**Enhancing Indoor Air Quality Through Smart Home Control Systems**

**Abstract**

This research aims to design and develop an intelligent indoor air quality system utilizing the air quality sensor technology. The fundamental architecture of the model strives to establish a comprehensive indoor air quality automation system that enhances the overall health and well-being of occupants within an apartment's indoor environment, while considering the implementation of technology, including smart indoor air quality and home automation systems.

The air quality sensor effectively tracks critical indicators such as temperature, humidity, CO2, VOCs, and PM2.5. This system seamlessly integrates air quality sensors with wall socket thermostats. Through the amalgamation of sensor technology, data analysis, and control mechanisms, it will ensure the continuous monitoring, thorough analysis, and effective regulation of these vital parameters.

Additionally, this research aims to address the question: 'How can we implement technology, including smart indoor air quality and home automation systems, to enhance overall indoor living conditions, promote well-being, and ensure data security?' Furthermore, this thesis encompasses the creation of a highly user-friendly web interface tailored for occupants. The system's performance will be rigorously evaluated through experiments conducted in residential settings, and to facilitate in-depth analysis, historical data will be stored locally.

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# **1. Research Objectives:**

## **1.1 Design and Development:**

Design and develop a comprehensive smart indoor air quality system that integrates the air quality sensor for monitoring humidity, temperature, CO2 levels, volatile organic compounds (VOCs), and PM2.5 dust particles in a Finnish residential environment.

## **1.2. Sensor Selection:**

Having used the air quality sensor for an extended period, I can attest to its accuracy, reliability, and high environmental sensitivity. Before data collection, conducting calibration is essential to ensure the highest quality data is obtained.

## **1.3 Real-time monitoring and data analytics:**

Implement real-time data monitoring techniques and analyze them using analytical methods. Store the data in various formats for future use. Explore statistical data analysis by employing basic analysis approaches to identify patterns and trends of the elements in different indoor locations. Compare the findings with the previous data to gain insights.

## **1.4 Develop data pipeline and automation ML model:**

Develop a data pipeline to process and train machine learning models using collected data. Deploy the models with new API data to enhance performance. Create an automation system that incorporates control algorithms, notification mechanisms, and user preferences to enable automatic control of wall sockets and air cooler devices, optimizing indoor air quality.

## **1.5 Performance Evaluation:**

Evaluate the performance and effectiveness of the developed smart indoor air quality system in a residential environment. Conduct experiments and measurements to compare the system's performance in terms of air quality improvement, energy efficiency, occupant comfort, and user satisfaction.

## **1.6 User Interface:**

Design and develop a user-friendly graphical interface that allows occupants to interact with the smart indoor air quality system. Investigate methods to provide real-time feedback, energy consumption reports, and customizable options.

# **2. Introduction**

Finland's residential environment differs significantly from most other countries, primarily due to its cold weather conditions. The construction of residential and commercial houses in Finland is tailored to cope with the harsh weather. Apartments, detached, and single houses are designed to be airtight and rely on a central heating system during the winter season. Given that occupants spend a substantial amount of time indoors, maintaining good indoor air quality is vital to prevent severe health issues. Several factors, including humidity, CO2 levels, temperature, and PM2.5 concentrations, influence indoor air quality.

Several elements contribute to poor indoor air quality, such as chemicals produced during cooking in the kitchen, inadequate humidity levels due to an inefficient central exhaust system, and insufficient ventilation. These factors can lead to various health issues in the long term, including respiratory problems, dry eyes, allergies, throat irritation, and exacerbate other health-related conditions.

## **2.1 Significance**

The main objective of the research is to assess indoor air quality and tackle the challenges related to monitoring and controlling indoor pollution. Poor air quality can lead to various health issues, such as respiratory problems, allergies, dry eyes, and other related ailments. Therefore, maintaining good indoor air quality is crucial, especially in airtight apartments in Finland, to ensure overall health and well-being.

The research focuses on utilizing key parameters from the sensor to implement effective indoor air quality management by:

**2.1.1** To monitor key parameters such as temperature, humidity, CO2, VOCs, and PM2.5 particles using the sensor.

**2.1.2** Develop a system capable of providing accurate real-time data and auto-alerts for air quality levels.

**2.1.3** Evaluate the system's effectiveness in controlling indoor pollution through automated processes.

**2.1.4** Assess the system's potential for energy efficiency and cost-effectiveness in maintaining good indoor air quality.

The research aims to implement a reliable smart indoor air quality system to offer several health-related benefits and enhance occupant convenience.

**2.1.5** Improve indoor air quality, comfort, and overall well-being by creating a healthier indoor environment.

**2.1.5** Mitigate health risks for occupants with existing health-related issues by providing a healthy indoor environment.

**2.1.6** Develop an energy-efficient system by integrating Wi-Fi sockets and utilizing Machine Learning models for optimal control and setting appropriate thresholds.

# **3. Background and Technology**

## **3.1 Understanding Indoor Air Quality**

Indoor air quality refers to the varied elements present in the indoor environment, including temperature, humidity, CO2, VOCs, and PM2.5 particles. These elements play a vital role in ensuring healthier indoor air quality. According to EU data, over 670,000 people died from respiratory diseases in 2012, with air pollution being a major contributing factor. It causes various health-related issues. Following the COVID crisis, work-life has undergone a complete transformation, with a growing number of companies opting for remote work as the new norm. This shift not only conserves company resources but also hasn't shown any decline in productivity.

Living in a lifestyle where individuals spend extended hours within tightly sealed homes, especially during dry winters when the air is already parched, emphasizes the need for good indoor air quality to safeguard our health. This thesis proposes the utilization of air quality sensors to monitor the five major elements and their integration into home automation systems. This integration aims to monitor all parameters and automate home appliances to enhance indoor air quality.(Zhou et al., 2020)

## **3.2 Smart Home Control System**

Technology is undergoing rapid evolution, and the Internet of Things (IoT) stands out as an area experiencing tremendous growth. The integration of IoT with smart home control systems through the internet represents one of the most popular innovations, rapidly advancing. The internet serves as the bridge connecting IoT devices, enabling real-time data monitoring and user-controlled functionalities. This complex system offers numerous benefits, allowing users to remotely operate home appliances and curtail unnecessary energy consumption. Additionally, the smart home control system aids disabled individuals in effortlessly managing home appliances without extra physical exertion.

Within this thesis, an indoor air quality sensor is employed, connected via the internet, and utilizing machine learning models to regulate and optimize indoor air quality, thereby fostering a healthier indoor environment.(Venkatraman et al., 2021)

# **4. Literature Review**

## **4.1 Historical Overview**

Indoor air quality plays a major role in occupant health and well-being. These days, it is a hot topic in the research community as researchers aim to identify different aspects of indoor air pollution problems and how they create health-related issues. This problem was first identified in 1983 by the World Health Organization (WHO) and was given the name 'Sick Building Syndrome' (SBS). This syndrome was associated with many health-related problems, including cardiovascular diseases, skin disorders, and allergies, which were widely observed and experienced.

The initial approach to preventing these syndromes primarily focused on regular HVAC system maintenance, periodic cleaning, filter replacement, and the replacement of water-stained tiles and carpeting. However, addressing these issues has gained significant attention in this area over the past decade.

Finland's residential environment differs significantly from most other countries, primarily due to its cold weather conditions. The construction of residential and commercial houses in Finland is tailored to cope with the harsh weather. Apartments, detached, and single houses are designed to be airtight and rely on a central heating system during the winter season. Given that occupants spend a substantial amount of time indoors, maintaining good indoor air quality is vital to prevent severe health issues. Several factors, including humidity, CO2 levels, temperature, and PM2.5 concentrations, influence indoor air quality.

Several elements contribute to poor indoor air quality, such as chemicals produced during cooking in the kitchen, inadequate humidity levels due to an inefficient central exhaust system, and insufficient ventilation. These factors can lead to various health issues in the long term, including respiratory problems, dry eyes, allergies, throat irritation, and exacerbate other health-related conditions.

The integration of Indoor air quality sensors into home automation systems is an incredible combination that improves occupant health and provides an easier living environment. Beside this, other IoT sensors can be easily integrated with smart home systems to offer numerous benefits, including enhanced security, efficient energy management, and cost-effective operation. This integration is particularly advantageous for older adults and disabled occupants. With a smart home system, you can control various aspects, such as lighting switches, remotely turning lights on and off via a mobile application. Additionally, you can remotely monitor security cameras, which helps protect individual houses from burglars.

This narrative literature review will focus on exploring how technology can effectively manage and improve indoor air quality, elevate overall living conditions, enhance occupant well-being, and ensure robust data security using state-of-the-art methods. Our main research question is: "How can we implement technology, including smart indoor air quality and home automation systems, to enhance overall indoor living conditions, promote well-being, and ensure data security?

## **4.2 Evolution of Indoor air quality and home automation system**

With the revolution in cutting-edge technology and the development of indoor air quality monitoring systems, unprecedented progress has been witnessed in recent years. Researchers are innovating ideas to enhance indoor air quality and optimize parameters such as temperature, humidity, CO2, VOCs, and PM2.5 particulate matter through Wi-Fi-enabled IoT devices like sensors integrated with HVAC thermostats. Additionally, the use of predictive machine learning models to optimize indoor air quality and their deployment through continuous integration and continuous automated deployment (CI/CD) with the Microsoft Azure pipeline have also been notable. There has been continuous development and numerous innovative experiments in the field of indoor air quality systems. (Raj et al., 2021)

Similarly, there have been numerous innovative evolutions in the field of home automation systems over the last decade, with the arrival of AI technology. Home automation development primarily focuses on two aspects: the first is ensuring the safety, health, and comfort of occupants while making household operations more convenient, especially by reducing energy consumption using IoT sensor automation technology. The second aspect is to assist elderly and disabled occupants in controlling their home appliances through mobile applications using home automation technology.

## **4.3 Some remarkable work done in indoor air quality and home automation systems.**

Here are some landmark studies seen in recent years in the field of indoor air quality and home automation systems:

**Title: Internet of Things (IoT) Enabled Smart Indoor Air Quality Monitoring System** (Zhou et al., 2020)

**Study objectives:** The study objectives were to present a smart indoor air quality monitoring system that utilizes IoT technology and LoRaWAN protocol to detect and analyze air quality in indoor environments. The system includes sensors, a control center, and actuators to monitor and control air quality. The paper also discusses the importance of indoor air quality and the use of AQI to classify air quality based on its properties.

**Method:** This section describes the methodology used in the study, including hardware and software, and sets the thresholds for the humidifier, alerting occupants through a messaging mechanism. The same approach is applied to other parameters.

**Findings:** The purpose of the paper is to present a smart indoor air quality monitoring system that uses IoT technology and LoRaWAN protocol to detect and analyze air pollutants in indoor environments.

**Title: Smart Real-Time Indoor Air Quality Sensing System and Analytics** (Urku & Agrawal, 2018)

**Study objectives:** The focus of the paper is to present a smart real time indoor air quality sensing system and analytics. The excerpt discusses various studies related to indoor air quality sensing, monitoring, and prediction.

**Methods:** The section describes the methodology used in the study, including the hardware and software components, threshold-based algorithm, ML algorithm, and analysis of data generated by sensors. The architectural design of the system development is also explained.

**Findings:** The text discusses various findings related to indoor air quality sensing and analysis, including the concentration of carbon dioxide (CO2) in indoor environments, the impact of smoking on indoor air pollution, the use of cloud-based approaches for real time measurement of particulate matter (PM2.5), the role of sensor networks in detecting indoor air pollutants, the impact of

household activities and cooking methods on indoor air quality, the use of air quality data for building models to reduce indoor PM2.5, the development of indoor air quality systems based on IoT, the use of machine learning approaches for analyzing air pollution data, and the assessment and prediction of air quality using computational models. The text also mentions that the concentration and composition of particles in indoor air are affected by both indoor and outdoor pollution sources.

**Title: Indoor air quality monitoring system for smart buildings** (Chen et al., 2014)

**Study objectives:** The study objectives were to introduce a real system that monitors indoor air quality in different areas of a building and to offer actionable and energy efficient suggestions to HVAC systems based on the collected data.

**Methods:** The text describes a real system that was deployed in the offices of 4 Microsoft campuses in China to monitor indoor air quality. However, the excerpt does not provide information about the specific methods used in the system.

**Findings:** The system introduced in the paper is to instantly monitor indoor air quality on different floors of a building, enabling Microsoft employees to enquire the air quality of a place by using a mobile phone or checking a website. The information can guide a user's decision making, e.g., finding the right time to work out in the gym or turn on individual air filters in her own office.

**Title: IoT Based Indoor Air Quality and Smart Energy Management for HVAC System** (Dhanalakshmi et al., 2020)

**Study objectives:** The study objectives were to propose a simple HVAC control system that automates the HVAC operation in real time by considering energy management policies and user preferences, and to evaluate the effectiveness of HVAC mathematically.

