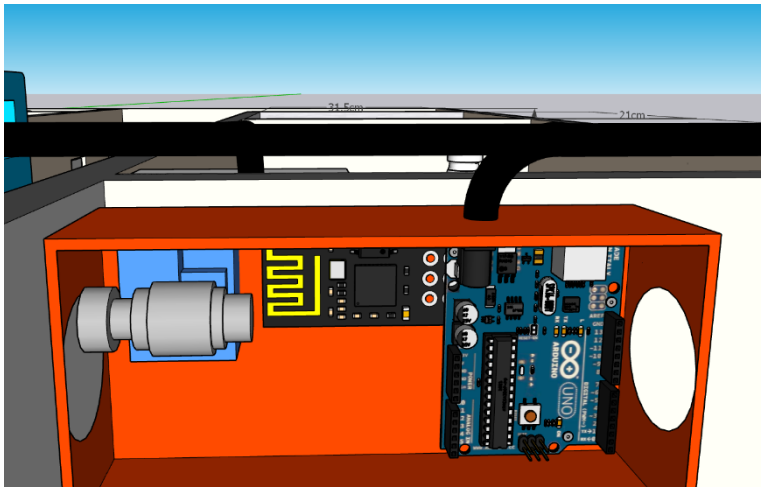


Figure 7. Control room view of the prototype.

Next, the actual miniature model using marine plywood materials was developed. It has the dimensions of 96 cm × 78 cm × 26 cm and is divided into sections representing the control room, lecture room, laboratory room, men's comfort room, women's comfort room, and the main tank room.

Then, the various sensing, processing, and network components were integrated into the Arduino Mega 2560 microcontroller unit using the Arduino Integrated Development Environment (IDE) application and the C++ programming language. First, 4 YF-S201C water flow sensors were installed, two in each comfort room, to measure the volumetric flow rate of water based on the Hall-effect turbine mechanism. Each sensor produces clock pulses proportional to the flow rate of water, which is then further processed by the Arduino Mega 2560 to determine the instantaneous and total water usage. This sensor type was used due to its affordability, reliability, and interoperability with digital systems. Alongside the water flow sensors, the authors used four pairs of wire probes functioning as water leak sensors, and installed two in each comfort room. The detectors operate based on the principle of electrical conductivity due to the presence of water, which generates a low-voltage signal. These detectors are low-cost, simple to set up, and have a quick response time, which makes them ideal for continuous monitoring of water leakage.

Afterward, two non-invasive current sensors were incorporated, one for each lecture and laboratory room, to measure electricity consumption through electromagnetic induction. These sensors are capable of detecting electrical usage in a real-time manner and can detect abnormal operating conditions, making them reliable and accurate sensors for monitoring purposes.

For the communication layers, the Arduino Mega 2560 was interfaced with the ESP8266 WiFi module via Universal Asynchronous Receiver/Transmitter (UART) and programmed using the Arduino IDE.

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Operationally, the Arduino Mega 2560 reads data from the water sensors, leak detectors, and current sensors, then sends this data to the ESP8266 via UART. Then, the ESP8266 WiFi module connects to the TP-Link Archer C50 model router, operating at the 2.4 GHz band, which provides internet access to the Blynk Cloud IoT platform for persistent, real-time data communication. The ESP8266 WiFi module obtains an IP address from the router through the Dynamic Host Configuration Protocol (DHCP) to transmit sensor data. Moreover, the authors used the Blynk Cloud IoT platform to deploy the system's cloud-based visualization dashboard, remote access, and system control, while local data logging and analysis were implemented using XAMPP with PHP and MySQL for back-end management. The Blynk Cloud was chosen for its low-latency data synchronization, scalability, and interoperability.

Furthermore, the mobile app was developed using Android Studio and the Java programming language. The Android-based app provides the user with real-time sensor data and notification alerts. The mobile app is intuitive and has seamless integration with the Blynk Cloud IoT platform, thereby enhancing user awareness and responsiveness to abnormal operating conditions of the system. Contextually, the mobile application was designed such that, initially, the user has to proceed to the login interface. If the credentials are correct, the system shall proceed with reading of the sensors' data, i.e., water flow and current, and then display it through the mobile app. Meanwhile, if the power rating is greater than 100 watts and/or the water flow pressure is less than 71.3 psi, the mobile application alerts the user to make necessary interventions on the detected leakage.

