INDOOR AIR QUALITY OF LIBRARIES AND LABORATORIES IN A TERTIARY INSTITUTION AND RISK FACTORS FOR RESPIRATORY SYMPTOMS AMONG STUDENTS.

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CERTIFICATION

This is to certify that this research titled **"INDOOR AIR QUALITY OF LIBRARIES AND LABORATORIES IN A TERTIARY INSTITUTION AND RISK FACTORS FOR RESPIRATORY SYMPTOMS AMONG STUDENTS."** was carried out by **"FAVOUR AISEOSA IYORE"** and presented to the Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, Benin City; in partial fulfilment of the requirements for the award of Bachelor of Science (B. Sc) in Environmental Management and Toxicology. It was conducted under suitable conditions, was carefully supervised and subsequently approved as having met the requirements for the award of a Bachelor of Science degree in Environmental Management and Toxicology.

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(HEAD OF DEPARTMENT)

DECLARATION

I **"FAVOUR AISEOSA IYORE"** declare that **"INDOOR AIR QUALITY OF LIBRARIES AND LABORATORIES IN A TERTIARY INSTITUTION AND RISK FACTORS FOR RESPIRATORY SYMPTOMS AMONG STUDENTS"** is my work and that all sources that I have used or quoted have been acknowledged using complete references and that this work has not been submitted before for any other degree at any other university.

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FAVOUR AISEOSA IYORE **DATE**

DEDICATION

This project is dedicated to God Almighty for His grace, wisdom, and strength throughout my academic journey. I also dedicate it to my loving parents Mr. and Mrs. Iyore Imafidon, whose support and prayers have carried me through every stage of this work.

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ABSTRACT

This study evaluated indoor air quality and examined major risk factors for respiratory symptoms among students who used University of Benin libraries and laboratories. The concentrations of particulate matter, carbon dioxide, and formaldehyde were measured during the morning and afternoon sampling periods, and a structured questionnaire was used to collect demographic, environmental, and health data. Statistical analyses included paired-samples t tests and chi-square tests, with significance set at $p < 0.01$. The mean pollutant concentrations range from 14.5 ± 0.6 to 24.1 ± 3.1 μg/m³ ($PM_{2.5}$), 27.0 ± 1.5 to 43.2 ± 6.7 μg/m³ (PM_{10}), 399.5 ± 0.3 to 404.4 ± 4.7 ppm (CO_2), and 0.003 ± 0.000 to 0.026 ± 0.012 mg/m³ (HCOH), 24.6 ± 0.2 °C to 32.6 ± 3.7 °C (Temperature), and 69.1 ± 0.5% RH to 78.3 ± 0.6% RH (Relative Humidity).The mean pollutant concentrations did not differ significantly between the morning and afternoon samples, indicating temporal stability. In contrast, environmental factors were significantly associated with symptom prevalence. Notably, a highly significant but inverse relationship emerged for cleaning frequency: participants reporting daily cleaning reported the highest symptom prevalence compared with those reporting monthly cleaning. Demographic variables such as age and sex were not significant predictors of symptoms. These findings indicate that respiratory health risks in these indoor settings are driven less by short-term fluctuations in measured pollutants and more by shortcomings in building maintenance. The inverse association suggests that cleaning activities themselves through resuspension of particles or exposure to cleaning chemicals may function as primary irritants. Interventions should therefore prioritize improved cleaning practices and remediation of structural dampness to reduce respiratory health risks effectively.

CHAPTER ONE

1.1 Introduction

Assessing indoor air quality (IAQ) in educational institutions is an effective way to prevent adverse public health consequences. Students and staff spend prolonged periods in enclosed indoor spaces such as libraries and laboratories. Given that indoor air pollution is one of the top five environmental threats to human health worldwide, prioritizing the health of individuals in these settings is crucial (Adamopoulos et al., 2025). Respiratory illnesses significantly impact global health, with indoor air pollution causing an estimated 3.2 million deaths annually in 2020 (WHO, 2024). The severity of symptoms varies with exposure, ranging from short-term effects such as headaches and eye irritation to long-term conditions such as asthma and cardiovascular diseases (Manisalidis et al., 2020). Poor IAQ in educational settings can lead to "sick-building syndrome" and increase the risk of respiratory infections, allergies, and asthma. Prolonged exposure to high pollutant levels has been linked to severe illnesses and can even disrupt cognitive functions, potentially hindering academic success (Adamopoulos et al., 2025). Libraries pose unique IAQ challenges because of the large volume of books and paper and often outdated ventilation systems. These materials can promote the growth of molds such as *Cladosporium* and *Aspergillus*, which are linked to respiratory issues (Hayleeyesus and Manaye, 2014). Chemical pollutants from deteriorating books and adhesives release formaldehyde and volatile organic compounds (VOCs), while paper degradation and dust accumulation can increase $PM_{2.5}$ levels to 40–70% of outdoor levels (Wu et al., 2018). High occupancy also leads to elevated carbon dioxide (CO_2) levels, worsening air quality. University laboratories present IAQ challenges distinct from those of chemical fumes, particulate matter, and biological

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contaminants. Studies have shown that even with safety protocols, inadequate ventilation can lead to elevated CO_2 (up to 1,710 ppm) and TVOC levels (exceeding 3,600 µg/m³) during experiments (Seseña et al., 2022; Ugranli et al., 2015). Microbial contamination is also a concern (Ghosh et al., 2024). These pollutants are associated with symptoms of "Sick Building Syndrome," such as headaches, in 32.5% of inhabitants (Ghosh et al., 2024). Natural ventilation often falls short of air exchange standards (Seseña et al., 2022), underscoring the need for better IAQ management.

Indoor air quality (IAQ) is a critical but underresearched public health concern in Nigerian tertiary institutions, particularly in Edo State. There is a notable lack of comprehensive data on specific pollutants, such as particulate matter (PM), volatile organic compounds (VOCs), and microbial aerosols, in university libraries and laboratories. Furthermore, the direct link between these IAQ parameters and student respiratory health risks is not well understood. Abulude et al. (2022) measured pollutants such as formaldehyde (HCHO) and total VOCs (TVOCs) in academic environments, but their study did not connect these findings to student health outcomes or associated risk factors. Without this crucial evidence, institutions cannot assess the true health implications of poor IAQ effectively or prioritize interventions. This study aims to address this gap by characterizing pollutant profiles and examining their correlation with respiratory health risks to provide data for policy and remediation efforts. This study provides evidence-based data on the indoor air quality of tertiary institutions. By examining IAQ in academic buildings, this research offers insights that can inform policy decisions. ventilation and environmental management. This study contributes to the body of knowledge on the relationships between indoor environmental quality and student health and academic performance. By highlighting

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potential health risks such as respiratory issues, this research raises awareness among students and staff, encouraging proactive steps toward creating healthier learning environments.

1.2 Aim and Objectives of the Study

The aim of this study was to assess indoor air quality (IAQ) in selected libraries and laboratories within a tertiary institution and to examine the risk factors for respiratory symptoms associated with exposure to indoor air pollutants among students using facilities.

The specific objectives of this study were as follows:

1. Measure the levels of selected indoor air pollutants ($PM_{2.5}$, PM_{10}, CO_2, VOCs, HCOC, temperature, and relative humidity) in selected libraries and laboratories.

2. Determine the variation in indoor air quality (IAQ) parameters.

3. Determine the prevalence of common respiratory symptoms among students.

4. Examine the risk factors associated with reported respiratory symptoms among the students.

5. Examine the associations between risk factors and reported respiratory symptoms

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CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Overview of Indoor Air Quality

Indoor air quality (IAQ) pertains to the air quality inside and surrounding buildings, particularly for the health and comfort of people. Comprehending and managing prevalent indoor contaminants helps mitigate the danger of health issues within enclosed environments. Indoor air quality is influenced by indoor pollutants and the intrusion of outdoor air. (US EPA, 2025).

2.2 Common air pollutants in Libraries and Laboratories

2.2.1 Volatile organic compounds

Volatile organic compounds (VOCs) are gaseous chemicals that are released from liquids or solids and are characterized by their high volatility, typically indicated by boiling points between 50°C and 240°C. These compounds are found in much higher concentrations indoors (at least ten times greater than outdoors), regardless of geographic area (U.S. EPA, 2022). Among the most common VOCs is formaldehyde, a colourless gas with a strong odour that is off-gaseous from standard building materials such as plywood, particleboard, and various adhesives. The World Health Organization classifies these compounds into four categories on the basis of their volatility: very volatile organic compounds (VVOCs) with boiling points of 50–100°C; standard VOCs (100–240°C); semivolatile organic compounds (SVOCs) (240–380°C); and particulate organic matter (POM) (>380°C) (WHO, 2010). Typical VOCs include formaldehyde, benzene, toluene, xylene, acetone, and methylene chloride, whereas SVOCs, which have lower volatility (boiling points of 260–400°C), include phthalates, polycyclic aromatic hydrocarbons (PAHs),

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pesticides, and perfluorinated substances (PFASs). These semivolatile compounds are distributed between gaseous and particulate phases and accumulate in household dust, airborne particles, and ventilation systems (Harrad et al., 2010; Pagonis et al., 2019).

2.2.2 Particulate matter ($PM_{2.5}$ and PM_{10})

A mixture of solid particles and liquid droplets suspended in air is referred to as particulate matter (PM). Chemical reactions between various contaminants typically result in the formation of particulate matter (PM) in the atmosphere. The size of the particles has a direct effect on their penetration. Fine inhalable particles with a diameter of 2.5 micrometers or less are classified as $PM_{2.5}$, whereas particles with a diameter of 10 micrometers or less are classified as PM_{10}. These particles have the ability to enter the bloodstream and lungs deeply, resulting in respiratory irritation, inflammation, and long-term health problems such as cardiovascular illnesses, bronchitis, and asthma. (Manisalidis et al., 2020)

2.2.3 Biological contaminants

Biological contaminants, including bacteria, fungi, algae, mites, insect remnants, animal epithelia, and their byproducts, including endotoxins, mycotoxins, and volatile organic compounds, originate from biological sources. Research has demonstrated that indoor air may be polluted with biological contaminants, such as bacteria, spores, yeasts, fungi, and secondary metabolites (e.g., bacterial endotoxins, peptidoglycans, pollens, viruses, and protozoa) (Ite & Ite, 2024). Biological contaminants are categorized according to their ability to elicit allergenic, infectious, toxic, or inflammatory reactions in humans (Kumar et al., 2021).

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2.3 Sources of Indoor Air Pollution in Libraries and Laboratories

Indoor air pollution sources in libraries are influenced by a range of factors related to building design, materials, occupant activities, and external influences. Notably, building materials and furnishings are significant contributors, as paints, adhesives, and finishes can release volatile organic compounds (VOCs) and other harmful chemicals. Effective moisture management is vital for preventing the growth of molds, which are common biological contaminants (Abulude et al., 2024). The importance of ventilation systems cannot be overstated, as inadequate design or maintenance of heating, ventilation, and air conditioning (HVAC) systems can lead to stagnant air and increased pollutant levels. Additionally, occupant activities contribute to the introduction of various pollutants. The handling of materials such as books and documents can release particulate matter. Electronic devices, along with printing and photocopying, generate pollutants, including electromagnetic radiation, heat, VOCs, toner dust, and ozone. A high density of occupants can result in increased carbon dioxide (CO_2) emissions, whereas food and beverage consumption can introduce odors and airborne particles. Personal habits also have an impact on indoor air quality (Mansor et al., 2021). Cleaning products and personal items can also be sources of indoor pollutants. Libraries often contain common chemical contaminants such as particulate matter, VOCs, and formaldehyde. The presence of formaldehyde, carbon monoxide (CO), and carbon dioxide (CO_2) serves as indicators of chemical contamination, with their levels being influenced by the number of occupants (Mansor et al., 2021; Ukëhaxhaj et al., 2023).