**Methods:** An air sensor is integrated with the HVAC system to manage overall temperature, humidity, and chemical levels, and to implement an algorithm for energy management.

**Findings:** The proposed system is built on top of IoT (Internet of Things) framework

**Title: Secure smart home automation and monitoring system using internet of things** (Al-Gburi & Abdul-Rahaim, 2022)

**Study Objectives:** The proposed system is based on real data transmission for data exchanges between Arduino and IoT sensors.

**Method:** Used different sensor to monitor authorised and unauthorised persons and send audio alert when sensor readings exceed normal value. The system also recognised the possibility of unauthorised access to use the card identification (ID) with RFID and prevented bypassing the identity to theft or unauthorised opening of the door. The normal readings for distance, smoke, CO, and LPG were reported as 16 cm, 22, 20, and 46, respectively, while the abnormal readings were reported as 20, 13402, 7301, and 5102 for the 1st abnormal state and 27, 10211, 6256, and 5097, respectively. The network delay and data traffic latency were enhanced in the proposed system for compared data in wireless IoT sensors.

**Findings:** The text mentions current findings on the effect of measured environmental parameters on indoor air quality, individual thermal comfort and living behaviour in smart homes for the temperate climate zone

Based on the above research studies, it is evident that a tremendous number of different ideas have been developed in the field of indoor air quality and home automation systems. Some of these concepts have been uniquely developed and implemented.

## **4.4 The current state-of-art**

The most recent research that I have found in Mendeley is titled 'Thermal, Lighting, and IAQ Control System for Energy Saving and Comfort Management.' The objectives of this study include creating a simulation and control framework for home and building automation, with a specific focus on the heating, ventilating, and air conditioning (HVAC) processes. The study also aims to highlight energy-saving capabilities by integrating both energy-consuming and green energy-supplying renewable sources, such as heat pumps, artificial lighting, and fresh air flow. Furthermore, it employs various control mechanisms to achieve energy savings and maintain comfort levels.

Overall, this study aims to provide a comprehensive framework for home and building automation that optimizes energy use, maintains comfort, and reduces environmental impact through the integration of advanced control systems and renewable energy sources.

## **4.5 Outstanding Challenges and Gaps**

### **4.5.1 Data Security and Privacy**

**Challenge:** During my research paper search and studies, I haven't come across any single paper that adequately addresses data security concerns for either indoor air quality or home automation systems. While I did find one paper that briefly discussed VPN integration with home automation, it lacked in-depth coverage. One of the primary challenges in the development of home automation systems is ensuring robust data security and privacy. Given that these systems collect and transmit sensitive data about indoor environments and occupants' behaviour, there is a significant risk of data breaches and privacy issues, particularly when the entire system is connected to the internet.

**Gap:** When it comes to the critical aspects of data security and privacy, existing literature falls short in providing comprehensive solutions and guidelines for the implementation of secure smart home systems. There is a pressing need for further research in areas such as encryption methods, the integration of VPNs with indoor air quality and home automation systems to enhance data transmission protocols, and the development of user-friendly privacy settings.

### **4.5.2 Cost effective solution**

**Challenge:** The cost of indoor air quality and home automation systems can be prohibitively high for many households, limiting their accessibility to a broader population.

**Gap:** Research should prioritize the development of cost-effective solutions to make smart home technologies more affordable and accessible to a wider audience. This includes exploring open-source platforms, innovative sensor technologies, and strategies for modifying existing homes with smart systems.

### **4.5.3 Energy Saving**

**Challenge:** The energy consumption associated with indoor air quality and home automation systems poses a significant challenge in a time when energy costs are on the rise due to various factors. There is a need for a comprehensive calculation of the energy savings achievable using these systems.

**Gap:** Research should concentrate on conducting detailed energy savings calculations by comparing energy consumption before and after the implementation of indoor air quality and home automation systems. This will allow occupants to visualize the difference and assess the potential cost savings associated with the adoption of such technology.

In conclusion, indoor air quality and home automation systems hold immense promise for enhancing well-being and living conditions. However, as we've explored, there are several significant challenges and gaps that demand attention. These include the need for robust data security and privacy solutions, the development of cost-effective technologies to ensure accessibility, and comprehensive energy-saving measures. As we move forward, addressing these challenges will be crucial to creating healthier, more comfortable, and environmentally sustainable indoor environments for all.

# **5. Research Methodology**

## **5.1 System Development**

### **5.1.1 Objectives**

The objective is to design and develop a comprehensive smart indoor air quality system by integrating the Awair Element air quality sensor. The system will monitor humidity, temperature, CO2 levels, volatile organic compounds (VOCs), and PM2.5 dust particles in residential environments in Finland.

A diagram of a network

Description automatically generated

### **5.1.2 Hardware Selection**

#### **5.1.2.1 Sensor**

The Awair Element sensor is considered one of the best indoor air monitoring devices available in the European market. I have been using this sensor for the past three years for various purposes. This research provides yet another opportunity to utilize this device and explore its usability in smart indoor systems. The sensor offers accurate and reliable data on all required elements, making it highly environmentally sensitive. It is crucial to conduct proper calibration to ensure the collection of high-quality data.

A white rectangular object with a green light

Description automatically generated

<https://www.getawair.com/products/element>

A screen shot of a computer

Description automatically generated

#### **5.1.2.2 Data Collection and Storage**

Data is primarily extracted from the Awair Element sensor through API calls at five-minute intervals. The extracted data is then stored in an external hard drive using the Raspberry Pi in three different formats: CSV, JSON, and PostgreSQL. Currently, the code has been successfully implemented on a dedicated MacBook Pro while waiting for the delivery of the Raspberry Pi. Once the Raspberry Pi is received, the external drive and the sensor will be connected to it.

A screenshot of a device

Description automatically generated

#### **5.1.2.3 Smart Devices Integration**

##### **5.1.2.3.1 Raspberry Pi 4 Computer**

The Raspberry Pi 4 serves as the central node to which all scripts, including the sensor connections, are integrated. A Python script manages the data pipeline, while the machine learning model operates within this node. The device boasts a high-end configuration, enabling seamless handling of moderate computational loads without encountering performance issues. Below are highlighted key features and specifications of this setup.

* 8 GB LPDDR4-2400 SDRAM RAM
* 1.5 GHz Broadcom BCM2711 64-bit ARM Cortex-A72 Quad-core CPU
* Bluetooth 5.0
* Dual-band 802.11ac Wi-Fi
* 2 x micro-HDMI (up to 4K60p for one screen, or 4K30p for two screens)
* 3.5 mm audio
* Gigabit Ethernet
* 4 x USB
* microSD card reader
* Raspberry Pi 40-pin GPIO connector
* 2-channel MIPI DSI display port
* 2-channel MIPI CSI camera port
* Power supply: 15 W (5 V / 3 A) via USB-C or 5 Vdc GPIO connector
* Power over Ethernet (PoE) supported.

A close-up of a computer chip

Description automatically generated

<https://www.raspberrypi.com/products/raspberry-pi-4-model-b/>

##### **5.1.2.3.2 TaPo Mini Smart Wi-Fi Socket**

A small remote-controlled smart socket can be easily managed through a smart device, enabling users to control it from their home's Wi-Fi network or even remotely via the internet. It's an ideal solution for conveniently turning electrical appliances on and off. Additionally, the socket includes a physical button, allowing manual control.

During my research, I discovered the most intriguing feature of this device – API calls available on pypi.org. These API calls provide usage time data for the socket. Leveraging this data, I developed a code that calculates electricity costs and consumption in kwh. Moreover, I implemented a threshold with an automated time interval, enabling the socket to turn on and off automatically when the threshold is crossed.

A white electrical outlet with a green light

Description automatically generated

<https://www.tapo.com/us/product/smart-plug/>

Here are some key features of this fascinating device that makes it an essential addition to any smart home setup.

* Model: Tapo P100
* Current data: 230 V, 50 Hz, 10 A
* Continuous switching power max. 2300 W (resistive load)
* The power light indicates whether the socket is on/off.
* A separate power switch enables operation without a smart device and control.
* Wireless standard: Wi-Fi 802.11b/g/n (2.4GHz), Bluetooth 4.2 (only used during commissioning)
* Amazon Alexa and Google Assistant compatible
* The Tapo app can be downloaded for Android and iOS devices.
* Dimensions: 51 x 72 x 40 mm
* Operating temperature: +0°C ~ +35°C, for indoor use only

##### **5.1.2.3.3 Air Cooler Nedis**

The Nedis air cooler is an excellent product that fits my research objective of improving indoor air quality on a budget. I was searching for a cost-effective device capable of regulating indoor humidity, temperature, and PM2.5 particles. This air cooler fulfils all these requirements as it efficiently maintains indoor humidity, temperature, and even includes an ionizer function to manage PM2.5 particles in the indoor environment.

The apartment where I conducted my experiment has always faced issues with low humidity, despite having a central exhaust system. The existing system did not provide the necessary humidity level required for optimal air quality. However, since I started using this air cooler, all five key parameters, including humidity, have been well-maintained.

For full automation, the Nedis air cooler is connected to a Wi-Fi smart power socket, allowing it to respond to predictions from the ML model and adjust according to the set thresholds. I will provide further analysis of the experiment in a subsequent section.

* Product: Air Cooler
* Power Input: 220 - 240 VAC; 50 / 60 Hz
* Power: 65 W
* Air Volume: 215 m3/h
* Ionizer Function: Yes
* Automatic air swing: Yes
* Timer: 1-7h
* Remote Control: Yes

<https://nedis.fi/fi-fi/product/kodintarvikkeet-ja-asuminen/ilmanlaatu/ilman-jaahdyttimet/550784567/smartlife-mobiili-ilmajaahdytin-vesisailion-tilavuus-5-l-3-vaihteinen-215-m3h-oskillaatio-kaukosaadin-sammutusajastin-ionisointi-toiminto>

A diagram of a computer tower

Description automatically generated

## **5.2 Sensor Integration**

Sensor integration is a critical and vital part of building a smart indoor air quality system. It encompasses everything from selecting the ideal location for the sensor to capturing all the necessary parameters and establishing a well-structured data pipeline for further processing. Here are the key steps involved in sensor integration.

### **5.2.1 Sensor Selection**

The Awair Element sensor is a smart device that monitors indoor air quality. It provides detailed information about various air quality parameters such as temperature, humidity, CO2 levels, and particulate matter (PM2.5). This high-end sensor offers exceptional accuracy in indoor air quality monitoring. Additionally, it features an easy-to-use API enabled through the Awair Element app, allowing users to access data and display parameters effortlessly. The sensor has been functioning smoothly with API calls and effectively stores data in the specified path.

### **5.2.2 Placement and Installation**

Since there is a single sensor installed inside my apartment and API call is enabled through the app, it is convenient to install sensors in different locations within my apartment, such as the working room, bedroom, living room, and kitchen hall. In this case, the sensor is in different rooms, but most of the time, it remains on my working table. The temperature, humidity, and other parameters in the entire apartment are almost the same, except for the kitchen where there are chemicals, resulting in slightly higher PM2.5 levels while cooking. Otherwise, the air quality is similar in the rest of the rooms.

### **5.2.3 Data Acquisition and visualisation**

Data is retrieved from the sensor through the API by enabling the API option from the mobile app and accessing the device's IP address on a web browser. This action displays a page with the data, which looks something like this:

Url = 'http://192.168.0.104/air-data/latest'

{"timestamp":"2023-11-02T21:01:24.091Z","score":86,"dew\_point":2.38,"temp":21.03,"humid":29.16,"abs\_humid":5.34,"co2":553,"co2\_est":729,"co2\_est\_baseline":37143,"voc":152,"voc\_baseline":38312,"voc\_h2\_raw":26,"voc\_ethanol\_raw":37,"pm25":17,"pm10\_est":18}

The next step is to connect to the API through Python code. I am using pandas for the API connection, and here is the code with the necessary Python libraries. I am attaching my code for the API call below. The idea is to store the data in three different formats: CSV, JSON, and PostgreSQL.