Overall, the proposed system utilized various sensors, network components, a microcontroller unit, and software components to simulate the real-time measurement, processing, and transmission of physical and environmental parameters. The extent of using each hardware and software component is grounded on the principles of suitability, cost-effectiveness, interoperability, and sustainability for IoT architecture.

Testing and Deployment

As for the testing procedure, certain tests were designed in order to scientifically answer the hypotheses of the study (Table 1).

Table 1. Testing design.

Approach	Hypotheses-based Technical Testing
Null Hypotheses (H_0)	H_{01} = There is no significant difference in the functional correctness of the system in detecting electricity consumption in lecture and laboratory rooms. H_{02} = There is no significant difference in the functional correctness of the system in detecting water consumption in men's and women's comfort rooms. H_{03} = There is no significant difference in the timeliness of the system in notifying the user of detected water and electricity leaks in the lecture, laboratory, men's and women's comfort rooms.

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Level of Significance	95% confidence level, 5% error
Sample Distribution	Two-tailed
Sample Size	10 test cases for each group
Statistical Methods	Independent T-test (H_{01} and H_{02}); Analysis of Variance (ANOVA) (H_{03})
Statistical Analysis	If $P < 0.025$, reject the H_0

This study aimed to establish that the system is consistently accurate and real-time in detecting water consumption or leaks in men's and women's comfort rooms, and electricity consumption or leaks in lecture and laboratory rooms. Hence, the authors proposed the following hypotheses:

- H_{01} = There is no significant difference in the functional correctness of the system in detecting electricity consumption in lecture and laboratory rooms.
- H_{02} = There is no significant difference in the functional correctness of the system in detecting water consumption in men's and women's comfort rooms.
- H_{03} = There is no significant difference in the timeliness of the system in notifying the user of detected water and electricity leaks in the lecture, laboratory, men's, and women's comfort rooms.

As for the H_{01}, the power consumption was recovered, measured in Watts (W), of 2 identical 5mm LED night lamps installed in both lecture and laboratory rooms. Here, the data were recorded based on a sampling of ten (10) test cases per hour interval.

Meanwhile, for H_{02}, the water consumption was also recorded, measured in liters per second (l/m), of two identical water flow sensors installed in both lecture and laboratory rooms. Here, the data were recorded based on ten test cases with 30-minute intervals for each observation.

Then for the H_{03}, the time was also recorded on how fast the system sends notifications, measured in seconds, in case of detected water and electricity leaks in the simulated rooms. The observation time is within an hour with sample ten test cases.

The null hypotheses were tested using the Independent Samples T-test (H_{01} and H_{02}) and Analysis of Variance (ANOVA) (H_{03}) based on a 95% confidence level and 5% error. The analysis was done through a two-tailed approach, with ten test cases for each group. As such, if the computed significance level (P) is less than 0.025, the authors would then reject the null hypothesis.

RESULTS

Actual Prototype and Mobile Application

This study aimed to design, develop, and test a water and electricity monitoring system using the IoT architecture. The following figures and tables show the actual results of various activities to achieve the pre-

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defined objectives. Figure 8 illustrates the actual picture of the miniaturized system. It is composed of (1) control room, which houses the main circuitry of the Arduino Mega, the ESP8266 WiFi module, and the automatic transfer switch. This section controls all the processes of the system. It also has (2) laboratory room and (3) lecture room, which both have 220VAC outlets and light bulbs. Both rooms have built-in non-invasive current sensors to detect power consumption and leakage. It also has comfort rooms for (5) women and (6) men, which both have PVC tubes and water flow sensors to detect water consumption and leaks. Lastly, the system has a (7) main tank room, which houses a mini tank that serves as a reservoir for water supply to the comfort rooms.

