Design and Implementation of a Radio Frequency Identification Automating Lighting and Electrical Appliance Control in An Office System

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Received: 07th Dec 2025 | Received Revised Version: 29th Dec 2025 | Accepted: 19th Jan 2026 | Published: 07th Feb 2026

Volume 08 Issue 02 2026 | Crossref DOI: 10.37547/tajet/Volume08Issue02-06

Abstract

Radio Frequency Identification (RFID) technology offers an innovative approach to automating lighting and appliance control systems in office environments. This abstract outlines the design and implementation of an RFID control system that manages lighting and appliances in an office setting. Authorized RFID cards are used to activate appliances upon entry, while continuous RFID scanning ensures that devices are turned OFF automatically when no card is detected. The system was designed using an Arduino Nano microcontroller, an MFRC522 RFID reader, and a 5V relay module. Simulations were conducted using Fritzing, Tinkercad and Arduino IDE to validate practical circuit design and control logic. The physical prototype was tested in an office environment, demonstrating effective control of lighting and a connected 746W A/C appliance. The system was implemented in an office with ten 18W LED lamps achieving a lux level of 500 and 1 HP air conditioner. The ratio of controlled light with RFID to unmonitored RFID is 1:3 indicating that the RFID controlled light energy consumption is 67% lower. The results highlight the potential of RFID technology in modernizing office spaces, improving resource management, and minimizing energy wastage.

Keywords: RFID (Radio Frequency Identification), AIDC (Automatic Identification and Data Capture), RFID card, RFID reader.

Cite This Article: Oyeleye, M. O., & Iyanda, O. I. (2026). Design and Implementation of a Radio Frequency Identification Automating Lighting and Electrical Appliance Control in An Office System. The American Journal of Engineering and Technology, 8(2), 44–53. https://doi.org/10.37547/tajet/Volume08Issue02-06

1. Introduction

1.1 Background of study

The increased interest in home automation and smart lighting control in recent times can be attributed to technological progress and an increasing demand for convenience, energy efficiency, and security in residential environments. Conventional means of controlling lighting, like manual switches and remote controls, frequently do not offer the level of adaptability and automation functionalities sought after by residents [1].

Escalating electricity tariffs are posing a significant challenge for institutions globally, including universities. This initiative aspires to not only mitigate the financial encumbrance faced by the university but also to foster a more sustainable in electrical saving cost in future. A significant portion of this expenditure can be attributed to avoidable energy waste. Traditional lighting systems, despite being essential, often operate continuously regardless of occupancy. This lack of adaptability leads to lights being left on in unoccupied spaces, contributing to unnecessary energy wastage.

One of the most promising technologies that can help achieve this is through the use of Radio Frequency Identification (RFID) technology. It is a member of the family of Automatic Identification and Data Capture (AIDC) due to the usage of low-power radio waves to transfer data between the reader and card [2]. RFID systems employ small, wireless devices called RFID cards. It is a miniature electronic circuit capable of storing information, processing and radio communication [3]. The cards derive their power while they are inside the signal range of the Reader (up to 15m) [4]. It transmits unique identification codes when in proximity to a reader device. RFID reader is a device used to gather information from the RFID card. The RFID reader uses radio waves to transfer the data from the RFID card to the reader [5]. When the RFID card comes within the range of the scanning antenna, an electromagnetic (EM) energy will trigger the RFID card to start sending information in the form of radio waves. These radio waves are then picked up by the antenna and will then send to the reader which will then decode the waves as digital information.

By integrating RFID technology with home lighting systems, it becomes possible to turn lights and the appliances on or off simply by presenting an authorized RFID card to a reader [6].

The primary objective of this is to design and implement an RFID-based control switch system for an office. The system aims to provide a user-friendly and secure method for authorized individuals to control the lights and the air-conditioner in the office, eliminating the need for manual switches. Additionally, the system can be configured to automatically turn lights on or off based on the presence or absence of authorized RFID cards, potentially leading to energy savings and enhanced security [6].

