Major Research Project

Exploring Indoor Air Quality Dynamics in Office Environments: A Comprehensive Investigation into IAQ Trends and Occupants Health Perception

Submitted By

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CERTIFICATE

This is to certify that the work titled '**Exploring Indoor Air Quality Dynamics in Office Environments: A Comprehensive Investigation into IAQ Trends and Occupants Health Perception**' as part of the Major Project submitted by Sanchit Nanglia in the 4th Semester of MBA (DSM, DTU) was conducted under my guidance and supervision.

This work is his original work to the best of my knowledge and has not been submitted anywhere else for the award of any credits / degree whatsoever.

The project is submitted to Delhi School of Management, Delhi Technological University in partial fulfilment of the requirement for the award of degree of Masters of Business Administration.

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DECLARATION

I hereby declare that the work titled '**Exploring Indoor Air Quality Dynamics in Office Environments: A Comprehensive Investigation into IAQ Trends and Occupants Health Perception**' as part of my major project submitted by me as the Major Report for 4th Semester in MBA (DSM, DTU) under the guidance of Ms. Mohit Beniwal is my original work to the best of my knowledge and has not been submitted anywhere else. The report has been written by me in my own words and not copied from elsewhere. Anything that appears in this report which is not original has been duly and appropriately referred/ cited/ acknowledged.

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EXECUTIVE SUMMARY

Indoor air quality in Office Spaces plays a critical function in the health, productivity, and well-being of occupants. With people spending a a large chunk of their time, ensuring high-quality indoor air is essential. Poor IAQ can lead to various health issues and reduce productivity levels among occupants, highlighting the importance of understanding and improving IAQ in Office Spaces.

The aim of this report is to furnish a comprehensive analysis of IAQ in Office Spaces, including an examination of factors influencing IAQ, common pollutants found in Office Spaces, measurement techniques for assessing IAQ, health impacts of poor IAQ on occupants, strategies for improving IAQ, and economic benefits associated with enhancing IAQ in Office Spaces. This document also explores occupants' perceptions of IAQ and its impact on their health and well-being, providing insights into how occupants perceive and experience indoor environmental quality.

Factors contributing to IAQ in Office Spaces include outdoor air pollution, building design and construction materials, HVAC systems, indoor activities, and occupant behavior. Understanding these factors is crucial for identifying sources of indoor air pollutants and putting into practice practical mitigating techniques.

Common indoor air pollutants found in Office Spaces include Volatile Organic Compounds , Particulate matter, carbon dioxide (CO2), temperature (T) and relative humidity (RH), and biological contaminants such as mold, bacteria, and allergens. These pollutants can originate from various sources within buildings and pose significant health risks to occupants.

Various techniques are available for assessing IAQ in Office Spaces, including real-time monitoring, air sampling and analysis, ventilation assessments, and building inspections. These techniques allow for the identification and quantification of indoor air pollutants, helping stakeholders make informed decisions regarding IAQ management.

Poor IAQ can have detrimental effects on occupants' health, including respiratory problems, allergic reactions, asthma exacerbations, cephalalgia in the heads, fatigue, and decreased cognitive function. Long-term exposure to air contaminants inside may also increase the risk of developing chronic diseases such as cardiovascular disease and cancer.

Occupants' perceptions of IAQ and its impact on their health and well-being play a crucial role in shaping their indoor environment experience. Understanding occupants' perceptions and experiences can provide valuable insights into areas for improvement and help tailor IAQ management strategies to better meet occupants' needs.

Several strategies can be employed to improve IAQ in Office Spaces, including proper ventilation and air filtration, source control measures, regular maintenance of HVAC systems, use of low-emission building materials, and implementation of indoor air quality management plans. By adopting these strategies, stakeholders can effectively mitigate indoor air pollutants and create healthier indoor environments for occupants.

Investing in IAQ improvements in Office Spaces can yield significant economic benefits, including reduced healthcare costs, increased productivity and performance among

occupants, lower absenteeism rates, improved tenant satisfaction and retention, and enhanced building value and marketability. These economic benefits outweigh the costs associated with IAQ improvements, making it a sound investment for building owners and operators.

In conclusion, this document underscores the importance of understanding and improving IAQ in Office Spaces for the health, productivity, and well-being of occupants. By addressing IAQ issues through comprehensive analysis and considering occupants' perceptions, stakeholders can create healthier and more sustainable indoor environments that benefit both occupants and the bottom line.

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1. INTRODUCTION

1.1 Background

In the bustling global of Office Spaces, where countless individuals spend the majority of their waking hours, the first-rate of indoor air holds paramount significance. Indoor air best serves as a crucial determinant of inhabitants health, productivity, and usual well-being. From workplace complexes to retail spaces, instructional establishments to healthcare facilities, the excellence of the air we breathe indoors immediately impacts our consolation, performance, and durability.

The importance of IAQ in Office Spaces can not be overstated. As people spend about 90% of their time inside, the satisfaction of the air they breathe performs a pivotal position in their fitness and productivity. Poor IAQ has been related to a myriad of fitness issues, inclusive of respiratory ailments, allergic reactions, fatigue, and cephalalgia in the heads, that could notably impair occupants' capability to characteristic optimally within their professional environments. Moreover, compromised IAQ can exacerbate current health conditions and make contributions to absenteeism, in addition impacting organizational productivity and bottom lines.

Recognizing the criticality of information and enhancing IAQ, it becomes vital to delve into the multifaceted components of this domain. The contemporary-day emphasis on sustainable and wholesome constructed environments underscores the need for comprehensive techniques to enhance IAQ in commercial settings. By addressing the root causes of poor IAQ and imposing effective mitigation measures, stakeholders can create environments conducive to occupant health, productivity, and typical delight.

1.1.1 Importance of Indoor Air Quality

Indoor Air Quality holds a critical role in shaping the health, comfort, and productivity of occupants within Office Spaces. The indoor air quality that humans breathe directly impacts our well-being in several ways, making it imperative for stakeholders to prioritize IAQ management.

First and foremost, IAQ significantly influences occupants' health. An assortment of health problems, such as allergies, cephalalgia in the heads, exhaustion, and respiratory disorders, can be brought on by bad IAQ. Exposure to pollutants such as dust, mold, volatile organic compounds, particulate matter, carbon dioxide and airborne pathogens can exacerbate existing health conditions and increase the risk of developing new ones. For individuals spending long hours indoors, especially in commercial settings, where the concentration of pollutants may be higher due to factors like inadequate ventilation and the presence of chemicals from construction materials and furnishings, ensuring good IAQ is essential for safeguarding their health and well-being.

Moreover, IAQ directly impacts occupants' both ease and efficiency. Bad IAQ may result in discomfort, causing symptoms like dryness and irritation in the eyes, nose, and throat, as well as feelings of fatigue and difficulty concentrating. These issues can hinder individuals' ability to perform tasks efficiently and effectively, ultimately impacting organizational productivity

and performance. Conversely, good IAQ promotes a healthier and comfortable indoor space, enabling inhabitants to work, learn, shop, or receive care without unnecessary distractions or discomfort.

Beyond its immediate effects on occupants, IAQ also intersects with broader goals of energy efficiency, sustainability, and regulatory compliance. Efficient HVAC systems and building designs that prioritize IAQ contribute to reduced energy consumption and lower operating costs. Additionally, promoting good IAQ aligns with sustainability objectives by reducing environmental impacts associated with indoor air pollution and improving overall occupant well-being. Furthermore, regulatory agencies increasingly recognize the importance of IAQ standards in ensuring healthy indoor environments, with compliance measures in place to protect occupants from exposure to harmful pollutants.

1.1.2 Elements That Affect the Quality of Indoor Air

A multitude of factors impact the quality of indoor air within Office Spaces, ranging from the design and operation of ventilation systems to the materials used in construction and even the activities of occupants. Understanding these factors is crucial for effectively managing IAQ and creating healthier indoor environments.

Ventilation Systems: Properly designed, operated, and maintained ventilation systems are fundamental to maintaining good IAQ. Ventilation systems ensure the removal of indoor contaminants by the exchange of fresh outside air with indoor air regulating temperature and humidity levels. Design considerations such as the placement of air intakes and exhausts, air filtration, and airflow patterns play a significant role in the effectiveness of ventilation systems. Regular upkeep, such as filter cleaning, ductwork, and components, is crucial for preventing the buildup of contaminants and ensure optimal system performance.

Building Materials and Furnishings: The materials used in construction, as well as furniture and furnishings, can release the volatile organic compounds into the indoor environment. Volatile Organic Compounds are released from various sources such as paints, adhesives, carpets, and upholstery. Over time, these emissions can contribute to poor IAQ and pose health risks to occupants. Selecting low-emission building materials and furnishings and allowing for proper off-gassing before occupancy can help mitigate this issue. Additionally, incorporating strategies like air sealing and using air purifiers with activated carbon filters can help remove VOCs from the indoor environment.

Occupant Activities: The activities of building occupants can have a significant impact on IAQ. Common activities like smoking and using cleaning products can significantly impact IAQ by introducing pollutants into the indoor environment. For instance, smoking introduces harmful chemicals from tobacco smoke, while cleaning products often contain volatile chemicals that increase indoor air pollution. Educating occupants about the potential effects of their activities on IAQ and promoting the use of environmentally friendly products and practices can help minimize indoor pollution sources.

Outdoor Air Pollution: Outdoor air pollution may penetrate through ventilation systems into indoor rooms, doors, windows, and cracks in the building envelope. Particulate matter, nitrogen dioxide, ozone, and volatile organic compounds are examples of pollutants that can enter buildings from vehicle emissions, industrial activities, and natural sources. The quality of outdoor air can significantly impact IAQ, especially in urban areas with high levels of

pollution. Proper filtration and ventilation strategies, as well as sealing building envelopes to reduce infiltration, can help mitigate the effects of outdoor air pollution on indoor air quality.

Maintenance Practices: Maintenance practices, particularly related to air conditioning, ventilation, and heating systems, play a crucial role in maintaining good IAQ. Poorly maintained HVAC systems can turn into havens for mold growth, bacteria, and other contaminants, which can then be circulated throughout the building. Regular inspection, cleaning, and servicing of HVAC equipment, as well as prompt repair of leaks and malfunctions, are essential to prevent IAQ issues related to HVAC systems.

1.1.3 Common Indoor Air Pollutants

Indoor air quality is influenced by various pollutants that can have adverse effects on human health and well-being. Understanding these typical indoor air contaminants, their sources, control measures, and associated health effects is essential for effectively managing IAQ in Office Spaces.

Volatile Organic Compounds:

- Organic chemicals that easily evaporate into the air at room temperature. They are emitted from a broad variety of sources, including building materials, furnishings, cleaning products, and personal care products. Common VOCs include formaldehyde, benzene, toluene, and xylene.
- Sources: VOCs can be emitted from paints, adhesives, carpets, upholstery, solvents, and consumer products such as air fresheners and cosmetics.
- Control Measures: Selecting low-VOC or zero-VOC building materials, furnishings, and products can help reduce emissions. Adequate ventilation and air filtration systems can also help dilute and remove VOCs from indoor air.
- Health Effects: Short-term exposure to VOCs can cause discomfort in the throat, nose, and eyes, cephalalgia in the heads, dizziness, and nausea. Long-term exposure to certain VOCs, such as formaldehyde, may increase the risk of respiratory problems, cancer, and other serious health effects.

Particulate Matter:

- It refers to tiny particles suspended in the air, including dust, dirt, pollen, and smoke. PM sizes can differ, with smaller particles (PM2.5 and PM10) posing greater health risks as they can penetrate deep into the respiratory system.
- Sources: PM can originate from indoor sources such as Printing ,Photocopying, Fax Machines, Poorly maintained HVAC systems, Construction or Renovation work and Cleaning Activities.
- Control Measures: Using HEPA filters can assist removing PM from indoor air. Proper ventilation and source control measures, such as eliminating smoking indoors and reducing combustion activities, can also help reduce PM levels.
- Health Effects: Exposure to PM can aggravate respiratory conditions such as asthma and bronchitis, as well as increase the risk of cardiovascular diseases, lung cancer, and premature death.

Carbon Dioxide:

- It is a gas with no color or smell that exists organically in the air. Indoor CO2 levels can rise due to inadequate ventilation or high occupant density, leading to potential health and comfort issues.
- Sources: CO2 is generated by human respiration.
- Control Measures:Increasing ventilation rates and ensuring proper airflow can help reduce indoor CO2 levels. Monitoring CO2 levels and adjusting ventilation systems accordingly can also help maintain optimal IAQ.
- Health Effects: Elevated CO2 levels can cause symptoms such as cephalalgia in the heads, dizziness, tiredness and trouble focusing. Extended exposure to elevated CO2 levels has been shown to reduce productivity and cognitive performance.

Temperature and Relative Humidity:

- These both are important factors that influence IAQ and occupant comfort. High or low temperatures and humidity levels can create conditions conducive to the growth of mold, bacteria, and other indoor pollutants.
- Sources:Temperature and humidity levels can be affected by factors such as outdoor weather conditions, HVAC system performance, and occupant activities.
- Control Measures:Maintaining indoor temperature and humidity within recommended ranges (around 68-76°F and 30-60% relative humidity) can help prevent IAQ problems. Proper HVAC system design, operation, and maintenance are essential for controlling indoor climate conditions.
- Health Effects:Extreme temperatures and humidity levels can exacerbate respiratory conditions, trigger allergies, and increase the risk of heat-related illnesses.

Implementing effective ventilation, filtration, and source control measures can help mitigate IAQ problems and promote occupant health and well-being.

1.1.4 Measurement Techniques

Maintaining good Indoor air quality in Office Spaces requires accurate and reliable measurement and monitoring techniques. These techniques range from spot measurements to continuous monitoring using advanced sensors, enabling stakeholders to assess IAQ parameters effectively and take appropriate corrective measures when necessary.

Spot Measurements:

Spot measurements involve taking discrete measurements of IAQ parameters at specific locations within a building using portable monitoring devices. Parameters commonly measured include concentrations of organic volatiles, Particulate matter, carbon dioxide (CO2), temperature, and relative humidity. Spot measurements provide snapshots of IAQ conditions at a particular moment in time and can be useful for identifying localized IAQ issues or assessing the effectiveness of mitigation measures.

Continuous Monitoring:

Continuous monitoring involves the use of sensors and data logging systems to continuously measure and record IAQ parameters over time. Advanced sensor technologies allow for real-time monitoring of multiple IAQ parameters simultaneously, providing comprehensive

insights into IAQ dynamics within a building. Continuous monitoring systems can be integrated with building management systems (BMS) to automatically adjust ventilation rates and other HVAC parameters based on IAQ conditions.

Importance of Regular IAQ Assessments:

Regular IAQ assessments are essential for identifying IAQ issues, evaluating the effectiveness of IAQ management strategies, and ensuring compliance with IAQ standards and regulations. By conducting periodic IAQ assessments, proprietors of buildings, facility managers, and occupants can proactively identify potential IAQ problems before they escalate and implement corrective measures to address them. Regular IAQ assessments also help track changes in IAQ over time and assess the impact of building modifications or operational changes on IAQ.

Corrective Measures:

Based on the results of IAQ assessments, various corrective measures can be implemented to improve IAQ in Office Spaces. These measures may include: source control, ventilation optimization, filtration and air cleaning, humidity control, occupant education.

Measurement and monitoring techniques play a crucial role in maintaining good IAQ in Office Spaces. Spot measurements and continuous monitoring using advanced sensors enable stakeholders to assess IAQ parameters effectively and identify potential IAQ issues. Regular IAQ assessments are essential for implementing corrective measures to improve IAQ and create healthy indoor environments for building occupants. By proactively managing IAQ through measurement, monitoring, and corrective action, stakeholders can enhance occupant health, comfort, and productivity while ensuring compliance with IAQ standards and regulations.

1.1.5 Economic and Productivity Benefits of Improved Indoor Air Quality:

Improving indoor air quality in Office Spaces not only contributes to the health and well-being of occupants but also yields significant economic benefits for building owners, operators, and businesses. By investing in IAQ improvements, stakeholders can realize cost savings, productivity gains, and enhanced occupant satisfaction, ultimately generating a positive return on investment (ROI).

Reduced Healthcare Costs:

Improving IAQ can lead to a reduction in healthcare costs associated with occupant illnesses and absenteeism. Poor IAQ has been linked to respiratory ailments, allergies, and other health problems, resulting in increased healthcare utilization and absenteeism among building occupants. By creating healthier indoor environments, owners and operators of buildings may lower healthcare expenses and improve overall occupant health, translating into tangible cost savings.

Increased Productivity:

Studies have consistently shown that good IAQ is positively correlated with higher productivity levels among building occupants. Improved IAQ reduces symptoms such as cephalalgia in the heads, fatigue, and respiratory issues, allowing occupants to work more

comfortably and efficiently. Additionally, better IAQ can enhance decision-making and cognitive functioning abilities, further boosting productivity. The increased productivity resulting from IAQ improvements can have a significant impact on business performance and profitability.

Lower Absenteeism:

Poor IAQ will lead to increased absenteeism due to illness among building occupants. By improving IAQ and creating healthier indoor environments, owners and operators of buildings can lower absenteeism rates and minimize the disruptions caused by employee absences. Lower absenteeism rates result in improved workforce productivity and reduced costs associated with hiring temporary replacements or overtime labor.

Enhanced Occupant Satisfaction and Retention:

Providing a comfortable and healthy indoor environment enhances occupant satisfaction and retention rates. Occupants are more likely to be satisfied with their work environment and remain loyal to companies that prioritize their health and well-being. By investing in IAQ improvements, building owners and operators can attract and retain top talent, reduce turnover costs, and foster a positive organizational culture.

Examples of Studies Demonstrating ROI:

Numerous studies have demonstrated the economic benefits of IAQ improvements for building owners and operators:

- A study conducted by **Lawrence Berkeley National Laboratory** found that doubling the ventilation rates in office buildings resulted in an average productivity gain of $6,500 per employee per year, far exceeding the associated energy costs.
- A study published in the **Journal of Occupational and Environmental Medicine** estimated that improving IAQ in office buildings could lead to annual savings of $6 to $14 billion in the United States due to reduced healthcare costs and increased productivity.
- Research conducted by the **World Green Building Council** found that investing in green building features, including IAQ improvements, can lead to a 7% increase in asset value and a 6% increase in rental income for commercial properties.
- Poor indoor air quality has been projected to cause economic losses in the tens of billions of dollars annually, according to a research conducted by the Environmental Protection Agency (EPA). There will be significant cost savings from even the smallest expenditure made to improve air quality.

These examples highlight the significant ROI potential of IAQ improvements for those who own and operate buildings. By prioritizing IAQ management and implementing cost-effective strategies to enhance IAQ, stakeholders can realize substantial economic benefits while creating healthier and more productive indoor environments for occupants.

1.2 Problem Statement

In recent decades, there have been a growing concern regarding the office's interior air quality Spaces and its profound impact on the health and well-being of occupants. As individuals spend a substantial amount of time inside, particularly in commercial settings

such as offices, schools, hospitals, and retail spaces, the standard of the indoor environment becomes a critical determinant of overall health. Poor IAQ relates to various health issues, including respiratory problems, allergies, fatigue, cephalalgia in the heads, and decreased cognitive function, ultimately affecting occupants' productivity and quality of life. Despite advancements in building technologies and regulations aimed at improving IAQ, challenges persist, necessitating comprehensive research to understand the underlying factors contributing to IAQ degradation in Office Spaces and their consequences on occupants' health and well-being.

One of the primary challenges in investigating IAQ in Office Spaces is the complex and dynamic nature of indoor environments. Office Spaces often host diverse activities, accommodate fluctuating occupant densities, and utilize various Air conditioning, ventilation, and heating systems, all of which can significantly influence IAQ parameters for instance, humidity, temperature, ventilation rate, and concentration of indoor air pollutants. Moreover, the sources of indoor air pollutants are multifaceted, ranging from building materials, furniture, cleaning products, and electronic equipment to outdoor pollutants infiltrating through ventilation systems and openings. Understanding the intricate interactions among these factors and their impact on IAQ requires interdisciplinary research efforts integrating expertise from fields such as architecture, engineering, environmental science, and public health.