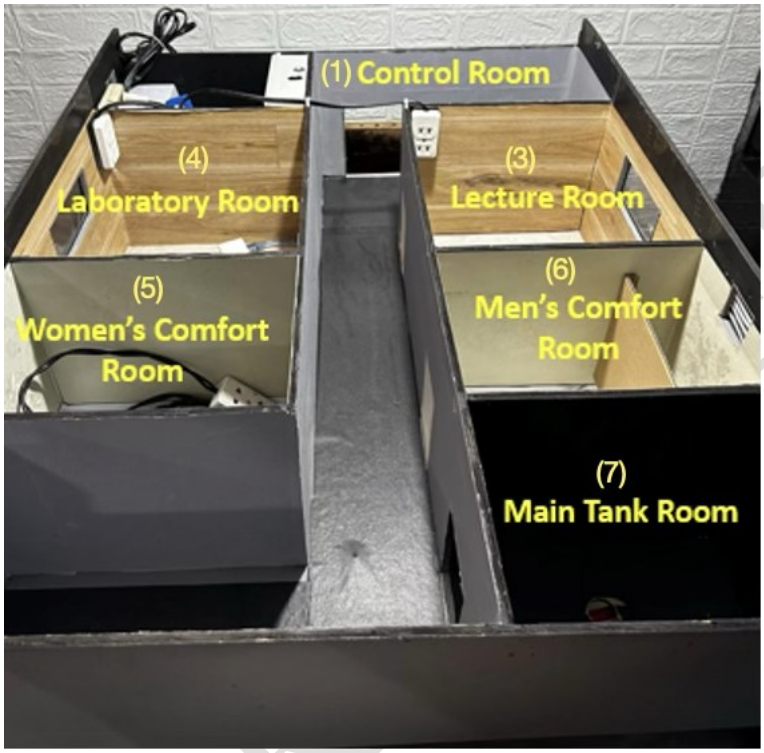


Figure 8. Actual picture of the system's miniature model with different rooms.

Figures 9A, 9B, 10A, and 10B show the actual pictures of the ESP8266 WiFi module and Arduino Mega microcontroller, water flow sensors, non-invasive current sensors, and automatic transfer switch, respectively. Meanwhile, Figures 11A - 11D show the actual pictures taken during the design and development phases, the actual miniature model of the prototype, verification of the data logs, and the actual testing activity, respectively.

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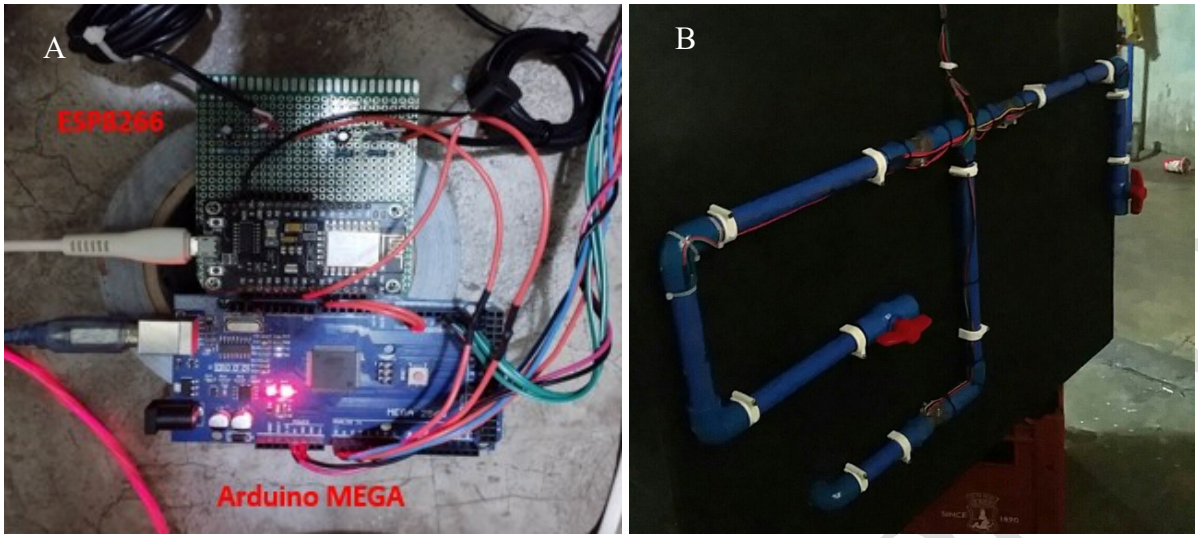


Figure 9. Actual pictures of the (A) ESP8266 WiFi module and Arduino Mega microcontroller, and (B) water flow sensors embedded in the pipelines.

