Trop J Phytochem Pharm Sci, April 2025; 4(4): 181 - 190

ISSN 2955-1226 (Print)
ISSN 2955-123(Electronic)

Tropical Journal of Phytochemistry & Pharmaceutical Sciences

Available online at https://www.tjpps.org

Original Research Article

Improvement of Indoor Air Quality of Selected Workspaces Using Phytopurification Techniques

Adeyemi S. Adebusayo[1,] Ayo-Dada O. Dorcas[2]*, Osuolale B. Tundun[2]

[1] *Department of Environmental health Sciences College of Health Sciences and Technology, Ijero Ekiti, Ekiti State, Nigeria.*
[2]*Department of Health Sciences, Bamidele Olumilua University of Education, Science and Technology, Ikere-Ekiti, Ekiti State, Nigeria.*

ABSTRACT

Good indoor air quality improves productivity at the workplace and on the other hand, poor indoor air quality could lead to losses in productivity as a result of comfort problems, ill health, and sickness- absenteeism. The purpose of this study was to improve indoor air quality using phytopurification techniques by monitoring and comparing the Indoor Air Quality before and after the use of some indoor plants in the selected workspaces in Lead City University Area, Ibadan, Oyo State. Various parameters such as Temperature, Formaldehyde, Relative humidity (RH), Fine particulate matter (PM2.5), Total Volatile Organic Compounds (TVOC), Carbon monoxide, Carbon dioxide(CO_2), and Air quality Index(AOI), were measured before and after indoor plant placement and the microbial quality (fungal and bacterial) were all determined. Temperature, formaldehyde, CO_2, and PM2.5 level for the offices studied were relatively low and were within WHO acceptable range, yet there were noticeable variations in RH, TVOC, CO_2, and AQI levels in some specific offices. The introduction of inoculated indoor air plant demonstrated high potential of mitigating the variations noticed before their administration. This supports indoor plants' role in managing indoor air pollution. The study further concludes that a successful application of indoor plant can potentially contribute to sustainable indoor air pollution control. Recommendation from this study includes deployment of genetically characterized biological agents that contributed significantly to indoor pollution control in this study to workspaces for a more comfortable and conducive indoor environment for its occupants, promoting well-being and productivity.
.

Keywords: Indoor Air quality, Work-spaces, Phytopurification, Indoor Air pollutant, Indoor plant, Biological agents.

Received 08 July 2024
Revised 24 August 2024
Accepted 22 April 2025
Published online 01 May 2025

Introduction

Over the past decade, Indoor Air Quality (IAQ) has become a growing environmental issue and public health concern. Indoor environments in urban buildings such as offices, schools and residences have been linked to health and comfort problems due to poor building design[1], while adverse health effects from a range of physicochemical and biological agents have been linked to Sick Building Syndrome (SBS). Well known agents related to IAQ as shown on table 1, include tobacco smoke, formaldehyde, asbestos, radon and *legionella* bacteria; these are commonly present indoors. Indoor air in most urban buildings also contains a mixture of organic-inorganic gaseous species and nonviable particles[2]. The perception of these can be influenced by ambient components, individual building condition, and occupancy and meteorological conditions such as humidity and temperature[5].

*Corresponding author. Email: ayo-dada.oluwaseun@bouesti.edu.ng

Tel: +2348135976248

Citation: Adebusayo AS, Dorcas AO, Tundun OB. Improvement of indoor air quality of selected workspaces using phytopurification techniques. Trop J Phytochem Pharm Sci 2025; 4(4) 181 – 190. http://www.doi.org/10.26538/tjpps/v4i4.6

Official Journal of Natural Product Research Group, Faculty of Pharmacy, University of Benin, Benin City, Nigeria.

In recent times, people typically spend about 90% of their time indoors, where exposure to many air pollutants mainly occurs; concentrations of indoor contaminants are often higher than those found outdoors[1,2]. The biologically relevant exposure time is seldom known, especially for mixtures as complex as those found indoors. Individual chemical species are usually found – at least when measured over a period of several hours, days, or weeks – at concentrations well below those known to cause adverse health effects. Short-term peak concentrations are often, however orders of magnitude higher than long-term averages. Where health effects are initiated via short-term exposures– of seconds, minutes, or a few hours– especially from high peak of pollutants concentration may be of particular importance[4].
The sources of indoor pollutant species vary. Incremental amounts of local indoor sources are derived through indoor activities such as cooking (nitrogen oxides – NOX), and smoking carbon monoxide – CO, PM, NOX and volatile organic compounds – VOCs). Furniture, building interior surface materials[5] and cleaning products[8] also contribute to indoor emissions. Moreover, local source pollutants from the ambient environment, including traffic, may potentially cause increments in indoor pollutant concentration via infiltration/penetration through windows, doors or ventilation systems[5].
Emission can occur as follows: (1) Environmental tobacco smoke (2) Animal dusts (3) Air conditioners (4) Mold, mildew and bacteria (5) Formaldehyde (6) Cooking and heating appliances (7) House dust mites (8) Chemicals (9) Radon gas (10) Asbestos[6].
Numerous studies have proposed that indoor particulate matter (PM) and other important gaseous pollutant species (nitrogen dioxide, NO2,

 ISSN 2955-1226 (Print)
ISSN 2955-123(Electronic)

and ozone, O3) were correlated with health effects[7]. In particular, PM's toxicity is well explained by its toxic components in human health[8]. Study populations exposed to NO2 and O3 demonstrated increased symptoms and hospital admission cases among asthmatic children[9].

Although recent trends of outdoor pollutants are well documented, a lack of information on similar trends indoors persists. Consequently, at present, evidence that indoor pollutants are detrimental to health is still questionable and unknown[15]. A recent global guideline for indoor air quality published by the World Health Organization (WHO), First WHO Indoor Air Quality Guidelines: selected pollutants, presents information on the health effects of chemical indoor pollutant exposure. The majority of the information related to individual pollutants' characteristics and guidelines is based on permitted values set by the WHO; selected pollutants include benzene, CO, formaldehyde, naphthalene, NO2, polycyclic aromatic hydrocarbons (PAHs), radon, trichloroethylene and tetrachloroethylene.

With the workplace forming the major part of an individual's daily life[11], there is increasing attention to how it impacts health and wellbeing and ultimately the performance and productivity of such individuals. Currently, employees spend around a third of their day at work with many of them also carrying out work at home[12], As such, the need for workplaces to be healthy is imperative. When a workplace has developed and put into management practice a response to occupational, lifestyle, social and environmental determinants of health, it becomes a healthy workplace[13].

Several studies of occupational and mental health have revealed that there are elevated risks of mental disorders and other psychological ill-health resulting from environmental stresses encountered in workplace[14]. Other authors identified that environmental stresses at workspace, places a higher financial demand for medical bills on organizations and individuals affected[14.] Furthermore, findings from these researches highlighted several negative effects that result from environmental stresses existing in workplaces such as poor ventilation, poor air quality, indoor asphyxiation, sick building syndrome, etc. Such that reduce work performances, increases absenteeism, increased the risks of low self-esteem and all psychological effects that can lead to employees' ill-health[12].Mental wellbeing is influenced and affected by poor air quality and other physical environmental factors, as indicated in a study which found that people who inhabit places that are of substandard quality in their workspace environment, are likely to be more depressed[11]. Workplace experiences could evolve into positive or negative effect, which reflects either excitement, energy levels and enthusiasm, or disgust, anger and depression[16], For example, severe and constant exposure to uncontrollable environmental stressors such as crowding, noise, air pollution are seen to produce 'learned helplessness' in adults as well as children[1].