Furthermore, while IAQ monitoring and assessment methodologies exist, there is a need for more sophisticated and comprehensive approaches to accurately characterize IAQ in Office Spaces. Traditional methods often involve periodic sampling and analysis of select pollutants, which may not capture the temporal and spatial variability of IAQ or identify emerging contaminants with potential health implications. Advancements in sensor technologies, data analytics, and modeling techniques offer promising avenues for real-time, continuous monitoring of IAQ parameters, enabling proactive interventions to maintain optimal indoor environments and mitigate health risks. However, the implementation of such innovative approaches requires overcoming technical challenges, ensuring data reliability and privacy, and establishing standardized protocols for IAQ assessment in Office Spaces.

Moreover, while the importance of IAQ for occupants' health and well-being is widely recognized, there remains a gap in translating research findings into actionable policies and practices for building design, operation, and management. Building codes and standards provide essential guidelines for IAQ management; however, their effectiveness in addressing contemporary IAQ challenges and promoting occupant health needs to be evaluated and potentially revised to align with current scientific knowledge and best practices. Additionally, building owners, facility managers, and occupants play crucial roles in maintaining IAQ through proper ventilation, cleaning practices, and behavior modifications. Hence, fostering awareness, education, and stakeholder engagement are integral to promoting IAQ improvements and ensuring the adoption of evidence-based IAQ strategies in Office Spaces.

Furthermore, the COVID-19 outbreak has heightened awareness of indoor environments' role in disease transmission and emphasized the need for resilient, healthy buildings that prioritize IAQ. As Office Spaces adapt to evolving public health concerns and occupant expectations, there is an opportunity to integrate IAQ considerations into broader strategies for building resilience, sustainability, and occupant comfort. However, the extended effects of pandemic-

related measures, such as increased ventilation rates, indoor air filtration, and remote work practices, on IAQ and occupants' well-being remain uncertain and warrant thorough investigation.

In conclusion, addressing the multifaceted challenges associated with IAQ in Office Spaces requires a holistic research approach encompassing IAQ monitoring, assessment, modeling, policy analysis, and stakeholder engagement. By advancing our understanding of IAQ dynamics, identifying effective mitigation strategies, and promoting collaborative efforts among stakeholders, this research aims to contribute to creating healthier, more sustainable indoor environments that enhance occupants' health, well-being, and productivity in Office Spaces.

1.3 Purpose of the study

This research study aims to comprehensively investigate IAQ in a typical office building in Delhi NCR, focusing on key parameters such as Particulate matter, Carbon Dioxide, Volatile Organic Compounds , Temperature, and Relative Humidity.

Therefore, this study aims to address the multifaceted challenges associated with IAQ in Office Spaces through a comprehensive research framework encompassing various objectives:

1.3.1 Assessing Indoor Air Quality:

This study seeks to evaluate the prevailing trends in IAQ parameters within office environments, including but not limited to levels of Particulate matter, Volatile Organic Compounds , carbon dioxide, temperature, and humidity. By monitoring IAQ parameters over time, the research aims to identify patterns, fluctuations, and potential sources of indoor air pollutants, thereby gaining insights into the dynamic nature of IAQ within office spaces.

1.3.2 Examining Occupants' Health Perception:

The research endeavors to understand the perceptions of office occupants regarding their health and well-being within the indoor environment. Through surveys and questionnaires administered to occupants, the study will explore the prevalence and frequency of reported symptoms related to poor IAQ, such as respiratory issues, cephalalgia in the heads, eye irritation, and fatigue. Additionally, occupants' awareness of IAQ issues and their perceived impact on health and productivity will be investigated to ascertain the level of knowledge and concern among office occupants.

1.3.3 Analyzing IAQ and Perception Independently:

It's crucial to note that this research does not aim to establish a correlation or relationship between IAQ parameters and occupants' health perception. Rather, the study will independently analyze IAQ trends and occupants' health perception to provide a holistic understanding of indoor environmental conditions and occupants' experiences within office settings.

1.3.4. Studying Basic Knowledge:

In addition to assessing IAQ trends and occupants' perception, this research attempts to offer a basic understanding of indoor air quality fundamentals. Common pollutants, their sources, and potential health impacts on occupants will be explored to enhance stakeholders' knowledge of IAQ management in office spaces and the need for proactive measures to ensure a healthy indoor environment.

1.4 Scope of the study

The scope of this research study encompasses a comprehensive examination of indoor air quality in Office Spaces, with a particular focus on a typical office environment located in Delhi NCR. The study will utilize IAQ sensors to collect data on key IAQ parameters, including Particulate matter, total volatile organic compounds, carbon dioxide (CO2), temperature (Temp), and relative humidity (RH). Through systematic data collection, analysis, and interpretation, the study seeks to accomplish the following goals within its defined scope:

1.4.1 Characterization of IAQ Parameters:

The study will focus on characterizing the levels of PM, TVOC, CO2, Temp, and RH within the selected office building. By deploying IAQ sensors in various indoor spaces such as workstations, meeting rooms, corridors, and common areas, the study will collect real-time data to quantify the concentrations of these IAQ parameters. This characterization will provide insights into the baseline IAQ status of the office environment and identify potential sources of indoor air pollution.

1.4.2 Temporal Analysis of IAQ:

The scope of the study includes analyzing the temporal variability of IAQ parameters over different time scales, including daily, weekly, and seasonal variations. By collecting continuous data over an extended period, the study will examine patterns and trends in IAQ levels, such as diurnal fluctuations and long-term trends. Understanding the temporal dynamics of IAQ is essential for identifying periods of elevated pollutant levels and implementing targeted interventions to mitigate IAQ issues.

1.4.3 Comparison of Guidelines and Standards for IAQ :

This study will assess the IAQ data collected from the office building against relevant IAQ standards, guidelines, and regulations established by local authorities and international organizations. By comparing measured IAQ levels with established thresholds and benchmarks, the study will evaluate compliance with recommended guidelines for occupant health and well-being. Any deviations from regulatory standards will be identified, and recommendations for corrective actions will be proposed to ensure compliance and improve IAQ management practices.

1.4.4 Occupants Perception Assessment:

Administration of surveys and questionnaires to office occupants to assess their awareness, concerns, and perceptions regarding the effects of IAQ on health and productivity. Investigation of the prevalence and frequency of reported symptoms related to poor IAQ, such as respiratory issues, cephalalgia in the heads, eye irritation, and fatigue, to understand occupants' experiences and challenges. Exploration of occupants' satisfaction levels with ventilation, temperature control, and overall air quality in the workplace, including factors influencing their perceptions.

1.4.4 Identification of Indoor Air Pollution Sources:

Within the defined scope, the study aims to identify and characterize sources of indoor air pollution within the office building. By analyzing IAQ data alongside building occupancy patterns, activities, and building systems operation, the study will pinpoint specific sources or activities contributing to increased concentrations of contaminants like TVOCs and CO2. This information will inform targeted interventions and mitigation strategies to address indoor air pollution sources effectively.

1.4.5 Assessment of Indoor Thermal Comfort:

In addition to IAQ parameters, the scope of the study includes assessing indoor thermal comfort by monitoring temperature (Temp) and relative humidity (RH) levels within the office building. Thermal comfort is crucial for productivity and well-being of occupants, and deviations from optimal temperature and humidity ranges can lead to discomfort and dissatisfaction. By evaluating thermal conditions alongside IAQ parameters, the study will identify correlations between indoor environmental factors and occupant satisfaction.

1.4.6 Recommendations for IAQ Improvement:

Based on the findings from IAQ monitoring, data analysis, and occupant feedback, the study will develop evidence-based recommendations for improving IAQ and indoor environmental quality in the office building. These recommendations may include measures such as optimizing ventilation systems, implementing indoor air filtration technologies, adopting low-emission building materials and furnishings, and promoting occupant awareness and behavior change initiatives. The goal is to provide actionable strategies and interventions that can be implemented by building owners, facility managers, and occupants to enhance IAQ and promote a healthier indoor environment.

2. LITERATURE REVIEW

In the bustling world of Office Spaces, where countless individuals spend the majority of their waking hours, the standard of indoor air quality holds paramount importance. Indoor air quality serves as a critical determinant of occupants' health, productivity, and overall well-being. From office complexes to retail spaces, educational institutions to healthcare facilities, the indoor air quality that we breathe directly influences our comfort, performance, and longevity.

The significance of IAQ in Office Spaces cannot be overstated. As individuals spend over ninety percent of the time indoors, the degree of the air quality they breathe plays a pivotal role in their health and productivity. Poor IAQ has been linked to a myriad of health issues, including respiratory ailments, allergies, fatigue, and cephalalgia in the heads, which can seriously hinder inhabitants' capacity to function optimally within their professional environments. Moreover, compromised IAQ can exacerbate existing health conditions and contribute to absenteeism, further impacting organizational productivity and bottom lines.

Recognizing the criticality of understanding and improving IAQ, it becomes imperative to delve into the multifaceted aspects of this domain. The modern-day emphasis on sustainable and healthy built environments underscores the need for comprehensive strategies to enhance IAQ in commercial settings. By addressing the root causes of poor IAQ and implementing effective mitigation measures, stakeholders can create environments conducive to occupant health, productivity, and overall satisfaction.

This document aims to serve as a comprehensive resource on IAQ in Office Spaces, offering insights into various facets of this crucial subject matter. From identifying common pollutants to exploring measurement techniques and health impacts, each aspect of IAQ will be thoroughly examined. Additionally, strategies for improving IAQ will be elucidated, encompassing both preventive measures and remedial actions to address existing issues.

The primary purpose of this document is to equip stakeholders with the knowledge and tools necessary to navigate the complexities of IAQ management effectively. By providing a thorough analysis of IAQ-related factors, this document seeks to empower decision-makers, facility managers, building occupants, and other relevant parties to proactively address IAQ concerns within their respective spheres of influence. Furthermore, by highlighting the

economic benefits associated with improved IAQ, this document endeavors to underscore the compelling business case for investing in IAQ management initiatives.

In essence, this document serves as a cornerstone for advancing the conversation surrounding IAQ in Office Spaces, emphasizing its pivotal role in safeguarding occupant health, enhancing productivity, and fostering thriving built environments. By fostering a deeper understanding of IAQ dynamics and promoting actionable strategies for improvement, this document endeavors to catalyze positive change and promote the creation of healthier, more sustainable commercial spaces.

2.1 Importance of Indoor Air Quality

Indoor Air Quality holds a critical role in shaping the health, comfort, and productivity of occupants within Office Spaces. The standard of indoor air quality directly impacts our well-being in several ways, making it imperative for stakeholders to prioritize IAQ management.

First and foremost, IAQ significantly influences occupants' health. Poor IAQ can lead to a variety of medical conditions, such as allergies, cephalalgia in the heads, tiredness, and respiratory concerns. Exposure to pollutants such as dust, mold, particulate matter, volatile organic molecules, carbon dioxide and airborne pathogens can worsen current medical issues and raise the chance of developing new ones. For individuals spending long hours indoors, especially in commercial settings, where the concentration of pollutants may be higher due to factors like inadequate ventilation and the presence of chemicals from construction materials and furniture, ensuring good IAQ is essential for safeguarding their health and well-being.

Moreover, IAQ directly impacts occupants' ease and efficiency. Poor IAQ may cause discomfort, causing signs and symptoms like dryness and irritation of the eyes, nose, and throat, as well as feelings of fatigue and difficulty concentrating. These issues can hinder individuals' ability to perform tasks efficiently and effectively, ultimately impacting organizational productivity and performance. Conversely, good IAQ promotes a welcoming and comfortable indoor space, enabling in occupants to work, learn, shop, or receive care without unnecessary distractions or discomfort.

Beyond its immediate effects on occupants, IAQ also intersects with broader goals of energy efficiency, sustainability, and regulatory compliance. Efficient HVAC systems and building designs that prioritize IAQ contribute to reduced energy consumption and lower operating costs. Additionally, promoting good IAQ aligns with sustainability objectives by reducing

environmental impacts associated with indoor air pollution and improving overall occupant well-being. Furthermore, regulatory agencies increasingly recognize the importance of IAQ standards in ensuring healthy indoor environments, with compliance measures in place to protect occupants from exposure to harmful pollutants.

Given the multifaceted impact of IAQ on health, comfort, productivity, energy efficiency, sustainability goals, and regulatory compliance, proactive management of IAQ is essential. This entails implementing comprehensive strategies to identify and address sources of indoor air pollution, optimizing ventilation systems, utilizing air purification technologies, and promoting best practices in building operation and maintenance. By prioritizing IAQ management, stakeholders can create indoor environments that support occupants' health, well-being, and productivity while aligning with broader goals of energy efficiency, sustainability, and regulatory compliance.

2.2 Elements That Affect the Quality of Indoor Air

The quality of indoor air is affected by a variety of factors within Office Spaces, ranging from the design and operation of ventilation systems to the materials used in construction and even the activities of occupants. Understanding these factors is crucial for effectively managing IAQ and creating healthier indoor environments.

2.2.1 Ventilation Systems:

Properly designed, operated, and maintained ventilation systems are fundamental to maintaining good IAQ. Ventilation systems ensure fresh outside air being exchanged with indoor air, reducing indoor contaminants, and regulating temperature and humidity levels. Design considerations such as the placement of air intakes and exhausts, air filtration, and airflow patterns play a significant role in the effectiveness of ventilation systems. Regular maintenance, including cleaning filters, ductwork, and components, is essential to prevent the buildup of contaminants and ensure optimal system performance.

2.2.2 Building Supplies and Furnishings

The materials used in construction, as well as furniture and furnishings, can release more pollutants, such as volatile organic compounds, into the indoor air. VOCs are released from diverse materials, including paints, carpets, adhesives and upholstery. Over time, these emissions can contribute to poor IAQ and pose health risks to occupants. Selecting low-emission building materials and furnishings and allowing for proper off-gassing before occupancy can help mitigate this issue. Additionally, Volatile organic compounds can be

eliminated from indoor spaces by employing air purifiers with activated carbon filters and air sealing.

2.2.3 Occupant Activities:

The activities of building occupants can have a significant impact on IAQ. Common activities such as smoking, and using cleaning products can introduce pollutants into the indoor air. Cleaning agents, for example, can release volatile organic compounds, while smoking introduces harmful chemicals from tobacco smoke. Educating occupants about the potential effects of their activities on IAQ and promoting the use of environmentally friendly products and practices can help minimize indoor pollution sources.

2.2.4 Outdoor Air Pollution:

The air pollution outside may penetrate through ventilation systems into indoor spaces, doors, cracks and windows within the envelope of the building. Particulate matter, ozone, organic molecules that are volatile and nitrogen dioxide are examples of pollutants that can enter buildings from the emissions of automobiles, industrial processes, and natural sources. The quality of outdoor air can significantly impact IAQ, especially in urban areas with high levels of pollution. Proper filtration and ventilation strategies, as well as sealing building envelopes to reduce infiltration, can help mitigate the effects of outdoor air pollution on indoor air quality.

2.2.5 Maintenance Practices:

Maintenance practices, particularly related to heating, ventilation, and air conditioning (HVAC) systems, play a crucial role in maintaining good IAQ. Poorly maintained HVAC systems could turn into mold havens, bacteria, and other contaminants, which can then be circulated throughout the building. Regular inspection, cleaning, and servicing of HVAC equipment, as well as prompt repair of leaks and malfunctions, are essential to prevent IAQ issues related to HVAC systems.

In conclusion, IAQ in Office Spaces is influenced by a combination of factors, including ventilation systems, building materials, occupant activities, outdoor air pollution, and maintenance practices. Effective IAQ management requires a holistic approach that addresses these factors to create healthier and more comfortable indoor environments for building occupants.

2.3 Common Indoor Air Pollutants

Indoor air quality is influenced by various pollutants that can have adverse effects on human health and well-being. Understanding these typical indoor air contaminants, their sources, control measures, and associated health effects is essential for effectively managing IAQ in Office Spaces.

2.3.1 Volatile Organic Compounds :

- These are organic compounds that readily evaporate into the atmosphere at ambient temperature.They are emitted from an extensive array of sources, including construction materials, furniture, items for cleaning and personal hygiene. Common VOCs include formaldehyde, benzene, toluene, and xylene.
- Sources: VOCs can be emitted from paints, adhesives, carpets, upholstery, solvents, and consumer products such as air fresheners and cosmetics.
- Control Measures: Selecting low-VOC or zero-VOC building materials, furnishings, and products can help reduce emissions. Adequate ventilation and air filtration systems can also help dilute and remove VOCs from indoor air.
- Impacts on Health: Exposure to volatile organic compounds for a brief period of time may trigger ocular, nasal, and throat discomfort. cephalalgia in the heads, dizziness, and nausea. Long-term exposure to certain VOCs, such as formaldehyde, may increase the potential for respiratory issues, cancer, and other serious health effects.

2.3.2 Particulate matter:

- It is used to describe microscopic airborne particles, such as dust, dirt, pollen, and smoke. PM can vary in size, with smaller particles (PM2.5 and PM10) posing greater health hazards since they might enter the respiratory system.
- Sources: PM can originate from indoor sources such as Printing, Photocopying, Fax Machines, Poor HVAC systems, Any type of Construction or Renovation Work,
- Control Measures: Using air purifiers with HEPA filters can help remove PM from indoor air. Proper ventilation and source control measures, such as eliminating smoking indoors and reducing combustion activities, can also help reduce PM levels.
- Health Effects: Exposure to PM can aggravate respiratory conditions such as asthma and bronchitis, as well as increase the risk of cardiovascular diseases, lung cancer, and premature death.

2.3.3 Carbon Dioxide (CO2):

- It is an odorless, colorless gas that exists in the atmosphere by nature. Indoor CO2 levels can rise due to inadequate ventilation or high occupant density, leading to potential health and comfort issues.
- Sources: CO2 is generated by human respiration.
- Control Measures:Increasing ventilation rates and ensuring proper airflow can help reduce indoor CO2 levels. Monitoring CO2 levels and adjusting ventilation systems accordingly can also help maintain optimal IAQ.
- Health Effects: Elevated CO2 levels can result in symptoms including cephalalgia in the heads and lightheadedness, fatigue, and trouble focusing. Extended exposure to elevated CO2 levels has been shown to reduce productivity and cognitive abilities.

2.3.4 Temperature and Relative Humidity:

- They both are also important factors that influence IAQ and occupant comfort. High or low temperatures and humidity levels can create conditions conducive to the growth of mold, bacteria, and other indoor pollutants.
- Sources:Temperature and humidity levels can be affected by factors such as outdoor weather conditions, HVAC system performance, and occupant activities.
- Control Measures:Maintaining indoor temperature and humidity within recommended ranges (around 68-76°F and 30-60% relative humidity) can help prevent IAQ problems. Proper HVAC system design, usage, and upkeep are essential for controlling indoor climate conditions.
- Health Effects:Extreme temperatures and humidity levels can exacerbate respiratory conditions, trigger allergies, and increase the risk of heat-related illnesses.

Implementing effective ventilation, filtration, and source control measures can help mitigate IAQ problems and promote occupant health and well-being.

2.4 Measurement Techniques

Sustaining excellence in IAQ in Office Spaces requires accurate and reliable measurement and monitoring techniques. These techniques range from spot measurements to continuous monitoring using advanced sensors, enabling stakeholders to assess IAQ parameters effectively and take appropriate corrective measures when necessary.

2.4.1 Spot Measurements:

Spot measurements involve taking discrete measurements of IAQ parameters at specific locations within a building using portable monitoring devices. Parameters commonly measured include levels of Volatile Organic Compounds , Particulate matter, Temperature, Relative Humidity and Carbon Dioxide. Spot measurements provide snapshots of IAQ conditions at a particular moment in time and can be useful for identifying localized IAQ issues or assessing the effectiveness of mitigation measures.

2.4.2 Continuous Monitoring:

Continuous monitoring involves the use of sensors and data logging systems to continuously measure and record IAQ parameters over time. Advanced sensor technologies allow for real-time monitoring of multiple IAQ parameters simultaneously, providing comprehensive insights into IAQ dynamics within a building. Continuous monitoring systems can be integrated with building management systems (BMS) to automatically adjust ventilation rates and other HVAC parameters based on IAQ conditions.

Importance of Regular IAQ Assessments:

Regular IAQ assessments are essential for identifying IAQ issues, evaluating the effectiveness of IAQ management strategies, and ensuring compliance with IAQ standards and regulations. By conducting periodic IAQ assessments, proprietors of buildings, facility managers, and occupants can proactively identify potential IAQ problems before they escalate and implement corrective measures to address them. Regular IAQ assessments also help track changes in IAQ over time and assess the impact of building modifications or operational changes on IAQ.

