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Research Article

Indoor air quality of academia-related workshops based on health complaints

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Abstract

Indoor Air Quality (IAQ) is a result of the interaction between micro-environmental conditions, location, and building characteristics. IAQ directly affects human health, comfort, productivity, and performance. However, very little attention has been paid to the IAQ of nonindustrial workshops.

This cross-sectional survey aimed to determine the IAQ of academia-related workshops based on the factors such as the microbial load (including bacteria, fungi, and actinomycetes), particulate matter (PM) content, presence of chemical pollutants (such as ammonia [NH_3], volatile organic compounds [VOCs], and formaldehyde [HCHO]), and physical conditions (such as temperature [T°C], relative humidity [RH%], light intensity, noise, dewpoint and air speed). Moreover, the perception weights of IAQ factors affecting the indoor comfort condition were also examined.

A two-stage viable, Andersen cascade impactor, was used by suctioning air onto the selective culture media. The PM content was determined by using a preweighted membrane filter. Portable air quality monitors were used to estimate the chemical and physical factors. A questionnaire survey was employed to assess the health complaints and the participants' perception weights on the indoor environmental parameters (such as thermal, acoustic, visual environment, and air quality).

The concentrations of mesophilic bacteria, fungi, and actinomycetes were found to be higher indoors than outdoors, with indoor/outdoor (I/O) values of 3.13, 1.56, and 1.53, respectively. The Global Index of Microbial Contamination/m^3 exceeded 7,000 colony forming units/m^3 in approximately 46% of the workshop areas. The I/O ratios of PM, VOCs, HCHO, and NH_3 were 1.69, 1.52, 0.65, and 0.6, respectively. T°C and RH% values ranged 18–35°C and 40–56%, respectively.

Özet

İç Hava Kalitesi (IAQ), mikro çevre koşulları, konum ve bina özellikleri arasındaki etkileşimin bir sonucu olup, insan performansını ve sağlığını etkiler. Endüstriyel olmayan atölyelerin IAQ çok az dikkat edilmiştir. IAQ, insan sağlığını, konforunu ve üretkenliğini doğrudan etkiler.

Akademi ile ilgili atölyelerde IAQ faktörlerini belirlemek için kesitsel bir araştırma yapılmıştır. IAQ faktörleri mikrobiyal (bakteriler, mantarlar ve aktinomisetler), partikül madde (PM), kimyasal [amonyak (NH_3), uçucu organik bileşikler (VOC) ve formaldehit (HCHO)] ve fiziksel (sıcaklık [T°C], bağıl nem [RH%], ışık yoğunluğu, gürültü, çiğlenme noktası ve hava hızı) düzeyleri açısından incelenmiş ve iç mekan konforunu etkileyen IAQ faktörlerinin algılama ağırlıkları değerlendirilmiştir.

Seçici kültür ortamlarına hava emerek iki aşamalı Andersen numune alıcı kullanılmıştır. PM, önceden tartılmış membran filtre kullanılarak ölçülmüştür. Kimyasal ve fiziksel faktörleri ölçmek için taşınabilir hava kalitesi monitörleri kullanılmıştır. Sağlık şikayetlerini ve katılımcıların iç ortam parametrelerine (termal, akustik, görsel ortam ve hava kalitesi) ilişkin algı ağırlıklarını belirlemek için bir anket kullanılmıştır.

İç mekanlarda dış mekanlara göre mezofilik bakteriler mantar ve aktinomisetlerin konsantrasyonlarının daha yüksek olduğunu ortaya koymuştur. İç mekan/dış mekan (I/O) değerleri sırasıyla 3,13, 1,56 ve 1,53 olarak ölçülmüştür. Mikrobiyal Kontaminasyon Küresel Endeksi/m^3 atölyelerin yaklaşık %46'sında 7000 koloni oluşturan birim/m^3'yi aşmıştır. PM, VOCs, HCHO ve NH_3'ün I/O oranları sırasıyla 1,69; 1,52; 0,65 ve 0,6 olarak ölçülmüştür. T°C ve RH% değerleri sırasıyla 18-35°C ve 40-56% arasında değişmiştir. Gürültü değerleri iç ve dış ortamda 70 desibel (dBA) değerini aşmıştır. Işık yoğunluğu

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Noise values exceeded 70 dBA in both the indoor and outdoor environments. Light intensity was also unacceptable (≤ 300 lux) at 84.6% of the workshop areas. VOCs and dewpoint revealed significant positive and negative effects on microbial viability, differing with regard to the microbial type. Fatigue (45.5%), allergies (38.6%), and headache (35.2%) were the common complaints of the occupants. All of the tested IAQ parameters influenced the workplace environment, with noise ranking as the main factor (40.9%).

Microbial air quality is differently associated with the indoor environmental factors. The IAQ in the workshops was poor and potentially affected the occupant's well-being. The perception of comfort varied among the occupants under the same IAQ factors. Thus, corrective actions based on comparative analysis should be implemented to promote the indoor quality of even nonindustrial and academia-related workplaces.

atölyelerin %84,6'sında kabul edilemez düzeyde (≤ 300 lux) idi. VOC'ler ve çiğlenme noktası, mikrobiyal canlılık üzerinde önemli pozitif ve negatif etkiler göstermiş, mikrobiyal türe göre farklılık göstermiştir. Yorgunluk (%45,5), alerji (%38,6) ve baş ağrısı (%35,2) katılımcılar arasında en sık görülen sağlık şikayetleriydi. Tüm IAQ parametreleri işyeri ortamını etkilemiş olup, gürültü katılımcıların konforunu etkileyen ana faktör (%40,9) olarak sıralanmıştır.

Mikrobiyal hava kalitesi, iç ortam faktörleriyle farklı şekilde ilişkiliydi. Atölyelerde IAQ kötüydü ve katılımcıların' refahını potansiyel olarak etkiledi. Aynı IAQ faktörleri altında katılımcılar arasında konfor algısı farklılık gösterdi. Karşılaştırmalı analiz yoluyla, işyerlerinin iç ortam kalitesini iyileştirmek için düzeltici önlemler alınmalıdır.

Keywords: indoor air quality, nonindustrial workshops, deposited dust, particulate morphology, microorganisms, VOCs, noise, lighting, health complaint, satisfaction

Introduction

Indoor Air Quality (IAQ) is influenced by multiple interrelated factors, including building activities and materials, ventilation efficiency, emission sources, and both geographical and microclimatic conditions (Apte & Salvi, 2016; Tran et al., 2020; Chawla et al., 2023). Air pollutants, thermal comfort, illumination level, and noise pollution are the key factors that significantly impact IAQ (Tang et al., 2020; Roumi et al., 2022; Wu et al., 2023). Indoor air pollution levels are often reported to be 2–5 times higher than outdoor (United States Environmental Protection Agency [U.S. EPA], 2025a), with indoor environments emitting wide array of hazardous pollutants such as volatile organic compounds (VOCs), particulate matter (PM), and microorganisms (Kumar & Imam, 2013).

Among these pollutants, microorganisms are pervasive in indoor environments, and present substantial public health risks (DiCarlo et al., 2016; U.S. EPA, 2025b). Numerous studies have evaluated microbial air quality across both industrial (Gilbert & Duchaine, 2009; Mackiewicz et al., 2015; Thorne, 2019; Quintana et al., 2020; Quintanilla-Martinez et al., 2022; Tyagi & Srivastava, 2023) and public (Shiferaw et al., 2016; Osman et al., 2017; Abdel Hameed et al., 2018; Pyrri et al., 2020; Nath et al., 2023) settings. The diversity and concentration of microbial populations in indoor air are shaped by geographical location, weather conditions, and human activities (Rai et al., 2021). Inhalation exposure to airborne microbes can trigger respiratory infections, allergic reactions, hospital-acquired (nosocomial) diseases, and symptoms associated with sick building syndrome (SBS) (Dyląg, 2017). Furthermore, microbial contamination contributes to the biodeterioration of structural materials (Kadaifciler, 2017; Lippai et al., 2024).

PM, one of the most critical indoor pollutants, is composed of both primary particles (emitted directly from anthropogenic or natural sources) and secondary particles (formed through complex chemical reactions in the atmosphere) (Juda-Rezler et al., 2020). Indoor PM concentrations are influenced by external air quality, building envelope characteristics, ventilation rates, material composition, and human activities (Cheng, 2017; Melymuk et al., 2020). Elevated PM levels have been documented in specific workplaces, including metal and wood working facilities (Abdel Hameed et al., 2000; Insley et al., 2019, Buljat et al., 2024). The shape, size, and chemical composition of PM vary significantly, which determines its toxicity and surface-soiling potential (DiBernardino et al., 2021; Park et al., 2018). Therefore, both the mass concentration and chemical composition of PM should be analyzed to understand its full impact on human health.