Indoor air pollution in laboratory environments is generated by experimental activities and the surrounding environmental conditions. Common pollutants found in these settings include particulate matter, trace elements, inorganic gases, bioaerosols, and both volatile and semivolatile organic compounds. The source of particulate matter is often linked to combustion,

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chemical powders, human activities, and the influx of outdoor air through ventilation systems (Ugranli et al., 2016). Trace elements such as Fe, Zn, and Pb may be introduced into the indoor environment through outdoor infiltration or through indoor processes such as material degradation and laboratory experiments (Seseña et al., 2022). Inorganic gases, including CO_2, CO, and NO_2, are produced from human respiration, chemical reactions, fuel combustion, and the use of laboratory equipment. Bioaerosols, which include bacteria and fungi, are produced from human activities and lab materials such as cultures and plant samples (Ugranli et al., 2016; Seseña et al., 2022). The emission of VOCs and SVOCs occurs during training and experimental procedures, particularly in chemistry laboratories, which significantly adds to indoor air pollution.

2.4 Health effects of poor indoor air quality

Inadequate indoor air quality (IAQ) poses a serious danger to human health, contributing to millions of deaths each year. Exposure to various indoor contaminants can result in a broad spectrum of diseases, which include both immediate and long-term health repercussions. With respect to respiratory health, poor IAQ can result in numerous acute and chronic symptoms and illnesses:

2.4.1 Acute effects: Short-term exposure to air pollutants is closely associated with symptoms such as coughing, breathlessness, and wheezing. It can also aggravate asthma and other respiratory conditions, leading to increased hospitalization rates. When inhaled, volatile organic compounds (VOCs) can cause immediate issues such as irritation of the eyes, nose, and throat, as well as headaches. Furthermore, low indoor humidity can contribute to acute symptoms affecting

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the eyes and airways, resulting in dry and fatigued eyes and reduced mucociliary clearance. (Manisalidis et al., 2020).

2.4.1 Chronic Effects: Extended exposure to poor indoor air quality is correlated with more severe and chronic respiratory conditions. Particulate matter (PM), a complex mixture of inorganic and organic substances, can penetrate deeply into the lungs and introduce foreign chemicals into the bloodstream, increasing the likelihood of cardiorespiratory diseases and lung cancer. Chronic exposure to high levels of VOCs can lead to respiratory disorders. Diseases such as chronic obstructive pulmonary disease (COPD), asthma, bronchiolitis, and lung cancer are caused primarily by these pollutants. Poor air quality in educational institutions, for example, has been shown to result in health complications and acute symptoms that hinder students' performance. (Hasager et al., 2020; Van T. et al., 2020).

2.5 Respiratory Symptoms and Risk Factors

2.5.1 Individual risk factors

Individual characteristics such as asthma, smoking, allergies, and genetic predispositions significantly influence the impact of poor indoor air quality (IAQ) on respiratory health in libraries and laboratories.

2.5.1.1 Asthma

considerably enhances the likelihood of experiencing respiratory symptoms in environments with deficient indoor air quality (IAQ), such as libraries and laboratories. Indoor pollutants, including particulate matter, volatile organic compounds (VOCs), carbon dioxide, and allergens (for example, mould and dust mites), can trigger and intensify asthma symptoms, particularly in

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poorly ventilated areas where these pollutants accumulate (Ezeamii et al., 2025; Kourkouta et al., 2015). For individuals with asthma, such exposure results in oxidative stress and airway inflammation, leading to more frequent and severe asthma attacks (Bronte-Moreno et al., 2023). Elevated levels of CO_2 and pollutants such as diesel exhaust particles further exacerbate symptoms and contribute to an increase in asthma-related absenteeism (Ezeamii et al., 2025; Bronte-Moreno et al., 2023). The combination of multiple pollutants and prolonged exposure in libraries and laboratories creates particularly high risks for those with asthma, potentially leading to chronic respiratory issues and greater healthcare needs (Kourkouta et al., 2015).

2.5.1.2 Smoking

Smoking is a significant individual risk factor that exacerbates respiratory symptoms associated with poor indoor air quality in environments such as libraries and laboratories. It weakens the body's pulmonary defenses by damaging the airway epithelium, reducing the effectiveness of mucociliary clearance, and increasing the risk of infections and exposure to airborne pollutants. The combination of smoking and indoor pollutants leads to synergistic inflammatory effects, which increase both the risk and severity of respiratory conditions such as asthma and COPD (Sales et al., 2019).

2.5.1.3 Genetic predisposition

Genetic predisposition also plays a vital role. Research has shown that individuals with asthma-related genetic variants may experience worsened lung function when exposed to indoor pollutants, such as PM_{10} (Hüls et al., 2020). Genetic differences in antioxidant defenses can lower the body’s capacity to neutralize oxidative stress from pollutants such as ozone, increasing susceptibility to lung injury and inflammation (Kodavanti, 2019). Moreover, variations in

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stress–response systems such as the hypothalamic–pituitary–adrenal (HPA) axis may impair immune regulation under pollutant exposure, leading to chronic inflammation and respiratory complications (Kodavanti, 2019). Notably, ancestry-specific genetic traits have been associated with stronger gene–environment interactions, particularly among individuals of Black African descent, highlighting the need to consider demographic factors in IAQ risk management (Hüls et al., 2020).

2.5.2 Environmental risk factors

2.5.2.1 Humidity

Increased humidity levels encourage the growth of mold and dust mites, which are well-known triggers for respiratory ailments such as asthma and allergic rhinitis (Abulude & Ademilua, 2024). Within laboratory environments, high humidity can also accelerate chemical reactions, leading to the release of toxic gases. Conversely, insufficient humidity can result in dryness of the respiratory tract, which may lead to irritation and discomfort (Ugranli et al., 2016). The ideal relative humidity range for libraries and laboratories is recommended to be between 30–50% to reduce these risks (Abulude & Ademilua, 2024).

2.5.2.2 Ventilation

Poor ventilation represents a major risk factor for respiratory symptoms in both libraries and laboratories. When ventilation is inadequate, it can cause the accumulation of indoor air pollutants such as particulate matter (PM), volatile organic compounds (VOCs), and carbon dioxide (CO_2), which can aggravate respiratory conditions such as asthma and allergies (Abulude & Ademilua, 2024).

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Owing to their chemical usage, laboratories require mechanical ventilation systems such as HVAC and fume hoods to effectively remove hazardous pollutants from the outdoors (Ugranli et al., 2016). In contrast, libraries may utilize natural ventilation; however, this can be insufficient if the quality of outdoor air is poor or if the building's design restricts airflow (Abulude & Ademilua, 2024).

2.5.2.3 Temperature

Severe temperature conditions can aggravate respiratory issues. High temperatures in laboratory settings can increase the volatility of chemicals, resulting in higher levels of volatile organic compounds (VOCs), whereas low temperatures may impair the performance of ventilation systems (Ugranli et al., 2016). In library environments, temperature variations can also impact the release of pollutants from building materials and furniture (Abulude & Ademilua, 2024). Ensuring a stable temperature within the comfort range (e.g., 20–26°C) is vital for maintaining respiratory health (Ugranli et al., 2016).

2.5.2.4 Specific pollutants

Particulate matter ($PM_{2.5}$ and PM_{10}): These particles, which arise from dust, outdoor pollution, and the activities of occupants, have the ability to infiltrate the lungs deeply, leading to inflammation and worsening respiratory conditions (Abulude & Ademilua, 2024; Ugranli et al., 2016). Volatile organic compounds (VOCs): Released from cleaning agents, construction materials, and laboratory substances, VOCs such as formaldehyde can provoke irritation in the respiratory system and result in headaches and dizziness (Abulude & Ademilua, 2024; Ugranli et al., 2016). Carbon dioxide (CO_2): Increased levels of CO_2, frequently a consequence of inadequate ventilation, may result in drowsiness and diminished cognitive abilities, thereby

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indirectly impacting respiratory comfort (Abulude & Ademilua, 2024). Biological contaminants: Moulds, bacteria, and allergens flourish in moist environments and can lead to infections and allergic reactions (Abulude & Ademilua, 2024).

2.6 **Mitigation strategies for indoor air pollution in libraries and laboratories**

2.6.1 Regular maintenance and cleaning practices

Consistent cleaning and maintenance are crucial for the control of dust, mold, and microbial contaminants within indoor settings. It is advisable to utilize wet cleaning methods instead of dry sweeping to prevent the resuspension of particles (Idris et al., 2020). In addition, HVAC systems should be regularly serviced, which entails replacing filters and cleaning ducts, to ensure that they operate efficiently. Managing moisture is another vital component, as moist environments promote mould growth. Quickly addressing leaks and maintaining relative humidity levels between 40% and 60% can help alleviate these concerns (Yang, 2017).

2.6.2 Local Exhaust Ventilation

The installation of local exhaust systems in proximity to sources of pollution, such as chemical fume hoods within laboratories, facilitates the capture of contaminants prior to their dispersion into the indoor atmosphere (Bayram Zumrut et al., 2024). These systems prove particularly beneficial in environments where hazardous substances are managed, guaranteeing that pollutants are efficiently eliminated at their origin.

2.6.3 Substitution of Hazard

Equipment: Substituting equipment that generates dust with alternatives that utilize closed systems can greatly decrease particulate matter emissions. For example, in laboratory settings,

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manual sieves can be substituted with automated, enclosed machines to limit the spread of dust (Bayram Zumrut et al., 2024). This approach is especially beneficial for lowering occupational exposure to hazardous particulates.

2.6.4 Monitoring and regular IAQ assessments

The continuous assessment of indoor air quality (IAQ) parameters, such as particulate matter (PM) concentrations, carbon dioxide (CO_2), and volatile organic compounds (VOCs), is essential for pinpointing sources of pollution and evaluating the effectiveness of mitigation measures. Real-time data can be obtained through the use of portable sensors and fixed monitoring systems, which enables timely interventions (Idris et al., 2020). Moreover, the regular disinfection of surfaces and books with UV lamps or nontoxic disinfectants can significantly decrease microbial contamination (Yang, 2017).

2.6.5 Education and awareness programs

Increasing awareness among users of libraries and laboratories is essential for maintaining optimal indoor air quality (IAQ). Educational programs can inform both staff and students about practices, including effective ventilation, minimizing the use of aerosol products, and upholding personal hygiene (Gbotoso & Abulude, 2024). Basic measures, such as handwashing and standing clear of strong fragrances, can greatly diminish indoor pollutants. Furthermore, institutions should present informational posters and guidelines to support these practices.

2.6.7 Indoor Plants for Air Purification

The integration of indoor plants serves as a natural and visually appealing method to increase the indoor air quality (IAQ). Species such as aloe vera, spider plants, and bamboo palms are capable

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of absorbing carbon dioxide (CO_2), volatile organic compounds (VOCs), and various pollutants through phytoremediation (Yang, 2017). Nonetheless, it is important to exercise caution by avoiding plants that are overly fragrant or produce high levels of pollen, as these may provoke allergic reactions. Strategic placement, such as positioning them near windows or on shelves, can optimize their air-purifying capabilities while ensuring a pleasant indoor atmosphere.

