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Microbial air quality in a complex public building: influence of work type, height level and environmental stressors

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Abstract

The behavior of indoor microbial air community is not well understood due to complex functional characteristics of building and environmental stressors. This study aims to understand behavior of microbial air community in relation to work type, height level and environmental factors in a complex built environment. A field survey was conducted at random sites of a research institute. Air microbial (bacteria, fungi & actinomycetes), chemical (PM, NO_2, SO_2, NH_3 & HCOH) and physical ($T^{\circ}C$, RH%, noise, lighting & electromagnetic strength) parameters were measured using integrated and real-time instruments. The overall microbial concentrations averaged 4451 CFU/m^3 (95% CI: 3795-5107 CFU/m^3), 916 CFU /m^3 (95% CI: 745-1087 CFU /m^3), 556 CFU /m^3 (95% CI: 473-639 CFU/m^3) and 197 CFU/m^3 (95% CI: 140- 254 CFU/m^3) for environmental bacteria, mesophilic bacteria, fungi and actinomycetes, respectively. Global index of microbial contamination was significantly high at the hospital and near surface ground level. Amplification index of microbial concentration was ≥1.5 at 14% of total sites. Microbial concentrations decreased with increasing height level. Environmental stressors had complex interactions with microbial concentrations. Multiple linear regressions showed that ventilation influenced environmental bacteria. RH% and PM positively influenced mesophilic bacteria and fungal concentrations, respectively. Standardizing environmental factors could control microbial community in buildings.

Keywords: Built environment; Microbial air community; Air quality; Height level; Ventilation; Lighting; Electromagnetic field.

1. Introduction

Indoor environmental quality (IEQ) results from interaction of climate, topography, location and building design. After the global energy crises of the 1970s, buildings have been regulated to meet energy efficiency criteria [1] by reducing indoor air circulation. The harmful pollutants have increased because of poor indoor air quality [2]. People spend ~ 80–90% of their time indoors, and studies have indicated that a range of comfort and health related effects are linked to building characteristics [3, 4]. Indoor environmental quality is affected by many factors like indoor air quality, physical factors (thermal, acoustic and visual) and occupant's behavior [5]. IEQ of a building has a direct effect on the comfort, health and productivity of the occupants [6]. To achieve a good indoor air quality (IAQ) it is necessary to monitor certain levels of pollutants. IAQ can be affected by different pollutants such as carbon dioxide, smoke, dust, total volatile organic compounds, ozone, microorganisms, chemical substances/ or any other elements negatively affects health and human comfort [**7**]. Indoor air pollutants can cause short term and long term health problems [8]. IAQ is characterized by significant variability of physical, chemical and microbiological parameters [9-14]. IAQ varies depending on location of the building, number of occupancy and outdoor and indoor air sources [15]. Microorganisms present in public buildings can influence their structural conditions and occupant's health. Air is one vehicle that helps spread of biological contamination in indoor environments. Biological particles (bioaerosols) are ubiquitous in built environment [16]. Biological particles are particles of biological origin suspended in the air such as bacteria, fungi, viruses, microbial toxins, plant debris, pollen grains and enzymes [17] Biological particles are transported up in the air as free (single cells, spores or aggregates) or attached to non-biological particles [18-19]. Indoor microbial air communities have been studied in various indoor environments such as homes, offices, schools, hospitals and other private and public buildings [20-23]. The airborne microbial communities have shown variations in numbers and types, depending on the kind of indoor environment, sources of contamination and microclimatic factors [24]. The proliferation of indoor airborne microorganisms indicates possible risks [25-26] affecting human health [27] and wellbeing [28]. Airborne microorganisms in built environments can cause infectious diseases, respiratory diseases and sick building syndrome [29-32]. Indoor microbial air contamination (distribution,

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concentration and diversity) is influenced by many factors including "outdoor atmosphere, ventilation, occupant's microbiome and building design" [33-35]. Indoor microbial air quality is changed over short time periods, depending on particle size, occupancy density, vegetation cover, geographical characters and seasonal changes [36-38]. The composition of airborne flora greatly varies as a function of geographical locality, emission rate, meteorological situation and sampling time [39]. Meteorological conditions and air pollutants influence transport and viability of airborne microorganisms [40]. Complex interactions are found between environmental stressors and the survival of airborne microorganisms [41-42]. The transport mechanism of microbial community in indoor environment is not well understood [43] due to complex functional characteristics of buildings and environmental stressors. The association between microbial air community with work type and environmental stressors is essential to mitigate its detrimental-effects on health and materials. There is a knowledge gap of how air pollutants and physical stressors interacted with microbial air community in built environments. The present study aims to investigate microbial air quality of a complicated public building (a research institute) in relation to work type, height level and environmental factors (climatic & air quality). Understanding the behavior of indoor microbial community under different environmental stressors could determine problems that should be solved. The outcomes of the study are 1) to cover knowledge gap on microbial air quality nearby ground surface height level, and 2) to standard environmental factors could be used to improve indoor microbial community.

2. Materials and methods

2.1.Description of sampling sites

Sampling was carried-out at 9 main separated-buildings of a multidisciplinary R&D research/educational institute in Egypt. A total of 132 sites (104 indoor and 28 outdoor) were randomly evaluated at all the buildings. The selected sites vary in respect to occupant's density and activity, ventilation, nature of work, location and height level. The selected sampling sites included "laboratories, training halls, administration offices, hospital and workshops" (Fig. 1). The research institute is located in an urban area characterized by high population intensity, busy traffic streets, parking, commercial activities, workshops and other educational premises. A variety of permanent green cover is found inside the institute campus without a predominant green cover outside the institute. The main characteristics of the sampling sites are described in Table 1.

