

Evaluating the Performance of a Smart VCR System Using Python for Data Analysis Based on IoT

Paritesh Nim^{1,*}, Deepak Shukla², Amit Chandak³

Abstract

Commercial buildings use a significant amount of electricity, with around 60% to 80% being attributed to the (Heating, Ventilation, and Air Conditioning) HVAC system. Implementing Internet of Things (IoT) and smart sensors can help reduce this consumption by 10% to 30%. To lower the electricity usage of air conditioners, a study has proposed an IoT-based smart VCR system with sensors, meters, gateway, and cloud computing modules. This system is designed to collect data and regulate the VCR system based on the set temperature, while also monitoring real-time power consumption through datasets. This allows each meter to control its corresponding compressor's cooling and heating operations, enabling local energy management. Additionally, the energy-saving strategy helps alleviate the power grid burden and reduces the load on the power station, leading to a positive impact on greenhouse gas reduction. This temperature takes into account the occupants' well-being and reduces power consumption. Furthermore, this model utilizes eco-friendly refrigerants.

Keywords: ESP32, Python, Internet of Things (IoT), VCR System

INTRODUCTION

Automatic air-conditioning systems with passive infrared (PIR) sensors include the most advanced technology for detecting people and movement indoors. These systems can adjust the temperature, weather, and air-conditioning/heating patterns based on real-time data obtained using PIR sensors. The research method aims to increase energy efficiency, reduce operating costs, and increase the comfort of building occupants by ensuring that security is provided only when and where desired [2]. IoT-enabled smart air-conditioning systems use sensors and data analytics to instantly adapt to changes, increase personal comfort, and reduce energy wastage. These systems offer promising solutions for traditional communication problems. The performance metrics include energy efficiency, temperature control, response time, and customer satisfaction. Through rigorous testing and analysis, this research methodology aims to provide insights into the performance of smart air-conditioning systems [4–10].

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Working Principle

- *Thermostat sensing:* The system's thermostat senses the temperature in each cabin individually.
- *Temperature control:* Based on the sensed temperature, the thermostat signals the system to adjust the cooling output to maintain the desired temperature set by the user.
- *Compressor operation:* The compressor, a crucial component, is responsible for pressurizing and circulating the refrigerant throughout the system.

- *Evaporation and condensation:* The refrigerant undergoes a cycle of evaporation and condensation, absorbing heat from the indoor air (evaporation) and releasing it outside (condensation) the air circulation, and circulates the conditioned air through the ducts and vents, distributing it evenly in each cabin.
- *Multiple cabin control:* Automation features enable independent control of each cabin's temperature, allowing for personalized comfort settings in different locations [15–18].
- *Energy efficiency measures:* Modern systems often incorporate energy-efficient technologies, such as variable-speed compressors and smart sensors, to optimize performance and reduce energy consumption.
- *Remote monitoring and control:* Automation may include remote monitoring and control capabilities, allowing users to manage air-conditioning systems from different locations using smart devices. By combining these principles, the 1.5TR AC system ensures efficient and customized cooling for various cabins, adapting to different temperature requirements and locations.

RESEARCH AREA

Block C of the IPS Academy, Institute of Engineering and Science, Indore, comprises various faculty cabins for academic and research-oriented work. Out of all the cabins, five of them relate to a 1.5 T single AC [17–23]. Figure 1 shows an image of the installed window AC, whereas Figure 2 depicts the installation of the air circulation system through the (Chlorinated Polyvinyl Chloride) CPVC pipes into the faculty cabins. The air circulation in the cabins was controlled using a suction fan, as shown in Figure 3.

The current study attempts to develop IoT IoT-based smart VCR system for automatic control of installed AC according to the comfort of the users. To sense the activities in the cabin, such as the motion of the human or user and temperature within the cabin, a PIR sensor, relay switch, and ESP32 Microcontroller will be implemented [25–32]. Finally, the accumulated sensor data will be analyzed using Python, which finally suggests the operation of the AC. The sensors and connectors used are shown in Figures 4 and 8, respectively.



Figure 1. Installed 1.5 T window AC.



Figure 2. Air circulation system.

Components

- *PIR Sensor*—Passive infrared (PIR) sensor allows motion sensing, which is almost always used to detect whether a human has moved in or out of the sensor range.
- *Relay*—A relay protects the electrical system from too high a voltage or current, allowing the safe operation of any equipment it connects to [33–42].
- *ESP32*—It is a low-cost and highly versatile microcontroller used for various applications, including wireless communication, IoT (Internet of Things) devices, home automation, robotics, and embedded systems.
- *USB Cable*—To effectively, quickly, and properly gather or transfer data from one device to another.
- *Jumper*—A connecting wire allows the electric current to travel from one point to another without resistivity.



Figure 3. Air circulation controlling system using a suction fan.