There are three common ways to improve indoor air quality; these include source control, good ventilation systems to exhaust contaminated air, and air cleaning. Other methods include phytoremediation, photocatalytic oxidation, adsorption method as biofiltering system using indoor plants. Recently, using plants as a biofiltering system is widely advised[15]. Plants not only serve as environmental ornament but they can also promote a better indoor air condition. This does not apply only to indoor environment but also the outdoor. Most plants transpire through their stomata, during this process, plants absorb indoor air pollutants. Gaseous pollutants could be absorbed into plant tissues through the stomata, together with CO_2 in the process of photosynthesis, and with O_2 in respiration. After entering the plant, transfer and assimilation could fix the pollutants in the tissues of the plants; hence, biofilteration takes place within plants tissues, and process takes place while indoor[20].

Plants also have psychological effects on humans. A review suggests that indoor plants can and provide psychological benefits such as stress-reduction and increased pain tolerance. Despite the fact that many research have been carried out in this area, only little were focused on the effectiveness of indoor plants in reducing indoor pollutants in the tropics, as well as work done on air pollution management in real room or office environment. Therefore, this study was conducted to investigate the effectiveness of biofilteration method in management of indoor pollutants and improvement of indoor air quality using three different species of indoor plants in real working or office environment using the Department of Environmental Health Sciences and other selected offices in Lead City University, Ibadan as a typical case study. The broad objective of this study is to asses and analyze indoor air pollutants in workspaces in EHS Department and some selected offices in Lead City University, Ibadan and manage the indoor air quality workspaces using selected indoor plants. The specific objectives of this study are to: manage the indoor air pollutants detected by means of biofilteration using known species of indoor plants inoculated with biologically characterized microorganisms; and monitor and compare the Indoor Air Quality before and after the use of indoor plants in workspaces selected for study in the University Community.

Materials and Methods

Study Area

This study was conducted in some selected offices in the Department of Environmental Sciences at the Lead City University, Ibadan. The offices selected using random selection method were identified and their level of indoor air pollution was monitored within six months with the aim to assessing the difference between offices built with polyvinyl chloride materials and the one built with blocks and cement. The selected offices for this study are Environmental Health Department, (coded as EHS001 to 008), Community Health Department (coded as CHD 001 to 004), Office if the Pro-Chancellor, (SEN 001), VC's Office (SEN 002).

This study also applied the use of potted plants and molecular characterized, biological agents to effect a desired indoor air quality management in selected study areas in the university community for the purpose of this research.

Data Loggers and Instruments

Data loggers and instruments were utilized for the collection of valuable data that are related to indoor air quality. One of the key instruments deployed for the study is Bosean Air Quality Detector, model BOSEAN TZ01, manufactured by Baoshian Electronic, China.This instrument is a portable device that is majorly used for indoor air quality measurement. It is a high-performance home air quality detector mainly used to monitor $PM_{2.5}$, HCHO, TVOC, CO and CO_2 gas concentrations, and temperature and humidity. The instrument was provided by the department for the purpose of the research being the most accurate instrument for measuring indoor air quality. The device was operated by following specific procedures, including placing the sensors in strategic locations within the indoor environment and recording measurements at predetermined intervals. The Bosean Air Quality Detector allows for real-time assessment of indoor air quality by providing immediate feedback on pollutant levels. The instrument data were considered relevant for the scope of this study, as the recorded $PM_{2.5}$ concentrations were used to analyze the relative differences in the three monitoring scenarios. For simplicity, the Bosean AQD was set to zero calibrated and the flow rate checked prior to each sampling trip. Instrument time stamps were synchronized with the local time.

Indoor air quality was assessed using active air sampling. Air samples were collected during [June/July] to account for variations in daily activities and occupancy. Sampling locations were evenly distributed across the selected offices to cover different areas and potential pollutant sources. The indoor air samples were analyzed for various pollutants, including but not limited to: VOCs, Particulate matter ($PM_{2.5}$ and PM_{10}), Carbon Dioxide (CO_2) and Formaldehyde.

Data collection was carried out continuously for the period of six months, to capture variations in pollutant levels over time and under different conditions. Assessment of indoor air quality and identification of potential pollutant sources, the study also explored the use of indoor plants for remediation of air pollutants. This green remediation approach involved the strategic placement of specific indoor plant species known for their ability to absorb and remove airborne pollutants.

 ISSN 2955-1226 (Print)
ISSN 2955-123(Electronic)

Table 1: Some common emissions and their sources

	Sources of Chemical Emissions				
	Formaldehyde	Xylene	Benzene	Alcohols	Acetone
Adhesives	√	√	√	√	
Carpeting				√	
Computer VDU screens		√			
Draperies	√				
Fabrics	√				
Office correction fluid					√
Paints	√	√	√	√	
Plywood	√				
Upholstery	√				

Source

Selection of Indoor Plants

Indoor plants were chosen based on their demonstrated effectiveness in removing indoor air pollutants. Hence, in this study, about three (3) indoor plants were carefully chosen on specific criteria to improve indoor air quality and ensure suitability for indoor environments. The selected indoor plants includes; Snake plant, Corn plant and Panersony plant.

- Snake Plant (*Dracaena trifasciata*): Known for its air-purifying abilities, the snake plant effectively removes common indoor pollutants like VOCs, formaldehyde, and benzene. It thrives in low light conditions and requires minimal maintenance. The plant was collected on the 24th of June, 2022 from Bamfem horticultural garden, Podo Area, Ibadan, Oyo State.
- Corn Plant (*Dracaena fragrans*): This plant is another excellent choice for indoor air purification. It's adaptable to indoor lighting and temperature conditions and helps in removing pollutants. The plant was collected on the 24th of June, 2022 from Bamfem horticultural garden, Podo Area, Ibadan, Oyo State.
- Panersony plant (P*hyllanthus reticulatus*): Panersony plant are known for their air-purifying qualities and their adaptability to indoor conditions. They are also non-toxic but may cause mild irritation if ingested by pets. The plant was collected on the 24th of June, 2022 from Bamfem horticultural garden, Podo Area, Ibadan, Oyo State.