# imported all the necessaries files that we needed

import pandas as pd

import requests

import time

import json

import datetime

import csv

import psycopg2

import threading

import os

from tabulate import tabulate

# avoide system sleep type in command terminal "caffeinate" press enter

# to stop caffeinate press "Ctrl+C"

# Created a function in which connection is established

host = os.environ.get('CONTAINER\_IP')

port = os.environ.get('PORT')

database = os.environ.get('DATABASE')

user = os.environ.get('USER')

password = os.environ.get('PASS\_WORD')

url = os.environ.get('API\_LINK')

def awair\_api\_call():

conn1 = psycopg2.connect(

host=host,

port=port,

database=database,

user=user,

password=password

)

conn1.autocommit=True

cur1 = conn1.cursor()

cur1.execute("SELECT 1 FROM pg\_catalog.pg\_database WHERE datname = 'awair'")

exists = cur1.fetchone()

if not exists:

cur1.execute("CREATE DATABASE awair")

conn1.set\_session(autocommit=True)

try:

conn = psycopg2.connect(

host=host,

port=port,

database=database,

user=user,

password=password

)

except psycopg2.Error as e:

print(e)

try:

cur = conn.cursor()

except psycopg2.Error as e:

print("Error: Could not get the crusor to the database")

print(e)

conn.set\_session(autocommit=True)

try:

cur.execute("CREATE TABLE IF NOT EXISTS awair\_data(awair\_id BIGSERIAL PRIMARY KEY, \

timestamp timestamp,score int, \

dew\_point NUMERIC,temp NUMERIC,humid NUMERIC, \

abs\_humid NUMERIC,co2 int,co2\_est int, \

co2\_est\_baseline int, \

voc int,voc\_baseline int,voc\_h2\_raw int, \

voc\_ethanol\_raw int,pm25 int,pm10\_est int,location VARCHAR);")

except psycopg2.Error as e:

print("Error: Issue creating table")

print(e)

try:

cur.execute("CREATE TABLE IF NOT EXISTS awair\_owner\_details(owner\_id SERIAL PRIMARY KEY, \

owner\_name VARCHAR(50), \

owner\_country VARCHAR(50), owner\_address VARCHAR(50), owner\_phone VARCHAR, owner\_email VARCHAR);")

except psycopg2.Error as e:

print("Error: Issue creating table")

print(e)

cur.execute("INSERT INTO awair\_owner\_details(owner\_name,owner\_country,owner\_address,owner\_phone,owner\_email) VALUES ('Shardendu Jha', \

'Finland','Janonhanta 1 C 200','0442138793','apps00@gmail.com')")

data1 = None

while True:

List2 = []

Url = url # api url path

request1 = requests.request("GET", Url,timeout=30)

data1 = request1.json()

add\_new\_col = {'location':'Janonhanta1,Vantaa,Finland'}

add\_bew\_col\_serial = {}

data1.update(add\_bew\_col\_serial)

data1.update(add\_new\_col)

List2.append(data1)

headers = ['timestamp','score','temp','humid','co2', \

'voc','pm25','pm10\_est','location']

table\_data = []

for row in List2:

table\_data.append([row.get(key, '') for key in headers])

print('')

print(' Live Sensor Parameters')

print(tabulate(table\_data, headers=headers, tablefmt='pretty'))

time.sleep(300)# call every 5 min

values = [v for k, v in List2[0].items()]

sql = "INSERT INTO awair\_data (timestamp,score,dew\_point,temp,humid,abs\_humid, \

co2,co2\_est,co2\_est\_baseline,voc,voc\_baseline,voc\_h2\_raw, \

voc\_ethanol\_raw,pm25,pm10\_est,location) VALUES ({})".format(','.join(['%s'] \* len(values)))

cur.execute(sql, values)

# save data as csv file

c\_columns = ['timestamp','score','dew\_point','temp','humid','abs\_humid', \

'co2','co2\_est','co2\_est\_baseline','voc','voc\_baseline','voc\_h2\_raw', \

'voc\_ethanol\_raw','pm25','pm10\_est','location']

csv\_file = os.environ.get('CSV\_FILE')

path = os.environ.get('CSV\_PATH')

if os.path.exists(path):

with open(csv\_file, "a+") as add\_obj:

writer = csv.DictWriter(add\_obj, fieldnames=c\_columns)

for data in List2:

writer.writerow(data)

else:

try:

with open(csv\_file, "w") as awair\_file:

writer = csv.DictWriter(awair\_file, fieldnames=c\_columns)

writer.writeheader()

for data in List2:

writer.writerow(data)

except ValueError:

print("I/O error")

#save data as json file.

json\_file = os.environ.get('JSON\_FILE')

path = os.environ.get('JSON\_PATH')

if os.path.exists(path):

with open(json\_file, 'r') as s\_file:

try:

existing\_records = json.load(s\_file)

except json.decoder.JSONDecodeError:

existing\_records = []

for record in List2:

existing\_records.append(record)

with open(json\_file, "w") as j\_file:

json.dump(existing\_records, j\_file, sort\_keys=True, indent=4)

else:

with open(json\_file, "w") as f:

json.dump(List2, f, sort\_keys=True, indent=4)

if \_\_name\_\_ == '\_\_main\_\_':

awair\_api\_call()

The code has been running smoothly for the last month, and I haven't noticed any issues except for occasional problems with the Wi-Fi connection. Specifically, connection problems arise when using the API URL from three different scripts simultaneously. To address this, I divided the functionality into two scripts: one for data acquisition and another for data processing and deploying the machine learning model. Additionally, I integrated the automation system with an air cooler device based on the predicted values. The system is now capable of sending notifications through email.

#### **5.2.3.1 Data Visualization**

Now that the data has been successfully retrieved, the next step is to examine the data and identify relationships between the columns.

# import nec  
import pandas as pd  
pd.options.mode.chained\_assignment = None # default='warn'  
import json  
import csv  
import matplotlib.pyplot as plt  
import seaborn as sns

awair\_csv\_data = pd.read\_csv("awair\_01-03-23\_work\_room.csv")

awair\_csv\_data.dtypes

awair\_id int64  
timestamp object  
score int64  
dew\_point float64  
temp float64  
humid float64  
abs\_humid float64  
co2 int64  
co2\_est int64  
co2\_est\_baseline int64  
voc int64  
voc\_baseline int64  
voc\_h2\_raw int64  
voc\_ethanol\_raw int64  
pm25 int64  
pm10\_est int64  
location object  
dtype: object

awair\_csv\_data.head()

awair\_id timestamp score dew\_point temp humid \  
0 1 2023-03-01 16:24:15.963 84 2.80 21.02 30.07   
1 2 2023-03-01 16:29:07.203 84 2.82 21.02 30.11   
2 3 2023-03-01 16:34:08.829 83 2.96 21.12 30.23   
3 4 2023-03-01 16:39:10.114 83 2.99 20.89 30.71   
4 5 2023-03-01 16:44:11.385 84 2.81 20.92 30.27   
  
 abs\_humid co2 co2\_est co2\_est\_baseline voc voc\_baseline voc\_h2\_raw \  
0 5.50 730 990 35939 357 38152 25   
1 5.51 754 1068 35938 368 38152 25   
2 5.56 786 971 35938 385 38152 25   
3 5.58 796 1041 35937 384 38152 25   
4 5.50 750 1015 35936 352 38152 25   
  
 voc\_ethanol\_raw pm25 pm10\_est location   
0 36 1 2 Janonhanta1,Vantaa,Finland   
1 36 1 2 Janonhanta1,Vantaa,Finland   
2 36 1 2 Janonhanta1,Vantaa,Finland   
3 36 1 2 Janonhanta1,Vantaa,Finland   
4 36 1 2 Janonhanta1,Vantaa,Finland

selected\_required\_columns = awair\_csv\_data[['timestamp','temp','humid','co2','voc','pm25','location']]

selected\_required\_columns.head()

timestamp temp humid co2 voc pm25 \  
0 2023-03-01 16:24:15.963 21.02 30.07 730 357 1   
1 2023-03-01 16:29:07.203 21.02 30.11 754 368 1   
2 2023-03-01 16:34:08.829 21.12 30.23 786 385 1   
3 2023-03-01 16:39:10.114 20.89 30.71 796 384 1   
4 2023-03-01 16:44:11.385 20.92 30.27 750 352 1   
  
 location   
0 Janonhanta1,Vantaa,Finland   
1 Janonhanta1,Vantaa,Finland   
2 Janonhanta1,Vantaa,Finland   
3 Janonhanta1,Vantaa,Finland   
4 Janonhanta1,Vantaa,Finland

selected\_required\_columns['timestamp'] = pd.to\_datetime(selected\_required\_columns['timestamp']).dt.strftime('%d/%m/%Y %H:%M')

selected\_required\_columns

timestamp temp humid co2 voc pm25 \  
0 01/03/2023 16:24 21.02 30.07 730 357 1   
1 01/03/2023 16:29 21.02 30.11 754 368 1   
2 01/03/2023 16:34 21.12 30.23 786 385 1   
3 01/03/2023 16:39 20.89 30.71 796 384 1   
4 01/03/2023 16:44 20.92 30.27 750 352 1   
... ... ... ... ... ... ...   
8517 23/06/2023 16:42 26.36 39.41 457 76 3   
8518 23/06/2023 16:47 26.32 39.29 451 72 3   
8519 23/06/2023 16:52 26.29 39.35 446 65 2   
8520 23/06/2023 16:58 26.32 39.90 446 71 3   
8521 23/06/2023 17:03 26.34 41.83 466 83 3   
  
 location   
0 Janonhanta1,Vantaa,Finland   
1 Janonhanta1,Vantaa,Finland   
2 Janonhanta1,Vantaa,Finland   
3 Janonhanta1,Vantaa,Finland   
4 Janonhanta1,Vantaa,Finland   
... ...   
8517 Janonhanta1,Vantaa,Finland   
8518 Janonhanta1,Vantaa,Finland   
8519 Janonhanta1,Vantaa,Finland   
8520 Janonhanta1,Vantaa,Finland   
8521 Janonhanta1,Vantaa,Finland   
  
[8522 rows x 7 columns]

selected\_required\_columns.rename(columns = {'timestamp':'DateTime', 'temp':'Temp',  
 'humid':'Humid', 'co2':'Co2', 'voc':'Voc', 'pm25':'Pm25', 'location':'Location'},  
 inplace = True)

selected\_required\_columns

DateTime Temp Humid Co2 Voc Pm25 \  
0 01/03/2023 16:24 21.02 30.07 730 357 1   
1 01/03/2023 16:29 21.02 30.11 754 368 1   
2 01/03/2023 16:34 21.12 30.23 786 385 1   
3 01/03/2023 16:39 20.89 30.71 796 384 1   
4 01/03/2023 16:44 20.92 30.27 750 352 1   
... ... ... ... ... ... ...   
8517 23/06/2023 16:42 26.36 39.41 457 76 3   
8518 23/06/2023 16:47 26.32 39.29 451 72 3   
8519 23/06/2023 16:52 26.29 39.35 446 65 2   
8520 23/06/2023 16:58 26.32 39.90 446 71 3   
8521 23/06/2023 17:03 26.34 41.83 466 83 3   
  
 Location   
0 Janonhanta1,Vantaa,Finland   
1 Janonhanta1,Vantaa,Finland   
2 Janonhanta1,Vantaa,Finland   
3 Janonhanta1,Vantaa,Finland   
4 Janonhanta1,Vantaa,Finland   
... ...   
8517 Janonhanta1,Vantaa,Finland   
8518 Janonhanta1,Vantaa,Finland   
8519 Janonhanta1,Vantaa,Finland   
8520 Janonhanta1,Vantaa,Finland   
8521 Janonhanta1,Vantaa,Finland   
  
[8522 rows x 7 columns]

# check data type  
print(selected\_required\_columns.dtypes)

DateTime object  
Temp float64  
Humid float64  
Co2 int64  
Voc int64  
Pm25 int64  
Location object  
dtype: object

# Check for missing values  
print(selected\_required\_columns.isna().sum())

DateTime 0  
Temp 0  
Humid 0  
Co2 0  
Voc 0  
Pm25 0  
Location 0  
dtype: int64

# Check for duplicate rows  
print(selected\_required\_columns.duplicated().sum())

56

# Drop duplicate rows  
selected\_required\_columns = selected\_required\_columns.drop\_duplicates()

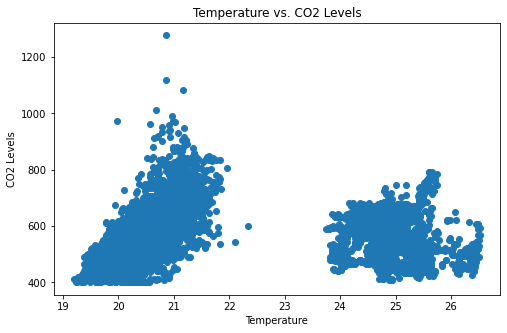
selected\_required\_columns

DateTime Temp Humid Co2 Voc Pm25 \  
0 01/03/2023 16:24 21.02 30.07 730 357 1   
1 01/03/2023 16:29 21.02 30.11 754 368 1   
2 01/03/2023 16:34 21.12 30.23 786 385 1   
3 01/03/2023 16:39 20.89 30.71 796 384 1   
4 01/03/2023 16:44 20.92 30.27 750 352 1   
... ... ... ... ... ... ...   
8517 23/06/2023 16:42 26.36 39.41 457 76 3   
8518 23/06/2023 16:47 26.32 39.29 451 72 3   
8519 23/06/2023 16:52 26.29 39.35 446 65 2   
8520 23/06/2023 16:58 26.32 39.90 446 71 3   
8521 23/06/2023 17:03 26.34 41.83 466 83 3   
  