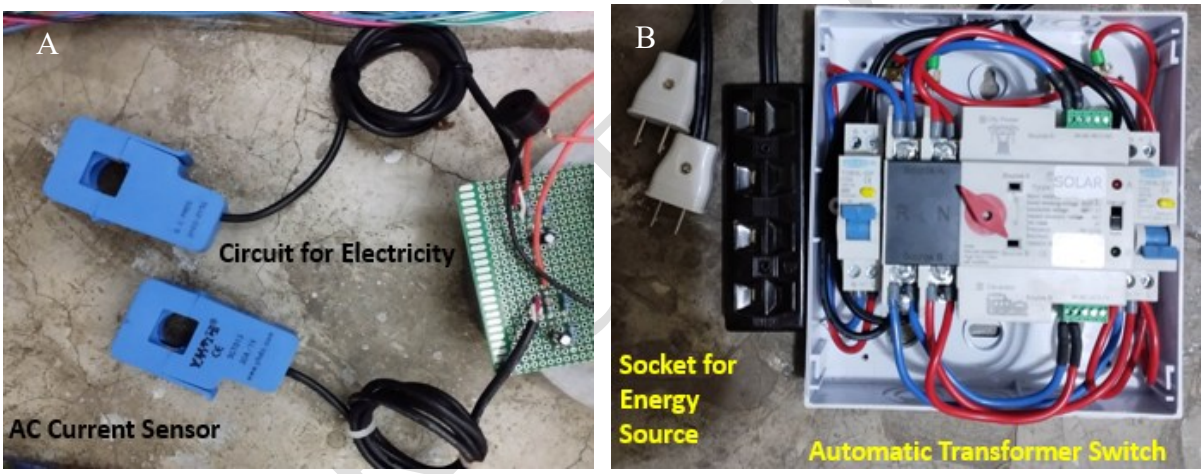


Figure 10. Actual picture of the (A) non-invasive current sensors, and (B) automatic transfer switch

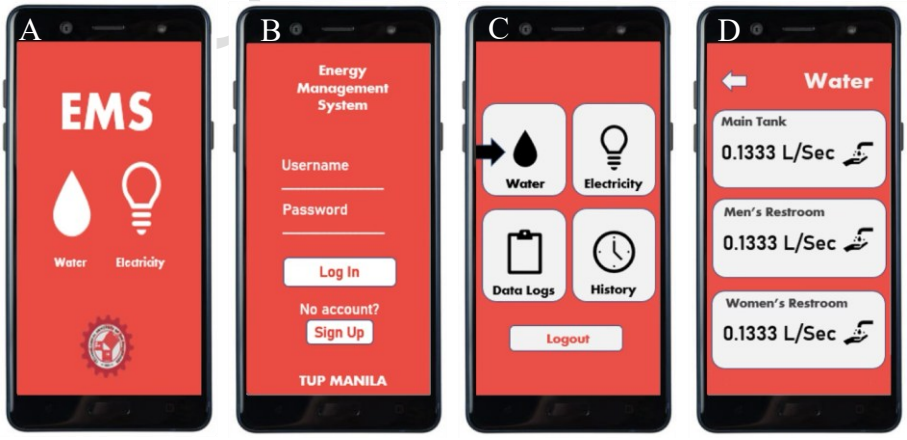
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Figure 11. Some actual pictures taken during the design and development phase (A), prototype miniature mode (B), checking of data logs (C), and testing activity (D).

Furthermore, Figures 12A - 12D show screenshots of the graphical user interface (GUI) of the mobile app's home screen, login page, water monitoring menu, and real-time water flow data, respectively. Then, Figures 13A - 13D show the GUIs of the electricity monitoring menu, real-time electricity consumption data, warning notification on water leakage, and the detected water leakage location or room, respectively. Lastly, Figures 14A - 14D show the GUIs of the mobile app in terms of warning notification on water leakage, detected electricity leakage location or room, data logs main menu, and data logs location, and overall history of defects or leakage detected, respectively.



