1. Abstract:

This paper was prepared to derive a correlation by comparing and analyzing U.S. outdoor public air data (OAD) and indoor air data (IAD). While the importance of air quality has become more prominent since the COVID-19 pandemic, modern people are based only on data on outdoor air quality, even though they live indoors more than 80% a day, and are not aware of how different the actual indoor air quality is from outdoor air quality. That is, it can be said that the general public's interest in indoor air quality is weaker than that of outdoor air quality. In this paper, we directly measure U.S. indoor air data using Arduino, Raspberry Pie, and various sensors and conduct a comparative analysis with outdoor air data provided by the government and institutions to derive correlations. Through this, it visualizes and presents how much difference occurs in indoor air from the outdoor air.

1. Introduction:

Air pollution, such as yellow dust and fine dust, is a problem that all countries and institutions are trying to solve in modern society. The importance of air quality is a fact that everyone knows well. In addition, the importance of air quality has become more prominent since the COVID-19 pandemic. The U.S. Centers for Disease Control and Prevention (CDC) officially recognizes air transmission as a major transmission route for COVID-19, and the World Health Organization (WHO) also includes air transmission as a COVID-19 transmission route.

With the above importance, many people check outdoor air quality data (fine dust and ultrafine dust concentrations) provided by the government or provided by each institution every day before starting their daily routine. Nevertheless, it can be said that the general public's interest in indoor air quality is weaker than that of outdoor air quality.

According to the U.S. Environmental Protection Agency, indoor air, where modern people live more than 80% to 90% of the day, is 100 times more polluted than outside air; and a study also suggested that indoor air pollutants are 100 times more likely to be delivered to human lungs than air pollutants. The American Lung Association (ALA) also announced that indoor harmful substances are two to five times more than outdoor air and that there are cases of 100 times more harmful substances. Analysts say that various chemical components discharged from walls and furniture, beds, pillows, house dust, and dust caused by human movement are combined, polluting indoor air.

In this paper, we compare major indoor air pollutants and factor data provided by the Environmental Protection Agency (EPA) with data measured directly in the actual indoor environment to see how much difference there is between external air data provided by countries or institutions and actual indoor air data. Through this, it analyzes how much outdoor air such as fine dust and ultrafine dust, which people use as the basis for daily activities, correlates with indoor air that works for a long time, and presents the measurement results.

Arduino and raspberry pi, temperature and humidity sensors, fine dust sensors, and gas sensors were used as measuring devices (systems) for analyzing indoor air quality data. Data were measured and collected periodically in the same place planned time.

1. Literature review:

At the end of the twenty-one centuries, numerous researches and studies showed that most people in public believed that it was way more dangerous to stay outside, as the risks from poor quality outdoor air were higher than those from indoor contamination. At that time, an investigation found out that in the United States, individuals spent 88% of their time inside buildings, 7% in a vehicle, and only 5% of the time was actually spent outside. (Jones, 1999) However, even people believe that staying inside is safer, evidence shows that indoor concentrations of many pollutants are often higher than the same pollutants outside. In the research from A.P. Jones, the sick building syndrome (SBS) have been conducted mostly in office environments; and the symptoms of SBS are usually identical. Some common symptoms of sick building syndrome contain headache and nausea, nasal congestion, chest congestion, eye problems, throat problems, fatigue, chills and fever, muscle pain, neurological symptoms, dizziness, and dry skin. (Jones, 1999) Compared to the health related to the outside, the sick building syndrome might be more mysterious and harder to solve. Furthermore, in the twenty-two years later, people are unable to control to stay inside or outside as the COVID-19 pandemic provides limited choices to go. Thus, it is important for people to know the exact air quality from both sides to choose the best option.

There was also a study which focus on the comparison of indoor and outdoor concentrations of CO at public school. As the former research mainly reveals the change of different air elements in the private places such as living room and kitchen, this research starts to learn the changes in the normal public places. According to Chaloulakou, and Mavroidis, they measured Indoor and outdoor CO concentrations at a school near the center of Athens during May and June 1999 and also during December 1999. (Chaloulakou & Mavroidis., 2002) The observation mentioned that in the research, the indoor and outdoor diurnal concentration cycles followed the similar patterns, while indoor concentrations would have a delayed response when out door concentration changes. Furthermore, the CO concentration would be higher during the winter and compared to the data collected during the summer. (Chaloulakou & Mavroidis., 2002) The research also shows that without well-designed building, the outdoor and indoor air quality would have a high I/O concentration ratios.

