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Reliable Integration of Neural Network and Internet of Things for Forecasting, Controlling, and Monitoring of Experimental Building Management System

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Abstract: In this paper, Internet of Things (IoT) and artificial intelligence (AI) are employed to solve the issue of energy consumption in a case study of an education laboratory. IoT enables deployment of AI approaches to establish smart systems and manage the sensor signals between different equipment based on smart decisions. As a result, this paper introduces the design and investigation of an experimental building management system (BMS)-based IoT approach to monitor status of sensors and control operation of loads to reduce energy consumption. The proposed BMS is built on integration between a programmable logic controller (PLC), a Node MCU ESP8266, and an Arduino Mega 2560 to perform the roles of transferring and processing data as well as decision-making. The system employs a variety of sensors, including a DHT11 sensor, an IR sensor, a smoke sensor, and an ultrasonic sensor. The collected IoT data from temperature sensors are used to build an artificial neural network (ANN) model to forecast the temperature inside the laboratory. The proposed IoT platform is created by the ThingSpeak platform, the Bylink dashboard, and a mobile application. The experimental results show that the experimental BMS can monitor the sensor data and publish the data on different IoT platforms. In addition, the results demonstrate that operation of the air-conditioning, lighting, firefighting, and ventilation systems could be optimally monitored and managed for a smart system with an architectural design. Furthermore, the results prove that the ANN model can perform a distinct temperature forecasting process based on IoT data.

Keywords: building management system; Internet of Things (IoT); artificial neural network; programmable logic controller; Arduino; ESP8266; forecasting temperature

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Citation: Essa, M.E.-S.M.; El-shafeey, A.M.; Omar, A.H.; Fathi, A.E.; Maref, A.S.A.E.; Lotfy, J.V.W.; El-Sayed, M.S. Reliable Integration of Neural Network and Internet of Things for Forecasting, Controlling, and Monitoring of Experimental Building Management System. *Sustainability* **2023**, *15*, 2168. https://doi.org/10.3390/su15032168

Academic Editors: Tibor Holczinger, Judit Szűcs and Tibor Guzsvinecz

Received: 7 December 2022
Revised: 13 January 2023
Accepted: 17 January 2023
Published: 24 January 2023

1. Introduction

Use of energy is becoming increasingly important in different types of buildings [1–7]. The buildings include homes, schools, offices, hospitals, and factories, which are considered the main partners in energy consumption. In building subsystems, cooling and heating systems, including safety, water, lighting, and similarly linked building subsystems, are responsible for the majority of the energy consumed by buildings (30–40% of global energy use) [1–7]. As a result, major efforts have been made to increase efficient use of energy in buildings, increase energy savings, and decrease energy consumption in buildings. Efficient energy use is achieved by meeting the required demands at the lowest possible cost without sacrificing environmental friendliness. In many emerging and developed countries, increasing energy efficiency is regarded as the best way to meet and overcome ever-increasing energy demands. However, improving the energy efficiency of these systems requires more effort because they frequently have to meet the requirements of fluctuating energy, complicated operating requirements, and comfort requirements [5–9]. A new generation of intelligent buildings that are better suited to the goals of property owners and managers are being pushed forward by Internet of Things (IoT) [1–3]. An IoT enables operational systems to deliver more accurate and helpful information, enhancing operations and delivering the greatest customer experience [2–4]. Most buildings have intelligence incorporated into them through HVAC, lightning protection, or fire safety [6]. However, today, more can be learned from creation of information, and better decisions may be made as a result. There are many examples to show how this is being carried out for many types of buildings [4–7]. As a result, a building management system based on IoT is proposed in this paper to solve the problems of energy. The topic of BMS-based IoT is a very interesting research point for many researchers, as discussed in the following section. This paper is organized as follows: Section 2 demonstrates related works and a literature review, while Section 3 discusses the methodology used in this article. The BMS is discussed in Section 4, while the IoT is shown in Section 5. Section 6 depicts and explains the ANN architecture. Finally, the results are discussed in Section 7.

2. Related Works

This study is concerned with providing a practical design and implementation of the BMS by controlling the operation of loads, monitoring their status, and monitoring sensor readings. The sensors' readings are used to build a forecasting temperature model based on AI. In this research, control and monitoring of the smart system are performed via IoT. The proposed system is characterized by being more reliable as a result of the multiplicity of methods of controlling the loads' operation and the multiplicity of monitoring ways, meaning that, in the event of any failure, another way of control and monitoring is available. We conducted an analytical review of the previous literature that was published in BMS, IoT, AI, and smart buildings in order to clarify the goal of this research. The papers that contributed significantly to our study are presented in the following paragraphs.

The BMS is considered a smart system based on computer control. It is installed in different types of buildings to monitor and control the mechanical and electrical equipment, such as security systems, power systems, lighting, and fire systems [1–10]. In Ref. [1], the main goal of this study is to combine alert systems based on the IoT with models of BIM to observe different services and facilities of buildings for the duration of their operational phases and to digitally visualize their conditions. In addition, the article in [1] proposes a combination of a digital framework founded via BIM and IoT platforms to deliver effective maintenance services for building infrastructure. In Ref. [2], the paper provides a comprehensive study of review research on the applications of IoT technology in commercial and residential buildings. The study of residential buildings is categorized into three divisions: intelligent energy management systems, home automation, and healthcare facilities [2]. Further, in Ref. [2], the literature for commercial buildings is organized into four categories: facilities for healthcare, buildings for offices, structures for educational institutions, restaurants, and retail establishments. In Ref. [3], the development phase of a low-cost IoT solution for a kindergarten school is described. In Ref. [3], a set of sensors was designed on a battery-powered communication board, simplifying the setup process. Moreover, a set of sensors, such as humidity, temperature, air quality, luminosity, and monitoring solutions for energy, are used in [3].

The consumption and usage of energy in the building management system (BMS) are optimized based on a fuzzy logic algorithm and IoT, as demonstrated in [4]. Sensing devices, including smart meters, are used to collect data in [4]. An interesting development is use of machine learning to monitor and analyze the data output of the smart meters so as to check if this information is true or false [5]. By providing information throughout graphic depictions for energy consumption and environmental factors of indoor and outdoor environments, such as brightness, humidity, and temperature, a new method of interacting with and monitoring local users is developed [6]. The drawbacks and benefits of various technologies in a modern building automation system (BAS) are presented in [7]. In addition, it suggests an architecture that combines the IoT paradigm with the KNX of Things [7]. BAS are currently confronted with a significant challenge as their requirements and expectations have shifted from standalone automation services to solutions that enable BAS to easily interact with IoT devices [7]. Consumption of energy is proposed to be reduced by utilizing an energy management system (EMS) that employs the protocols of message queuing telemetry transport (MQTT) and LoRa modulation in [8]. A group of sensors with a power source attached and a micro-controller with a LoRa communication interface are assembled to form nodes, which are then used to feed electrical power data to a customized energy monitoring system [8]. A study of a safe smart building and efficient energy-saving architecture based on advancement of IoT technology is discussed in [9]. It also suggests an architecture of smart construction that utilizes an IoT platform to manage the performance of all technological equipment in order to achieve energy efficiency [9]. The study demonstrates that using the CoAP in the smart building reduces energy usage by about 30.86 percent, which is less than the MQTT case [9]. To increase security, a combination of the DTLS protocol with the secure hash algorithm (SHA-256) using optimization processes from the certificate authority (CA) is also developed in [9]. The research in [10] is developed to reduce electrical energy consumption through control of air conditioners using deep learning and IoT technology. Furthermore, a DL approach is proposed to build a model for a people detection system based on the YOLOv3 approach to count people in a specific area [10]. Use of ML is also suggested for developing a predictive maintenance system for building installation [11]. Studying investigation of use of a low-cost solution, the Arduino UNO in conjunction with the Wi-Fi module (ESP8266), which helps to process and transfer sensed information to the thing that speaks cloud, which is typically comprised of various sensors, such as temperature, humidity, and moisture, is provided in [12]. Consumption of energy for a building is forecasted based on a neural network with adaptive long-short-term memory that is tuned by a genetic algorithm, as discussed in [13]. The research in [14] presented a trained adaptive neurofuzzy inference system (ANFIS) model based on genetic algorithm (GA) to improve forecasting accuracy and reliability for construction labor productivity. It is suggested to develop an automated system for tracking attendance of students via principal component analysis (PCA), face recognition, Eigen face values, and convolutional neural networks (CNN) in [15]. In [15], a new approach is presented that utilizes the algorithm of local binary patterns (LBP) and image processing methods such as contrast adjustment. The study in [16] introduced creation and development of an integrated management system for smart buildings. The proposed system combines systems based on smart surveys and augmented-reality-based smart promotion systems [16]. Different types of technologies, such as guest guidance smart devices for evacuation, speech, video utilization technology, announcement, music, and technology, and face recognition technology, are suggested in [16]. Development of equipment based on affordable vehicle recognition and cameras and a counting approach using techniques of advanced machine learning to meet the requirements of a certain model of assessment for noise are discussed in [17]. The research in [18] discusses cyber security for online bank databases and application of digital technology to manage online databases for banks. Furthermore, the research in [18] introduces improvements to the management information system (MIS) to improve the bank's sustainability in the Vietnamese economy. In Ref. [19], the paper discusses the effectiveness of security operations monitoring (SOCs) for smart buildings. Further, the objective of research in [19] is to increase the dependency of modern society on IT systems and infrastructures for essential services. In Ref. [20], the challenge of improving the efficiency of production and resilience of crops based on IoT is discussed. The description of a Bayesian network that is proposed to construct an assessment model for a smart home based on an IoT network is given in [21]. Based on the discussed papers, it is very clear that the study of the management systems of buildings is very interesting and important for increasing energy savings and decreasing energy consumption. The contribution of the paper could be summarized in main points as follows:

1. Implement an experimental BMS system based on IoT technology.
2. Design a real IoT platform and dashboard using the Bylink dashboard and the ThingSpeak platform for BMS.
3. Investigate a new integration of PLC, Arduino Mega 2560, and ESP8266 with each other that makes the system more reliable and efficient.
4. Monitor the status of measurement sensors, such as an IR sensor, an ultrasonic sensor, a smoke sensor, and a temperature sensor.
5. Using ANN, create a forecasting model based on data collected from the IoT system.
6. Monitoring and control of sensors and loads using the Bylink mobile application.
7. Control the operation of A/C, lighting systems, ventilation, and firefighting systems based on IoT technology.
8. Save energy and decrease consumption by controlling the operation of the A/C and lighting systems.
9. Design the architectural layout of the BMS with detailed drawings and suggest the FM200 system for the firefighting system.
10. Demonstrate a report for all controlled and monitored values based on IoT.

3. Methodology

In this research, the applied methodology is experimental investigation for smart building. The ladder diagram programming for PLC, Bylink, and the ThingSpeak platform are used to collect data in the education laboratory. The goal is to collect data on the working environment's ambient temperature, humidity, smoke detector, and lighting.

3.1. Programmable Logic Contaroller (PLC)

The programmable logic controller (PLC) is a hardware device that is used to control operations that require logic, counting, timing, and network connectivity [22,23]. It is also used to automate industrial activities, such as monitoring and managing the machines on an assembly line in a factory [24]. The PLC has input and output connected to outside fields. Sensors, switches, and pushbuttons are frequently used as PLC inputs. Further, loads are connected as PLC outputs. Ordinary programming languages are not the same as the language used to operate a PLC. A schematic diagram of PLCs' components is provided in Figure 1. The PLC consists of input and output modules, a power supply, a central processing unit (CPU), and memory (see Figure 1). The ladder diagram is the used programming language in the paper due to its simplicity, easy to monitor, and most common language. The Siemens S7-1200 PLC (Siemens Egypt, cairo, Egypt) was the type of PLC employed in this study.