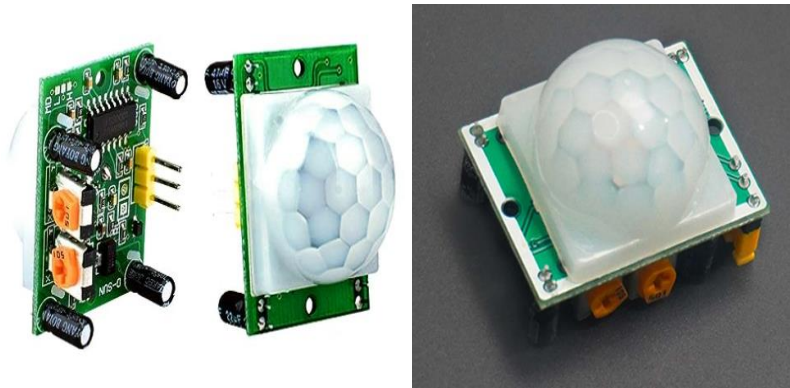


Figure 4. PIR sensor.

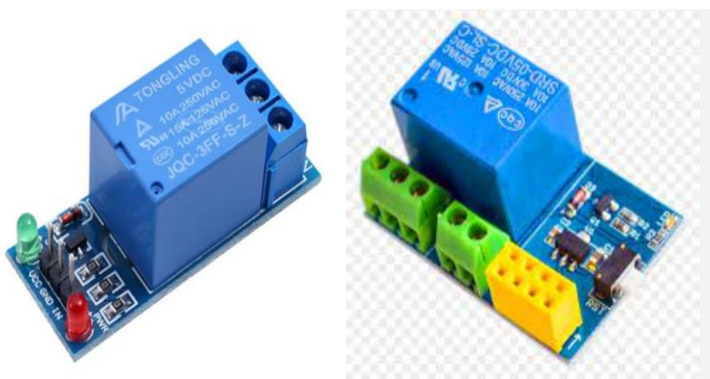


Figure 5. Relay switch.

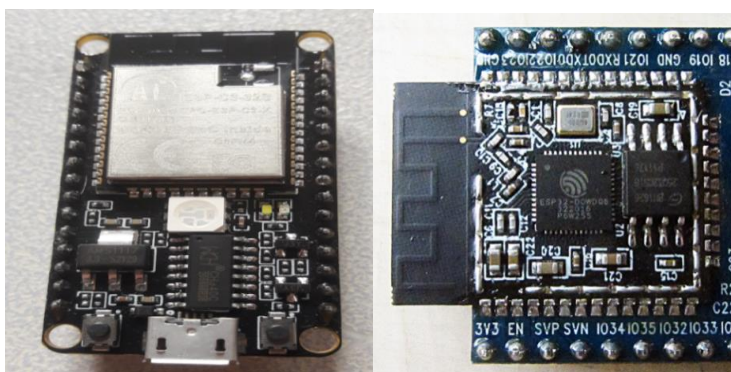


Figure 6. ESP32 microcontroller.

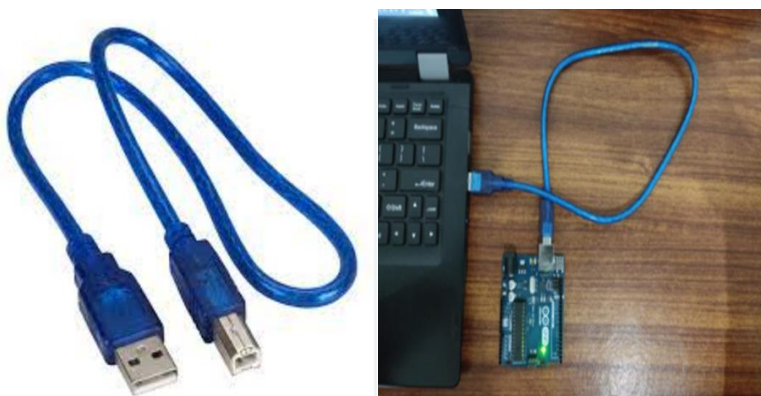


Figure 7. USB cable connector.

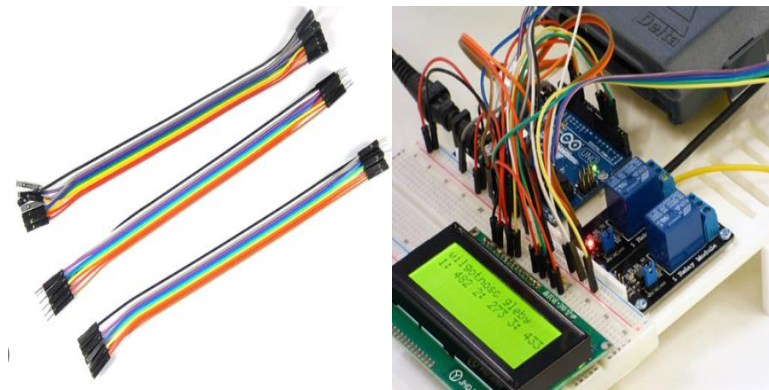


Figure 8. Jumper.

Objectives of the Study

Intelligent climate control solutions that leverage human presence detection have been developed and implemented to explore automation in air-conditioning systems with passive infrared (PIR) sensors. Dynamically adjusting heating, cooling, and airflow based on real-time occupants aims to optimize energy efficiency and enhance user comfort through this approach [43–52].