In order to conduct the work to test air quality, Pillai et al had represented the simplest air quality monitoring devices based on Controller Area Network Protocol. In Pillai’s module, there were sensor nodes which comprised of CAN controllers and transceivers. Each node is connected to some Volatile Organic Compound sensors, which would monitor environment and put sensor data into CAN bus repeatedly. Furthermore, there was also a motor control node that helped turn on alarm and switch on a fan whenever the sensor data crossing some predefined limit. (Bhattacharya et al., 2012) In the module of Bhattacharya’s research, they prepared TGS 2442 and TGS 4161 for measuring Carbon monoxide (CO) and Carbon dioxide (CO2); They also used Atmega1281 as the system’s microcontroller and “Xbee module from Digi as the ZigBee based wireless communication module operating at 2.45 GHz”. Bhattacharya also used DustTrak DRX Aerosol monitor Model 8533 from TSI Incorporated for real time dust testing on PM1.0, PM2.5, PM4.0, and PM10.0. (Bhattacharya et al., 2012) The research result showed that in the graph where the X-axis is time of the day, Y-axis is CO concentration, there is some rise in concentration of CO observed in kitchen during cooking time, but the content of CO and CO2 is generally decreasing as time goes by. (Bhattacharya et al., 2012)

According to the research of *A Cost-Effective Wireless Sensor Network System for Indoor Air Quality Monitoring Applications*, the researcher used Arduino Uno microcontroller board to collect and process data from the sensor, and used Digi Xbee module configured as coordinator to for a mesh network topology using the ZigBee protocols. Furthermore, there were two types of sensor shields designed with necessary interfacing circuit for different air elements. The type I sensor would like to process the CO2, Volatile organic compounds (VOC), temperature, and humidity; and the Type II sensor process CO, Ozone, temperature, and humidity. The complete module contained MG811, TGS2602, MQ7, MQ131, RTH03 sensors. (Abraham & Li, 2014) In the other research about Air quality monitoring system based on IoT, Somansh Kumar implemented Raspberry Pi as the major node controlling system to detect and process different environmental variables like particulate matter, Carbon Monoxide, Carbon Dioxide, Temperature, Humidity, and Pressure. The researcher also implemented Arduino Uno to connect Raspberry Pi to gather data. The sensor types the researcher used were DSM501A, DHT11, BMP180, MQ9 and MQ135. (Kumar & Jasuja, 2017)

Jones, A. P. (1999, October 4). *Indoor Air Quality and health*. Atmospheric Environment. Retrieved February 12, 2022, from https://www.sciencedirect.com/science/article/pii/S1352231099002721

S. Bhattacharya, S. Sridevi and R. Pitchiah, "*Indoor air quality monitoring using wireless sensor network*," 2012 Sixth International Conference on Sensing Technology (ICST), 2012, pp. 422-427, doi: 10.1109/ICSensT.2012.6461713.

Bhattacharya, S., Sridevi, S., & Pitchiah, R. (2012). *Indoor air quality monitoring using wireless sensor networkIndoor air quality monitoring using wireless sensor networkIndoor air quality monitoring using wireless sensor network*. IEEE Xplore. Retrieved February 12, 2022, from https://ieeexplore.ieee.org/xplore/home.jsp

Abraham, S., & Li, X. (2014, August 15). *A cost-effective wireless sensor network system for indoor air quality monitoring applications*. Procedia Computer Science. Retrieved February 13, 2022, from https://reader.elsevier.com/reader/sd/pii/S1877050914009454?token=EE676DF3A9083E35D19FB5BB7B46CE533A653D76B70A9029DA9846E08849DBA3221441761374CE4A96ADEE6EBBEC5C01&originRegion=us-east-1&originCreation=20220212222359

Kumar, S., & Jasuja, A. (2017). *Air quality monitoring system based on IoT using Raspberry Pi*. IEEE Xplore. Retrieved February 13, 2022, from <https://ieeexplore.ieee.org/xplore/home.jsp>

Chaloulakou, & Mavroidis, I. (2002). Comparison of indoor and outdoor concentrations of CO at a public school. Evaluation of an indoor air quality model. Atmospheric Environment (1994), 36(11), 1769–1781. https://doi.org/10.1016/S1352-2310(02)00151-6

4. System Design

In this study, indoor air is measured using various hardware sensors. Indoor air pollutants, including temperature and humidity, fine dust, temperature and humidity, and carbon monoxide, are measured and loaded into the database. (The hardware sensor selection criteria used here were selected as sensors that can be compared by EPA in the United States.) The method of storing data is to store it as a LAN connection on a local computer because it does not need to be stored in real-time communication due to the nature of research that collects data at a set specific time. After that, data is collected, stored, and extracted from the data server for a certain period of time, and compared and analyzed with external data, which is public data of the U.S. EPA. Visualization and analysis are conducted using the Python library. The overall system plan is as shown in Figure 1.

Diagram

Description automatically generated with medium confidence

Figure 1.

A. Hardware Architecture

Hardware basically used aurduino uno rev3 (2), pms 5003 (fine dust sensor), dht 11 (temperature and humidity sensor), mq2 (gas sensor), and mq131 (gas sensor). The sensor selection criteria consisted of sensors capable of extracting external air components provided by EPA, and two Arduinoes were used due to the research characteristics in which relatively many sensors were used.