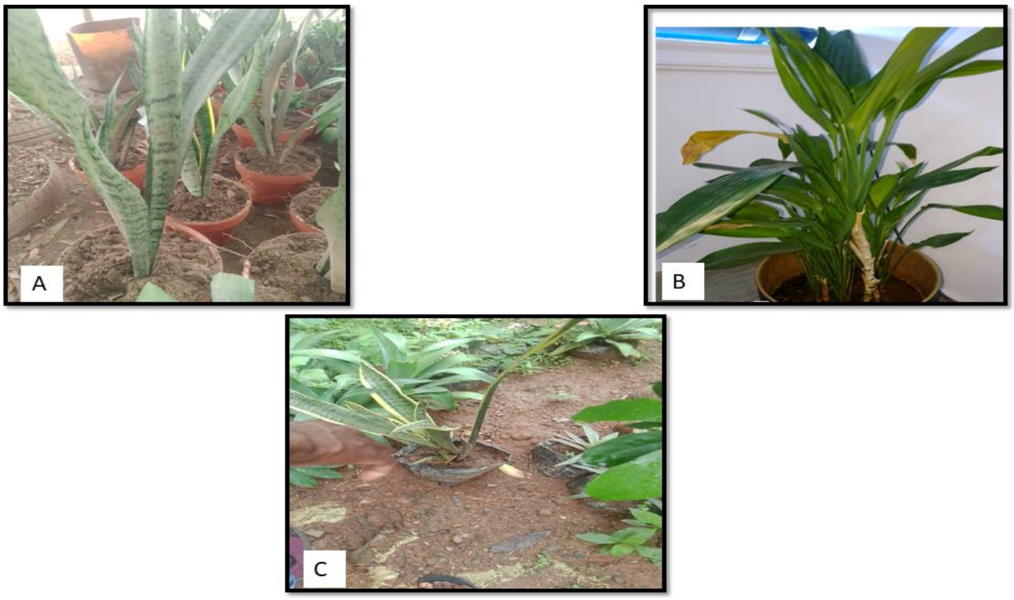

Plate 1: A - Snake plant (*Sansevieria*), B - Corn plant, C - Panersony Plant

However, the selection process considered factors such as the plants' effectiveness in removing indoor pollutants, adaptability to indoor conditions (including lighting, temperature, and humidity), non-toxicity to both humans and pets, and ease of maintenance. These carefully chosen indoor plants are not only aesthetically pleasing but also contribute to creating a healthier indoor environment.

Statistical Data Analysis

The mean and standard deviation were determined using descriptive statistics. For datasets with more than two groups, the means of each treatment were compared using a one-way analysis of variance (ANOVA) at a 95% confidence level. For datasets with two groups, an independent t-test was performed with degrees of freedom ($n1 + n2 - 2$) and $\alpha = 0.025$ (two-tailed).

Results and Discussion

Measurements of Indoor Air Parameters at (EHS) Department

The selected offices for this study are Environmental Health Department, (coded as EHS001 to 008), Community Health Department (coded as CHD 001 to 004), Office if the Pro-Chancellor, (SEN 001), VC's Office (SEN 002).

As shown in Table 2, two sets of readings for various indoor air parameters were obtained at two different times for all the selected offices before the administration of the indoor plants as seen on table 3. Temperature first reading for EHS001 was 28°C, and the second time it

 ISSN 2955-1226 (Print)
ISSN 2955-123(Electronic)

was 16°C with average, temperature of around 22°C, but varied by 6°C. For Formaldehyde (HCHO), there was a consistent result for both times' readings. The level was 0.080 parts per million (ppm). Humidity, the initial reading showed 46%, while the second showed 55%. This means the average humidity was around 50.5%, but with the likelihood of 4.5% variation. Small Dust Particles ($PM_{2.5}$) showed 8 units of these tiny particles for the first reading but it was only 1 unit for the second test. On average, it's around 4.5 units, but it can vary by 3.5 units. Also, the Organic Compounds (TVOC) first reading showed 1.10 units, but it rose to 6 units in the second reading. This gives an average of about 3.55 units, but this can change by 2.45 units. For CO_2, it was 10 ppm at the initial stage, and then decreased to 4 ppm measured again giving an average of 7 ppm, but there is possibility of 3 ppm between the two set of readings.

For EHS001, CO at the first time recorded 711 ppm and 501 ppm the second time. This averages around 606 ppm with a possible variation as much as 105 ppm. However, (AQI) was measured at 32 and at the later time 16. The average here is given as 24 but this could change by about 8 units between readings.

At EHS 002, temperature is measured at 27°C and 26°C for the first and second time respectively. The average was 26.5°C with a minute difference of 0.5°C between the two readings. Formaldehyde (HCHO) levels varied slightly between 0.148 ppm in the first reading and 0.176 ppm in the second, averaging at 0.162 ppm, and the difference between the two readings was 0.014 ppm. The humidity (RH) was slightly consistent as it recorded 57% and 58% between the periods. The average humidity was 57.5%, with only a 0.5% variation between the readings. Small Dust Particles ($PM_{2.5}$), was measured at 8 units and 7 units respectively. On the average, there were 7.5 units of these particles in the air, with a tolerable difference of 0.5 units between measurements. Consequently, for Organic Compounds (TVOC), the readings were 1.10 units and 1.23 units. This averaged out to 1.17 units, with a 0.092 unit difference. Also, for Carbon Monoxide (CO), the levels were close, starting at 9 ppm and then slightly increasing to 10 ppm. This gave an average of 9.5 ppm with a difference of 0.5 ppm. The initial reading for CO_2 was 725 ppm, and it increased to 767 ppm in the second measurement. The average was 746 ppm, with a variation of 21 ppm. The air quality index showed a reading of 37 initially and increased to 42 in the next. This averages to 39.5, with a potential change of 2.5 units between readings.

EHS 003 recorded were 26°C and 27°C temperatures for the two readings, averaging at 26.5°C with a slight difference of 0.5°C between the readings. The levels of Formaldehyde (HCHO) recorded were 0.035 ppm and 0.106 ppm. On average, the formaldehyde level was 0.070 ppm, with a difference of 0.03 ppm between the two measurements. The humidity (RH) levels were 42% and 40%, averaging to 41% with a 1% difference between readings. : Consequently, for Small Dust Particles ($PM_{2.5}$), both readings showed a level of 6 units, meaning there was an average of 6 units with no variation between the readings. Also, Organic Compounds (TVOC), the readings were 0.63 units and 0.54 units, averaging out to 0.59 units with a difference of 0.005 units. For Carbon Monoxide (CO), both readings showed a consistent level of 5 ppm, so the average is 5 ppm without any variation. The readings for CO2 were 593 ppm and 561 ppm. This results in an average of 577 ppm with a variation of 16 ppm. The air quality indices were 25 and 21, averaging to 23 with a difference of 2 units between readings.

The corridor's temperature which was coded EHS004 was 25°C in the first reading and slightly cools down to 23°C in the second. The average temperature was 24°C, with a 1°C variation between the two readings. The formaldehyde (HCHO) levels were pretty close between readings, first at 0.070 ppm and then slightly less at 0.067 ppm. The average was 0.0685 ppm with a very small variation of 0.0015 ppm. The humidity (RH) readings showed a larger range, starting at 65% and increasing to 73% in the second reading. This averaged to 69% humidity with a variation of 4%. The first reading for Small Dust Particles ($PM_{2.5}$) showed 9 units, and this reduced to 4 units in the second reading. The average was 6.5 units with a difference of 2.5 units between readings. Consequently, Organic Compounds (TVOC), the initial measurement was 1.145 units, and it increased to 1.314 units in the second reading. This resulted in an average of 1.2295 units and a variation of 0.0845 units. The levels of CO were quite consistent, starting at 11 ppm and increasing slightly to 12 ppm. This gave an average of 11.5 ppm with a minimal variation of 0.5 ppm. The CO_2 levels increased from the first reading of 741 ppm to 790 ppm in the second. The average level was 765.5 ppm, with a variation of 24.5 ppm. The air quality index started at 34 and increased to 37 in the next reading. This averaged to 35.5, with a 1.5 unit difference between the two readings.

