IOT ENABLED INDOOR AIR SUSTAINABILITY MONITORING

FINAL YEAR PROJECT UG – 2020

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CERTIFICATE

This is to certify that the Final Year Project titled

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ABSTRACT

In the realm of construction management research, a fascinating and forward- thinking trend has emerged – the integration of “***Building Information Modelling(BIM), Internet of Things (IoT), and Digital Twin technology.*** This amalgamation of cutting-edge technologies is reshaping the way we approach construction and facility management. Our journey is aligned with this innovative trajectory.

We addressed the problem of the Indoor Air Environment which is becoming oneof the most severe public health risks. Its dangers are prevalent and yet unnoticed.We tried to solve the problem by doing indoor air monitoring through various sensors and then transferring the data live into Revit model through Arduino, Google sheets, Excel and finally Dynamo. It took extensive coding especially inArduino, google sheets and dynamo to make it a reality. Making the process live allowed us to modify our 3d model from a static Revit model to a dynamic digitaltwin. This integration is seen less in the industry but has potential and is getting more and more coverage day by day. It already has its place in Mechanical and Aerospace engineering and the next stop is civil engineering. Through this, the user can see the real time changes in the parameters just by looking at the changesin the model. The model can also show physical changes in its color to show warning signs or a good functioning asset. In the end, we analyzed the data and came up with the conclusion that the monitored indoor environment was unsustainable and needed remedy measures to make it feasible for public health.

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LIST OF ABBREVIATIONS

BIM	Building Information Modelling
IOT	Internet of Things
GUI	Graphical User Interface
ICT	Information and Communication Technology
DT	Digital Twin
MQTT	Message Queuing Telemetry Transport

CHAPTER 1

INTRODUCTION

In the realm of construction management research, a fascinating and forward- thinking trend has emerged – the integration of ***Building Information Modelling(BIM), Internet of Things (IoT), and Digital Twin technology.*** This amalgamation of cutting-edge technologies is reshaping the way we approach construction and facility management. Our journey is aligned with this innovative trajectory.

1.1 BIM

Revolutionary digital technology and methodology have extensive applications in the architecture, engineering, and construction (AEC) industries. The evolution and implementation of BIM technology have been tracked through extensive global surveys in the global construction industry since 2007. There has been significant change over that period and dramatic implementations have increased over the past few years. BIM implementation programs have been introduced throughout the world (smith, 2014)**.**

1.2 IOT

IOT is one of the most significant drivers of construction 4.0 across all project phases from design to construction and operation. (galic, 2021**).** IoT holds enormous promise for the development of innovative new applications across a wide range of industries, categorized across 3 major domains: social, environmental, and economical, interconnecting various aspects for improvising the quality of everyday life (borgia, 2014). IoT as an enabling technology for achieving targets of Net zero buildings (mumovic, 2021**).**

1.3 DIGITAL TWIN

The conception of a Digital Twin in AEC-FM industry comprises of three majorintegrating components: Wireless Sensor Network (WSN), data analytics, and 3Dmodel (extracted from BIM) of the physical asset (building, bridge, etc.), facilitating real-time data visualization, comfort enhancement, data-driven decision making as well as improvising building efficiency consequently emphasizing its utilization for existing buildings (retrofitting with sensors) and operational phase of assets (khajavi, 2019)**.**

1.4 Existing Research

Digital twins (DTs) for indoor air sustainability monitoring are an evolving field,integrating advanced technologies to create real-time, dynamic models of indoorenvironments. These models help monitor, simulate, and optimize indoor air quality (IAQ) for sustainability and occupant health. Here are some key aspects and existing research areas:

Key Aspects

1.4.1 Integration of Sensors and IoT

Sensors play a vital role in monitoring various indoor air quality (IAQ) parameters, including CO2 levels, particulate matter (PM2.5 and PM10), volatile organic compounds (VOCs), humidity, and temperature. These sensors continuously track environmental conditions, providing valuable data to assess and improve air quality in real-time.

When connected via IoT platforms, these sensors enable seamless data transmission, offering real-time updates that are crucial for the accurate and timely management of digital twin models. By integrating IoT connectivity, the sensors provide continuous feedback, ensuring that the digital twin reflects the current state of the environment with precision.

1.4.2 Data Analytics and Machine Learning

- **Predictive Analytics**

Machine learning algorithms analyze historical and real-time data to predict trends, detect anomalies, and suggest interventions for maintaining optimal IAQ.

- **Simulation Models**

Advanced simulations to understand the impact of different ventilation strategies, occupancy patterns, and external weather conditions on IAQ.

1.4.3 Integration with Building Information Modeling (BIM)

- **BIM Models**

Combining BIM with digital twins provides a comprehensive view of the building's physical and functional characteristics, enhancing the accuracy of the IAQ model.

- **Energy and Sustainability**

Analyzing the energy performance and sustainability of buildings alongside IAQ to achieve holistic improvements.

1.4.4 User Interface and Visualization

- **GUI**

Graphical user interfaces display real-time data and insights, making it easier for building managers and occupants to understand and act upon IAQ information.

- **Augmented Reality (AR)**

AR applications provide immersive visualization of air quality data in physical space.

1.4.5 Communication Protocols

MQTT Lightweight communication protocol for efficient data transfer between sensors and digital twin platforms, ensuring timely updates.

1.5 Existing Research Areas

1.5.1 Health Impact Studies

Research on the correlation between indoor air quality and occupant health, focusing on minimizing exposure to harmful pollutants and improving overall well-being.

1.5.2 Energy Efficiency and IAQ Balance

Studies exploring the trade-offs between energy efficiency measures (e.g., airtight buildings) and maintaining high IAQ, and finding optimal solutions for both.

1.5.3 Real-time Monitoring and Control

Development of systems for continuous monitoring and automatic control of ventilation and air purification systems based on real-time IAQ data.