2.6.8 Enhanced Ventilation Systems

Effective ventilation is crucial for preserving high indoor air quality (IAQ) in libraries and laboratories. Natural ventilation methods, such as the opening of windows and doors, can assist in reducing indoor pollutants; however, they may prove inadequate in spaces with high occupancy. To guarantee stable air exchange rates, mechanical ventilation systems, including HVAC units, should be implemented. As noted by Gbotoso and Abulude (2024), well-structured ventilation systems can greatly reduce the concentrations of particulate matter (PM), volatile organic compounds (VOCs), and carbon dioxide (CO_2). Moreover, energy recovery ventilation (ERV) systems can increase airflow while reducing energy waste, rendering them a sustainable option for the long-term management of IAQ.

2.6.9 Use of low-emission building materials and furnishings

The decision regarding construction and furnishing materials is critical in curbing indoor air pollution. Libraries and laboratories must prioritize materials that exhibit low emissions of formaldehyde, benzene, and other harmful VOCs. For example, low-VOC paints, adhesives, and certified wood products can significantly diminish off-gass (Gbotoso & Abulude, 2024). Yang (2017) also stressed the importance of selecting furniture made from solid wood or other nontoxic materials to reduce indoor air contamination. By opting for environmentally responsible

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materials, institutions can create healthier indoor environments from the beginning. The mitigation of indoor air pollution in libraries and laboratories requires a comprehensive approach that combines ventilation improvements, low-emission materials, regular maintenance, and user education. By implementing these strategies, institutions can safeguard the health and well-being of occupants while promoting sustainable indoor environments.

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CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area and sampling sites

The study was conducted within the University of Benin, Ugbowo Campus, Benin city, Edo State, Nigeria, which is located at latitude 6.3993° N and longitude 5.6126° E. The University is a major tertiary institution in southern Nigeria with an estimated student population of over 77,000. It comprises several faculties, administrative buildings, academic blocks, laboratories, and libraries, all of which serve the teaching, research, and learning needs of the university community. For this study, sampling was carried out at selected locations within the John Harris Library and departmental laboratories in the Faculty of Life Sciences. The library sampling points included the Circulation Section, Reference Section, Veterinary Medicine Library, Arts Library, and Library Extension. The laboratory sampling points were the Department of Biochemistry Laboratory, the Department of Science Laboratory Technology Laboratory, and the Limnology Laboratory in the Department of Plant Biology and Biotechnology. These specific facilities were chosen because of their high occupancy rates, prolonged periods of use by both students and staff, and inherent potential for the accumulation of indoor air pollutants. All sampling was conducted during typical academic activities to ensure that the data collected accurately represented the environmental conditions normally present within these spaces. Sampling took place during regular academic activities to reflect typical environmental conditions within the spaces.

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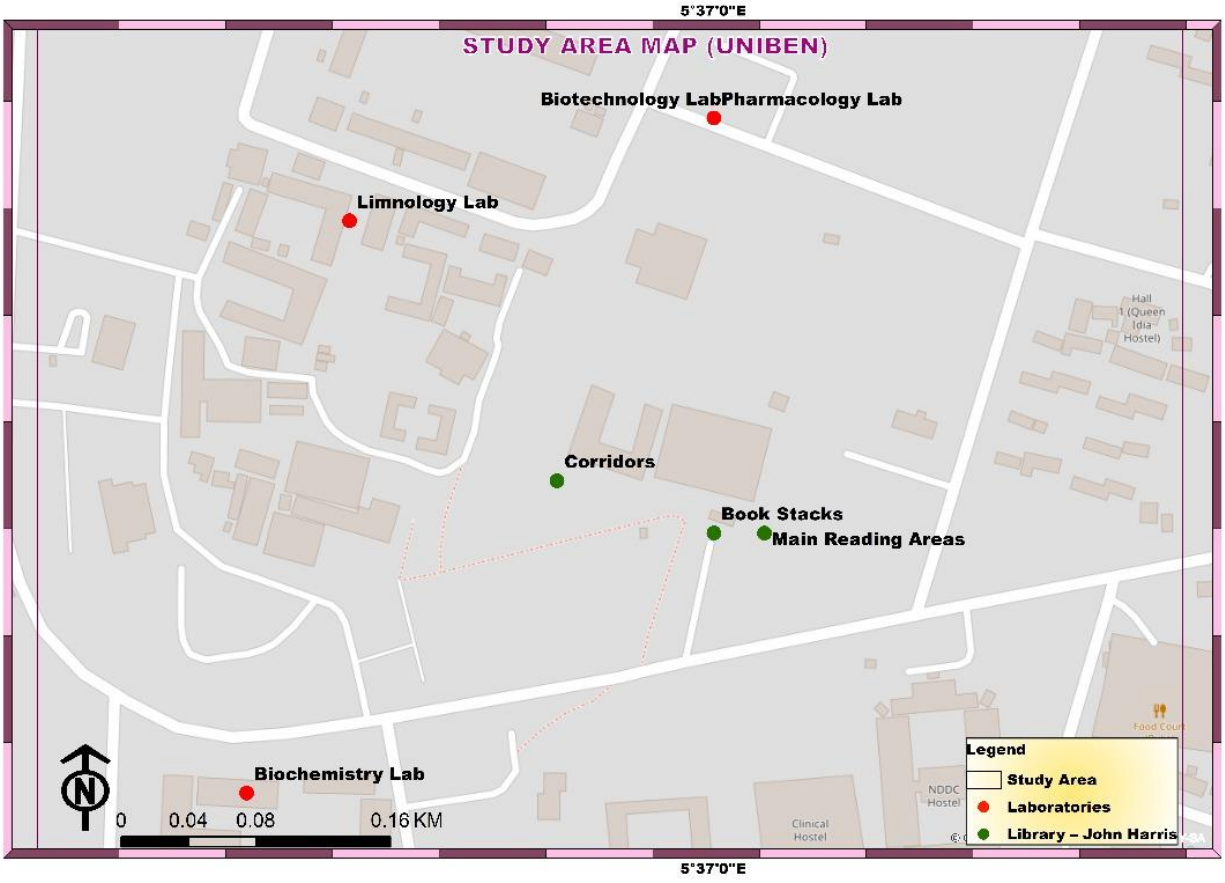

Figure 3.1: Map of the study area

3.2 Description of Sampling sites:

The John Harris Library: This is the main academic library of the University of Benin and is strategically situated along the main drive of the Ugbowo Campus between the Students' Complex (Basement) and the Students' Halls of Residence, directly opposite the Clinical Students Hostel (Medical Hostel). The building has three levels: the basement, the ground floor, and the first floor. The basement houses the bindery, reprography, audio–visual, archival, and canteen sections. The ground floor accommodates facilities such as the Security Post, Journal Unit, Waiting Area, Readers' Conveniences, Catalogue Cabinets, Online Public Access

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Catalogue (OPAC) points, Reference Desk, Circulation Section, and various administrative units. The first floor contains open shelves, special collections, reserved units (textbook collection units), pharmacy libraries, management sciences libraries, and study carrels. Samples for indoor air quality assessment were collected from key points of interest within the library: the Circulation Section, Reference Section (with a reading room and bookshelves), Veterinary Medicine Library (reading room), Arts Library (reading room and bookshelves), and the Library Extension.

The laboratory sampling sites were all located within the Faculty of Life Sciences. These included the Department of Biochemistry Laboratory, used for biochemical experiments and student practicals; the Department of Science Laboratory Technology Laboratory, where a variety of analytical and experimental activities are conducted; and the Limnology Laboratory in the Department of Plant Biology and Biotechnology, which focuses on the study of freshwater ecosystems. All these laboratories are heavily utilized by undergraduate students for routine practical sessions, research projects, and specialized experiments, making them suitable for the assessment of indoor air quality parameters such as $PM_{2.5}$, PM_{10}, CO_2, VOCs, formaldehyde, temperature, and relative humidity.

3.3 Study Design

This study employed a **cross-sectional field measurement design** to assess the relationship between indoor air quality (IAQ) and the prevalence of respiratory symptoms among students and staff. A **cross-sectional design** was chosen because it allows for the simultaneous collection of data on both environmental exposures (IAQ parameters) and health outcomes (respiratory symptoms) at a single point in time. This approach is efficient for providing a snapshot of the

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current situation and is particularly suitable for initial investigations into potential links between indoor environments and health. By using this design, researchers were able to measure pollutant concentrations in libraries and laboratories while concurrently gathering self-reported health information from individuals using those spaces. This facilitated the direct correlation of the environmental data with the health data.

3.4 Selection of Sampling Areas

The sampling areas were purposively selected rather than randomly chosen. The primary reason for this nonrandom selection was to target locations where the potential for exposure to indoor air pollutants was highest. The rationale for this selection was twofold: the chosen libraries and laboratories are heavily frequented by many students and staff for extended periods. This high occupancy creates conditions conducive to the buildup of common indoor pollutants, such as carbon dioxide (from respiration, volatile organic compounds (VOCs) from building materials and cleaning products), and particulate matter ($PM_{2.5}$, PM_{10}). By focusing on these high-traffic areas, this study aimed to assess the most relevant exposure scenarios. These specific locations have characteristics that make them more prone to pollutant accumulation. Labs often use chemicals and reagents that can emit VOCs and other gaseous pollutants. Libraries, with their extensive collection of books, furniture, and frequent human activity, can accumulate dust, mold spores, and other particles. Purposely selecting these sites ensured that the study captured data from environments where indoor air quality issues were most likely to occur, thus increasing the study's relevance and the potential for observing a link between air quality and health symptoms.

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Table 3.1 Coordinates for the library and laboratories

Library				
Book Stacks/Shelving Areas	6°23'46"N, 5°37'0"E			
Main Reading Areas	6°23'46"N, 5°37'01"E	6°23'46"N, 5°37'0"E	6°23'49"N, 5°36'54"E	6°23'47"N, 5°36'57"E
Circulation Desk/Staff Areas	6°33'46"N, 5°37'0"E			
Corridors/Hallways Immediately Outside Libraries	6°23'47"N, 5°36'57"E	6°23'47"N, 5°36'57"E		
Laboratories	Bch lab	Limnology Lab	Pharmacology lab SLT	Biotechnology lab SLT
Indoor	6°23'41"N, 5°36'51"E	6°23'52"N, 5°36'53"E	6°23'54"N, 5°37'0"E	6°23'54"N, 5°37'0"E
Corridors/Hallways Immediately Outside Labs			6°25'54"N, 5°37'0"E	

3.5 Air Quality Sampling and Meteorological Parameters

Air quality sampling was conducted over an eight-week period (July–September 2025) to capture both within-day and weekly variations. Sampling was performed once a week, with measurements taken during two distinct time slots—morning and afternoon—to coincide with peak usage hours in both the selected libraries and laboratories. For the measurements, two portable air monitoring devices were used to ensure accuracy and consistency. The

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concentrations of key indoor air pollutants were measured in situ at predetermined locations within each facility. The parameters measured included particulate matter ($PM_{2.5}$, PM_{10}), carbon dioxide (CO_2), volatile organic compounds (VOCs), and formaldehyde. A handheld smart air quality monitor (BR-Smart-126 series) was the primary device used. It is equipped with sensitive sensors and a digital LCD screen for real-time data display. All measurements were taken in triplicate at each site at a height of approximately 1.5 m above the ground, which represents the average human breathing zone. The mean values obtained for each parameter were then calculated and compared against the World Health Organization (WHO) 24-hour air quality guideline limits to assess the quality of the indoor air. Meteorological parameters, including temperature and relative humidity, were measured concurrently with the air quality sampling. These data were recorded via the built-in sensors of the BR-Smart-126 series monitor and a separate smart sensor (model AS8700A). All the instruments were operated in strict accordance with the manufacturer's guidelines, and their calibration was verified before each sampling day to ensure the accuracy and reliability of the data.

3.6 Structured Questionnaire for Health and Exposure Information

A structured questionnaire was developed to collect information on respondents' health status, work history, and potential exposure to air pollutants. The questionnaire will undergo expert review and pretesting to ensure validity, clarity, and ease of completion. This process helps refine the questions, minimizes ambiguity, and ensures that the tool is appropriate for the target population.