Corrective Measures:

Based on the results of IAQ assessments, various corrective measures can be implemented to improve IAQ in Office Spaces. These measures may include: source control, ventilation optimization, filtration and air cleaning, humidity control, occupant education.

Measurement and monitoring techniques have a vital part in maintaining good IAQ in Office Spaces. Spot measurements and continuous monitoring using advanced sensors enable stakeholders to assess IAQ parameters effectively and identify potential IAQ issues. Regular IAQ assessments are essential for implementing corrective measures to improve IAQ and create healthy indoor environments for building occupants. By proactively managing IAQ through measurement, monitoring, and corrective action, stakeholders can enhance occupant health, comfort, and productivity while ensuring compliance with IAQ standards and regulations.

2.5 Economic and Productivity Advantages of Better IAQ

Improving the Office's IAQ Spaces not only contributes to the health concerns and well-being of occupants but also yields significant economic benefits for building owners, operators, and businesses. By investing in IAQ improvements, stakeholders can realize cost savings, productivity gains, and enhanced occupant satisfaction, ultimately generating a positive return on investment (ROI).

Reduced Healthcare Costs:

Improving IAQ can lead to a reduction in healthcare costs associated with occupant illnesses and absenteeism. Poor IAQ has been linked to respiratory ailments, allergies, and other health problems, resulting in increased healthcare utilization and absenteeism among building occupants. By creating healthier indoor environments, building owners and operators can lower healthcare expenses and improve overall occupant health, translating into tangible cost savings.

Increased Productivity:

Studies have consistently shown that good IAQ is positively correlated with higher productivity levels among building occupants. Improved IAQ reduces symptoms such as cephalalgia in the heads, fatigue, and respiratory issues, allowing occupants to work more comfortably and efficiently. Additionally, better IAQ can enhance cognitive processes and the capacity for making decisions, further boosting productivity. The increased productivity resulting from IAQ improvements can have a significant impact on business performance and profitability.

Lower Absenteeism:

Poor IAQ could lead to increased absenteeism due to illness among building occupants. By improving IAQ and creating healthier indoor environments, building owners and operators can reduce absenteeism rates and minimize the disruptions caused by employee absences. Lower absenteeism rates result in improved workforce efficiency and lower expenses associated with hiring temporary replacements or overtime labor.

Enhanced Occupant Satisfaction and Retention:

Providing a comfortable and a safe indoor atmosphere enhances occupant satisfaction and retention rates. Occupants have a higher probability of being satisfied with their work environment and remain loyal to companies that prioritize their health and well-being. By investing in IAQ improvements, building owners and operators can attract and retain top talent, reduce turnover costs, and foster a positive organizational culture.

Examples of Studies Demonstrating ROI:

Numerous studies have demonstrated the economic benefits of IAQ improvements for building owners and operators:

- A study conducted by **Lawrence Berkeley National Laboratory** found that doubling the ventilation rates in office buildings resulted in an average productivity gain of $6,500 per employee per year, far exceeding the associated energy costs.

- A study published in the **Journal of Occupational and Environmental Medicine** estimated that improving IAQ in office buildings could lead to annual savings of $6 to $14 billion in the USA due to reduced healthcare costs and increased productivity.
- Research conducted by the **World Green Building Council** found that investing in green building features, including IAQ improvements, can lead to a 7% increase in asset value and a 6% increase in rental income for commercial properties.
- Poor indoor air quality has been projected to cause economic losses in the tens of billions of dollars annually, according to research conducted by the Environmental Protection Agency (EPA). There will be significant cost savings from even the smallest expenditure made to improve air quality.

These examples highlight the significant ROI potential of IAQ improvements for owners of buildings and operators. By prioritizing IAQ management and implementing cost-effective strategies to enhance IAQ, stakeholders can realize substantial economic benefits while creating healthier and more productive indoor environments for occupants.

RESEARCH METHODOLOGY

This section provides a detailed overview of the research design, data collection methods, sampling strategy, approaches for analysing data and ethical issues.

3.1 Research Design

The research design for this study is primarily quantitative, aiming to gather and examine numerical information on key IAQ parameters, including PM, CO2, VOCs, temperature, and relative humidity. The study adopts a cross-sectional design, capturing IAQ measurements at a particular moment in time to assess the current IAQ status of the selected office building. Additionally, the research incorporates elements of descriptive and analytical research, aiming to characterize IAQ levels, identify potential sources of indoor air pollution, and evaluate compliance with IAQ standards and guidelines.

3.2 Deductive Research

This research adopts a primarily Deductive approach, wherein existing theories, frameworks, and empirical evidence inform the development of research hypotheses and guide data collection and analysis. However, the study also integrates elements of inductive reasoning, allowing for the exploration of emerging patterns, trends, and insights from the collected data that may contribute to the generation of new knowledge and hypotheses.

3.3 Sampling Method

The sampling method employed in this study is purposive sampling, wherein the offices building in Delhi NCR is selected based on its representativeness of typical Office Spaces in the region. Purposive sampling allows for the selection of a specific sample that aligns with the research objectives and facilitates the collection of relevant IAQ data. Within the selected building, specific sampling locations are identified to ensure adequate coverage of different indoor environments, such as workstations, meeting rooms, corridors, and common areas.

3.4 Data Collection

Data collection involves the deployment of IAQ monitoring equipment, including sensors for PM, CO2, TVOC, temperature, and relative humidity. The study utilizes laser-based sensors for PM2.5 measurement, non-dispersive infrared (NDIR) sensors for CO2 detection, metal oxide semiconductor (MOS) sensors for TVOC monitoring, and conventional temperature and humidity sensors. Each sensor operates based on specific working principles, covering different IAQ parameters and providing real-time measurements.

3.5 What is Indoor air quality ?

The quality of air inside buildings and structures,concerning the well-being and convenience of inhabitants. It includes a range of elements, including temperature, humidity, and the presence of contaminants, and air flow levels. Good IAQ is essential for maintaining a healthy and comfortable indoor environment, as poor air quality can lead to a range of health issues, including respiratory problems, allergies, and discomfort. Monitoring and managing IAQ involve identifying and mitigating sources of indoor pollution, ensuring proper ventilation, and maintaining optimal temperature and humidity levels to promote the well-being and productivity of building occupants.

3.6 What is Sick Building Syndrome?

SBS is a term utilized to characterize a range of symptoms experienced by occupants in the office spaces, that are linked to spending time in that particular environment. These symptoms often improve when individuals leave the building and may include cephalalgia in the heads, dizziness, nausea, fatigue, discomfort in the throat, nose, or eyes and difficulty concentrating.

The World Health Organization defined Sick Building Syndrome as "circumstances where building inhabitants appear to be affected acutely in terms of their comfort and health by their time spent there, but no particular ailment or reason may be found.”

3.5 Working Principles of IAQ Sensors

Laser-based Sensors: These sensors utilize light scattering principles to detect and quantify particulate matter suspended in the air. The air sample is exposed to a laser beam, and the measurement of dispersed light is to estimate the concentration of particulate matter. These sensors offer high sensitivity and accuracy for detecting fine particulate matter.

Infrared sensors that are not dispersive: Dispersive-free infrared sensors track the amounts of carbon dioxide based on the infrared light's absorption by carbon dioxide molecules. The sensor emits infrared light at specific wavelengths, and the quantity of light that is absorbed by carbon dioxide molecules is correlated with the amount of carbon dioxide present in the atmosphere. NDIR sensors provide reliable measurements of CO2 levels with minimal cross-sensitivity to other gases.

Sensors using metal oxide semiconductors: It detects VOCs based on the changes in electrical conductivity when exposed to VOCs in the air. VOC molecules adsorb onto the surface of the sensor, bringing about a shift in resistance, which is proportionate to the VOC concentration present. MOS sensors offer rapid response times and are suitable for monitoring TVOC levels in indoor environments.

3.6 Coverage Area, Monitor Density and Placement Guidelines.

It is critical to understand the following terms for deploying effective IAQ monitoring strategies in commercial spaces.

Coverage Area: Coverage density relates to spatial area covered by a single air quality monitoring device. In other words, it defines how much physical space one monitor is

capable of monitoring effectively. This metric is essential for determining the quantity of monitors required to adequately cover a given indoor environment.

Monitor Density: Monitor density is the number of air quality monitors deployed within a specific area or space. It directly correlates with coverage density and is influenced by variables like the size of the room, layout, occupancy patterns, and sources of indoor air pollution. Higher monitor density may be necessary in larger or more complex environments to ensure comprehensive coverage and accurate monitoring of IAQ parameters.

Placement Guidelines: Placement guidelines provide recommendations for the optimal positioning of air quality monitors to achieve reliable measurements and meaningful insights into IAQ. Several factors influence placement decisions:

- Proximity to Pollution Sources: Monitors should be placed in close proximity to indoor air pollution causes, such HVAC systems if not maintained properly, printers and high density areas.
- Ventilation Pathways: Positioning monitors along ventilation pathways, including air intake and exhaust vents, can help assess how well ventilation systems work in maintaining indoor air quality.
- Occupancy Areas: Placing monitors in areas with high occupancy, such as offices, classrooms, or conference rooms, provides insights into human-related pollutants (e.g., CO2) and overall occupant comfort.
- Spatial Considerations: Distributing monitors evenly throughout the indoor environment ensures comprehensive coverage and minimizes monitoring blind spots. Considerations should be given to room size, layout, and potential barriers to airflow.
- Height Placement: Mounting monitors at an appropriate height (typically at breathing level, around 4 to 6 feet above the ground) ensures that measurements accurately represent the air quality experienced by occupants.

3.7 Calibration of Sensors

It is the act of contrasting the measurements made by an instrument or device to a known reference standard. For continuous IAQ monitoring devices, calibration involves adjusting the instrument's settings or parameters to ensure that its measurements accurately reflect the true concentration of air pollutants or parameters being monitored.

Continuous IAQ (Indoor Air Quality) monitoring devices play a crucial role in assessing and managing indoor air quality in various environments, including Office Spaces and industrial facilities. Calibration of these monitoring devices is essential to ensure the precision and the validity of the information they provide. Let's delve into the process of calibration and why it's important:

Importance of Calibration:

Calibration is necessary for a number of reasons:

- Accuracy: It makes certain that the measurements provided by IAQ monitoring devices are accurate and reliable. Over time, sensors may drift or become less accurate due to environmental factors, aging, or normal wear and tear. Calibration helps correct these inaccuracies and maintains the device's measurement accuracy.

- Reliability: Reliable data is crucial for making informed decisions about indoor air quality management and implementing appropriate mitigation measures. Calibrated IAQ monitoring devices provide trustworthy data that stakeholders can rely on to assess indoor air quality conditions accurately.
- Compliance: In certain industries or applications, compliance with regulatory standards or guidelines is mandatory. Calibration ensures that IAQ monitoring devices meet the required accuracy and performance criteria, enabling compliance with relevant regulations and standards.
- Consistency: Calibrated monitoring devices help maintain consistency in data collection and analysis over time. Consistent measurements are essential for detecting trends, identifying patterns, and evaluating the effectiveness of IAQ management strategies.

Calibration Process:

The calibration process typically involves the following steps:

- Selection of Calibration Standards:Choose appropriate reference standards or calibration gases that closely match the target pollutants or parameters being monitored by the IAQ device.
- Adjustment or Correction: Use calibration techniques to adjust the device's settings or output to match the reference standard. This may involve modifying sensor sensitivity, zero-point calibration, or applying correction factors.
- Verification: After calibration, verify the accuracy of the device by conducting validation tests or comparing its measurements to independent reference measurements.
- Documentation:Maintain detailed documentation of the calibration procedure, such as calibration dates, procedures followed, calibration findings, as well as any adjustments made to the device.

3.8 Dashboard Integration Indoor Air Quality Management

The combination of an IAQ monitor, its Wi-Fi-connected feature, and the dashboard capability which processes its raw data and converts it into actionable insights help improve decision-making on indoor air quality. Through real-time monitoring, data visualization, customization of alerts, historical analysis, comparative benchmarking, as well as advanced analytics, stakeholders can be more involved in the active management of indoor air quality and ensure a conducive and healthier indoor office.

It's important to recognize that merely collecting data isn't sufficient; we need devices that aid in interpreting this data to make informed decisions. IAQ monitor, connected to a dashboard, provides not only raw data but also actionable insights:

Real-Time Data Collection:

The IAQ monitor continuously gathers data on various air quality parameters such as PM, CO2, VOC, humidity as well as temperature. With its Wi-Fi connectivity, this data is transmitted in real-time to a central dashboard accessible to stakeholders.

Comprehensive Data Visualization:

A user-friendly interface is offered by the dashboard to visualise the data that has been gathered in various formats such as graphs, charts, and heatmaps. This comprehensive visualization allows stakeholders to identify patterns, trends, and other fluctuations in indoor air quality over time.

Customizable Alerts and Notifications:

The IAQ monitor, integrated with the dashboard, allows users to set customizable thresholds for different air quality standards. If these limits are surpassed, the system produces alerts and notifications, prompting immediate attention and action from stakeholders.

Historical Data Analysis:

In addition to real-time monitoring, the dashboard archives historical data, enabling retrospective analysis of air quality trends and patterns. This historical perspective is invaluable for identifying long-term trends, seasonal variations, and recurring air quality issues.

Comparative Analysis and Benchmarking:

The dashboard facilitates comparative analysis by allowing users to benchmark current air quality measurements against historical data or established indoor air quality standards and guidelines. This comparative analysis helps in assessing progress, evaluating the effectiveness of mitigation measures, and identifying areas for improvement.

Decision Support System:

Ultimately, the IAQ monitor and dashboard serve as a decision support system, empowering stakeholders to make informed decisions regarding indoor air quality management. By translating unprocessed data into useful data, these tools enable the implementation of targeted interventions to improve quality of office space, improve occupant health and ease, and optimize energy efficiency.

3. CASE STUDY

4.1 An overview of the case

IAQ is a critical component of preserving a healthy and productive environment within Office Spaces. Poor IAQ can have detrimental effects on the inhabitants' health and welfare, leading to various respiratory issues, allergies, and other health concerns. Understanding the factors influencing IAQ and the impact they have on occupants is crucial for creating environments conducive to productivity and well-being.

This case study focuses on investigating the IAQ of two Office Spaces: the National Centre for Disease Control (NCDC) located in Civil Lines, Delhi, and National Thermal Power Corporation Limited (NTPC) situated in the Lodhi Road, Delhi. The study aims to collect the data points for IAQ parameters at these two buildings, considering the presence of HVAC systems in NCDC and NTPC. Additionally, the study aims to analyze the impact of filtration and ventilation on IAQ parameters and their subsequent effects on occupants' health and well-being.

4.1.1 Introduction to the Companies

National Centre for Disease Control (NCDC)

NCDC, located in Civil Lines, Delhi, is a premier institute under the Ministry of Health and Family Welfare, Government of India. It serves as a national apex technical organization for disease prevention and control in India. With a focus on epidemiology, disease surveillance, and outbreak investigation, NCDC plays a pivotal role in safeguarding public health. The building houses various departments, including the Estimation Department, where the IAQ sensor will be installed for this study.

National Thermal Power Corporation Limited (NTPC)

NTPC Limited (formerly known as National Thermal Power Corporation Limited) is India's largest power utility company, headquartered in New Delhi, India. As a leading public sector undertaking under the Ministry of Power, Government of India, NTPC plays a crucial role in the country's energy sector. With a strong focus on power generation, renewable energy, and sustainable development, NTPC contributes significantly to India's energy security and economic growth.

4.1.2 Benefits of HVAC on IAQ

Systems for air conditioning, ventilation, and heating are essential for preserving optimal IAQ within Office Spaces. These systems regulate temperature, humidity levels, and airflow, thereby controlling indoor pollutants and ensuring a comfy and well environment for occupants. The key benefits of Air conditioning units on IAQ include:

Filtration: HVAC is a high-efficiency filter system capable of effectively eliminating airborne pollutants. including pollen, dust, and other contaminants, thereby improving IAQ thus lowering the possibility of respiratory issues among occupants.

Ventilation: Proper aeration is vital for diluting contaminants of indoor and replenishing the office air with fresh outside air. HVAC systems facilitate adequate ventilation, ensuring the

circulation of clean air over the entire office space and lowering the accumulation of harmful gases and odors.

Temperature and Humidity Control: HVAC systems maintain optimal temperature and moisture content, preventing the spread of mildew and mould, which are common indoor air pollutants. By regulating these parameters, HVAC systems assist in creating a healthy indoor environment and mitigate the risk of respiratory infections and allergies.

4.1.3 Installation of IAQ Sensors

In this study, IAQ sensors will be installed at specific locations within both NCDC and NTPC to monitor various IAQ parameters, including particulate matter smaller than 10 microns, or PM10, Particulate matter with a diameter of less than 2.5 microns, or PM2.5, CO2 (Carbon Dioxide), TVOC, temperature (Temp), and relative humidity (RH). At NCDC, the IAQ sensor will be installed in the Estimation Department, while at NTPC, it will be installed in the Accounts Department. These locations were chosen to represent areas where employees spend a substantial amount of time during working hours.

4.1.4 Occupancy and Activities

Both Establishment Section, NCDC and Accounts Section, NTPC have a workforce of 24 & 20 employees respectively. At NCDC, the workplace primarily involves administrative tasks related to disease control and epidemiological research. On the other hand, NTPC's activities revolve around the financial activities for power generation. The nature of activities in these buildings may contribute to the generation of indoor pollutants, necessitating effective IAQ management measures.

4.1.5 Environmental Factors

The outdoor locations of NCDC and NTPC in Civil Lines, Delhi, and Lodhi Road, Delhi, respectively, experience varying levels of air pollution, as reflected in the Air Quality Index (AQI). Delhi, being a metropolitan city, often faces challenges related to air pollution due to vehicular emissions, industrial activities, and geographical factors. These environmental factors can significantly influence IAQ within the respective buildings, highlighting the importance of effective filtration and ventilation systems.

4.1.6 Construction Supplies and Furnitures

The choice of building materials and furnishings can impact IAQ by emitting Volatile Organic Compounds and other indoor pollutants. At NCDC and NTPC, sustainable woods are used for furniture and interior fittings, emphasizing environmental sustainability and minimizing the emission of harmful chemicals. Additionally, factors such as paint, adhesives, and cleaning products used in both buildings can contribute to indoor air pollution, necessitating careful selection and management to ensure optimal IAQ.

4.2 Information Gathering

4.2.1 Methodology for Gathering Data

This case study employs a continuous data collection approach to capture a comprehensive understanding of Indoor air quality parameters within the National Centre for Disease Control (NCDC) and National Thermal Power Corporation Limited (NTPC)

buildings over a four-week period. We opted for a dual data collection frequency - hourly and daily - to balance the need for granular detail with efficient data management and analysis. This time frame allows for sufficient data capture while adhering to project time constraints and ensuring timely reporting.

4.2.2 How was the data collected?

We installed an IAQ monitor in National Centre for Disease Control (NCDC) and National Thermal Power Corporation Limited (NTPC). Here are the details of the monitor:

4.2.3 Understanding HVAC System in office spaces

HVAC stands for Heating, Ventilation, and Air Conditioning. It's basically an umbrella term for the system that keeps us comfortable indoors throughout the year. Here's a breakdown of its functions:

Heating: Keeps us warm during cold weather.

Ventilation: Brings in fresh air and removes stale air, controlling humidity levels for better comfort and indoor air quality.

Air Conditioning: Cools us down during hot weather.

So, while an air conditioner (AC) just cools a space, an HVAC system encompasses both heating and cooling, along with ventilation for complete climate control.