1.5.4 Standards and Protocol

Establishing industry standards and best practices for implementing digital twins in IAQ monitoring, ensuring interoperability, and data consistency.

1.5.5 Case Studies and Pilot Projects

Documentation of successful implementations of digital twins in various building types (e.g., residential, commercial, educational) showcasing the benefits and challenges encountered.

Example: Projects and Applications

- **Project Haystack**

An open-source initiative to streamline the exchange of data among smart devices and equipment in buildings, contributing to the development of digital twins.

- **Horizon 2020 Projects**

European Union-funded projects focusing on smart and sustainable cities, often incorporating digital twin technologies for various applications including IAQ. The field of digital twins for indoor air sustainability monitoring is rapidlygrowing, driven by advancements in sensor technology, data analytics, and IoT.Ongoing research and pilot projects continue to push the boundaries, aiming tocreate healthier and more sustainable indoor environments.

1.6 Research Gap

For this study, the research gap was analyzed extensively through a literature review.

PAPER	FINDINGS
Maskuriy, R., Selamat, A., Ali, K.N., Maresova, P. and Krejcar, O., 2019. Industry 4.0 for the construction industry—how ready is the industry? *Applied Sciences*, *9*(14), p.2819.	IOT allows information exchange of real time data across different platforms.
Tang, S., Shelden, D.R., Eastman, C.M., Pishdad-Bozorgi, P. and Gao, X., 2019. A review of building information modeling (BIM) and the internet of things (IoT) devices integration: Present status and future trends. *Automation in Construction*, *101*, pp.127-139.	Data from IoT by integration with AI techniques provide us valuable insights and enables informed decision making.
Lu, Q., Xie, X., Heaton, J., Parlikad, A.K. and Schooling, J., 2020. From BIM towards digital twin: strategy and future	It is used for monitoring and optimization of building performance in real-time.

development for smart asset management. *Service Oriented, Holonicand Multi-agent Manufacturing Systemsfor Industry of the Future: Proceedings of SOHOMA 2019 9*, pp.392-404.	
Zaballos, A., Briones, A., Massa, A., Centelles, P. and Caballero, V., 2020. A smart campus' digital twin for sustainable comfort monitoring. *Sustainability*, *12*(21), p.9196.	DT enables sustainability assessment of assets.
McGill, G., Oyedele, L.O. andMcAllister, K., 2015. An investigation of indoor air quality, thermal comfort and sick building syndrome symptoms in UKenergy efficient homes. *Smart and Sustainable Built Environment*, *4*(3), pp.329-348.	Indoor air pollutants from materials, appliances, cooking, other activities, or due to inadequateventilation, have a profound impacton climate change.
Azhar, S., 2011. Building information modeling (BIM): Trends, benefits, risks, and challenges for the AECindustry. *Leadership and management in engineering*, *11*(3), pp.241-252.	Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry (S.AZHAR).

1.7 Research Objectives

1. To identify the benefits of BIM, Digital Twin and IoT.
2. To measure and assess carbon emissions of a residential building using IoT devices.

3. To develop BIM model depicting air quality parameters for improved sustainability.
4. To enable stakeholders to claim their construction sustainable.

1.8 Relevance to National Needs

Indoor air sustainability monitoring is highly relevant to the national needs of Pakistan for several reasons:

1.8.1 Public Health Improvement

- **Reducing Respiratory Diseases**

Pakistan faces a high burden of respiratory diseases due to poor air quality, both indoors and outdoors. Monitoring and improving indoor air quality can significantly reduce the incidence of asthma, bronchitis, and other respiratory illnesses.

- **Mitigating Effects of Pollution**

Urban areas in Pakistan, such as Karachi, Lahore, and Islamabad, often suffer from high levels of outdoor air pollution. Indoor air monitoring can help identify and mitigate the infiltration of outdoor pollutants into indoor spaces.

1.8.2 Enhancing Living Conditions

- **Improving indoor Environments**

Many buildings in Pakistan, especially in densely populated urban areas, suffer from inadequate ventilation and exposure to pollutants from cooking, heating, and other activities. Monitoring IAQ helps ensure healthier living environments.

- **Comfort and Productivity**

Better indoor air quality enhances comfort and productivity in homes, schools, and workplaces, contributing to overall well-being and economic productivity.

1.8.3 Energy Efficiency and Sustainability

- **Optimizing Energy Use**

Efficient monitoring and management of IAQcan lead to better energy management in buildings. This includes optimizing HVAC systems to balance air quality and energy use, reducing overall energy consumption.

- **Sustainable Building Practices**

Emphasizing indoor air quality aligns with broader goals of sustainable development. It promotes the use of eco- friendly building materials and designs that enhance natural ventilation and reduce dependency on energy-intensive air conditioning systems.

1.8.4 Educational and Institutional Benefits

- **Healthier Learning Environments**

Schools and universities can greatly benefit from improved IAQ, as it is linked to better student performance,attendance, and overall health. Healthy indoor air diminishes the risk of respiratory issues and allergies, leading to fewer illnesses and, consequently, fewer absences from school. This is especially important for students who may be more vulnerable to such issues.

- **Public Awareness and Education**

National initiatives on indoor air quality monitoring can raise awareness about the importance of air quality and foster a culture of health and environmental consciousness. On a larger scale, these national efforts could help create and enforce safety standards for public spaces, making sure places like schools, hospitals, and offices have clean, safe air for everyone, especially children, the elderly, and those with health conditions.

1.8.5 Economic Impact

- **Healthcare Cost Reduction**

Improving indoor air quality (IAQ) in Pakistan could make a real difference in the nation's healthcare system, helping to lower the costs associated with treating respiratory and pollution-related illnesses. Many urban areas in the country struggle with indoor air pollution from cooking, heating, and various household chemicals, which can take a serious toll on health. Conditions like asthma, chronic obstructive pulmonary disease (COPD), and allergies are on the rise, affecting the quality of life for countless individuals and families.