1.2. Overview of Lighting Systems

An essential element of quotidian existence, illumination significantly influences our security, ease, and efficiency of task performance. The utilization of lighting within architectural structures consumes substantial energy; hence, it is imperative to prioritize conservation initiatives in this domain [7]. Lighting in buildings uses a large amount of energy, so it is important to focus conservation efforts there [8].

Modern lighting systems outperform conventional systems in nearly every aspect, especially in terms of energy efficiency, longevity, and user control [9]. While the initial cost may be higher, the savings in energy and maintenance costs make modern lighting systems more economical in the long run [10]. Modern lighting not only enhances the aesthetics of a space but also provides the flexibility to create more comfortable and productive environments [11]. Additionally, automatic lighting systems can be programmed to adjust lighting levels depending on the time of day or specific user preferences, further optimizing energy consumption and increasing user comfort [12].

2. Methodology

The methodology used in this research includes both theoretical and practical aspects.

The design and simulation of the RFID-controlled light switch were initially carried out using special software tools. This includes modeling the circuit components, RFID reading interface, and control logic, followed by rigorous simulations to validate the functionality and performance of the system under various conditions. The theoretical design is then translated into a physical prototype. Prototype development includes the selection and integration of suitable hardware components such as RFID readers, microcontrollers, relays and lighting fixtures. The prototype is thoroughly tested and refined to ensure its reliability and compliance with design specifications. Providing a brief contextual overview, key components such as the RFID Sensor (MFRC522) and card, Arduino nano microcontroller, 5V Relay, and a buck Converter for stepping down (reduce) a higher DC voltage to a lower DC voltage efficiently.

2.1. Data Collection

Data was collected from the concerned office. The collected data include office space dimensions and the existing installed number of lamps.

2.2. Steps Taken to Achieve the Objectives

2.2.1 Design of a Lighting System for the Office

In order to achieve (design of a lighting system for the office), measurement of the office was taken using measuring tape. The Lumen equation (equation 1) was used in order to determine the number of lamps to be used.

$$N = \frac{A \times L}{U_f \times M_f \times L} [13] \qquad \text{Equation (1)}$$

Where A is area of the office room; N is number of Lamps to be used; L is required lux

level for the office space; Uf is utilization factor; Mf is maintenance Factor and L is lumen output per lamp.
Uf is 0.7 [14]
Mf is 0.9 [14]

2.2.2. Design of the RFID control switch system

It utilizes an MFRC522 RFID reader to detect RFID tags or cards and controls a relay switch based on the presence of a registered card.

The device allows for the registration of new RFID cards by holding down two push buttons simultaneously for a period of 2 seconds. When this happens, the system enters card registration mode, indicated by the green LED turning on. In this mode, the RFID reader actively scans for a new card to be registered.

When a new card is detected in registration mode, its unique UID is stored in the EEPROM, and the green LED confirms the successful registration by remaining on for a brief period. Once the card is registered, the system exits the registration mode, and the green LED turns off, while the red LED remains off to indicate the presence of a valid card.

2.2.3 Simulation of the RFID-controlled control switch system on Arduino

Figure 1 shows the Arduino codes. [15].

Figure 1a

Figure 1b

Figure 1c

Figure 1d

Figure 1e

Figure 1a to Figure 1e is a single picture but was broken down into parts to show all the codes visibility.

The circuit is then simulated in Arduino IDE to check its functionality. During the simulation, virtual RFID cards with predefined UIDs are presented to the RFID sensor and the reaction of the relay and light bulb is observed. Its integration with the Arduino Nano is achieved through the Serial Peripheral Interface (SPI) communication protocol, along with a dedicated reset pin.

The Reset (RST) pin on the MFRC522 module was connected to Digital Pin 9 of the Arduino Nano. This pin is crucial for initializing or resetting the RFID reader, ensuring it starts in a known state for reliable operation.The Serial Data (SDA) pin, also known as the Slave Select (SS) pin, on the MFRC522 module was connected to Digital Pin 10 of the Arduino Nano. In SPI communication, the Slave Select pin enables communication with a specific slave device, in this case, the RFID reader.