PLCs use computers to control mechanical equipment and smart buildings [24–27]. PLC is designed for use in manufacturing facilities, power factor correction, building automation, and integration with IoT [22–27]. PLCs operate various applications using sequential logic instructions that are programmed using the appropriate programming languages. Through input and output interfaces, every computer can communicate with external devices. To control industrial mechanical devices, however, a conventional microprocessor immediately has several drawbacks. Most computers lack much robust design for industrial operation, which makes them readily destroyed when used in industrial environments [22,24]. Therefore, specific microcomputers that are hardened for industrial use must be installed in factories [22,24]. The second drawback is that ordinary microcomputer I/O interfaces are never made to withstand the voltages and currents of PLC electric transmission. The computer output port needs to be remote from electricity in order to prevent damage, so an external device, such as a relay, must be operated on a circuit with AC volts. As a result, various isolation devices, such as relays and contactors, are used in this paper to prevent direct connections between highly inductive loads and PLC outputs.

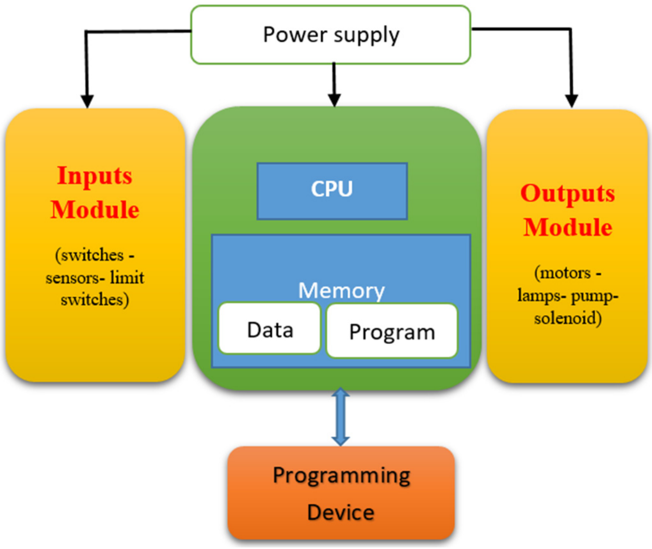

Figure 1. Schematic diagram of PLC components.

3.2. ThingSpeak Platform

The interface offers straightforward IoT object communication capabilities in addition to other intriguing implementations. Additionally, ThingSpeak enables user to create apps based on the sensor data [28–30]. It offers data collection, processing, and simple visualizations in virtually real time. The so-called channels, which provide the user with several functions, are where the data are kept [28]. The ThingSpeak website claims that the application programming interface (API) functions as shown in Figure 2. Essentially, "things" are devices equipped with sensors to gather data. Simple "Hypertext Transfer Protocol" (HTTP) POSTs, which are similar to visiting a website and submitting a form, are used to send and receive data. This exchange takes place in plaintext, JSON, or XML. After that, the data are transferred to the cloud, where they can be used for a variety of things [29,30]. Data can then be gathered and sent to the cloud, which then delivers messages to the object (such as commands or selections).

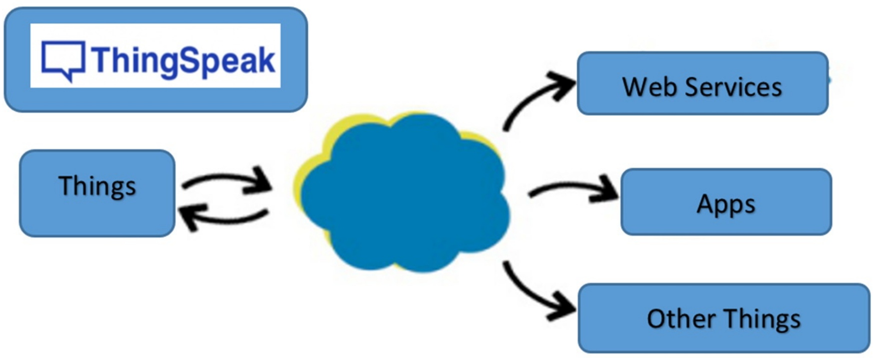

Figure 2. ThingSpeak interface.

The IoT service (ThingSpeak), which interacts with a virtual server, processes data sent by a device via an HTTP request (communication). Direct communication between the server, the IoT service, and the application is possible. Finally, there are requirements for security and data transfer management at all communication levels, from the device to the application [28]. Unfortunately, ThingSpeak does not provide any technical documentation on how the various components of the diagram are handled. However, given enough time and knowledge, one should be able to find the answer by studying the (open-source) code base [28,29].

The main feature that sets ThingSpeak apart from its rivals is the ability to build public channels, which fosters a sense of community. It is noted to be the only open data platform in "the cloud" created exclusively for the IoT. Additionally, the API makes it very simple to visualize the obtained data using spline plots [28–30]. In comparison to other open-source APIs, it is, therefore, more aesthetically pleasing and makes it easier to examine acquired data. ThingSpeak makes use of Phusion Passenger Enterprise, a web and application server, which is another plus [28–30].

3.3. Bylink Platform

Blynk is considered an IoT platform that employs remote control of electrical and electronic apparatus through its Android and iOS apps [31–33]. It presents a dashboard with the ability for users to build a GUI using various widgets. Furthermore, Blynk can save and display sensor data from widely used hardware platforms, such as Arduino, ESP8266, Raspberry Pi, SparkFun, and others [31,32]. The three most important Blynk components are the app, server, and libraries (see Figure 3) [31–33]. Apps can aid in the interface's creation. All the communication between the hardwires and apps is managed by the server. Additionally, libraries enable command-based hardware connections with the server. User can control all devices that are connected to the Blynk server using its app. The Blynk app now has additional buttons that can be used to turn on and off switches [31–33].

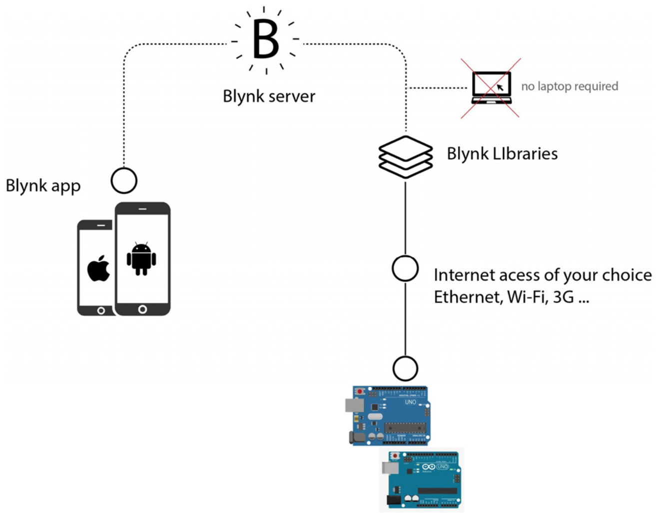

Figure 3. Components of Bylink.

3.4. Hardware Implementation

The experimental system consists of (1). Bylink IoT dashboard: to control the system and visualize the status of various system sensors based on the Bylink server; (2). ThingSpeak IoT platform: it is another way to monitor the sensors and control the operation of loads based on ThingSpeak platform; (3). IoT mobile application: it is used to monitor and control the smart system using mobile apps; (4). power supply: it is used to supply the voltage (24 VDC) to different loads and sensors; (5). Wi-Fi camera HD C6N EZVIZ: it is operated based on Wi-Fi connection to track the people motion inside the laboratory; (6). DC motor: to emulate the operation of ventilation system, and its voltage is 24 VDC; (7). lamps module (24 VDC): to emulate the lighting system and indicate the operation of the motor and other loads; (8). distributor: it is used to distribute the 24 VDC to the whole system; (9). pushbuttons: to start and stop the system; (10). relay module: it is an electromechanical switch that is used to transfer the control signal from the output of the PLC to real loads; (11). PLC Siemens S7-1200: it is used to be the brain of the system, which controls the system based on a ladder diagram program; (12). Arduino Mega 2560 (two modules): to control the system in parallel with a PLC; (13). LCD module: to display the measurement of temperature and humidity sensors; (14). ultrasonic sensor: to measure the level of water; (15). Node MCU ESP8266 (two module): to achieve the IoT connections; (16). IR sensor: to detect motion inside the laboratory; (17). smoke sensor: to detect smoke; (18). DHT11 sensor: to measure temperature and humidity.

In this article, we are measuring various parameters in building, such as temperature, humidity level, smoke detection, motion, and level of water. Based on the measured values, the hardware system will give orders to another piece of equipment to control and monitor the system, such as filling a tank, opening a ventilation system, indicating someone enters a laboratory, then operating the lighting system, or operating a firefighting system if the smoke sensor detects smoke in the laboratory or the temperature exceeds an exact degree, then operating the A/C. The ThingSpeak and Bylink platforms are proposed as an IoT platform for monitoring the status of system variables and indicating a visual and audible alarm if the smoke sensor activates. The PLC (Siemens S7-1200) is used to control the operation of loads. Furthermore, the MCU ESP8266 node is used to send control signals to the PLC via Wi-Fi and sensor data to IoT ThingSpeak and Bylink (the dashboard platform and mobile application). To complete the IoT tasks, we used two ESP8266 to make the system more reliable. In addition, an Arduino Mega 2560 is utilized to send the data to the LCD screen (16 × 2) module and PLC. In a laboratory, a camera Wi-Fi is used to track the movement of people. This camera is only to secure and record the behavior of people inside the laboratory. The schematic wiring diagram of the experimental system is shown in Figure 4. A practical photo for implementation of the BMS test rig with components is depicted in Figure 5. Figure 6 demonstrates an interior shot of a laboratory with an experimental BMS system.

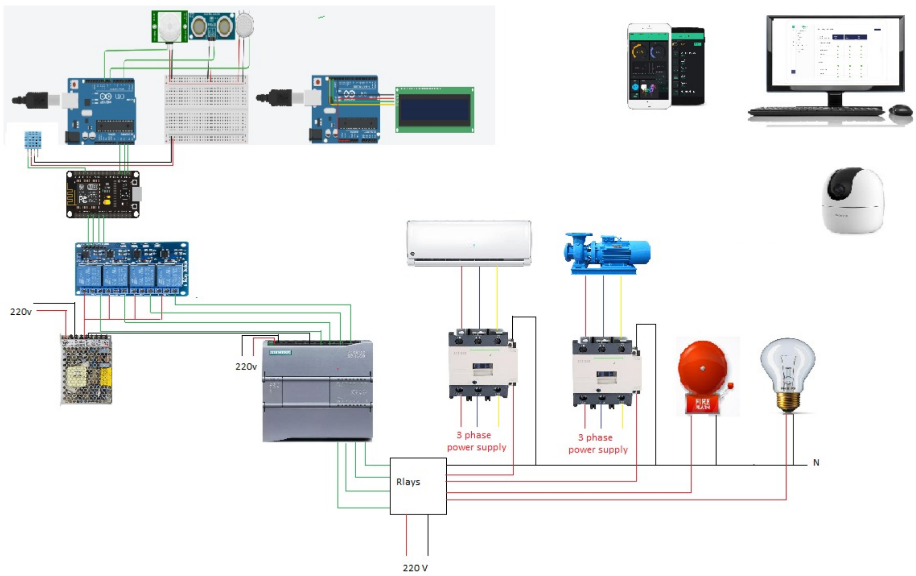

Figure 4. Schematic wiring diagram of BMS installation in laboratory.