By focusing on better air quality, like promoting cleaner cooking fuels, ensuring good ventilation, and using air purifiers, Pakistan can significantly reduce the number of people suffering from these health issues. When fewer people are dealing with respiratory illnesses, not only does it mean they can live healthier lives, but it also eases the burden on hospitals and clinics.

- **Enhanced Worker Productivity**

Healthier work environments lead to fewer sick days and higher productivity, contributing to economic growth. It contributes to economic growth on a larger scale. A more productive workforce means businesses can expand, hire more people, and invest in better resources. This growth fuels the economy by increasing consumer spending and creating a positive cycle that benefits everyone.

1.8.6 Policy and Regulatory Development

- **Setting Standards**

Developing national standards and regulations for indoor air quality can help ensure consistent and safe indoor environments across the country. Creating national standards and regulations for indoor air quality (IAQ) is a vital step in ensuring that everyone across the country has access to safe and healthy indoor environments.

- **Compliance and Monitoring**

Implementing IAQ monitoring systems supports compliance with environmental and health regulations, ensuring that buildings adhere to national and international standards.

1.8.7 Addressing Urbanization Challenges

Rapid urbanization in Pakistan requires effective urban planning strategies that consider air quality. Integrating IAQ monitoring into urban planning helps create healthier cities.

Indoor air sustainability monitoring is crucial for Pakistan's national needs as it addresses public health issues, enhances living conditions, promotes energy efficiency, supports educational and economic goals, aids in policy development, and helps manage the challenges of urbanization. By prioritizing IAQ, Pakistan can ensure healthier, more sustainable, and resilient communities.

1.8.8 Application

Our study is not without precedent, as similar investigations have been undertaken for offices, smart campuses (massa, 2020), urban settings, **(**park, 2020**)** and residential buildings (arva arsiwala, 2023**)**. However, our unique contribution lies in our intent to transform and redefine the concept of a built environment. One intriguing suggestion in this regard is the transformation of a residential building which has the potential to serve as a distinct and interesting case study.

CHAPTER 2

LITERATURE REVIEW

2.1 Construction Industry

The construction industry has been facing immense backlash due to its to slow pace in adapting to the advanced technology. Therefore, the industry needs to bring a shift in its policies regarding quality, productivity, and sustainability (Rajesh & Haraprasad, 2022). The construction industry is different from others owing to the unique characteristics of having lots of different shareholders (Azhar, 2008). The major need of the construction industry is to become sustainable for our environment.

2.2 Indoor Air Sustainability in Construction

The construction industry needs to take into consideration the indoor air sustainability, the creation of buildings that ensure provision of good indoor air and healthy environments with no negative effects on the environment. A few areas related to indoor air sustainability within the construction industry include:

2.2.1 Design and Planning

- **Ventilation Systems**

Ventilation systems should be designed properly with regard to the required indoor-to-outdoor air exchange. Natural ventilation strategies should be adapted and implemented together with mechanical systems in order to be able to enhance the indoor air quality. Proper air flow through the building reduces the accumulation of indoor air pollutants such as CO_2, VOCs and particulate matter (PM2.5 and PM10).

- **Building Orientation and Layout**

Incorporating natural daylight into building design not only reduces the need for artificial lighting but also contributes to a healthier indoor environment. Placing windows, skylights, and light shelves to ensure that natural light penetrates deep into interior spaces can optimize daylighting. Light shelves and reflective surfaces can be used to distribute natural light more evenly within a room, reducing glare and shadows.

2.2.2 Material Selection

Making the use of recycled, eco-friendly, and sustainable materials in design and construction a top priority is one of the most effective methods to do this. These materials promote a better interior environment for the occupants in addition to assisting in waste reduction and resource conservation. Reclaimed wood, recycled steel, and even environmentally friendly concrete derived from industrial wastes can be used to minimize the use of virgin resources and lower the energy required to produce new materials. These decisions drastically reduce the carbon footprint associated with traditional building and keep tonnes of garbage out of landfills.

2.2.3 Construction Practices

- **Dust Control**

A crucial but frequently disregarded component of environmentally friendly construction is dust control. Dust and other particle matter are easily released into the air during construction, endangering the environment, increasing air pollution, and putting the health of neighbouring communities and workers at risk. Effective dust control techniques can help us greatly lessen these adverse effects and promote a safer and cleaner environment.

- **Moisture Management**

Moisture in buildings is one of the most crucial things you can do to guarantee a happy and healthy living environment. Moisture can promote the growth of harmful pollutants, which is not only unsightly but also poses a major risk to the health of those who live or work in the area and the quality of the indoor air.

2.2.4 Building Systems and Technologies

- **HVAC Systems**

A high-efficiency HVAC system installation is among the most intelligent methods to guarantee a cosy and hygienic interior space. Modern HVAC systems are made to do more than simply heat or cool a room; they also filter and purify the air, which has a significant impact on the quality of air we breathe. Dust, pollen, pet dander, and other airborne pollutants that would otherwise spread throughout a building can be eliminated by advanced filtration systems. Dangerous airborne particles can accumulate in a house or business with inadequate ventilation or an antiquated air conditioning system. This may result in many difficulties, such as allergies being triggered or respiratory troubles developing. On the other hand, sophisticated filters that are made to capture these minute particles are used in high-efficiency HVAC systems.