VOCs are another critical group of indoor air contaminants, consistently found in higher concentrations indoors compared to outdoor (Nurmatov et al., 2015; Spinazzè et al., 2020). VOCs, including formaldehyde (HCHO), are released from a range of sources such as building materials, insulation foams, cleaning agents, furnishings, and human activities (Mangotra & Singh, 2024). Building materials alone can contribute up to 40% of total indoor VOCs emissions, depending on the building's age, type, and prevailing temperature and humidity conditions (Missia et al., 2010; Zhu et al., 2024). Notably, newly constructed or recently renovated buildings exhibit significantly higher VOC levels than older structures (Holøs et al., 2018). In Chinese residential, educational, and office buildings, median HCHO concentrations ranged between 94–163 µg/m³, with 46–91% of sampled buildings, exceeding the standard threshold of 100 µg/m³ (Fang et al., 2022). Formaldehyde is classified as a Group 1 human carcinogen by the International Agency for Research on Cancer IARC, 2006).

Ammonia (NH_3) is a dominant basic gas present in both indoor and outdoor environments (Li et al., 2020). Emissions originate from various sources, including livestock, decomposition of organic matter, industrial and vehicular emissions, combustion activities, building materials, paints, and even human metabolism and exhaled breath (Li et al., 2022; Lefferts & Castell, 2022). NH_3 also plays a critical role in atmospheric chemistry, particularly in the formation of secondary PM (Wyer et al., 2022). Studies from Chinese college dormitories reported mean NH_3 concentrations of 0.59 mg/m³, exceeding the national standard threshold (GB/T

18883–2002). Chronic exposure to NH_3 has been linked to neurophysiological disturbances, mucous membrane irritation, and headache (California Office of Environmental Health Hazard Assessment, 1999; Pacharra et al., 2016; Sun et al., 2024).

Physical parameters, including thermal conditions, directly affect both IAQ and occupant well-being (Asadi et al., 2017). Thermal discomfort, particularly temperatures > 26°C, has been shown to negatively impact productivity (Lan et al., 2011), whereas uncontrolled fluctuations in temperature and humidity can damage building materials (Camuffo, 2019). High temperatures, low air exchange, elevated humidity, excessive light intensity, and poor air quality are commonly associated with SBS symptoms (Akova et al., 2022).

A prior assessment of academia workshop environments categorized their indoor environmental quality (IEQ) as Class D (IIEQ score of 10–32.5), indicating a high-risk classification according to the IEQ Index model (Abdel Hameed et al., 2023). Walkthrough inspections of these workshops revealed several concerns, including high humidity levels, visible dust and dirt accumulation, inadequate ventilation, fungal growth, and musty odors. Occupants also reported health-related complaints potentially linked to these environmental deficiencies.

Given these observations, the present study aims to investigate IAQ-related factors within academic workshop settings; examine the influence of micro-environmental parameters on airborne microbial composition; identify the prevalence and extent of indoor fungal contamination; and determine the perception weightage of various IAQ factors to pinpoint the primary contributors to occupant satisfaction. The findings are intended to draw attention to potential IAQ hazards in nonindustrial academic and public workshop settings, and support the development of threshold guidance values tailored for such environments.

Materials and Methods

IAQ Factors and Sampling Workshops

A cross-sectional survey of IAQ (including microbial, PM, chemical, and physical) factors was conducted in 13 workshops related to academia building. The workshops are namely "wood, alumina, glass, painting, plumbing, welding, car garage & maintenance, scientific equipment maintenance, cooling, oil extraction, marble and granite test, water pump station, and electricity station." These workshops cannot be classified as the same as industrial workshops despite performing technical/ or professional tasks related to public building activities. The workshops are located in different buildings and differ in their total area (range: 40–187 m^2), height above the ground level (–3 m to + 6 m), number of occupants (range: 3–22 persons/location), and ventilation mode. Poor ventilation rate, dampness, musty odor, and crowding are the common characteristics of the workshops. Natural ventilation (openings) is the main ventilation type; however, mechanical ventilation (fans/no air conditioner) is operated in some workshops. The academic building is located in the Dokki district, Giza governorate. This district is an urban area characterized by heavy anthropogenic activities, high traffic, commercial activities, hospitals, offices, and numerous educational facilities, with rare and permanent vegetation cover. The description of the sampling sites and timetable schedule for the IAQ measurements has been presented in Table 1.

Sampling Campaign

A total of 28 samples (a minimum of 2 event/workshop) and 6 samples (at least one sample/month) were collected from inside and outside the workshops, respectively. The sampler/monitor was placed at approximately 1.5–2 m height on a flat surface, approximately 1–2 m away from the openings and disturbance of direct obstacles. The outdoor sampling was conducted approximately 3–4 m outside of the main building, away from any distinct emission sources. The indoor and outdoor samples were almost collected in parallel.

The measurements of the chemical and physical parameters were performed at the beginning and the end of each sampling event (approximately 2 readings/event), except for the PM, with one PM sample collected at every sampling event. The air samples were collected during the normal working days, which lasted approximately 4–5 h, during 10:00 and 15:00 hours, which is the period of full capacity of the work activity. The sampling was conducted on Mondays through Thursdays of the last weeks of each month, during the period between May and December 2022.

Sampling of the Airborne Microorganisms

A two-stage viable particle sampler (TE-10-160, Tisch Environmental Cleves, OH, USA) was used to collect airborne microorganisms (National Institute for Occupational Safety and Health, 1998). This device separates particles into fine (≤ 2.5 µm) and coarse (≥ 7 µm) size ranges and operates at the recommended flow rate of 28.3 L/min for 5 min; it was run in duplicate. Trypticase soya agar supplemented with 0.25% cycloheximide, malt extract agar supplemented with 0.01% chloramphenicol, and starch casein agar media were used to culture bacteria, fungi, and actinomycetes, respectively. The culture plates of fungi and actinomycetes were incubated at 28°C ± 2°C for 5 and 7–14 days, respectively, whereas those of environmental and mesophilic (human-related) bacteria were incubated at 30°C ± 2°C for 48 h and at 37°C for 48–72 h, respectively. Positive hole correction was applied to the raw colony forming unit (CFU) recorded on each plate and by using the CFU with sampling time and flow rate; the concentration was calculated and expressed as CFU/m^3 of air (Andersen, 1958).

Fungal isolates were identified through direct observation of micro- and macro-morphological features by reverse and surface coloration of colonies on Sabouraud's dextrose agar, Czapek dox agar, potato dextrose agar (Difco, Detroit, MI) and malt extract agar media (Hi-media laboratories, Mumbai, India) with the use of keys for taxonomic literature (Ellis, 1971; Raper & Fennell, 1977; Barnett & Hunter, 1999; Pitt & Hocking, 2009).

Table 1. Description of the sampling sites and sampling timescale for the IAQ tests.

Number	Workshop	Building floor	Ventilation type/ quality*	Area (m^2)	Average number of occupants	Measurement timescale (day/ month)
1	Wood	Separated building/ ground floor	Natural/bad	184	22	28/9; 29/9 & 18/10
2	Alumital	Separated building/ ground floor	Natural/moderate	110	8	15/11 & 22/11
3	Glass	2nd floor	Natural/moderate	95	8	28/9 & 19/12
4	Painting	Basement	Natural/bad	97	12	18/10 & 25/10
5	Plumbing	Basement	Natural/bad	112	9	11/10 & 25/10
6	Welding	Ground floor	Natural/bad	120	3	22/11 & 15/11
7	Car garage & maintenance	Ground floor	Natural/moderate	150	17	24/5 & 21/9
8	Scientific equipment maintenance	2nd floor	Natural/bad	30	6	24/5 & 22/6
9	Cooling	Ground floor	Natural/bad	62	6	14/9 & 20/9
10	Oil extraction	Basement	Natural/moderate	40	3	14/9, 12/12 & 19/12
11	Marble and granite test	Basement	Natural/bad	40	4	15/11 & 12/12
12	Water pump station	Ground floor	Natural/moderate	176	3	18/10 & 15/11
13	Electricity station	Ground floor	Natural/moderate	28	3	20/9 & 18/10
14	Outdoor air	External environment/ outside main buildings	-	-	-	24/5, 22/6, 21/9; 18/10, 22/11 & 12/12

IAQ = indoor air quality.