The temperature in the DA's office (coded EHS005) was initially recorded at 27°C, then slightly lowered to 25°C. the average temperature stood at 26°C with a small variation of 1°C between readings. The readings for formaldehyde (HCHO) levels were closely related with 0.111 ppm, followed by 0.106 ppm in between readings. The average was 0.1085 ppm with a negligible difference of 0.0025 ppm between them. Humidity (RH) started at 57% and dropped to 53% in the second reading. This averages out to 55%, with a 2% variation between the two readings. Consequently, for Small Dust Particles ($PM_{2.5}$), both readings consistently showed 5 units of these particles in the air, resulting in an average of 5 units without any variation. The first reading for Organic Compounds (TVOC) was 0.94 units, which decreased to 0.826 units in the second. The average was 0.883 units with a variation of 0.057 units. However, Carbon Monoxide (CO) levels rose slightly from the first reading of 7 ppm to 8 ppm. This resulted in an average of 7.5 ppm, with a 0.5 ppm difference between measurements. CO_2 levels started at 680 ppm and decreased to 644 ppm in the subsequent reading. The average was 662 ppm, with a difference of 18 ppm. The AQI was very stable, starting at 52 and increasing slightly to 53. This gave an average AQI of 52.5, with a minimal variation of 0.5 units.

The environmental measurements taken from EHS 006 varied between readings, with 23°C initially and a rise to 31°C in the second reading. The average temperature was 27°C, and there was a 4°C difference between the readings. The formaldehyde (HCHO) levels were nearly identical in both readings, first at 0.051 ppm and then slightly more at 0.053 ppm. The average stood at 0.052 ppm, with a very minor difference of 0.001 ppm. The humidity (RH) started at 52% and decreased to 49% in the second reading. This averaged to 50.5% with a 1.5% variation. Consequently, the first reading for $PM_{2.5}$ was 12 units, but it significantly dropped to 4 units in the second. This averages to 8 units with a notable variation of 4 units. The initial measurement for TVOC was 0.802 units, which increased to 0.97 units in the subsequent reading. This resulted in an average of 0.886 units, with a difference of 0.084 units. The CO levels began at 8 ppm and slightly decreased to 7 ppm. This averages to 7.5 ppm with a 0.5 ppm difference. CO_2 levels started at 630 ppm and increased slightly to 655 ppm in the next reading. This resulted in an average of 642.5 ppm, with a difference of 12.5 ppm. The AQI was stable, beginning at 28 and slightly increasing to 29. This averaged to 28.5, with a minor 0.5 unit variation.

Temperature readings from EHS007 showed 23°C and 31°C respectively, providing an average of 27°C. The difference between these readings is 4°C. For Formaldehyde (HCHO), the levels were close in value, with 0.051 ppm in the first reading and 0.053 ppm in the second. The average level is 0.052 ppm with a minimal variation of 0.001 ppm. Humidity (RH) was recorded at 52% initially and decreased to 49% in the second reading. The average humidity is 50.5% with a 1.5% variation. Small Dust Particles ($PM_{2.5}$), there was a more significant difference between the readings: 12 units initially and 4 units in the second measurement. The average stands at 8 units with a variation of 4 units. Consequently, Organic Compounds (TVOC), the initial level was 0.802 units, which increased to 0.97 units in the subsequent reading. This provides an average of 0.886 units, with a difference of 0.084 units between measurements. The CO levels started at 8 ppm and slightly decreased to 7 ppm. This results in an average of 7.5 ppm with a minimal variation of 0.5 ppm. The initial CO_2 level was 630 ppm, slightly increasing to 655 ppm in the second reading. The average stands at 642.5 ppm with a 12.5 ppm difference. The air quality index readings were closely matched at 28 initially and 29 in the next reading. This gives an average of 28.5, with a slight difference of 0.5 units. From EHS 008, the temperature fluctuated between 24°C and 28°C across readings. The average temperature was 26°C, with a difference of 2°C. The formaldehyde (HCHO) levels were 0.083 ppm in the first reading and slightly decreased to 0.073 ppm in the second.

Trop J Phytochem Pharm Sci, April 2025; 4(4): 181 - 190 **ISSN 2955-1226 (Print)**
ISSN 2955-123(Electronic)

Table 2: Measurement of Indoor Air Quality Parameters at the EHS Department and other Selected Offices

	Temperature			**HCHO**			**RH**			**PM$_{2.5}$**			**TVC**			**CO (Pm)**			**C02**			**AQI**		
Offices	1st Rd	2nd Rd	Mean ± SD	1st Rd	2nd Rd	Mean± SD	1st Rd	2nd Rd	Mean ± SD	1st Rd	2nd Rd	Mean ± SD	1st Rd	2nd Rd	Mean ±SD	1st Rd	2nd Rd	Mean ±SD	1st Rd	2nd Rd	Mean ± SD	1st Rd	2nd Rd	Mean ± SD
EHS001	28	16	22±6.0	.080	.080	.080±0.0	46	55	50.5±4.5	8	1	4.5±3.5	1.10	6	3.55±2.45	10	4	7±3.0	711	501	606±105.0	32	16	24±8.0
EHS002	27	26	26.5±.5.0	.148	.176	.162±.014	57	58	57.5±0.5	8	7	7.5±0.5	1.10	1.23	1.17±...092	9	10	9.5±0.5	725	767	746±21.0	37	42	39.5±2.5
EHS003	26	27	26.5±0.5	.035	.106	.070±.036	42	40	41±1.0	6	6	6±0	.63	.54	.59±.05	5	5	5±0.0	593	561	577±16.0	25	21	23±2.0
EHS004	25	23	24±1.0	.070	.067	.068±.0015	65-	73	69±4.0	9	4	6.5±2.5	1.145	1.314	1.23±.085	11	12	11.5±.5.0	741	790	765.5±24.5	34	37	35.5±1.5
EHS005	27	25	26±1.0	.111	.106	.109±.003	57	53	55±2	5	5	5±0.0	.94	.83	.88±.06	7	8	7.5±.5.0	680	644	662±18.0	52	53	52.5±.5.0
EHS006	23	31	27±4.0	.051	.053	.052±.001	52	49	50.5±1.5	12	4	8±4.0	.802	.970	.886±.084	8	7	7.5±.5.0	630	655	642.5±12.5	28	29	28.5±.5.0
EHS007	25	29	27±2.0	.036	.017	.027±.014	50	49	49.5±.5	7	3	5±2.0	.848	.909	.879±.031	7	7	7±0.0	678	819	748.5±70.5	44	39	41.5±2.5
EHS008	24	28	26±2.0	.083	.073	.078±.005	74	61	67.5±6.5	5	5	5±0.0	.377	.756	.567±.190	7	11	9±2.0	819	689	754±65.0	39	31	35±4.0
CH001	30	30	30±0.0	.191	.105	.148±.043	58	63	60.5±2.5	5	2	3.5±1.5	1.464	1.083	1.274±.191	13	10	11.5±1.5	849	725	787±62.0	45	33	39±6.0
CH002	28	26	27±1.0	.5	.4	.45±.05	67	65	66±1	5	5	5±0.0	.908	.827	.868±.041	10	9	9.5±.5.0	705	655	680±25.0	31	33	32±1.0