Current research activities are aimed at the following objectives.

1. Develop a sensor-based real-time data monitoring system for an Air Conditioner using PIR sensors, relay switches, and an ESP32 Microcontroller.
2. To analyze real-time data with the help of Python software.
3. Optimization of real-time data for providing users with comfortable sustainable solutions.

Enhanced energy efficiency, Improved System Performance, Optimized Load Management, Environmental Impact.

By addressing these objectives, a study on automation in VCR systems can contribute to the advancement of efficient, reliable, and sustainable cooling technologies.

LITERATURE REVIEW

Gupta proposed a smart IoT-based air-conditioning system by applying the concept of the IoT to provide a suitable thermally comfortable environment for the system to save electricity, power, and energy, as well as to control temperature [3].

Peng Yang proposed a discrete-time adaptive neural network control for WME and compression refrigeration systems by applying the concept of discrete adaptive neural network controllers for two refrigeration systems and the corresponding discrete-time adaptive updating strategy [1].

Ikram Mostefa Tounsi proposed a Numerical analysis of indoor air quality in an open room: The effect of the outlet opening by applying the concept of examining the impact of outlet position on indoor thermal comfort and heat transfer under turbulent conditions using the K- ϵ model Finite volume method was used to solve governing equations of continuity, energy, and concentration [16].

Maiorino proposed the ART.I.CO. (Artificial Intelligence for Cooling): An innovative method for optimizing the control of refrigeration systems based on Artificial Neural Networks is a novel control method based on the use of Artificial Neural Networks to optimize the operation of refrigeration systems equipped with a fixed-speed compressor. Artificial Neural Networks can be successfully applied to optimize the ON/OFF control loop of refrigeration systems, considering both plug-in and built-in solutions [24].

Gill proposed an adaptive neuro-fuzzy inference system approach to predict the mass flow rate of R-134a/ LPG using dimensional analysis to provide generalized dimensionless parameters and to reduce the number of input parameters. The adaptive neuro-fuzzy inference system provided the best statistical prediction efficiency [53].

METHODOLOGY

The methodology used to achieve the objectives of the research is shown in Figure 9.

Accumulation and the Installation of the Sensor

Coding for the ESP32 Microcontroller is done on the Arduino IDE Tools for controlling the servo motor which is connected to the PIR sensor which detects the motion and allows the flipper which is connected to the servo motor to open and close the air vent of the cabin while detecting the motion which is shown in Figure 10 and the installing and arranging of the servo motor, PIR sensor is shown in Figure 11.

The Collection of the Data

Digital thermostats were used to observe the temperature of cabin-1, cabin-2, and cabin-3, which were installed in the cabins, and the temperature of the cabins was observed with different occupancies of the cabins while the AC was running consistently [54, 55]. The thermostat installed in the cabins is shown in Figure 12.

Coding For the ESP-32 Microcontroller on the Arduino IDE, the calibration of the PIR sensor and coding for the servo motor testing are shown in Figure 13. The combined coding testing of the PIR sensor motion detection and servo motor degree rotation with motion detection are shown in Figure 14.

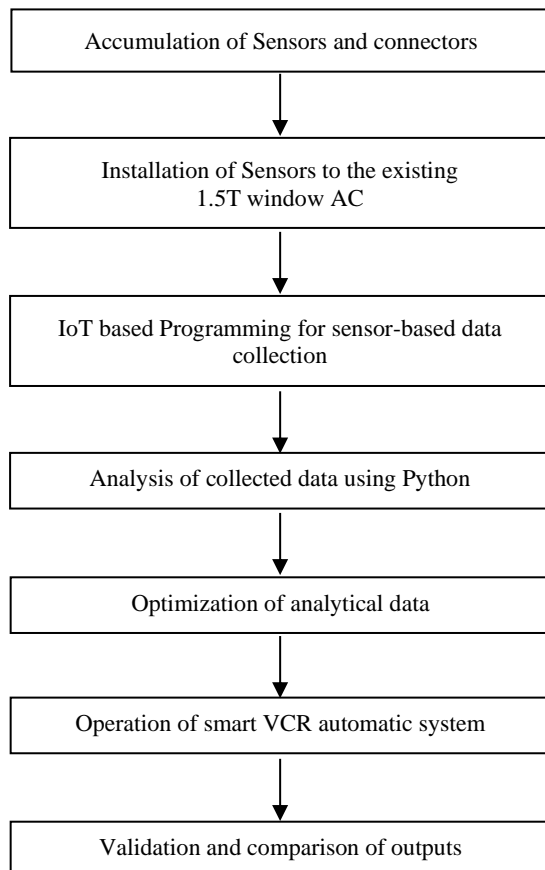


Figure 9. Methodology.