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Figure 12. Graphical user interface screenshots of the mobile application's (A) home screen, (B) login page, (C) water monitoring menu, and (D) real-time water flow data.

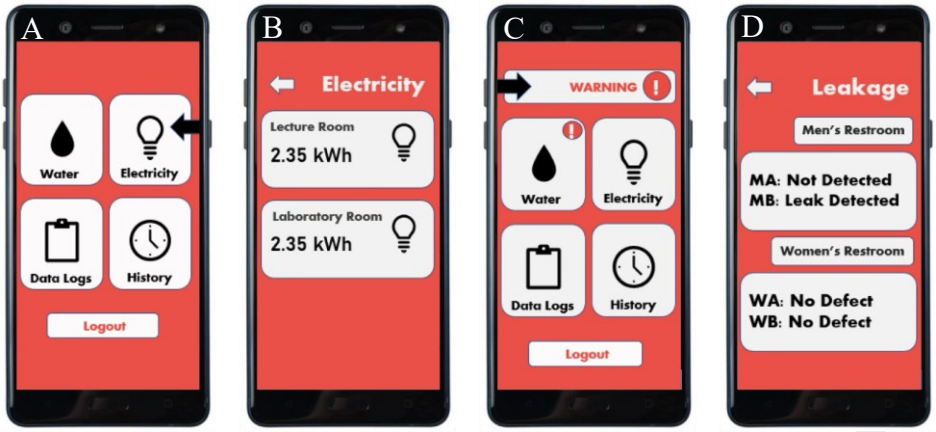


Figure 13. Graphical user interface screenshots of the mobile application's (A) electricity monitoring menu, (B) real-time electricity consumption data, (C) warning notification on water leakage, and (D) detected water leakage location or room.



Figure 14. Graphical user interface screenshots of the mobile application's (A) warning notification on water leakage, (B) detected electricity leakage location or room, (C) data logs main menu, (D) data logs location, and (E) overall history of defects or leakage detected.

Hypotheses Testing Results

As a next step, the authors carried out a series of technical procedures to determine the functional correctness and timeliness of the system, and subsequently, in testing the null hypotheses of the study. For the first H_0, the authors compared the electricity consumption data captured from both lecture and laboratory rooms through their respective non-invasive current sensors. Table 2 shows the comparative matrix of actual electricity consumption in both rooms, measured in Watts (W).

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Table 2. Comparative matrix on the electricity consumption in both lecture and laboratory rooms.

Test Case	Lecture Room (W)	Laboratory Room (W)
1	0.29	0.28
2	0.28	0.27
3	0.26	0.22
4	0.26	0.24
5	0.27	0.28
6	0.26	0.24
7	0.25	0.29
8	0.23	0.26
9	0.25	0.27
10	0.23	0.26

Meanwhile, Table 3 shows the descriptive statistics of the gathered data. As shown, the average power consumption in the lecture and laboratory rooms was 0.258 W and 0.261 W, respectively. The standard deviations (SD) are 0.018 W and 0.021 W, while the standard error of the mean (SEM) are 0.006 and 0.007, respectively. The results are based on the use of LED night lamps for both rooms, with a total of 10 test cases in each group, measured at a 30-minute interval.

Table 3. Descriptive statistics on the detected electricity consumption of lecture and laboratory rooms.

Group	Total Number	Mean	SD	SEM
Lecture Room	10.00	0.258	0.018	0.006
Laboratory Room	10.00	0.261	0.021	0.007

A two-tailed, independent *t*-test showed that there was no significant difference in the functional correctness of the system in detecting electricity consumption of LED night lamps between the lecture and laboratory rooms (0.258 ± .018 W; 0.261 ± .021 W), t (18) = -0.325, P = 0.749. Hence, the first null hypothesis (H_{01}) was accepted.

Afterwards, the second null hypothesis was tested, H_{02}, by comparing the water consumption data captured from both men's and women's comfort rooms through their respective water level sensors. Table 4 shows the comparative matrix of actual water consumption in both women's and men's comfort rooms.