Suspended and Deposited Particulates

Suspended PM was collected on a preweighed cellulose nitrate membrane filter (25 mm-diameter, 0.45 µm-pore size) using an open face filter holder and a vacuum pump calibrated to draw 15 L/min for 4–5 h. The PM mass concentration was calculated and expressed as microgram per cubic meter of air (µg/m^3). The shape (morphology) of the PM collected from some workshops was analyzed with the high-resolution scanning electron microscope (SEM; Quanta FEG 250, FEL Company, Netherlands, Electron Unit of Microscopy, NRC). The chemical species of the PM sample collected from the auto-mechanic (car maintenance) workshop were only examined by using an energy-dispersive X-ray analyzer (EDAX) attached to the electron microscope.

The deposited (settled) dust was determined using a passive collector (170-mm height, 80-mm diameter) by positioning the collector approximately 2–3 m above the floor surface in the center of the workshop. The dust collectors were harvested after 3 months of exposure, and the deposited dust was carefully transferred to dry-sterilized preweighted beakers. The dust rate was then calculated and expressed as milligram per square meter per day (mg/m^2/day).

Chemical Pollutants (i.e., VOCs, HCHO & NH_3)

A portable digital Aeroqual-Series 200 detector (Auckland, New Zealand) was used to measure the levels of VOCs and NH_3. Moreover, a portable air quality monitor (Yvelines air quality monitor, Model: HTO-131, USA) was used to measure the HCHO levels. The levels of the chemical pollutants were expressed as milligram per cubic meter of air (mg/m^3) for VOCs and as microgram per cubic meter of air (µg/m^3) for HCHO and NH_3.

Physical Factors (i.e., Noise, T°C, Relative Humidity [RH%], Light and Air Speed)

The noise levels were determined by using a sound level meter (model RO-1350, Taiwan) positioned approximately 1.5 m above the ground surface level, no closer than 3 m to any reflecting surface, and expressed as decibel-A (dBA). The light intensity was measured at nearly 4 points/location with a light meter (Light meter-TM-201, Taiwan) and expressed as lux. T°C and RH% were measured using a thermo-hygrometer (Sato-PC 5,000, China) (ASTM 2015). The air velocity (m/s) was measured using an anemometer (ABH-4225, Taiwan). The physical parameters were measured at the start time (10:00 – 11:00 AM) and at the end time (2:00 – 3:00 PM) of each sampling event.

Survey of the Complaints Related to the Indoor Environment

A questionnaire survey was administered to 88 randomly selected subjects, with no inclusion or exclusion criteria. The survey items were general questions based on the frequent occurrence of the health symptoms for 3 days per week in the past 4 weeks before the survey. These symptoms appeared daily or nearly every working day and disappeared/or got better when the employee left the workplace. The questionnaire listed the following general symptoms: shortness of breath, wheezing, cough, sneezing, stuffy nose, throat irritation, allergy, watering eyes, dry eyes, irritation of the eyes, headache, fatigue, dizziness, and nausea (Mendell et al., 2003; Azuma et al., 2022). Moreover, the weighting of four IAQ factors (i.e., temperature, light intensity, noise, and air quality [ventilation/odor]) that affected the occupant's satisfaction was analyzed with reference to the questionnaire-based survey so as to determine the major IAQ factor affecting the worker's comfort.

Statistical Analysis

Descriptive (i.e., range, mean, standard deviation (SD), and 95% confidence intervals) and nonparametric statistics were employed to analyze the obtained data. Spearman's rank-correlation test was performed to determine the relationships between the chemical and physical factors with the microbial load. $p \leq 0.05$ was considered to indicate statistical significance.

QA/QC

QA/QC was applied using duplicate samples in each sampling event for the determination of the microbial load and the presence of physical and chemical parameters. A blank membrane filter and culture media were maintained to standardize the PM and microbial pollutants, respectively. The sampling devices were verified against the calibrated reference equipment. Statistical analysis was performed to interpret the obtained data. The outdoor samples were collected on the same days for IAQ assessments.

Results and Discussion

Microbial Air Quality

Indoor microbial air quality depends on the shear force, microbial type, indoor sources, outdoor air quality, occupant's intensity, nature of work, and the ventilation mode (Romano 2023). The summary of the indoor and outdoor microbial air quality is presented in Table 2 and Figure 1. The airborne microbial concentrations varied with regard to the workshops. The concentrations of environmental bacteria, mesophilic bacteria, fungi, and actinomycetes averaged 4,646 CFU/m^3 (95% confidence interval [CI] 2,308–6,984 CFU/m^3), 1,931 CFU/m^3 (95% CI 1,186–2,677 CFU/m^3), 825 CFU/m^3 (95% CI 490–1,159 CFU/m^3) and 532 CFU/m^3 (95% CI 153–862 CFU/m^3), respectively. The indoor/outdoor (I/O) ratios were 0.95, 3.13, 1.56, and 1.53 for the corresponding microbial indicators, respectively. The highest concentration of mesophilic bacteria (4,531 CFU/m^3) was recorded in the cooling workshop. The highest loads of fungi (2,841 CFU/m^3) and actinomycetes (2,254 CFU/m^3) were detected in the water pump workshop. Environmental bacteria (19,378 CFU/m^3) were detected in the highest concentration in the marble and granite test workshop (Figure 1), suggesting that the dust-raising activities increased the bacterial counts relative to the fungal counts.

Table 2. Range, mean, and 95% CI of indoor/outdoor microbial parameters in the workshops.

Parameter	Indoor environment (Range) [mean ± SD]	95% CI	Outdoor environment (Range) [mean ± SD]	95% CI
Environmental bacteria–CFU/m³	(1,594–19,378) [4,646 ± 4,464]	2,308–6,984	(1,366–11,081) [4,867 ± 4,383]	571.7–9,162
Mesophilic bacteria–CFU/m³	(524–4,531) [1,931 ± 1,423]	1,186–2,677	(71–1,021) [617 ± 396.4]	228–1,005
Fungi–CFU/m³	(362–2,841) [825 ± 638.7]	490–1,159	(387.5–692.6) [527 ± 144]	385–668
Actinomycetes–CFU/m³	(59–2,254) [532 ± 667]	153–862	(131–674) [348 ± 231]	122–574

CFU = colony-forming unit; CI = confidence interval; SD = standard deviation.

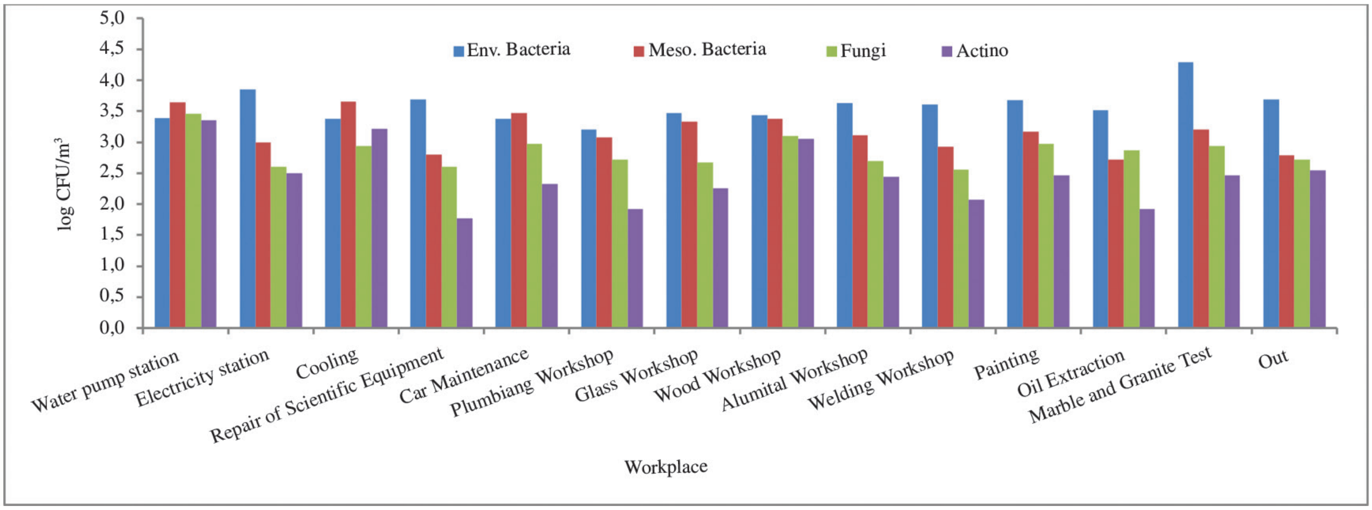

Figure 1. Log concentrations of airborne microbial parameters in the workshops.