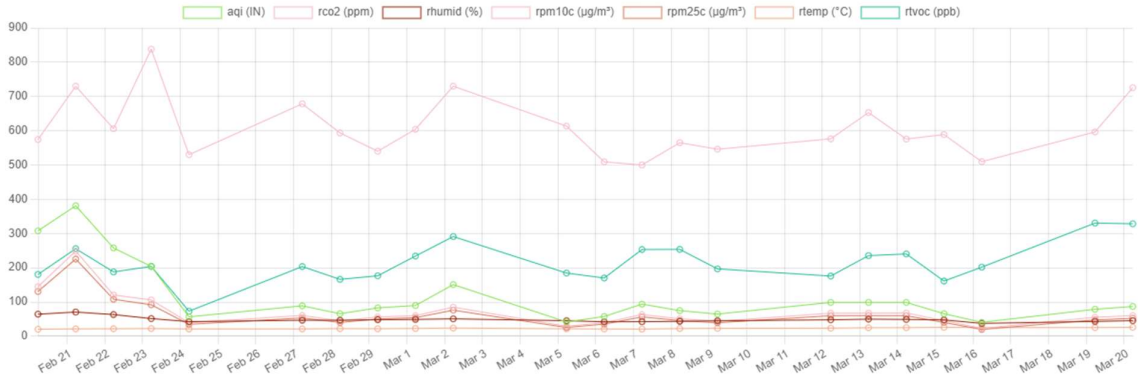
4.2.4 Understanding Air Quality Readings

An invaluable resource for deciphering air quality values is the accompanying table of breakpoints. For instance, if the Overall Index is less than 50, with some variance in pollutant concentrations, the air quality is considered good. We can determine which pollutant to concentrate on if the Overall Index value is high by looking at the concentrations of each individual pollutant as well as the principal pollutant.

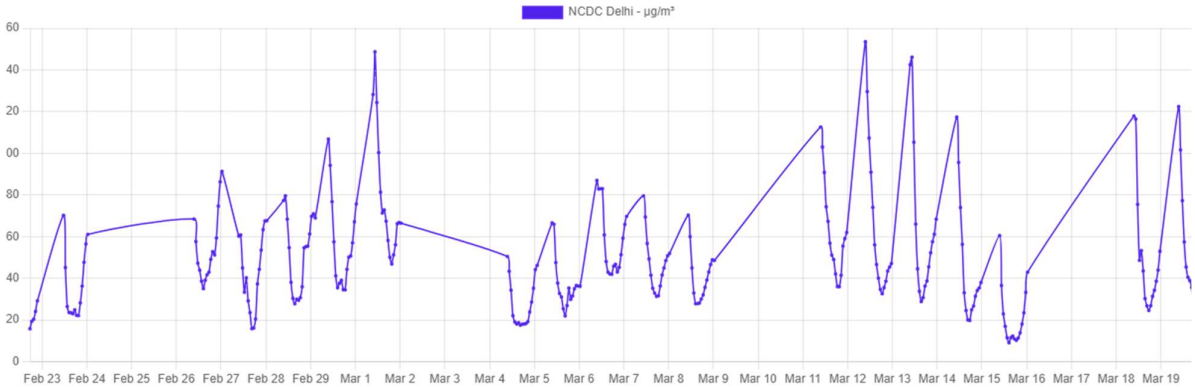
Index Category	Index Value	$PM_{2.5}$ (µg/m³)	CO_2 (ppm)	TVOC (ppb)	TVOC (µg/m³)	O_3 (ppb)	O_3 (µg/m³)
Good	0 - 50	0 - 12	400 - 1000	0 - 220	0 - 1005.5	20 - 50	39.2 - 98.0
Moderate	51 - 100	12.1 - 35.4	1001 - 1500	221 - 660	1005.6 - 3016.7	51 - 100	98.1 - 196.2
High	101 - 150	35.5 - 55.4	1501 - 2000	661 - 1430	3016.8 - 10056.1	101 - 165	196.3 - 323.7
Very High	151 - 200	55.5 - 150.4	2001 - 2500	1431 - 2200	10056.2 - 15084.2	166 - 205	323.8 - 402.3
Very High	201 - 300	150.5 - 250.4	2501 - 5000	2201 - 3300	15084.3 - 20112.3	206 - 405	402.4 - 794.9
Very High	301 - 500	250.5 - 500.4	5001 - 10000	3301 - 5500	20112.4 - 25140.5	406 - 605	795.0 - 1187.6

4.2.5 Case 1: National Centre for Disease Control (NCDC)

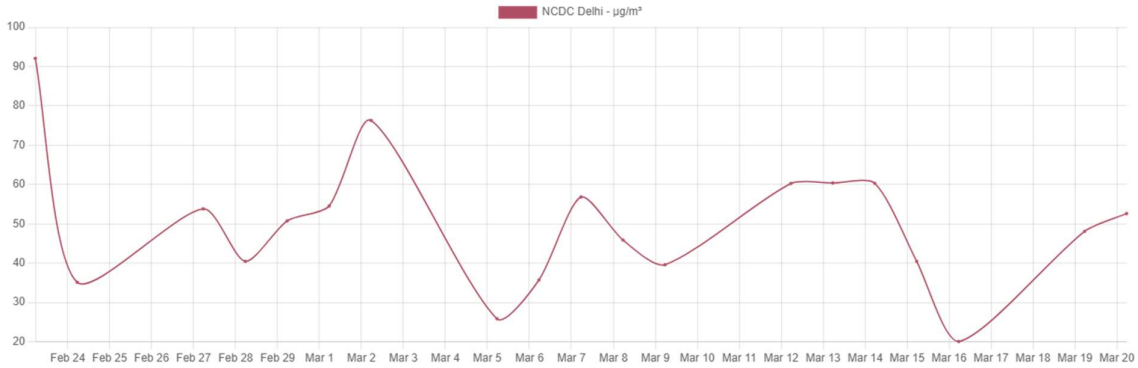
IAQ Data



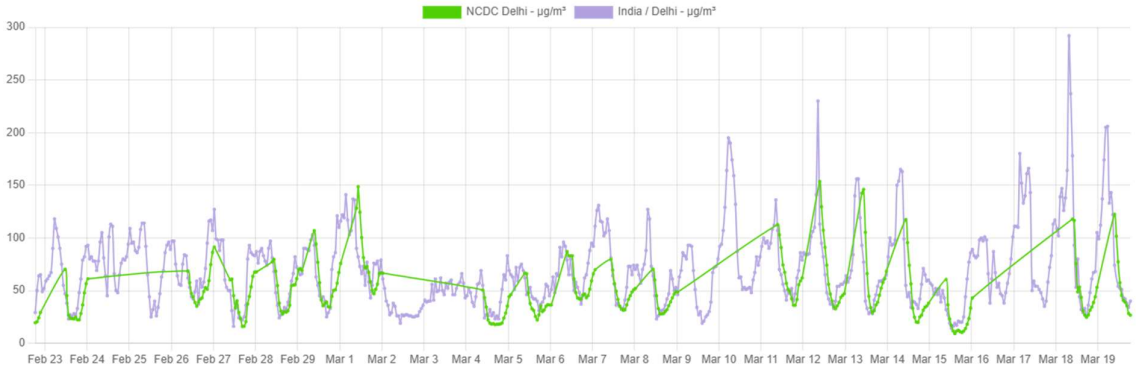
PM2.5 (Data collected every hour)



PM2.5 (Records Every Day)



PM2.5 Indoor and Outdoor Comparison:



Observations:

- Levels of PM2.5 are high during working hours (09:30 to 18:30). **The average PM2.5 values during working hours are 39.9 ug/m3.**
- The average PM2.5 levels during non-working hours are 70.41 ug/m3.
- Comparing the trends with a public outdoor sensor, it's totally different from that. So, it's probably safe to say that **PM levels in the building are not being driven by outdoor air.**
- The HVAC System was on during working hours, we have seen a drop in PM during working hours, there is a clear indication of that. It depicts that the **ventilation system is filtering air properly but it is still not in the good range as the PM2.5 levels outdoors in Delhi are generally very high. Hence, the filtration system is working.**
- PM2.5 levels are high on nights which clearly indicates that the **HVAC System was off after working hours.**

In normal office buildings, we usually see one of two trends:

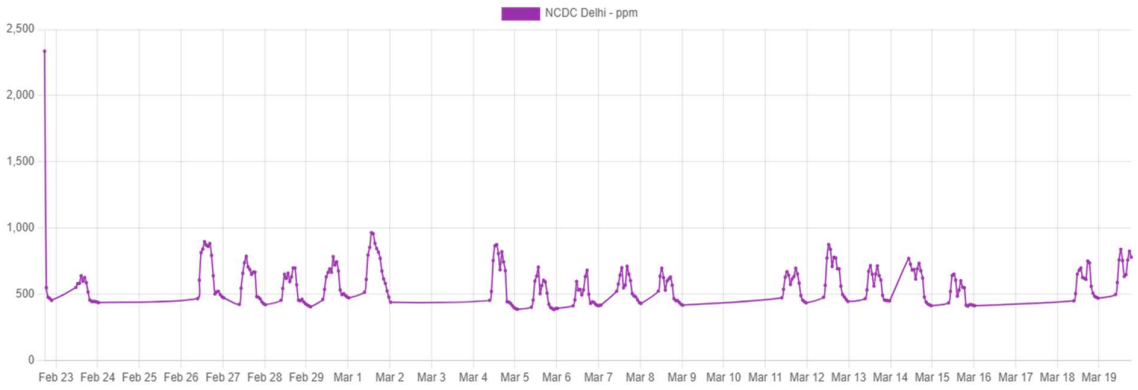
- [**Most common trend**] PM levels decrease during the day (because the HVAC system is ventilating/filtering it out), increase after work hours (the HVAC system shuts down/lowers its filtration rate), and then decrease at the start of the next working day. **In this common trend, the PM levels would increase at night + over the weekend**, since the HVAC system is likely optimized to not run when no one is in the building.

- [**Uncommon, but plausible trend**] PM levels increase during the day (because the activities in the building might increase PM levels), decrease overnight (because those activities have come to a stop), and increase again during the next working day. **It's a bit opposite of what we would expect, but we can see this type of scenario as well**, depending on what type of building we are in.

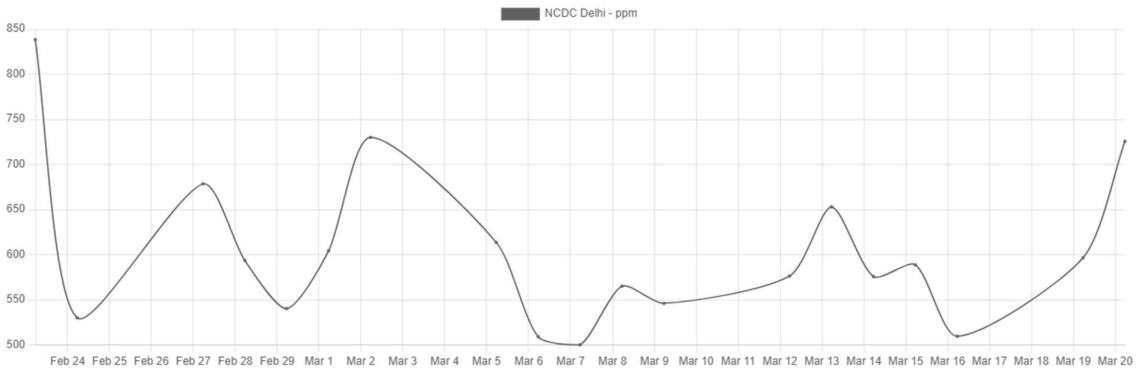
Analysis:

- Based on our inclusion of an outdoor monitor**, the HVAC system is really doing much filtering and the PM levels and patterns are not a byproduct of the outside air patterns.**
- But there is a need to maintain and upgrade the existing filtration systems.

CO2 (Hourly Data)



CO2 (Daily Data)



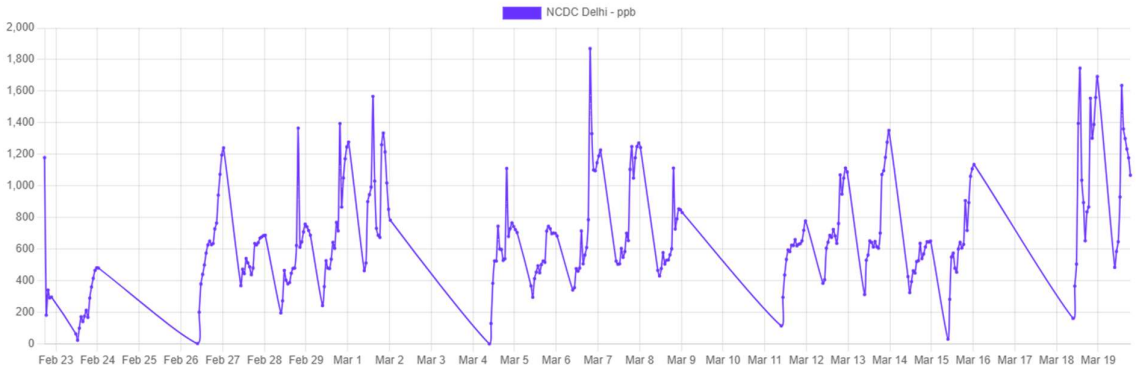
Observations:

- CO2 never a primary pollutant during the entire duration, implying excellent ventilation.
- CO2 levels are really good during working hours (09:30 to 18:30). **The average CO2 values during working hours are 588.82 ppm.**
- The average CO2 levels during non-working hours are 620.58 ppm. That means the **natural ventilation in the building is really good**.
- CO2 readings were comparatively high, i.e. 1000 ppm on March 01, 2024, which depicts that there might be some meeting/conference going on at that time. The spike generally indicates the presence of a lot of people near the device.

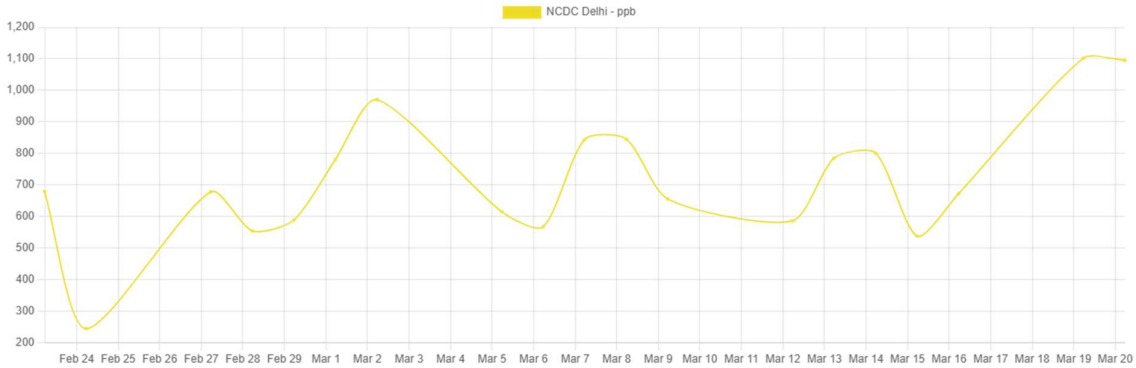
Analysis:

- CO2 levels look normal across the board.
- They don't have a general trend everyday which depicts that they don't have fixed lunch hours. Otherwise, if people go for lunch at the same time, there is a decrease in the CO2 levels.
- They have great CO2 levels even on weekends and at night, which means that there is a source of ventilation in the room.

TVOC (Hourly Data)



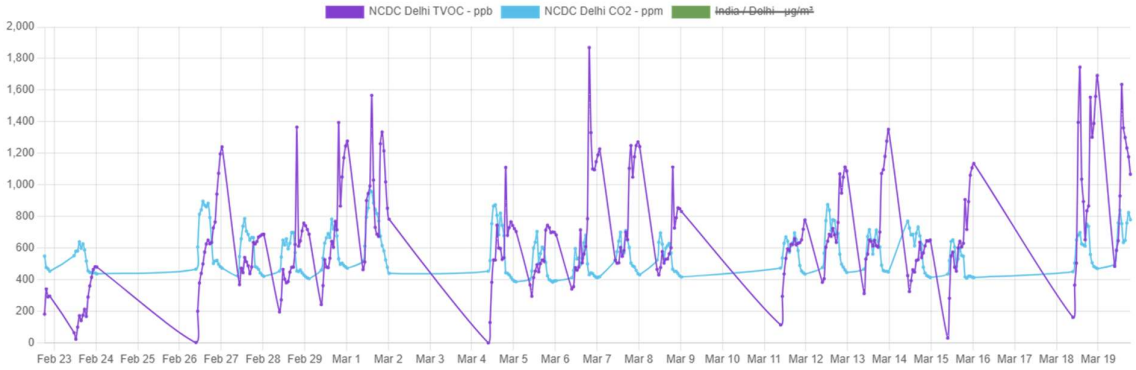
TVOC (Daily Data)



Observations:

- From the 4 weeks data-points, it's hard to decipher anything concrete as there is no uniform pattern of VOCs.
- For the most part, VOC levels are “low” – if we’re going with our good range of 0 - 220 ppb, ~90% of the readings remain below that number. VOCs also get tricky with sanitation practices and furniture, but to see VOC levels in “Good” range for a vast majority of a month is a good sign.
- The average TVOC value during working hours is 238.26 ppb, which is satisfactory. And the average TVOC value during non-working hours is 148.97 ppb.

Let’s look at patterns for the device between CO2 and VOCs.



This implies that there is something that is causing the TVOC levels to spike up as the CO2 levels are low, which would indicate that the space has **good ventilation** to keep the CO2 values low but not VOCs as there are some sources that are causing it to remain high.

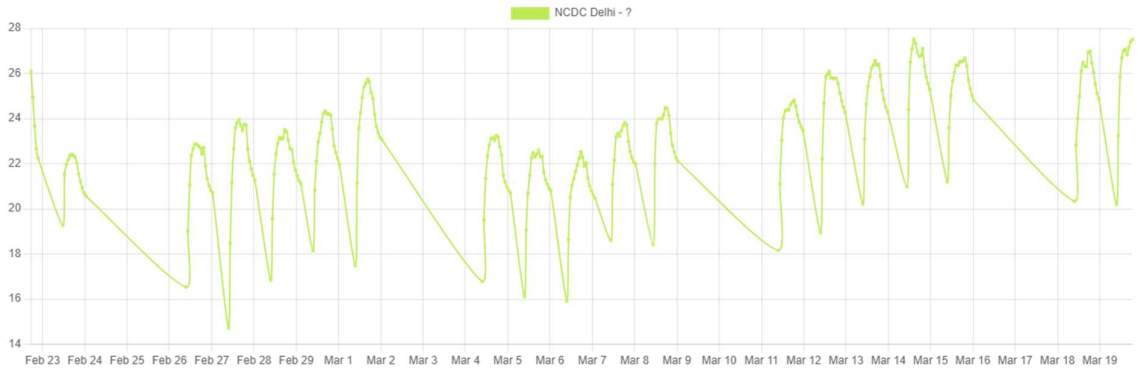
Notes:

- The first thing we want to determine from VOC readings is if there is a clear pattern of behavior – specifically, if there is a gradual increase pattern at night because that would help indicate if there are VOC emitters in any of these spaces (as night time is the best time for VOC emitters to slowly increase the VOCs in a space, since HVAC systems are usually shut off at this time).
- While we can see the device doesn’t detect a large enough gradual night time increase to suggest that there is a source of VOCs in any of their areas.

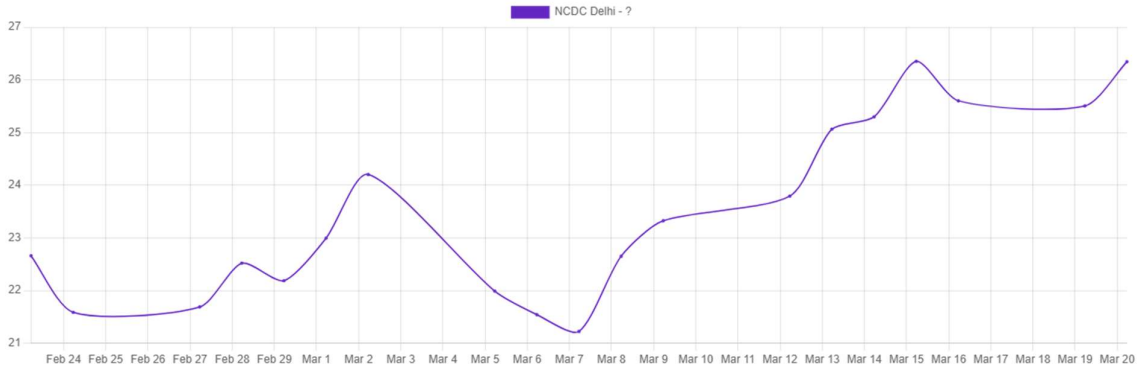
Analysis:

- The VOC levels throughout 4 weeks are not good. There is a need to find out the sources of VOCs and eliminate them.
- The general sources of TVOCs are furniture, carpets, cleaning agents, etc.