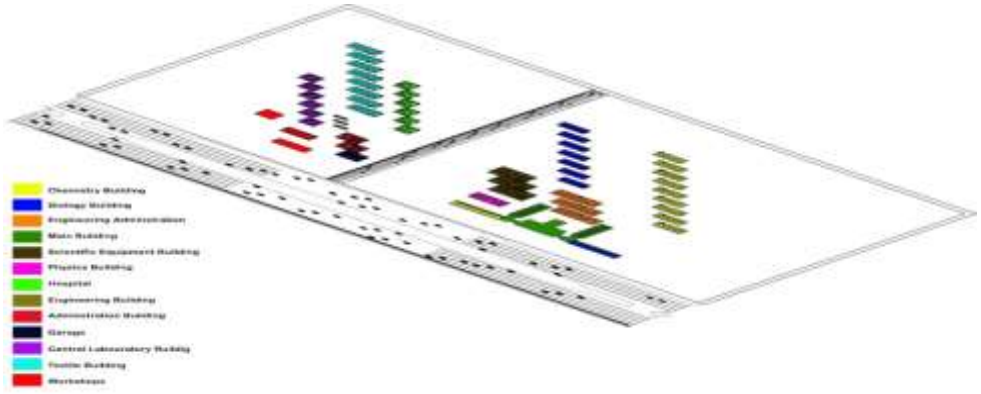

Fig. 1. Diagram of the R&D research institute buildings

Table 1. The characteristics of the sampling sites under investigation

Variable	Site					
	Chemical Labs	Biological Labs	Physical Labs	Offices	Hospital	Workshops
Number of sites	29	41	3	15	3 clinics	13
Nature of work	Organic, Inorganic & Physical Chemistry, almost chemical materials are used.	Basic microbiology, Biotechnology, Parasitology, Algae, Botany & Zoology media and materials are used.	Physical equipment & Electron microscopy unit.	Administration offices and training halls	Dental clinic, Out-patient clinics & radiology and sonar unit.	Wood, Aluminium, Glass, Painting, Car mechanic, Plumbing & Welding workshops
Ventilation mode	Mechanical + natural	Mechanical + natural	Mechanical + natural	Mechanical	Mechanical + natural	Natural + some mechanical fans
Cleanliness	moderate	good	bad	moderate	good	very bad
Average number of occupants	~ 4	~ 4	~ 4	~ 6	~ 8-25	~ 20
Area (m^2)	~ 40-60	~ 40–50	~ 20–60	~ 20–40	~ 40–80	~ 40–120
Height level from ground (m)	–3 – 9	3–20	6–15	3–6	–3–12	0–3

*Mechanical ventilation: Air conditioning systems + fans

2.2.Sampling strategy

Sampling of microbial (bacteria, fungi and actinomycetes), physical (T°C, RH%, noise, lighting, electromagnetic strength and ventilation rate) and air pollutants (PM, NO_2, SO_2, HCOH and NH_3) parameters was taken at representative sites along over the institute's buildings. The sampling was taken on working days, with normal activities and the presence of the minimum occupancy density, and lasted ~ 4-5 hours between 10:00 AM and 15:00 PM. The sampling was collected 2 days/week on Monday and Tuesday from December 2019 to July 2022. Indoor sampling was taken at a height of 1.5m above the floor ground surface, and the outdoor (comparison) sampling was taken at places with available electricity~ 2m from the main gate of a building/or in corridor. Integrated sampling was used to determine concentrations of microorganisms, PM, HCOH, NH_3, SO_2 and NO_2. Moreover the real time portable monitors (short term measurements) were used to measure T°C, RH%, dew point, air velocity, noise, lighting and electromagnetic field.

2.3. Sampling of airborne microorganisms

Indoor/ outdoor airborne microorganisms were collected using Andersen Two-stage viable cascade impactor (TE-10-160, Tisch Environmental Cleves, OH, USA) according to EN: 13098: 2000 [44]. It separates particles into fine (≤2.5 µm) and coarse (≥7 µm) size ranges, operating at flow rate of 28.3 *l*/min for 5 min to prevent overloading the plates. Malt Extract Agar supplemented with chloramphenicol, Trypticase Soya Agar supplemented with 0.25% cycloheximide, and Starch Casein Agar media were used to enumerate fungi, bacteria and actinomycetes, respectively. Two consecutive samples (one hour between each sampling trial) were collected during each sampling event due to short sampling time.

2.4. Microbial analysis

The plates of fungi and actinomycetes were incubated at 25°C for 5 and 28 °C for 7-14 days, respectively. Bacterial plates were incubated at 28°C for 48hr for growing environmental bacteria (environmental origin) and at 37°C for 24hr for growing mesophilic bacteria (human-related bacteria). The resultant colonies were counted and the positive hole-correction was applied to the raw colony forming unit (CFU) recorded on each plate prior to calculation of the colony forming unit per cubic meter of the air (CFU/m^3) [45].

2.5. Air pollutants

Particulate matter (PM) was collected on a pre-weighed cellulose nitrate membrane filter (diameter 25 mm, pore size 0.45 µm) with a vacuum pump calibrated to draw 15 l/ min for 4-5hr. The mass of PM was calculated and concentration was expressed as microgram per cubic meter of the air (µg/m^3). Sequential 4-5hr air samples for formaldehyde (HCOH) and ammonia (NH_3) were collected using a vacuum pump calibrated to draw 0.5 l/ min. The concentration of formaldehyde was determined using the 3-methyl-2-benzothiazolone hydrazone hydrochloride [46]. Ammonia concentration was determined using dilute sulfuric acid as an absorbing reagent followed by reaction with Nessler's reagent [47]. Sulphanilamide diazotization and West and Gaeke methods were used to measure nitrogen dioxide (NO_2) and sulfur dioxide (SO_2), respectively. The sampling was carried-out using glass bubblers containing 50 ml of 0.1N sodium hydroxide and 0.1M sodium tetra-chloromercurate solutions to measure NO_2 and SO_2, respectively [46]. The samples were colorimetric measured using spectrophotometer (Unicom spectrophotometer model 300).