 Location   
0 Janonhanta1,Vantaa,Finland   
1 Janonhanta1,Vantaa,Finland   
2 Janonhanta1,Vantaa,Finland   
3 Janonhanta1,Vantaa,Finland   
4 Janonhanta1,Vantaa,Finland   
... ...   
8517 Janonhanta1,Vantaa,Finland   
8518 Janonhanta1,Vantaa,Finland   
8519 Janonhanta1,Vantaa,Finland   
8520 Janonhanta1,Vantaa,Finland   
8521 Janonhanta1,Vantaa,Finland   
  
[8466 rows x 7 columns]

# Calculate summary statistics  
summary\_stats = selected\_required\_columns.describe()  
summary\_stats

Temp Humid Co2 Voc Pm25  
count 8466.000000 8466.000000 8466.000000 8466.000000 8466.000000  
mean 21.193946 30.098590 539.975549 189.684975 5.258091  
std 1.902502 9.844159 88.074945 136.421431 16.483485  
min 19.200000 13.440000 400.000000 20.000000 0.000000  
25% 20.000000 23.082500 480.000000 118.000000 1.000000  
50% 20.370000 28.110000 520.000000 156.000000 2.000000  
75% 21.150000 35.057500 585.000000 234.000000 5.000000  
max 26.520000 58.970000 1277.000000 4288.000000 593.000000

# Visualize temperature and CO2 levels using scatter plot  
plt.figure(figsize=(8,5))  
plt.scatter(selected\_required\_columns['Temp'], selected\_required\_columns['Co2'])  
plt.xlabel('Temperature')  
plt.ylabel('CO2 Levels')  
plt.title('Temperature vs. CO2 Levels')  
  
plt.show()



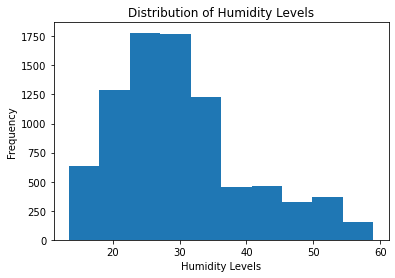
# Calculate correlation between temperature and humidity  
correlation = selected\_required\_columns['Temp'].corr(selected\_required\_columns['Humid'])  
correlation

0.788192191676409

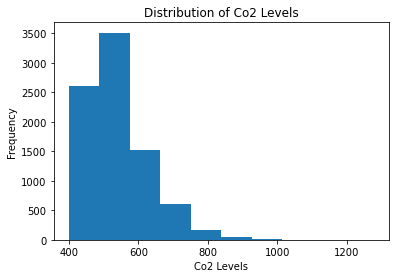
# Create a histogram of PM2.5 levels  
plt.hist(selected\_required\_columns['Pm25'], bins=10)  
plt.xlabel('PM2.5 Levels')  
plt.ylabel('Frequency')  
plt.title('Distribution of PM2.5 Levels')  
plt.show()



# Create a histogram of Humidity levels  
plt.hist(selected\_required\_columns['Humid'], bins=10)  
plt.xlabel('Humidity Levels')  
plt.ylabel('Frequency')  
plt.title('Distribution of Humidity Levels')  
plt.show()



# Create a histogram of Humidity levels  
plt.hist(selected\_required\_columns['Co2'], bins=10)  
plt.xlabel('Co2 Levels')  
plt.ylabel('Frequency')  
plt.title('Distribution of Co2 Levels')  
plt.show()



# Create a histogram of Humidity levels  
plt.hist(selected\_required\_columns['Voc'], bins=10)  
plt.xlabel('Voc Levels')  
plt.ylabel('Frequency')  
plt.title('Distribution of Voc Levels')  
plt.show()

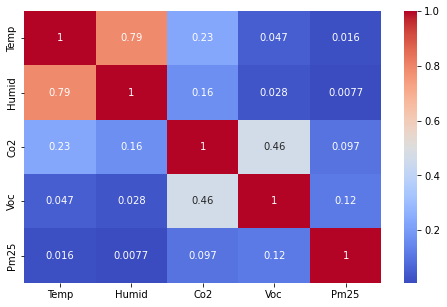


correlation\_matrix = selected\_required\_columns.corr()  
print(correlation\_matrix)

Temp Humid Co2 Voc Pm25  
Temp 1.000000 0.788192 0.229747 0.047183 0.015863  
Humid 0.788192 1.000000 0.164586 0.028436 0.007677  
Co2 0.229747 0.164586 1.000000 0.461918 0.097326  
Voc 0.047183 0.028436 0.461918 1.000000 0.115755  
Pm25 0.015863 0.007677 0.097326 0.115755 1.000000

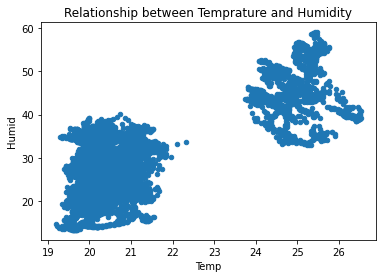
plt.figure(figsize=(8,5))  
sns.heatmap(correlation\_matrix, annot=True, cmap='coolwarm')

<AxesSubplot:>



plt.figure(figsize=(8,5))  
selected\_required\_columns.plot(x='Temp', y='Humid', kind='scatter')  
plt.xlabel('Temp')  
plt.ylabel('Humid')  
plt.title('Relationship between Temprature and Humidity')  
plt.show()

<Figure size 576x360 with 0 Axes>



#### **5.2.3.2 Data Storage and Management**

Data storage is a crucial component of any data-related project. In this case, the collected data is stored in both a 500GB capacity external hard drive and a PostgreSQL database Docker container. Storing the data in PostgreSQL allows for the creation of a Visual frontend dashboard along with data pipeline through the cloud for future use. The 500GB capacity of the external hard drive is currently sufficient for this project, but it can be extended as needed.

A computer hard drive in a black box

Description automatically generated

## **5.3 Automation and Data Analysis**

### **5.3.1 Data pipeline**

A data pipeline, in the context of a smart indoor air quality system, refers to a series of steps and processes that collect, process, and analyze data from various sources to provide valuable insights, enabling real-time monitoring and control of air quality. In this section, a comprehensive overview of the entire data pipeline process and the methods used to manage it are presented. I have provided the data source and the scripts for collecting sensor data in the Data Acquisition section.

The sensor data is initially collected from the sensors and stored both in an external drive and a Docker container. Subsequently, ingestion scripts are utilized to pull data from the source and incorporate it into the pipeline for further data preprocessing. Once the data is preprocessed, it is stored in an external hard drive as well as in PostgreSQL as processed data. It then proceeds through the pipeline to train a machine learning model, which is deployed on live sensor data. The predicted values are stored in an external drive and the PostgreSQL Docker container for additional functionality.

A diagram of a data processing process

Description automatically generated

After collecting data from the sensor, the next step is to ingest it into a pipeline for cleaning and training the machine learning model. Here are the scripts for data pre-processing.

# Data loading and preprocessing

import pandas as pd

import os

import csv

import time

current\_directory = os.path.dirname(os.path.abspath(\_\_file\_\_))

row\_data = os.environ.get('CSV\_FILE')

processed\_data = os.environ.get('load\_processed\_data')

def data\_preprocessing():

while True:

# Load the collected data into a DataFrame

awair\_csv\_data = pd.read\_csv(row\_data)

selected\_required\_columns = awair\_csv\_data[['temp', 'humid', 'co2', 'voc', 'pm25']]

selected\_required\_columns = selected\_required\_columns.dropna()

selected\_required\_columns = selected\_required\_columns.drop\_duplicates()

csv\_file = processed\_data

if os.path.isfile(csv\_file):

# Load the existing data to check for duplicates

existing\_data = pd.read\_csv(csv\_file)

# Concatenate the existing data and new data

combined\_data = pd.concat([existing\_data, selected\_required\_columns])

# Drop duplicates based on all columns

combined\_data = combined\_data.drop\_duplicates()

# Save the combined data to the CSV file

combined\_data.to\_csv(csv\_file, index=False)

else:

try:

# Create a new CSV file without a header if it doesn't exist

selected\_required\_columns.to\_csv(csv\_file, header=True, index=False)

except ValueError:

print("I/O error")

time.sleep(300)

if \_\_name\_\_ == '\_\_main\_\_':

data\_preprocessing()

### **5.3.2 Machine Learning Model**

Data processing and the implementation of ML models are critical components of a smart indoor air quality system. In this section, multiple areas are covered, ranging from data processing to ML model selection, evaluation, optimization, and real-time data prediction. Here, you will find a detailed explanation of data processing and ML model development.

* **Linear Regression**
* **Decision Tree Regressor**
* **Random Forest Regressor**

from sklearn.linear\_model import LinearRegression

from sklearn.tree import DecisionTreeRegressor

from sklearn.svm import SVR

from sklearn.ensemble import RandomForestRegressor

# Let's create multiple model to predict different parameters

# model for temprature prediction

def temp\_pred\_model():

model\_temp = LinearRegression()

return model\_temp

def humid\_pred\_model():

model\_humid = LinearRegression()

return model\_humid

def co2\_pred\_model():

model\_co2 = RandomForestRegressor(random\_state=42)

return model\_co2

def voc\_pred\_model():

# Initialize and train the RandomForest model

model\_voc = RandomForestRegressor(random\_state=42)

return model\_voc

def pm25\_pred\_model():

# Initialize and train the RandomForest model

model\_pm25 = RandomForestRegressor(random\_state=42)

return model\_pm25

from models import model

from sklearn.model\_selection import train\_test\_split

import pandas as pd

from sklearn.metrics import mean\_squared\_error

from sklearn.ensemble import RandomForestRegressor

import os

load\_processed\_data\_model = os.environ.get("load\_processed\_data")

def temp\_pred\_model():

# Load the collected data into a DataFrame

awair\_csv\_data = pd.read\_csv(load\_processed\_data\_model)

selected\_required\_columns = awair\_csv\_data

# Split the data into input features (X) and target variable (y)

X = selected\_required\_columns.drop('temp', axis=1)

y = selected\_required\_columns ['temp']

# Split the data into training and testing sets

X\_train, X\_test, y\_train, y\_test = train\_test\_split(X, y, test\_size=0.2, random\_state=42)

# Initialize and train the linear regression model

model\_temp = model.temp\_pred\_model()

# # Fit the model on the training data

model\_temp.fit(X\_train, y\_train)

#Make predictions using the trained model on the test set.

y\_pred = model\_temp.predict(X\_test)

# print(f"Y\_pred : {y\_pred}")

# # Evaluate the model on the testing data

score = model\_temp.score(X\_test, y\_test)

# print('Test Score for temperature')

# print("===========================================================")

# print(f"test\_score\_temperature: {score}")

# print("===========================================================")

return model\_temp, score

def humid\_pred\_model():

# Load the collected data into a DataFrame

awair\_csv\_data = pd.read\_csv(load\_processed\_data\_model)

selected\_required\_columns = awair\_csv\_data

# Split the data into input features (X) and target variable (y)

X = selected\_required\_columns.drop('humid', axis=1)

y = selected\_required\_columns ['humid']

# Split the data into training and testing sets

X\_train, X\_test, y\_train, y\_test = train\_test\_split(X, y, test\_size=0.2, random\_state=42)

# Initialize and train the linear regression model

model\_humid = model.humid\_pred\_model()

# # Fit the model on the training data

model\_humid.fit(X\_train, y\_train)

#Make predictions using the trained model on the test set.

y\_pred = model\_humid.predict(X\_test)

# print(f"Y\_pred : {y\_pred}")

# # Evaluate the model on the testing data

score = model\_humid.score(X\_test, y\_test)

# print('Test Score for humidity')

# print("===========================================================")

# print(f"R-squared score humidity: {score}")

# print("===========================================================")

return model\_humid, score

def co2\_pred\_model():

# Load the collected data into a DataFrame

awair\_csv\_data = pd.read\_csv(load\_processed\_data\_model)

selected\_required\_columns = awair\_csv\_data

# Split the data into input features (X) and target variable (y)

X = selected\_required\_columns.drop('co2', axis=1)

y = selected\_required\_columns ['co2']

# Split the data into training and testing sets

X\_train, X\_test, y\_train, y\_test = train\_test\_split(X, y, test\_size=0.2, random\_state=42)

# Initialize and train the RandomForest model

model\_co2 = model.co2\_pred\_model()

# # Fit the model on the training data

model\_co2.fit(X\_train, y\_train)

#Make predictions using the trained model on the test set.

y\_pred = model\_co2.predict(X\_test)

# print(f"Y\_pred : {y\_pred}")

# # Evaluate the model on the testing data

mse = mean\_squared\_error(y\_test, y\_pred)

# print('Test Score for co2')

# print("===========================================================")

# print(f"Mean Squared Error co2: {mse}")

# print("===========================================================")

return model\_co2, mse

def voc\_pred\_model():