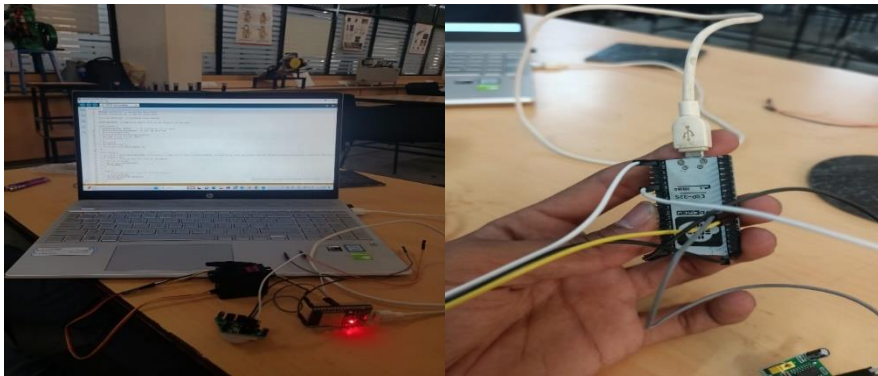


Figure 10. Programming of ESP32.



Figure 11. Installation of the Servo Motor with the Flipper in the Cabin.

Data Analysis on Python

All data analysis was programmed in Python and Jupyter Notebook using the libraries provided by Python, and the libraries used are Numpy, Pandas, and Matplotlib.pyplot, Seaborn, and Plotly.express, which are mentioned below in Figure 15.

Loading the Dataset

The loading of the dataset was done by the pandas library, which is shown in Figure 16, and the dataset loaded using the pandas library with the coding is shown in Table 1.



Figure 12. Digital thermostats observing the temperature of the cabin.

```

1  #define pirPin 18 // pin for pir sensor
2  #define servoMotor 26 // pin for servo motor
3
4  #define pirPin2 17
5  #define servoMotor2 25
6
7
8  #define pirPin3 19
9  #define servoMotor3 27
10
11 #include <Servo.h> // including servo library
12
13 Servo myservo;
14 Servo myservo2;
15 Servo myservo3; // making an object of Servo for using it in the code
16
17 void setup() {
18   pinMode(pirPin, INPUT);
19   pinMode(pirPin2, INPUT);
20   pinMode(pirPin3, INPUT); // setting pir pin as input
21   myservo.attach(servoMotor);
22   myservo2.attach(servoMotor2);
23   myservo3.attach(servoMotor3); // setting servo pin
24   Serial.begin(115200);
25   Serial.print("Calibrating Sensor");
26   for (int i = 0; i < 30; i++) {
27     Serial.print(".");
28   }
29   delay(50);
30   Serial.println("");
31   Serial.println("All sensors Ready.");
32 }
33
34 void loop() {
35   int value = digitalRead(pirPin);
36   int value2 = digitalRead(pirPin2);
37   int value3 = digitalRead(pirPin3); // if value is hig
38   if (value == 1) {
39     // Motion detected keep the servo at 180 degree.
40     myservo.write(0);
41     Serial.print("Cabin 1 : ");
42     Serial.println("Motion");
43     delay(1000);
44   }
45
46   else {
47     // motion not detected keep the servo at 0 degree.
48     myservo.write(90);
49     Serial.print("Cabin 1 : ");
50     Serial.println("No Motion");
51     delay(1000);
52   }
53
54   // for cabin 2
55
56   if (value2 == 1) {
57     // Motion detected keep the servo at 180 degree.
58     myservo2.write(0);
59     Serial.print("Cabin 2 : ");
60     Serial.println("Motion");
61     delay(1000);
62   }
63
64   else {
65     // motion not detected keep the servo at 0 degree.
66     myservo2.write(90);
67     Serial.print("Cabin 2 : ");
68     Serial.println("No Motion");
69

```

Figure 13. Coding for the Servo Motor, and PIR sensor in ESP32 microcontroller.

```

69   Serial.println("No Motion");
70   delay(1000);
71 }
72
73
74 // for cabin 3
75
76 if (value3 == 1) {
77   // Motion detected keep the servo at 180 degree.
78   myservo3.write(0);
79   Serial.print("Cabin 3 : ");
80   Serial.println("Motion");
81   delay(1000);
82 }
83
84 else {
85   // motion not detected keep the servo at 0 degree.
86   myservo3.write(90);
87   Serial.print("Cabin 3 : ");
88   Serial.println("No Motion");
89   delay(1000);
90 }
91 }

```

Figure 14. Coding using the Arduino IDE ESP32 module.

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
import plotly.express as px
import plotly.graph_objects as go
```

Figure 15. Importing the libraries.