3.7 Sample size determination

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The total study population included 180 students from the laboratory and library during the period of the study. The Taro Yamane method (1967) was used to determine the sample size. The formula was as follows:

$$n = \frac{N}{1 + N \times e^2}$$

where:

- n is the calculated sample size,
- N is the population size (here, 140, the estimated exposed population),
- e^2 is the margin of error (here, 0.05, or 5%).

This formula assumes a 95% confidence level and a 50% response distribution.

$$n = \frac{140}{1 + 140 \times 0.05^2}$$

$$n = 103.7$$

3.8 Reliability of the questionnaires

Internal consistency was not applicable to this study, but its reliability was ensured by the use of standardized protocols throughout the data collection process. Cronbach's alpha test was performed to assess the reliability of the structured questionnaire (Bonnet and Wright, 2015). The resulting alpha value of >0.85 indicated strong internal consistency for the survey instrument.

3.9 Ethical Considerations and Data Protection

Informed consent was obtained from all survey respondents. Participation in the study was entirely voluntary and anonymous, with respondents being fully briefed on the study's purpose and their right to withdraw at any time. The confidentiality of all the data were strictly maintained in accordance with the ethical principles outlined in the Declaration of Helsinki. For

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the air quality measurements, formal permission was secured from the heads of the various academic departments and the authorities of the university library. This step ensured full compliance with institutional and community regulations, granting appropriate access to all the sampling locations.

3.10 Data analysis

The collected air quality data will be examined via descriptive statistics, such as the means and standard deviations, alongside inferential statistical methods such as analysis of variance (ANOVA) performed with SPSS version 22.0 for Windows. Data from the questionnaires will be presented as percentages and frequency distributions. The relationships between identified risk factors and respiratory symptoms will be evaluated via chi-square tests and logistic regression models. Statistical significance was recognized at a p value less than 0.05.

CHAPTER FOUR

4.0 RESULTS

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Figure 4.1 presents the mean $PM_{2.5}$ levels in the library, revealing a consistent diurnal trend where morning concentrations exceed afternoon concentrations across all four monitoring sites. The highest exposure was recorded in the Corridor/Hallway in Morning (22.05 μg/m³)**,** likely reflecting high foot traffic, whereas the lowest exposure was recorded in the Main Reading Area in the Afternoon (14.55 μg/m³)**.** The standard error bars demonstrate slightly greater data variability in the morning samples (SEM 1.1–1.4) than in the afternoon samples (SEM 0.6–0.9).

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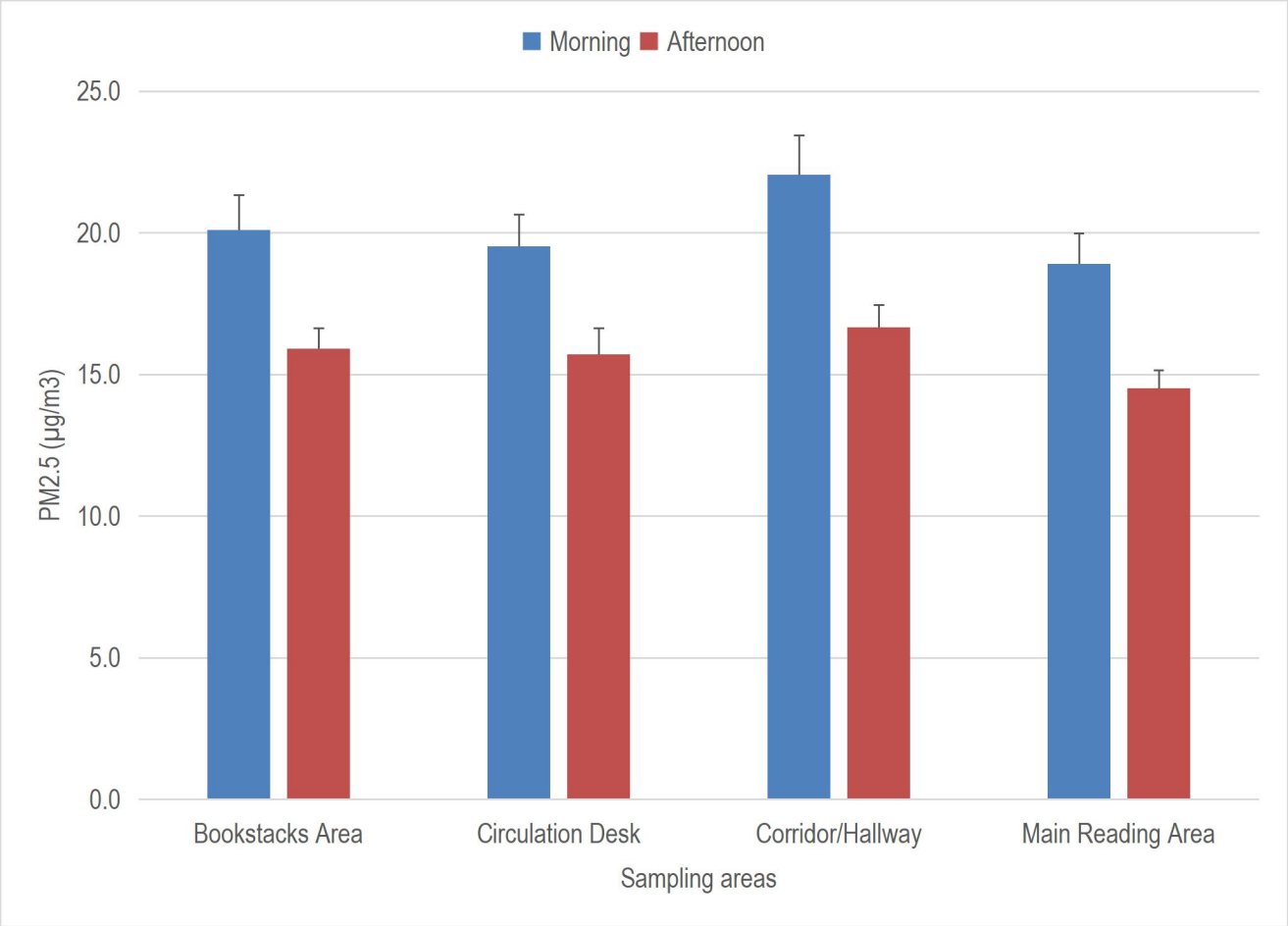

Figure 4.1: Mean concentrations of $PM_{2.5}$ (µg/m³) across morning and afternoon sampling periods.

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The PM_{10} data, displayed in Figure 4.2, mirror the $PM_{2.5}$ pattern by showing elevated mean concentrations during morning compared with afternoon across all the sampling points. The Bookstack Area registered the maximum particle load in Morning (37.5 $\mu g/m^3$), in contrast with the lowest concentration found in the Main Reading Area in the Afternoon (27.0 $\mu g/m^3$). A notable distinction from the $PM_{2.5}$ data is the high variability observed in the morning PM_{10}b measurements. With error bars indicating variability up to 3.1 (corridor/hallway) in Morning versus a stable range of 1.5--2.1 in the afternoon, the data suggest that the PM_{10} sources at the start of the day were subjected to greater fluctuations**.**

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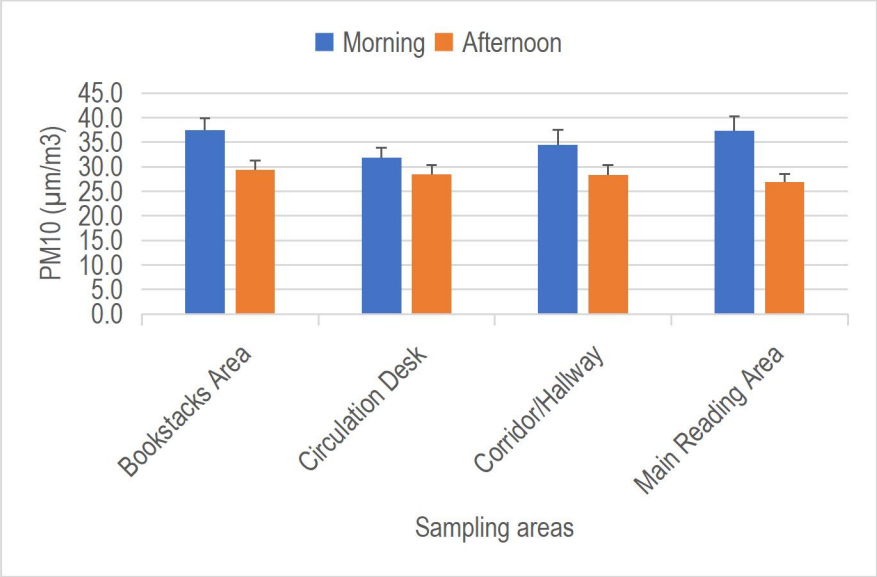

Figure 4.2: Mean concentrations of PM_{10} ($\mu g/m^3$) across the morning and afternoon sampling periods.

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Figure 4.3 presents the average carbon dioxide (CO_2) concentrations, which showed striking temporal and spatial homogeneity across the four library sampling locations. Unlike the particulate matter results, the CO_2 means clustered tightly at approximately 400.0 ppm for both the morning and afternoon periods. This visual stability is reinforced by the incredibly small and consistent standard error of the mean (SEM) error bars (0.3 ppm) across all eight measurements.

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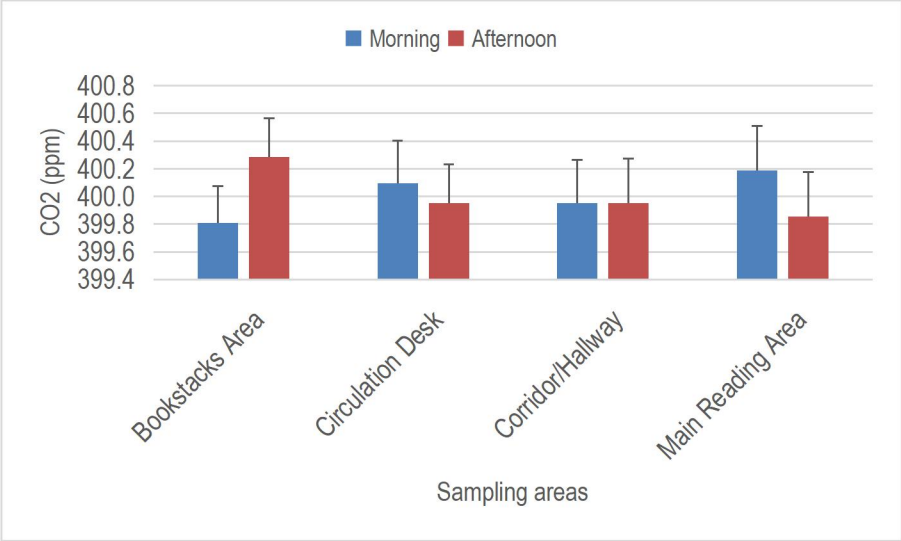

Figure 4.3: Mean concentrations of CO_2 (ppm) across the morning and afternoon sampling periods.

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Figure 4.4 shows the mean concentrations of formaldehyde (HCOH), a key volatile organic compound, across the four library sampling points. The visualization reveals extreme stability and very low absolute concentrations, with all means falling between 0.003 and 0.005 ppm. Unlike particulate matter, there is no clear directional trend favouring either the morning or afternoon period. The data exhibit negligible variability, with the error bars (standard error of the mean, SEM) effectively equal to zero (0.001) for all the measurements.