Airborne microorganisms are randomly transmitted between the indoor and outdoor environments. Indoor microorganisms originate from indoor sources and natural/or anthropogenic surrounding activities. The I/O ratios of microbial air parameters indicated that the indoor environment was the main contributor of mesophilic bacteria, fungi, and actinomycetes, whereas the outdoor environment was the main contributor of environmental bacteria. I/O value > 1 indicates that biocontamination originates from the indoor environment (Roshan et al., 2019; Jabeen et al., 2023). Overcrowding, poor ventilation, and adequate moisture facilitate the emission of bacteria and fungi indoors (Crawford et al., 2015). Actinomycetes are not normal indoor microbial flora, and their presence has been associated with abnormal situations such as presence of dampness and mold (Nevalainen et al., 1991). Actinomycetes are associated with the complaints of odor in buildings (Nevalainen et al., 1990). The low counts of actinomycetes may be attributed to their complex natural aerosolization mechanism, considering that they have small spore sizes approximately ≤ 1 µm, which requires high air current to release them into the air (Reponen et al. 1998).

Natural ventilation, through openings, is the main ventilation mode in most workshops. The studied workshops had inadequate and bad ventilation (air velocity ≤ 0.15 m/s), which directly affected microbial concentrations and types. I/O ratio, a relative standard, was applied to establish the presence or absence of indoor biologically derived sources and the outdoor infiltration factor. Natural ventilation increases the fungal counts and mechanical ventilation reduces their counts (MacIntosh et al., 2006), and infiltration brings exogenous microbes to the indoor environment (Zhong et al., 2016). Mechanical ventilation (rarely operated at these workshops) has higher air exchange rates compared to natural ventilation, which consequently reduces the indoor microbial content (Langer & Bekö, 2013).

Indices of Biocontamination

An assessment of the contamination levels was performed using three evaluation indices for microbiological pollution, namely "Global Index of Microbial Contamination per cubic meter of air (GIMC/m^3), amplification index (AI), and the index of microbial contamination (IMC), (Dacarro et al., 2005). GIMC/m^3 was calculated as the sum of the total counts of microbial parameters in each workshop. IMC was determined by calculating the ratio of the CFU/m^3, as measured for mesophilic and environmental bacteria at the same sampling site. AI is calculated as the ratio between the GICM/m^3 values measured indoors and outdoors, and it is an indicator of microbial accumulation indoors (Grisoli et al., 2019).

The summary of the biocontamination indices in the workshops is depicted in Table 3 and Figure 2. The GIMC/m^3 index values ranged between 10^3 CFU/m^3 and 10^4 CFU/m^3 and exceeded 7,000 CFU/m^3 at nearly 46% of the total workshops. The greatest GIMC/m^3 was detected in the marble and granite test workshop (22,110 CFU/m^3) and the lowest in the plumbing workshop (3,373 CFU/m^3) (Figure 2a). The values of the AI and IMC indices were ≥ 1 at 61.5% and 15% of the total workshops, respectively. GIMC/m^3, IMC, and AI achieved the highest values in the marble and granite test, water station, and cooling workshops, respectively (Figure 2a and b). The GMIC/m^3 values profile was in the following sequence: marble and granite test > water pump > cooling > electricity > wood > painting > car maintenance > alumital > repair of scientific equipment > glass > welding > oil extraction> plumbing. The workshops had higher microbial air loads (GIMC/m^3 ≥ 7,000 CFU/m^3) when compared to other public buildings, such as hospitals, libraries, schools, and child daycares in Egypt (Abdel Hameed et al., 2018).

Fungal Diversity

The identification of airborne fungal spores is a critical issue to determine their sources, health problems, and proactive steps so as to reduce the exposure. A total of 25 fungal taxa were identified at all workshops, including *Absidia*, *Acremonium*, *Alternaria*, *Aspergillus flavus (A. flavus)*, *Aspergillus niger*, *Aspergillus ochraceus*, *Aspergillus terreus*, *Aspergillus versicolor (A. versicolor)*, *Aspergillus fumigatus (A. fumigatus)*, other *Aspergillus*, *Aureobasidium*, *Cladosporium*, *Curvularia*, *Drechslera*, *Emericella*, *Epicoccum*, *Fusarium*, *Monilia*,

Table 3. Range, mean, and 95% CI of biocontamination indices at the workshops.

Biocontamination index	Air environment			
	Indoor		Outdoor	
	(Range) [mean ± SD]	95% CI	(Range) [mean ± SD]	95% CI
GIMC/m³	(3,374–22,111) [7.909 ± 4,662]	5,467–10,351	(2,713–12,331) [6,358.5 ± 4,324]	2,120.8–10,596
AI	(0.4–3.22) [1.45 ± 0.92]	0.95–1.95	–	–
IMC	(0.1–1.92) [0.64 ± 0.59]	0.32–0.96	–	–

GIMC = global index of microbial contamination; AI = amplification index; IMC = index of microbial contamination; CFU = colony-forming unit; CI = confidence interval; SD = standard deviation.

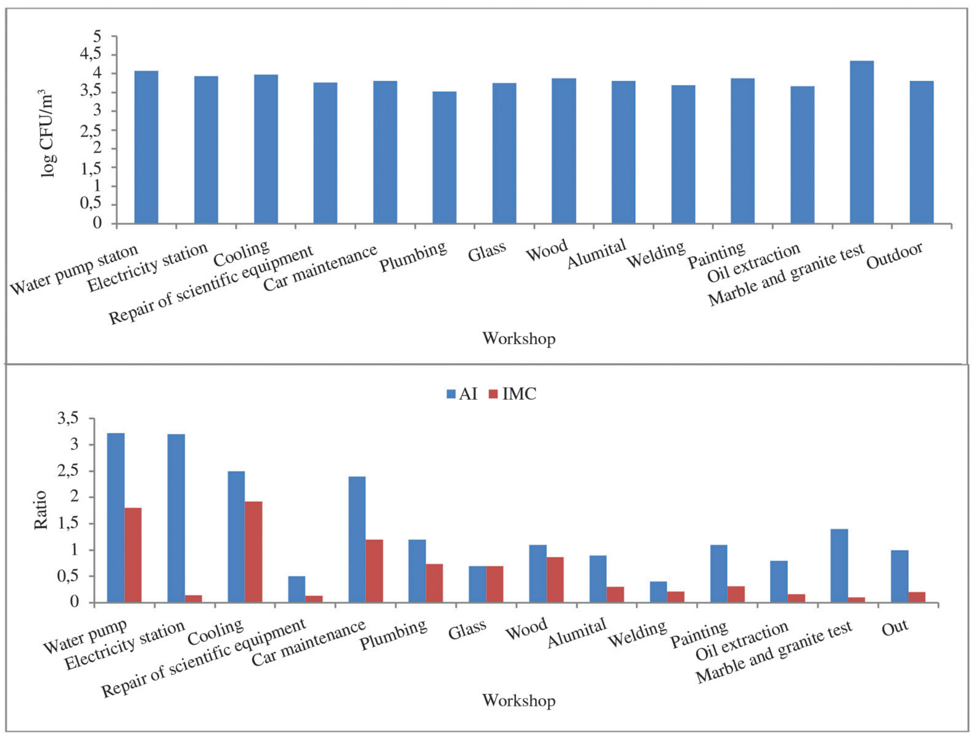

Figure 2. Air biocontamination indices at different workshops (a: GIMC/m³; b: AI and IMC). CFU = colony-forming unit; GIMC = global index of microbial contamination; AI = amplification index; IMC = index of microbial contamination.

Nigrospora, Penicillium, Rhizopus, sterile hyphae, *Trichoderma, Trichothecium,* and yeast.