The flowchart of the BMS operation based on the sensors used in this paper is shown in Figure 7. The sensor libraries are first loaded from the Arduino IDE, then the program will be executed, and the LCD will display the sensors data. Furthermore, the sensor data will be published via the ThingSpeak IoT platform. The obtained data from sensors could be visualized throughout the platform of the ThingSpeak-based public channel, as shown in Figure 8.

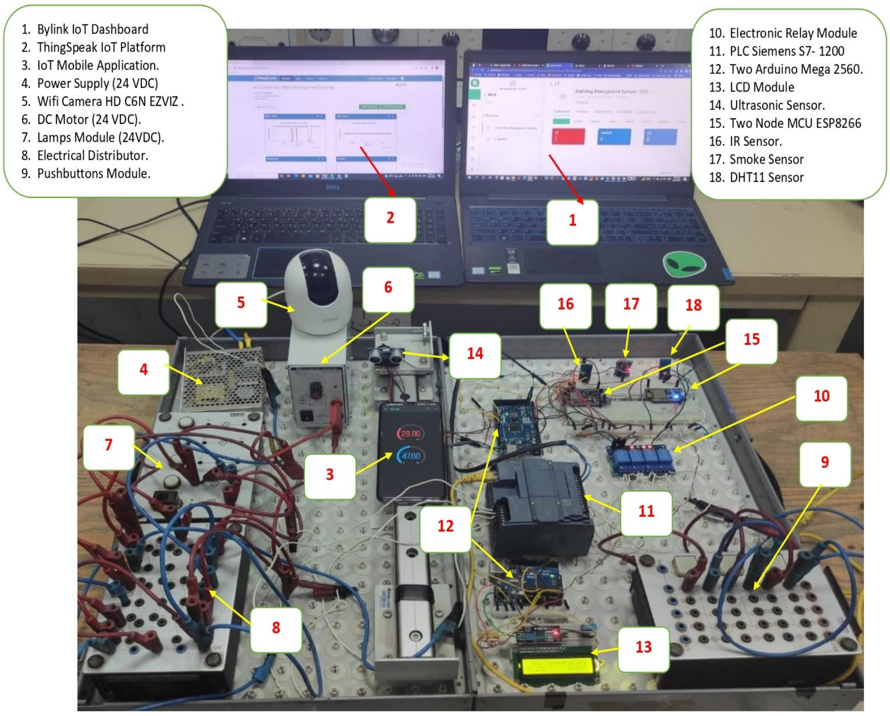

Figure 5. Real photo of experimental BMS system.

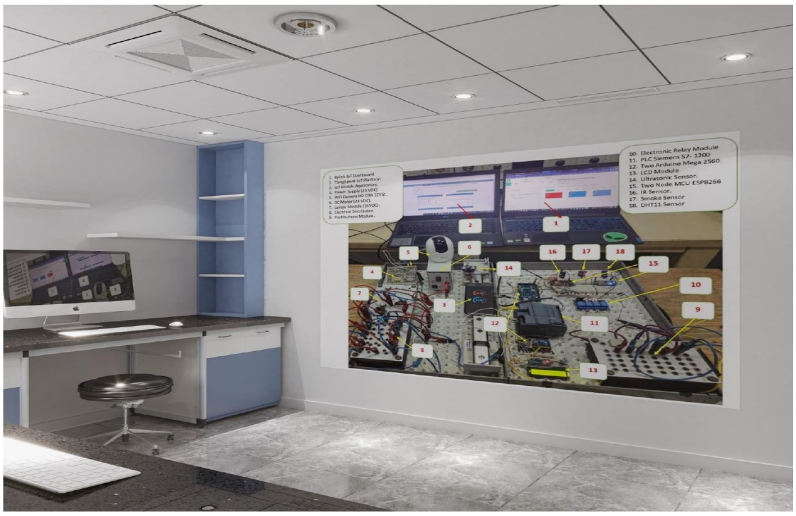

Figure 6. Interior shots of laboratory with experimental BMS system.

One of the advantages of the ThingSpeak is that it provides many features, such as sending a message to Twitter through a tweet (the "ThingTweet") and allowing it to be sent at a specific time (the "ThingTime"). In addition, ThingSpeak is equipped with MATLAB analysis, MATLAB visualization, and many other features. Therefore, ThingSpeak played an effective role in designing the proposed system in this research.

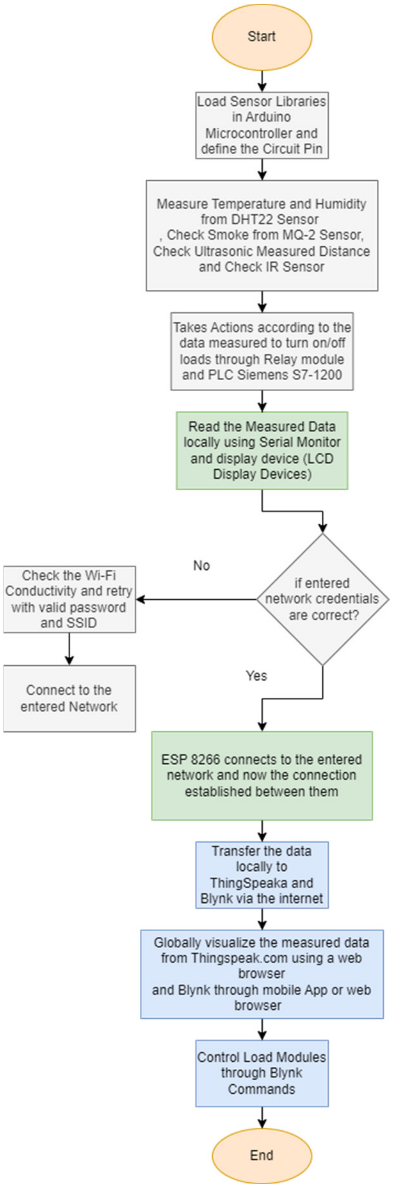

Figure 7. Flowchart of experimental system operation.

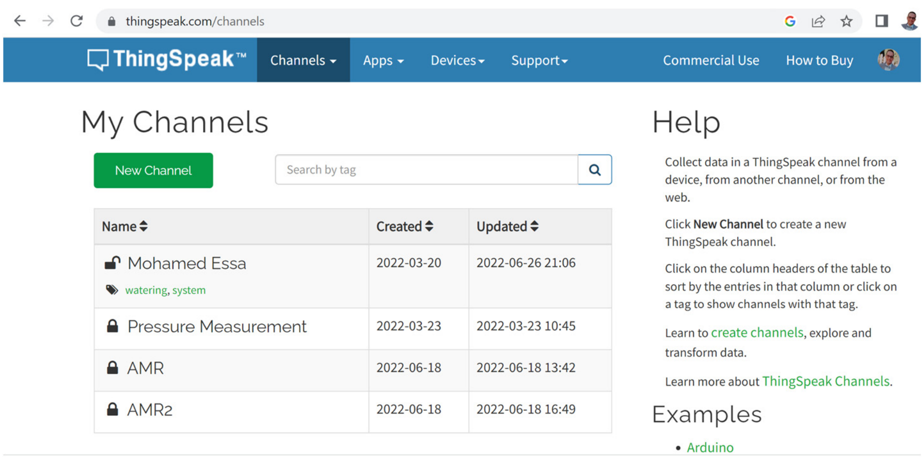

Figure 8. ThingSpeak platform.

4. Building Management System (BMS)

A BMS is considered to be an intelligent control system that controls and regulates various configurations of facility subsystems [34–38]. The regulation process is completed automatically based on monitoring and enforcing predetermined parameters (or set points) and regulating their operation and performance [34–38]. The main object of BMS is to ensure security and efficient operations of the facility and its services [36,37]. Further, it also aims to maximize the efficiency of the monitored subsystems and their controls [36,37,39,40]. The BMS controls a variety of crucial components, including [34–40]:

1. The heating, ventilation, and air-conditioning system "HVAC": The BMS is linked to sensors for measuring temperature, pressure, and humidity in the exhaust and ducts. The alarm is activated if any of these parameters exceed predetermined levels.
2. The technical system of steam: In cases where the quality of the product is at risk, the BMS should sound an alert if temperature and pressure in the piping system drop below the set values to clean the whole steam.
3. Laminar flow units, central heat blowers, central fume collection, and a central vacuum system: The BMS keeps tabs on how well these systems are functioning, enabling prompt maintenance of any defective components. Alarms would sound if there was an unexpected failure, and the product could then be safeguarded as needed.
4. Chilled water system: The BMS has the potential to oversee the chillers in a building, ensuring that coolant temperatures and water are properly managed and pumps are properly distributed throughout the distribution loop.
5. Central heating: to ensure that hot water is distributed effectively throughout the building. The BMS can keep tabs on both the temperature and status of the pumps.
6. Safety systems and firefighting: The recommended material in this paper is the FM200 system.
7. The electrical monitoring system: The BMS can monitor the consumed power as well as the status of the main electrical sensors and switches.

Architecture of BMS System

The system architecture description is provided to clarify the relationship between the different equipment and components. Different BMS professionals may have slightly different topologies that are commonly acceptable [34–38]. The architecture of the BMS system is categorized into three levels, as shown in Figure 9. The BMS system has logic controls, such as those for the damper actuators, AHU motor, and chilled water valve operation [39,40]. Further, it has the advantage of monitoring the temperature sensors, the filters' differential pressure switches, and the fan's current transducers switch, pressure sensor, and duct smoke detector. It can demonstrate a report for all controlled and monitored values based on IoT [41–43]. Figure 10 demonstrates different ways for monitoring and controlling devices in BMS, such as remote notification, operator tasks, and a trend viewer. We selected an educational laboratory as a case study in this paper. The ceiling plan and looking-up plan for the laboratory are shown in Figure 11. In addition, this figure displays the distribution of mechanical, electrical, and plumbing (MEP) installations, such as electrical, HVAC, firefighting, and fire detectors. Figure 12 shows interior laboratory shots for the ceiling plan (looking up plan). The details of the third-party control panel of the BMS, such as cable installation, are provided in Figure 13.

Figure 9. Level of BMS system architecture.

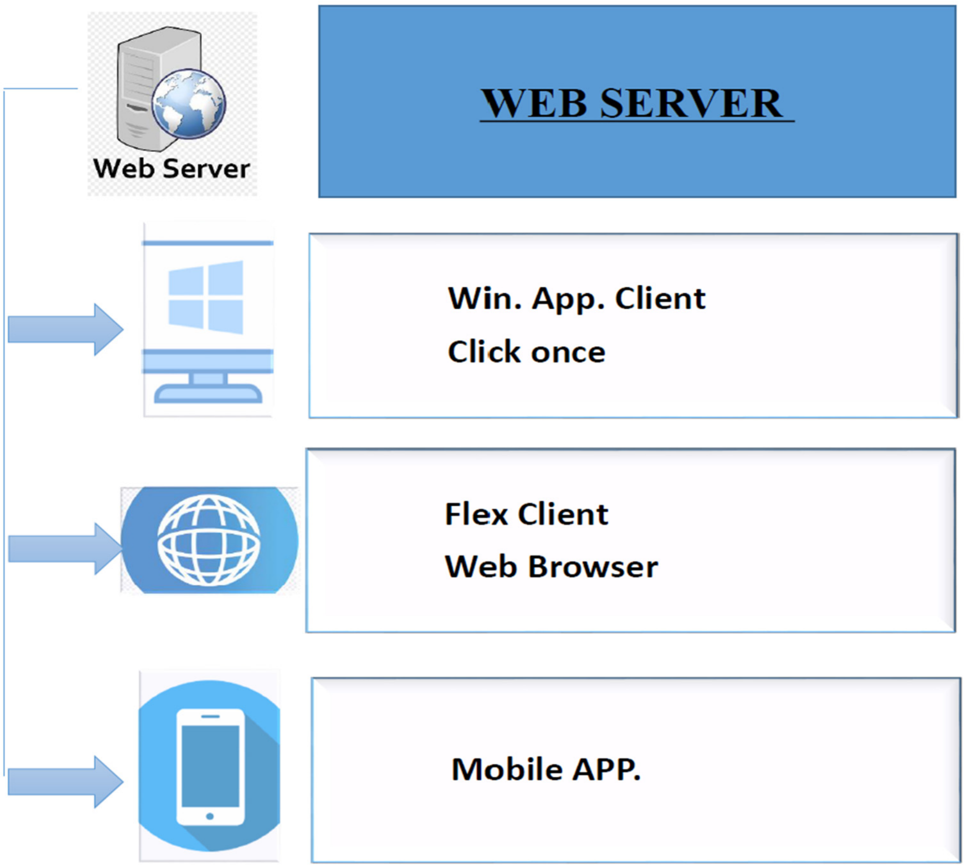

Figure 10. Easy operation and monitoring system.