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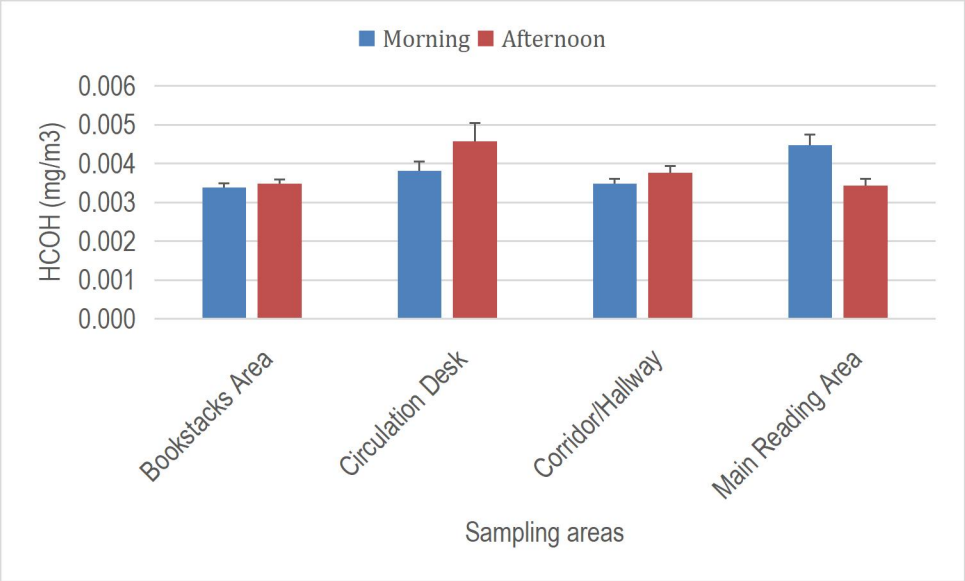

Figure 4.4: Mean concentrations of HCOH (mg/m³) across the morning and afternoon sampling periods.

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Figure 4.5 shows the mean temperature recordings across the four library sampling points. Unlike the particulate pollutants, the temperature data show a clear and expected trend: afternoon temperatures were consistently higher than morning temperatures across all locations. The largest thermal difference was noted in the main reading area, which increased from a mean of 24.6°C in the morning to 27.0°C in the afternoon. The highest overall mean temperature (27.0°C) was also recorded in this area in the afternoon. The error bars (standard errors of the means) are uniformly low (ranging from 0.1--0.2), indicating very little variability within the temperature measurements for both time periods.

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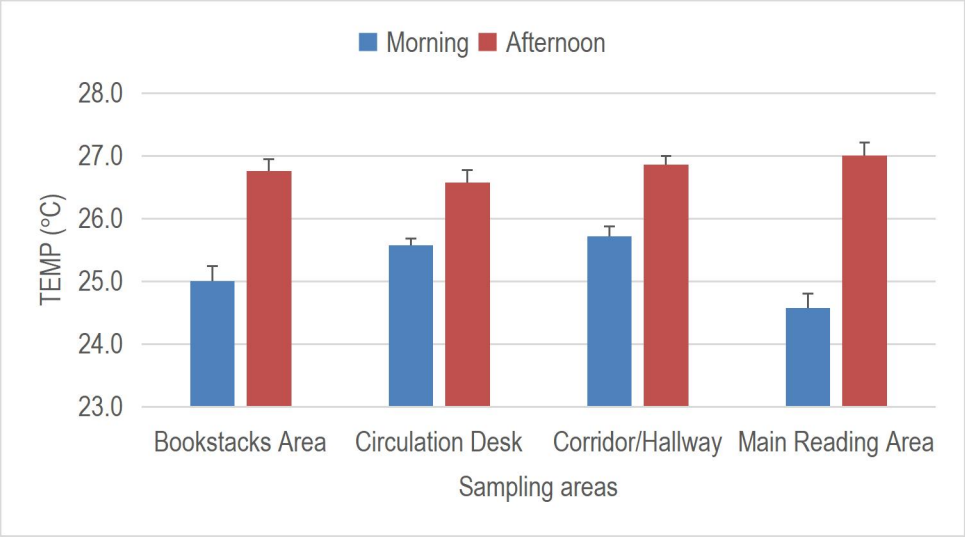

Figure 4.5: Mean concentrations of temperature (°C) across the morning and afternoon sampling periods.

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The mean relative humidity (Rh%) for each of the four library sampling locations is shown in Figure 4.6. The morning Rh% was substantially higher than the afternoon Rh% at all locations, indicating clear and consistent diurnal variation. The temperature increase shown in Figure 4.5 is inversely related to this trend, which is to be expected. The Corridor/Hallway area had the lowest mean Rh% in the afternoon (69.1%), whereas the main reading area had the highest Rh% in the morning (78.3%). On average, there was an 8--9 percentage point difference between the morning and afternoon humidity levels.

Low variability within the humidity measurements is indicated by the uniformly low standard error of the mean (standard error of the mean) bars, which range from 0.4--0.8.

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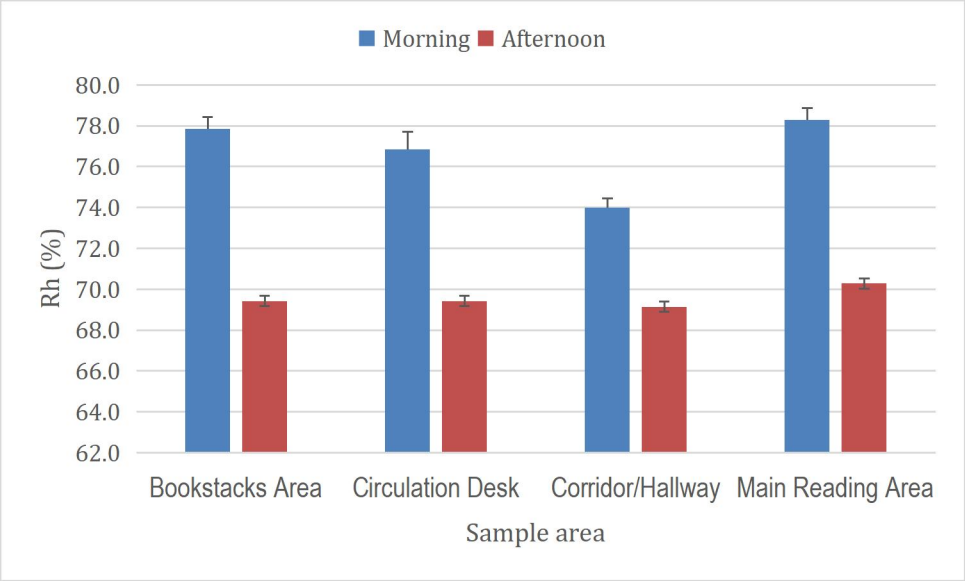

Figure 4.6: Mean concentrations of Rh **(%)** across the morning and afternoon sampling periods.

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Figure 4.7 shows the mean $PM_{2.5}$ concentrations across the four laboratory sampling points. The visual trend of higher morning concentrations than afternoon concentrations was consistent across all four lab locations. The highest overall mean was recorded in the second SLT Lab in the morning (24.1 μm/m³), whereas the lowest was recorded in the PBB Lab in the afternoon (15.6 μm/m³). The chart highlights a key factor contributing to the overall nonsignificant statistical finding: the high variability in the morning measurements. The error bar for the BCH Lab in the morning (3.3 μm/m³) is more than three times the error in the afternoon (1.0 μm/m³), and the second SLT Lab also has a high morning error (3.1 μm/m³). This large, inconsistent variability across the morning measurements confirms that while the means may be visually different, the data scatter is too wide to establish a statistically significant temporal difference.

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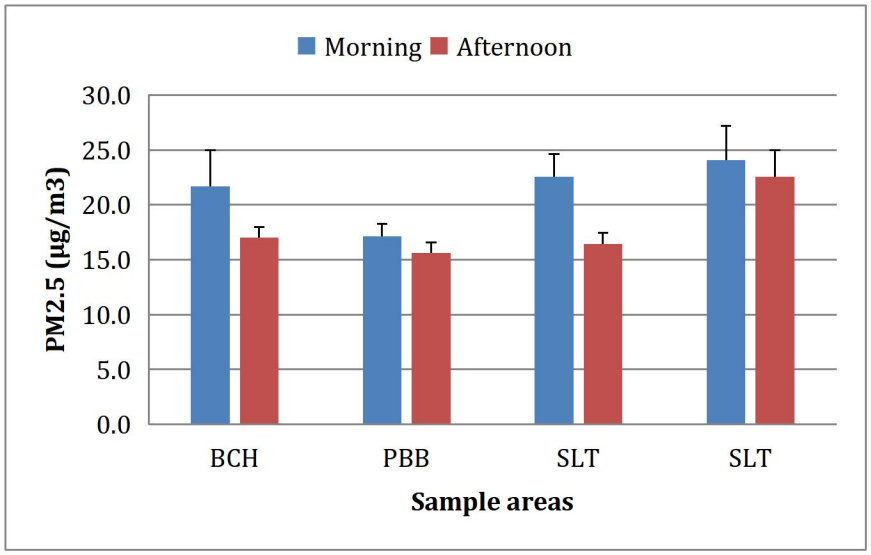

Figure 4.7: Mean concentrations of $PM_{2.5}$ (µg/m³) across the morning and afternoon sampling periods.

Figure 4.8 displays the mean PM_{10} concentrations across the four laboratory sampling points. The overall visual trend decreased from morning to afternoon, with the highest concentration recorded in the BCH Lab in the morning (43.2 $\mu m/m^3$) and the lowest in SLT Lab 1 in the afternoon (30.7 $\mu m/m^3$). Notably, one location, the second SLT Lab, shows a slight inverse trend, with the afternoon mean (31.2 $\mu m/m^3$) being higher than the morning mean (29.0 $\mu m/m^3$). The error bars (standard error of the mean) highlight the extreme variability of the morning measurement in the BCH Lab (6.7), which is dramatically larger than the corresponding afternoon error (1.9).

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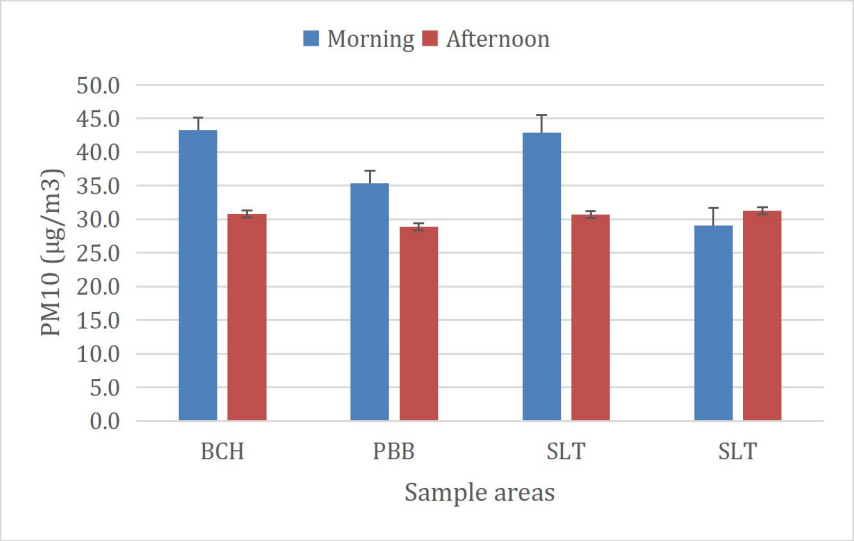

Figure 4.8: **M**ean concentrations of PM_{10} (µg/m³) across the morning and afternoon sampling periods.