```
df = pd.read_csv("AC Final Data.csv")
```

```
df
```

Figure 16. Dataset loading.

Preprocess Data

Data preprocessing is mentioned below in Table 2.
 df.describe()

Table 1. Dataset.

	Date	Time	C1_Temp	C2_Temp	C3_Temp	Occupancy-1	Occupancy-2	Occupancy-3
0	1/1/2024	11:00:00 AM	24.56	20.63	22.12	0	1	1
1	1/1/2024	5:00:00 PM	25.69	24.69	22.33	0	0	1
2	1/1/2024	4:00:00 PM	25.25	21.42	22.63	0	1	1
3	1/1/2024	9:00:00 AM	24.69	25.69	20.6	0	0	1
4	1/1/2024	3:00:00 PM	22.83	22.15	25.69	1	2	0
...
1825	6/30/2024	#####	22.7	27.44	26.5	2	0	0
1826	6/30/2024	5:00:00 PM	22.35	30.2	22.4	1	0	1
1827	6/30/2024	6:00:00 PM	22.9	28.8	23.6	1	0	1
1828	6/30/2024	10:00:00 AM	27.44	27.19	22.63	0	0	1
1829	6/30/2024	9:00:00 AM	24.5	27.94	27.31	1	0	0

1830 rows × 8 columns

Table 2. Data preprocessing.

	C1_Temp	C2_Temp	C3_Temp	Occupancy-1	Occupancy-2	Occupancy-3
count	1830	1830	1830	1830	1830	1830
mean	25.3186	25.242492	25.10698	0.851366	0.9	0.898361

std	2.28668	2.191648	2.009874	0.853889	0.891825	0.778011
min	20.63	20.63	21.21	0	0	0
25%	23.63	23.63	22.63	0	0	0
50%	25.63	25.88	25.94	1	1	1
75%	26.81	26.63	26.31	1	2	1
max	29.94	29	29	3	3	3

df.info()

<class 'pandas.core.frame.DataFrame'>

RangeIndex: 1830 entries, 0 to 1829

Data columns (total 8 columns):

Column Non-null Count Type

- 0 Date 1830 non-null object
 - 1 Time 1830 non-null object
 - 2 C1_Temp 1830 non-null float64
 - 3 C2_Temp 1830 non-null float64
 - 4 C3_Temp 1830 non-null float64
 - 5 Occupancy-1 1830 non-null int64
 - 6 Occupancy-2 1830 non-null int64
 - 7 Occupancy-3 1830 non-null int64
- dtypes: float64(3), int64(3), object (2)

memory usage: 114.5+ KB

RESULT AND ANALYSIS

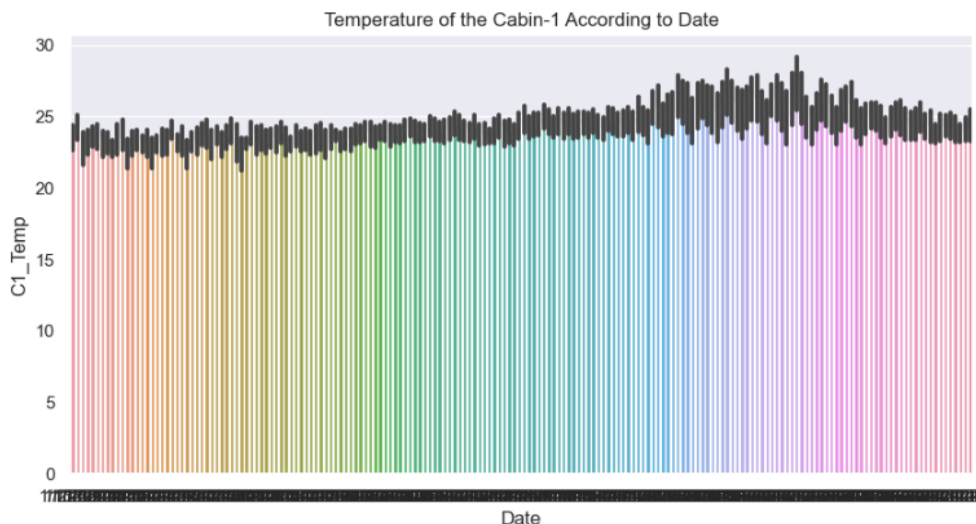
The results and the analysis of the research work are done by the use of Matplotlib.pyplot and seaborn library, and the various graphs, bars, and plots show the result analysis.

Exploratory Data Analysis (EDA)

EDA shows the result of the temperature differences of cabin-1, cabin-2, and cabin-3 according to the date, which is graphically represented by the bars and the plot shown in Figure 17.

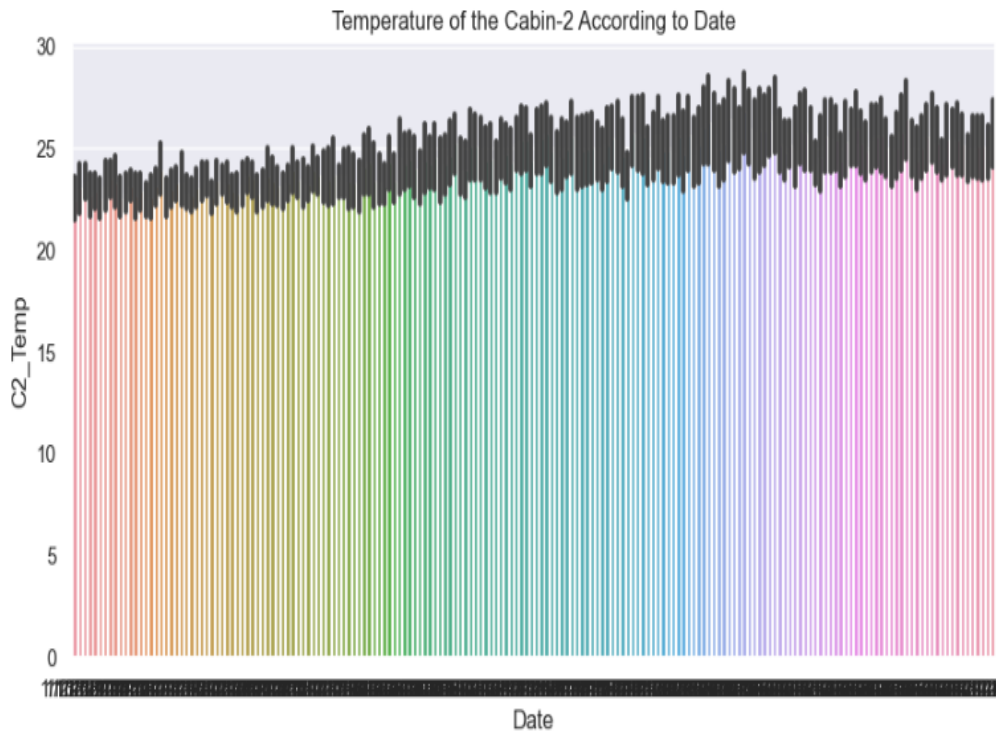
```
sns.barplot(x = df.Date, y = df.C1_Temp)
plt.title("Temperature of the Cabin-1 According to Date")
plt.show
```