2.6. Physical parameters

Noise was measured using Sound Level Meter (model RO-1350, Taiwan) located~1.5 m above the ground surface level and no close than 3 meter to any reflecting surface. Significant /or accidental anthropogenic emitted noise were excluded, and noise level was expressed as decibel-A (dBA). The lighting intensity was measured at ~4 points at each location using Light Meter (Light meter-TM-201, Taiwan). The lighting level was expressed as lux. Electromagnetic field measurements were performed using TES 593 electro-smog-meter (TES Electrical Electronic Corp, China). The TES 593 meter covers a wide range of frequencies (10 MHz - 8 GHz). The instrument was allowed to stabilize for ~3 min before reading. The electrical and magnetic fields were expressed as volt per meter (V/m) and millitesla (mT), respectively.

Temperature (T°C) and relative humidity (RH %) were measured using thermo-hygrometer (Sato-PC 5000, made in China) and air velocity (m/s) by using anemometer (ABH-4225, made in Taiwan). Air exchange rate (ACH) is estimated by using equation (1) and ventilation rate (m^3/h. p) is computed using equation (2). In general, the mechanical ventilation is the main mode operated to introduce fresh air indoors; however the natural ventilation is limited and insensible at almost sites.

$$\mathrm{ACH} = \frac{gas}{V} \qquad eq.1$$

$$\text{Ventilation rate}\left(\frac{\mathrm{m}^3}{\mathrm{h}}.\mathrm{p}\right) = \frac{\text{ACH x room volume}}{Np} \qquad eq.2$$

Where:

ACH: air exchange rate/hour

gas: total flow of fresh air introduced into room (m^3/h).

V: volume of room (m^3).

2.7. Statistical analysis

Shapiro-Wilk test was applied to verify normality of the data distribution. Descriptive statistics (range, mean, standard deviation and percentiles) and non-parametric tests were used to analysis the data. Mann Whitney U-test was used to ascertain the significance of differences between microbial air concentrations in different sites. Spearman's rank correlation test was used to determine the relationships between airborne microbial concentrations with environmental stressors. Multiple linear

regression models were used to figure-out the main independent factors affecting microbial concentrations (Statistical Package for Social Sciences, software version 22.0, IBM Corp., Chicago). A probability of less or equal to P≤ 0.05 was considered a significant.

3. Results and Discussion

3.1. Microbial air contamination in relation to nature of work

The summary of indoor/outdoor microbial airborne concentrations is shown in Table 2. Concentrations of environmental bacteria, mesophilic bacteria, fungi and actinomycetes ranged between $2.87x10^2$ – $1.6x10^4$ CFU/m^3, $1.1x10^1$ – $4.531x10^3$ CFU/m^3, $7.1x10^1$ – $2.742x10^3$ CFU/m^3 and $1.8x10^1$ – $2.24x10^3$ CFU/m^3, respectively. The concentrations of environmental bacteria in the hospital significantly differed ($p \leq 0.014$) with those detected in laboratories of chemistry and physics and offices. The concentrations of mesophilic bacteria significantly differed ($p \leq 0.007$) between the workshops and laboratories, higher concentrations shifted toward the workshops. Significant differences were found between fungal concentrations in the workshops with laboratories of chemistry and physics and hospital as well. Actinomycetes concentrations significantly differed in the workshops with both laboratories of biology and physics. The profile of microbial air quality was in order of hospital > chemistry labs > offices >biology labs > workshops > physics labs for environmental bacteria; workshops > hospital >offices > chemistry labs >physics labs > biology labs for mesophilic bacteria; workshops > chemistry labs > offices > biology labs> physical labs> hospital for fungi, and workshops > offices >chemistry labs > hospital>biology labs> physical labs for actinomycetes.

The profile of microbial air quality varied in respect to the nature of work. The workshops had the worst microbial air quality. This is because workshops are mainly located in the basement /or close to the ground surface and characterized by damp building's materials. The highest concentration of environmental bacteria was found in the hospital. This is because it is located close proximity to a heavy traffic road with no access restriction and high human activities. Higher concentration of actinomycetes (~10^3 CFU/m^3) in the workshops indicates a bad situation of microbial air quality. Actinomycetes are ubiquitously found in waste, soil and dust. Actinomycetes concentrations are usually low indoors but their concentrations tend to be high with abnormal situations such as moisture damaged buildings [48]. The presence of actinomycetes in indoor environment is an indication of air bio-contamination [49]. On the other hand fungi are commonly associated to the outdoor environment. Soil and vegetation are the main contributors of atmospheric fungi [50]. Moreover fungi are well grown in indoor air temperature ≥ 25°C, high relative humidity and poor cleanliness conditions [51-52].

Airborne microbial concentrations are widely varied in relation to sources, occupant activities, building design and internal environmental conditions which facilitate/or limit the aerial transport and viability of microorganisms [53]. Variation of occupant's density and activity, nature of work and interference of outdoor environmental conditions affected microbial loads, differently [54]. Airborne bacteria from outdoor environment enter indoor spaces through open doors and windows [55]. Air flow in rooms varies according to their design, manner of operation, ventilation type, size and shape [56]. Ventilation modifies characteristics of indoor air as natural ventilation increases infiltration of outdoor microorganisms, however mechanical ventilation reduces outdoor microbial infiltration [57]. The changes in climate conditions influence airflow, particularly in buildings with poor insulation and ventilation. Climate change consequently alters indoor microbial air quality [58], increasing contamination by human-sourced population.