Temperature (Hourly Data)



Temperature (Daily Data)



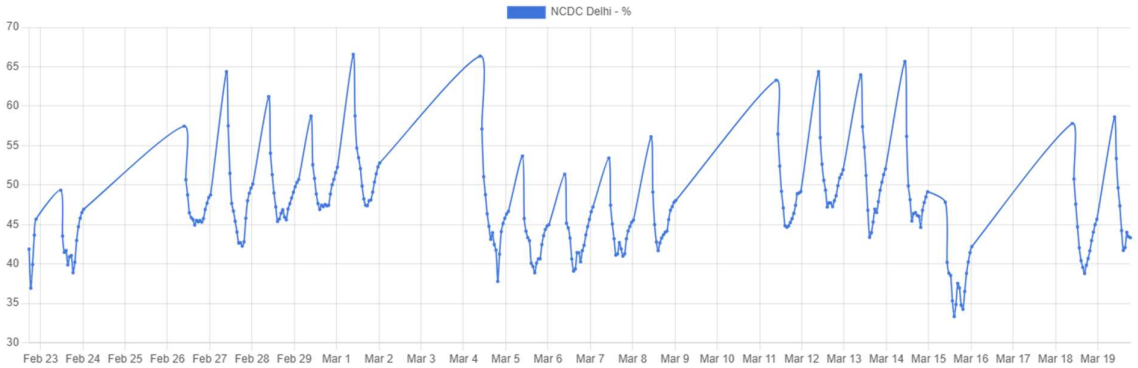
Observation:

- The temperature values are majorly between 20-25 degrees.
- There is a sudden change in the graph around 9:30 am almost everyday. We can say that the HVAC System starts working at this time.
- In the months of February and March, the outdoor temperature is between 15-25 degrees with a gentle breeze.
- This means that there is a heating system in the HVAC which is managing the temperature within the premises.
- There is a drop in the temperature everyday in the second half, which means they are switching off the HVAC system (which is doing heating only). So, we can conclude that the HVAC System is working mostly during the first half as the temperature increases outdoors generally in the second half and the heating is not required.

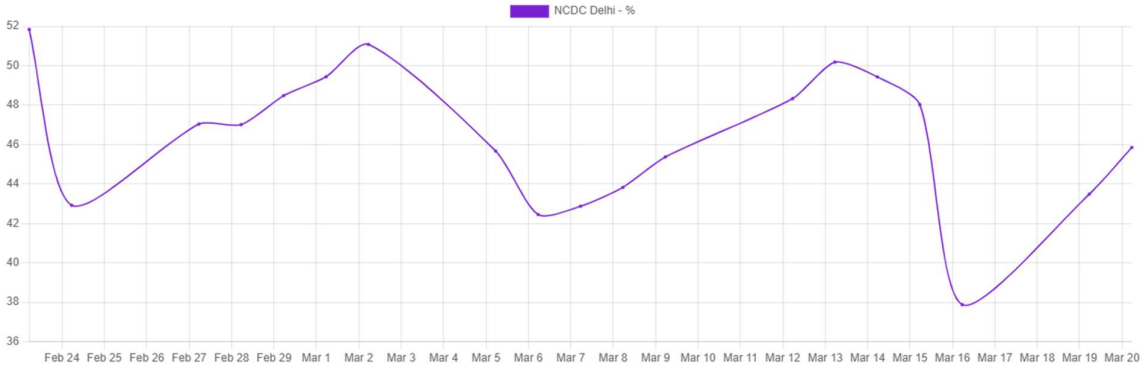
Analysis:

- NCDC has an HVAC System which is working efficiently to maintain the temperature between 20-25 degrees.

Relative Humidity (Hourly Data)



Relative Humidity (Daily Data)



Analysis:

- Average Humidity levels during working hours is 44.91%
- Humidity levels are between 39-45%.
- Humidity levels fall around 10:30 am and increase after 9:30 generally. It shows that the HVAC System works between this time.

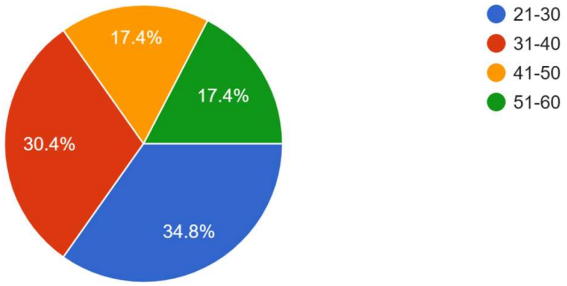
IAQ Survey by building occupants

This report also summarizes the findings from a recent Indoor air quality survey distributed to occupants of the Establishment Section. The questionnaire was distributed among the occupants after the data collection from IAQ sensor, aimed to assess occupant experiences and identify any potential IAQ concerns. A total of 24 participants completed the questionnaire, providing valuable insights into the current indoor environment.

Question 1: Age Group

a. **21 to 30**
b. **31 to 40**
c. **41 to 50**
d. **51 to 60**

Responses



Observation

- A majority of respondents (34.8%) fell within the 21-30 age group.
- This is followed by the 31-40 (30.4%).
- The least no. of respondents are from 41-50 and 51-60 (17.4% each)

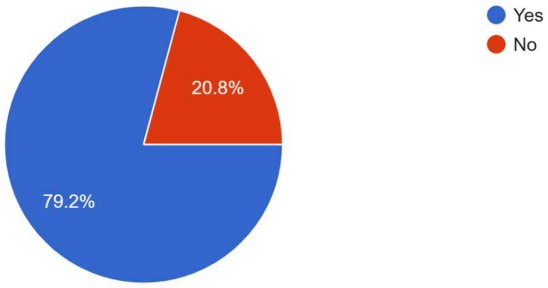
Conclusion

The distribution of respondents across different age groups provides valuable demographic insights into the occupant profile of the Establishment Section.
The predominant presence of younger to middle-aged individuals underscores the importance of considering their specific needs and preferences in addressing any potential Indoor Air Quality concerns and optimizing the indoor environment to support their well-being and productivity.

Question 2: Are you aware of Indoor air quality and its potential impact on health and well-being?

a. **No**
b. **Yes**

Responses



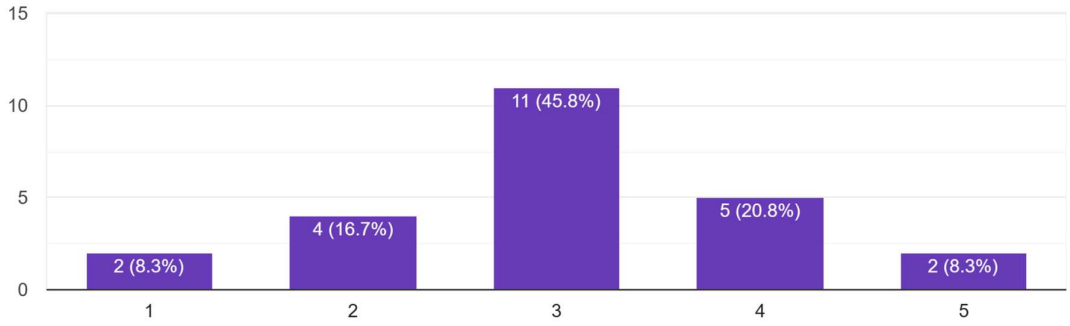
Observation

- The analysis of questionnaire data shows that a majority of respondents (19 out of 24, or 79.2%) were aware of IAQ and its potential influence on well-being and health.

Conclusion:

The impressive level of knowledge of IAQ among respondents highlights the level of participation of the survey population in efforts to improve indoor air quality. By leveraging this existing knowledge and encouraging continuing education and participation, stakeholders can better collaborate to provide strategies for indoor spaces that are healthy and safe for all building occupants.

Question 3: What grade would you give to the overall air quality in your workplace? 1-Very Poor, 2-Poor, 3-Average, 4-Good, 5-Excellent



Observation

- The analysis of the question on overall air quality in the workplace reveals that a majority (11 out of 24, or 45.8%) of the respondents rated the air quality as Average (3). This is followed by Good (4) at 20.8% (5 responses) and Poor (2) at 16.7% (4 responses).
- It's also worth noting that 2 respondents (8.3%) rated the air quality as Very Poor (2) and 2 respondents (8.3%) as Excellent. This implies that there is potential for enhancement in IAQ for a significant portion of the occupants.

Conclusion

Ensure proper ventilation by opening windows and doors regularly, and by maintaining a good working condition of the HVAC system. Address any moisture problems like leaks or condensation to prevent mold growth.

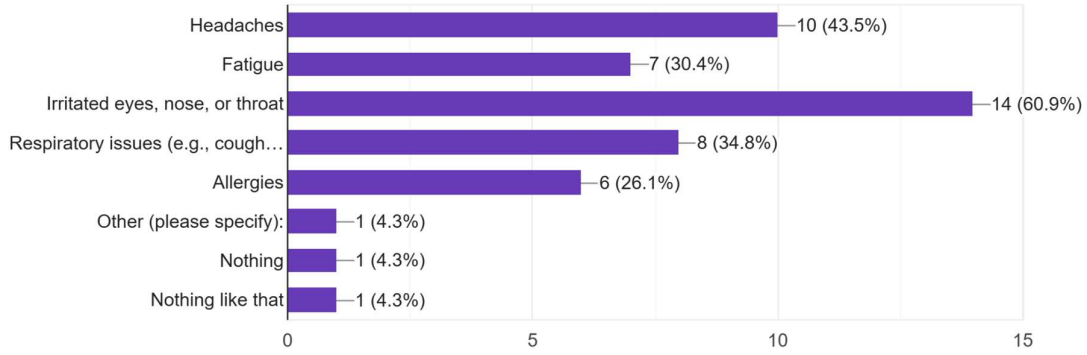
Minimize the utilisation of cleaning supplies, air fresheners, other sources of Volatile Organic Compounds . Regularly clean carpets and upholstery to remove dust, allergens, and pet dander. Indoor vegetation can be beneficial to elevate the quality of the air by removing contaminants.

Install continuous monitoring devices to understand the IAQ levels and connect it to BMS to do Demand Controlled Ventilation and improve filtration capacities as and when required.

Question 4: Do you sometimes experience any of the following symptoms connected to subpar indoor air quality? (Select all that apply)

a. **Cephalalgia in the heads**
b. **Fatigue**
c. **Irritated eyes, nose, or throat**
d. **Respiratory issues (e.g., coughing, shortness of breath)**
e. **Allergies**
f. **Other (please specify):**
g. **Other:**

Responses



Observations

- Irritated eyes, nose, or throat was the most frequently reported symptom, with 14 out of 24 respondents (60.9%) indicating that they experience this sometimes.

- Cephalalgia in the heads were reported by 10 respondents (43.5%).
- Fatigue was reported by 7 respondents (30.4%).
- Respiratory issues were reported by 8 respondents (34.8%)
- 6 respondents (26.1%) reported allergies.

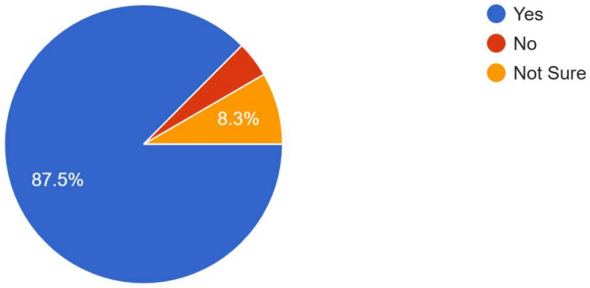
Conclusion

A significant portion of respondents (over 40%) reported experiencing symptoms commonly associated with poor quality of indoor air, for example irritated nostrils, eyes or throat (50%), cephalalgia in the heads (44.4%), and fatigue (33.3%). Further detailed investigation into potential air quality issues and implementation of corrective measures is required.

Question 5: Do you know if your workplace has a Air conditioning, ventilation, and heating system?

a. **Yes**
b. **No**
c. **Not Sure**

Responses



Observation

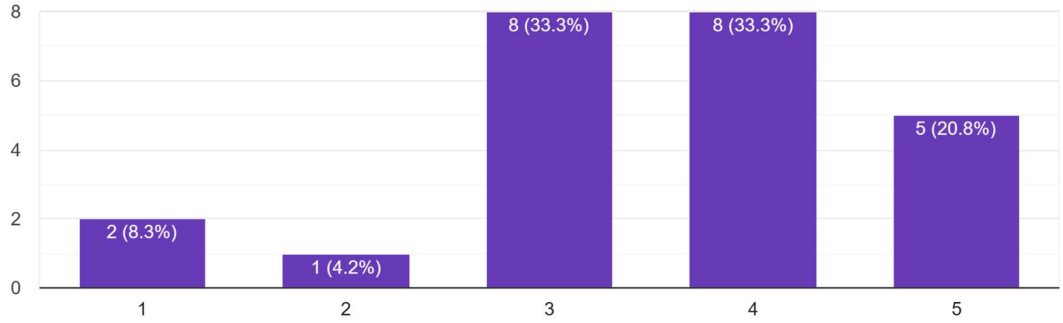
- The analysis of the survey data indicates that a vast majority of respondents (21 out of 24, or 87.5%) were aware that their workplace has a Air conditioning, ventilation, and heating system. Only a small number of respondents indicated that their workplace does not have an HVAC system (1 out of 24, or 4.2%) and only 8.3% (2 respondents) said they are not sure whether there is an HVAC system or not.

Conclusion

In conclusion, the high knowledge of HVAC systems among the respondents highlights the importance of these systems in maintaining the thermal comfort and indoor air quality in the workplace spaces. However, a knowledge gap exists, as reflected by the 12.5% of occupants who lack awareness of HVAC systems. To bridge this gap and empower occupants to contribute to a healthy work environment, we recommend implementing knowledge sessions specifically designed for them.

Question 6: To what extent are you happy with the ventilation in your workspace? 1-Very Dissatisfied, 2-Satisfied, 3-Enough Satisfied, 4-Satisfied, 5-Very Satisfied

Responses



Observation

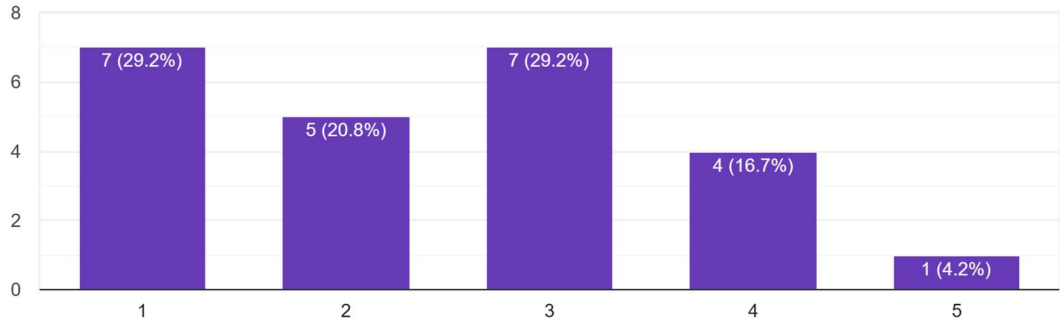
- Enough Satisfied (3) : Nearly 33.3% (each) of respondents felt the ventilation in their workplace was neither particularly good nor bad.
- Satisfied (4): 4 respondents (33.3%) were satisfied with the ventilation.
- Very Satisfied (5): 5 respondents (20.8%) were very satisfied with the ventilation.
- Dissatisfied (2): 1 respondent (4.2%) indicated dissatisfaction with the ventilation.
- Very Dissatisfied (1): 2 respondents (8.3%) were very dissatisfied with the ventilation.

Conclusion

These results suggest that there is room for improvement in ventilation for a significant portion of the occupants. It's important to investigate the reasons behind the dissatisfaction and take steps to address them. This could involve increasing ventilation rates, improving air filtration, or making adjustments to the temperature and humidity controls.

Question 7: How often do you notice odors or unusual smells in your workspace? 1-Never, 2-Rarely, 3-Sometimes, 4-Often, 5-Always

Responses



Observations

- Never: 7 respondents (29.2%) said that they never notice unusual smell in workplace.

- Sometimes: 7 respondents (16.7%) saod they sometimes smell unusual smell in workplace.
- A smaller percentage of respondents indicated that they sometimes (20.8%), and often (16.7%) notice odors or unusual smells.
- One respondent (4.2%) indicated that they always notice odors or unusual smells in their workspace.

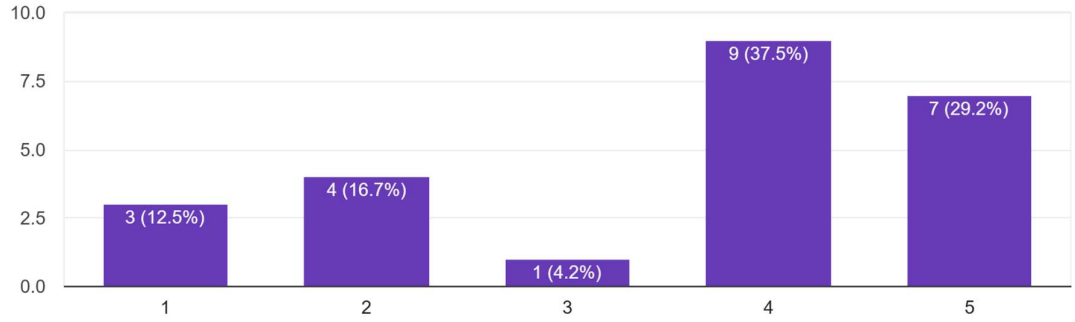
Conclusion

The data shows that while a majority of respondents do not frequently experience odors, there is a notable proportion that does encounter occasional to frequent odor issues. Addressing these concerns through targeted interventions, such as reviewing cleaning products, improving ventilation, or identifying specific sources of odors, can assist in a more comfortable and pleasant indoor environment for all occupants.

Question 8: To what extent are you happy with the temperature control in your workspace?

1-Very Dissatisfied, 2-Dissatisfied, 3-Enough Satisfied, 4-Satisfied, 5-Very Satisfied

Responses



Observation

- Satisfied: 9 respondents (37.5%) were satisfied with temperature control in the workplace.
- Very Satisfied: 7 respondents (29.2%) were very satisfied with temperature control in the workplace.
- Dissatisfied: 4 respondents (16.7%) were satisfied with temperature control in the workplace.
- Very Dissatisfied: 3 respondents (12.3%) were very dissatisfied with temperature control within the workplace.
- Enough Satisfied: 1 respondent (4.2%) said he is enough satisfied.
-

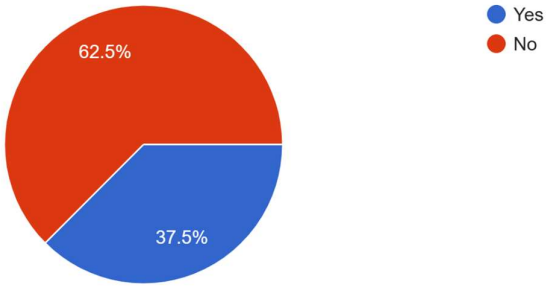
Conclusion:

While a significant portion of respondents expressed satisfaction with the temperature control, there is also a notable number who are dissatisfied. It's important to investigate the reasons behind the dissatisfaction and consider adjustments to improve temperature control for better comfort in the workplace.

Question 9: Do you have any concerns about potential indoor air pollutants (e.g., dust) in your workplace?

a. **Yes**
b. **No**

Responses



Observation:

- A majority of the occupants (15 out of 24 respondents, or 62.5%) did not expressed concerns about potential indoor air pollutants in their workplace.
- Nine respondents (37.5%) reported having any concerns.

Conclusion:

It's important to take action despite the lack of concern from a majority. People may not always recognize the signs of poor indoor air quality or attribute health problems to it.

Consider conducting IAQ testing to recognise any pollutants and their concentrations.