# Load the collected data into a DataFrame

awair\_csv\_data = pd.read\_csv(load\_processed\_data\_model)

selected\_required\_columns = awair\_csv\_data

# Split the data into input features (X) and target variable (y)

X = selected\_required\_columns.drop('voc', axis=1)

y = selected\_required\_columns ['voc']

# Split the data into training and testing sets

X\_train, X\_test, y\_train, y\_test = train\_test\_split(X, y, test\_size=0.2, random\_state=42)

# Initialize and train the RandomForest model

model\_voc = model.voc\_pred\_model()

# # Fit the model on the training data

model\_voc.fit(X\_train, y\_train)

#Make predictions using the trained model on the test set.

y\_pred = model\_voc.predict(X\_test)

# print(f"Y\_pred : {y\_pred}")

# # Evaluate the model on the testing data

mse = mean\_squared\_error(y\_test, y\_pred)

# print('Test Score for voc')

# print("===========================================================")

# print(f"R-squared score voc: {mse}")

# print("===========================================================")

return model\_voc, mse

def pm25\_pred\_model():

# Load the collected data into a DataFrame

awair\_csv\_data = pd.read\_csv(load\_processed\_data\_model)

selected\_required\_columns = awair\_csv\_data

# Split the data into input features (X) and target variable (y)

X = selected\_required\_columns.drop('pm25', axis=1)

y = selected\_required\_columns ['pm25']

# Split the data into training and testing sets

X\_train, X\_test, y\_train, y\_test = train\_test\_split(X, y, test\_size=0.2, random\_state=42)

# Initialize and train the RandomForest model

model\_pm25 = model.pm25\_pred\_model()

# # Fit the model on the training data

model\_pm25.fit(X\_train, y\_train)

#Make predictions using the trained model on the test set.

y\_pred = model\_pm25.predict(X\_test)

# print(f"Y\_pred : {y\_pred}")

# # Evaluate the model on the testing data

mse = mean\_squared\_error(y\_test, y\_pred)

# print('Test Score for pm25')

# print("===========================================================")

# print(f"R-squared score pm25: {mse}")

# print("===========================================================")

return model\_pm25, mse

import sys

import io

sys.path.insert(0, 'src')

from train import temp\_pred\_model,humid\_pred\_model,co2\_pred\_model,voc\_pred\_model,pm25\_pred\_model

import datetime

import pandas as pd

import time

import requests

import csv

import numpy as np

from sklearn.impute import SimpleImputer

import os

url = os.environ.get('API\_LINK')

predicted\_data = []

def live\_sensor\_data():

sensor\_data = []

Url = url # api url path

request = requests.request("GET", Url)

data = request.json()

add\_new\_col = {'location':'Janonhanta1,Vantaa,Finland'}

add\_bew\_col\_serial = {}

data.update(add\_bew\_col\_serial)

data.update(add\_new\_col)

sensor\_data.append(data)

return sensor\_data

def temp\_test\_prediction():

# Predict temperature for new data

# Retrieve live sensor data

live\_data = live\_sensor\_data()

# Create DataFrame

df = pd.DataFrame(live\_data)

# Select relevant columns

selected\_real\_time\_data = df[['humid', 'co2', 'voc', 'pm25']]

# Drop NaN values and duplicates

selected\_real\_time\_data = selected\_real\_time\_data.dropna().drop\_duplicates()

# Set column names

selected\_real\_time\_data.columns = ['humid', 'co2', 'voc', 'pm25'] # Assign appropriate column names

# Impute missing values if any

imputer = SimpleImputer(strategy='mean') # Use appropriate strategy

selected\_real\_time\_data\_imputed = imputer.fit\_transform(selected\_real\_time\_data)

# Retrieve current time

current\_time = datetime.datetime.now().strftime('%Y-%m-%d %H:%M:%S')

predicted\_data.append({"DateTime": current\_time})

# Load temperature prediction model

model\_temp, score = temp\_pred\_model()

predicted\_data.append({"Temperature\_Test\_Score": score})

# Make predictions

prediction\_temperature = model\_temp.predict(selected\_real\_time\_data\_imputed)

extracted\_value = prediction\_temperature[0]

predicted\_data.append({"Temperature\_Predicted\_Value": extracted\_value})

return extracted\_value

def humid\_test\_prediction():

# Predict humidity for new data

# Retrieve live sensor data

live\_data = live\_sensor\_data()

# Create DataFrame

df1 = pd.DataFrame(live\_data)

# Select relevant columns

selected\_real\_time\_data\_humid = df1[['temp', 'co2', 'voc', 'pm25']]

# Drop NaN values and duplicates

selected\_real\_time\_data\_humid = selected\_real\_time\_data\_humid.dropna().drop\_duplicates()

# Set column names

selected\_real\_time\_data\_humid.columns = ['temp', 'co2', 'voc', 'pm25'] # Assign appropriate column names

# Impute missing values if any

imputer = SimpleImputer(strategy='mean') # Use appropriate strategy

selected\_real\_time\_data\_humid\_imputed = imputer.fit\_transform(selected\_real\_time\_data\_humid)

# Retrieve current time

current\_time = datetime.datetime.now().strftime('%Y-%m-%d %H:%M:%S')

predicted\_data.append({"DateTime": current\_time})

# Load humidity prediction model

model\_humid, score = humid\_pred\_model()

predicted\_data.append({"Humidity\_Test\_Score": score})

# Make predictions

prediction\_humid = model\_humid.predict(selected\_real\_time\_data\_humid\_imputed)

extracted\_value = prediction\_humid[0]

predicted\_data.append({"Humidity\_Predicted\_Value": extracted\_value})

return extracted\_value

def co2\_test\_prediction():

# Predict CO2 for new data

# Retrieve live sensor data

live\_data = live\_sensor\_data()

# Create DataFrame

df2 = pd.DataFrame(live\_data)

# Select relevant columns

selected\_real\_time\_data\_co2 = df2[['temp', 'humid', 'voc', 'pm25']]

# Drop NaN values and duplicates

selected\_real\_time\_data\_co2 = selected\_real\_time\_data\_co2.dropna().drop\_duplicates()

# Set column names

selected\_real\_time\_data\_co2.columns = ['temp', 'humid', 'voc', 'pm25'] # Assign appropriate column names

# Impute missing values if any

imputer = SimpleImputer(strategy='mean') # Use appropriate strategy

selected\_real\_time\_data\_co2\_imputed = imputer.fit\_transform(selected\_real\_time\_data\_co2)

# Retrieve current time

current\_time = datetime.datetime.now().strftime('%Y-%m-%d %H:%M:%S')

predicted\_data.append({"DateTime": current\_time})

# Load CO2 prediction model

model\_co2, mse = co2\_pred\_model()

predicted\_data.append({"Co2\_Test\_Score": mse})

# Make predictions

prediction\_co2 = model\_co2.predict(selected\_real\_time\_data\_co2\_imputed)

extracted\_value = prediction\_co2[0]

predicted\_data.append({"Co2\_Predicted\_Value": extracted\_value})

return extracted\_value

def voc\_test\_prediction():

# Predict VOC for new data

# Retrieve live sensor data

live\_data = live\_sensor\_data()

# Create DataFrame

df3 = pd.DataFrame(live\_data)

# Select relevant columns

selected\_real\_time\_data\_voc = df3[['temp', 'humid', 'co2', 'pm25']]

# Drop NaN values and duplicates

selected\_real\_time\_data\_voc = selected\_real\_time\_data\_voc.dropna().drop\_duplicates()

# Set column names

selected\_real\_time\_data\_voc.columns = ['temp', 'humid', 'co2', 'pm25'] # Assign appropriate column names

# Retrieve current time

current\_time = datetime.datetime.now().strftime('%Y-%m-%d %H:%M:%S')

predicted\_data.append({"DateTime": current\_time})

# Load VOC prediction model

model\_voc, mse = voc\_pred\_model()

predicted\_data.append({"VOC\_Test\_Score": mse})

# Convert DataFrame to NumPy array after setting column names

selected\_real\_time\_data\_voc\_array = selected\_real\_time\_data\_voc.to\_numpy()

# Make predictions using array without feature names

prediction\_voc = model\_voc.predict(selected\_real\_time\_data\_voc\_array)

extracted\_value = prediction\_voc[0]

predicted\_data.append({"VOC\_Predicted\_Value": extracted\_value})

return extracted\_value

def pm25\_test\_prediction():

# Predict PM2.5 for new data

# Retrieve live sensor data

live\_data = live\_sensor\_data()

# Create DataFrame

df4 = pd.DataFrame(live\_data)

# Select relevant columns

selected\_real\_time\_data\_pm25 = df4[['temp', 'humid', 'co2', 'voc']]

# Drop NaN values and duplicates

selected\_real\_time\_data\_pm25 = selected\_real\_time\_data\_pm25.dropna().drop\_duplicates()

# Set column names

selected\_real\_time\_data\_pm25.columns = ['temp', 'humid', 'co2', 'voc'] # Assign appropriate column names

# Impute missing values if any

imputer = SimpleImputer(strategy='mean') # Use appropriate strategy

selected\_real\_time\_data\_pm25\_imputed = imputer.fit\_transform(selected\_real\_time\_data\_pm25)

# Retrieve current time

current\_time = datetime.datetime.now().strftime('%Y-%m-%d %H:%M:%S')

predicted\_data.append({"DateTime": current\_time})

# Load PM2.5 prediction model

model\_pm25, mse = pm25\_pred\_model()

predicted\_data.append({"Pm25\_Test\_Score": mse})

# Make predictions

prediction\_pm25 = model\_pm25.predict(selected\_real\_time\_data\_pm25\_imputed)

extracted\_value = prediction\_pm25[0]

predicted\_data.append({"Pm25\_Predicted\_Value": extracted\_value})

return extracted\_value

from src.sensor\_api import sensor\_api\_connection

from src.models import model\_test\_with\_live\_data

from src.data\_loader import data\_loader

from src.air\_cooler\_integration import air\_cooler

from src.WiFi\_Socket import tapo\_info

from src.current\_weather\_outdoor import current\_weather\_outside

import threading

import time

import psycopg2

import csv

import os

import pandas as pd

import datetime

from tabulate import tabulate

host = os.environ.get('CONTAINER\_IP')

port = os.environ.get('PORT')

database = os.environ.get('DATABASE')

user = os.environ.get('USER')

password = os.environ.get('PASS\_WORD')

predicted\_csv = os.environ.get('predicted\_data')

def outside\_weather\_now():

while True:

current\_weather\_outside.outdoor\_weather()

def awair\_row\_data():

while True:

sensor\_api\_connection.awair\_api\_call()

def data\_preprocess():

while True:

data\_loader.data\_preprocessing()

def model\_execution\_with\_live\_data():

while True:

model\_test\_with\_live\_data.temp\_test\_prediction()

model\_test\_with\_live\_data.humid\_test\_prediction()

model\_test\_with\_live\_data.co2\_test\_prediction()

model\_test\_with\_live\_data.voc\_test\_prediction()

model\_test\_with\_live\_data.pm25\_test\_prediction()

predicted\_values = model\_test\_with\_live\_data.predicted\_data

pred\_temp\_value = predicted\_values[2]

pred\_temp\_humid = predicted\_values[5]

pred\_temp\_co2 = predicted\_values[8]

pred\_temp\_voc = predicted\_values[11]

predicted\_temp\_pm25 = predicted\_values[14]

pred\_temp\_value\_only = []

for k,temp in pred\_temp\_value.items():

pred\_temp\_value\_only.append(round(temp, 2))

pred\_humid\_value\_only = []

for k,humid in pred\_temp\_humid.items():

pred\_humid\_value\_only.append(round(humid, 2))

pred\_co2\_value\_only = []

for k,co2 in pred\_temp\_co2.items():

pred\_co2\_value\_only.append(co2)

pred\_voc\_value\_only = []

for k,voc in pred\_temp\_voc.items():

pred\_voc\_value\_only.append(voc)

pred\_pm25\_value\_only = []

for k,pm25 in predicted\_temp\_pm25.items():

pred\_pm25\_value\_only.append(pm25)

headers = ['Predicted Temperature','Predicted Humidity','Predicted Co2','Predicted Voc','Predicted Pm25']

zipped\_values = list(zip(pred\_temp\_value\_only,pred\_humid\_value\_only,pred\_co2\_value\_only,pred\_voc\_value\_only,pred\_pm25\_value\_only))

print('')

print(' Predicted Parameters')

print(tabulate(zipped\_values , headers=headers, tablefmt='pretty'))