```
<function matplotlib.pyplot.show(close=None, block=None)>
```



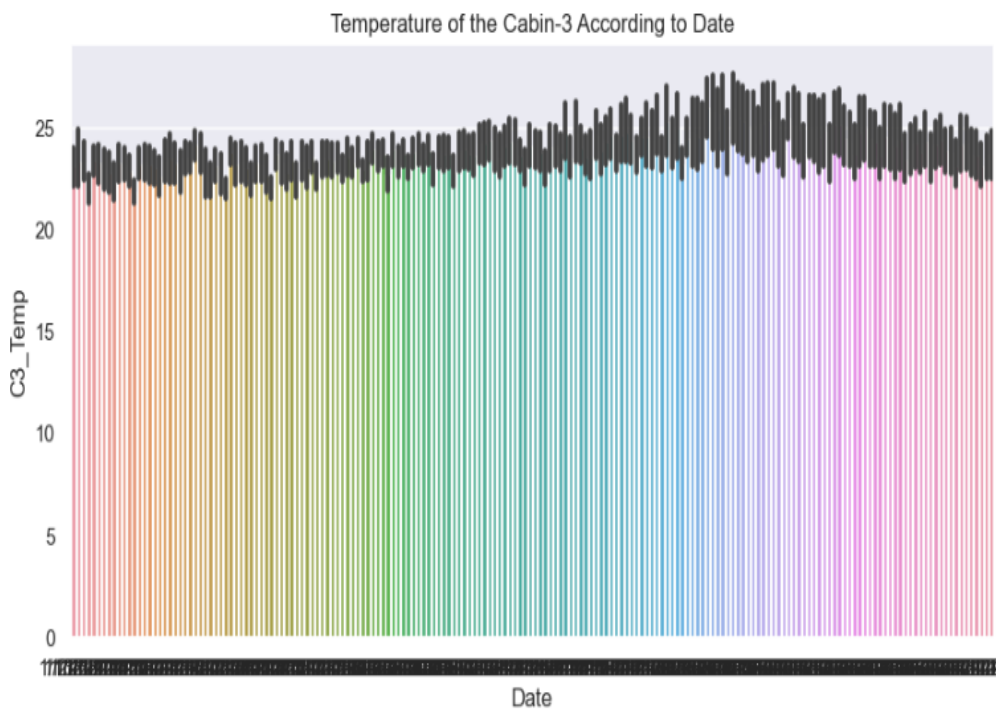
```
sns.barplot(x = df.Date, y = df.C2_Temp)  
plt.title("Temperature of the Cabin-2 According to Date")  
plt.show
```

```
<function matplotlib.pyplot.show(close=None, block=None)>
```



```
sns.barplot(x = df.Date, y = df.C3_Temp)  
plt.title("Temperature of the Cabin-3 According to Date")  
plt.show
```