The Serial Clock (SCK) pin on the MFRC522 module was connected to Digital Pin 13 of the Arduino Nano. This pin provides the clock signal that synchronizes data transfer between the Arduino and the RFID reader, a fundamental aspect of SPI communication. The Master Out Slave In (MOSI) pin on the MFRC522 module was connected to Digital Pin 11 of the Arduino Nano. This pin is used by the Arduino (the master in this SPI setup) to send data to the RFID reader. The Master In Slave Out (MISO) pin on the MFRC522 module was connected to Digital Pin 12 of the Arduino Nano. This pin is used by the RFID reader to send data back to the Arduino.

The Voltage Common Collector (VCC) pin on the MFRC522 module was connected to the 5V pin of the Arduino Nano. This provides the necessary power supply for the RFID reader to operate. Various scenarios are simulated, e.g. showing a valid card to turn on the lights, showing an invalid card, and removing a valid card to turn off the lights. Simulation is also used to fine-tune the timing and logic of the scenario Arduino code to ensure smooth and reliable operation of the light switch.

2.2.4 Power Consumption Calculation

In order to calculate the unmonitored (no controlled) operation and controlled operation, Load survey is calculated.

$$P = I \times V_S \times P_f \; X \; P_f \qquad \text{Equation (2)}$$

Where I is current; P is total power; Pf is power factor; Pf is 0.8.

2.2.5 Construction of the Hardware

After successful simulation, the circuit is built on a breadboard. The components are carefully placed and connected together according to the circuit diagram designed in Fritzing and Tinker cad Circuits. Jumper wires are used to make the necessary connections between components and the Arduino Nano. The breadboard provides a flexible and practical platform for prototyping the circuit before transferring it to a more permanent setup. The Arduino Nano is programmed using the Arduino IDE to implement the control logic for the light switch. The code handles reading the RFID card UID, comparing it with stored valid UIDs, and controlling the relay to activate or deactivate the light bulb. After the successful operation of the breadboard model, the circuit is transferred to a printed circuit board (PCB) for a more durable and compact design.

2.2.6 Installation of the RFID control switch and Lighting system

The RFID controlled switch and designed lamps with the existing I HP A/C were installed using installation tools and materials.

3. Results and Discussion

The simulation results RFID-control switch is presented in Table 1 and Figure 2.

Table 1: Simulation Results RFID-control switch on Arduino IDE

TEST CASE	EXPECTED OUTCOME	ACTUAL OUTCOME
Registered card detected	Relay turns ON, Green LED ON	Relay turns ON, Green LED ON
Unauthorized card scanned	No action, Red LED ON	No action, Red LED ON
card detected after 5 sec	Relay turns OFF	Relay turns OFF