Aspergillus (57.9%), *Penicillium* (9.34%), *Cladosporium* (4.84%), and *Alternaria* (3.42%) were the dominant fungal taxa. Fungal diversity was the highest at the wood workshop (13/ 25,~52%) and lowest at the plumbing workshop (6 /25, ~24%). *Aspergillus* constituted the largest counts, with 36–2,699 CFU/m³, at almost all the workshops. The highest counts of *Aspergillus*, *Alternaria*, *Cladosporium*, and *Penicillium* were detected in the water pump station, painting, granite and marble test, and oil extraction workshops, respectively (Figure 3). The secondary (*Alternaria*, *Cladosporium*, *A. flavus*, *A. versicolor*, *Penicillium,* and *Emericella*) and tertiary (*A. fumigatus*, *Nigrospora*, *Aureobasidium*, *Fusarium*, *Trichoderma*, *Monilia,* yeast, and sterile hyphae) fungal colonizers grew well at moderate and high water activities, respectively.

Generally, the characteristics of the surrounding environment and buildings, human activity, ventilation rate, and microclimatic conditions affect fungal counts and diversity (Hoekstra et al., 1994; Loukou et al., 2024). The dominance of primary fungal colonizers can be attributed to the fact that they are easily liberated into the air when disturbed, can adapt to atmospheric transport, and grow well in diverse habitats with minimal nutrients. Globally, *Aspergillus* and

Penicillium species are dominant in different climatic conditions (Mousavi et al., 2016), colonize damp materials (Horner, 2006), and prefer air humidity (Wilkie et al., 2023). The phyloplane taxa, *Alternaria*, *Cladosporium, Epicoccum,* and *Drechsler*a (naturally grow on leaves and other plant surfaces) dominate the outdoor environment (Levetin & Dorsey, 2006). *Penicillium*, a soil fungus, predominates in most regions and is replaced by *Aspergillus* in humid environments (Lacey et al., 1991). The tertiary fungal colonizers grow on most building materials in the presence of adequate moisture, with at least 0.65 water activity required for growth (Lacey & Dutkiewicz, 1994). The presence of primary, secondary, and tertiary fungal colonies indicates the fluctuation and stratification of microclimatic conditions, which warrants intervention to control dampness and dust.

Monitoring of microbial air quality is important as a regulatory compliance as well as for biological risk assessment. Although it is difficult to establish a dose–response relationship on the basis of the existing epidemiological data, the numbers and types of microorganisms detected can offer a useful index for evaluating IAQ (Grisoli et al., 2019).

Universally, there are no acceptable/official permissible values for airborne microorganisms. The Commission of the European Communities suggests < 500 CFU/m^3 and ≥ 2,000 CFU/m^3 as intermediate and high biocontamination, respectively, in a nonindustrial environment (Commission of the European Communities, 1993). Microbial counts > 1,000 CFU/m^3 indicates biocontamination (Occupational Safety and Health Administration [OSHA], 1992). Concentrations of bacteria > 3,000 CFU/m^3, fungi > 10,000 CFU/m^3, and actinomycetes > 100 are suggested as strongly microbial contaminated air (Polish Standard/PN-89/Z-04111/03, 1989). Fungal count ≥ 100 CFU/m^3 indicates the presence of an indoor source (Ohgke et al., 1987) and an abnormal condition when the count exceeds 500 CFU/m^3 (Reynolds et al., 1990). In Sweden, the concentration of *Aspergillus* species should be < 50 CFU/m^3 (Holmberg, 1987).

Actinomycetes count ≥ 100 CFU/m^3 indicates a damp environment and high microbial pollution (Breza–Boruta & Paluszak, 2007). Miller et al. (1988) reported that toxigenic and pathogenic fungi are unacceptable in indoor air, and if one of the counts of fungal species is > 50 CFU/m^3, indoor air is acceptable if the mixture of fungal species is < 150 CFU/m^3 and phylloplane fungi is < 300 CFU/m^3. The World Health Organization (WHO) expert group on the assessment of the health risks of biological agents in the indoor environment suggests that the l0^3 microorganisms/m^3 is generally considered the maximum safety level (Macher et al., 1995). Microbial air counts at the academia workshops exceeded some of the previously recommended limit values.

Suspended and Deposited PM

The concentrations of the suspended and deposited dust in the workshops are presented in Table 4. The concentrations of PM were 83–536 µg/m^3, with a mean of 287 µg/m^3 (95% CI 172–366 µg/m^3) in the indoor environment and 169 µg/m^3 (95% CI 112–226 µg/m^3) in the outdoor environment. The I/O ratio of PM was 1.69, indicating that indoor activities were the main contributor of particulates. Heavy dust contamination ≥ 400 µg/m^3) was detected in the welding, glass, car maintenance, wood, marble, and granite test workshops. The greatest PM concentration (536 µg/m^3) was detected in the welding workshop, as the nature and composition of the PM affected its mass concentration.

The deposited dust rate averaged 71.9 mg/m^2/day (95% CI 33.5–110.3 mg/m^2/day) inside the workshops. The highest and lowest deposited dust rates were detected in the wood (258 mg/m^2/day) and oil extraction (1.75 mg/m^2/day) workshops, respectively. Dust deposition inside the workshops widely varied, depending on the nature and capacity of the work and the infiltration factor. The calculation of the particle size is of great concern to determine the removal process and exposure risks. The particle sizes ranged between ≤ 5 and ≥ 20 µm. The deposition velocity is computed from the deposited dust rate (µg/m^2/h) and volumetric concentration (µg/m^3), and it is determined by the size, air turbulence, RH, thermal

Table 4. Range, mean, and 95% CI concentrations of indoor/outdoor particulates and chemical pollutants at the workshops.

Parameter	Indoor environment		Outdoor environment	
	(Range) [mean ± SD]	**95% CI**	**(Range) [mean ± SD]**	**95% CI**
PM-µg/m^3	(83–536) [287 ± 218]	172–366	(111–250) [169 ± 58.5]	112–226
Deposited dust-mg/m^2/day	(1.75–258) [72 ± 70.6]	33.5–110	–	–
HCHO-µg/m^3	(123.8–316) [226 ± 61]	193–259	(230–541) [343 ± 105]	258–427
NH_3-µg/m^3	(45.6–395) [157 ± 123]	90–224	(0.0–658) [258 ± 273]	38–478
VOCs- mg/m^3	(0.47–8.57) [2.5 ± 2.27]	0.96–3.74	(0.36–3.7) [1.65 ± 1.14]	0.37–2.57

CI = confidence interval; PM = particulate matter; HCHO = formaldehyde; NH_3 = ammonia; VOCs = volatile organic compounds.

gradient, and eddy diffusion (Lai & Nazaroff, 2000). In this study, the lowest deposition velocity (1.3E02 cm/s) was detected in the oil extraction workshop and the highest (1.13 cm/s) in the plumbing one. Particle sizes ≤ 5 µm were detected in the oil extraction, repair of scientific equipment, and water pump workshops.

The mass concentration, composition, size, and shape of the PM vary with the dust origin and the formation process (Morawska & Salthammer, 2003; Dong et al., 2019; Zhang et al., 2022). The study of the physical properties of suspended particles helped understand their behavior and removal process. Figure 4 depicts the SEM images and EDAX analytical approach of PM. The shape of the particles varied from being fairly simple and regular to irregular/or complex ones. The shapes are varied within rounded and smooth surfaces, crystalline, and small and elongated fibers. This variation confirmed that the particles had various contributors such as fly ash, diesel soot, fossil fuel burning, and organic origin. The regular fibrous/elongated shape was detected in the wood workshop, whereas small agglomerate spherical particles were detected in the auto mechanic workshop (Figure 3). Tiwar et al. (2024) reported that quartz (rock particles) and tapered fibers dominated in the glass workshop, spherical particles (Si, Al, and Fe-rich) produced from combustion, and irregular blocky particles (Fe, Si, Ca, and Mg-rich) produced by mechanical processes.

Chemical Air Pollutants

The average values of indoor HCHO, NH_3, and VOCs were 226 µg/m^3 (95% CI 193–259 µg/m^3), 157 µg/m^3 (95% CI 90–224 µg/m^3), and 2.52 mg/m^3 (95% CI 0.96–3.74 mg/m^3), respectively (Table 4). The highest values of the corresponding air chemical pollutants were measured at the electricity station (316 µg/m^3), car garage and maintenance (395 µg/m^3), and oil extraction (8.57 mg/m^3) workplaces, respectively. The I/O ratios of HCHO, NH_3, and VOCs were 0.65, 0.6, and 1.5, respectively. The indoor environment was the main contributor of VOCs. The VOCs and HCHO are generally linked and emitted from a variety of natural and human-caused sources (Hansen, 1999; Kumar et al., 2021; Dehghani et al., 2024). Surprisingly, the HCHO values were higher outdoors than indoors. HCHO is formed through the atmospheric oxidation of VOCs and the reaction among O_3, alkenes, and terpenes (Liu et al., 2023) and anthropogenic sources of industrial and vehicle emissions and vegetation. HCHO values were higher in the ambient air, especially in the urban environment (Salthammer et al., 2010).