```
<function matplotlib.pyplot.show(close=None, block=None)>
```



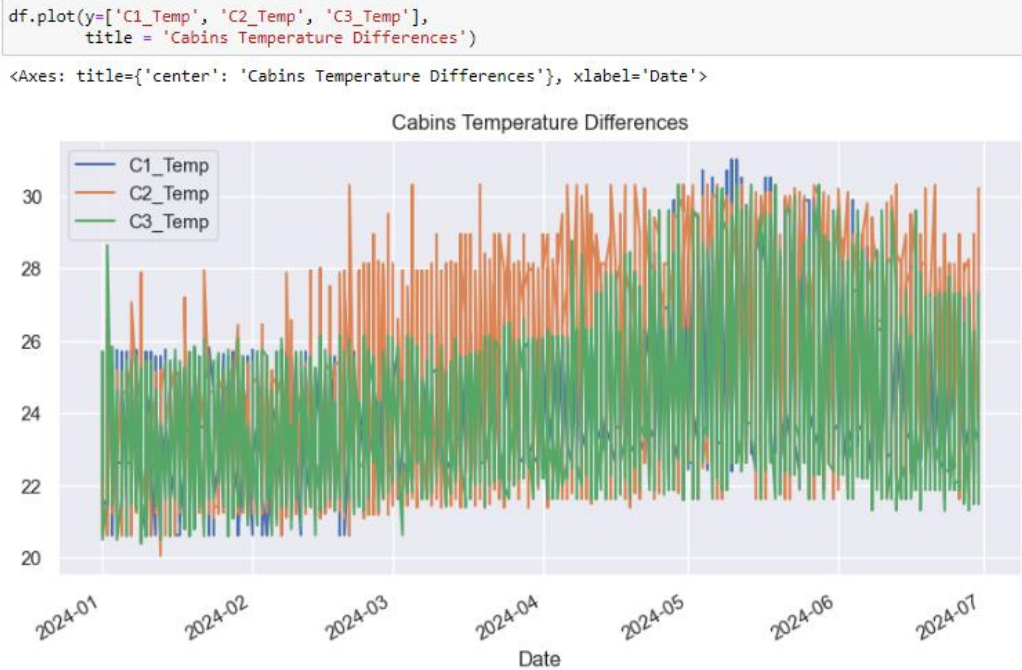
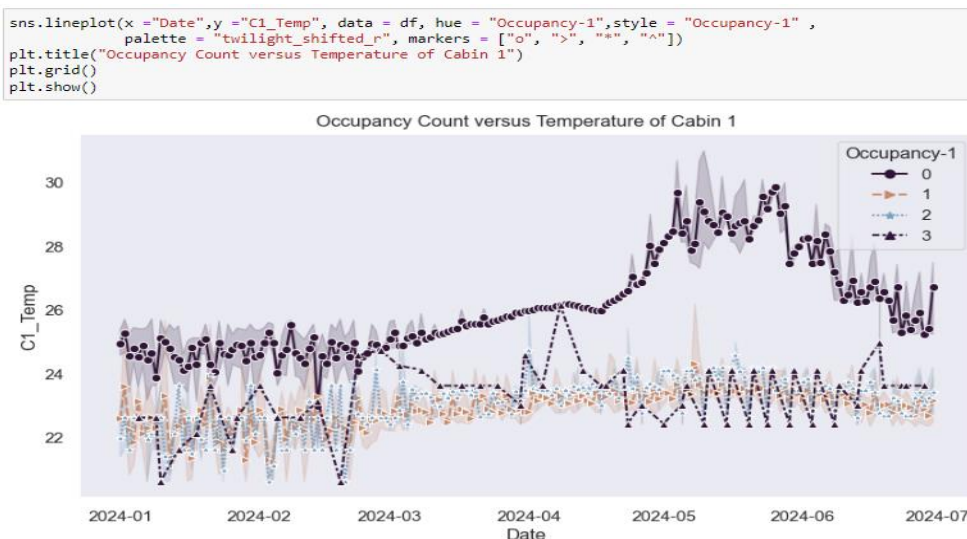


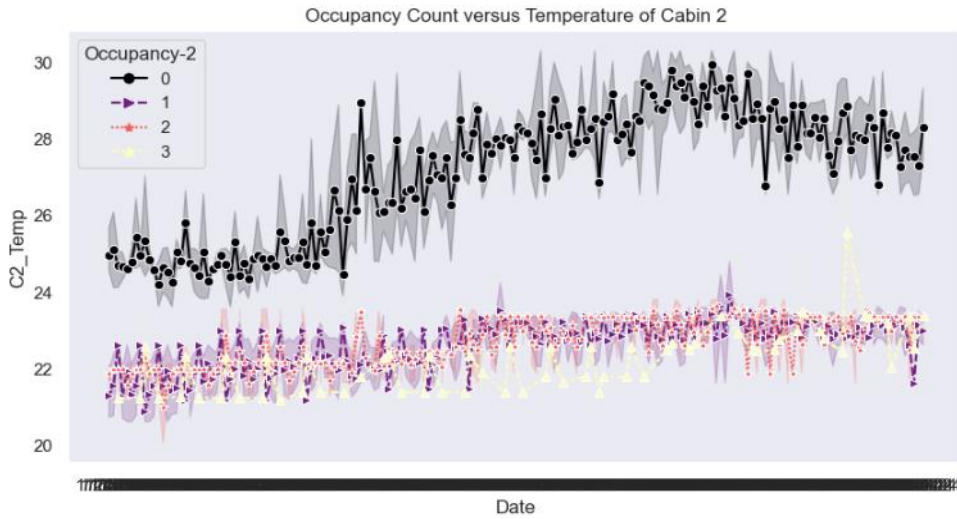
Figure 17. Temperature Differences of Cabin-1, Cabin-2 and Cabin-3.

The occupancy count of the cabin is represented graphically by the following graph occupancy count in cabin-1, cabin-1, and cabin-3 compared with the temperature in Figure 18.

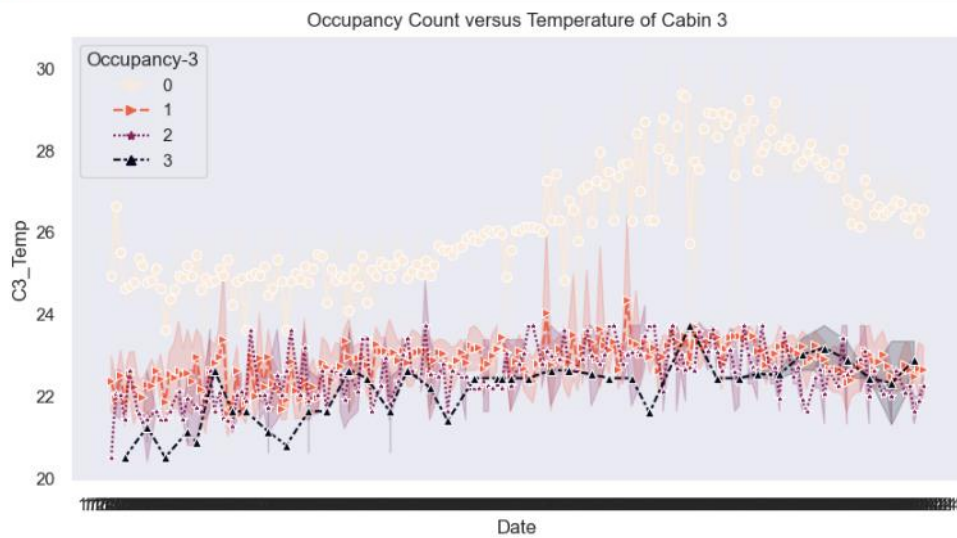
Data analysis and data visualization were applied to the dataset using Python, a Jupyter notebook with the libraries provided by Python. The results are graphically represented by various types of bars, plots, and graphs, and it is found that in the research study, the IoT-based AC system works efficiently using the sensors and servo motor. The result shows that if the occupancy of the cabin is 0 then the temperature of the cabin increases effectively due to the no motion is detected by the sensor in the cabin and the sensor allows the servo motor to close the air vent of the cabin and minimize the air wastages’ when the occupancy of the cabin is 1, 2 or more than 2 the sensor able to detect the human motion and allows to open the air vent of the cabin by which the temperature decreases effectively to users comforts and the temperature of the cabin is controlled by the IoT-based smart AC system having a sensor and servo motor to fulfill the research study.