# # print(temp,humid)

air\_cooler.air\_coller\_integration(temp,humid)

conn1 = psycopg2.connect(

host=host,

port=port,

database=database,

user=user,

password=password

)

conn1.autocommit=True

cur1 = conn1.cursor()

cur1.execute("SELECT 1 FROM pg\_catalog.pg\_database WHERE datname = 'awair'")

exists = cur1.fetchone()

if not exists:

cur1.execute("CREATE DATABASE awair")

conn1.set\_session(autocommit=True)

try:

conn = psycopg2.connect(

host=host,

port=port,

database=database,

user=user,

password=password

)

except psycopg2.Error as e:

print(e)

try:

cur = conn.cursor()

except psycopg2.Error as e:

print("Error: Could not get the cursor to the database")

print(e)

conn.set\_session(autocommit=True)

try:

cur.execute("CREATE TABLE IF NOT EXISTS predicted\_data (id SERIAL PRIMARY KEY,\

DateTime TIMESTAMP,\

Temperature\_Test\_Score NUMERIC,\

Temperature\_Predicted\_Value NUMERIC,\

Humidity\_Test\_Score NUMERIC,\

Humidity\_Predicted\_Value NUMERIC,\

Co2\_Test\_Score NUMERIC,\

Co2\_Predicted\_Value NUMERIC,\

VOC\_Test\_Score NUMERIC,\

VOC\_Predicted\_Value NUMERIC,\

Pm25\_Test\_Score NUMERIC,\

Pm25\_Predicted\_Value NUMERIC);")

except psycopg2.Error as e:

print("Error: Issue creating table")

print(e)

record = {}

for item in predicted\_values:

key = list(item.keys())[0]

value = item[key]

record[key] = value

columns = ', '.join(record.keys())

placeholders = ', '.join(['%s'] \* len(record))

sql = f"INSERT INTO predicted\_data ({columns}) VALUES ({placeholders})"

try:

cur.execute(sql, list(record.values()))

conn.commit()

except psycopg2.Error as e:

print("Error:", e)

conn.rollback()

# save data as csv file

csv\_file = predicted\_csv

# Merge dictionaries into a single dictionary

merged\_data = {}

for item in predicted\_values:

merged\_data.update(item)

# Check if the file exists and write data accordingly

with open(csv\_file, 'a', newline='') as csvfile:

writer = csv.DictWriter(csvfile, fieldnames=merged\_data.keys())

if csvfile.tell() == 0: # If the file is empty, write header

writer.writeheader()

writer.writerow(merged\_data)

time.sleep(600)

def energy\_consumption():

while True:

tapo\_info.energy\_time\_calculation()

if \_\_name\_\_ == '\_\_main\_\_':

import concurrent.futures

import warnings

def suppress\_warnings():

warnings.filterwarnings(action='ignore', category=UserWarning, module='sklearn')

# Call suppress\_warnings() before executing the functions that trigger the warnings

suppress\_warnings()

with concurrent.futures.ThreadPoolExecutor() as executor:

# Submit both functions for execution

current\_weather = executor.submit(outside\_weather\_now)

api\_row\_data = executor.submit(awair\_row\_data)

future\_data = executor.submit(data\_preprocess)

future\_model = executor.submit(model\_execution\_with\_live\_data)

energy\_data = executor.submit(energy\_consumption)

# Wait for both functions to complete

concurrent.futures.wait([future\_model, energy\_data, api\_row\_data, future\_data])

### **5.3.3 Real-time Monitoring**

#### **5.3.3.1 Notification Mechanism**

The notification mechanism in an indoor air quality system plays a crucial role as a means of communication between the system and its users. It enables alerts, updates, and notifications to inform users about the indoor air quality status or any exceeding thresholds of specific parameters.

In this case, automatic notifications have been set up for the temperature and humidity parameters. The scripts for automatic email notifications are as follows:

import os

import smtplib # SMTP client session

from email.message import EmailMessage # for email notification

import ssl # for security

import bcrypt

email\_notification = os.environ.get('email')

email\_notification\_password = os.environ.get('email\_password')

def send\_email\_notification\_turn\_on():

email\_sender = email\_notification

email\_password = email\_notification\_password

email\_receiver = email\_notification

subject = 'Awair sensor notification'

body = """

Subject: Awair sensor temperature notification!

Your room temperature has exceeded the threshold, and the air cooler has turned on successfully.

Regards,

Test Company,

Vantaa, Finland

"""

em = EmailMessage()

em['From'] = email\_sender

em['To'] = email\_receiver

em['Subject'] = subject

em.set\_content(body)

context = ssl.create\_default\_context()

with smtplib.SMTP\_SSL('smtp.gmail.com', 465, context=context) as smtp:

smtp.login(email\_sender,email\_password)

smtp.sendmail(email\_sender,email\_receiver,em.as\_string()) # Send email

def send\_email\_notification\_turn\_off():

email\_sender = email\_notification

email\_password = email\_notification\_password

email\_receiver = email\_notification

subject = 'Awair sensor notification'

body = """

Subject: Awair sensor temperature notification!

Your room temperature has exceeded the threshold, and the air cooler has turned off successfully.

Regards,

Test Company,

Vantaa, Finland

"""

em = EmailMessage()

em['From'] = email\_sender

em['To'] = email\_receiver

em['Subject'] = subject

em.set\_content(body)

context = ssl.create\_default\_context()

with smtplib.SMTP\_SSL('smtp.gmail.com', 465, context=context) as smtp:

smtp.login(email\_sender,email\_password)

smtp.sendmail(email\_sender,email\_receiver,em.as\_string()) # Send email

#### **5.3.3.2 Wi-Fi socket connection**

The Tapo Wi-Fi mini socket has been installed with the air cooler device and connected through the IP address to retrieve the data and control it using specific functions. Below is the script for the Tapo mini socket to manage turn on and turn off events through integration with SmartThings:

import json

import requests

import pandas as pd

import psycopg2

import os

host = os.environ.get('CONTAINER\_IP')

port = os.environ.get('PORT')

database = os.environ.get('DATABASE')

user = os.environ.get('USER')

password = os.environ.get('PASS\_WORD')

smartthings\_url = os.environ.get('smart\_things\_url')

accesstoken\_smarttings = os.environ.get('access\_token\_smartthings')

# deviceendpoint\_smartthings = os.environ.get('device\_endpoint\_smartthings')

deviceid = os.environ.get('device\_id')

api\_url = smartthings\_url

access\_token = accesstoken\_smarttings

# Example endpoint to get devices

devices\_endpoint = '/v1/devices'

headers = {

'Authorization': f'Bearer {access\_token}',

'Content-Type': 'application/json'

}

# Make a GET request to retrieve devices

response = requests.get(api\_url + devices\_endpoint, headers=headers)

plug\_info = []

if response.status\_code == 200:

devices = response.json()

plug\_info.append(devices)

# print(devices)

# Process devices data here

else:

print(f"Failed to retrieve devices. Status code: {response.status\_code}")

def air\_cooler\_power\_turn\_on():

api\_url = smartthings\_url

access\_token = accesstoken\_smarttings

# Example endpoint to control a device (replace with the actual device ID)

device\_id = deviceid

control\_endpoint = f'/v1/devices/{device\_id}/commands'

headers = {

'Authorization': f'Bearer {access\_token}',

'Content-Type': 'application/json'

}

# Payload to turn on the device

payload = {

'commands': [

{

'component': 'main',

'capability': 'switch',

'command': 'on'

}

]

}

# Make a POST request to turn on the device

response = requests.post(api\_url + control\_endpoint, json=payload, headers=headers)

if response.status\_code == 200:

print("Device turned on successfully!")

else:

print(f"Failed to turn on the device. Status code: {response.status\_code}")

def air\_cooler\_power\_turn\_off():

api\_url = smartthings\_url

access\_token = accesstoken\_smarttings

# Example endpoint to control a device (replace with the actual device ID)

device\_id = deviceid

control\_endpoint = f'/v1/devices/{device\_id}/commands'

headers = {

'Authorization': f'Bearer {access\_token}',

'Content-Type': 'application/json'

}

# Payload to turn off the device

payload = {

'commands': [

{

'component': 'main',

'capability': 'switch',

'command': 'off'

}

]

}

# Make a POST request to turn off the device

response = requests.post(api\_url + control\_endpoint, json=payload, headers=headers)

if response.status\_code == 200:

print("Device turned off successfully!")

else:

print(f"Failed to turn off the device. Status code: {response.status\_code}")

def check\_device\_status(access\_token, device\_id):

api\_url = smartthings\_url

status\_endpoint = f'/v1/devices/{device\_id}/status'

headers = {

'Authorization': f'Bearer {access\_token}',

'Content-Type': 'application/json'

}

# Make a GET request to retrieve device status

response = requests.get(api\_url + status\_endpoint, headers=headers)

if response.status\_code == 200:

device\_status = response.json()

return device\_status

else:

print(f"Failed to get device status. Status code: {response.status\_code}")

return None

def is\_air\_cooler\_power\_on():

# Usage: Call the function with your access token and device ID to check the status

access\_token = accesstoken\_smarttings

device\_id = deviceid

status = check\_device\_status(access\_token, device\_id)

if status is not None:

pass

# print("Device status:", status)

# Accessing switch status value

switch\_status = status['components']['main']['switch']['switch']['value']

print(switch\_status)

conn1 = psycopg2.connect(

host=host,

port=port,

database=database,

user=user,

password=password

)

conn1.autocommit=True

cur1 = conn1.cursor()

cur1.execute("SELECT 1 FROM pg\_catalog.pg\_database WHERE datname = 'awair'")

exists = cur1.fetchone()

if not exists:

cur1.execute("CREATE DATABASE awair")

conn1.set\_session(autocommit=True)

try:

conn = psycopg2.connect(

host=host,

port=port,

database=database,

user=user,

password=password

)

except psycopg2.Error as e:

print(e)

try:

cur = conn.cursor()

except psycopg2.Error as e:

print("Error: Could not get the crusor to the database")

print(e)

conn.set\_session(autocommit=True)

try:

cur.execute("""

CREATE TABLE IF NOT EXISTS device\_status (

id BIGSERIAL PRIMARY KEY,

status VARCHAR,

CONSTRAINT unique\_device\_status UNIQUE (status)

);

""")

except psycopg2.Error as e:

print("Error: Issue creating table")

print(e)

sql = "INSERT INTO device\_status(status) VALUES (%s) ON CONFLICT DO NOTHING;"

try:

cur.execute(sql, (switch\_status,))

except psycopg2.Error as e:

print("Error: Issue inserting data")

print(e)

if switch\_status == "on":

return True

else:

return False

#### **5.3.3.3 Air cooler automation**

Air cooler automation refers to the process of automating the operation and control of an air cooler system to optimize its performance and energy efficiency. The air cooler system is connected to a Tapo Wi-Fi socket, and a threshold is set based on the predictions from the ML model using new data. This automation significantly reduces energy consumption and minimizes human efforts. The script is designed to automatically shut down the air cooler when the prediction threshold is exceeded and sends an email notification to the user. Below is the script, including the ML prediction:

## **5.4 Energy Efficiency**

Calculating energy consumption for an air cooler system involves estimating the amount of electrical energy consumed by the cooler over a specific period. The Wi-Fi smart socket provides only the usage time, and the rest of the calculations are done according to a specific formula. The results are saved as a CSV file for further analysis. The full script is provided below the formula.