Although VOCs are the main pollutants affecting the IAQ, there are no global/local limits on them. Some countries have recommended permissible limits, such as 200 µg/m^3 by Belgium, 1,000 μg/m^3 by South Korea (International Society of Indoor Air Quality and Climate, n.d.), and 3,000 µg/m^3 by Finland (Tuomi & Vainiotalo, 2016). The value of 500 µg/m^3 is recommended as a background level for VOCs (Bluyssen et al., 2005). VOCs were detected in high values, exceeding the recommended permissible limit of 3 mg/m^3 at 30% of the workshop areas (such as glass, aluminum, oil extraction, and painting workshops). However, the American Conference of Government Industrial Hygienists (ACGIH, 2012), the Occupational Safety and Health Administration (OSHA, 1992), the World Health Organization (WHO, 2000), and Danish guidelines (Nazaroff & Weschler, 2004) have recommended HCHO limit values of 370 µg/m^3/8 h, 920 µg/m^3/8 h, 100 µg/m^3, and 100 µg/m^3, respectively. HCHO values exceeding the limits have been set by the Danish guidelines and the WHO (100 µg/m^3) in all workshops under investigation.

NH_3 values varied at 45.6–395 µg/m^3 inside the workshops, with an overall average of 157 µg/m^3. The average value of NH_3 was within the recommended limits of 0.2 mg/m^3 (Standardization Administration of China, 2002) and 17 mg/m^3 (Health and Safety Executive, 2018). NH_3 values exceeded the threshold limits of 0.2 mg/m^3 in 30.7% of the total studied workshops (including water pump, car maintenance, plumbing and cooling workshops). The present results are compatible with those reported for residences (0.21 mg/m^3), offices (0.26 mg/m^3), and school buildings (0.15 mg/m^3) in China (Sun et al., 2021).

Physical Parameters

A summary of the levels of physical parameters at the workshops is presented in Table 5. Indoor and outdoor noise levels ranged at 54–87 dBA. The noise levels averaged 71 dBA (95% CI 66–76 dBA) inside and 74 dBA (95% CI 70.8–77 dBA) outside the workshops. The noise level was ≥ 70 dB in 53% of the total workshops. The noise level exceeded the minimum comfort level in the public buildings (60 dBA) in almost all the workshops, except at the oil extraction workshop (54 dBA). The highest noise level (87 dBA) was recorded at the wood workshop, exceeding the Egyptian permissible limit level of 85 dBA for the industrial sector (Egyptian Environmental Affairs Agency, 1994). The light intensity levels varied at 41–317 lux, with an average level of 176 lux (95% CI 132–222 lux). Light intensity was detected at very low levels at the welding and plumbing workshops (41–54 lux). The light intensity ranges (41–317 lux) were below the acceptable minimum level of 300 lux (NP 061, 2002) at 84.6% of the total workshops.

The temperature, RH, and dew point measurements averaged 28.4°C (95% CI 25.1°C–31.7°C), 48.8% (95% CI 46–53.7%), and 17.2°C (95%CI 14.3°C–20.1°C), respectively (Table 5). The highest reading of T°C (35°C) was determined at the glass workshop. The highest readings of RH% (58%) and dew point (21.4°C) were detected at the car maintenance workshop. The readings of temperature ≥ 30°C and RH ≥ 50% were, respectively, measured at 69.2% and 46.2% of the total workshops. The mean value of the RH was intermediate (48.8%), and temperature (28.4ºC) did not comply with the comfortable condition. The OSHA provides guidance for air temperature and RH ranges within 20°C–24.4°C and 20–60%, respectively (OSHA, n.d.). The dew point values exceeded the upper limit of 16.8°C (ASHRAE Standard 55, 2010) at 61.5% of the total workshops. The measurements of air velocity were below the recommended limit of 0.15–0.50 m/s (Sulaiman et al., 2013). Low air velocity causes air stagnation and, consequently, poor ventilation, helping accumulate pollutants.

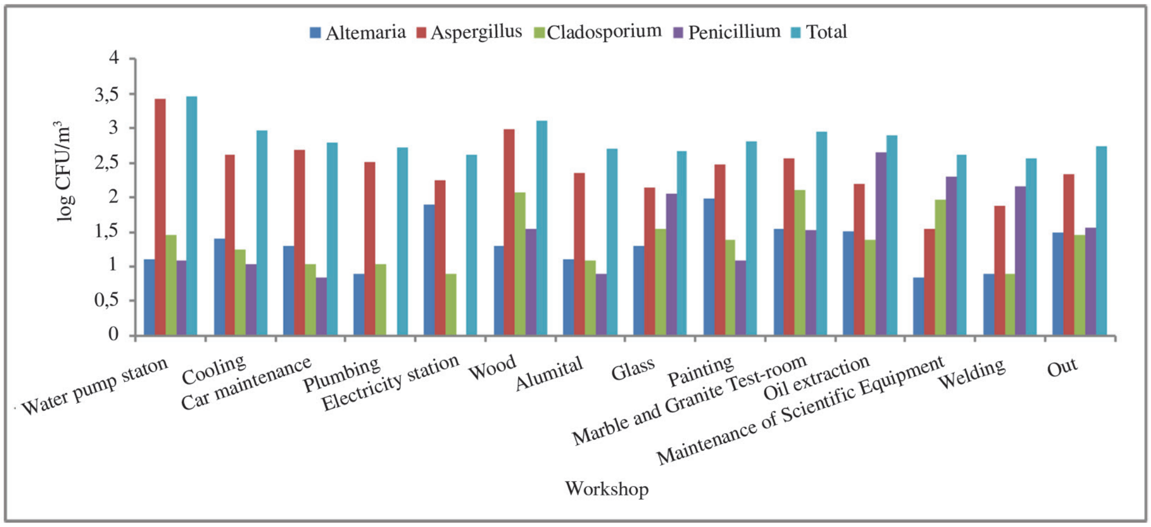

Figure 3. Log counts of the total and dominant fungal taxa in different workshops.