- **Air Purification**

Adding air purification systems to your home or office can make a huge difference in the air you breathe every day. We often don't think much about indoor air quality, but it can have a big impact on our health and comfort, especially if the air is filled with dust, allergens, or even invisible particles like bacteria and viruses. Using air purifiers help make sure the air is clean, fresh, and safe to breathe. One of the most popular and effective types of air purifiers uses HEPA filters. These filters are designed to trap even the tiniest particles, like pollen, pet dander, and dust. If you have allergies or asthma, or if you just want to keep the air in your home cleaner, a HEPA filter can be a game-changer. These filters quietly pull in air, catch the particles that can trigger allergies or make breathing uncomfortable, and then release clean air back into your space, helping you feel more at ease.

2.2.5 Utilizing IoT

- **Real-time Monitoring**

Using IoT enabled sensors to monitor indoor air quality constantly keeps checking the air to make sure it’s safe and comfortable. These sensors keep an eye on important things like CO_2 levels, humidity, temperature, and any pollutants in the air, providing real-time updates to maintain a healthy environment.

Real-time monitoring of the environmental parameters keeps a continuous track of the changes in the environment, which helps in carrying out remedial steps when needed.

- **Regular Maintenance**

Routine maintenance of HVAC systems, air purifiers, and ventilation components is essential for keeping your indoor air clean and fresh. Regular changing HVAC filters (every 1-3 months) keeps dust and allergens at bay and ensures your system runs efficiently. Maintenance of ventilation and UV system also play a crucial role in making of a healthy sustainable environment.

2.2.6 Sustainable Building Construction

- **LEED Certification**

Complying with standards like LEED (Leadership in Energy and Environmental Design), which includes guidelines for maintaining indoor environmental quality play a vital role in the sustainability of building construction.

- **WELL Building Standard**

Adopting the WELL Building Standard, emphasizes on improving human health and well-being through superior building design, particularly in terms of air quality.

2.2.7 Occupant Health and Comfort

- **Healthier Indoor Environments**

Designing indoor spaces that enhance the health, comfort, and productivity of occupants by ensuring optimal air quality.

- **Thermal Comfort:**

Achieving a balance between air quality and thermal comfort is necessary to create a pleasant indoor climate for all occupants.

2.2.8 Better Ventilation

Implementing energy-efficient ventilation strategies that provide fresh air while conserving energy. Smart building systems utilize real-time air quality data to adjust ventilation and filtration, optimizing both air quality and energy efficiency.

2.2.9 Policy and Regulation Compliance

- **Building Codes**

It is crucial to comply with local and international building codes and standards that require specific air quality measures during construction.

- **Environmental Regulations**

Adhering to environmental regulations is necessary to limit the use of harmful materials and practices in construction.

Numerous green building projects worldwide like Bullitt Centre in Seatle, implement advanced air indoor quality strategies along alongside other sustainable practices. Also contemporary smart buildings employ integrated systems to dynamically monitor and manage air quality, ensuring optimal conditions for occupants while minimizing energy consumption.

2.3 Building Information Modelling (BIM)

BIM is able to deal with digital information relatively easily. BIM is not the software but rather a process that runs in tandem with other software. It facilitates both the design and the execution of operational information in a project (Popov, 2010). BIM promises to deliver the expected changes in the construction sector.

The capabilities of BIM open in many directions:

- 3D models holding up information like length, width, and height.
- 4D Scheduling i.e.,3D Models combined with the project schedule with task sequencing.
- 5D Cost Estimation; Cost details associated with a 4D Model.
- 6D Model-based analysis for the early and accurate decision-making process
- 7D Models for Operation and Maintenance
- 8D Modelling for Risk Assessment (Winberg & Dahlqvist, 2010).

BIM allows the exchange of relevant information throughout the project lifecycle, which reduces costs, improves efficiency, and shortens the duration of a project. Visualizing the project reduces costs, enhances efficiency, and minimizes the project duration (Deng, 2019). BIM recognizes and analyzes issues before real construction. Issues of coordination are resolved by BIM, and the recognition of material quantities is automated. BIM has been successfully implemented in various fields of management of a construction project and has shown to be an effective tool in solving problems in the construction industry (Darko).

Indoor air quality (IAQ) monitoring is all about accessing real-time sensor data enabling the detection of pollutants that include carbon dioxide (CO_2), volatile organic compounds, particulate matter within a similar size to diesel exhaust particles as well nitrogen oxides such as NO in parts per billion(ppb). 5) and other important parameters such as temperature and humidity. These sensors monitor the pollutants at all times, which gives useful data for analysis and guards against a deterioration in air quality going unnoticed. It is important to monitor these elements as part of better understanding the state indoor environments are in and for ensuring occupant safety.

This data goes to process and analyse to catch the trends in IAQs, identify problems etc. So you can detect problems, like a large amount of some pollutant that has no reason to be there (bad ventilation or more things causing harm). This data is more like the internet of things in an office, and allows buildings to be proactive when it comes to keeping track of indoor environmental quality.

Besides real-time monitoring, historical data is leveraged to model different possible scenarios affecting IAQ. For example, variables associated with ventilation system modifications and occupancy levels that impact air quality can be modelled to forecast the effect these will have on indoor environment. This way, such simulations enable testing and refining building systems, even without the turn off process of real operations — these are means to address your interior air quality proactively as well.

Utilizing digital twin technology to maximize building performance A digital twin of the building allows operations to be controlled, such as heating and air conditioning (HVAC) systems by using real-time data or historical data. By doing so, it guarantees a good IAQ at the same time that energy efficiency is maximized and building environmental impact decreases. These technologies can be used to tune building operations for comfort and sustainability alike.

CHAPTER 3

METHODOLOGY

3.1 Monitoring of Data

An operational asset was selected for the monitoring of Indoor Air quality. The building is in Sector I-10. It's a five Marla double story building constructed wayback in 1998. To get the data sensors such as DHT11 and SGP 40 were used. DHT11 was used to measure temperature, humidity and heat index. SGP40 gaveus raw TVOC signals. This data was obtained in Arduino IDE, and it was obtainedin various spaces of which we have Revit images below.