This is just an example:

**step-1** 65 watts X 3 hours = 195 watt-hours per day

**step-2** 195 watt-hours per day / 1000 = 0.195 kWh per day

**step-3** 0.195 watt-hours per day X 30 days = 5.85 kWh per month

**step-4** 5.85 kWh per month X €0.13 per kWh = €0.76 per month

from datetime import datetime

import requests

import time

import os

import csv

import psycopg2

host = os.environ.get('CONTAINER\_IP')

port = os.environ.get('PORT')

database = os.environ.get('DATABASE')

user = os.environ.get('USER')

password = os.environ.get('PASS\_WORD')

smartthings\_url = os.environ.get('smart\_things\_url')

# deviceendpoint\_smartthings = os.environ.get('device\_endpoint\_smartthings')

accesstoken\_smarttings = os.environ.get('access\_token\_smartthings')

deviceid = os.environ.get('device\_id')

energy\_cal\_starttime = os.environ.get('energy\_cal\_start\_time')

energy\_cal\_endtime = os.environ.get('energy\_cal\_end\_time')

electricity\_cal\_cost = os.environ.get('electricity\_cost')

def check\_device\_status(access\_token, device\_id):

api\_url = smartthings\_url

status\_endpoint = f'/v1/devices/{device\_id}/status'

headers = {

'Authorization': f'Bearer {access\_token}',

'Content-Type': 'application/json'

}

# Make a GET request to retrieve device status

response = requests.get(api\_url + status\_endpoint, headers=headers)

if response.status\_code == 200:

device\_status = response.json()

return device\_status

else:

print(f"Failed to get device status. Status code: {response.status\_code}")

return None

def calculate\_total\_used\_time(time\_data):

start\_times = []

end\_times = []

for entry in time\_data:

if 'start\_time' in entry:

start\_times.append(datetime.strptime(entry['start\_time'], '%Y-%m-%dT%H:%M:%S.%fZ'))

elif 'end\_time' in entry:

end\_times.append(datetime.strptime(entry['end\_time'], '%Y-%m-%dT%H:%M:%S.%fZ'))

total\_used\_time = 0

paired\_times = zip(sorted(start\_times), sorted(end\_times))

for start\_time, end\_time in paired\_times:

total\_used\_time += (end\_time - start\_time).total\_seconds()

return total\_used\_time

def energy\_time\_calculation():

while True:

# Usage: Call the function with your access token and device ID to check the status

access\_token = accesstoken\_smarttings

device\_id = deviceid

status = check\_device\_status(access\_token, device\_id)

if status is not None:

pass

# print("Device status:", status)

# Accessing switch status value

switch\_status = status['components']['main']['switch']['switch']['value']

switch\_timestamp = status['components']['main']['switch']['switch']['timestamp']

# Printing the switch status

# print("Switch status:", switch\_status)

# print("Switch timestamp:", switch\_timestamp)

s\_columns = ['start\_time']

e\_columns = ['end\_time']

start\_times = []

end\_times = []

if switch\_status == "on":

start\_on\_timestamp = switch\_timestamp

start\_times.append(start\_on\_timestamp)

csv\_file = energy\_cal\_starttime

path = energy\_cal\_starttime

if os.path.exists(path):

with open(csv\_file, "a+") as add\_obj:

writer = csv.DictWriter(add\_obj, fieldnames=s\_columns)

file\_content = open(csv\_file).read()

for data in start\_times:

if data not in file\_content:

writer.writerow({'start\_time': data})

else:

try:

with open(csv\_file, "w") as awair\_file:

writer = csv.DictWriter(awair\_file, fieldnames=s\_columns)

writer.writeheader()

for data in start\_times:

writer.writerow({'start\_time': data})

except ValueError:

print("I/O error")

# print(start\_times)

conn1 = psycopg2.connect(

host=host,

port=port,

database=database,

user=user,

password=password

)

conn1.autocommit=True

cur1 = conn1.cursor()

cur1.execute("SELECT 1 FROM pg\_catalog.pg\_database WHERE datname = 'awair'")

exists = cur1.fetchone()

if not exists:

cur1.execute("CREATE DATABASE awair")

conn1.set\_session(autocommit=True)

try:

conn = psycopg2.connect(

host=host,

port=port,

database=database,

user=user,

password=password

)

except psycopg2.Error as e:

print(e)

try:

cur = conn.cursor()

except psycopg2.Error as e:

print("Error: Could not get the crusor to the database")

print(e)

conn.set\_session(autocommit=True)

try:

cur.execute("CREATE TABLE IF NOT EXISTS start\_time\_data(id BIGSERIAL PRIMARY KEY,start\_time timestamp,\

CONSTRAINT unique\_start\_time UNIQUE (start\_time));")

except psycopg2.Error as e:

print("Error: Issue creating table")

print(e)

for timestamp\_value in start\_times:

sql = "INSERT INTO start\_time\_data(start\_time) VALUES (%s) ON CONFLICT DO NOTHING;"

cur.execute(sql, (timestamp\_value,))

elif switch\_status == "off":

start\_of\_timestamp = switch\_timestamp

end\_times.append(start\_of\_timestamp)

csv\_file = energy\_cal\_endtime

path = energy\_cal\_endtime

if os.path.exists(path):

with open(csv\_file, "a+") as add\_obj:

writer = csv.DictWriter(add\_obj, fieldnames=e\_columns)

file\_content = open(csv\_file).read()

for data in end\_times:

if data not in file\_content:

writer.writerow({'end\_time': data})

else:

try:

with open(csv\_file, "w") as awair\_file:

writer = csv.DictWriter(awair\_file, fieldnames=e\_columns)

writer.writeheader()

for data in end\_times:

writer.writerow({'end\_time': data})

except ValueError:

print("I/O error")

else:

print("Invalid timestamp")

conn1 = psycopg2.connect(

host=host,

port=port,

database=database,

user=user,

password=password

)

conn1.autocommit=True

cur1 = conn1.cursor()

cur1.execute("SELECT 1 FROM pg\_catalog.pg\_database WHERE datname = 'awair'")

exists = cur1.fetchone()

if not exists:

cur1.execute("CREATE DATABASE awair")

conn1.set\_session(autocommit=True)

try:

conn = psycopg2.connect(

host=host,

port=port,

database=database,

user=user,

password=password

)

except psycopg2.Error as e:

print(e)

try:

cur = conn.cursor()

except psycopg2.Error as e:

print("Error: Could not get the crusor to the database")

print(e)

conn.set\_session(autocommit=True)

try:

cur.execute("CREATE TABLE IF NOT EXISTS end\_time\_data(id BIGSERIAL PRIMARY KEY,end\_time timestamp,\

CONSTRAINT unique\_end\_time UNIQUE (end\_time));")

except psycopg2.Error as e:

print("Error: Issue creating table")

print(e)

for timestamp\_value in end\_times:

sql = "INSERT INTO end\_time\_data (end\_time) VALUES (%s) ON CONFLICT DO NOTHING;"

cur.execute(sql, (timestamp\_value,))

csv\_file = energy\_cal\_endtime

path = energy\_cal\_endtime

merged\_data = []

if os.path.exists(path):

with open(csv\_file, 'r') as readfile:

reader = csv.DictReader(readfile)

for row in reader:

merged\_data.append(row)

csv\_file = energy\_cal\_starttime

path = energy\_cal\_starttime

if os.path.exists(path):

with open(csv\_file, 'r') as readfile:

reader = csv.DictReader(readfile)

for row in reader:

merged\_data.append(row)

# print(merged\_data)

# total\_used\_time = calculate\_total\_used\_time(merged\_data)

# print(f"The total used time is: {total\_used\_time} seconds")

start\_time\_value = []

end\_time\_vlaue = []

for data in merged\_data:

for key, value in data.items():

if key == 'start\_time':

start\_time\_value.append(value)

if key == 'end\_time':

end\_time\_vlaue.append(value)

electricity\_cost\_data = []

for start, end in zip(start\_time\_value, end\_time\_vlaue):

starttime = datetime.fromisoformat(start[:-1])

endtime = datetime.fromisoformat(end[:-1])

duration = (endtime - starttime).total\_seconds() / 60

# print(f"Start time: {starttime}, End time: {endtime}, Used time: {duration} minutes")

device\_capacity = 65 # in watts, device\_consume\_electricity

min\_in\_hrs= round(duration/60,2) #calculate\_total\_min\_in\_hours\_in\_day

watt\_hours = round(device\_capacity \* min\_in\_hrs,2) # watt\_hours\_per\_day

kwh = round(watt\_hours / 1000,2) # total\_kwh\_per\_day

price\_per\_kwh = 0.13 # 0.13 cents per hour,price\_per\_kwh

e\_tranf\_cost = round(0.3 \* kwh,2) # electricity\_transfer\_cost

e\_tax\_cost = round(0.3 \* kwh,2) # electricity\_tax

calculate\_electricity\_cost= price\_per\_kwh \* kwh

total\_cost = round(calculate\_electricity\_cost + e\_tranf\_cost + e\_tax\_cost,2) # total\_eletricity\_cost

electricity\_cost\_data = [{'Start\_time': start,'End\_time': end,

'Used\_time\_hrs': min\_in\_hrs,

'Price\_per\_kwh\_cents': price\_per\_kwh,

'Transfer\_per\_kwh': e\_tranf\_cost,

'Tax\_per\_kwh': e\_tax\_cost,

'Total\_cost\_euro': total\_cost}]

column\_name = ["Start\_time", "End\_time", "Used\_time\_hrs", "Price\_per\_kwh\_cents",

"Transfer\_per\_kwh", "Tax\_per\_kwh", "Total\_cost\_euro"]

csv\_file = electricity\_cal\_cost

path = electricity\_cal\_cost

if os.path.exists(path):

with open(csv\_file, 'a+') as addfile:

writer = csv.DictWriter(addfile, fieldnames=column\_name)

file\_content = open(csv\_file).read()

for data in electricity\_cost\_data:

if f"{data['Start\_time']},{data['End\_time']}" not in file\_content:

writer.writerow(data)

else:

try:

with open(csv\_file, 'w') as writefile:

writer = csv.DictWriter(writefile, fieldnames=column\_name)

writer.writeheader()

for data in electricity\_cost\_data:

writer.writerow(data)

except ValueError:

print("I/O error")

conn1 = psycopg2.connect(

host=host,

port=port,

database=database,

user=user,

password=password

)

conn1.autocommit=True

cur1 = conn1.cursor()

cur1.execute("SELECT 1 FROM pg\_catalog.pg\_database WHERE datname = 'awair'")

exists = cur1.fetchone()

if not exists:

cur1.execute("CREATE DATABASE awair")

conn1.set\_session(autocommit=True)

try:

conn = psycopg2.connect(

host=host,

port=port,

database=database,

user=user,

password=password

)

except psycopg2.Error as e:

print(e)

try:

cur = conn.cursor()

except psycopg2.Error as e:

print("Error: Could not get the crusor to the database")

print(e)

conn.set\_session(autocommit=True)

try:

cur.execute("""

CREATE TABLE IF NOT EXISTS cost\_analysis\_data (

id BIGSERIAL PRIMARY KEY,

start\_time TIMESTAMP,

end\_time TIMESTAMP,

used\_time\_hrs NUMERIC,

price\_per\_kwh\_cents NUMERIC,

transfer\_per\_kwh NUMERIC,

tax\_per\_kwh NUMERIC,

total\_cost\_euro NUMERIC,

CONSTRAINT unique\_cost\_analysis\_data UNIQUE (id)

);

""")

except psycopg2.Error as e:

print("Error: Issue creating table")

print(e)

check\_sql = """

SELECT COUNT(\*) FROM cost\_analysis\_data

WHERE Start\_time = %s AND End\_time = %s

"""

# Insert data into the PostgreSQL database

for data in electricity\_cost\_data:

# Check if data exists in the table

cur.execute(check\_sql, (data['Start\_time'], data['End\_time']))

result = cur.fetchone()[0]

# If data doesn't exist, insert it

if result == 0:

sql = """

INSERT INTO cost\_analysis\_data (

Start\_time, End\_time, Used\_time\_hrs, Price\_per\_kwh\_cents,

Transfer\_per\_kwh, Tax\_per\_kwh, Total\_cost\_euro

) VALUES (%s, %s, %s, %s, %s, %s, %s)

ON CONFLICT DO NOTHING;

"""

values = (

data['Start\_time'],

data['End\_time'],

data['Used\_time\_hrs'],

data['Price\_per\_kwh\_cents'],

data['Transfer\_per\_kwh'],

data['Tax\_per\_kwh'],

data['Total\_cost\_euro']

)

cur.execute(sql, values)

time.sleep(300)

## **5.5 Security and Privacy**

In a smart indoor air quality system, security and privacy are crucial factors that must be carefully considered and implemented to protect user's data and ensure the system's integrity. Here's how security and privacy factors are relevant in such a system and how to safeguard our valuable data from unwanted attacks.

**5.5.1 Data Protection**

The smart indoor air quality system collects and processes data from sensors, such as temperature, humidity, VOC, and PM2.5 levels. In this case, there is a single sensor. This data contains sensitive information about the occupants' individual habits and their indoor environment. Implementing strong data security secure data storage, and secure communication protocols between the sensor and the central system is essential to protect against unauthorized access. Having deployed the entire development within the DPN (Decentralized Private Network) ecosystem using the Deeper Connect Device for the past four years, starting from its initial developmental stages, the system has evolved significantly, becoming notably stable and secure. Given the robust security provided by the DPN infrastructure, I have found that employing additional data encryption methods for formats like CSV or JSON may be unnecessary.

The Deeper Network offers comprehensive protection for our network and data. It's prudent to delve into the details of the Deeper Network's capabilities and how it fortifies our network and data integrity.

A rectangular device with wires connected to it

Description automatically generated

### **5.5.2 User Authentication and Authorization**

User authentication and authorization are critical components of secure systems and applications. They help ensure that only legitimate and authorized users can access resources, protecting against unauthorized access. There are some rules that can be considered for implementation.

Common practices for user authentication and authorization include:

**a. Strong Password Policies:** Enforcing strong password requirements, such as length, complexity, and regular password changes, to protect against brute-force attacks.

**b. Multi-Factor Authentication (MFA):** Implementing MFA to add an extra layer of security. This can include a combination of something the user knows (password), something the user has (a physical token), and something the user is (biometrics).

**c. Role-Based Access Control (RBAC):** Adopting RBAC to manage permissions based on predefined user roles. This ensures that users only have access to resources relevant to their roles.