Table 4. Comparative matrix of water consumption in both women's and men's comfort rooms.

Test Case	Women's Comfort Room (l/m)	Men's Comfort Room (l/m)
1	0.53	0.67
2	4.53	4.27
3	4.53	3.87
4	6.13	4.93
5	4.40	6.00
6	4.93	6.67

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7	3.60	3.60
8	3.07	2.67
9	6.67	4.80
10	5.47	4.93

On the other hand, Table 5 shows the descriptive statistics of the gathered data. As shown, the average water consumption in the lecture and laboratory rooms was 4.386 l/m and 4.241 l/m, respectively. The standard deviation (SD) was 1.732 l/m, and 1.701 l/m, and the standard error of the mean (SEM) was 0.548 and 0.538, respectively. The results were based on a total of 10 test cases in each group, measured at 30-minute intervals.

Table 5. Descriptive statistics on the detected water consumption of women's and men's comfort rooms.

Group	Total Number	Mean	SD	SEM
Women's Comfort Room	10.000	4.386	1.732	0.548
Men's Comfort Room	10.000	4.241	1.701	0.538

A two-tailed, independent *t*-test found that there was no significant difference in the functional correctness of the system in detecting the water consumption between the women's and men's comfort rooms (4.386 ± 1.732 l/m, 4.241 ± 1.701 l/m, $t(17.994) = 0.189$, $P = 0.852$). Hence, the authors accepted the second null hypothesis (H_{02}).

Then, the third null hypothesis, H_{03} was tested by comparing the speed of notification of the mobile application, once a leak is detected in either of the lecture, laboratory, women's, and men's comfort rooms. Table 6 shows the comparative matrix on the mobile app's speed of notification on detected water and electricity leaks, measured in seconds (s).

Table 6. Comparative matrix on the mobile app's speed of notification on detected water and electricity leaks.

Test Case	Lecture Room (s)	Laboratory Room (s)	Women's Comfort Room (s)	Men's Comfort Room (s)
1	0.500	0.600	0.700	0.800
2	0.600	0.500	0.600	0.500
3	0.700	0.600	0.700	0.600
4	0.500	0.700	0.600	0.500
5	0.600	0.800	0.600	0.600
6	0.500	0.500	0.500	0.600
7	0.800	0.600	0.500	0.600
8	0.500	0.500	0.600	0.500
9	0.700	0.700	0.700	0.600
10	0.700	0.600	0.700	0.700

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Table 7 shows the descriptive statistics relative to the H_{03} testing. As shown, the average speeds of notification for the lecture, laboratory, women's, and men's comfort rooms were 0.610, 0.610, 0.620, and 0.600 seconds, respectively. The standard deviation (SD) and standard error of the mean (SEM) were 0.035, 0.031, 0.025, and 0.030 seconds, and 0.110, 0.099, 0.079, and 0.094, respectively. The results were based on a total of ten test cases in each group, measured over a 1-week duration.

Table 7. Descriptive statistics on the mobile app's speed of notification on detected water and electricity leaks.

Group	Total Number	Mean	SD	SEM
Lecture Room	10.000	0.610	0.035	0.110
Laboratory Room	10.000	0.610	0.031	0.099
Women's Comfort Room	10.000	0.620	0.025	0.079
Men's Comfort Room	10.000	0.600	0.030	0.094

Lastly, the H_{03} was tested using ANOVA and found that the sum of squares (SS), degrees of freedom (*df*), and mean square (MS) between and within groups were 0.002 and 0.334, 3 and 36, and 0.001 and 0.009, respectively. Furthermore, results revealed that there was no statistically significant difference in the timeliness of the mobile application in notifying the user of detected water and electricity leaks in lecture, laboratory, men's, and women's comfort rooms, as determined by one-way ANOVA, where $F(3, 36) = 0.072$, $P = 0.975$.