Figure 1: Living Room of Operational Asset being monitored

Figure 2: Bedroom of Operational Asset being monitored

Figure 3: Kitchen of Operational Asset being monitored

Figure 4: Revit 3D Model of Operational Asset

3.2 Live Connection of Data to Revit model

Data was connected so that it will go in real time from ARDUINO IDE to Googlesheets then to REVIT Model. This required extensive coding in Arduino IDE, then in google script and in dynamo.

Figure 5: Path of Data

Parameters were created in Revit spaces so that data could go in them through dynamo nodes.

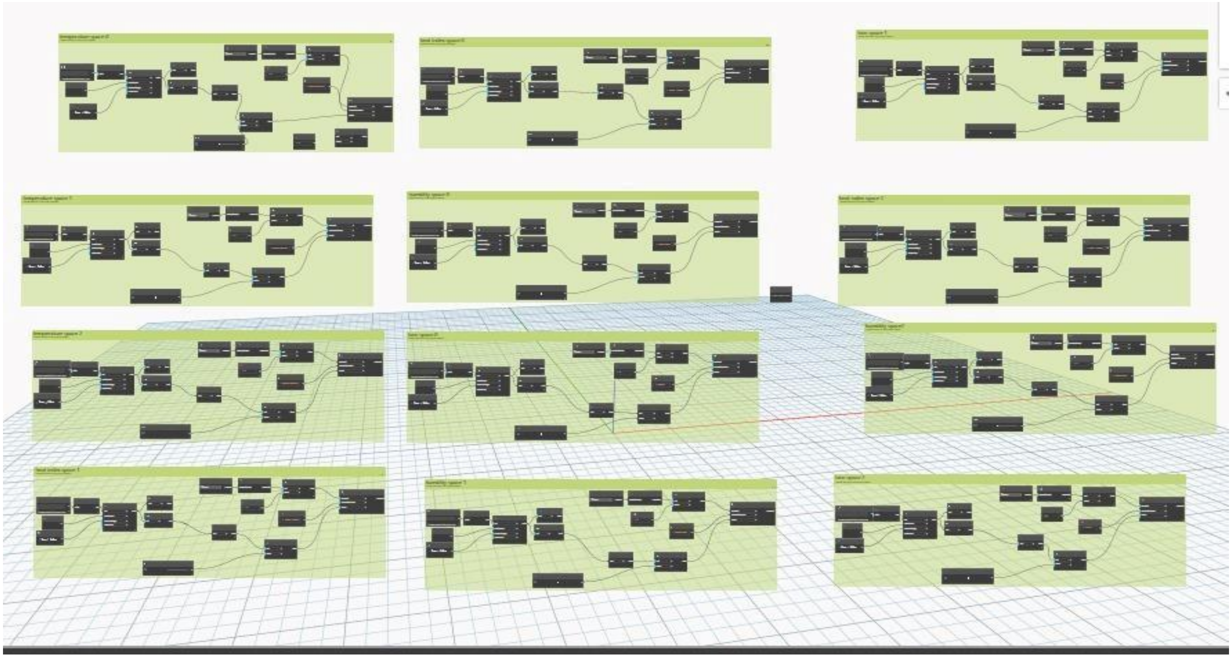

Figure 6: Dynamo code to enable live transfer of data

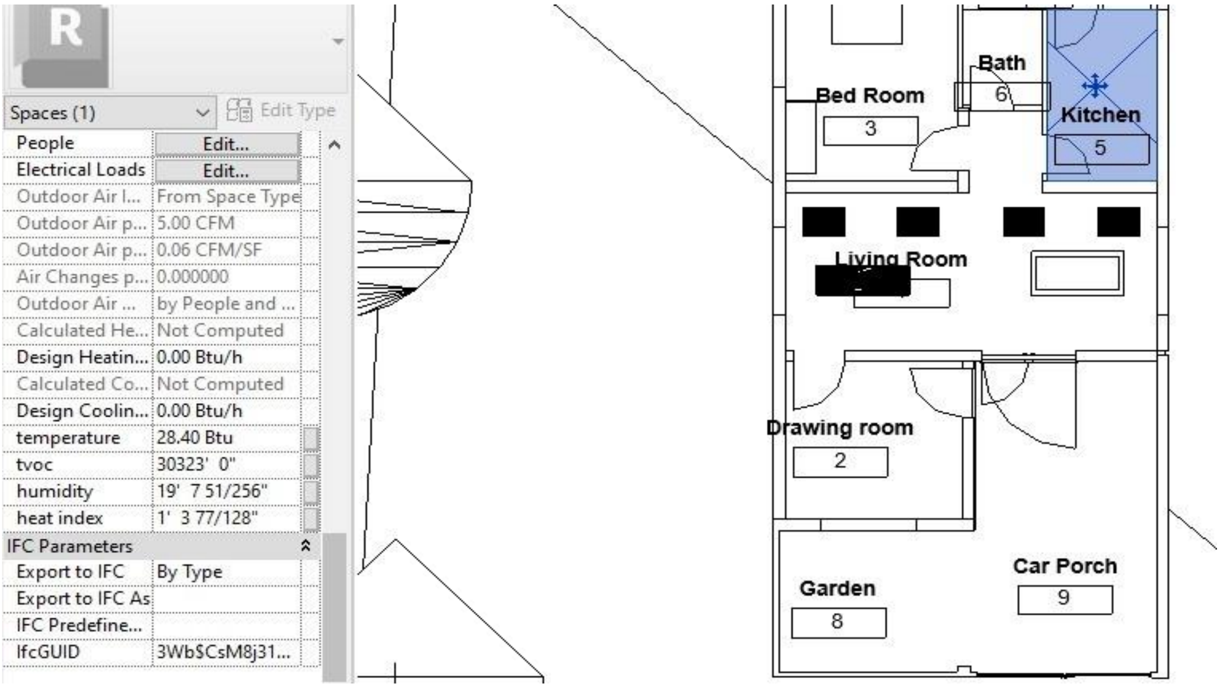

Figure 6: Data going live into the parameters

In the Revit model in Figure 6, spaces are created as shown. The live data obtained from IoT devices and stored in google sheets is transferred to the model through dynamo code and saved to the specified spaces created. For each space created, the values of the environmental parameters i.e temperature, humidity, heat index and TVOCs can be recorded.