Figure 2 shows the result of the RFID control switch simulation on Arduino IDE

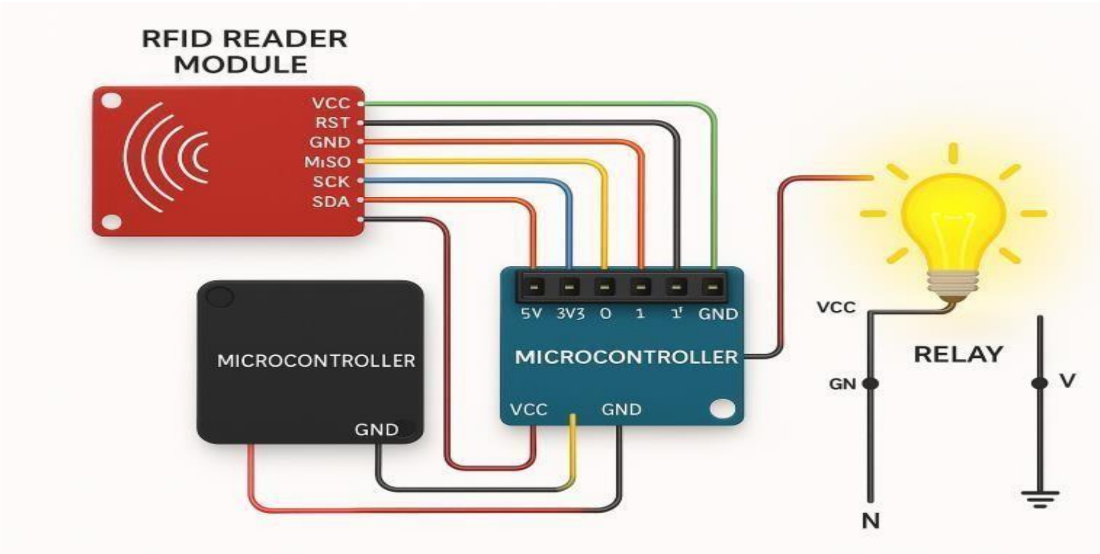

Figure 2: RFID Control switch system on Arduino

When the card is detected, the system checks whether the card matches the registered UID stored in the EEPROM. If the scanned card matches the registered card, the following actions occur:

i. The relay is switched on, powering the bulb.

ii. The red LED turns off, and the green LED turns on, providing visual feedback that a valid card has been detected and the system is operational.

If the registered card is removed from the vicinity of the RFID reader, the system performs periodic checks every 5 seconds. If the card is no longer in range, the relay is turned off, the green LED turns off, and the red LED turns back on to indicate that no valid card is detected, and the system is in its inactive state.

3.1 Result of the Installation of the RFID-controlled switch and Lighting system

The result of the designed lamps is presented in Table 2. The layout of designed lamps is presented in Figure 3.

Table 2: Designed lamps

Type of Lamps	Lamps Watts (W)	Total Area (m^2)	Lux Level (E)	Uf	Mf	Lumen	Designed Lamps ((L x B x E)/(Uf x Mf x L))	Recommended Lamps
LED	18	16.276	500	0.7	0.9	1300	9.9	10

Approximately 10 lamps is required to achieve a lux level of 500 in the office space The number of designed lamps used was determined with the Lumen equation where we took into consideration, the total area of the office space, Illumination level, Utilization factor, Maintenance factor and the Lumen Output per lamp. Ten new lamps were installed which is the recommended number of lamps. 500 Lux level was achieved with lux meter. The placement of the lamps themselves is determined taking into account factors such as office layout, desired lighting levels, and aesthetic preferences.

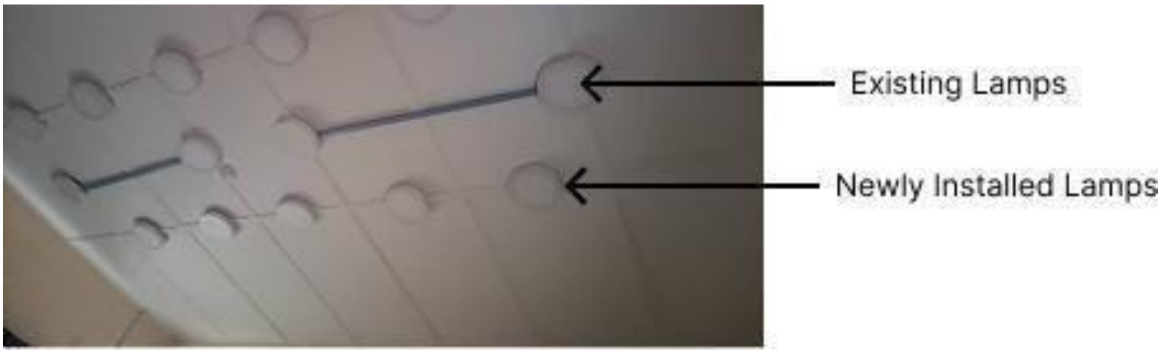

Figure 3: Existing and the newly installed lighting system in OFF position

The existing lighting system (the four lamps in the middle) was unable to provide the required lux level, for the concerned office space. The total illumination level of existing lamps was 200 lux which was lower than the required lux level of the office lamp (500 lux) [16].