Table 2. Airborne microbial concentrations in respect to the nature of work

Variable	Biology labs	Chemistry labs	Physics labs	Offices	Workshop	Hospital
Environmental bacteria	287–16068 (3440±2339)	1934–19378 (6446±4513)	2114–2620 (2385±208)	1034–8396 (3952±2345)	1533-7036 (3399±1469)	8200-10651 (9363±1004)
Mesophilic bacteria	11–2542 (473±530)	14–2957 (901±760)	412–616 (498±86)	14–2360 (1131±785)	526–4531 (2016±1374)	1011–1506 (1323±222)
Fungi	71–2742 (467±421)	142–1743 (641±371)	253–440 (373±85)	192–1133 (491±237)	34–2841 (794±649)	492–2167 (366±114)
Actinomycetes	18–438 (96±77)	24–679 (198±178)	24–84 51±25)	106–457 (243±114)	35–2241 (665±540)	107–204 (151±50)

Range, (mean ± sd)

3.2. Microbial–contamination in relation to height level

In the present study the height level of buildings was divided into 4 stages 1) stage-0 (–3–4m); 2) stage-1 (>4–10m); 3) stage-2 (>10–16m) and 4) stage-3 (>16–30 m). In general the microbial air concentrations showed a decreasing trend with increasing height above ground surface (Table 3). Microbial air concentrations significantly differed ($p \leq 0.0146$) in stage-0 with other stages, the higher concentration shifted toward the stage-0 (–3–4m). The mean concentrations of environmental bacteria, mesophilic bacteria, fungi and actinomycetes were 5394 CFU/m^3, 1850 CFU/m^3, 803 CFU/m^3 and 427 CFU/m^3 at stage-0 (–3–4m), respectively and their concentrations reached 2457 CFU/m^3, 390 CFU/m^3, 303 CFU/m^3 and 75 CFU/m^3 for the corresponding microbial parameters at stage 3 (>16–30 m (Table 3). This is due to almost human activities are performed near the ground surface level; the direct effect of soil and vegetation [59-60] and increase ventilation rates with increasing height level. Airborne bacterial community decreased roughly with increasing height in green spaces [61]. Surface-upper air currents can be well mixed by atmospheric turbulence and dilution [62], decreasing microbial concentrations with height elevation above the ground surface. Vertical microbial variation reflects the effect of outdoor local sources and their microbial loads. Bowers et al. [63] found that higher bacterial diversity in mountain due to the influence of surrounding vegetation. The

height of planetary boundary layer differs with season; airborne microorganisms can be accumulated in lower surfaces in cold season than other seasons [64]. Moreover, temperature inversion constitutes an effective barrier for particles diffusion, raising PM pollution index nearby the ground surface [65].

Table 3. Air microbial concentrations in respect to height level

Variable	Height level			
	Stage-0 (–3–4m)	Stage-1 (>4–10m)	Stage-2 (>10–16m)	Stage-3 (>16–30m)
Environmental bacteria	1594–19378 (5394±3755)	1034–19104 (4785±3672)	287–8200 (3217±1836)	1538–3679 (2457±702)
Mesophilic bacteria	524–4531 (1850±1093)	18–2616 (709±663)	209–1827 (562±573)	18–1696 (390±482)
Fungi	361–2841 (803±545)	107–1287 (497±267)	71–2742 (505±539)	131–542 (303±130)
Actinomycetes	35–2254 (427±536)	23–457 (146±114)	0.0–438 112±109)	35–142 (75±34)

Range, (mean ± sd)

3.3. Air bio-contamination indices

Global index of microbial contamination (GIMC/m^3), mesophilic bacterial contamination index (IMC) and amplification index (AI) are used to determine indoor bio-contamination [66]. Figure 2 (a–d) illustrates the summary of microbial indices. The GIMC values ranged between 358–22110 GIMC/m^3, with the highest values were found in the hospital (11204 GIMC/m^3) and stage-0 (8474 GIMC/m^3) in respect to the nature of work and the height level, respectively.

IMC values were found in the range of 0.0–1.9; with mean values were less than 1, and the highest values were found in the workshops (0.8) and stage-0 (0.51). IMC index indicates the presence of obligated mesophilic bacteria in the indoor environment due to hypoventilation and overcrowding. On the other hand AI values ranged between 0.1–3.7, with an order of magnitude was hospital > workshops > physics labs > offices > chemistry labs > biology labs in respect to the nature of work (Fig. 2 b); and stage 0 > stage-1 > stage- 2 > stage-3 in respect to the height level (Fig. 2d). AI values exceeded 1.5 at ~14% of the total sampling sites, indicating an accumulation of microorganisms in indoor environment. However the results of AI values confirmed that the outdoor environment was considered the main indoor microbial contributor in ~86% of the investigated sites.