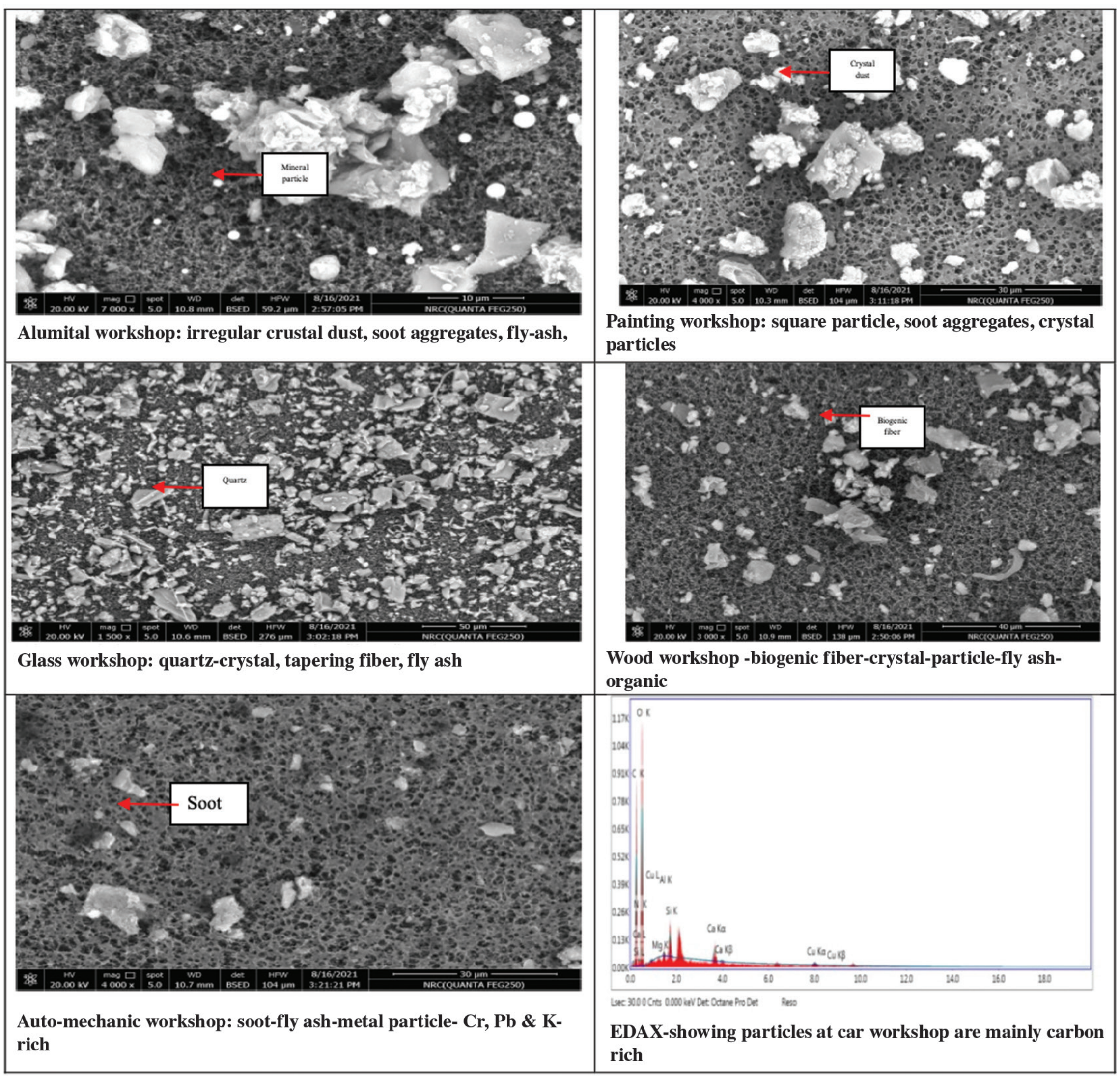

Figure 4. SEM images and EDAX analytical approach of PM samples from different workshops. SEM = scanning electron microscopy; EDAX = energy-dispersive X-ray analysis; PM = particulate matter.

Relationships Between Air Microorganisms and Environmental Stressors

The correlations between microbial air quality and environmental factors are shown in Table 6. A wide range of correlations were detected, depending on the microbial type and environmental factors. PM, HCHO, and VOCs showed similar correlation pattern with airborne microorganisms. They were negatively correlated with mesophilic bacteria, fungi, and actinomycetes and positively correlated with environmental bacteria. The VOCs and HCHO values adversely affected the bacterial and fungal viabilities. VOCs react with O_2 to form open air factor, inactivating microorganisms by damaging enzymes and DNA (Donaldson & Ferris, 1975). It has been suggested that indoor activities and indoor conditions are the main contributors of VOCs, HCHO, PM, mesophilic bacteria, fungi, and actinomycetes. PM positively and negatively correlated with the microbial parameters, confirming that PM had diverse contributors. The environmental bacteria may be associated with the outdoor infiltrated PM. Mesophilic bacteria, fungi, and actinomycetes may be emitted directly from the indoor environment, independent of the PM contributors. Indoor PM has small sizes (≤ 20 μm) and a more toxic chemical composition, which may negatively affect microbial viability (Sillanpää et al., 2005). PM has detrimental/or supportive effects on microbial viability (Matthias-Maser, 1998), depending on its composition and tenacity. Moreover, PM acts as a carrier/or niche of nutrients for microorganisms and affects their behavior in the air environment (Alghamdi et al., 2014; Soleimani et al., 2022).

T°C and RH% differently affected microbial viability. T°C displayed a considerable influence on microbial viability relative to RH% (Table 5). The dew point significantly supported the survival of actinomycetes (r = 0.66, $p \leq 0.05$), mesophilic bacteria (r = 0.67, $p \leq 0.05$), and fungi (r = 0.42) (Table 5). Environmental bacteria significantly correlated with the dew point (r = -0.53, $p \leq 0.05$), NH_3 (r = -0.53, $p \leq 0.05$), and VOCs (r = 0.53, $p \leq 0.05$). Several studies have reported contradictory associations between airborne microorganisms and environmental factors. Dennis and Lee (1988) reported the best survival of aerosolized *Legionella* at 90% RH%, which was intermediate at 30% and poor at 60%. However, Hambletonet et al. (1983) found the best survival of *Legionella* at 65% and the worst at 90% and 30%. Frohlich-Nowoisky et al. (2014) concluded that high RH (70–80%) promoted airborne microbial survivability. The death rates of some gram-positive and gram-negative bacteria showed an increase at intermediate RH% (50–70%) to high (70–90%) (Won & Ross, 1969; Hatch et al., 1970). RH% ≤ 65% had a negative effect on the survival of airborne bacteria and fungi (Karbowska-Berent et al., 2011). Temperature ≥ 24°C decreased the survival of airborne bacteria (Tang, 2009), whereas higher temperatures increased their survival (Smets et al., 2016).

Table 5. Range, mean, and 95% CI values of indoor/outdoor physical parameters at the workshops.

Parameter	Indoor environment		Outdoor environment	
	(Range) [mean ± SD]	95% CI	(Range) [mean ± SD]	95% CI
T°C	(18–35) [28.4 ± 6.1]	25.1–31.7	(18–35) [29.8 ± 7.7]	22.2–37
RH%	(40–56) [48.8 ± 5.3]	46–53.7	(37–46) [42 ± 4]	39.6–44.6
Dew point-T°C	(7.1–22.7) [17.2 ± 5.6]	14.3–20.1	(6.4–19.8) [16 ± 6.5]	12.5–19.5
Noise-dB	(54–87) [71 ± 9.1]	66–76	(68–79) [74 ± 6]	70.8–77
Lighting-lux	(41–317) [176.4 ± 83]	132–222	–	–

CI = confidence interval; SD = standard deviation; T°C = temperature in degrees Celsius; RH% = relative humidity.

Table 6. Spearman's rank correlations between air microorganisms and indoor environmental stressors.

Microorganism	Chemical pollutant				Physical factors				
	PM	HCHO	NH_3	VOCs	T°C	RH%	Dewpoint	Noise	Lighting
Environmental bacteria	0.10	0.29	–0.53*	0.53*	–0.19	–0.34	–0.53*	–0.09	0.02
Mesophilic bacteria	–0.02	–0.38	0.17	–0.68	0.51	0.00	0.67*	0.07	0.05
Fungi	–0.21	–0.20	0.12	–0.19	0.29	0.05	0.42	0.08	0.40
Actinomycetes	–0.13	–0.30	0.07	–0.60*	0.57*	–0.06	0.66*	0.24	–0.06

*$p \leq 0.05$.
PM = particulate matter; HCHO = formaldehyde; NH_3 = ammonia; VOCs = volatile organic compounds; T°C = temperature in degrees Celsius; RH% = relative humidity.

Insignificant correlations were detected between bacteria and temperature, RH, and dust level (Cho et al., 2019). Fungal concentrations were higher with high RH values (Rodriguez-Rajo et al., 2005; Erkara et al., 2008), although some researchers have reported the opposite (Sabariego et al., 2000). No correlations were detected between temperature and RH with the counts of airborne bacteria and fungi (Andriana et al., 2023). The RH negatively affects microbial viability due to the changes in the lipid bilayers of the cell membrane, which affect the cell surface protein configuration (Hurst et al., 2007).

Noise and light intensity did not affect the viability of airborne microorganisms. Light intensity and noise were positively correlated with mesophilic bacteria and fungi, and negatively with actinomycetes and environmental bacteria, respectively (Table 5). Human activity and its intensity probably raise the noise level and increase the load of resuspended microorganisms. Light has a lethal effect on microbial viability, as it produces air ions that accelerate the physical decay rate of microorganisms through attraction/agglomeration (Krueger et al., 1969; Krinsky, 1976). The positive ions cause the physical decay of microorganisms (through inactivation of the surface protein) and the negative ions exhibit physical and biological effects on DNA (Pepper & Greba, 2015). The agglomeration of bioparticles increases aerosol mass and enhances their deposition (Murdoch et al., 2013). Environmental factors synergistically affect the integrity/biological activity of microorganisms (Verreault et al., 2014). Therefore, understanding the effect of environmental factors on the survival of airborne microorganisms is critical to address their transmission and fate and design corrective actions.