Implement strategies in enhancing IAQ, such as:

Ensuring proper aeration and air filtration

Lowering sources of pollutants like cleaning products or off-gassing furniture

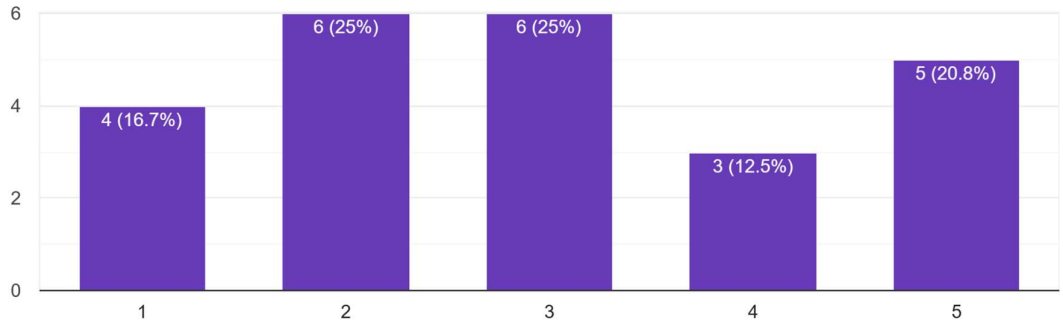
Maintaining a comfortable humidity level

Educating occupants about indoor air quality and its importance for health

Question 10: How often are windows and doors opened in your workspace to allow fresh air circulation?

1-Never, 2-Rarely, 3-Sometimes, 4-Often, 5-Always

Responses



Observation

- Sometimes: 6 occupants (25%) sometimes aerate the space by opening the windows and doors in the workplace.
- Rarely: 6 occupants (25%) rarely aerate the space by opening the doors and window panes.
- Always: 5 occupants (20.8%) always aerate the space by opening the doors and window panes.
- Often: 3 occupants (12.5%) often aerate the space by opening doors and window panes.
- Never: 1 occupant (16.7%) never aerate the space by opening the doors and window panes.

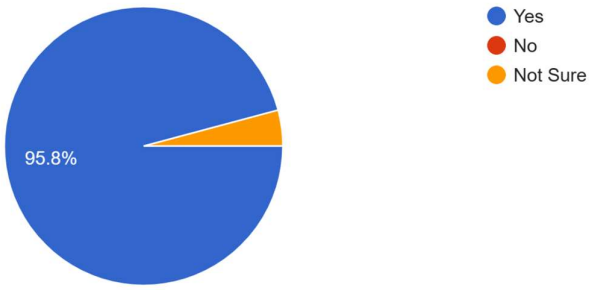
Conclusion

While a significant portion of occupants aerate the space by opening the windows and doors at least sometimes, a sizable minority rarely or never do so. This suggests potential issues with stale air or reliance on mechanical ventilation. Encouraging more frequent opening of windows and doors, when weather permits, could improve indoor air quality and occupant comfort.

Question 11: Do you believe that improving indoor air quality could positively impact your work performance and well-being?

a. **Yes**
b. **No**
c. **Not sure**

Responses



Observation

- The overwhelming majority (23 out of 24 respondents, or 95.8%) believe that improving indoor air quality would positively impact their work performance and well-being. This indicates a strong understanding among occupants of the connection between IAQ and overall health and productivity.
- Only one respondent (4.2%) was unsure about the potential benefits of improved IAQ.

Conclusion

This suggests a receptive environment for implementing strategies to enhance IAQ. With nearly everyone recognizing the potential benefits, addressing IAQ concerns is likely to be well-received by the workforce.

Findings & Recommendations

Findings of the study:

Based on the data collected for 28 days at NCDC Delhi, here are the average values of the pollutants during working and non-working hours:

Pollutant	Overall Index	PM2.5 (µg/m³)	CO2 (ppm)	TVOC (ppb)	Temp (C)	RH (%)
Working Hours	69.52	39.93	558.82	238.26	23.77	44.91
Non-Working Hours	82.03	70.41	620.58	148.97	21.94	50.48
Avg. Daily Values	86.53	49.96	603.94	214.90	23.50	46.38

PM2.5 Levels: High PM2.5 levels during working hours indicate a need for improved filtration systems. The HVAC system shows some effectiveness in filtering but needs maintenance and upgrades.
CO2 Levels: Generally good CO2 levels indicate excellent ventilation, with occasional spikes during meetings or high occupancy times.
TVOC Levels: TVOC levels fluctuate but generally remain in the "low" range, indicating satisfactory air quality.
Temperature and Humidity: HVAC system efficiently maintains temperature and humidity levels within the comfort range.
Occupant Survey Findings:

- Awareness: Most occupants are aware of IAQ and its impact on health.

- Air Quality Perception: A significant portion rates air quality as average, indicating room for improvement.
- Symptoms: Many occupants report symptoms related to poor IAQ, highlighting the need for detailed investigation and corrective measures.
- Ventilation and Temperature Control: Mixed responses indicate a need for better ventilation and temperature control strategies.
- Odors and Unusual Smells: Occasional reports of odors suggest a need for targeted interventions to identify and eliminate sources.
- Impact of IAQ on Work Performance: Nearly all respondents believe that improving IAQ would positively impact their work performance and well-being.

Recommendations:

Filtration System: Upgrade and maintain the existing filtration systems to reduce PM2.5 levels and improve indoor air quality.

Ventilation: Encourage more frequent opening of windows and doors for fresh air circulation, when weather permits.

HVAC System: Optimize HVAC system settings for better filtration and ventilation, especially during working hours.

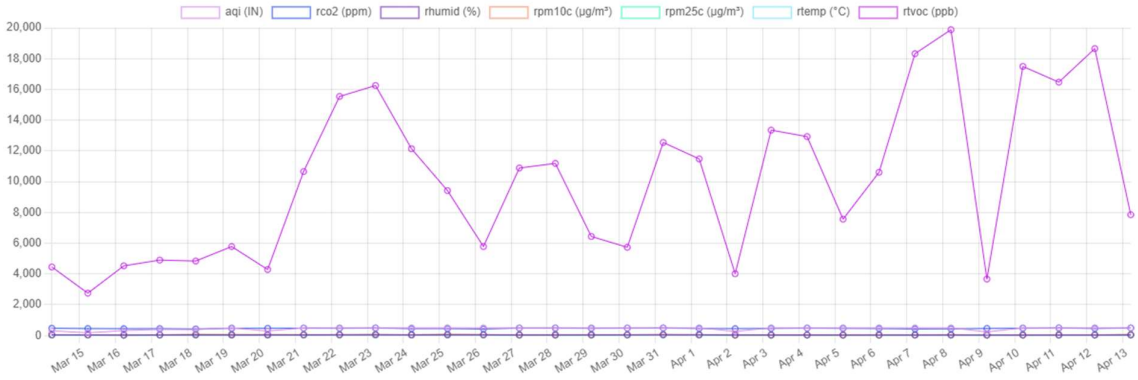
Identify VOC Sources: Conduct a thorough investigation to locate and eradicate the sources of VOCs, such as cleaning products and furnishings.

Occupant Education: Provide education sessions on IAQ and encourage active participation in maintaining a healthy indoor environment.

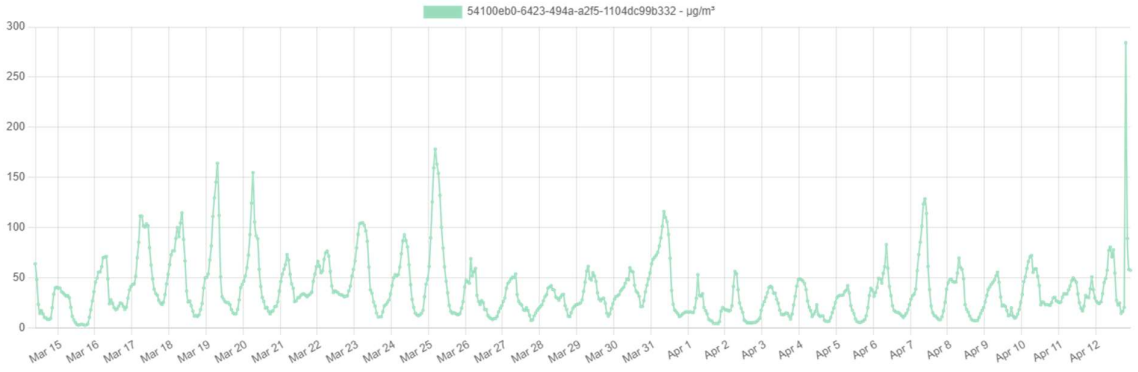
Continuous Monitoring: Install continuous monitoring devices connected to the Building Management System (BMS) for Demand Controlled Ventilation and timely adjustments to filtration capacities.

4.2.6 Case 2: National Thermal Power Corporation Limited (NTPC)

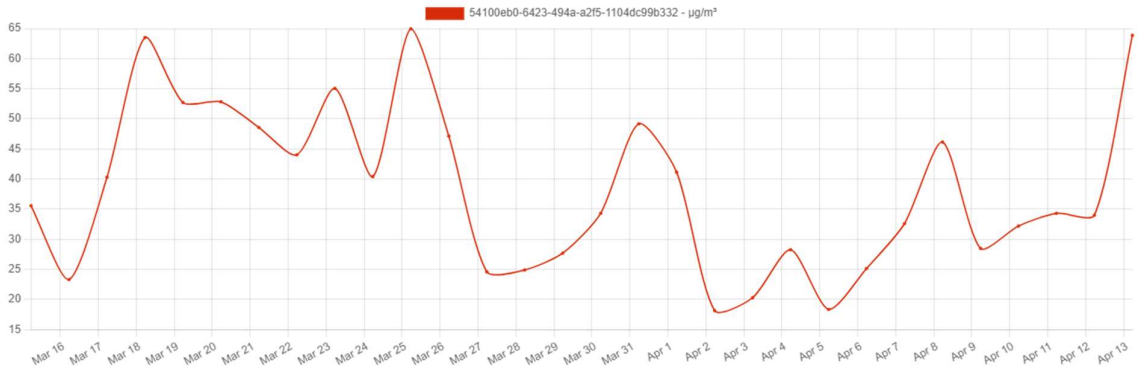
IAQ Data



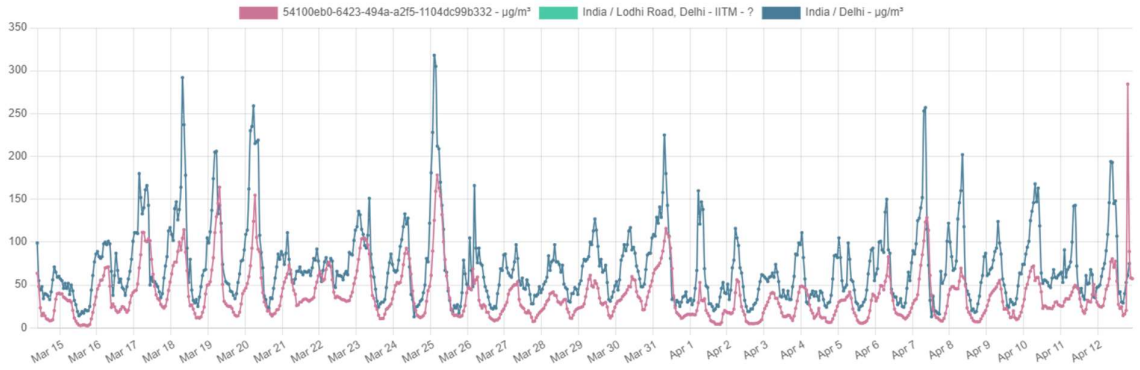
PM2.5 (Data collected every hour)



PM2.5 (Records Every Day)



PM2.5 Comparing Outdoor and Indoor Levels:



Observations:

- Levels ofPM2.5 are in good range during working hours (09:30 to 18:30). **The average PM2.5 values during working hours are 29.15 ug/m3.**
- The average PM2.5 levels during non-working hours are 45.98 ug/m3
- Comparing the trends with a public outdoor sensor, the pattern is very similar. So, it's probably safe to say that **PM levels in the building are being driven by outdoor air.**
- The HVAC System was on during working hours, we have seen a drop in PM during working hours, there is a clear indication of that. It depicts that the **HVAC system is filtering air properly but it is still not in the good range as the PM2.5 levels outdoors in Delhi are generally very high. Hence, the filtration system is working.**
- PM2.5 levels are high on nights which clearly indicates that the **HVAC System was off after working hours.**

In normal office buildings, we usually see one of two trends:

- [**Most common trend**] PM levels decrease during the day (because the HVAC system is ventilating/filtering it out), increase after work hours (the HVAC system shuts down/lowers its filtration rate), and then decrease at the start of the next

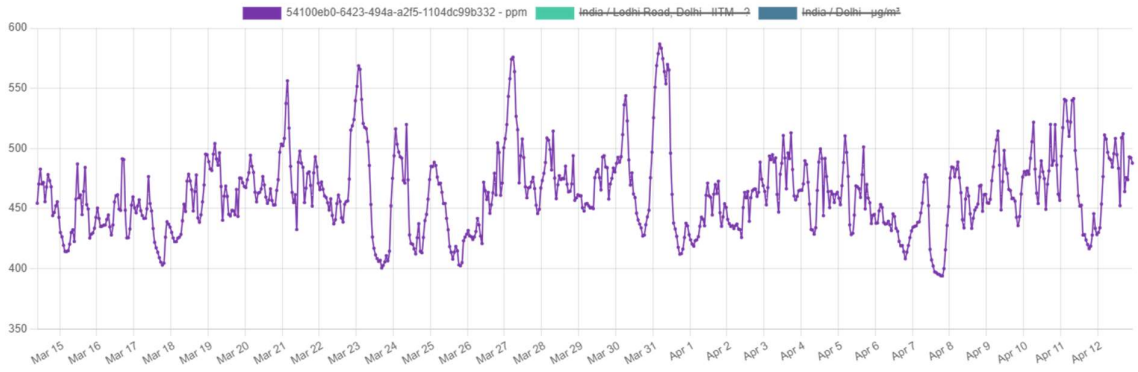
working day. **In this common trend, the PM levels would increase at night + over the weekend**, since the HVAC system is likely optimized to not run when no one is in the building

- [**Uncommon, but plausible trend**] PM levels increase during the day (because the activities in the building might increase PM levels), decrease overnight (because those activities have come to a stop), and increase again during the next working day. **It's a bit opposite of what we would expect, but we can see this type of scenario as well**, depending on what type of building we are in.

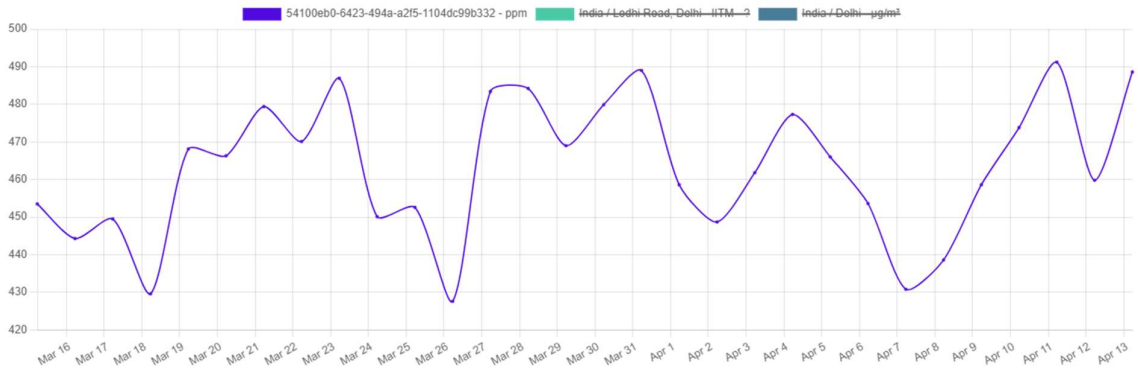
Analysis:

- Based on our inclusion of an outdoor monitor**, the HVAC system is really doing much filtering and the PM levels and patterns are not a byproduct of the outside air patterns.**
- But there is a need to maintain and upgrade the existing filtration systems.

CO2 Hourly:



CO2 Daily:



Observations:

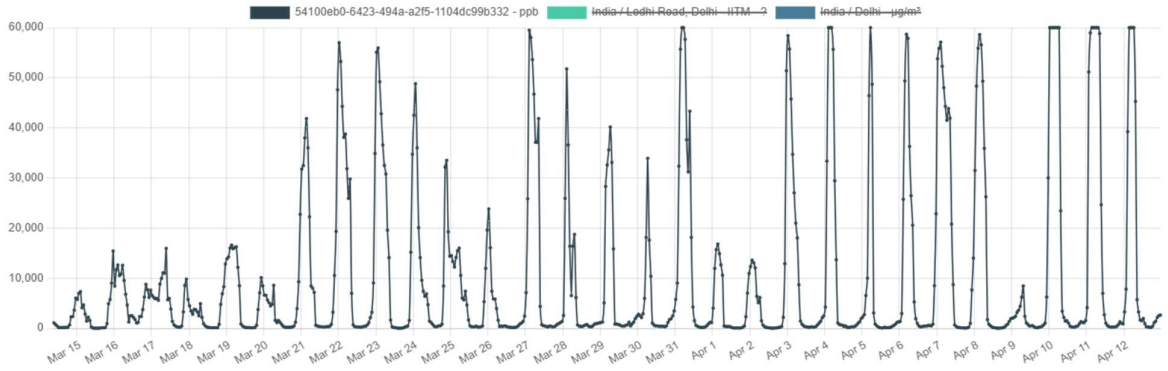
- CO2 never a primary pollutant during the entire duration, implying excellent ventilation.
- CO2 levels are really good during working hours (09:30 to 18:30). **The average CO2 values are between 394 ppm and 584 ppm.**

- The average CO2 levels during working hours are 455 ppm and non-working hours are 470 ppm. That means the **ventilation in the building is really good**.

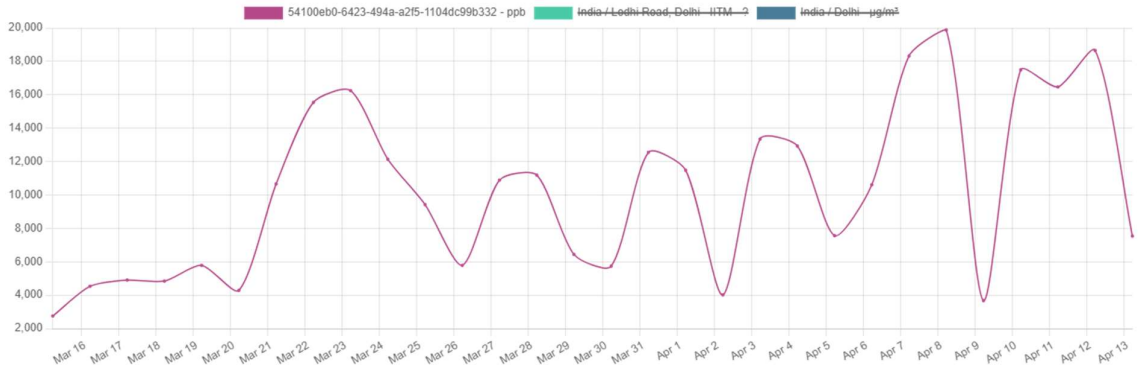
Analysis:

- CO2 levels are excellent across the board.
- They don't have a general trend everyday which depicts that they don't have fixed lunch hours. Otherwise, if people go for lunch at the same time, there is a decrease in the CO2 levels.
- They have great CO2 levels even on weekends and at night, which means that there is a source of ventilation in the room.