### **5.5.3 Network Security**

Network security is one of the key components of computer technology, as it allows you to protect computer networks and resources from unauthorized access, attacks, and other security threats. Here are some key components of network security that are relevant to this research:

**a. Firewall:** Firewalls are security devices that act as a barrier between an internal network and the outside world, controlling incoming and outgoing network traffic based on predefined rules. They can be set up through the internet router or a personal computer operating system.

**b. Virtual Private Networks (VPNs) or Decentralized Private Networks (DPNs)**

DPNs create secure encrypted tunnels over a public network (e.g., the internet), allowing remote users to access the internal internet securely through a decentralized VPN. The Deeper Connect device is a great example available in the market that includes a DPN, enterprise-grade cybersecurity, a secure gateway protecting all IoT devices, blocking all ads, including on YouTube, and easy configuration with a simple plug-and-play setup.

A group of objects in a room

Description automatically generated

<https://deeper-network.medium.com/deeper-connect-mini-its-functions-and-importance-503291f8969>

* **Step 1:** Connect the Deeper Connect device between the modem and the router via Ethernet.
* **Step 2:** Power on the Deeper Connect device.
* **Step 3:** Access the Deeper Connect software called AtomOS by entering the given IP address 11.22.33.44 in the browser.

I have this device installed in my workplace, where the air sensor and all the computers, including Wi-Fi sockets, are attached to the network. It's been working flawlessly, providing protection against all kinds of attacks while remaining invisible to the IP, etc. You can also tunnel the domain or IP as per the requirements. I have been using this device for the last four years now.

A screenshot of a computer

Description automatically generated

### **5.5.4 Privacy Concern**

The system should always respect the user's privacy rights and ensure that the data collected from indoor sensors is used only for its intended purpose. A clear and transparent privacy policy should be communicated to users, detailing how their data will be used, stored, and shared. In this case, all sensor data will be stored individually for each user, so there is no question of agreeing with any third party. However, the normal practice should be transparent and clearly communicated to the users.

## **5.6 Performance Evaluation**

Performance evaluation is a crucial part of a smart indoor air quality system that involves assessing various aspects to ensure its effectiveness, efficiency, and user satisfaction. Let's not only evaluate the air quality sensor but also all the devices attached to it and their performances.

### **5.6.1 Air quality Monitoring**

The Awair Element API is working smoothly, and it has been successfully storing data in the target destination without any errors for the last thirty days. The performance of the API is satisfactory.

### **5.6.2 Data Storage Capacity**

The external drive used for data storage has a capacity of 500 GB. The performance of the external hard drive has been smooth, and no-load pressure has been identified.

### **5.6.3 Scalability**

In terms of scalability, all the connected devices, such as the Raspberry Pi 4 where scripts are running, the data storage hard drive, the Wi-Fi mini socket, and the air cooler, have been performing very well even as the amount of data has been increasing over time.

#### **5.6.3.1 Wi-Fi mini socket**

The automation Wi-Fi socket has performed very well so far. I initially expected some latency, but it accepts commands quickly and efficiently, turning on and off according to the given commands with impressive speed.

#### **5.6.3.2 Notification**

The email notification mechanism is working without any obstacles. When the threshold exceeds, the notifications come right after the cooler turns on and off. So far, there hasn't been any problem with the notifications.

#### **5.6.3.3 Security and Privacy**

The entire network of the workplace is protected by VPN/DPN devices, making it difficult for anyone to attack through the internet. In terms of physical data security, the external hard drive is located under my supervision, and access to that specific area is restricted to prevent tampering or theft. Additionally, there is a backup in PostgreSQL as well as on the password-protected Raspberry Pi 4.

#### **5.6.3.4 Air cooler**

The air cooler device is working fine, following the ML scripts. It's interesting to observe how the scripts send commands, and the cooler turns on accordingly, while receiving notifications through email.

#### **5.6.3.5 Responsiveness**

So far, all the devices and input commands are responding as expected, and there haven't been any issues detected.

#### **5.6.3.6 ML Model**

There are three scripts running simultaneously. One script retrieves data from the external hard drive, processes and trains the model, and predicts the model with real-time data. Another script gathers real-time data from the sensor every five minutes and stores it on the external hard drive. The third script calculates the time and energy cost consumed by the cooler. All three scripts have been performing very well for the last few months.

#### **5.6.3.7 Real-Time data update**

The sensor API calls are made every five minutes, providing exact data that matches what is displayed on the sensor itself. I haven't found any issues with the frequency and consistency of the data updates.

#### **5.6.3.8 Energy Efficiency**

The energy calculation script is working smoothly and provides comprehensive data for analyzing the cost of electricity consumption. It also allows defining the price of electricity, including electricity transfer costs and VAT (Value Added Tax). The script is performing extremely well and is highly satisfactory, but there is still room for further enhancement.

### **5.6.4 User Satisfaction**

Occupant comfort and health are the priorities when using air quality devices in our homes to protect against various health-related issues. The main objective of this research is to achieve better air quality while staying inside airtight apartments. In this section, I have used two data sets from the rooms and workplace inside the residential apartment in Vantaa, where I live, and compared them before and after implementing the automation system with the air cooler in two different rooms. This will provide insight into how these parameters can directly affect our health.

#### **5.6.4.1 Data from workplace before using automation system with air cooler:**

The data has been collected from 01-03-2023 to 26-03-2023 in the work room to analyze the important parameters directly related to occupant health. The significant parameters considered are humidity, CO2, VOCs, and PM2.5, which are taken into consideration for this analysis.

A screenshot of a computer screen

Description automatically generated

**5.6.4.1.1 Humidity Distribution**

A diagram of a distribution of humidity

Description automatically generated

The standard humidity level is considered normal within the range of 40 to 50. According to the histogram distribution of humidity levels, the maximum number of distributions falls between 15 to 35, with very few distributions between 40 to 60. The data indicates that most humidity levels are below 35, suggesting poor indoor humidity. This can directly affect the occupants' health, leading to issues such as breathing difficulties and throat dryness. Indoor humidity is also influenced by the humidity levels outside the building and the effectiveness of ventilation.

##### **5.6.4.1.2 CO2 Distribution**

A graph of a distribution of co2 levels

Description automatically generated

The standard CO2 level from 0 to 600 is normal. According to the above histogram, the maximum frequency of the CO2 level falls between 400 to 600, and some values are counted above the standard level. The numbers are not so significant between 600 to 900, which are not ideal but not alarming either. Overall, the CO2 level depends on several factors, such as the number of people living in the space and the duration of their stay. However, the numbers are generally satisfactory for the occupants' health perspective.

##### **5.6.4.1.3 PM2.5 Distribution**

A blue bar graph with white text

Description automatically generated

The standard PM2.5 level from 0 to 15 is normal. According to the histogram distribution graph, the frequency of PM2.5 levels remains within the normal range throughout the month. PM2.5 levels depend on several factors, such as dust coming through the ventilation, exhaust, and dust from clothes. The data shows that the level of dust particles is within the normal range, so it doesn't negatively affect the occupants' health.

##### **5.6.4.1.4 VOC Distribution**

A blue bar graph with white background

Description automatically generated

The standard VOCs (Chemical) level from 0 to 333 is considered normal. According to the histogram distribution, the frequency of VOCs is within the normal level. Chemical readings depend on factors like cooking oil, perfume, or any sort of chemical smells in the surroundings. The level of chemicals is within the normal range, ensuring the occupants' health is safe with such readings.

##### **5.6.4.2.1 Data from bedroom after using automation system with air cooler:**

The data was collected from 23-06-2023 to 12-07-2023 in the bedroom, and the parameters were compared with the data before implementing the smart ML model. The compared parameters are directly related to occupant health, such as humidity, CO2, VOC, and PM2.5 levels.

A screenshot of a computer

Description automatically generated

##### **5.6.4.2.1.1 Humidity Distribution**

A diagram of a distribution of humidity

Description automatically generated

The histogram chart shows that the humidity level unexpectedly changed after using an automated smart air quality system with an air cooler. As you can see in the chart above, the frequency of humidity levels counted is between 40 to 60, which falls within the standard normal level for an indoor environment. The experiment demonstrates the effectiveness of maintaining occupants' indoor humidity levels through the automated air cooler system using the ML model.

##### **5.6.4.2.1.2 CO2 Distribution**

A graph of a distribution of co2 levels

Description automatically generated

The CO2 level has also improved compared to previous readings, as these readings are from the bedroom. There are several factors that can contribute to high CO2 levels. One reason is the number of people sleeping in the bedroom, especially during the night when occupants' breathing activities can increase CO2 levels. Another reason could be smoke coming from the kitchen while cooking. Overall, the CO2 level has improved and is satisfactory, posing no threat to the occupants' health.

Besides these, the VOCs and PM2.5 levels are almost the same as the workroom. There haven't been significant changes in VOCs and PM2.5 levels, and they are maintained under the standard level. The most significant changes that I have found in the comparison analysis of two different rooms, before using the smart automation ML model and after using the smart ML automation system, are in humidity and CO2 levels. These changes can cause several health-related issues. By implementing a smart indoor ML model with an air cooler, occupants can experience comfort in their living environment by paying a relatively small amount for electricity costs.

## **5.7. User Interface**

Designing a smart indoor air quality system application interface requires careful consideration of system functionality, user needs, and the display of relevant data in a clear and intuitive manner. Here are some key elements and features to consider when designing the user interface.

### **5.7.1 Dashboard**

Provide a clear overview of indoor air quality briefly. Display real-time data for temperature, humidity, CO2, VOC, and PM2.5 levels. Use charts, graphs, and cooler indications to present data in a visually appealing and easy-to-understand way.

### **5.7.2 Software Tools**

To create a user interface, the selection of compatible frameworks is equally important to bring flexibility to the application. The Flask framework would be used for the front end, while Python will be used for the back end, along with a PostgreSQL database.

### **5.7.3 Historical Data Visualization**

Provide the option to view historical data over time. Use a line chart or other visualization to view patterns and trends.

### **5.7.4 ML model Prediction**

Provide a clear view of each individual parameter's model prediction along with the plot.

### **5.7.5 Home Automation**

Provide an option to select devices that can be automated as per the model prediction. Also, offer the option to add additional devices for integration into the home automation system.

### **5.7.6 User Management**

Provide an option to create multiple users and grant them privileges to access specific tasks.

### **5.7.7 Alert and Notification**

Develop an automatic alarm system that triggers when parameter thresholds are exceeded, along with email notifications.

### **5.7.8 Energy Consumption**

Provide comprehensive details of electricity consumption.

# **6. Conclusion**

The indoor air quality system presented in this research experiment includes an Awair Element air sensor, a Tapo power socket, and an Air Cooler device, forming an integrated automation system aimed at safeguarding the overall indoor health of occupants. This experiment involves the real-time retrieval of indoor air quality data, subsequent data processing, and the deployment of various machine learning models into the integrated automation system. This combination utilizes a Wi-Fi-enabled power socket connected to the Air Cooler device, providing a comprehensive approach to monitor and enhance indoor air quality.

Throughout the experimental process, several key findings and outcomes have been observed, underscoring the potential impact of the system.

## **6.1 Summary of Key Findings**

In conclusion, the experiment has successfully achieved the objectives of designing, developing, and testing the indoor air quality system. The integration of Awair Element sensor parameters, including temperature, humidity, CO2, VOC, and PM2.5 particles, has facilitated the accurate real-time collection of data, which is then stored on an external hard drive. The data pipeline and processing procedures are effective in cleaning and preparing the data for deploying machine learning models. Basic data analysis is conducted to identify patterns and trends in the data. The deployment of a Linear Regression model with temperature and humidity as inputs yielded predictions with a satisfactory accuracy ranging from 76 to 77 percent. Notably, the correlation between temperature and humidity emerges as high, surpassing the correlation with other parameters as depicted in the heatmap chart. However, owing to lower correlations with the remaining parameters, the performance of the regression model fell short of expectations. Subsequently, a Random Forest Model was employed, leading to gradual improvements in predictions with the increase in data volume. The relatively lower r-squared score values indicate acceptable model performance; it's plausible that the limited volume of training data contributes to this outcome. It is anticipated that greater training data volume will yield more accurate results over time.

## **6.2 Implications for Indoor Air Quality**

Moreover, all devices, including the Tapo Wi-Fi power socket and integration devices, functioned flawlessly as anticipated, devoid of any reported difficulties or errors.

## **6.3 Future Directions**

Moving forward, there are plans to integrate a data pipeline with AWS cloud for further analysis purposes, along with the development of a user-friendly interface. This interface aims to enhance user interaction and accessibility. Additionally, external weather data will be incorporated into the automation system for analysis. Exploring additional options to augment the user interface application is also on the agenda.

In summation, the experiment has established a comprehensive smart indoor air quality system that directly benefits occupants, fostering a health-conscious indoor environment. There exists significant potential to refine the system further, transforming it into a comprehensive home automation solution, catering to individual occupants and their indoor health needs.

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