Figure 11. Ceiling plan (looking up plan) for laboratory.

Figure 12. Case study on laboratory: interior shots showing ceiling plan (looking up plan).

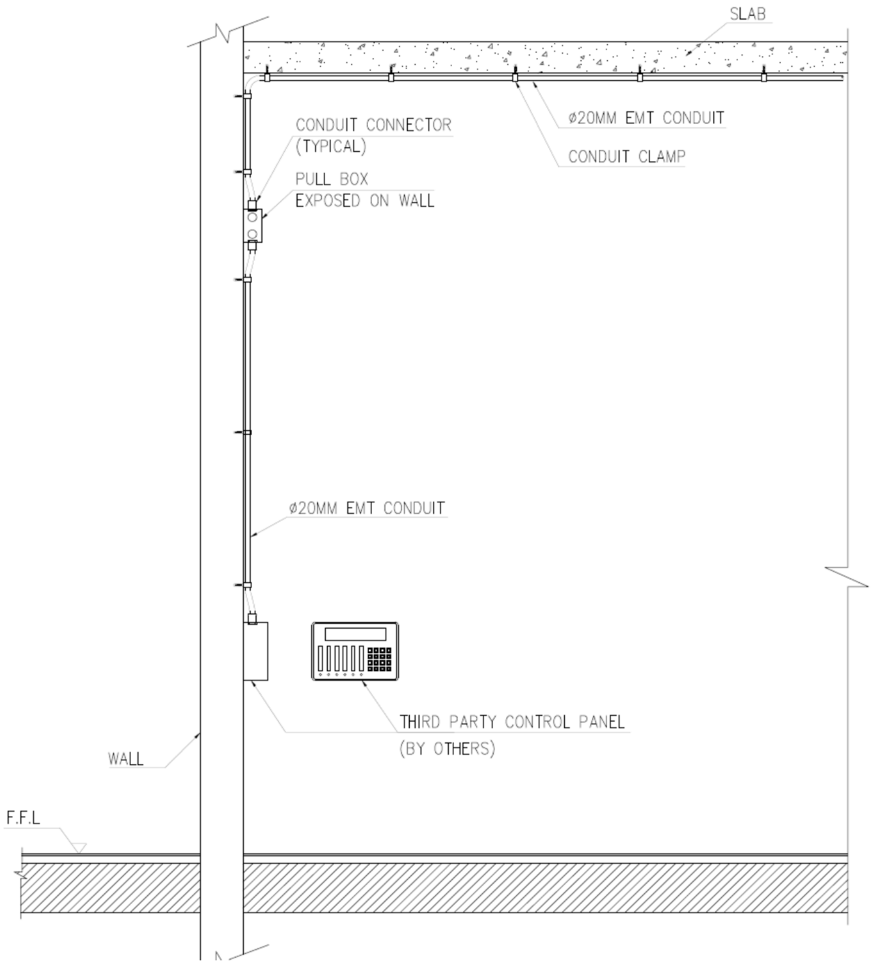

Figure 13. Third-party control panel BMS cables installation details.

5. Internet of Things (IoT)

IoT is adopted for a wide range of industries and other applications (see Figure 14) [41–48]. IoT is recommended to enhance efficiency of operation, provide good customer service, progress in making decisions, and develop the value of businesses [41–48]. The system of IoT is constructed from web-based smart devices that collect, send, and act on data from their environments via sensors, CPUs, and hardware communication. By connecting to an IoT gateway or other edge device, IoT devices can distribute sensor data that are either checked locally or moved to the cloud for exploration and analysis (see Figure 15). In fact, the IoT can be used to improve how people live, deal with situations, and achieve complete control over many aspects of their lives. Further, IoT is a good choice for businesses because it can provide smart tools to automate facilities and homes [41–46]. IoT can provide businesses with detailed information about the performance of machines and accurate status of systems that work to provide logistical operations [41–47].

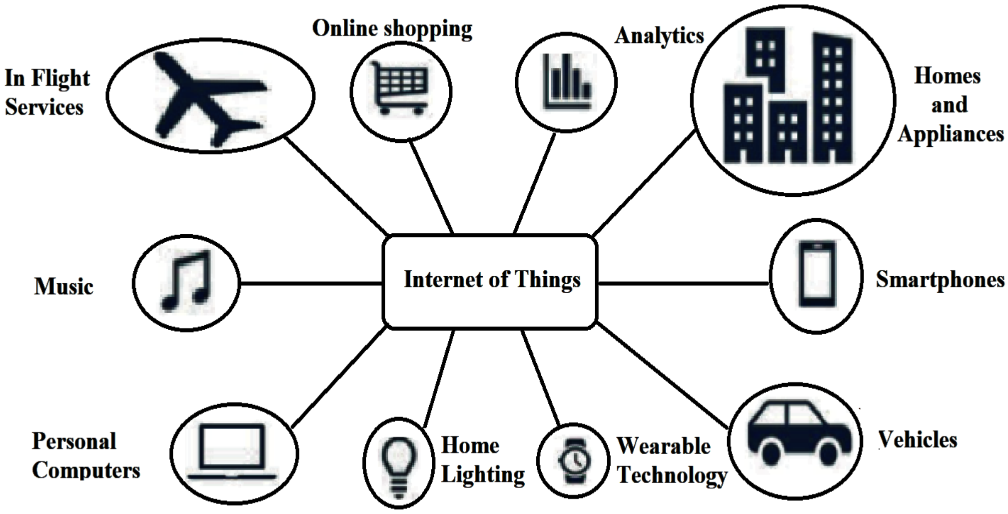

Figure 14. Practical applications of IoT.

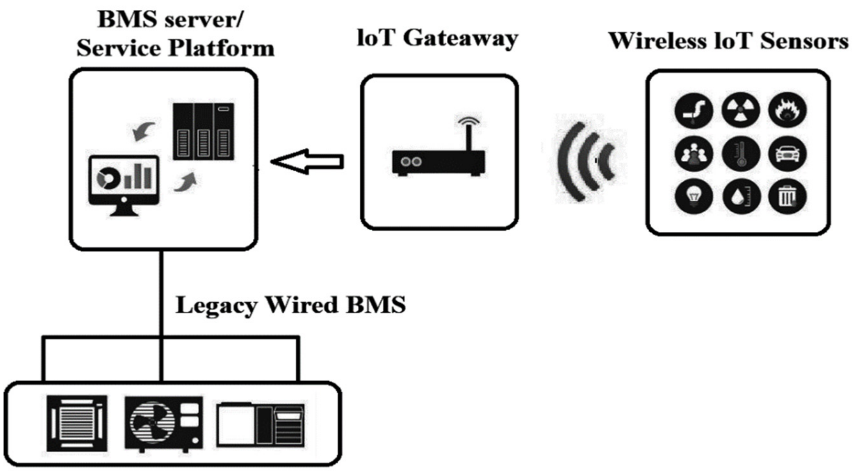

Figure 15. Flow of signals in IoT system for BMS.

6. Artificial Neural Network (ANN)

An ANN is a subset of machine learning that simulates and is inspired by the biological formation of the human brain, which completes complex calculations and analyses for the system [49–53]. ANNs consist of node layers. These layers are classified into input layers, one or more layers named hidden layers, and an output stage layer (see Figure 16) [49–53]. In addition, each artificial known neuron connects to another with different weights and information, which is then distributed for learning during training [49,50]. Each neuron has its threshold value: if the generated output for any individual node is greater than the defined threshold value, the node is triggered to send data to the next network layer. If it does not reach the value, then no data will pass to the next layer [50–53]. An ANN can learn from its experience, take action, and make decisions when it faces a similar environment. The importance of an ANN can be summarized as ANNs are able to perform more than one function simultaneously and work with incomplete knowledge. In addition, it is widely used in control applications, as proposed in this article, because of its flexibility with data. An ANN can be proposed to model non-linear and complex relationships based on its advantage of distributed memory [49,50,53].

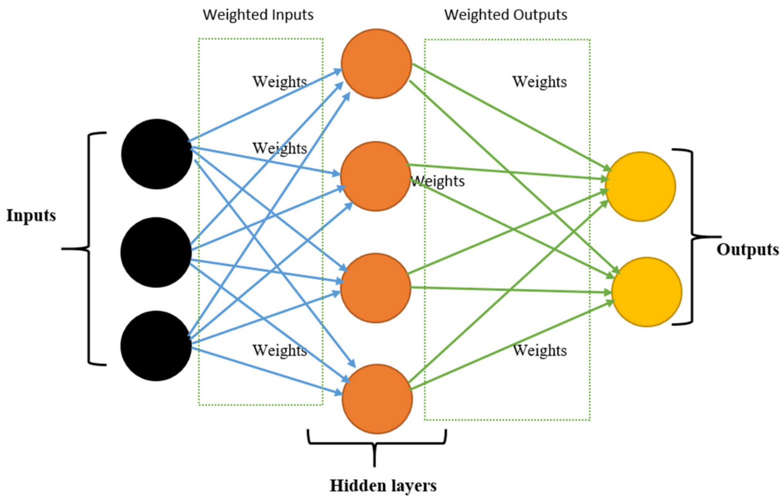

Figure 16. Simple architecture of ANN.

7. Results and Discussion

This section covers the results in detail. As mentioned, the main target of the paper is to design, implement, and test a small-scale BMS. The proposed BMS includes monitoring and controlling some variables, such as temperature, humidity, smoke detection, lighting level, and ventilation system. IoT technology is the core of the system. A novel integration of PLC (Siemens S7-1200) with Node MCU ESP8266 and Arduino Mega 2560 has been connected to efficiently perform the level of monitoring and control. The IoT-based ThingSpeak platform is used to publish and visualize the collected data from different sensors used in the experimental test rig. Further, it can sound an alarm if the sensors measure a value greater than a certain setting value. Several channels can be provided by ThingSpeak while allowing users to fully monitor channels publicly or privately or to react once a specific condition occurs (using Twitter, as an example). In addition, IoT is also established based on the Bylink package to monitor the data and control the operation of the system services. The system is designed and implemented practically to suit the features proposed in this research. The experimental system consists of three main stages, which are design of electrical and electronic circuits through simulation programs and testing them first before connecting them. The second stage is to test the experimental components through several checks and calibrations of the sensors used, as well as testing control devices, IoT, motors, lamps, relays, and contactors. As for the third stage, it is concerned with installation and connection of components to achieve the purpose of this research. When implementing the experimental part, security and safety standards were considered.