3.1.1. Installation of the RFID control switch

The RFID Control Switch is presented in Figure 4.

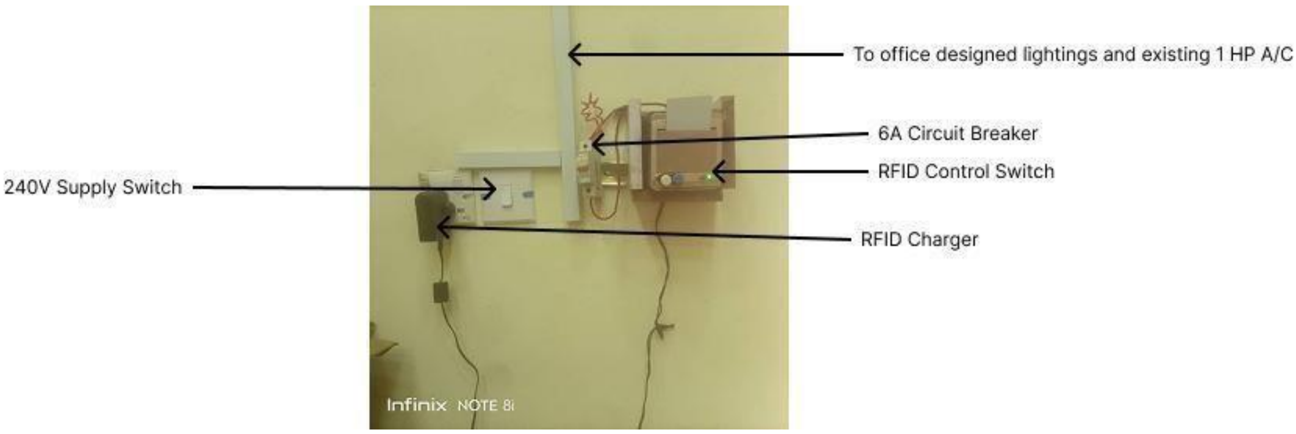

Figure 4: RFID Control Switch

The RFID controlled switch device is installed into the office's existing electrical infrastructure as in Figure 4. From Figure 4, the RFID control switch device is located at the right-hand side on entering the office. It is mounted at 1.2m height in accordance with the American Disable Act [17]. It is mounted on a wooden block fabricated to aid the mounting and support of the device. A charged charger is connected to the RFID controlled switch device where it is connected to the source to power the device and. The 6A circuit breaker is used to protect electrical circuits that are designed to handle a current of up to 6 amperes. It acts as a safety device to prevent overcurrent or short circuits that could potentially damage wiring, lighting systems and the air conditioner. Each of the ten 18-watt lamps are carefully wired to the controller, adhering to electrical safety standards and ensuring proper grounding.

Figure 5 presents the control switch of the A/C in OFF position before the RFID card was inserted into the reader. Also, Figure 6 presents A/C receptacle in OFF position and A/C IS OFF.

Figure 5: Control Unit OFF
(Red indicator ON)

Figure 6: A/C Receptacle OFF, A/C OFF

Figure 7 presents the ten lamps ON and A/C receptacle is ON thus A/C is ON (when the RFID card is inserted into the reader)

Figure 7: Installed control unit ON
showing ten lamps

Figure 8: A/C Receptacle ON, A/C ON

If the registered card is removed from the proximity of the RFID reader, the system executes periodic evaluations at five-second intervals. In the absence of the card within the designated range, the relay is deactivated, the green LED ceases illumination, and the red LED reactivates to signify that a valid card is not detected, thereby indicating that the system has entered its inactive state and the lighting system goes off.

3.1 Power Consumption Analysis

The office load survey is presented in Table 3.