DISCUSSION

Prototype Capabilities and Limitation

In this study, a system was designed, developed, and tested that aimed to enhance the monitoring of water and electricity consumption and leaks. Thus, reducing the negative effects of water and electricity leaks, such as safety hazards, structural damage, and significant costs (Hassan and Jasim 2021; Padillo et al. 2022). In consideration of the identified research gaps, the unique value proposition of this study is the integration of various technological strategies to monitor both water and electricity, with the intent of improving detection accuracy, speed, consistency, reliability, and cost-effectiveness. Specifically, the proposed system features a cyber-physical system based on the IoT architecture, comparable to the works of Che et al. (2021), Marathe et al. (2021), Gautam et al. (2020), Hassan and Jassim (2021), Wasoontaajoen et al. (2017), and Nataraj et al. (2022). The input modules of the proposed system are composed of 4 pieces of YF-S201C water flow sensors, the same strategy used by Che et al. (2021) and Marathe et al. (2021), connected to 2-wire probes to detect water leaks, and 2 pieces of non-invasive current sensors, similar to the work of Wasoontaajoen et al. (2017). The main microcontroller is the Arduino Mega (Gautam et al. 2020; Che et al. 2021), while the ESP866 WiFi module (Wasoontaajoen et al. 2017) facilitates internet connectivity with the cloud database (Hassan and Jassim 2021). The main output module of the

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system is the mobile application, which serves as the primary interface for the user in monitoring and controlling water and electricity consumption leaks via the internet. The app features secure user registration and data management modules to optimize user privacy, experience, and satisfaction. Lastly, the system is powered by an automatic control switch, which toggles between the main line and battery sources in case of power interruptions, which is similar to the strategy used in the study of Kanoi et al. (1995).

On the other hand, the mobile application is currently working on the Android operating system, and the wireless frequency coverage is from 2.4 GHz to 5 GHz only. Hence, future research should focus on the use of alternative Internet or offline connections, other mobile operating systems, and other connectivity protocols to enhance efficiency and cost-effectiveness. Also, the system has been tested in a miniature model; thus, future research should evaluate its reliability in a real-life setting over a longer period.

Performance Outcomes

To simulate the technical performance of the proposed system, the system was deployed in a miniaturized model to depict a real-life-like environment of an instructional area. The model has a control room, which houses the microcontroller unit and the WiFi module; miniature versions of a lecture room and laboratory room with built-in non-invasive current sensors to detect electricity consumption and leaks; and miniature versions of comfort rooms for women and men with built-in water flow sensors and wire-probes to detect water consumption and leaks.

Then, a series of technical tests were conducted to either accept or reject the proposed hypotheses. Based on the results of independent t-tests with unassumed equal variances, it was found out that there was no significant difference in the functional correctness of the system in detecting electricity consumption in lecture and laboratory rooms, as well as the water consumption in men's and women's comfort rooms. Likewise, based on the ANOVA results, it was also found that there was no significant difference in the timeliness of the system in notifying the user of detected water and electricity leaks in the lecture, laboratory, men's, and women's comfort rooms. Hence, the null hypotheses of the study were accepted. The results further imply that the proposed system is consistently accurate in detecting electricity and water consumption, and is consistently real-time in notifying users of detected electricity and water leaks. Overall, the proposed system is an accurate, timely, consistent, economical, and viable option in managing water and electricity consumption and leaks for households, businesses, government, and private firms. It can also be an illustrative and reliable proof of concept in managing water and electricity consumption for instructional purposes. The outcomes are expected to contribute to the United Nations'

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Sustainable Development Goals (SDG) on affordable and clean energy (SDG 7); and responsible consumption and production (SDG 12) (UNO 2015).

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GENERATIVE AI STATEMENT

The authors utilized generative artificial intelligence tools, such as ChatGPT-6 and Grammarly for Google Chrome version 14.1338.0, to evaluate the technical feasibility of the paper in terms of grammar, cohesiveness, tone, and scientific appeal.

ETHICAL CONSIDERATIONS

The authors designed, developed, and tested the prototype without the use of humans, animals, or the environment as "subjects". All activities were documented, communicated, approved, and guided by concerned professionals and authorities. All related scientific articles, patents, and resources in this paper were properly recognized and cited.

DECLARATION OF COMPETING INTEREST

The authors declare that there are no competing interests for any author.

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