Building-Related Complaints

Figure 5 shows the frequency of the health complaints related to IAQ among the workshop's occupants. The prevalence of symptoms varied among occupants, with fatigue (45.5%), allergies (38.6%), and headache (35.2%) being the most common ones. Stuffy nose and nausea (9.1% each) were the lowest prevailing symptoms among the occupants. Little attention has been paid to optimal IAQ for public and nonindustrial settings. Fatigue and headache were the most prevalent symptoms among the Egyptian office workers, who were influenced by physical and psychosocial work conditions (Abdel-Hamid et al., 2013). Air quality, temperature, noise, ventilation rate, and lighting condition were found to affect occupants' satisfaction (Felgueiras et al., 2023). Temperature ≥ 23°C led to thermal discomfort (Norbäck, 2009), and low RH% (≤ 50%) was related to upper respiratory symptoms (Wolkoff, 2008). The SBS symptoms were noted to intensify with temperature of 30°C relative to that at 22°C (Lan et al., 2011). Exposure to air pollutants (such as VOCs, HCHO, PM) has been related to SBS and irritation to the eyes and upper respiratory system (WHO, 2010; Kim et al., 2015; Chai et al., 2019). The occurrence of actinomycetes was associated with abnormal and hazardous situations such as moisture damage of the building (Rintala, 2011). Exposure to actinobacteria can cause infections, allergic reactions, and lung inflammation (Lacey & Crook ,1988; Schäffer et al., 2009). Occupants living in damp and moldy buildings report more symptoms of nausea, blocked nose, and fainting compared to those living in dry buildings (Platt et al., 1989).

Figure 6 displays the perception weights of satisfaction related to the four IAQ factors. The opinions of the occupants were ranked as noise (40.9%), lighting (25%), air quality (18.2%), and temperature (15.9%). There was a discrepancy between the perceptions of IAQ factors. The perception of comfort differs among people under the same IAQ. Perception is a combination of IAQ factors (WHO, 2001) and varies with respect to the threshold of IAQ factors and individual health conditions. Although temperature condition is the key factor affecting satisfaction globally, it had the least perception weight in this survey, attributable to the interaction of other factors (e.g., RH%, dew point, climatic condition, and wind speed) that enhance the comfort effect.

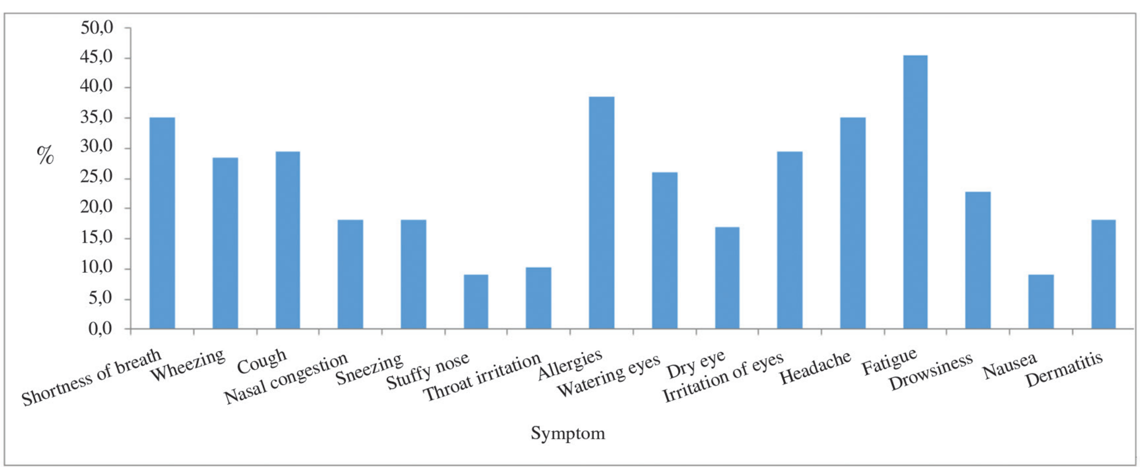

Figure 5. The prevalence of health complaints among the of workshop's occupants.

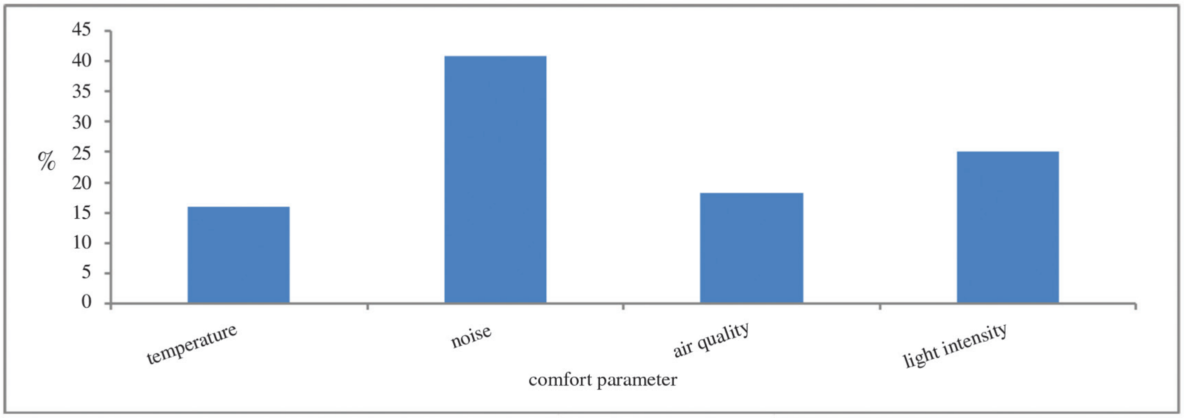

Figure 6. The prevalence of health complaints among the workshop's occupants.

Finally, there is a knowledge gap in relation to workshops associated with complex public buildings and academia. The main limitations of this comparative analysis are as follows: 1) the workshops carry out tasks similar to industry settings, but they cannot be considered as a real industrial sector, which raises confusion about the applicable guidance limits, 2) low numbers of sampling events and the wide variations among the workshop types, 3) no seasonal changes were considered (which play an important role in the perception of comfort), and 4) there was uncertainty of health complaints data due to confusion between workplace-related complaints and the existing health status of the occupants.

Conclusion

The evaluation of IAQ in workshop environments is inherently complex, influenced by microenvironmental conditions, microbial composition, and the behavior of airborne pollutants. Most IAQ parameters assessed in this study failed to comply with recommended threshold values. Airborne microbial concentrations were consistently higher indoors compared to outdoor (background). Notably, the upper bound of the 95% CI for the GIMC/m³ exceeded 7,000 CFU/m³ in approximately 46% of the workshops. The detection of actinomycete counts at or above 100 CFU/m³ further indicated abnormal, potentially hazardous conditions. PM varied significantly in terms of concentration, chemical composition, size, and morphology, largely depending on the nature of workshop activities. The presence and accumulation of deposited dust pose both health risks and potential material damage. Morphological characterization of PM using SEM imaging proved useful for understanding particle behavior and identifying pollution sources. VOCs exceeded the recommended limit of 3 mg/m³ in 30% of the workshops, whereas the noise levels surpassed the 60 dBA comfort threshold in most settings. Indoor temperatures (95% CI = 25.1°C–31.7°C) were above the optimal range of 20–24°C, although RH remained within acceptable limits (20–60%). Light intensity was found to be inadequate (≤ 300 lux) in nearly 80% of the workshops surveyed. Environmental parameters variably influenced microbial viability. VOC concentrations and dew point showed significant effects, whereas PM appeared to support the viability of environmental bacteria. These results suggest that poor IAQ may contribute to occupant health complaints, with noise being identified as the primary factor impacting occupant satisfaction. The findings underscore the urgent need for targeted IAQ management strategies, including moisture control, ventilation improvements, dust suppression, and optimized lighting conditions. Furthermore, this study highlights the necessity of establishing tailored IAQ guidelines for workshops associated with public buildings, where unique environmental and occupational conditions prevail.

Ethics

Ethics Committee Approval: Since the article does not contain any studies with human or animal subject, its approval to the ethics committee was not required.

Data Sharing Statement: All data are available within the study.

Footnotes

Author Contributions: Conceptualization: A.H.A.; Material supplying: S.E.G., Y.S., S.K.; Data acquisition: S.E.G., Y.S., S.K.; Data analysis/interpretation: S.E.G., Y.S., S.K.; Writing: A.H.A.; Critical review: A.H.A.

Conflict of Interest: The author declares no competing interests.

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