The results are divided into three scenarios, as discussed below:

- Scenario 1: Monitoring and Control of Temperature and Humidity

A DHT11 sensor is used to measure the temperature and humidity inside the laboratory that will be used to control the operation of the air conditioner. The sensor's collected data are then displayed on the LCD (Character LCD Module 20 Char. × 4 Lines) via Node MCU ESP8266 with a parallel path, and the sensor is connected directly as an input to the PLC. Based on a ladder diagram program for the PLC, the air conditioning emulator is connected as the digital output (DO) of the PLC to control the operation of A/C based on the measurement of the DHT11 sensor. The A/C and DO pins will be connected via a relay module to protect the PLC from any increasing current that could damage the PLC device. Figure 17 depicts the PLC ladder diagram for A/C operation control. Operation of A/C based on a PLC program can be completed in different ways, such as manual control using pushbuttons, temperature or heat sensors, and IoT mobile apps or IoT web dashboard (ThingSpeak and Bylink). The ESP8266 card is used to send the data to the ThingSpeak IoT platform, Bylink web dashboard, and Bylink mobile application. The ThingSpeak platform can send a Twitter message in the case of abnormal conditions of temperature and humidity measurement, for example (Figure 17). The IoT ThingSpeak can send out an alarm message when temperature and humidity exceed 20 degrees Celsius and 30%, respectively (see Figure 18). Monitoring of humidity-based IoT ThingSpeak platforms is shown in Figures 19 and 20. In addition, temperature reading is displayed in Figures 21 and 22. The published chart of humidity and temperature can be presented as several samples or samples with date and time, as shown in Figures 19–22. The ThingSpeak can display the sensors data as a numerical display (see Figure 23). We set a certain temperature and humidity as threshold values to show the visual alarm in red (alarm on) and green (normal condition). As a result, the visual alarm is shown in Figure 24. Figure 25 shows the humidity and temperature measurements on the Bylink mobile apps.

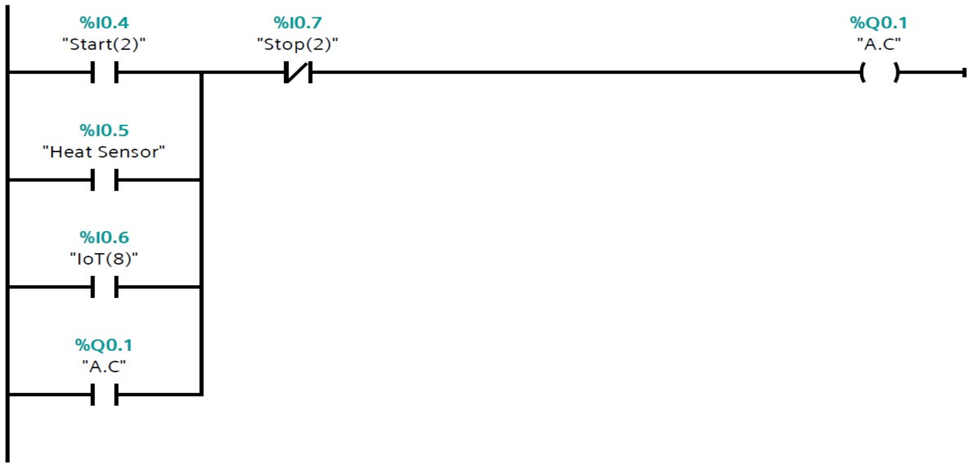

Figure 17. Ladder diagram of PLC for A/C operation control.

Figure 18. ThingSpeak-alarm-based Twitter.

ThingSpeak provided data storing where over 3500 samples have been taken for one day using the channels provided by ThingSpeak while allowing users to fully monitor channels publicly or privately or to react once a specific condition occurs (using Twitter, as an example).

- Scenario 2: Monitoring and Control of Lighting System

The BMS includes control and monitoring of the lighting-system-based IoT platform. An infrared (IR) sensor is used to perform this task based on the program in Figure 26. If the IR sensor detects a person nearby, it generates a signal, which is applied to PLC inputs, resulting in activation of PLC output pins. Following this action, the lighting system will be adjusted to accommodate the number of people in the laboratory. The sequence of lighting operation is designed based on software in Figure 26. Furthermore, the ESP8266 can send an order to a PLC to control the IoT lighting system (see Figure 26). To operate the lamps manually, the manual pushbutton can be used as an input to the PLC. The status of the IR sensor can be published via the ThingSpeak platform and Bylink IoT dashboard, as shown in Figure 27. As a conclusion, users can operate the lighting system in three ways (see Figure 26), such as manually, via IoT (Bylink and ThingSpeak), or via IR sensor.

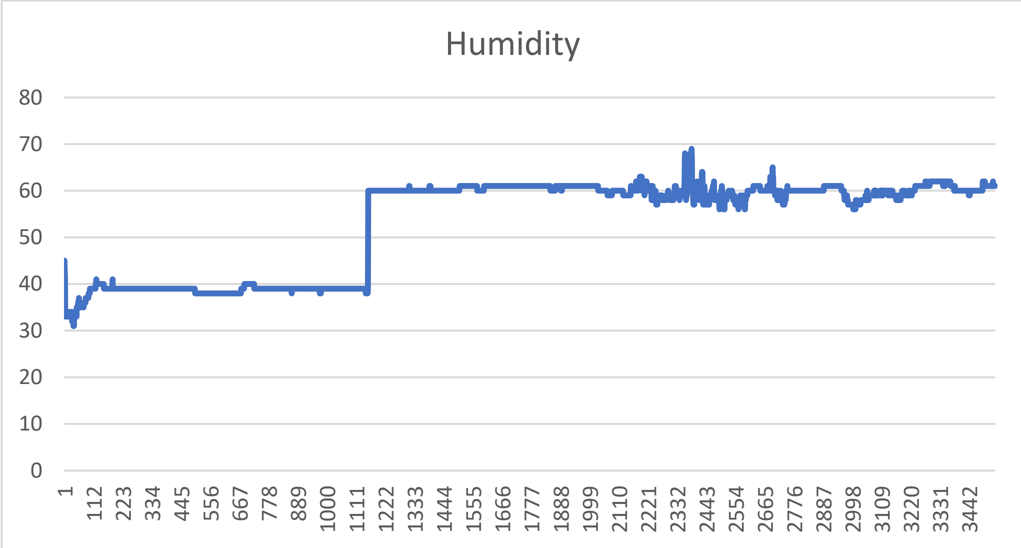

Figure 19. Humidity-monitoring-based ThingSpeak platform.

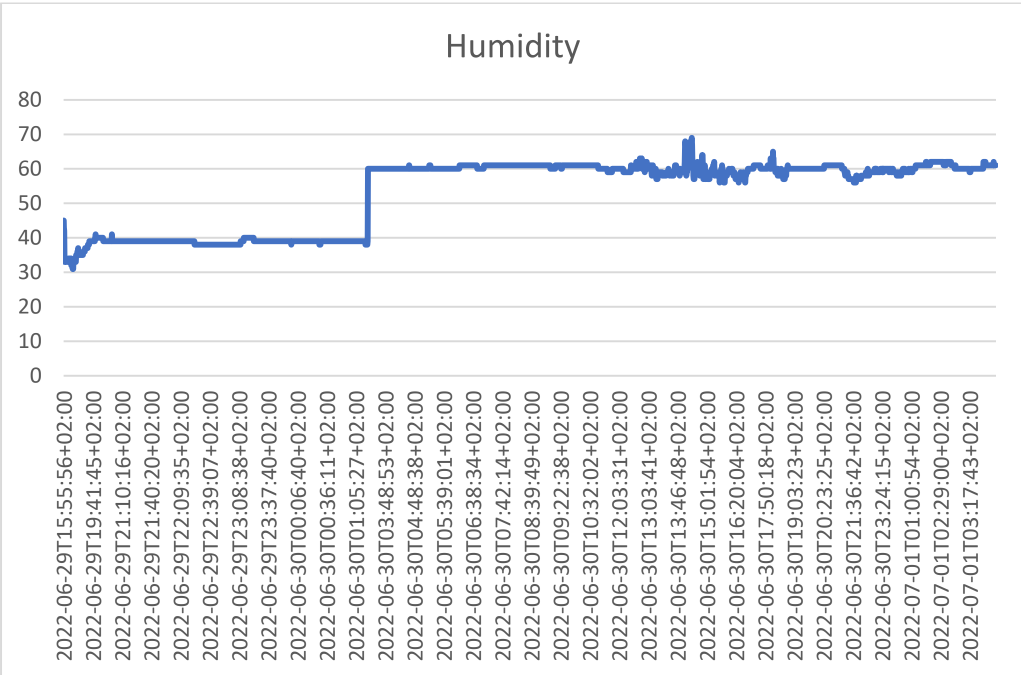

Figure 20. Humidity-monitoring-with-date-based ThingSpeak platform.

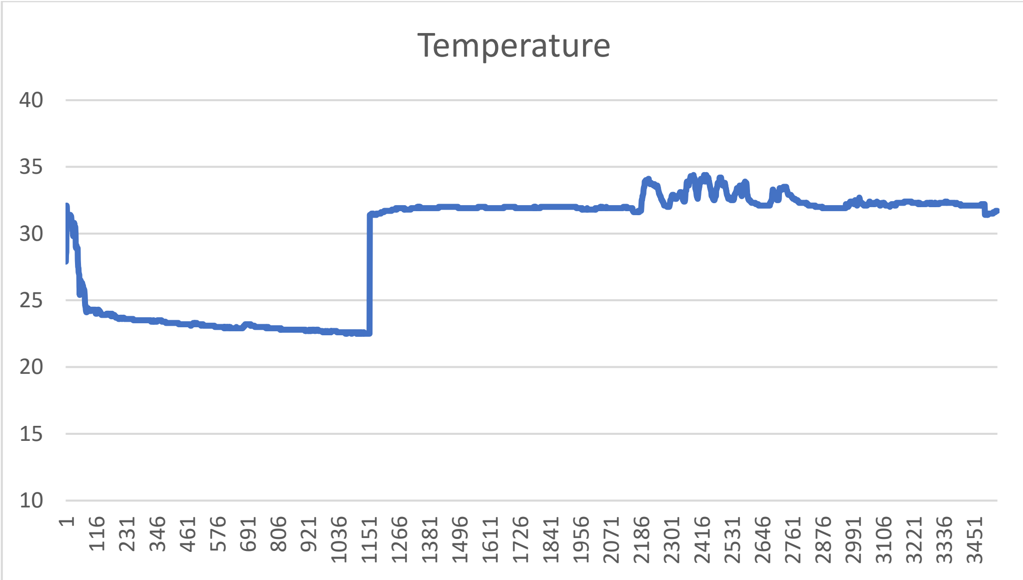

Figure 21. Sampled-temperature-data-based ThingSpeak platform.