TVOC (Hourly Data)



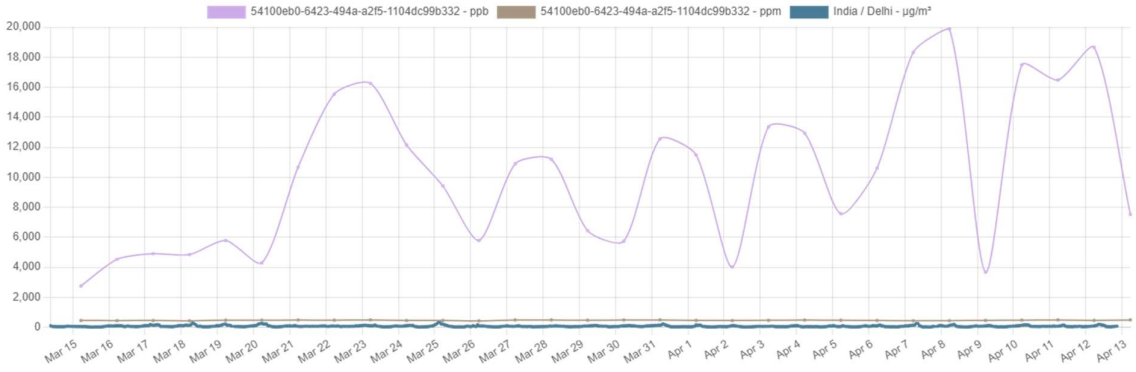
TVOC (Daily Data)



Observations:

- From the 4 weeks data-points, it's hard to decipher anything concrete as there is no uniform pattern of VOCs.
- For the most part, VOC levels are "high" – if we're going with our good range of 0-220 ppb, ~90% of the readings remain above that number. VOCs also get tricky with sanitation practices and furniture, but to see VOC levels in "Bad" range for a vast majority of a month is not a good sign.
- The average TVOC value during working hours is 1615.16 ppb. And the average TVOC value during non-working hours is 19070.65 ppb.

Let's look at patterns for the device between CO2 and VOCs.



This implies that there is something that is causing the TVOC levels to spike up as the CO2 levels are low, which would indicate that the space has **good ventilation** to keep the CO2 values low but not VOCs as there are some sources that are causing it to remain high.

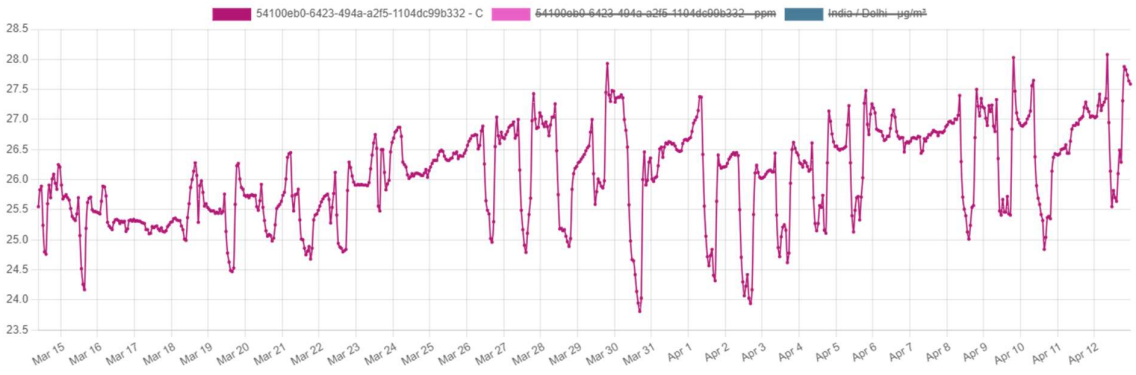
Notes:

- The first thing we want to determine from VOC readings is if there is a clear pattern of behavior – specifically, if there is a gradual increase pattern at night because that would help indicate if there are VOC emitters in any of these spaces (as night time is the best time for VOC emitters to slowly increase the VOCs in a space, since HVAC systems are usually shut off at this time).
- While you can see the device detect a large enough gradual night time increase to suggest that there is a source of VOCs in any of their areas.

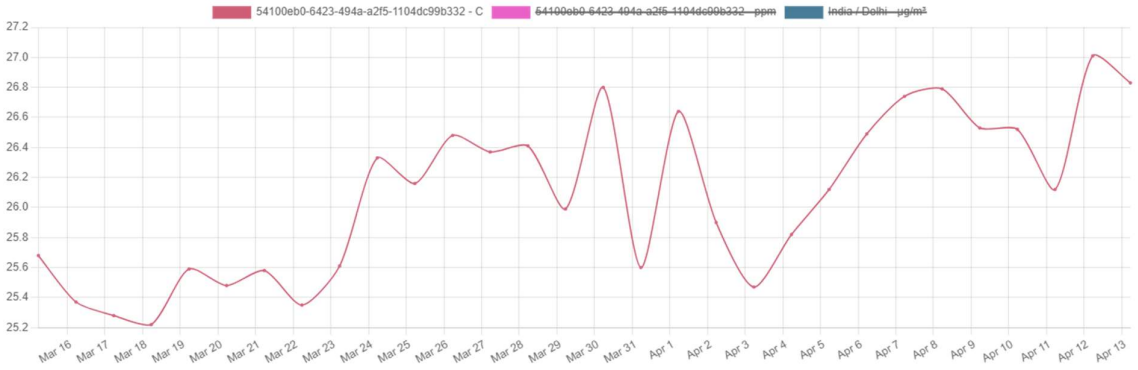
Analysis:

- The VOC levels throughout 4 weeks are poor. There is a need to find out the sources of VOCs and eliminate them.
- The general sources of TVOCs are furniture, carpets, cleaning agents, etc.

Temperature (Hourly Data)



Temperature (Daily Data)



Observation:

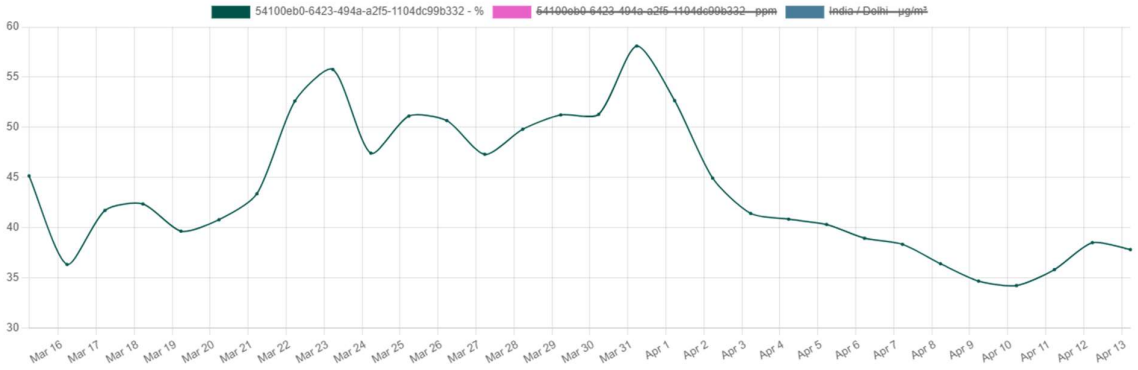
- The temperature values are majorly between 23-27 degrees.
- There is a sudden change in the graph around 9:30 am almost everyday. We can say that the HVAC System starts working at this time.
- The average temperature during working hours is 25.88 C and non-working hours is 26.49 C.

Analysis:

- NTPC has an HVAC System which is working efficiently to maintain the temperature between 23-27 degrees.

Relative Humidity (Hourly Data)

Relative Humidity (Daily Data)



Analysis:

- Average Humidity levels during working hours is 42.96% and non-working hours is 45.08%
- Humidity levels fall around 9:30 am and increase after 7:30 pm generally. It shows that the HVAC System works between this time.

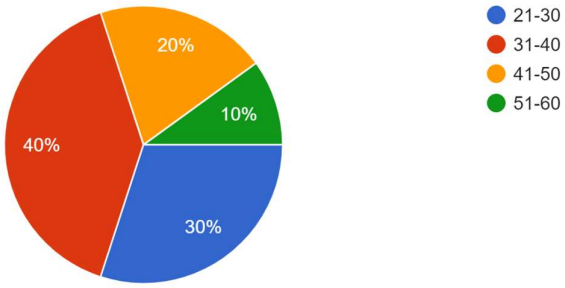
IAQ Survey by building occupants

This report also summarizes the findings from a recent Indoor air quality survey distributed to occupants of the Accounts Department. The questionnaire was distributed among the occupants after the data collection from IAQ sensor, aimed to assess occupant experiences and identify any potential IAQ concerns. A total of 20 participants completed the questionnaire, providing valuable insights into the current indoor environment.

Question 1: Age Group

e. **21-30**
f. **31-40**
g. **41-50**
h. **51-60**

Responses



Observation

- The largest proportion of respondents (40%) fell within the 31-40 age group.
- This is followed by the 21-30 (30%) and 41-50 (20%) age groups.
- The smallest number of respondents were only 2 in the 51-60 age group.

Conclusion

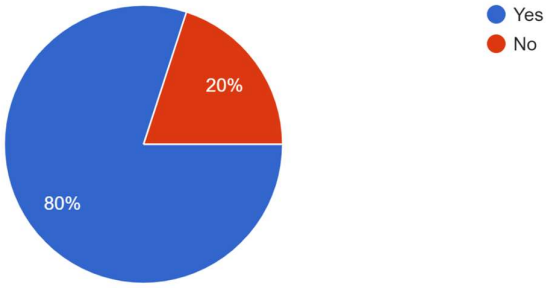
The distribution of respondents across different age groups provides valuable demographic insights into the occupant profile of the Accounts Department.
The predominant presence of younger to middle-aged individuals underscores the importance of considering their specific needs and preferences in addressing any potential Indoor Air Quality concerns and optimizing the indoor environment to support their well-being and productivity.

Question 2: Are you aware of Indoor air quality and its potential influence on health and well-being?

c. **No**

d. Yes

Responses



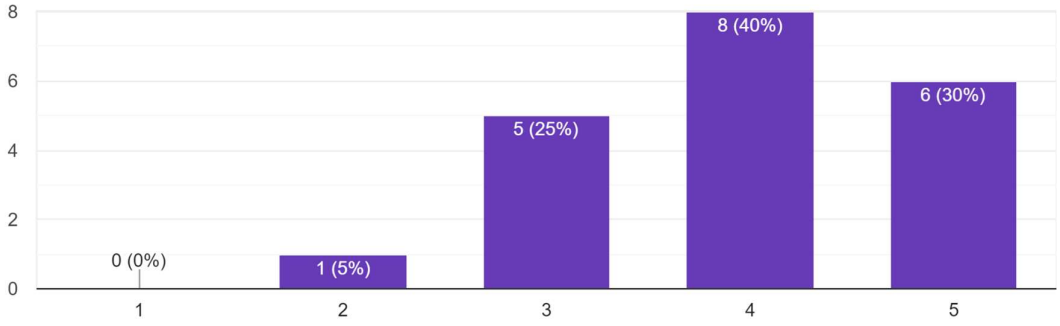
Observation

- A majority of respondents (16 out of 20, or 80%) were aware of IAQ and its potential influence on well-being and health.

Conclusion:

The impressive level of knowledge of IAQ among respondents highlights the level of participation of the survey population in efforts to improve indoor air quality. By leveraging this existing knowledge and encouraging continuing education and participation, stakeholders can better collaborate to provide strategies for indoor spaces that are healthy and safe for all building occupants.

Question 3: What ranking would you give to the overall air quality in your workplace? 1-Very Poor, 2-Poor, 3-Good, 4-Very Good, 5-Excellent



Observation

- The analysis of the question on overall air quality in the workplace reveals that a majority (8 out of 20, or 40%) of the respondents rated the air quality as Very Good. This is followed by Excellent at 30% (6 responses) and Good at 25% (5 responses).
- It's also worth noting that 1 respondent (5%) rated the air quality as Poor. This indicates that there is potential for enhancement in IAQ for a significant portion of the occupants.

Conclusion

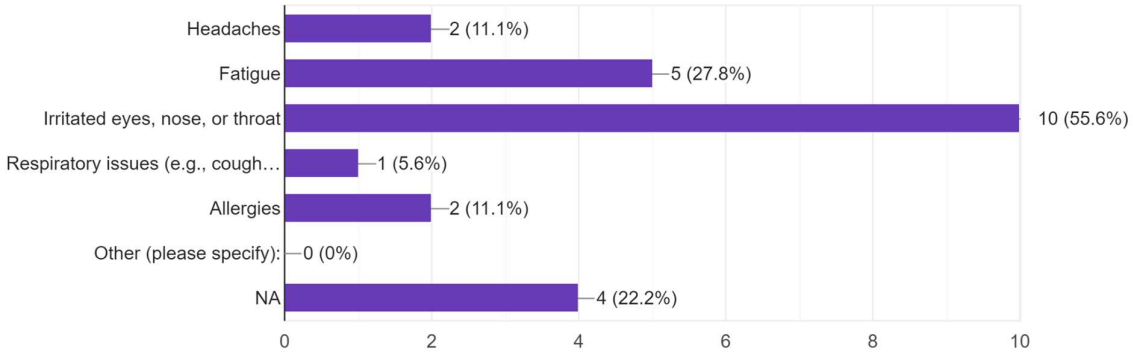
Minimize the usage of cleaning supplies, air fresheners, and other sources of Volatile Organic Compounds . Regularly clean carpets and upholstery to remove dust, allergens, and pet dander. Indoor vegetation would be able to help to elevate the quality of the air by removing pollutants.

Install continuous monitoring devices to understand the IAQ levels and connect it to BMS to do Demand Controlled Ventilation and improve filtration capacities as and when required.

Question 4: Do you sometimes experience any of the following symptoms connected to subpar indoor air quality? (Select all that apply)

h. **Cephalalgia in the heads**
i. **Fatigue**
j. **Irritated eyes, nose, or throat**
k. **Respiratory issues (e.g., coughing, shortness of breath)**
l. **Allergies**
m. **Other (please specify):**
n. **Other:**

Responses



Observations

- Irritated eyes, nose, or throat was the most frequently reported symptom, with 10 out of 20 respondents (55.6%) indicating that they experience this sometimes.
- Fatigue was reported by 5 respondents (27.8%).
- NA was reported by 4 respondents (22.2%).
- Cephalalgia in the heads and Allergies were reported by 2 respondents (11.1% each).
- Respiratory issues were reported by 1 respondent (5.6%).

Conclusion

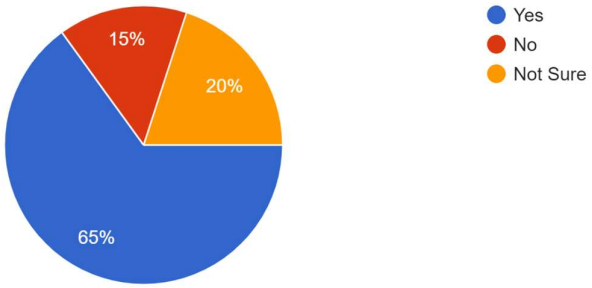
A significant portion of respondents (over 40%) reported experiencing symptoms commonly associated with poor air quality, such as irritated eyes, nose, or throat (50%), fatigue (27.8%).

Further detailed investigation into potential air quality issues and implementation of corrective measures is required.

Question 5: Do you know if your workplace has a Air conditioning, ventilation, and heating system?

d. Yes
e. No
f. Not Sure

Responses



Observation

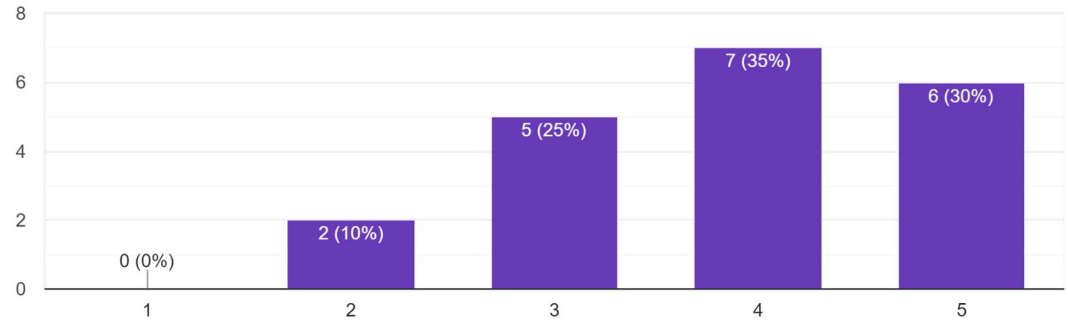
- The analysis of the survey data indicates that a vast majority of respondents (13 out of 20, or 65%) were aware that their workplace has a Air conditioning, ventilation, and heating system.
- Only a small number of respondents were unsure (4 out of 20, 20%) or indicated that their workplace does not have an HVAC system (3 out of 20, or 15%).

Conclusion

In conclusion, the high knowledge of HVAC systems among the respondents highlights the importance of these systems in maintaining thermal comfort and IAQ in the workplace. However, a knowledge gap exists, as reflected by the 35% of occupants who lack awareness of HVAC systems. To bridge this gap and empower occupants to contribute to a healthy work environment, we recommend implementing knowledge sessions specifically designed for them.

Question 6: To what extent are you happy with the ventilation in your workspace? 1-Very Dissatisfied, 2-Dissatisfied, 3-Enough Satisfied, 4-Satisfied, 5-Very Satisfied

Responses



Observation

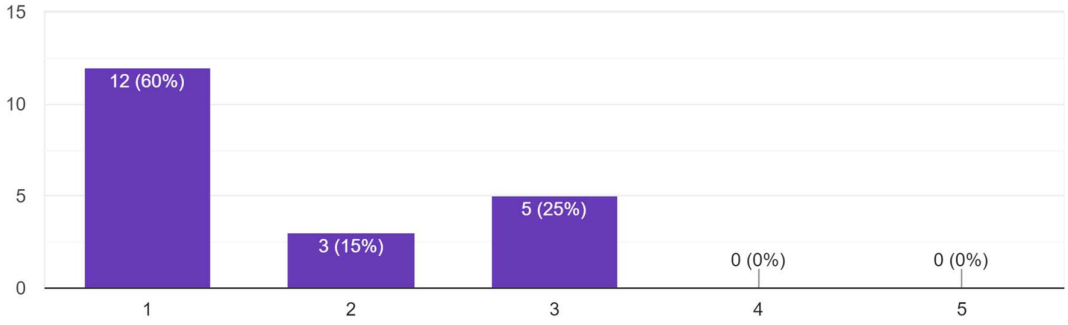
- Satisfied (4): This was the most common response, indicating that nearly 35% of respondents felt the ventilation in their workplace was satisfied.
- Very Satisfied (5): 6 respondents (30%) were very satisfied with the ventilation.
- Enough Satisfied (5): 5 respondents (25%) were enough satisfied with the ventilation.
- Dissatisfied (2): 2respondents (10%) indicated dissatisfaction with the ventilation.

Conclusion

These results suggest that there is room for improvement in ventilation for a significant portion of the occupants. It's important to investigate the reasons behind the dissatisfaction and take steps to address them. This could involve increasing ventilation rates, improving air filtration, or making adjustments to the temperature and humidity controls.

Question 7: How often do you notice odors or unusual smells in your workspace? 1-Never, 2-Rarely, 3-Sometimes, 4-Often, 5-Always

Responses



Observations

- Most respondents 60%) indicated that they never notice odors or unusual smells in their workspace.
- A smaller percentage of respondents indicated that they rarely (15%), sometimes (25%) notice odors or unusual smells.
- No respondents indicated that they always notice odors or unusual smells in their workspace.

Conclusion

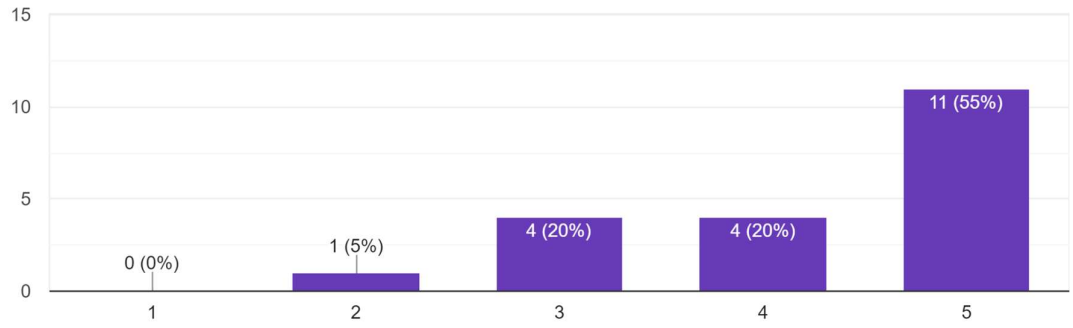
As can be seen from the table, over 60% of respondents reported never noticing any odors, but a substantial majority 40% indicated noticing odors with varying frequencies. This suggests that there might be occasional or recurring odor issues in the workspace that are not constant but noticeable to some occupants.

There is a need to review the products used for floor cleaning or any air fresheners that have been used.

Question 8: To what extent are you happy with the temperature control in your workspace?