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Figure 4.9 shows the mean carbon dioxide (CO_2) concentrations across the four laboratory sampling points. The visualization shows high spatial and temporal stability across three of the four locations, with means clustering tightly near the outdoor baseline of 400.0 ppm. However, a notable difference in the first SLT Lab afternoon measurement is highlighted in the chart. At 404.4 ppm, this point had the highest mean concentration. More importantly, its large error bar (4.7 ppm) showed that it was highly variable.

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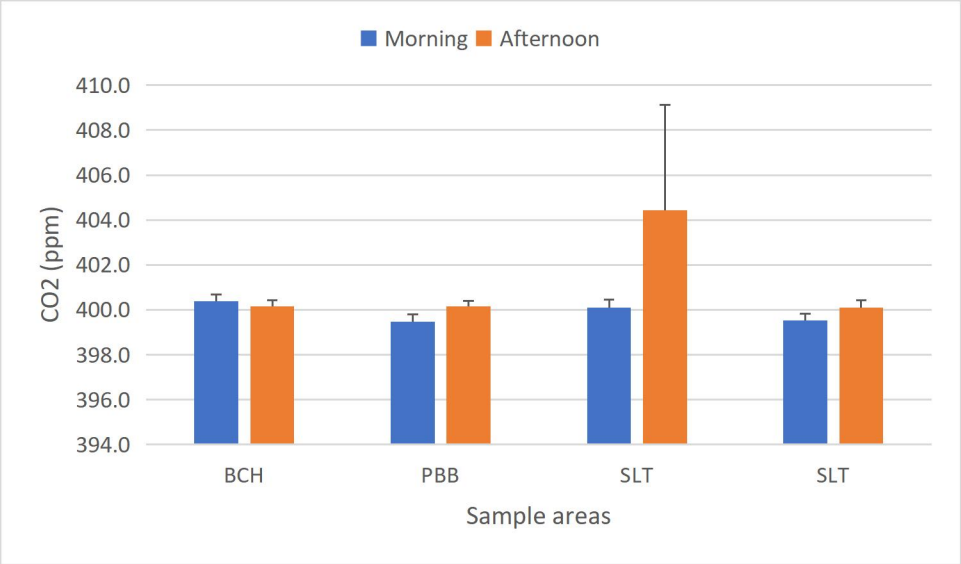

Figure 4.9: Mean concentrations of CO_2 (ppm) across the morning and afternoon sampling periods.

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Figure 4.10 reveals a notable pattern for HCOH, which contrasts with the extreme stability observed in the library (Figure 4.4). All laboratory locations, except for the PBB Lab, recorded significantly higher mean concentrations in the afternoon than in the morning, suggesting that the use of chemicals or the operation of equipment in the afternoon contributes to VOC emission. The most extreme concentration was observed in the second SLT Lab afternoon reading (0.026). Furthermore, the chart highlights a spike in variability in the afternoon. The error bar for the second SLT Lab afternoon measurement (0.012) is exceptionally large and is four times greater than the largest morning error. This high afternoon mean and high variability for HCOH concentrations point to sporadic, concentrated afternoon usage as a major source of this pollutant in the laboratory environment.

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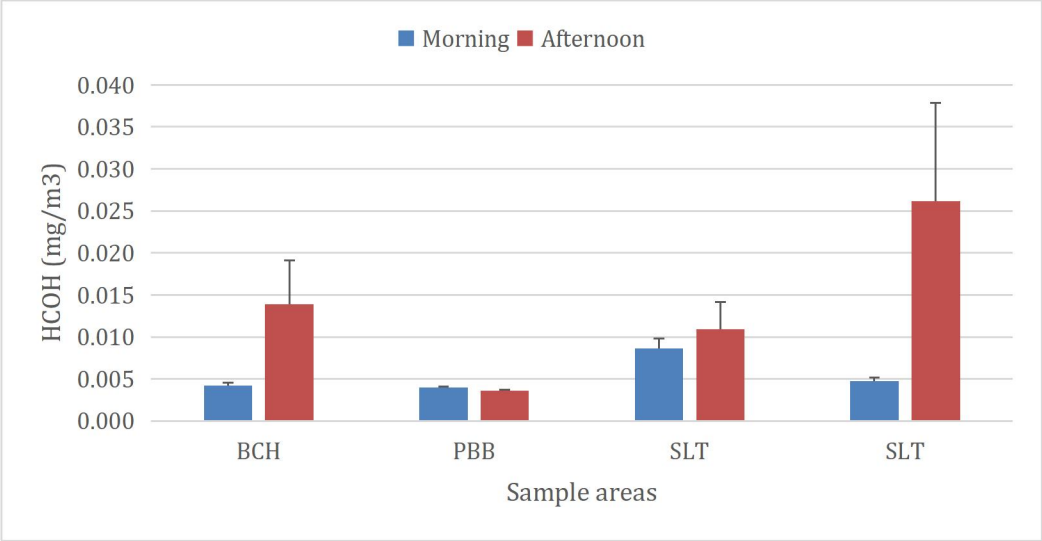

Figure 4.10: Mean concentrations of the air pollutant HCOH (mg/m³) across the morning and afternoon sampling periods.

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Figure 4.11 displays the mean temperature recordings across the four laboratory sampling points, revealing mixed thermal control within the laboratory spaces. While the BCH Lab and the second SLT Lab showed expected thermal increases in the afternoon, the first SLT Lab showed a slight decrease in temperature from morning (25.4 °C) to afternoon (25.1 °C). The most notable anomaly is the PBB Lab, which recorded the highest mean temperatures (32.0 °C in the morning and 32.6 °C in the afternoon), indicating significant thermal discomfort compared with the other spaces. The error bars (standard error of the mean, SEM) further highlight this inconsistency. The PBB Lab shows extremely high variability in both time periods (3.8 and 3.7).

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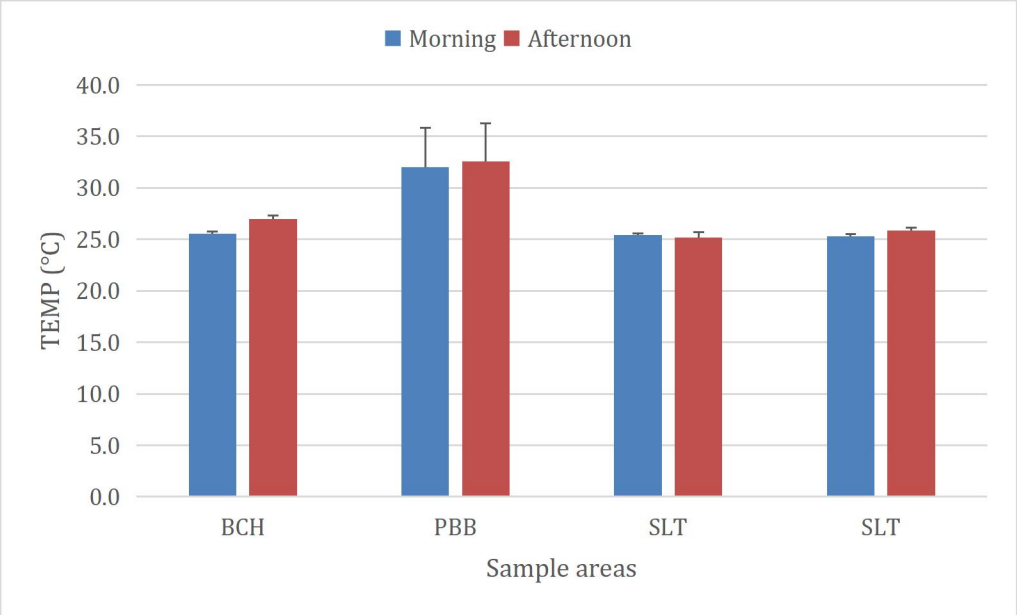

Figure 4.11: Mean concentrations of air pollutant temperatures (°C) across the morning and afternoon sampling periods.

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Figure 4.12 shows the mean relative humidity (Rh%) across the four laboratory sampling points. The visualization shows a uniform trend where the morning Rh% is consistently slightly higher than the afternoon Rh% across all locations. This trend is inversely related to the diurnal temperature change (Figure 4.11). The highest recorded mean Rh% was in the PBB Lab in the morning (75.9%), whereas the lowest was in the BCH Lab in the afternoon (71.1%). The magnitude of the temporal difference is small, generally less than 2 percentage points.

The error bars (standard errors of the means) are uniformly low (ranging from 0.4--0.9) across all 8 measurements, indicating high consistency in the humidity levels. This high temporal and spatial consistency for relative humidity provides strong visual evidence supporting the overall nonsignificant t test result in Table 4.1, suggesting that humidity, while high, was statistically stable in the laboratory environment.

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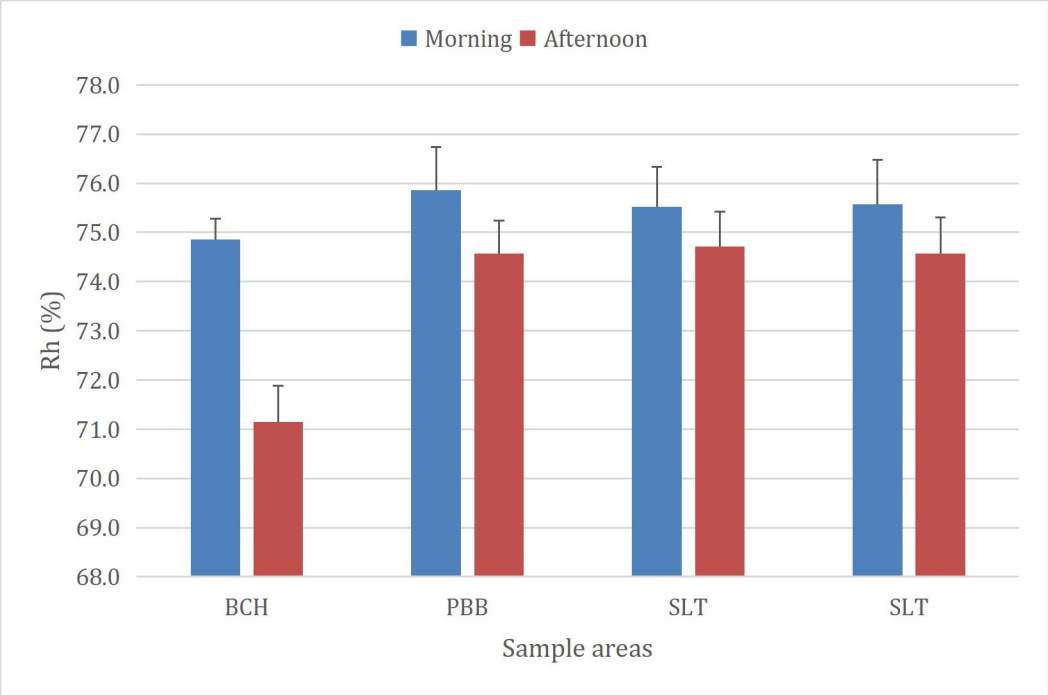

Figure 4.12: Mean concentrations of Rh (%) across the morning and afternoon sampling periods.

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The demographic characteristics of the 140 respondents are presented in Table 4.2. The sample was described on the basis of sex, age, and level of study. With respect to gender, the majority of the respondents were female (67.8%), followed by male (32.2%). The respondent's age was divided into several categories. The highest proportion of the sample fell within the 18–30 years bracket, accounting for 48% of the participants. The least represented group was the 31–40 years bracket at 19%. In terms of the level of study, the sample was predominantly composed of 500 samples (28.6%). A complete breakdown of the demographic characteristics is provided in Table 4.2.