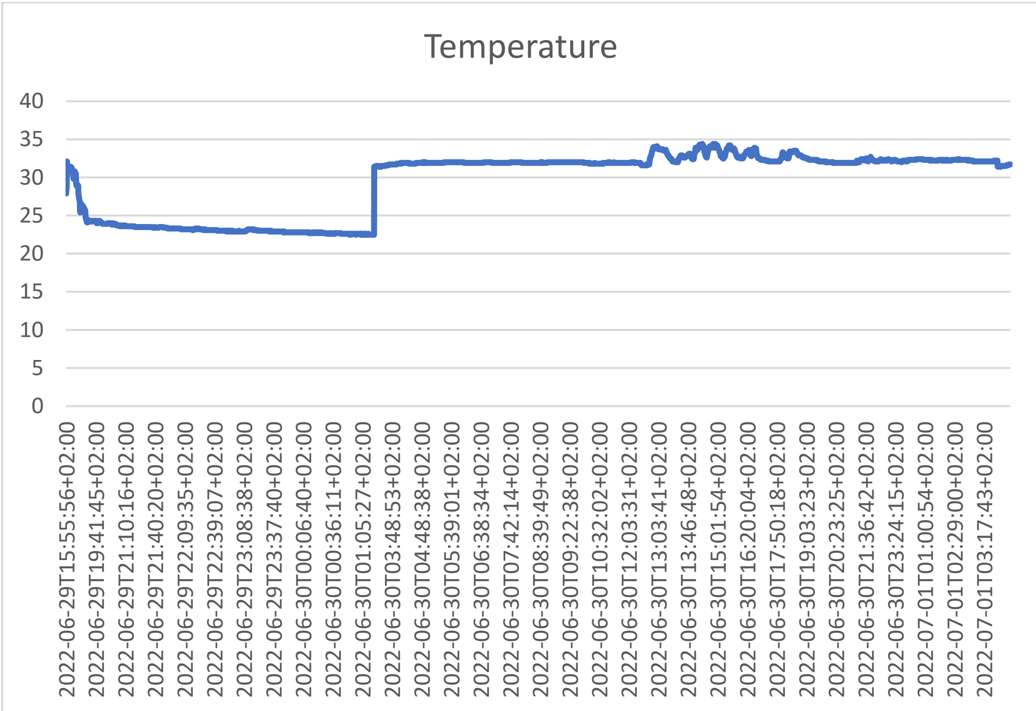

Figure 22. Temperature-monitoring-with-date-based ThingSpeak platform.

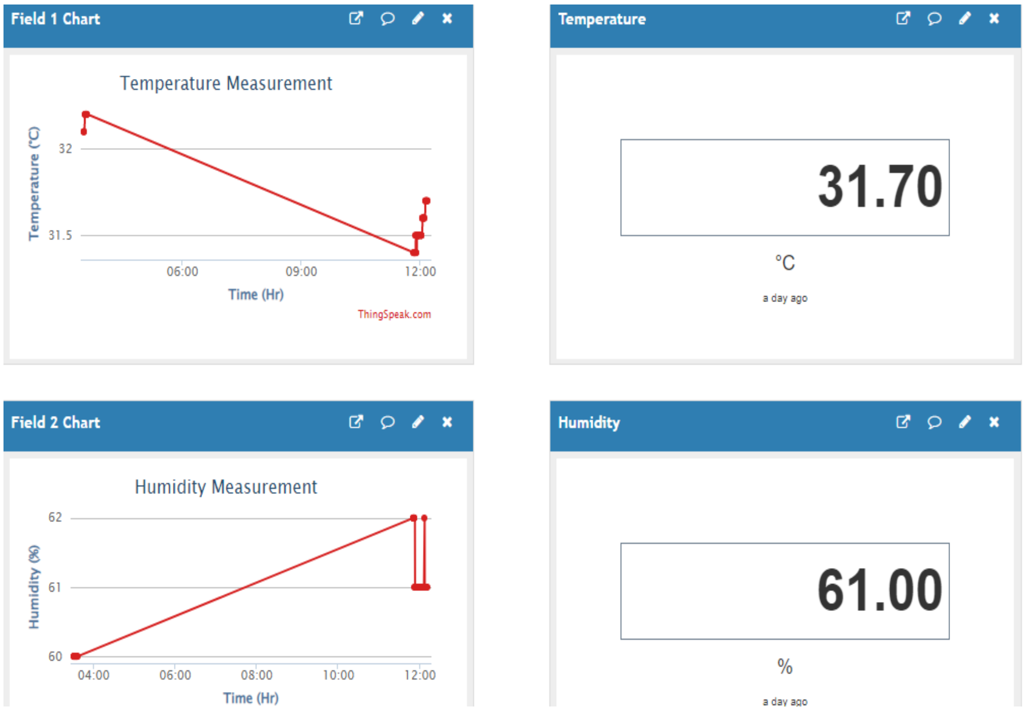

Figure 23. ThingSpeak data platform.

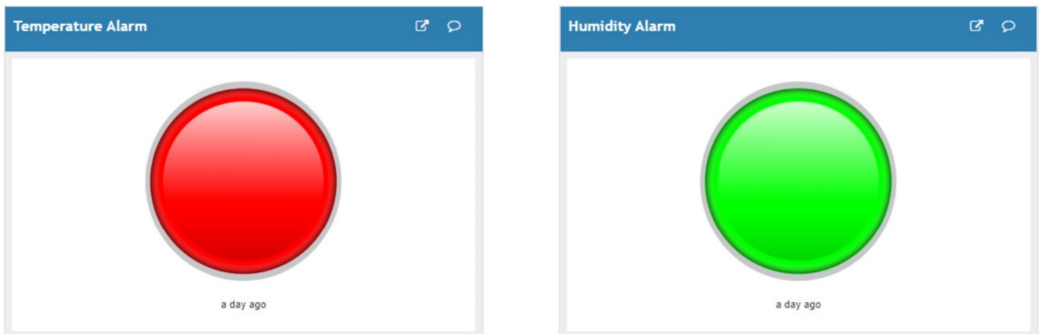

Figure 24. ThingSpeak alarm platform.

Figure 25. Monitoring-temperature- and humidity-based Bylink mobile application.

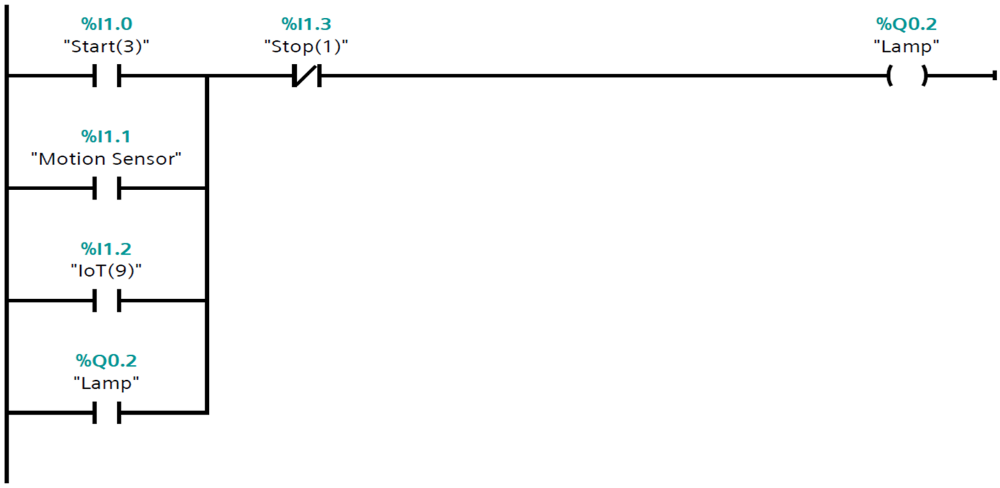

Figure 26. Ladder diagram of PLC for lighting system operation control.

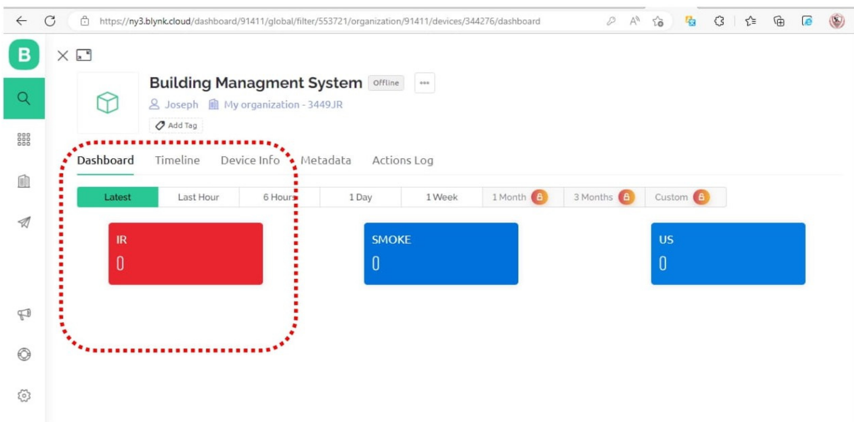

Figure 27. Monitoring-IR-status-based Bylink dashboard.

- Scenario 3: Monitoring and Control of Fire System

A smoke sensor is used to detect any smoke in the laboratory and then operate the fire system to extinguish the fire. The fire alarm system can be triggered in three ways: through an IoT dashboard or mobile app, a smoke sensor, or a manual pushbutton. The smoke sensor data are sent to the ThingSpeak and the Bylink platform to be visualized and published via the esp8266 module. Based on the occurrence of smoke detection, the ventilation system must be operated. In this article, the operation of the motor fan for ventilation is designed to be controlled based on the air quality sensor. Further, the system could be excited based on manual operation, an IoT platform and dashboard, and the air quality sensor.

The ladder diagram is shown in Figure 28. This figure displays the possible ways that can activate the fire alarm system. Further, Figure 29 introduces the alarm and display of smoke sensor status on the Bylink IoT dashboard. Figure 30 depicts the software used for the PLC in the case of the ventilation system. The IoT system for motor fan operation is described in Figure 31. In Figure 32, the designed IoT dashboard for experimental BMS is shown.

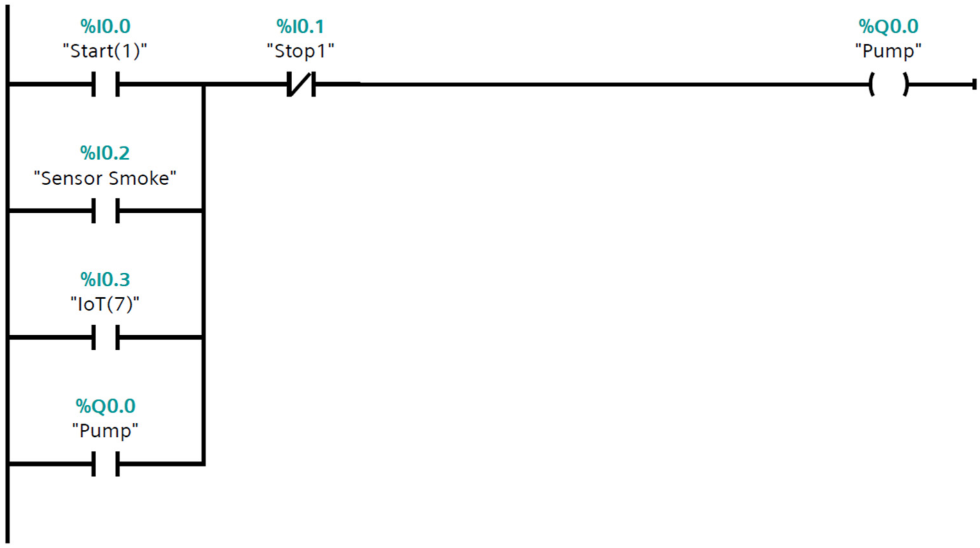

Figure 28. Ladder diagram of PLC for fire alarm system operation control.