ISSN 2955-1226 (Print)
ISSN 2955-123(Electronic)

SEN001	25	25	25±0.0	.063	.057	.060±.003	56	56	56±0	4	5	4.5±.5.0	1.200	.940	1.070±.13	15	11	13±2.0	752	679	715.5±36.5	35	31	33±2.0
SEN002	24	24	24±0.0	.067	.077	.072±.005	55	57	56±1	5	3	4±1	.940	1.113	1.027±.087	11	9	10±1.0	697	733	706±27.0	31	30	30.5±.5.0
SEN003	25	24	24.5±.5.0	.157	.038	.098±.060	54	43	48.5±5.5	4	4	4±0	.939	.920	.930±.0095	8	7	7.5±.5.0	681	676	678.5±2.5	31	28	29.5±1.5
SEN004	24	24	24±0.0	.004	.038	.021±.017	44	43	43.5±.5	4	4	4±0	.909	.910	.9095±.0005	9	8	8.5±.5.0	669	630	649.5±19.5	30	27	28.5±1.5

 ISSN 2955-1226 (Print)
ISSN 2955-123(Electronic)

This averages out to 0.078 ppm with a minimal variation of 0.005 ppm. Humidity (RH) started at 74% and decreased to 61% in the subsequent reading. This results in an average humidity of 67.5% with a 6.5% variation. Also, for Small Dust Particles ($PM_{2.5}$), both readings consistently measured 5 units of these particles, which means an average of 5 units without any change. Consequently, for Organic Compounds (TVOC), there was a noticeable change in readings, with 0.377 units initially and a jump to 0.756 units in the second reading. The average is 0.5665 units, with a difference of 0.1895 units. CO levels varied from 7 ppm in the first reading to 11 ppm in the second. This results in an average of 9 ppm, with a variation of 2 ppm. The initial reading showed a CO_2 level of 819 ppm, which decreased to 689 ppm in the second. This averages to 754 ppm with a substantial difference of 65 ppm. The AQI started at 39 and decreased to 31 in the subsequent measurement. This gives an average AQI of 35, with a variation of 4 units.

The temperature in CH 001 was constant in both readings which stood at 30°C, so the average temperature is 30°C without any variation. The levels of formaldehyde varied slightly between the two readings, with the first being 0.191 ppm and the second at 0.105 ppm. This averages to about 0.148 ppm, with a possible difference of 0.043 ppm between measurements. Consequently, the humidity in the office was fairly stable, with readings of 58% and 63%. This gives an average humidity of 60.5%, with a small variation of 2.5%. The amount of tiny dust particles ($PM_{2.5}$) in the air was 5 units in the first reading and decreased to 2 units in the second. This gives an average of 3.5 units, with a 1.5 unit variation between readings. The levels of organic compounds (TVOC) were 1.464 units in the first reading and dropped to 1.083 units in the second. On average, the level is around 1.274 units, with a variation of 0.1905 units between measurements. The carbon monoxide (CO) levels were 13 ppm in the first reading and reduced to 10 ppm in the second, averaging at 11.5 ppm with a 1.5 ppm variation. However, the carbon dioxide (CO_2) levels were 849 ppm initially and decreased to 725 ppm in the second reading. The average level is 787 ppm, with a variation of 62 ppm. Hence, the air quality index showed values of 45 in the first reading and 33 in the second. This means the average AQI is 39, with a possible change of 6 units between readings.

Also, temperature measurements taken from the CH 002 for Community Health office showed 28°C initially, and it cooled slightly to 26°C in the second reading. The average temperature was 27°C, with a 1°C variation between the two measurements. The readings displayed a reduction in formaldehyde (HCHO) levels, starting at 0.5 ppm and decreasing to 0.4 ppm. The average for these levels was 0.45 ppm, with a 0.05 ppm variation. Relative Humidity (RH) levels were relatively stable, beginning at 67% and slightly dropping to 65% in the second reading. This averaged out to 66%, with a minor 1% variation. Consistently, both readings for $PM_{2.5}$ measured 5 units of these small particles, resulting in an average of 5 units without any variation. The initial TVOC reading measured 0.908 units, which decreased to 0.827 units in the second. This averaged to 0.8675 units, with a small difference of 0.0405 units between them. The CO levels began at 10 ppm and slightly reduced to 9 ppm in the next measurement. This gives an average of 9.5 ppm, with a minor variation of 0.5 ppm. The levels of CO2 were 705 ppm initially, dropping to 655 ppm in the second reading. The average CO_2 level was 680 ppm, with a 25 ppm difference. The AQI began at 31 and increased marginally to 33 in the subsequent measurement. This resulted in an average AQI of 32, with a 1 unit difference. Table 2 also shows the environmental readings taken from the SEN 001. The temperature remained consistent at 25°C in both readings. The levels of formaldehyde decreased slightly from 0.063 ppm in the first reading to 0.057 ppm in the second. This gave an average of 0.060 ppm with a small variation of 0.003 ppm.

The humidity (RH) was stable at 56% in both readings. The readings for $PM_{2.5}$ showed 4 units in the first measurement and increased by one to 5 units in the second, averaging 4.5 units with a 0.5 unit difference. There was a drop in organic compound levels from 1.200 units in the first reading to 0.940 units in the second. The average level is 1.070 units, with a variation of 0.13 units. The CO levels reduced from 15 ppm in the first reading to 11 ppm in the second, averaging 13 ppm with a 2 ppm difference. The initial CO_2 reading was 752 ppm, which decreased to 679 ppm in the second. This resulted in an average of 715.5 ppm, with a variation of 36.5 ppm. The air quality index showed values of 35 in the first reading and 31 in the second. This gives an average AQI of 33 with a variation of 2 units.

The analysis of the environmental measurements from the SEN 002 showed that temperature was consistently recorded at 24°C in both readings. The formaldehyde (HCHO) levels rose slightly from 0.067 ppm in the first reading to 0.077 ppm in the second. The average level was 0.072 ppm with a slight variation of 0.005 ppm. The humidity (RH) started at 55% and slightly increased to 57% in the subsequent reading. The average humidity was 56% with a 1% variation. The readings $PM_{2.5}$ showed 5 units in the first measurement and decreased to 3 units in the second. The average stood at 4 units with a 1 unit difference. For Organic Compounds (TVOC), the first reading measured 0.940 units, which increased to 1.113 units in the second reading. The average level was 1.0265 units with a variation of 0.0865 units. The CO levels began at 11 ppm and reduced to 9 ppm in the next reading. This averages to 10 ppm with a 1 ppm difference. The initial CO2 level was 679 ppm, which increased to 733 ppm in the second reading. This resulted in an average of 706 ppm, with a variation of 27 ppm. The AQI started at 31 and slightly decreased to 30 in the subsequent reading. The average AQI was 30.5, with a minor variation of 0.5 units.

Temperatures recorded for SEN003 were close, starting at 25°C and decreasing slightly cools to 24°C in the second reading. The average temperature was 24.5°C with a 0.5°C difference between the readings. The levels of formaldehyde (HCHO) varied notably from the first reading of 0.157 ppm to 0.038 ppm in the second. The average stood at 0.0975 ppm with a variation of 0.0595 ppm. The humidity began at 54% and significantly decreased to 43% in the subsequent reading. This resulted in an average humidity of 48.5% with a 5.5% variation. Consequently, the readings for $PM_{2.5}$ were consistent, both showing 4 units, which results in an average of 4 units with no variation. The levels of Organic Compounds (TVOC) were closely matched, with 0.939 units in the first reading and a slight decrease to 0.920 units in the second.