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Table 4.2: Demographic characteristics of the respondents (N=140)

Variable	Category	Frequency (N)	Percentage (%)
Gender	Male	49	32.2
	Female	103	67.8
Age	<18yrs	20	13.2
	18−30yrs	73	48
	31−40yrs	19	12.5
	41−50yrs	17	11.2
	>51yrs	23	15.1
Level of study			
	100level	9	6.4
	200level	30	21.4
	300level	19	13.6
	400level	29	20.7
	500level	40	28.6
	600level	2	1.4
	Postgraduate	11	28.6

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Table 4.3 presents the reported health and environmental risk factors, including respiratory conditions, smoking status, and various study environment characteristics, among the 140 respondents. The vast majority of the respondents (92.1%) reported no preexisting respiratory conditions (e.g., asthma, allergies). The data on smoking status revealed that 6.4% of the respondents identified as smokers, whereas the majority (93.6%) reported nonsmoking. The average number of study sessions reported by respondents most frequently fell into the 3--5-hour category, accounting for 42.9% of the total. Regarding ventilation, the majority of the study spaces relied on mechanical systems (79%). The signs of dampness or mold growth in the study areas were reported to be low, with a percentage of 62.9%. For cleaning frequency, the most common response was daily, accounting for 72.1% of the responses. In terms of environmental conditions, the vast majority of respondents (62.9%) reported no signs of dampness or mould growth in their study area. Conversely, only a small minority (37.1%) indicated the presence of these signs. The detailed frequency and percentage breakdown of these reported risk factors are presented in Table 4.3.

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Table 4.3: Reported risk factors among respondents (N=140)

Variable	Category	Frequency (N)	Percentage (%)
Preexisting Respiratory Condition	No	129	92.1
	Yes	11	7.9
Smoking status	No	131	93.6
	Yes	9	6.4
Average Study Session	<1 hr.	7	5
	1-3 hrs	52	37.1
	3-5 hrs	60	42.9
	>5 hrs	21	15
Type of Ventilation System	Natural	45	32.1
	Mechanical	79	56.4
	Exhaust fans	16	11.4
Signs of dampness or mold growth	No	88	62.9
	Yes	52	37.1
Frequency of cleaning			
	Daily	101	72.1
	Weekly	26	18.6
	Biweekly	4	2.9
	Monthly	8	5.7

Table 4.4 summarizes the self-reported health effects among the respondents. Overall, the analysis indicated a low prevalence across all reported symptoms. For the main respiratory symptoms, the majority of respondents reported no experience with these conditions. Specifically, coughing persistent (not cold-related) was reported by only 15% of the sample, whereas wheezing or whistling in the chest had an even lower prevalence of 4.3%. Shortness of breath and chest tightness were similarly infrequent, with only 14.3% and 7.9% of respondents reporting yes, respectively. Non-respiratory symptoms also presented low prevalence rates. Runny or stuffy nose and frequent sneezing (both not cold-related) were reported by only 22.9% and 29.3% of the sample, respectively. The least common issue was itchy or watery eyes, which were reported by a small minority (13.6%). In summary, the data suggest that 140 respondents did not experience a widespread incidence of these specific health complaints. The complete frequencies and percentages are detailed in Table 4.4

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Table 4.4: Reported health effects among respondents (N=140)

Variable	Category	Frequency (N)	Percentage (%)
Coughing persistent not cold related	No	118	84.3
	Yes	21	15
Wheezing or whistling in the chest	No	134	95.7
	Yes	6	4.3
Shortness of breath difficulty breathing	No	120	85.7
	Yes	20	14.3
Chest tightness	No	129	92.1
	Yes	11	7.9
Runny or stuffy nose not cold related	No	108	77.1
	Yes	32	22.9
Sneezing frequent not cold related	No	99	70.7
	Yes	41	29.3
Itchy or watery eyes	No	121	86.4
	Yes	19	13.6

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A series of chi-square tests of independence were performed to examine the associations between persistent cough and various reported risk factors. The results are presented in Table 4.5. The analysis revealed no statistically significant association between sex and reporting of persistent cough, $x^2 = 0.065$, $p = 0.799$. These findings suggest that the frequency of persistent cough did not differ significantly across male and female respondents. Similarly, the age of the respondents was not significantly associated with persistent cough, $x^2 = 2.676$, $p = 0.445$. Although minor differences in prevalence rates may have been observed, they were considered to be due to chance variation. A highly significant association was established between preexisting respiratory conditions and persistent cough ($x^2 = 8.577$, $p = 0.003$). The prevalence of persistent cough was significantly higher among respondents who reported no preexisting respiratory condition (reported a cough rate of 76.2%) than among those who reported YES to have a preexisting condition (where the cough rate was only 23.8%). A statistically significant relationship was established between the frequency of cleaning and the reporting of persistent cough, $x^2 = 25.643$, $p = 0.001$. The data indicate that the prevalence of persistent cough was not uniform across cleaning frequencies. Specifically, the highest rate of persistent cough was found among the daily cleaning category, with a prevalence of 47.6%. Conversely, respondents who reported monthly cleaning had the lowest rate of persistent cough, at only 9.5%. The complete results of the chi-square analysis are presented in Table 4.5.

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Table 4.5: Association between persistent cough and reported risk factors

Variables	Persistent cough			
	Yes n (%)	**No n (%)**	**χ^2**	**(p value)**
Gender			**0.065**	0.799
Male	6 (28.6%)	37 (31.4%)		
Female	15 (71.4%)	81 (68.6%)		
Age			2.676	0.445
18-20yrs	7 (33.3%)	47 (39.8%)		
21-23yrs	9 (42.9%)	55 (46.6%)		
24-26yrs	4 (19.0%)	15 (12.7%)		
>26yrs	1 (4.8%)	1 (0.8%)		
Preexisting Respiratory Condition			8.577	**0.003**
No	16 (76.2%)	112 (94.9%)		
Yes	5 (23.8%)	6 (5.1%)		
Frequency in Cleaning			25.643	0.001
Daily	10 (47.6%)	90 (76.3%)		
Weekly	5 (23.8%)	21 (17.8%)		
Biweekly	4 (19.0%)	0 (0.0%)		
Monthly	2 (9.5%)	6 (5.1%)		

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A set of chi-square independence tests was performed to explore the relationships between self-reported wheezing over the past 12 months and various significant risk factors, as outlined in Table 4.6. The analysis revealed a mixed pattern of associations. A statistically significant association was found between smoking status and reporting of wheezing, $x^2 = 7.544$, $p = 0.006$. The prevalence of wheezing was higher among respondents who were smokers (reported a wheezing rate of 66.7%) than among those who were nonsmokers (reported a rate of 33.3%). On the other hand, no statistically significant associations were found between the reporting of wheezing and either signs of dampness ($x^2 = 2.344$, $p = 0.126$) or preexisting respiratory conditions ($x^2 = 5.621$, $p = 0.018$). This finding indicates that the frequency of wheezing did not significantly differ on the basis of the reported presence of dampness or the respondent's preexisting respiratory health. Finally, a significant association was also observed for the frequency of cleaning and wheezing ($x^2 = 21.971$, $p = 0.001$). The highest prevalence of wheezing was reported by respondents who selected the daily cleaning category, at 66.7%, whereas the lowest prevalence was found in the monthly group, at 0.0%. In summary, the prevalence of wheezing was significantly associated with both smoking status and the frequency of cleaning but not with signs of dampness or the presence of a preexisting respiratory condition. The complete findings are detailed in Table 4.6.

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Table 4.6: Association between wheezing in the past 12 months and reported risk factors

Variables	Wheezing in the past 12 months			
	Yes n (%)	**No n (%)**	**χ^2**	**(p value)**
Smoking status			7.544	0.006
No	2 (33.3%)	7 (5.2%)		
Yes	4 (66.7%)	127 (94.8%)		
Signs of Dampness			2.344	0.126
No	2 (33.3%)	86 (64.2%)		
Yes	4 (66.7%)	48 (35.8%)		
Preexisting Respiratory Condition			5.621	0.018
No	2 (33.3%)	125 (93.3%)		
Yes	4 (66.7%)	9 (6.7%)		
Frequency in Cleaning			21.971	0.001
Daily	4 (66.7%)	97 (72.4%)		
Weekly	0 (0.0%)	26 (19.4%)		
Biweekly	2 (33.3%)	2 (1.5%)		
Monthly	0 (0.0%)	8 (6.0%)		

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A third series of chi-square tests of independence was conducted to assess the associations between shortness of breath and selected risk factors, and the results are summarized in Table 4.7. The analysis revealed no statistically significant association between smoking status and shortness of breath (x^2 = 2.856, p = 0.091). In contrast, a statistically significant association was found with preexisting respiratory conditions (x^2 = <0.01, p = 0.001). In contrast, the prevalence of shortness of breath was significantly greater among respondents who reported no preexisting respiratory condition (reported a rate of 95.8%) than among those who reported yes to having a preexisting condition (where the rate was only 4.2%). Additionally, a significant association was observed for the frequency of cleaning (x^2 = 13.934, p = 0.008). The highest prevalence of shortness of breath for daily cleaning was 75.0%, whereas the lowest prevalence was found in the monthly category, at 5.0%. The complete findings are detailed in Table 4.7

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Table 4.7: Association between shortness of breath and reported risk factors

Variables	Shortness of Breath			
	Yes n (%)	**No n (%)**	**χ^2**	**(p value)**
Smoking status			2.856	0.091
No	114 (95.0%)	17 (85.0%)		
Yes	6 (5.0%)	3 (15.0%)		
Preexisting Respiratory Condition			15.802	<0.001
No	115 (95.8%)	14 (70.0%)		
Yes	5 (4.2%)	6 (30.0%)		
Frequency in Cleaning			13.934	0.008
Daily	90 (75.0%)	11 (55.0%)		
Weekly	22 (18.3%)	4 (20.0%)		
Biweekly	1 (0.8%)	3 (15.0%)		
Monthly	6 (5.0%)	2 (10.0%)		

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Another series of chi-square tests of independence was conducted to assess the associations between chest tightness and selected risk factors, such as sex, preexisting respiratory conditions, frequency of cleaning and average number of study sessions; the results are summarized in Table 4.8. The analysis failed to identify any statistically significant associations between chest tightness and the reported risk factors. Specifically, gender ($x^2 = 0.881$, $p = 0.348$), preexisting respiratory condition ($x^2 = 6.216$, $p = 0.013$), frequency of cleaning ($x^2 = 2.525$, $p = 0.641$), and average study session ($x^2 = 8.715$, $p = 0.641$) were not significantly related to the prevalence of chest tightness among respondents. The complete findings are detailed in Table 4.8.

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Table 4.8: Association between chest tightness and reported risk factors

Variables	Chest tightness			
	Yes n (%)	**No n (%)**	**χ^2**	**(p value)**
Gender			0.881	0.348
No	41 (31.8%)	2 (18.2%)		
Yes	88 (68.2%)	9 (81.8%)		
Preexisting Respiratory Condition			6.216	0.013
No	121 (93.8%)	11 (7.9%)		
Yes	8 (6.2%)	8 (72.7%)		
Frequency in Cleaning			2.525	0.641
Daily	93 (72.1%)	8 (72.7%)		
Weekly	25 (19.4%)	1 (9.1%)		
Biweekly	3 (2.3%)	1 (9.1%)		
Monthly	7 (5.4%)	1 (9.1%)		
Average Study Session			8.715	0.033
<1 hr	7 (5.4%)	0 (0.0%)		
1−3 hrs	52 (40.3%)	0 (0.0%)		
3−5 hrs	52 (40.3%)	8 (72.7%)		
>5 hrs	18 (14.0%)	3 (27.3%)		

The final set of association analyses, presented in Table 4.9, uses chi-square tests to investigate the relationships between itchy or watery eyes and key risk factors such as sex, preexisting respiratory conditions, signs of dampness/mould, and smoking status. The analysis failed to identify a statistically significant association between itchy/watery eyes and three of the factors examined: sex ($x^2 = 0.008$, $p = 0.93$), preexisting respiratory condition ($x^2 = 5.287$, $p = 0.021$), and smoking status ($x^2 = 0.158$, $p = 0.691$). The prevalence of itchy/watery eyes was therefore statistically independent of these risk factors. On the other hand, the prevalence of itchy/watery eyes was significantly greater (68.4%) among respondents who reported no signs of dampness or mold than among those who reported YES (31.6%). To summarize, the chi-square tests indicate that signs of dampness or mold are the only analysed factor significantly associated with the prevalence of itchy or watery eyes, whereas the remaining variables showed no such relationship. The complete findings are detailed in Table 4.9.