Above images show kitchen getting monitored and all the parameters required for monitoring of indoor air quality being updated live in Revit model. Same can be shown for Living room and Bedroom.

CHAPTER 4

RESULTS AND ANALYSIS

The final analysis depicted the indoor air quality (IAQ) scenario within the monitored kitchen and articulated several scopes for its betterment. The validity and importance of these findings are justified from the various published studies,research data, and statistical findings from several parts of the world.

4.1 Temperature and Humidity

The kitchen maintained warm temperatures and low humidity throughout the monitoring period. These two parameters have been widely researched and confirmed of its injurious effects on IAQ.

4.1.1 Temperature

- **Impact on VOC emissions**

Organic compounds volatize at higher temperatures, which result in a higher presence in the air. According to a study from the United States Environmental Protection Agency (EPA), it has been found that when the temperature increases above 25°C, then the emission of Volatile Organic Compounds from various household products increases by 10 to 15 times.

- **Impact on Health**

Exposure to high temperatures over a prolonged period leads to discomfort in the human body and heat stress. The research articles on Environmental Health Perspectives have confirmedthat chronic exposure to higher temperatures develops cardiovascular as well as respiratory diseases, and that older adults and children are themost affected.

4.1.2 Humidity

Low levels of humidity cause dryness in the respiratory tract. It leads to a lack in comfort and can cause health problems, such as dry skin and irritated eyes. ASHRAE advises keeping indoor humidity maintained between 30% and 60%.

Low levels of humidity cause dryness in the respiratory tract. It leads to a lack in comfort and can cause health problems, such as dry skin and irritated eyes. ASHRAE advises keeping indoor humiditymaintained between 30% and 60%.

4.2 TVOC (Total Volatile Organic Compounds) Levels

The TVOC levels in the kitchen were higher than the standard threshold specifiedby the sensor manufacturer. The Gauss index algorithm verified that the compensated TVOC values were above the acceptable level, and it was proved beyond doubt that the indoor air quality was not sustainable and may result in severe health damage.

TVOCs are a group of organic chemicals that easily turn into vapors or gases. They consist of a wide variety of chemicals such as benzene, formaldehyde, and toluene. A studyconducted by the World Health Organization (WHO) identified that prominent sources of TVOCs in indoor air include paints, varnishes and wax containing biocides, cleaning and disinfecting supplies, air fresheners, stored fuel and automotive products, hobby and craft supplies, dry-cleaned clothing, smoking, cooking, and other biological and chemical agents.