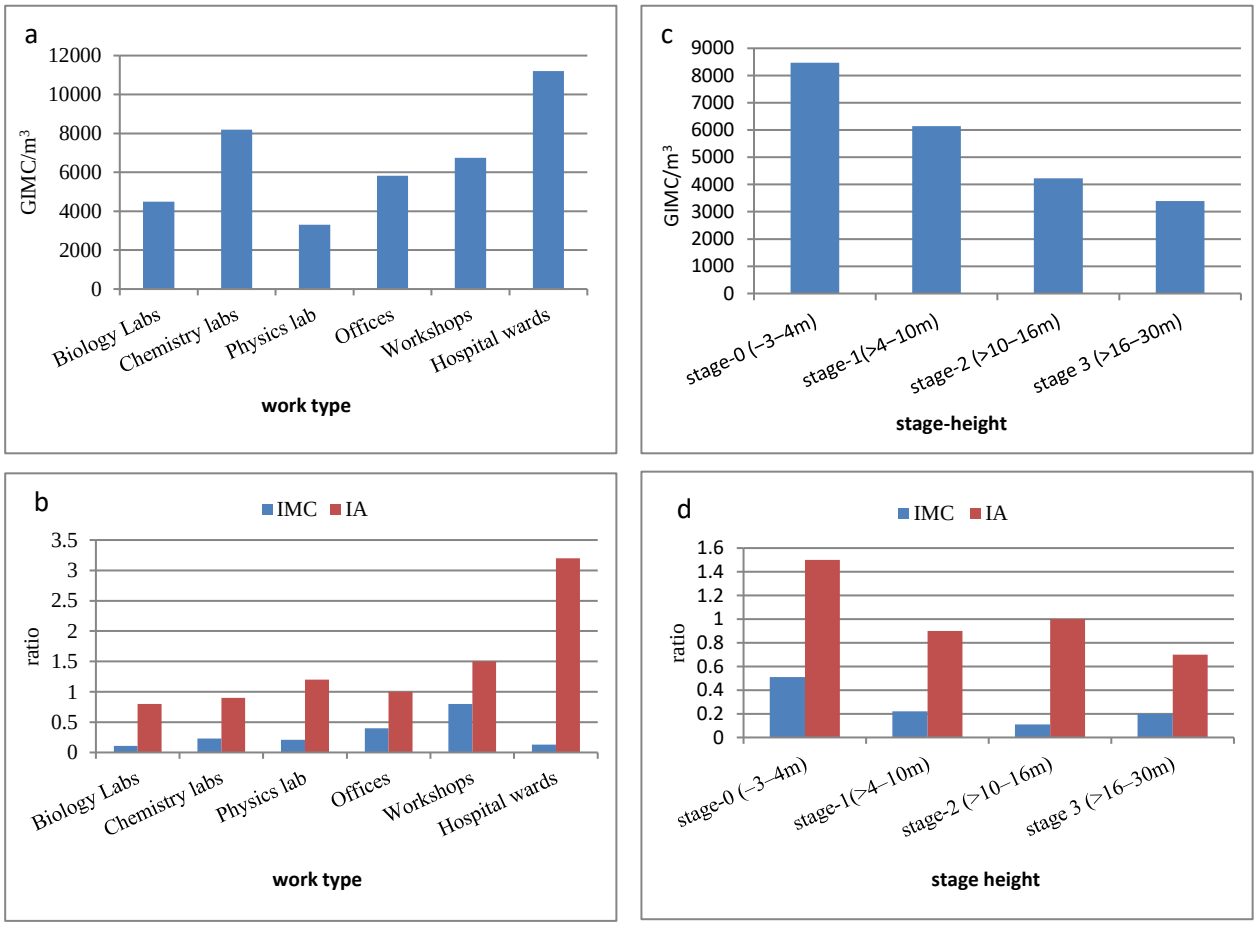

Fig. 2 a–d. Bio-contamination indices regarding to work type (a & b) and height level (c &d)

3.4. Interpretation of microbial concentrations

The overall airborne microbial concentrations at all the investigated sites averaged 4451 CFU/m^3 (95% CI: 3795-5107 CFU /m^3), 916 CFU /m^3 (95% CI: 745-1087 CFU /m^3), 556 CFU /m^3 (95% CI: 473-639 CFU /m^3) and 197 CFU /m^3 (95% CI: 140-254 CFU /m^3) for environmental bacteria, mesophilic bacteria, fungi and actinomycetes, respectively. Interpretation of airborne microbial data is difficult due to lack of universally accepted normative and reference values [67]. Considering the upper 95% confidence interval (CI), the concentrations of environmental bacteria, mesophilic bacteria, fungi and actinomycetes were >5000 CFU/ m^3, 1087 CFU /m^3, 639 CFU /m^3, and 254 CFU /m^3, exceeding the threshold limit values that have been set by some authors and international agencies. Fungal concentration > 500 CFU/m^3 indicates abnormal conditions in indoor environment [68]. The European Biological Agent's Expert recommends indoor airborne bacterial and fungal concentrations for living and public buildings of 5000 CFU /m^3 [69]. In this study and according to the European Commission Standards for non-industrial premises microbial concentrations could be classified as very high (>1000 CFU/m^3) for bacteria and medium (100–500 CFU /m^3) for fungi [70]. Airborne microbial concentrations exceeded the threshold limits have been set by the Korean Ministry of the Environment (800 CFU/m^3) for bacteria [29] and Indonesia Ministry of Health (700 CFU/m^3) for fungi [71]. The WHO has set a guideline for bacterial load not to exceed 500 CFU /m^3 in indoor environment [72]. Higher airborne fungal concentration in indoor environment could be a signal of the existence of a moisture problem and presence of internal sources. The indoor/outdoor ratios of microbial concentrations exceeded 1 at different sites (Fig. 2 b & d), indicating the presence of internal microbial sources. Moreover an indoor environment can be considered unusual when the microbial concentrations are at least an order of magnitude higher than that commonly occur in control environment [73].