```
sns.lineplot(x="Date",y="C2_Temp", data = df, hue = "Occupancy-2",style = "Occupancy-2" ,
            palette = "magma", markers = ["o", ">", "*", "^"])
plt.title("Occupancy Count versus Temperature of Cabin 2")
plt.grid()
plt.show()
```



```
sns.lineplot(x="Date",y="C3_Temp", data = df, hue = "Occupancy-3",style = "Occupancy-3" ,
            palette = "rocket_r", markers = ["o", ">", "*", "^"])
plt.title("Occupancy Count versus Temperature of Cabin 3")
plt.grid()
plt.show()
```



```
df.plot()
plt.title("Room Occupancy Count Versus Temperature of Cabins")
plt.show()
```

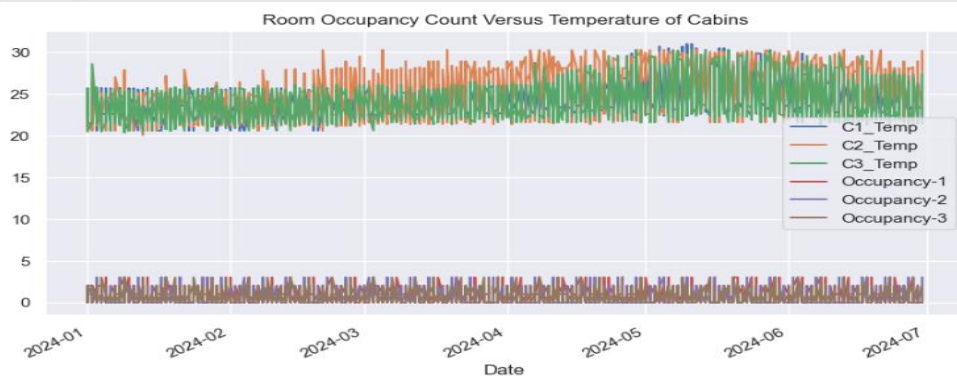


Figure 18. Cabin occupancy count versus temperature of Cabin-1, Cabin-2 and Cabin-3.

CONCLUSION

The automation of 1.5TR air-conditioning systems in different cabins has demonstrated significant improvements in terms of efficiency, comfort, and energy savings. By integrating advanced sensors, control algorithms, and IoT connectivity, these systems can dynamically adjust to various environmental conditions and user preferences to ensure optimal performance. The deployment of such automated systems has resulted in reduced energy consumption, lower operational costs, and enhanced user satisfaction through personalized climate control.

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