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Table 4.9: Association between itchy/watery eyes and reported risk factors

Variables	Itchy/watery eyes			
	Yes n (%)	**No n (%)**	**χ^2**	**(p value)**
Gender			0.008	0.93
No	6(31.6%)	37(30.6%)		
Yes	13(68.4%)	84(69.4%)		
Preexisting Respiratory Condition			5.287	0.021*
No	4(21.1%)	7(5.8%)		
Yes	15(78.9%)	114(94.2%)		
Signs of Dampness/mold			9.212	0.002*
No	13(68.4%)	39(32.2%)		
Weekly	6(31.6%)	82(67.8%)		
Smoking Status				
No	0(0.0%)	1(0.8%)	0.158	0.691
Yes	19(100.0%)	120(99.2%)		

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CHAPTER 5

5.0 Discussion

The results of this study indicate that the measured indoor air pollutant concentrations presented in Table 4.1 were statistically stable across the morning and afternoon sampling periods. Paired-samples t tests revealed no significant differences in the mean pollutant concentrations between these times ($p > 0.01$). Despite this temporal stability, several environmental risk factors, most notably cleaning frequency and visible signs of dampness or mold, were significantly associated with multiple self-reported respiratory and mucosal symptoms (Tables 4.5, 4.6, 4.7, 4.9). In some instances, the prevalence of specific respiratory symptoms, such as persistent cough and shortness of breath, was inversely associated with a preexisting respiratory condition (Tables 4.5, 4.7). The paired samples t test indicated that the mean concentrations of all analysed air pollutants did not differ significantly between the morning and afternoon sampling periods ($p > .01$). This result suggests a relatively stable indoor air environment within the monitored facilities during operational hours. This stability can be interpreted in several ways relative to the building's dynamics. The consistent nature of the means implies that pollutant levels may be governed primarily by steady, continuous sources within buildings. Potential contributors include sustained occupant-generated CO_2, ongoing emissions from building materials or furnishings, and persistent resuspension of settled dust. The impact of these internal sources appears strong enough to overshadow any typical time-of-day variations (such as traffic-related pollutants that might fluctuate outdoors). The nonsignificant difference points to a consistently operating mechanical ventilation system that may maintain a steady air exchange rate, effectively decoupling the indoor pollutant load from external diurnal factors. Crucially, this stability in measured pollutants highlights that the significant health symptoms reported by respondents

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(Tables 4.5--4.9) are likely not driven by acute temporal fluctuations in these specific pollutants but rather by chronic exposure to persistent indoor conditions rather than short-term fluctuations in the measured pollutants.

The descriptive statistics established the context for the study, showing that the majority of respondents reported a low prevalence of preexisting respiratory conditions (Table 4.3) and a low overall incidence of specific health symptoms (Table 4.4). This overall lower-than-anticipated baseline of reported symptoms means that the significant associations found later are particularly robust, as they relate a risk factor to a relatively rare event.

The chi-square analyses provided compelling evidence linking the maintenance quality of the study environment to student health outcomes. The analysis demonstrated a significant association between the observed frequency of cleaning (of the lab/library area) and the reporting of persistent cough, wheezing, and shortness of breath. This finding presented an inverse relationship with the expected pattern of reduced symptoms with increased cleaning. The highest prevalence of persistent cough (47.6%) was reported among respondents in the daily cleaning category, whereas the lowest rate was reported in the monthly/less cleaning category (only 9.5%). This unexpected result strongly suggests that the method or timing of cleaning acts as a pollutant source rather than a mitigant. The likely mechanism is that daily cleaning may involve dry sweeping or dusting methods that resuspend settled dust, biological allergens, and settled pollutants back into the breathing zone immediately before or during peak occupancy hours. Additionally, the frequent use of chemical cleaning products in daily protocols may contribute to high levels of volatile organic compounds (VOCs) and chemical irritants that trigger respiratory symptoms. This finding underscores that while maintenance is critical, the quality and timing of cleaning activities, not just the frequency, must be addressed as a primary intervention.

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The associations between signs of dampness/mold and itchy/watery eyes were also inverse: the symptom prevalence was significantly greater (68.4%) among respondents who reported no signs of dampness/mold than among those who reported YES (31.6%). This suggests that visible signs of dampness are not the primary cause. Instead, eye irritation may be driven by unseen contaminants such as airborne chemicals or low humidity that are present in areas that are otherwise well maintained (i.e., no visible dampness).

The prevalence of persistent cough (Table 4.5) and shortness of breath (Table 4.7) was greater among respondents who reported no preexisting respiratory conditions than among those who reported YES. This finding contradicts the expected pattern where individuals with a diagnosed respiratory condition are considered most vulnerable. The plausible explanations for this could be that the group with the highest symptom prevalence (those who answered no to the preexisting condition) may represent a population whose symptoms are solely caused by the building environment or who have an undiagnosed building-related illness (BRI). Several factors hypothesized to influence respiratory risk, such as sex, age, and smoking status, showed no statistically significant associations with any of the reported health outcomes across the chi-square tests. This finding suggests that, within the context of the study sample and facilities, the overwhelming influence of the environmental maintenance factors (cleaning, dampness) may supersede the role of these individual factors or that the sample may lack sufficient variability in key demographic predictors (e.g., a sample predominantly composed of young, nonsmoking students).

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The results indicate that the absolute mean concentrations of $PM_{2.5}$ exceed the current WHO guidelines and that the thermal parameters (temperature and relative humidity) fall well outside the established comfort and health-protective ranges set by the ASHRAE (Reference Guide for Indoor Air Quality in Schools, US EPA 2025). Although the temporal differences were not significant, these high baseline exposures confirmed that chronic environmental risk was present, increasing the susceptibility of the population to maintenance failures such as poor cleaning protocols. The primary public health implication is the need to shift the institutional focus from pollutant levels to controlling source factors and maintenance methods. The building itself, via its method (cleaning) and structure (dampness/temperature), acts as a significant respiratory and mucosal irritant source. This burden disproportionately affects a vulnerable, often undiagnosed, student population, impacting well-being and academic performance. On the basis of these significant findings, several key mitigation strategies are recommended to address the identified issues. The cleaning method must be immediately revised to mitigate the inverse association found, which primarily involves reducing dry sweeping in favour of using slightly moistened cloths, mops, or microfiber pads for surfaces and floors. Furthermore, it is essential to mandate the use of HEPA filter vacuum cleaners and damp wiping techniques for all horizontal surfaces and to schedule cleaning during low-occupancy hours. In addition to cleaning protocol changes, structural and thermal remediation is necessary to audit and eliminate all sources of dampness, addressing thermal anomalies to reduce the temperature and humidity to the ASHRAE comfort range (30–60%). Finally, ventilation optimization is critical, requiring a review of the HVAC system's filter efficiency to mandate Merv-13 or higher filtration to mitigate the steady-state load and ensure consistent air exchange.

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5. 1 Conclusion

On the basis of the findings of this study on the indoor air quality of libraries and laboratories and associated risk factors, while the measured air pollutant concentrations demonstrated temporal stability between the morning and afternoon sampling periods, the primary determinants of student respiratory health outcomes are related to building maintenance and structural integrity. This study conclusively identified the cleaning process itself (where daily frequency was associated with higher symptom rates) and the presence of signs of dampness or mold as the most significant environmental risk factors associated with the prevalence of self-reported symptoms, including persistent cough, wheezing, shortness of breath, and ocular irritation. The analysis revealed that the primary driver of student respiratory and mucosal symptoms was poor environmental maintenance. Furthermore, the absolute concentrations of $PM_{2.5}$ and the thermal parameters exceeded international health standards, confirming a baseline chronic environmental hazard. An intervention focused on improving cleaning methods and addressing structural dampness will yield the most immediate and significant benefits in improving IAQ and mitigating health risks for students in the institution's study areas. Conversely, demographic factors (age, gender) are not strong predictors of symptoms in this specific institutional setting. These findings underscore the urgent need for structural and procedural remediation to protect the health and academic well-being of the student population.

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APPENDICES

APPENDIX I: The questionnaire that was given to the students is included in this section (N=140)

This is a research survey; your cooperation in giving correct information on all the questions asked will be highly appreciated. Please complete ALL questions by selecting the response most appropriate to the question. The information so gathered will be used for academic purposes only.

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Section A: Demographics and General Health

1. Gender: Male () Female ()
2. Age: 18-20 () 21-23 () 24-26 () >26 ()
3. Level of Study: 100-level () 200-level () 300-level () 400-level () post-graduate ()
4. Do you have a pre-existing respiratory condition (such as asthma, chronic bronchitis, allergies)? Yes () No ()
5. Are you a smoker? Yes () No ()
6. Do you have anyone who smokes regularly in your home? Yes () No ()

Section B: Perceived Risk Factors

7. Average duration students spend per visit to library <1 hr () 1-3 hrs () 3-5 hrs >5 hrs ()
8. Average duration of a practical/session: <1 hr. () 1-2 hrs () 2-4 hrs () >4 hrs ()
9. Type of Ventilation System(s) Present in the library/Laboratory? Natural ventilation (windows, doors) () Mechanical ventilation (HVAC system, central air conditioning) Exhaust fans ()
10. Are windows and doors regularly opened for ventilation? Yes () No ()
11. Are there any visible signs of dampness or mold growth? Yes () No ()
12. Are there any noticeable odors Yes () No ()
13. Frequency of cleaning: Daily () Weekly () Bi-weekly () Monthly ()
14. Are pest control products (pesticides) used indoors? Yes () No ()
15. Are there any combustion sources within or near the facility? (e.g., Kerosene lamps, generators, gas heaters, laboratory burners, cooking areas? Yes () No ()
16. Are renovations or construction activities currently ongoing or recently completed in or near the facility? Yes () No ()

Section C: Respiratory Symptoms

17. In the past 12 months, have you experienced any of the following symptoms while using or after using the university library or laboratories? (Please tick 'Yes' or 'No' for each symptom)

21	Health effects	Yes	No
22	Coughing (persistent, not cold-related)		
23	Wheezing or whistling in the chest		
24	Shortness of breath / difficulty breathing		

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25	Chest tightness		
26	Runny or stuffy nose (not cold-related)		
27	Sneezing (frequent, not cold-related)		
28	Itchy or watery eyes		

Section D: Potential Home/External Risk Factors

29. What type of cooking fuel is primarily used in your home/residence? LPG (Cooking Gas) () Kerosene () Firewood () Electricity ()

30. Do you use a generator for electricity at your home/residence? Yes () No ()

31. Are there any visible signs of dampness or mold in your primary residence? Yes () No ()

32. Is your primary residence located near any major roads, industrial areas, or other significant outdoor pollution sources? Yes () No ()

APPENDIX II: Visual documentation of the monitoring equipment, sampling sites and administration of questionnaires.

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