3.5. Evaluation of air pollutants

Figure 3 shows the mean ± sd concentrations of air pollutants in respect to the nature of work. The concentrations of PM, HCOH, SO_2, NO_2 and NH_3 ranged within 56.7–757µg/m^3, 0–1080 µg /m^3, 0–1460 µg/m^3 and 0–359 µg/m^3 and 0-939 µg/m^3, respectively. The highest mean concentrations of HCOH (374 µg/m^3) and NH_3 (316 µg/m^3) were found in laboratories of biology. HCOH is usually used as sterilizing agent and NH_3 is related to cleaning products which are frequently applied in biological labs. PM and NO_2 were detected in the highest concentrations in the workshops, whereas the highest mean concentration of SO_2 was found inside the hospital environment (Fig. 3). The variations of outdoor-origin air pollutant (PM, SO_2 and NO_2) concentrations inside buildings confirm differences in infiltration rate and function of indoor/outdoor sources. Generally higher air pollutant concentrations were detected in sites–located close to busy traffic road with no restricted access to the buildings. Concentrations of NO_2 felt in the limit value set by the WHO (200 µg/m^3) and SO_2 exceeded the WHO´s limit value of 104 µg/m^3 at almost sampling sites [74]. PM concentrations did not exceed the Egyptian limit value (230µg/m^3) [75]. HCOH concentrations exceeded the WHO limit value of 100µg/m^3 [74]. NH_3 felt within the reference value of 175 µg/m^3 has set by the HSE [76], except for the biological labs and workshops.

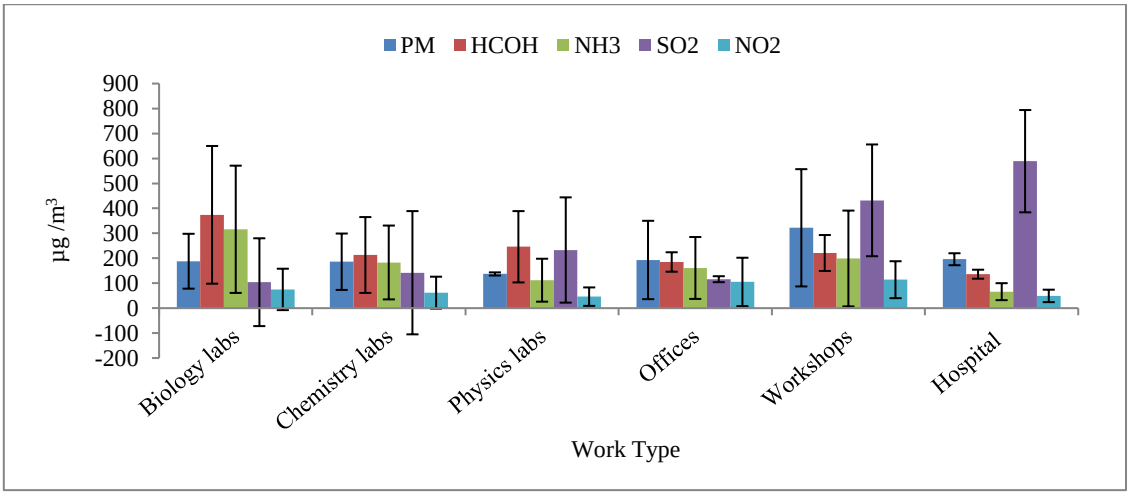

Fig. 3: The mean ± sd concentrations of air pollutants in respect to work type

3.6. Evaluation of physical parameters

Table 4 shows the measurements of indoor physical parameters. The measurements are widely varied in regarding to location, human activity and building characteristics. Noise levels ranged between 48–87 dBA, with a mean value exceeded e the minimum acceptable level (60 dBA) in ~ 78% of total sampling sites. Noise is mainly related to its high background value from traffic, air conditioning systems and audible equipment. Traffic is the main variable affected noise level indoors, confirming bad restriction and isolation of buildings under investigation. Lighting values ranged within 41–1480 lux in all sites. Lighting was insufficient to achieve the minimum acceptable level of 300 lux [77] in ~50% of the investigated sites. Wind speed values are found in the range of 0–1.4 m/s indoor buildings. The wind speed profile was: biology labs > chemistry labs > physics labs > offices > hospital > workshops (Table 4). Mechanical ventilation is always operated in the summer season while natural ventilation in the winter season. Air velocity rates were lower inside buildings than the standard

limit has set between 0.15 to 0.50 m/s [78]. Engineering countermeasures should be taken to increase up wind speed inside buildings to be 0.2 – 0.3 m/s in order to ensure adequate air flow rate [79].

Indoor temperature, relative humidity and dew point measurements ranged between 17–35.6ºC, 29.5–66.5% and 2.2–22.7ºC, respectively (Table 4). Temperature and relative humidity values were not comfort in some sampling sites. The average values of temperature and relative humidity were 25.9 ºC (95% CI: 24.58– 27.22ºC) and 50.4% (95% CI: 45.5–55.3%) in offices and 29.2ºC (95% CI: 22.41– 35.9 ºC) and 48.9% (95% CI: 41.88–55.92%) in the workshops, respectively. The acceptable temperature guidelines are within 20–23ºC in offices in temperate climate zone [80] and 20–22°C a situation of thermal well-being [81]. The ranges of relative humidity are coincided with the standard has recommended by ASHRAE 30%– 60% for thermal comfort in offices [79]. The dew points averaged 17.2ºC (95% CI: 9– 23.2 ºC) in the workshops. The OSHA [82] recommends indoor dew points within 4– 16.5ºC which it is compatible with dew point measurements (5–17ºC), except in the workshops (17.2 ºC, 95% CI: 9–23.2 ºC) and hospital (4.8 ºC, 95% CI: 4.3–5.2 ºC).

Electric and magnetic strengths are widely varied between 1.5– 242 V/m and 0.5– 437 mT, respectively (Table 4). The magnetic field was found to be above the threshold limit values of 0.5 mT (8-hr reference period/day) and 5 mT (for short period) [83]. However the electric field did not exceed the limit values of 10000 V/m and 30000 V/m for a working day and short period of time, respectively [83]. Electromagnetic field strength is related to equipment's size and power, operation mode and location of equipment. Obstacle and distance away from the source decrease electromagnetic field strength [84]. Such conditions are varied during *in situ* sampling according to the location's characteristics.