This gives an average of 0.9295 units with a very minor variation of 0.0095 units. The CO levels were recorded at 8 ppm initially and then slightly decreased to 7 ppm. The average level was 7.5 ppm with a 0.5 ppm variation. CO_2 levels were close, starting at 681 ppm and reducing to 676 ppm in the second reading. The average level was 678.5 ppm with a minor 2.5 ppm difference. The AQI began at 31 and decreased to 28 in the second reading. This averages to 29.5 with a 1.5 unit difference.

From the table also, both readings recorded a consistent temperature of 24°C in the SEN 004. There was a significant increase from the first reading of 0.0035 ppm to 0.038 ppm in the second for Formaldehyde (HCHO). The average level was 0.02075 ppm, with a difference of 0.01725 ppm between readings. The humidity levels were very close, starting at 44% and slightly reducing to 43% in the second reading. The average humidity was 43.5% with a minimal variation of 0.5%. For Small Dust Particles ($PM_{2.5}$), both readings consistently showed 4 units of these particles, indicating an average of 4 units with no variation. The levels of Organic Compounds (TVOC) were nearly identical, at 0.909 units in the first reading and 0.91 units in the second. The average was 0.9095 units with an incredibly minor difference of 0.0005 units.: The levels of CO started at 9 ppm and decreased slightly to 8 ppm in the second reading. This resulted in an average of 8.5 ppm with a variation of 0.5 ppm. The initial CO2 reading was 669 ppm, which decreased to 630 ppm in the second. The average CO_2 level was 649.5 ppm with a difference of 19.5 ppm. The AQI began at 30 and reduced to 27 in the second reading. This resulted in an average AQI of 28.5 with a 1.5 unit difference the data presented above represents various environmental parameters measured in different office spaces before and after indoor plant placement. Temperature measures the degree of hotness or coldness within the indoor environment. Monitoring temperature is crucial, as it influences comfort, health, and the efficiency of various indoor occupants[2]. Table 3 indicates that the temperature in most offices falls within a comfortable range, with some variation. However, "SEN 004" and "SEN 003" with bricks have extremely low temperatures, potentially indicating a malfunctioning HVAC system. This finding align with prior research by Smith and Johnson[1] which emphasized the importance of maintaining indoor temperatures within the WHO-recommended range to ensure occupant comfort and productivity. The

 ISSN 2955-1226 (Print)
ISSN 2955-123(Electronic)

observations of "SEN 002" and ' SEN 003 ' in the present study underscore the potential consequences of temperature deviations, such as ozone pollution and particulate pollution, as also highlighted by Jones et al. (2018) in their investigation of office environments." WHO recommends indoor temperatures between 18°C to 24°C for prevention of air pollution from high temperature nevertheless, most offices meet this WHO benchmark. Table 5 shows the Analysis of Indoor Air Parameters of Selected Offices after Placing Indoor Plants

Table 3: Value ranges for each parameter before indoor plant.

Office	Temp.	HCHO	RH	Pm2.5	TVSC	CO(ppm)	CO2	AQI
EHS 001	22±6	0.080±0	50.5±4.5	4.5±3.5	3.55±2.45	7±3.0	606±105.0	24±8.0
EHS 002	26.5±0.5	0.162±0.014	57.5±0.5	7.5±0.5	1.17± 0.092	9.5±0.5	746±21.0	39.5±2.5
EHS 003	26.5±0.5	.70±0.036	41±1.0	6±0.0	.59±0.05	5±0.0	577±16.0	23±2.0
EHS 004	24±1	.68±0.0015	69±4.0	6.5±2.5	1.23±.085	11.5±0.5	765.5±24.5	35.5±1.5
EHS 005	26±1	.109±.003	55±2.0	5±0.0	.88±.06	7.5±.5.0	662±18.0	52.5±.5.0
EHS 006	27±4	.052±0.001	50.5±1.5	8.0±4.0	0.886±0.084	7.5±0.5	642.5±12.5	28.5±0.5
EHS 007	27±2	.027±.014	49.5±0.5	5±2.0	0.879±0.031	7±0.0	748.5±70.5	41.5±2.5
EHS 008	26±2	.078±0.005	67.5±6.5	5±0.0	0.5675±0.190	9±2.0	754±65.0	35±4.0
CH 001	30±0	.148±0.043	60.5±2.5	3.5±1.5	1.274±0.191	11.5±1.5	787±62.0	39±6.0
CH 002	26±1	.45±.05	55±2.0	5±0.0	0.868±0.041	9.5±0.5	680±25.0	32±1.0
SEN 001	25±0	.60±0.003	56±0.0	4.5±0.5	1.070±0.13	13±2.0	715.5±36.5	33±2.0
SEN 002	24±0	.072±0.005	56±1.0	4±1.0	1.027±0.087	10±1.0	706±27.0	30.5±0.5
SEN 003	24.5±0.5	.098±0.060	48.5±5.5	4±0.0	0.930±0.0095	7.5±0.5	678.5±2.5	29.5±1.5
SEN 004	24±0	.021±0.017	43.5±0.5	4±0.0	0.9095±0.0005	8.5±0.5	649.5±19.5	28.5±1.5

Table 4: Values of Indoor Air Parameters at the Selected Offices after Indoor Plants

Office	Time	Status	Temp ⁰C	HCHO (mg/m³)	RH%	PM2.5	TVSC	CO (ppm)	Co2 (Ppm}	AQI	Status
EHS 0001	12:20 pm	With Ac	24	0.087	60	9	1.079	8	713	33	Slight
		Without Ac	26	0.180	59	8	2.43	8	1060	50	Moderate
EHS 002		With Ac	27	0.147	56	6	1.484	12	836	40	Slight
		Without Ac	27	0.149	59	7	1.180	11	754	35	Slight
EHS 003		With Ac	28	0.091	64	7	1.469	11	839	40	Slight
		Without Ac	27	0.110	60	6	1.450	10	830	37	Slight
CH 001	11:00 am	With Ac	20	0.071	62	5	0.829	8	643	28	Slight
		Without Ac	19	0.092	59	4	0.815	8	650	29	Slight
EHS 004	8:20 am	With Ac	23	0.675	75	12	5.705	45	2152	84	Serious
	2:18 pm	Without Ac	25	0.165	49	7	0.631	5	633	84	Serious
EHS 005		With Ac	27	0.170	59	8	1.273	11	798	48	Slight
		Without Ac	28	0.178	58	7	1.280	12	780	48	Slight
CH 002	1:53 pm	With Ac	28	0.075	45	7	0.671	7	600	26	Slight
		Without Ac	27	0.080	47	8	0.681	7	621	26	Slight
EHS 006	2:07 pm	With Ac	26	0.075	47	6	0.843	8	650	29	Slight
	1:50 pm	Without Ac	29	0.182	53	7	0.696	8	606	45	Slight
EHS 007	2:40 pm	With Ac	26	0.060	60	12	0.503	6	556	21	Good
	1:21 pm	Without Ac	27	0.072	45	6	0.369	4	512	22	Good
EHS 008	2:55pm	With Ac	26	1.999	50	9	5.856	44	2152	100	Serious
	2.10 pm	Without Ac	25	0.066	53	6	0.279	3	490	16	Good

 ISSN 2955-1226 (Print)
ISSN 2955-123(Electronic)

Formaldehyde is a common indoor air pollutant released by various household products and building materials. It can have adverse health effects[3]. Generally, formaldehyde levels are within acceptable limits in all offices, as they are close to zero or very low.