1-Very Dissatisfied, 2-Satisfied, 3-Enough Satisfied, 4-Satisfied, 5-Very Satisfied

Responses



Observation

- Around half (55%) of respondents reported being Very Satisfied, and another 20% reported being Satisfied.
- 20% of respondents indicated enough satisfied.
- Only 5% reported feeling Average about the temperature control.
- None of the respondent is very dissatisfied with temperature control.

Conclusion:

Conduct further investigation to understand the reasons for dissatisfaction. This could involve gathering specific feedback about what temperatures people find uncomfortable.

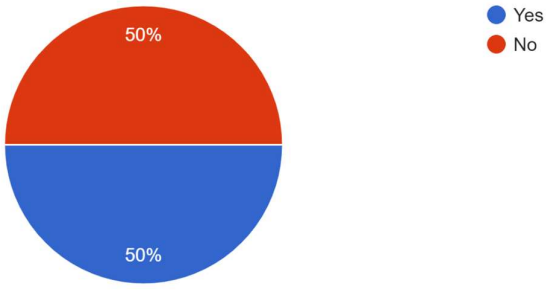
Explore options for adjusting the temperature control system to create a more comfortable environment for a wider range of occupants. This could involve zoning the temperature control system into different areas or allowing for more individual control.

Implement communication strategies to inform occupants about the temperature control system and how to adjust it if possible.

Question 9: Do you have any concerns about potential indoor air pollutants (e.g., dust) in your workplace?

c. **Yes**
d. **No**

Responses



Observation:

- Half of the occupants (10 out of 20 respondents, or 50%) expressed concerns about potential indoor air pollutants in their workplace.
- Ten respondents (50%) did not report having any concerns.

Conclusion:

While a half of them don't have worries, it's noteworthy that a half of occupants do. This suggests that a half of people having concerns might indicate the presence of potential IAQ issues. It is imperative to remember that people with respiratory sensitivities might be more likely to voice concerns, and some pollutants might not cause immediate noticeable symptoms.

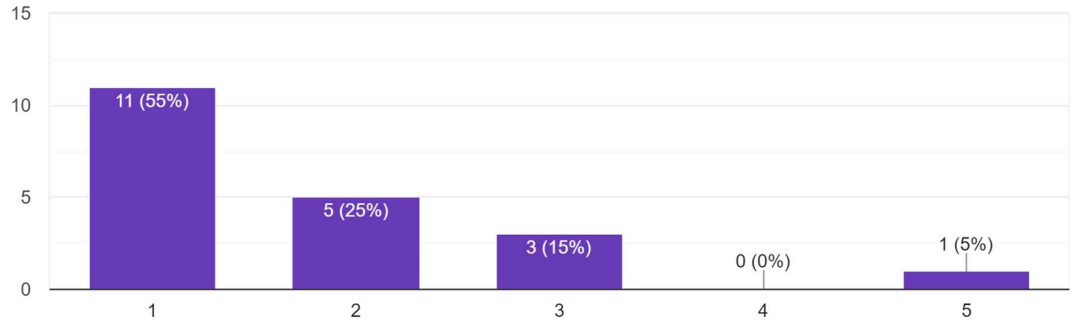
Considering the possible state of health implications of subpar IAQ, investigating these concerns could be helpful. This could involve testing indoor air quality or conducting a building assessment to identify any pollutant sources.

Even if the overall air quality seems satisfactory, addressing occupant concerns may encourage a more robust and comfortable working conditions for everyone.

Question 10: How often are windows and doors opened in your workspace to allow fresh air circulation?

1-Never, 2-Rarely, 3-Sometimes, 4-Often, 5-Always

Responses



Observation

- 11 or 55% occupants never aerate the space by opening the window panes and doors. 5 or 25% reported doing so rarely.
- 3 or 15% reported windows and doors are opened sometimes.
- Only 5% of respondents reported that windows and doors are never opened.

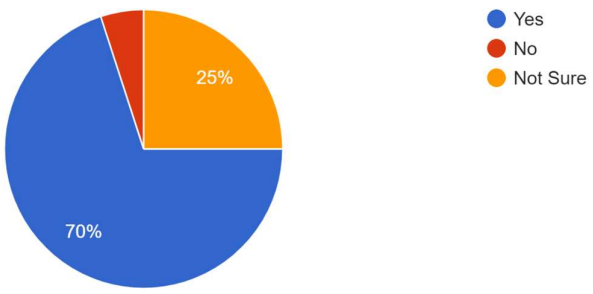
Conclusion

The findings demonstrate a positive approach to maintaining fresh air circulation in the workspace. However, there's an opportunity to encourage more frequent ventilation among those who never open windows and doors. This could be done through educational campaigns highlighting the benefits of fresh air or by investigating any potential reasons why some occupants might not be able to open windows (e.g., excessive noise from outside).

Question 11: Do you believe that improving indoor air quality could positively impact your work performance and well-being?

d. Yes
e. No
f. Not sure

Responses



Observation

- The overwhelming majority (14 out of 20 respondents, or 70%) believe that improving indoor air quality would positively impact their work performance and well-being. This indicates a strong understanding among occupants of the connection between IAQ and overall health and productivity.
- Only one respondent (5%) thinks that there are No potential benefits of improved IAQ and 5 respondents (25%) are not sure of potential benefits of improved IAQ on performance and well-being.

Conclusion

70% of the respondents believe improving IAQ would positively impact their work performance and well-being. This highlights a general awareness of the significance of having healthy indoor air quality for occupant health and productivity.

Findings & Recommendations

Findings of the NCDC:

Based on the data collected for 28 days at NCDC Delhi, here are the average values of the pollutants during working and non-working hours:

Pollutant	Overall Index	PM2.5 (µg/m³)	CO2 (ppm)	TVOC (ppb)	Temp (C)	RH (%)
Working Hours	69.52	39.93	558.82	238.26	23.77	44.91
Non-Working Hours	82.03	70.41	620.58	148.97	21.94	50.48
Avg. Daily Values	86.53	49.96	603.94	214.90	23.50	46.38

PM2.5 Levels: High PM2.5 levels during working hours indicate a need for improved filtration systems. The HVAC system shows some effectiveness in filtering but needs maintenance and upgrades.
CO2 Levels: Generally good CO2 levels indicate excellent ventilation, with occasional spikes during meetings or high occupancy times.
TVOC Levels: TVOC levels fluctuate but generally remain in the "low" range, indicating satisfactory air quality.
Temperature and Humidity: HVAC system efficiently maintains temperature and humidity levels within the comfort range.
Occupant Survey Findings:

- Awareness: Most occupants are aware of IAQ and its impact on health.
- Air Quality Perception: A significant portion rates air quality as average, indicating room for improvement.
- Symptoms: Many occupants report symptoms related to poor IAQ, highlighting the need for detailed investigation and corrective measures.
- Ventilation and Temperature Control: Mixed responses indicate a need for better ventilation and temperature control strategies.
- Odors and Unusual Smells: Occasional reports of odors suggest a need for targeted interventions to identify and eliminate sources.
- Impact of IAQ on Work Performance: Nearly all respondents believe that improving IAQ would positively impact their work performance and well-being.

Recommendations:

Filtration System: Upgrade and maintain the existing filtration systems to reduce PM2.5 levels and improve indoor air quality.

Ventilation: Encourage more frequent opening of windows and doors for fresh air circulation, when weather permits.

HVAC System: Optimize HVAC system settings for better filtration and ventilation, especially during working hours.

Identify VOC Sources: Conduct a thorough investigation to locate and eradicate the sources of VOCs, such as cleaning products and furnishings.

Occupant Education: Provide education sessions on IAQ and encourage active participation in maintaining a healthy indoor environment.

Continuous Monitoring: Install continuous monitoring devices connected to the Building Management System (BMS) for Demand Controlled Ventilation and timely adjustments to filtration capacities.

Findings of the NTPC:

Based on the data collected for 30 days at NTPC Delhi, here are the average values of the pollutants during working and non-working hours:

Pollutant	Overall Index	PM2.5 (µg/m³)	CO2 (ppm)	TVOC (ppb)	Temp (C)	RH (%)
Working Hours	104.28	29.15	455.28	1615.16	25.88	42.96
Non-Working Hours	378.62	45.98	470.07	19070.65	26.49	45.08
Avg. Daily Values	449.16	38.36	463.64	11176.78	26.21	44.22

PM2.5 Levels:

- During working hours (09:30 to 18:30), PM2.5 levels average 29.15 ug/m3, indicating good air quality.
- Levels rise to 45.98 ug/m3 during non-working hours, likely due to reduced HVAC filtration.
- The HVAC system is effective but needs improvement to meet outdoor air quality standards.

CO2 Levels:

- CO2 levels remain low (average 455 ppm during working hours) due to good ventilation.
- Consistent levels even on weekends and nights suggest continuous ventilation.

TVOC Levels:

- TVOC levels remain high, indicating sources like furniture or cleaning agents.
- A need to identify and eliminate VOC sources to improve indoor air quality.

Temperature and Humidity:

- Temperature is well-maintained (23-27 degrees), with HVAC system efficiency noted.
- Relative humidity levels indicate HVAC operation during specific hours.

Occupant Survey:

- Majority aged 31-40, aware of IAQ impact on health (80%).
- Most rate air quality positively but report occasional symptoms like irritated eyes and fatigue.
- Knowledge of HVAC systems is high (65%).
- Satisfaction with ventilation and temperature control varies, with room for improvement.

Recommendations:

Enhance Filtration Systems:
Based on the observed reduction in PM2.5 levels during HVAC operation, consider upgrading filtration systems to further improve air quality, particularly during non-working

hours when levels tend to be higher. Regular maintenance and replacement of filters should also be prioritized to ensure optimal performance.

Address VOC Emission Sources:
Identify and mitigate sources of Volatile Organic Compounds contributing to elevated indoor levels. This may involve reducing the usage of VOC-containing products, improving ventilation in areas prone to emissions, and selecting low-emission furniture and building supplies. Investigate and eliminate sources like furniture, carpets, and cleaning agents emitting VOCs.

Occupant Awareness and Engagement:
Conduct knowledge sessions on IAQ and HVAC systems for occupants.
Encourage more frequent ventilation practices, especially among those who never open windows.

Continuous Monitoring and Action:
Install continuous IAQ monitoring devices connected to BMS for real-time adjustments.
Address occupant concerns promptly through indoor air quality testing and corrective measures.

Educational Campaigns:
Promote awareness of IAQ benefits on health and productivity.
Provide guidelines on minimizing indoor air pollutants like VOCs and maintaining good ventilation practices.

Limitations of the study

Sample Size and Generalizability:

The sample size for NCDC is 24 participants and for NTPC is 20 participants, particularly the number of respondents to the IAQ survey, was relatively small, potentially limiting the findings applicability to larger populace or different types of commercial buildings. A more thorough knowledge of IAQ problems in multiple environments may be possible with future research including larger and more varied sample sizes.

Short Duration of Data Collection:

The data collection period for both the IAQ sensor readings and the questionnaire responses was limited to 28 days, which may not capture long-term trends or seasonal variations in indoor air quality. Extending the monitoring period could provide more robust data on IAQ dynamics over time, including fluctuations in pollutant levels and occupant perceptions.

Limited Data on Specific Pollutants:

While the study collected data on key IAQ metrics like CO2, PM2.5, and VOCs, moisture, as well as temperature, it did not investigate the presence of more possible contaminants therein, including formaldehyde, ozone, or specific Volatile Organic Compounds . Future research could explore a broader range of pollutants to comprehensively assess indoor air quality.

Self-Report Bias in Survey Responses:

The IAQ survey is based conclusions on the self-reported answers of building occupants. It could be biased due to things like recollection or social desirability. Individuals may overestimate or underestimate their IAQ perceptions or experiences, potentially influencing the accuracy of the survey results. Combining survey data with objective IAQ measurements can help mitigate this limitation.

Influence of External Factors:

External factors such as weather conditions, outdoor air pollution levels, nearby construction activities, or building maintenance practices could influence indoor air quality but were not systematically accounted for in the study. Controlling for these external variables or conducting sensitivity analyses could enhance the robustness of the findings.

Lack of Lab Tests for Detailed Analysis

Due to resource constraints, we were unable to conduct comprehensive lab tests for a detailed analysis of pollutants beyond the sensors' capabilities. This limitation may have affected the depth of our understanding of specific pollutants and their sources.

Inability to Rectify Issues During Monitoring

While monitoring IAQ parameters, we were not able to make real-time adjustments or implement purification measures to address identified issues. This limitation prevents us from evaluating the effectiveness of corrective actions on IAQ levels.

Absence of Post-Purification IAQ Measurement:

There was a lack of resources to implement corrective measures on indoor air pollution, we did not measure IAQ levels post-treatment. This lack of data hinders our ability to assess the immediate impact of purification measures on IAQ.

Limited Data on Specific Pollutants:

While the study collected data on key IAQ metrics like CO2, PM2.5, and VOCs, moisture, as well as temperature, it did not investigate the presence of more possible contaminants therein, including formaldehyde, ozone, or specific Volatile Organic Compounds . Future research could explore a broader range of pollutants to comprehensively assess indoor air quality.

5. CONCLUSION

The investigation into IAQ in office spaces has revealed critical insights into the potential health impacts of pollutants such as PM2.5, CO2, TVOC, as well as the significance of maintaining optimal relative humidity as well as temperature. Additionally, analyzing occupants' perceptions has highlighted the importance of understanding their experiences and concerns regarding IAQ. This conclusion synthesizes the findings and presents actionable recommendations to improve IAQ and promote occupants' health, well-being, and productivity.

Health Impacts of Indoor Air Pollution

Particulate Matter 2.5: The presence of high PM2.5 levels provides employees with serious health hazards. Prolonged exposure can lead to respiratory issues like expectorate, dyspnea, and exacerbation of asthma symptoms. It is imperative to address PM2.5 sources and implement effective filtration measures to mitigate health risks.

CO2: Elevated CO2 levels indicate inadequate ventilation, which can result in occupant discomfort, fatigue, cephalalgia in the heads, and reduced cognitive performance. Enhancing ventilation systems and optimizing airflow are crucial for maintaining CO2 levels within acceptable ranges and ensuring occupant well-being.

TVOC: Increased TVOC levels might irritate the trachea, nasal, and eyes, contributing to discomfort and potential long-term respiratory challenges. Identifying sources of VOCs, such as cleaning agents, furniture, and building materials, is essential for implementing targeted mitigation strategies and improving indoor air quality.

Temperature and RH: Poor temperature control and humidity levels can lead to occupant discomfort, decreased focus, and may exacerbate existing health conditions. Optimal temperature and RH management, coupled with effective HVAC systems, are vital for establishing a cozy and healthful office space.

Significance of Occupant Perception and Education

Understanding occupants' perceptions of IAQ is crucial for identifying IAQ issues, addressing concerns, and fostering a proactive approach to IAQ management. Educating occupants about IAQ, its impact on health, and simple practices to enhance IAQ can empower them to contribute to a healthier workplace environment. Building occupants' awareness and participation are key factors in maintaining sustainable IAQ improvements over time.

Benefits of Maintaining IAQ for Building Certifications

Achieving and maintaining IAQ standards aligned with certifications such as LEED, WELL, and RESET not only validates the commitment to occupant health and well-being but also offers tangible benefits:

Enhanced Occupant Satisfaction: Improved IAQ leads to higher occupant satisfaction, comfort, and overall well-being, fostering a positive work environment.

Increased Productivity: Healthy indoor environments contribute to higher productivity levels, reduced absenteeism, and improved employee morale and engagement.

Energy Efficiency: Implementing IAQ measures often aligns with energy-efficient practices, resulting in cost savings, reduced environmental impact, and sustainability benefits.

Recommendations for IAQ Improvement

1. Continuous Monitoring: To watch pollutant levels, spot trends, and take preventative action against IAQ problems, install real-time IAQ monitoring systems.
2. Enhance ventilation: Make sure ventilation systems are operating at peak efficiency to guarantee sufficient intake of fresh air, even distribution of airflow, and efficient removal of interior pollutants.
3. Improvements to HVAC mechanisms for filtering can remove allergens in the air to enhance indoor quality, volatile organic compounds, and particulate matter.
4. Occupant Engagement: In order to increase IAQ knowledge and best practices, it is important to educate and include occupants in IAQ activities through workshops, training sessions, and continuous contact.
5. Pursuit of Certification: To show a commitment to IAQ excellence, strategically coordinate IAQ improvement initiatives with building certification standards, aiming for LEED, WELL, or RESET certifications.

The quality of the air inside is vital to determine occupant health, comfort, and productivity in office spaces. By addressing pollutants such as CO2, TVOC, and PM2.5, optimizing temperature and RH levels, and considering occupants' perceptions, organizations can produce a more sustainable and healthy work atmosphere inside the office building. Investing in IAQ improvements not only benefits occupants' well-being but also aligns with building certifications, enhancing the overall quality and value of indoor spaces. Embracing a holistic approach to IAQ management is essential for building a healthier and more productive future workplace.

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7. ANNEXURE

Color Scale and Overall Index

The overall index will tell us which air pollutant to address first and will provide us a comprehensive, at-a-glance assessment of the air. For every pollutant, an index is computed using the same methodology and breakpoints as the AQI standard set by the EPA. The pollutant with the highest index is shown as the Overall Index.

The table below shows the breakpoints that were utilized to calculate the Overall Index values along with the color and category that went with them.

Index Category	Index Value	$PM_{2.5}$ (µg/m³)	CO_2 (ppm)	TVOC (ppb)	TVOC (µg/m³)	O_3 (ppb)	O_3 (µg/m³)
Good	0 - 50	0 - 12	400 - 1000	0 - 220	0 - 1005.5	20 - 50	39.2 - 98.0
Moderate	51 - 100	12.1 - 35.4	1001 - 1500	221 - 660	1005.6 - 3016.7	51 - 100	98.1 - 196.2
High	101 - 150	35.5 - 55.4	1501 - 2000	661 - 1430	3016.8 - 10056.1	101 - 165	196.3 - 323.7
Very High	151 - 200	55.5 - 150.4	2001 - 2500	1431 - 2200	10056.2 - 15084.2	166 - 205	323.8 - 402.3
Very High	201 - 300	150.5 - 250.4	2501 - 5000	2201 - 3300	15084.3 - 20112.3	206 - 405	402.4 - 794.9
Very High	301 - 500	250.5 - 500.4	5001 - 10000	3301 - 5500	20112.4 - 25140.5	406 - 605	795.0 - 1187.6

Occupants Survey

Indoor Air Quality (IAQ) Survey

Thank you for participating in this survey. Your feedback is valuable in helping us understand and improve indoor air quality in our workplace. All responses will be kept confidential and will be used for research purposes only.

1. Age Group

   Mark only one oval.

   - 21-30
   - 31-40
   - 41-50
   - 51-60

2. Are you aware of indoor air quality (IAQ) and its potential impact on health and well-being?

   Mark only one oval.

   - Yes
   - No

3. How would you rate the overall air quality in your workplace?
   1-Very Poor
   2- Poor
   3- Average
   4- Good
   5- Excellent

   Mark only one oval.

   1 2 3 4 5

   Very ◯ ◯ ◯ ◯ ◯ Excellent

4. Do you sometimes experience any of the following symptoms related to poor indoor air quality? (Select all that apply)

Tick all that apply.

- [ ] Headaches
- [ ] Fatigue
- [ ] Irritated eyes, nose, or throat
- [ ] Respiratory issues (e.g., coughing, shortness of breath)
- [ ] Allergies
- [ ] Other (please specify):
- [ ] Other: _____

5. Do you know if your workplace has a Heating, Ventilation, and Air Conditioning (HVAC) system?

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Not Sure

6. How satisfied are you with the ventilation in your workspace?
5- Very Satisfied
4- Satisfied
3- Enough Satisfied
2- Dissatisfied
1- Very Dissatisfied

Mark only one oval.

	1	2	3	4	5	
Very	◯	◯	◯	◯	◯	Very Satisfied

10. How often are windows and doors opened in your workspace to allow fresh air circulation?
5- Always
4- Often
3- Sometimes
2- Rarely
1- Never

Mark only one oval.

	1	2	3	4	5	
Nev	◯	◯	◯	◯	◯	Always

11. Do you believe that improving indoor air quality could positively impact your work performance and well-being?

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Not Sure