Table 3: Office Load Survey

S/N	APPLIANCES USED	POWER RATING	QUANTITY	TOTAL POWER	CURRENT(A) $\frac{P}{V_S}$
1	Light Bulbs	18W	10	180W	
2	A/C	746W	1	746W	
				946W	4.8A

3.2 Testing of the System in the Office and Power Consumption Analysis

Testing of an installed RFID control lighting and A/C control system is essential to ensure proper functionality and reliability. The unit was tested in OFF and ON load base on Tables 3.

Power consumption analysis is presented in Table 4.

Table 4: Power Consumption Analysis

OPERATION	CONNECTED APPLIANCES (A)	OPERATION (hr)	CONSUMPTION (W) (HrD x ICA x VS x PF)	POWER SAVED (kW)	% POWER SAVED
Unmonitored	4.8	24	22.12kW	14.35kW	67%
RFID Control	4.8	8	7.37kW		

HrD is daily hour operation; ICA is connected appliances current; VS is supply voltage Based on the testing analysis, a 67% reduction in power consumption was achieved by effectively regulating appliance usage through the RFID system daily. This translates to substantial energy savings and associated cost reductions for the organization.

4. Conclusion

In conclusion, the RFID control switch system demonstrated its potential to enhance energy efficiency, reduce operational costs, and improve user convenience in office environments. By automating the control of lights and appliances, the system significantly reduced power consumption and extended the lifespan of electrical devices.

The ratio of controlled light with RFID and 1HP air condition in an office to unmonitored is 1:3 indicating that the RFID controlled light energy consumption is 67% lower. The cost of Bill of Engineering Measurement and Evaluation for redesigned lighting controlled, 1 number of 1HP air conditioner and RIFD control is One hundred and fifty-eight thousand, one hundred and fifty naira,

₦158,150, (Appendix A1). This cost is 75.6% of a unit of hourly consumption of energy in the study area [a unit is ₦209.50K]. Considering the cost of energy, the cost of this project is favourable to the end user. This project provides a cost-effective solution for an energy-efficient office environment.

Additionally, there is a possibility for integration with other components within a comprehensive smart building frame, Fridge, Printer and other related appliances. Through proper planning, strategic placement of hardware, and tailored software configuration, the system can be adapted to various office layouts and customized to meet specific requirements. This project's significance serves as the prototype, laying the ground for scalable and adaptable systems that meet the needs of users.

5. Recommendations

It is recommended that the RFID control unit should have more than one output in order to control each appliance connected to it effectively. Furthermore, integrating the RFID system with existing and new building management systems (BMS) can provide a unified control interface for greater energy savings and improved overall building efficiency.

The authors wish to express his appreciation to Ige Rehoboth and Idoko Innocent for data acquisition and other relevant information for the research. Also, Engr. Oladunni G. A. is appreciated for installation counseling.

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APPENDIX A

Table A1: Bill of Engineering Measurement and Evaluation

S/N	MATERIAL	QUANTITY	UNIT RATE (₦)	TOTAL COST (₦):(K)
1	18-watt LED Panel Light	11	4000	44,000.00
2	Black Tape	2	500	1000.00
3	Pattress box	1	150	150.00
4	Trunking pipe	5	1000	5000.00
5	2.5mm wire (Red and Black)	55 yards	500	27500.00
6	4mm wire (Red and Black)	30 yards	800	24000.00
7	Screws	50		2000.00
8	RFID Sensor and Tags	1	3000	3000.00
9	Sensor Casing	1	3000	3000.00
10	Arduino Nano	1	8000	8000.00
11	5V relay	2	2000	4000.00
12	Screw Connector	3	500	1500.00
13	3.5mm LED Light	2	250	500.00
14	Bug Strip	2	250	500.00
15	Buck Converter	1	2000	2000.00
16	PCB	2	2000	4000.00
17	Soldering Lead	1	2000	2000.00
18	Push Buttons	1	1000	1000.00
19	6A Circuit Breaker	1	5000	5000.00
20	Miscellaneous			10000.00
	TOTAL			**158,150.00**