Table 4: The range and mean values of air physical parameters

Variable	Biology labs	Chemistry labs	Physics lab	Offices	Workshops	Hospital
TºC	(18.4–25) [21.4±1.8]	(18.4–25.5) [22±2]	(17–20) [18±0.95]	(19–30) [25.9±2.6]	(18.3–35.6) [29.2±6]	(17–20) [17.4±0.57]
RH%	(30–56.3) [44±6.5]	(31.2–58) [43±7.8]	(39–46.7) [42±3.3]	(29.5–66.5) [50.4±9.7]	(39–58.4) [48.9±6.2]	(38.8–42) [40.8±1.4]
Dewpoint (TºC)	(2.2–14.7) [8.6±2.9]	(2.6–15) [8.8±2.6]	(3.8–9.2) [4.7±1.6]	(8–19.6) [15±3.2]	(7.1–22.7) [17.2±5.3]	(3.6–9) [4.8±0.4]
E-field (V/m)	(2–242) [38.8±56]	(1.5-224) [24±48]	(2.5–64.6) [25.7±27]	(1.8–62) [18.5±20]	(1.1–108) [27±30.6]	(1.5–5) [3±4.2]
M-flux (mT)	(1.5–190) [60±45.7]	(0.5–437) [77.5±95]	(18.7–47.8) [35±12]	(12.5–152.5) [68.8±44]	(15.7–140) [62±40]	(49–106) [76.9±23]
Noise (dBA)	(53.8–78) [65.5±5]	(48–85) [68±8]	(52–61) [35±12]	(55–72) [66±4.9]	(61–87) [73±7.4]	(60–68) [64±3.4]
Lighting (Lux)	(138.9–1394) [517±285.8]	(175–925) [586±241]	(452–1480) [904±44.5]	(79.9–454) [374±279]	(41–617) [159±80]	(133.7–289) [218.9±64]
Wind velocity (m/s)	(0.2–1.4) [0.62±0.3]	(0–1.5) [0.5±0.3]	(0–1) [0.44±0.3]	(0–1.3) [0.57±0.3]	(0–0.3) [0.14±0.21]	(0–0.9) [0.3±0.15]

Range, (mean ± sd)

3.7. Interactions of air microorganisms and environmental stressors

Table 5 shows the correlations between indoor/outdoor environmental stressors and microbial air concentrations. A wide range of correlations were found depending on type of microorganism, environmental stressor and location. Air pollutants "HCOH, NH_3, NO_2 and SO_2" had detrimental /toxic effects on the survival of airborne microorganisms (Table 5). Significant negative correlations were found between HCOH ($p \leq 0.05$) and all microbial parameters, as HCOH is frequently used as a disinfectant agent. NO_2 reacts with water molecules to form nitric and nitrous acids; actively react with water protein [85]. NO_2 had a toxic effect on airborne microorganisms through denaturation of moieties [86]. However SO_2 leads to form a more toxic compound of H_2SO_4 which becomes lethal to microorganisms [87].

PM negatively correlated with indoor airborne microorganisms, except with actinomycetes. However PM positively correlated with the outdoor microorganisms (Table 5). These correlations could be attributed to different dust and microbial sources, sizes and composition of PM. PM includes abundant organic matters, nitrate and sulfate [88]. PM in indoor environment has smaller sizes and more toxic compounds than that in outdoor environment. Fine dust particles contain mainly soot, metals and secondary toxic compounds [89], However coarse particles contain minerals species from soil and biological origin particles [90], which may support microbial growth and survival. The composition of PM differently affects microbial survival. This is because PM may cause deleterious effect on microbial metabolism /or favor their adsorption to PM [91]. PM is highly related to bacterial concentration [92] and it carries microbial particles in the atmosphere [93].

Physical parameters showed less obvious interactions with air microorganisms than air pollutants. Negative correlations were found between lighting, air speed and air pressure with indoor microbial concentrations (Table 5). Temperature and relative humidity affect microbial concentrations differently, due to the movement of water molecules depends on relative humidity and temperature. Relative humidity negatively influenced microbial concentrations. Significant positive correlations were found between temperature with mesophilic bacteria, fungi and actinomycetes. High humidity (70–80%) favors airborne microbial survivability [94] and air pressure dilutes microbial concentrations [95]. Previous studies have shown that temperature ≥ 24ºC decreases survival of airborne bacteria [96]; however others have shown that higher temperature increases survival of airborne bacteria [39]. Changes in RH%, TºC and wind speed significantly influence microbial survivability. Bacterial concentrations were insignificantly correlated with temperature, relative humidity, dust level and carbon dioxide in