Arduino used in this study was used because it is the most common and commonly used board for sensor measurement and is used as a standard. The Arduino board was connected to the PC and USB to perform basic hardware setting. The Arduino specification is shown in Table 1. As for the fine dust sensor, a high-precision laser dust concentration sensor was used as the PMS 5003 dust sensor. It is a sensor that detects particles in the air and outputs data to UART. The specifications of the fine dust sensor are shown in Table 2. The product specifications of the temperature and humidity sensor are shown in Table 3, and it. In the case of the temperature and humidity sensor, it was removed and installed outside the measuring device because it had to be opened and exposed to flowing air. In the case of gas sensors, a total of two sensors were used, and mq2 sensors were used to measure carbon monoxide (CO), and mq131 sensors were used to measure nitrogen dioxide (NO) and ozone (Ozone). The specifications of the gas sensor are shown in table 4 and table 5, respectively.

Table. 1 .

Table 2.

Table 3 .

Table 4.

Table 5 .

[Fill out all sensor configurations.] table1~table5

B. Software Architecture Node-Red, Arduino integrated development environment, and Jupiter laptop were used as software.

1) Node-Red

Node-red is a flow-based development tool for programming hardware devices by wiring them as part of the Internet of Things. All processes are aggregated together in the flow, making it easy to grasp the data flow. It is used and shown above Node.js, and can be used to develop JavaScript functions. Also It uses Json(that’s Javascript object notation) to descrive its metadata.[1] Because JavaScript language can be used, and JSON-type files are convenient for data extraction, node-red was used.

[1]https://developer.ibm.com/blogs/top-5-reasons-to-use-node-red-right-now/

2) Arduino Integrated development environment

The Arduino integrated development environment is a development environment provided to users for programming. It supports tools necessary for programming, such as editors, compilers, and debugs that write code, helping users interface conveniently. It consists of four types: a program menu bar, a user tool bar, and a code editor console, and in this study, data values were uploaded through USB, so the required values were delivered to UART communication when Arduino MCU was executed.

3) Jupyter notebook

jupyter Laptop is an open source-based web application. In addition to Python, it provides a development environment that supports 40 program languages. Indoor air measurement data and outdoor air public data were compared and analyzed, and visualization was used because it was necessary to proceed with each unit. It is easy to import libraries for data analysis and check and document execution results.

4. Methology(Experimental)

In this study, measurements were conducted at a general indoor building in Purdue University from February 14 to 18, 2022 to measure indoor air in the United States, and there are a total of four indoor, dining court(ear hearts), gym cork, and WALC buildings. Schedule data was measured for 1 hour a day for each indoor place, and 120 data were secured by collecting 30 seconds for each sensor. 120 data per day were measured for a total of 5 days to collect 600 data per pollutant. Indoor air measurement items include carbon monoxide (CO), lead (Pb), NO2, Ozone, pm10, pm2.5, and SO2, which can be measured by a device sensor included in the U.S. Environmental Protection Agency (EPA) as components of outdoor air quality, and general temperature and humidity. The standard (level) for each pollutant is ug/m3 for fine dust and ppm for the remaining other substances based on the figures provided by EPA. In addition, data from February 2021 in Indiana Polis were used among outdoor data provided by the U.S. Environmental Protection Agency to increase the accuracy of comparison between directly measured data and public data

At the time of data collection, a table was designed based on each place [fig.2], and the data collected here were extracted in the form of CSV files. As a database, My SQL was used as a relational database. The Jupiter laptop was used as a program to analyze CSV files, the Pandas data analysis library provided by Python for data analysis, and the matplotilb visualization library for data visualization.

(Write how you visualized the daily average value after measurement)

5. Experimental Setup

6 RESULTS

a) PM2.5 comparison

b) PM10 comparison

c) No2 comparison

d) CO comparison

e) Ozone comparison

7. Conclusion & Discussion

Data sheet

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **K-SW SQUARE** | **Gym** | **Dining Courts** | **Libraries** |
| **14-Feb** | 120(rows) | 120(rows) | 120(rows) | 120(rows) |
| **15-Feb** | 120 | 120 | 120 | 120 |
| **16-Feb** | 120 | 120 | 120 | 120 |
| **17-Feb** | 120 | 120 | 120 | 120 |
| **18-Feb** | 120 | 120 | 120 | 120 |
| **SUM** | 600 | 600 | 600 | 600 |

A picture containing text, electronics

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|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **K-SW SQUARE** | **Sports Center** | **Dining Courts** | **Libraries** |
| **14-Feb** | 120 | 120 | 120 | 120 |
| **15-Feb** | 120 | 120 | 120 | 120 |
| **16-Feb** | 120 | 120 | 120 | 120 |
| **17-Feb** | 120 | 120 | 120 | 120 |
| **18-Feb** | 120 | 120 | 120 | 120 |
| **SUM** | 600 | 600 | 600 | 600 |

Data structure

Diagram

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