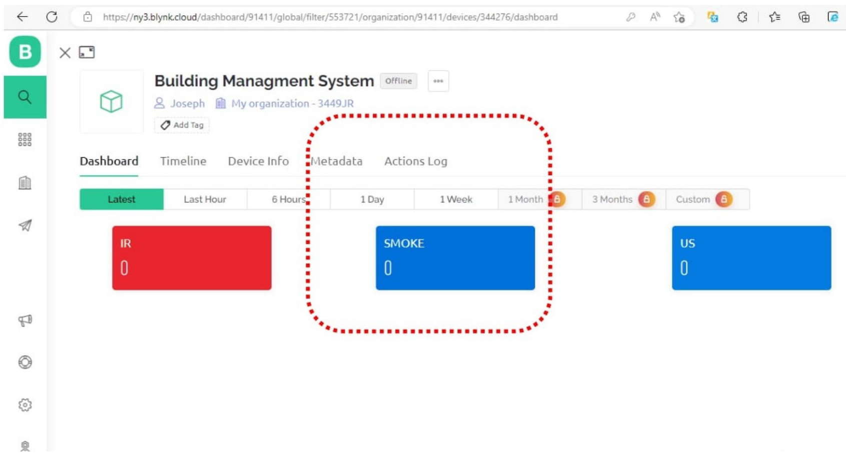

Figure 29. Monitoring-smoke-status-based Bylink dashboard.

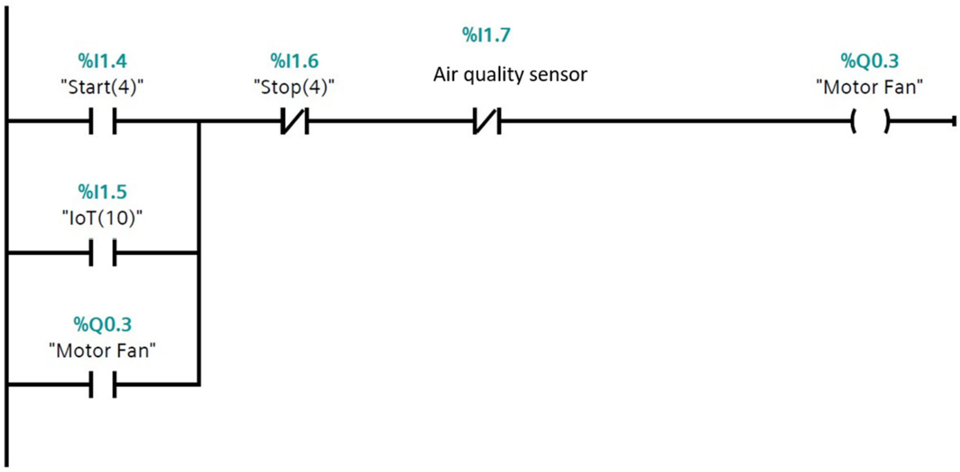

Figure 30. Ladder diagram of PLC for ventilation system.

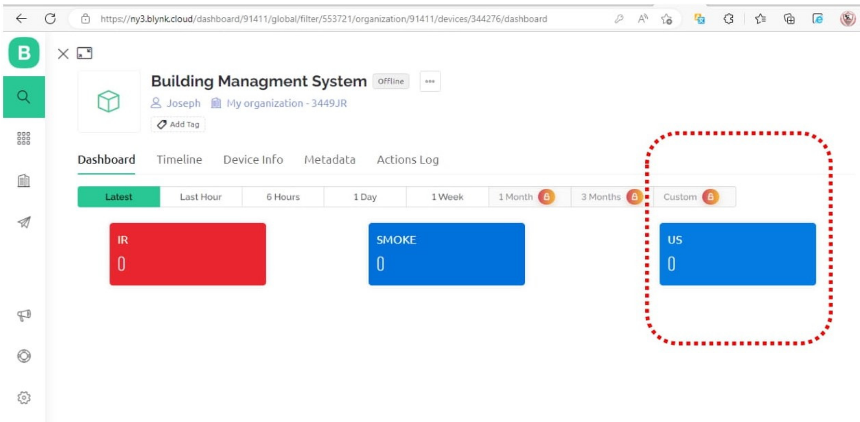

Figure 31. Monitoring-air-quality-sensor-status-based Bylink dashboard.

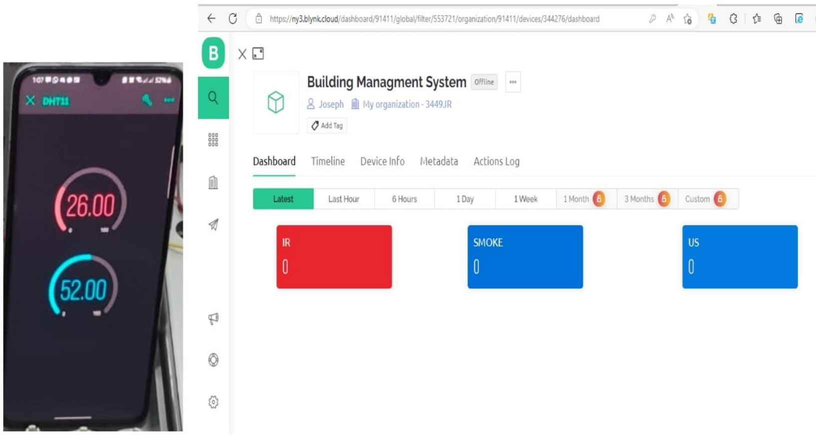

Figure 32. The IoT Bylink dashboard and mobile application for BMS.

- Scenario 4: Forecasting of Temperature-based Artificial Neural Network (ANN)

ThingSpeak can publish a measurement of the temperature sensor as a chart type and store the data in an Excel file, as shown in Figure 33. We exported data of around 3215 samples from open access channels of ThingSpeak to build a forecasting model of temperature. From Figure 33, it is very clear that IoT ThingSpeak can allow users to fully monitor channels publicly or privately or to react once a specific condition occurs (using Twitter, as an example). The ANN approach is proposed in this article to build the model due to many reasons. The reasons could be summarized as follows: ANN has the ability to store all sensors' information data on the whole network, the model can be built with insufficient knowledge, the network operates with good fault tolerance, and it also has the role of training different machines and performing parallel processing.

The structure of the ANN model is depicted in Figure 34. The ANN is built with three delayed temperature inputs and ten hidden layers, each with one output for the network. The Levenberg–Marquardt algorithm is used as a training algorithm due to the shorter required time. To build the model, we chose approximately 3000 samples. The samples are divided into three categories: 70% for training the network, 15% for validation, and 15% for testing the model. The mean square error (MSE) and regression value (R) are chosen as the evaluation criteria for the training model. The evaluation values in Table 1 demonstrate that the ANN model is acceptable based on a minimum MSE of around 0.04 for the training and testing phases and around 0.004 for the validation step. Furthermore, regression R values near 1 indicate a high degree of similarity between output and target temperature. The training performance of the ANN model based on different criteria is shown in Figures 35–38. Figure 35 presents the training regression, which shows a good model, while Figure 36 displays the error histogram with a value around zero. Moreover,

Figure 37 provides the best validation performance, which is around 0.004. The state of ANN training is depicted in Figure 38. To evaluate the model, several 215 samples are used to test the model. The MSE of the testing phase is around 0.026, which is very close to zero. The forecasting temperature and actual temperature are compared with a plot in Figure 39. Based on the discussed criteria, the ANN model is recommended for forecasting the temperature inside a laboratory.

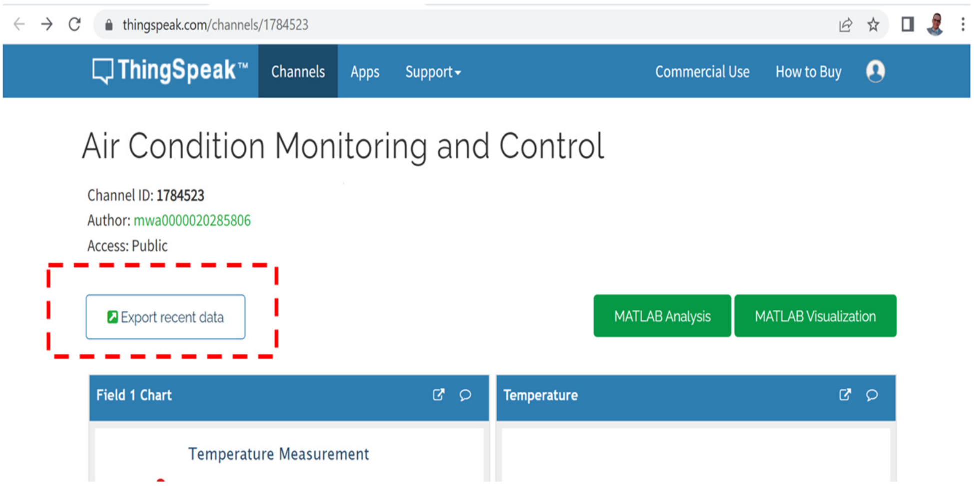

Figure 33. Export data of temperature sensor from ThingSpeak IoT platform.

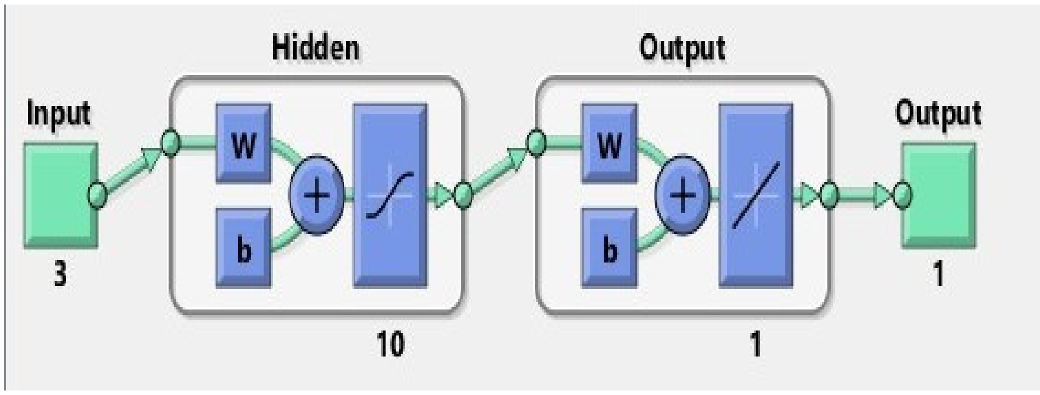

Figure 34. Structure of ANN.

Table 1. Training data of ANN model.

	Samples	MSE	R
Training	2100	0.0416	0.998
Validation	450	0.004	0.999
Testing	450	0.047	0.998

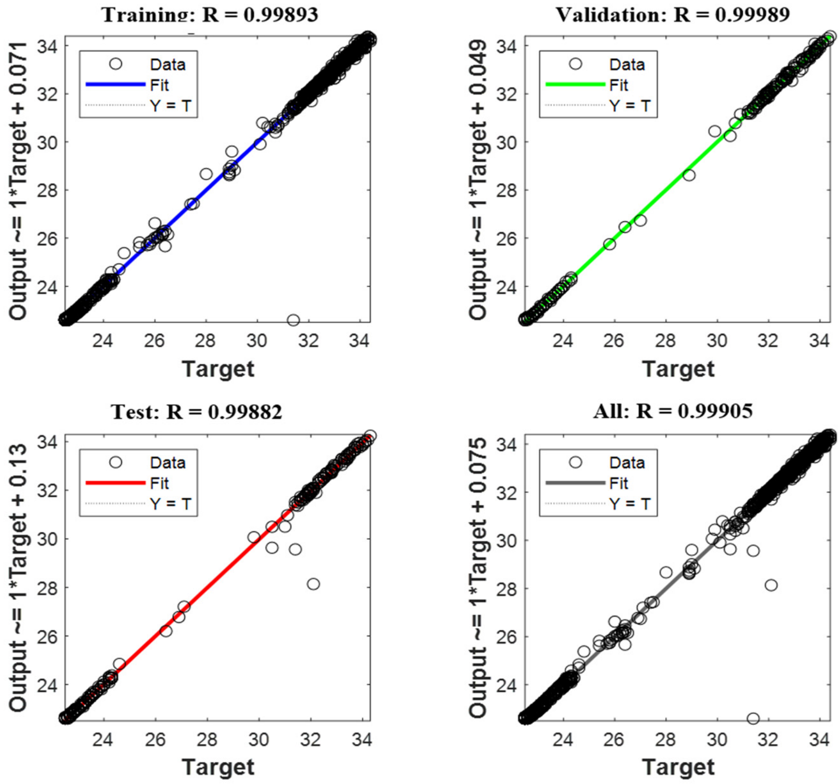

Figure 35. ANN training regression.