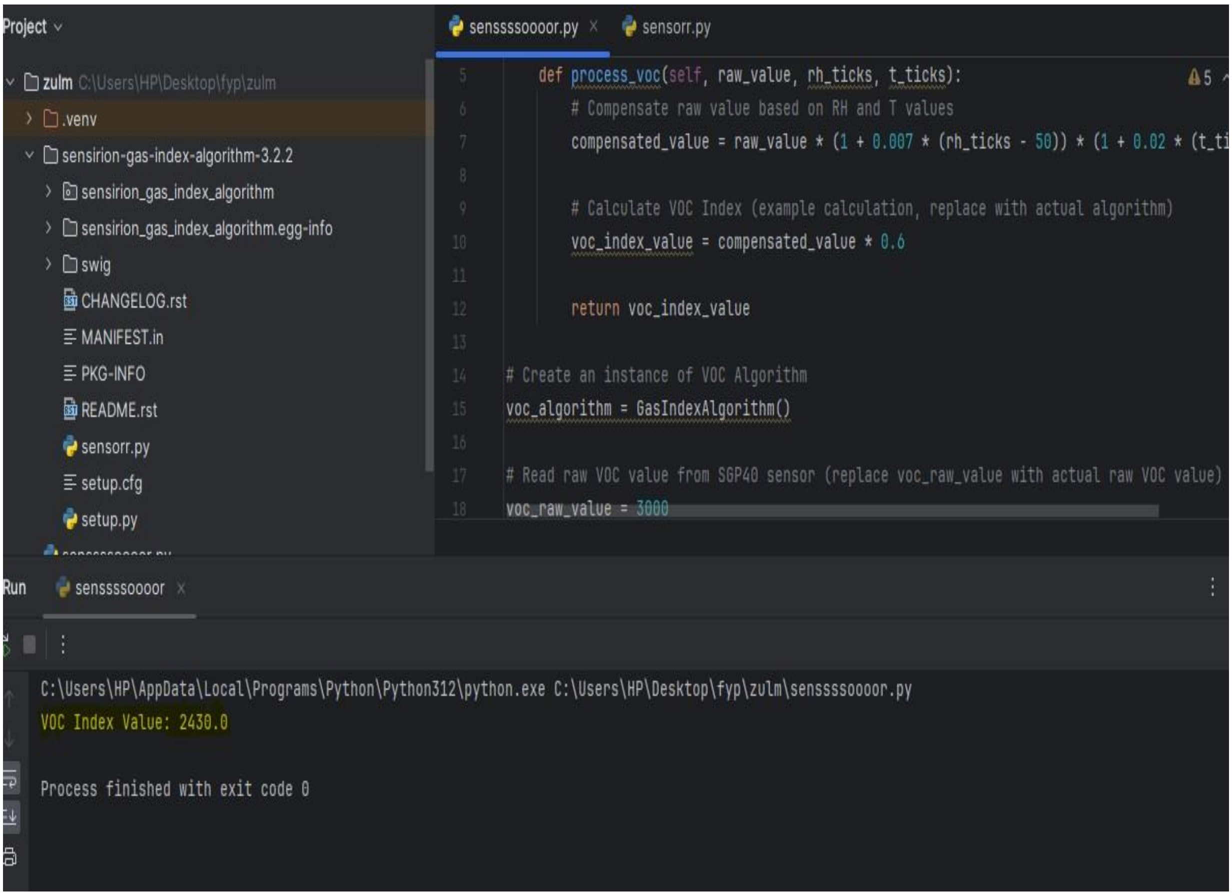

Figure 7: Gas Index Algorithm by PyCharm

- **Health Effects**

High levels of TVOCs cause various health disturbances, such as headaches, dizziness, allergies, respiratoryproblems and may also cause severe chronic diseases. Accordingto a study published in the Journal of Exposure Science &Environmental Epidemiology, an increased risk of asthma and other respiratory comorbidities has been seen after prolonged exposure to higher concentrations of TVOCs.

- **Statistical Evidence**

A recent study by the International Society of Indoor Air Quality and Climate (ISIAQ) identifiedthat more than 50% of indoor environments in urban areas have exceeded the standard levels set for TVOCs, and the unison result is that it poses a severe impact on the healthy maintenance of IAQ.

According to the report by Centers for Disease Control and Prevention (CDC), indoor air pollution, of which TVOCs have a significant contribution, causes around 2.7 million deaths annually worldwide due to respiratory and cardiovascular diseases.

These findings establish factual evidence to prove effective strategy requirementsto manage IAQ in residential areas. However, amelioration efforts directed at thetemperature, humidity, and TVOC are likely to have a much better effect on the prospect of better health indoors.

CHAPTER 5

CONCLUSION

The objectives of the project under consideration were centered on the assessment of several vital environmental variables in an indoor environment, namely temperature, relative humidity, heat index as well as the Total Volatile Organic Compounds (TVOCs). In this context, by comparing the empirically obtained data with rate values, we also revealed the sustainability and health safety of the studied environment. This analysis is important as the interior environments have a direct influence on the health, comfort, and subsequent performance of the occupants. The findings imply that a detailed understanding of IAQ is vital in numerous industrial and commercial applications; therefore, the significance of cautious management of indoor air substantiated.

5.1 Recommendations

Conclusions of the data analysis make it possible to propose several IAQ improvement measures in the monitored environment:

5.1.1 Temperature Control

Several practices can help maintaining environmental temperature. Some of the practices involve the following:

- **Implementation of Advanced HVAC systems**

Several times relied on the use of HVAC systems that have the capacity of regulating the temperature properly. Snow attributed this to the modern systems having sensors and automated controls as they can maintain the required temperatures better.

- **Regular Maintenance and Calibration**

Continue monitoring and managing harms by ensuring appropriate maintenance and calibration of HVAC systems so that temperature control is maintained within the intended range. These involve cleaning filters, leak detection, and thermostat calibration to optimally control temperatures.

5.1.2 Enhancement of Ventilation

It is important to observe natural and mechanical ventilation in that event as well.As for the suggestions on designing a new kitchen or remodeling the existing one,it is effective to increase fresh air exchange in the kitchen to decrease the level ofVOC and enhance the circulation of air. It can be achieved through interactions with fans, operable windows, and cross flow ventilation.

- Using windows and vent to create a way through which fresh air from the outside is allowed into the home and the inside air is allowed out. A specific strategy for enhancing cross-ventilation is beneficial, as the air movement between opposite room sides appears to enhance the transport processes.
- Ducted fans enable the extraction of indoor contaminants and excess temperature from the rooms. Using a range hood that can be hung above any kitchen stove can go a long way in removing pollutants that are common while cooking.
- Air purifiers with VOC filters will be extremely useful to remove and displace indoor air pollution and are preferred for such applications.
- Exclusion of some types of cleanness products, paints and furnishing releasing VOCs erases the origin of the pollution indoor at a remarkably high rate.
- It is possible to note that VOCs can be captured by activated carbon filters that are used in air purifiers to decrease their concentration in the air. HEPA filters that can effectively filter out pollutants and other particles such as air particulate matter.
- Thus, one can advise painting companies to reduce propagating VOC in their interiors by using eco-friendly cleaning materials which contain low VOC levels.

Refusing to organize foods and substances with a heavy odor around them.

- Effective from 1997, the use of low-VOC or zero VOC paints and finishes is preferred. The kind of right of decision-making that is associated with the use of furniture that is made from natural untreated materials.
- The humidity must be within a range because the mold and dust mites thrive in both low and high humidity levels: (30-50). The right level of humidity minimizes irritation of the respiratory system membranes and lower vocal cords.
- Dust mite control and mold can be achieved by ensuring the indoor humidity range remains between 30 to 50 percent. They exist in two types, those that humidify and those that dehumidify; the differences should be regulated to desirable amounts.
- We suggest that indoor plants which can effectively remove Volatile Organic Compounds from the environment will help in cleaning air within indoors. Some plants that are effective in cleaning the air are spider plants, peace lily, and Boston fern.
- The plants which can remove VOCs and Mitchell's consensus tar and enhance the quality of air indoors are spider plant, peace lily and Boston ferns. Maintaining the plants by watering or removing dust from their leaves is efficient all the time.