Korea care-centers [29]. Significant and in-significant positive associations were found between relative humidity with indoor bacterial and fungal growth [97- 98].
Wind speed negatively influences the spread and accumulation of microorganisms [99]. Wind speed can bring exogenous microbes to indoor environment [100] and helps atmospheric dilution. In this study wind speed showed positive correlations with concentrations of ambient fungi and actinomycetes. This confirms the importance of passive discharge mechanism in release of small spores (actinomycetes) and bacteria [101]. Mechanical and natural ventilation modes reduce/or increase indoor microbial contents. Mechanical ventilation has higher air exchange rate than natural one, decreasing indoor microbial contents [102]. Air exchange rate, particle size and human behavior affect infiltration of airborne microorganisms [103]. The sufficient air exchange rate/or direct air flow reduce contaminated air [104].
Weak positive correlations were found between noise levels and microbial types, except the environmental bacteria. Human activities and occupancy numbers raise both noise level and re-suspended dust load. Re-suspended dust may be considered a contributor for air microorganisms. Light wavelengths affect survival of bacteria associated dust, as visible/or ultraviolet lights reduce bacterial counts [105]. Surface bacterial counts decreased as light intensity increased [99]. Light produces air ions (negative and positive ions) which evoke a wide range of physiological and biochemical changes of microorganisms, increasing their decay rate [106]. Visible light has a lethal effect on microorganisms [107], depending on particle size, photo-sensation and relative humidity [108]. Some sampling sites have UV light which possibly involves free radicles, damaging DNA and enzymes of airborne microorganisms.
The degree of electromagnetic pollution is influenced by the microenvironment. Higher electrostatic charges are generated in low humidity, alters electromagnetic nature of microclimatic conditions [109]. Electric and magnetic fields can differently attract microorganisms. Positive and negative correlations were found between airborne microorganisms with magnetic and electric fields, respectively. Electrical field acts as a removal mechanism for particles, depending on particle size and localized electrical field strength [110]. Vertical electrical field reduced airborne microbial concentrations [111] and a positive correlation was found between air microbial concentration and magnetic field [112]. Electrical force increased the rate of physical decay of microorganisms through increasing electrostatic agglomeration and deposited faster to the ground [113]. It is suggested that the positive correlations between magnetic field and airborne microorganisms may be attributed to magnetic strength is not able of attracting microorganisms but it may stimulate their growth. PM showed positive correlation with all microbial parameters in the outdoor environment. Moreover outdoor airborne actinomycetes showed different correlations trend with environmental stressors, and more studies are needed to understand their behavior in the air environment (Table 5).
Multiple-linear regression analysis confirmed that environmental bacteria & actinomycetes were mainly affected by ventilation rate. Ventilation rate reduces microorganisms-related human origin by diluting air and introducing outdoor-environmental associated microorganisms [114]. RH% ($p \leq 0.004$) and magnetic field ($p \leq 0.05$) positively affected the survival of mesophilic bacteria and actinomycetes, respectively. PM ($p \leq 0.037$), HCOH ($p \leq 0.034$) and SO_2 ($p \leq 0.008$) affected the survival of fungi. In general the behavior of airborne microorganisms is influenced by different variables which induce selecting pressure on microbial composition. Statistical analysis showed that not all independent variables were necessary to impact airborne microorganisms. Particulate matter, temperature, lighting, ventilation rate and electrical field could be standardized to control microbial air quality in complex public buildings.

Table 5. Spearman's rank correlations between microorganisms and environmental stressors indoor/ outdoor environments

Variable	Environ-bacteria		Meso-bacteria		Fungi		Actinomycetes	
	In	Out	In	Out	In	Out	In	Out
SPM-µg/m^3	–0.12	0.28	–0.05	0.19	–0.23*	0.07	0.05	0.27
HCHO-µg/m^3	–0.28*	–0.27	–0.35*	–0.21	–0.35*	–0.36	–0.35	–0.03
NH_3- µg/m^3	–0.37*	–0.17	–0.48*	–0.36	–0.25*	–0.27	–0.08	0.22
SO_2- µg/m^3	–0.11	–0.17	–0.37*	–0.25	–0.37*	-0.49*	–0.44*	–0.58*
NO_2-µg/m^3	–0.31*	–0.03	–0.16	–0.11	–0.24*	–0.04	-0.11	0.12
T°C	0.04	0.02	0.30*	0.20	0.19*	0.06	0.40*	0.48*
RH%	–0.15	0.02	–0.12	–0.05	–0.26*	–0.03	–0.01	0.30
Pressure-Pa	–0.08	–0.06	–0.12	–0.15	0.01	–0.34	0.08	0.09
Wind speed- m/s	–0.05	–0.28	–0.3*	–0.16	–0.14	0.08	–0.27*	0.11
Dew point-T°C	–0.14	–0.04	0.13	–0.04	–0.03	–0.17	0.21*	0.34
E-strength -V/m	–0.08	–0.24	–0.11	–0.32	–0.03	–0.03	–0.11	0.08
M-strength- A/m	0.15	–0.10	0.02	–0.31	0.02	–0.24	0.08	0.19
Noise-dBA	0.08	–0.03	0.03	–0.03	0.11	0.01	0.14	0.30
Lighting- Lux	–0.12	–0.24	–0.23*	–0.24	0.01	–0.20	–0.25*	–0.17

* $p \leq 0.05$

4. Conclusion

Indoor microbial air quality is varied under field conditions in respect to locality and environmental parameters. Microbial air quality was the worst in sampling sites-located near-ground surface as well as sites with hypoventilation and overcrowding. The highest values of GIMC/m^3 were found in the hospital environment and the near-ground surface in respect to the nature of work and height level-elevation, respectively. Considering the upper 95% confidence interval (95%CI), concentrations of environmental bacteria, mesophilic bacteria, fungi and actinomycetes were >5000 CFU/ m^3, 1087 CFU /m^3, 639 CFU/m^3, and 254 CFU/m^3, exceeding the threshold limit values that have been set by some international agencies. The variation of outdoor-origin air pollutant (PM, SO_2 and NO_2) concentrations in indoor environment confirms the differences in infiltration rates and

function of indoor/outdoor sources. Complex interactions were found between airborne microbial concentrations and environmental factors. The behavior of microorganisms in the air environment is influenced by different variables which induce a selecting pressure on microbial composition. Air chemical pollutants showed more obvious influence on the survival of microorganisms than climatic and physical factors. Ventilation rate, electrical field, lighting and air chemical pollutants tended to decrease airborne microbial concentrations. Relative humidity and temperature affected the survival of airborne microorganisms in indoor environment, differently. PM, T^{o}C, lighting, ventilation rate and electrical field factors could be standardized to determine microbial air quality in the built environment. Management plan should be developed to minimize infiltration and remove indoor sources. Concentration and diversity of antibiotic resistance genes and specific microbial types are needed to study in the future.

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