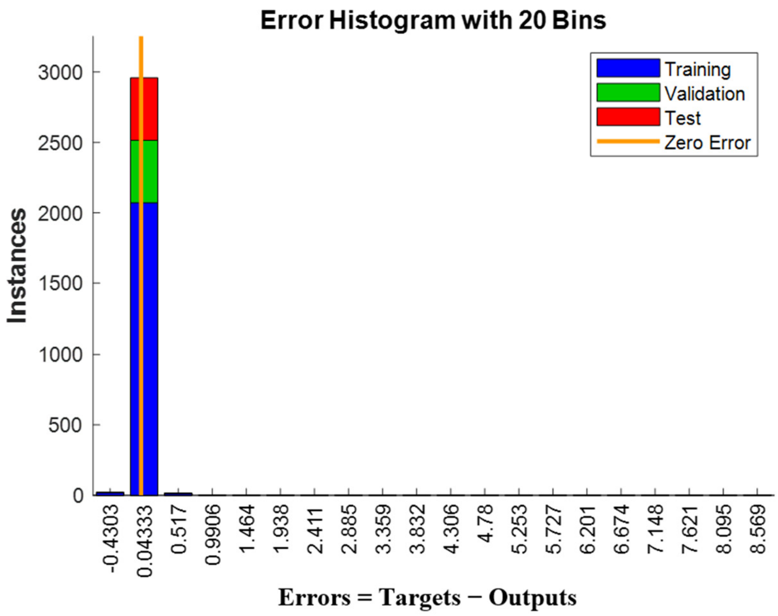

Figure 36. Error histogram with 20 bins.

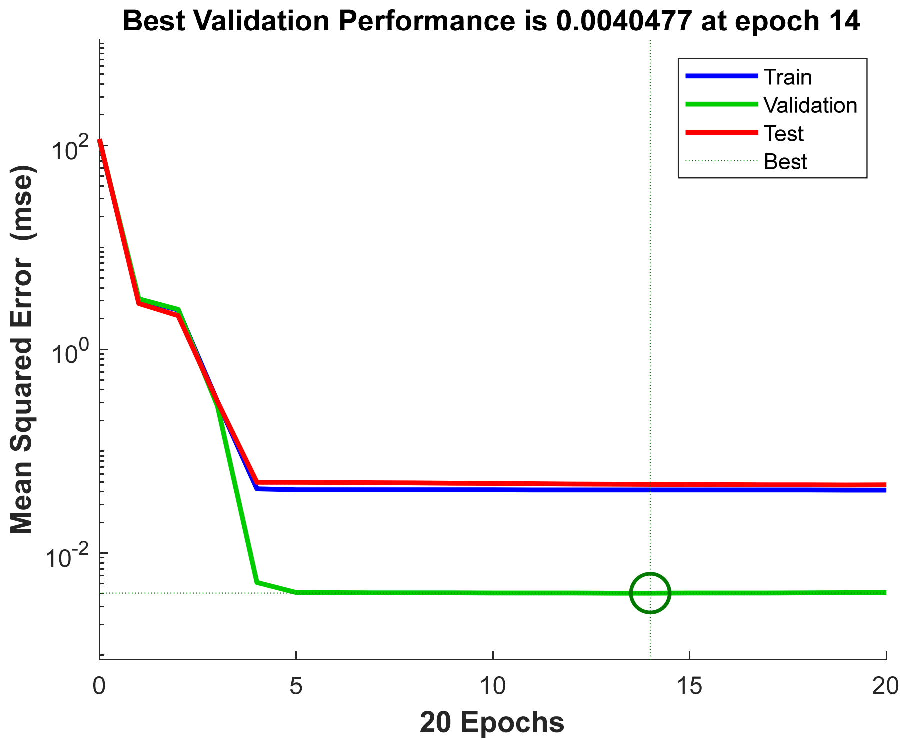

Figure 37. Best validation performance.

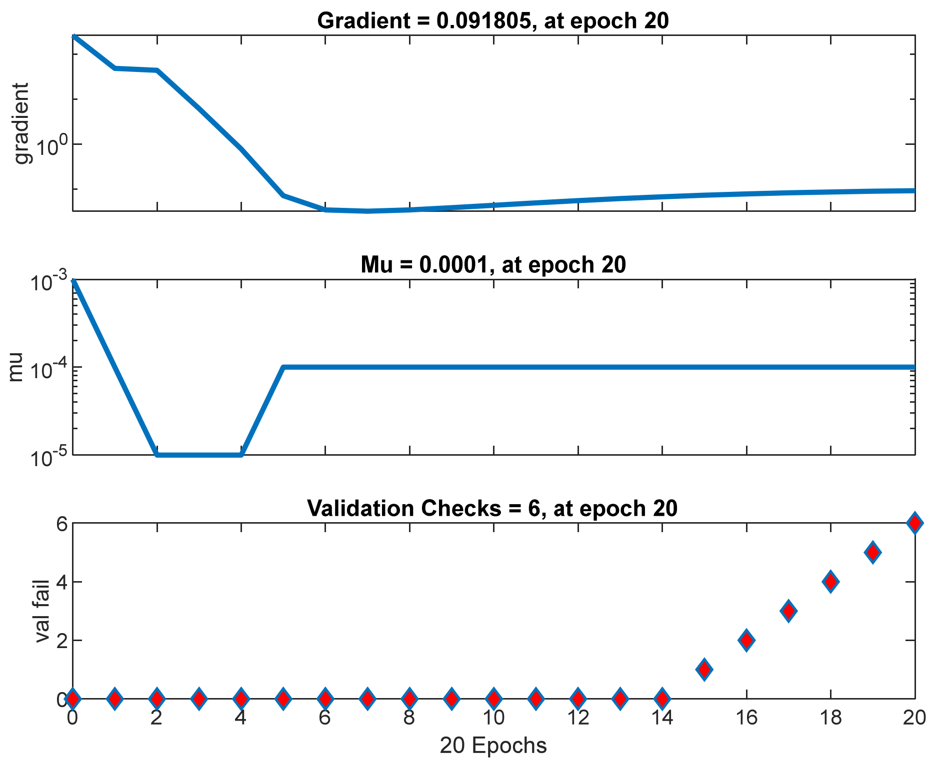

Figure 38. ANN training state.

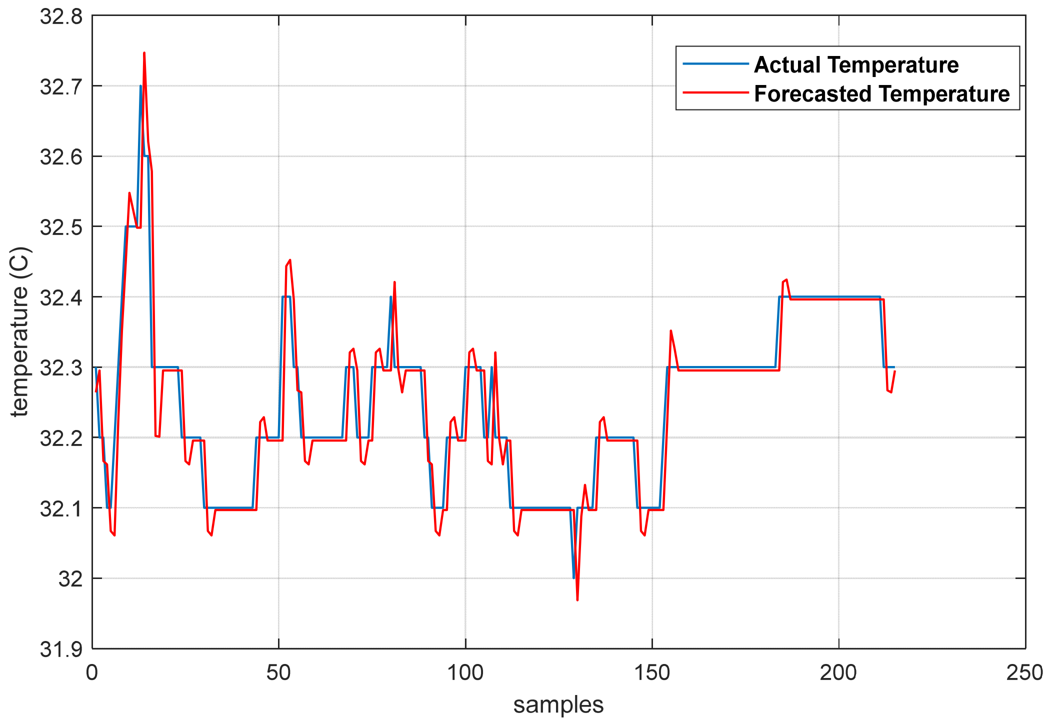

Figure 39. Forecasting temperature with actual temperature.

8. Conclusions

This paper discusses implementation of a smart system for an educational laboratory based on IoT technology and AI to manage energy consumption. The practical system has different controllers, such as Siemens S7-1200 PLC and Arduino Mega 2560, which makes the system more reliable and efficient. Hardware investigation of IoT is created through Node MCU ESP8266 to send and receive data based on Wi-Fi from and to PLCs and Arduinos. The IoT is designed by Bylink and the ThingSpeak platform. To check system reliability and performance, the proposed prototype BMS system was tested in a laboratory connected to various types of sensors (temperature and humidity sensors, motion sensor, smoke detector sensor, and air quality sensor). The sensors were linked to a dashboard with a visual and audible alarm system. The laboratory dashboards with physical parameters acquired from sensors were published and visualized via the Bylink dashboard and ThingSpeak. The collected data from temperature sensors were used to build an ANN model to forecast temperature. The ANN model showed a distinct approach to forecasting temperature based on good performance and evaluation criteria. In addition to the hardware BMS, an architectural BMS design was also proposed in this paper. As concluded, the proposed experimental BMS system could control operation of air conditioning, ventilation, firefighting, and lighting systems, monitor the status of sensors, and forecast the temperature. As a result, it can save energy and reduce energy consumption in the laboratory. In future work, voltage and current sensors will be used to measure voltage and current in the system. In addition, a camera will be suggested to count the number of persons inside the laboratory based on the YOLOv5 algorithm. The research will be expanded to five laboratories linked by a PLC network. Machine learning will be suggested for forecasting power consumption based on voltage and current data.

Author Contributions: Conceptualization, M.E.-S.M.E., M.S.E.-S. and J.V.W.L.; methodology, M.E.-S.M.E.; software, A.M.E.-s. and J.V.W.L.; validation, A.H.O., M.S.E.-S. and J.V.W.L.; formal analysis, A.M.E.-s., A.E.F. and M.S.E.-S.; investigation, M.E.-S.M.E., A.E.F. and A.S.A.E.M.; resources, M.S.E.-S.; data curation, A.H.O.; writing—original draft preparation, M.E.-S.M.E. and A.E.F.; writing—review and editing, M.E.-S.M.E., A.S.A.E.M. and J.V.W.L.; visualization, A.M.E.-s.; supervision, M.E.-S.M.E.; project administration, A.H.O. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to extend their sincere thanks and appreciation to the Academy of Scientific Research and Technology (ASRT), Cairo, Egypt for their assistance, advice, and provision of the components required to complete this research.

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

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