5.1.3 Expanded Sensor Network

Indoor air quality (IAQ) can be further bettered by proactively monitoring more pollutants than the aforementioned, such as CO2 and PM 10. 5 and PM10). These sensors offer insight as to the overall Indoor Air Quality (IAQ) of a building. For example, carbon dioxide sensors are great for checking the effectiveness of your HVAC system. The levels increase: Obviously, the only way that CO2 levels can go up is if ventilation goes down. So when you see your values increasing over time, it´s just another sign that something needs to be done with your existing system. On the other hand, PM2. Particulate matter is particularly relevant when it comes to health (since these pollutants have the potential to pose serious risks both for our respiratory and cardiovascular systems), so sensing elements defined within this class are PM10 sensors.

By expanding the IAQ monitoring system to multiple rooms and regions within a building, it provides an overview of air quality from different surrounding environments. It is a multi-room monitoring system that helps to identify worst-case IAQ locations and target interventions in those specific rooms. This holistic approach improves the broader air management strategy by properly handling site-specific concerns.

Furthermore, integrating IAQ monitoring with smart home systems enables autonomous management of air quality. Smart home technology can regulate the flow of fresh air, adjust heating and cooling systems, and initiate air cleaning processes based on real-time IAQ data. These systems operate independently, maintaining a healthy indoor environment without requiring human intervention. By automatically responding to changing conditions, they ensure optimal air quality and energy efficiency.

In addition to autonomous IAQ management, designing user-friendly interfaces and mobile applications provides occupants with easy access to IAQ data. These ergonomic and customer-centric platforms display real-time information and analytical insights about the indoor environment, empowering users to make informed decisions. If necessary, they can take action to adjust their indoor settings, improving comfort and air quality. This accessibility promotes greater awareness and engagement with indoor environmental conditions.

5.1.4 Future Work

Further work of the study will be the instalment of more sensors for other pollutants, implementation of machine learning for IAQ predictive analysis and lastly would be incorporating the IAQ system to the smart home system for the IAQ management to be done automatically.

5.2 Industrial Applications

5.2.1 Building Management Systems (BMS)

The research work deals with the implementation of sophisticated IAQ monitoring systems in coordination with the traditional as well as modern BMS for commercial buildings, offices, and industries. It will assist facility managers in promoting healthy living standards; thereby impacting the overall health of the workers and their productivity.

5.2.2 Healthcare Facilities

Adopting an IAQ monitoring system in hospitals, clinics, and other areas in orderto maintain a hygienic environment for both the patients and personnel. In this case, constant monitoring can reduce the chances of disease transmission or the spread of contaminants in the air.

5.2.3 Educational Institutions

A sample of employing IAQ monitoring in schools and universities so that the students and the staff can be in a good condition when learning and teaching. Some of the benefits associated with good IAQ include good thinking, the abilityto focus and work and overall performance as we study.

5.3 Large-scale Opportunities

5.3.1 Smart Cities

Designing IAQ monitoring technologies into smart city platform solutions to offer centralized and efficient air quality control at the city level. Enthusiastic data received from numerous places may contribute to adequately managing urban air quality and practicing effective policies and interventions bythe municipal authorities.

5.3.2 Residential Developments

Making IAQ monitoring an industry standard service offer for new building constructions. This can attract the kind of customer who is conscious about their health and cancreate new benchmarks on some of the greatest inventions such as houses that are friendly to the environment.

5.3.3 Corporate Responsibility

Promoting IAQ monitoring amongst the companies that are engaged in the CSR activity. This is a sign of the company's goodwill to the employees and society by promoting healthy and environmental friendly practices. Achieving seamless integration with smart home systems to allow autonomouscontrol of ventilation, heating, cooling, and air purification. Smart systems can adjust settings in real-time based on IAQ data, ensuring ahealthy indoor environment without manual intervention.

5.3.4 Policy making and Regulations

Presenting information and findings to the policy makers to enable them to set down policies and standards necessary for Indoor Air Quality. High quality IAQ data can help to establish structural frameworks that would helppreserve the health of the public and facilitate healthy use of Indoors.

Overall, it might be helpful for the project to integrate these IAQ monitoring system improvements in the future so that it can make a large-scale contribution to improving indoor air quality. Flexible and versatile technologies that allow fortheir integration and the ability to apply them across numerous industrial sectorshighlight the vast possibilities of use and the significance of the effects brought by the technologies.

5.4 Conclusion

Regarding the implemented IAQ monitoring, which was established and practiced within the proposed framework, IoT was utilized. It gave constant, 'live' feedback to help maintain the level of IAQ in a kitchen. The studies on airquality further supported the findings of the IAQ poll: it remains unsustainable and unsafe for occupants; hence the kitchen calls for changes.

Observing how IAQ management approaches could be implemented in live applications to manage construction projects and support the overlapping fields of green buildingand sustainable construction were valuable uses of this data, particularly in live stream monitoring through the IoT sensors, the Google Sheets tracking, and intothe Revit BIM application. It must be a strategy that should be implemented in other parts with high pollution concentration in a residential/ commercial buildingfor better indoor health conditions. At the onset of this study particular IAQ concerns in the kitchen were outlined and explored as well as a plan for a similarcontext in other settings was provided. Future inclusions would include installation of additional sensors for other air pollutants, inclusion of artificial intelligence and machine learning for analysis and predictions, and capability to interface IAQ with Smart Homes to allow for fully automated controls.

The project demonstrates the need to frequently check the environmental condition in the building to assess influences and to promote indoor environmenthealth. Temperature, humidity, heat index, and TVOCs are vulnerable indices, which, if managed appropriately, will help industries protect their workforce, increase productiveness, together with meeting legal requirements. The implementation of the suggested safety measures will not only enhance the quality of the indoor air but will also help in making the operation and manufacturing practice of the industry more responsible and eco-friendlier.Ongoing assessment and initiative-taking management of IEQ are vital to promote a safe, healthy, productive indoor environment for creating a more sustaining/ sustained built environment industry.

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