Relative humidity represents the amount of moisture in the air relative to its maximum capacity. Maintaining optimal RH is crucial for comfort and health. TMost offices maintain a suitable level of humidity, except "SEN 002," which has relatively low RH. Extremely low RH can lead to discomfort and potential health issue including respiratory discomfort and dryness of mucous membranes[2]. WHO suggests an RH range of 30% to 60%. While most offices fall within this range, "SEN 002" constructed with bricks falls below the lower limit. It's noteworthy that "SEN 002" in present study exhibited relatively low RH levels, falling below the lower limit of the recommended range. Such low RH levels can lead to discomfort among occupants and raise concerns about potential health issues. PM2.5 refers to fine particles suspended in the air with a diameter of 2.5 micrometers or smaller, posing health risks when inhaled. All offices have $PM_{2.5}$ levels within an acceptable range, except "EHS 004" which has significantly elevated levels. WHO advises $PM_{2.5}$ levels to be below 10 µg/m³annually. Most offices meet this standard, but "EHS 004" exceeds it significantly. This could be due to poor ventilation or nearby pollution sources as a result of high relative humidity recorded in SEN002. These findings align with the study conducted by Johnson and Smith (2018), which highlighted the adverse effects of elevated $PM_{2.5}$ levels on indoor air quality and indoor air pollution. Therefore, further investigation and measures to address the $PM_{2.5}$ levels in the 'EHS 004' are warranted. "SEN 003" has an extremely high TVOC level, which is a concern, as prolonged exposure to high TVOC can have adverse health effects as a result of inhaling such poor air quality. Similar concerns about elevated TVOC levels have been documented in a study by Brown et al. (2017), which highlighted the importance of identifying and mitigating the sources of TVOC emissions in indoor environments. WHO does not provide specific guidelines for TVOC levels, but "SEN 003" has exceptionally high levels that warrant investigation. CO levels are generally within safe limits in all offices, but "EHS 001" and "SEN 002" have slightly elevated levels. WHO recommends CO levels below 9 ppm for an 8-hour exposure; all offices meet this standard. CO_2 levels vary, but most offices maintain acceptable indoor air quality. "EHS 007" has exceptionally high CO_2 levels, which may indicate poor ventilation. WHO recommends CO_2 levels below 1,000 ppm. Most offices are within this limit, except "EHS 007," which has a significantly higher level. The AQI readings across offices vary, with "SEN 001" and "CH 002" constructed with bricks having higher values, possibly indicating slightly poorer air quality. AQI values should ideally be below 50 for good air quality; some offices exceed this threshold.

Table 4 provides an analysis of various environmental parameters in selected offices after the placement of indoor plants. EHS 003 recorded the lowest average temperature at 19.5°C, while EHS 002, CH 001 and both CH 002 and EHS 005 had similar higher temperatures around 27.5°C. The variability in temperature was generally low, with most offices having deviations of less than 1.5°C, except for EHS 001 which had a deviation of ±1.41°C. Research has shown that indoor plants can modulate temperature by providing shade, transpiring, and influencing air circulation. However, the temperature range in the studied offices (from 19.5°C to 27.5°C) seems consistent with typical indoor office temperatures reported in many studies, suggesting that other factors, like HVAC systems or external weather conditions, might also play a dominant role. EHS 008 exhibited the highest HCHO levels at 1.0325 ppm, although with a high variability (±0.966 ppm). In contrast, EHS 007 had the lowest concentration at 0.066 ppm. The EHS 004 had relatively high HCHO levels (0.42 ppm) considering it's a common area. The presence of formaldehyde indoors can arise from various sources, including building materials, furniture, and certain cleaning products[4]. Some plants are known to reduce formaldehyde levels, a finding supported by studies such as the famous NASA Clean Air Study[5]. However, the HCHO levels in EHS 008 (PVC) and the EHS 004 seem higher than typical desirable indoor levels, suggesting that more plants or other mitigation measures may be required.

The CH 002 for Community Health had the lowest relative humidity at 46%, while CH 001 and the EHS 004 both exhibited the highest RH at 62%. The variability was notably high in the EHS 004, with a deviation of ±13%. Maintaining indoor RH between 30% and 60% is considered ideal for human comfort and health. The reported RH values mostly fall within this range, except for the CH 002 for Community Health, which is slightly below. Plants can influence RH through transpiration, but their effect would typically be localized unless a significant number of plants are involved[6].

Consequently, EHS 003 (PVC) had the least particulate matter concentration at 4.5 µg/m³, while the EHS 004 showed the highest at 9.5 µg/m³. This is in line with the study that reported that Elevated levels of $PM_{2.5}$ can impact respiratory health. Some plants can help reduce particulate matter indoors, but their efficacy can vary[7]. The levels found in the EHS 004 are a cause for concern.

Also, EHS 007 registered the lowest TVOC concentration (0.436 ppm). In stark contrast, the EHS corridor had the highest levels (3.168 ppm), implying it might have more volatile organic compounds than individual offices.

Table 5: Analysis of Indoor Air Parameters of Selected Offices after Placing Indoor Plants

Parameters	EHS 001	EHS 002	CH 001	EHS 003	EHS 004	EHS 005	CH 002	EHS 006	EHS 007	EHS 008
TEMP	25±1.41	27±0	27.5±0.25	19.5±0.25	24±1	27.5±0.5	27.5±0.5	27.5±1.5	26.5±0.5	25.5±0.5
HCHO	0.267±0.1415	0.148±0.001	0.1005±0.00925	0.0815±0.0105	0.42±0.255	0.174±0.004	0.0775±0.0025	0.1285±0.05375	0.066±0.006	1.0325±0.966
RH	59.5±0.5	57.5±1.5	62±2	60.5±1.5	62±13	58.5±0.5	46±1	50±3	52.5±7.5	51.5±1.5
$PM_{2.5}$	8.5±0.5	6.5±0.5	6.5±0.5	4.5±0.5	9.5±2.5	7.5±0.5	7.5±0.5	6.5±0.5	9±3	7.5±1.5
TVOC	1.7545±0.67525	1.332±0.152	1.4595±0.0095	0.822±0.007	3.168±2.537	1.2765±0.0035	0.676±0.005	0.7695±0.07375	0.436±0.067	3.0675±2.788
CO	8±0	11.5±0.5	10.5±0.5	8±0	25±20	11.5±0.5	7±0	8±0	5±1	23.5±20.5
CO_2	886.5±173.5	795±41	834.5±4.5	646.5±3.5	1392.5±759.5	789±9	610.5±10.5	628±22	534±22	1321±831
AQI	886.5±173.5	795±41	834.5±4.5	646.5±3.5	1392.5±759.5	789±9	610.5±10.5	628±22	534±22	1321±831

Plants, particularly their roots and associated microorganisms, can remove VOCs from indoor air[8]. The high levels in the EHS 004 suggest a need for more effective remediation. EHS 007 had the least CO concentration (5 ppm), whereas the EHS 004 had a significantly high level of 25 ppm, with a high variability of ±20 ppm. EHS 007 (PVC) showed the lowest CO_2 concentration and AQI (both at 534). In contrast, the EHS 004 exhibited the highest levels for both parameters, with CO_2 at 1392.5 ppm and a similar AQI. It's worth noting that AQI values directly match the CO_2 values in the table, implying CO_2 might be the major determinant for AQI in these measurements. Elevated CO levels can pose health risks. The significantly high CO levels in the EHS 004 are concerning and may point to issues beyond plant remediation, like poor ventilation. Similarly, elevated CO_2 can indicate poor ventilation or high occupancy[9]. While plants do absorb CO_2, their impact on indoor CO_2 concentrations is often minimal unless the plant count is very high[10].

However, individual offices like EHS 003 and EHS 007 showed more favorable environmental conditions, with lower levels of pollutants. Conversely, common areas like the EHS 004 had comparatively higher pollutant concentrations. The placement of indoor plants might have varying effects across different spaces, and the EHS 004, in particular, might benefit from additional interventions.

Conclusion

This study assessed indoor air quality in workspaces, revealing generally acceptable conditions with some exceptions. Elevated levels of TVOC and PM2.5 in certain areas raised concerns, highlighting the need for continuous monitoring and targeted interventions. The study also explored the use of genetically characterized biological agents, such as Pseudomonas fluorescens and Bacillus subtilis, which showed promise in enhancing indoor air quality.

The study's findings underscore the importance of addressing HVAC issues, mitigating formaldehyde sources, improving relative humidity levels, reducing PM2.5, and deploying biological agents to create a healthier indoor environment. By implementing these recommendations, workplaces can promote well-being and productivity among occupants. The study provides actionable insights for sustainable indoor pollution control and highlights the need for further environmental monitoring to ensure comprehensive information on indoor air quality

Conflict of Interest

The authors declare no conflict of interest.

Author's Declaration

The authors hereby declare that the work presented in this article are original and that any liability for claims relating to the content of this article will be borne by them.

References

1. Sadrizadeh S, Yao R, Yuan F, Awbi H, Bahnfleth W, Bi Y, Cao G, Croitoru C, de Dear R, Haghighat F, Kumar P, Malayeri M, Nasiri F, Ruud M, Sadeghian P, Wargocki P, Xiong J, Yu W, Li B. Indoor air quality and health in schools: A critical review for developing the roadmap for the future school environment. J. Build. Eng. 2022; 57: 104908. ISSN 2352-7102. doi: 10.1016/j.jobe.2022.104908.
2. Nassikas NJ, McCormack MC, Ewart G, Balmes JR, Bond TC, Brigham E, Cromar K, Goldstein AH, Hicks A, Hopke PK, Meyer B, Nazaroff WW, Paulin LM, Rice MB, Thurston GD, Turpin BJ, Vance ME, Weschler CJ, Zhang J, Kipen HM. Indoor Air Sources of Outdoor Air Pollution: Health Consequences, Policy, and Recommendations: An Official American Thoracic Society Workshop Report. Ann Am Thorac Soc. 2024; 21(3):365-376. doi: 10.1513/AnnalsATS. 202312-1067ST. PMID: 38426826; PMCID: PMC10913763.
3. Vardoulakis S, Giagloglou E, Steinle S, Davis A, Sleeuwenhoek A, Galea KS, Dixon K, Crawford JO. Indoor exposure to selected air pollutants in the home environment: a systematic review.Int. J. Environ. Res. Public Health. 2020; 17(23):8972.
4. Dutkiewicz J, Cisak E, Sroka J, Wójcik-Fatla A, Zajac V. Biological agents as occupational hazards–selected issues. Ann. Agric. Environ. Med.. 2011; 18:286-93.
5. Gibbons SM, Gilbert JA. Microbial diversity–exploration of natural ecosystems and microbiomes. Curr. Opin. Genet. Dev. 2015;35:66-72.
6. Li K, Bihan M, Yooseph S, Methe BA. Analyses of the microbial diversity across the human microbiome. PLoS ONE. 2012; 7:32118.
7. Surtees R, Ariza A, Punch EK, Trinh CH, Dowall SD, Hewson R,Hiscox JA, Barr JN, Edwards TA. The crystal structure of the Hazara virus nucleocapsid protein. BMC Struct. Biol. 2015;15:1-3.
8. CrameriR. Recombinant Aspergillus fumigatus allergens: From the nucleotide sequences to clinical applications. Int. Arch. Allergy Immunol. 2018, 115, 99–114.
9. Holst GJ, Pedersen CB, Thygesen M, Brandt J, Geels C, Bønløkke JH, Sigsgaard T. Air pollution and family related determinants of asthma onset and persistent wheezing in children: nationwide case-control study. bmj. 2020; 19;370.
10. Vardoulakis S, Giagloglou E, Steinle S, Davis A, Sleeuwenhoek A, Galea KS, Dixon K, Crawford JO. Indoor exposure to selected air pollutants in the home environment: a systematic review. Int. J. Environ. Res. Public Health. 2020; 17(23):8972.
11. Sparks K, Faragher B, Cooper CL. Well-being and occupational health in the 21st century workplace. J Occup Organ Psychol. 2001; 74:487-509.
12. World Health Organization. Ambient air pollution. A global assessment of exposure and burden of disease. Geneva, Switzerland. W.H.O.; 2016. p. 1-121.
13. Nutbeam D, Lloyd JE. Understanding and responding to health literacy as a social determinant of health. Annu. Rev. Public Health. 2021; 42(1):159-73.
14. Gou Z, Lau SS. Sick building syndrome in open-plan offices. J Facilities Manag. 2012; 10:256-65.
15. Jim CY, Chen WY. Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China). J. Environ. Manag. 2018; 88;665-76.
16. Song JE, Kim YS, Sohn JY. The impact of plants on the reduction of volatile organic compounds in a small space. J Physiol. Anthropol. 2017; 26:599-603.
17. Teiri H, Hajizadeh Y, Azhdarpoor A. A review of different phytoremediation methods and critical factors for purification of common indoor air pollutants: an approach with sensitive analysis. Air Qual. Atmos. Health. 2021:1-9.
18. Oyabu, T., Sawada, A., Onodera, T., Takenaka, K., and Wolverton, B. Characteristics of potted plants for removing offensive odors: Sens. Actua. B. Chemical. 2017; 88; 131-136.
19. Mata TM, Oliveira GM, Monteiro H, Silva GV, Caetano NS, Martins AA. Indoor air quality improvement using nature-based solutions: design proposals to greener cities. Int. J. Environ. Res. Public Health. 2021; 11;18(16):8472.
20. Molina L, Wittich RM, van Dillewijn P, Segura A. Plant-bacteria interactions for the elimination of atmospheric contaminants in cities. Agronomy. 2021; 6;11(3):493.
21. Haslett SL, Thomas JC, Morgan WT, Hadden R, Liu D, Allan JD, Williams PI, Keita S, Liousse C, Coe H. Highly controlled, reproducible measurements of aerosol emissions from combustion of a common African biofuel source. Atmos. Chem. Phys. 2018; 18(1):385-403