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Chemical, Physical and Microbial Parameters inside a Research Building Environment.

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Abstract

In the frame of the strategic plan Egypt 2030- a goal to create a supportive workplace environment. Indoor environment quality (IEQ) is an important factor to identify building's performance and comfort level. Key environmental parameters-related to IEQ of a multidisciplinary scientific research buildings were evaluated. Air biological (bacteria & fungi), chemical (PM, NO_2, SO_2, NH_3, HCOH & VOCs) and physical (T°C, RH%, air velocity, noise, lighting & electromagnetic radiation) parameters were measured indoor/outdoor. The measurements were performed using integrated sampling and real-time portable data instruments. The 75th percentiles of airborne environmental bacteria, mesophilic bacteria and fungi were 5172 CFU/m^3, 1294 CFU/m^3 and 634 CFU/m^3, respectively. Indoor/outdoor (I/O) ratios of VOCs, NH_3 and PM were ≥1. However, I/O ratios of HCOH, SO_2 and NO_2were ≤ 1. Indoor temperature and relative humidity ranged between 17-35.6°C and 30-66.5%, respectively. Operative temperature averaged 23°C; it located within the comfort zone ≥20 –≤24°C in only ~ 43% of the investigated sites. Noise value exceeded the minimum acceptable level of 60 dBA in ~77.7% of sites. Lighting intensity did not achieve the minimum acceptable level of 300 lox in~ 48.5% of sites. The electric and magnetic strengths significantly fluctuated, ranging between 1-242 V/m and 0.5-437A/m, respectively. Thermal comfort, indoor air quality, noise and lighting are used to calculate IEQ index (I_{IEQ}). I_{IEQ} simulation revealed that the majority of the investigated sites had good IEQ conditions. I_{IEQ} helps identify ways to improve building environment.

Key words: research-built environment; indoor air quality; noise; ventilation; thermal comfort; IEQ index.

1. Introduction

People spend ~90% of their times in enclosed spaces. The building sector is considered one of the largest contributors to global CO_2 production and hence climate change [1, 2]. IEQ, building's performance, is an important factor affected human health; well-beings and inhabitant's comfort [3]. IEQ can help minimize energy consumption and achieve low carbon footprint of buildings [4].

The discomfort of occupant to indoor environment is not caused by a single parameter [5]. IEQ is related to many parameters, reflecting physiological and psychological influences [6]. IEQ depends on physical factors, indoor air quality (IAQ), building envelope, damp conditions, occupant's behavior and air infiltration [7-10]. A small number of buildings may be able to achieve thermal comfort [11]. Noise is one of the most frequent complaints by building users, negatively impact on work performance and environmental satisfaction [12]. Reducing of noise is a key toward supporting well beings and productivity [13].

Indoor air quality is related to indoor pollutant sources, outdoor environment, ventilation rate and human activities [14]. Indoor air pollutants may be comprised of physical, chemical and biological components [15]. Moisture content, temperature, air exchange rate and number of people significantly affect indoor microbial loads [16, 17].

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IEQ index (I_{IEQ}) is a good indicator used to determine building's performance and identify areas that require improvement [18]. No simple unified/or universal index has been successfully established to prescribe levels and components of IEQ [19, 20]. I_{IEQ} is created by integrating four key elements "operative temperature, IAQ, noise and lighting" [21-24].

Scientific researchers spend a large proportion of their times inside laboratories or offices, they may be exposed to different environmental contaminants. It is needed to identify factors negatively affected indoor environmental quality in order to improve the work environment. The present study aims to assess IEQ of a research building environment by 1) checking measurements of "bacteria, fungi, PM, VOCs, SO_2, NO_2, NH_3, HOCH, T°C, RH%, noise, lighting, electromagnetic strength and ventilation rate" against available standards and 2) assessing the overall I_{IEQ} simulation using key parameters"noise, lighting, thermal comfort and IAQ". It helps improve indoor conditions and determine priority for improvement.

Nomenclature

VOCs	Volatile organic compounds
HCOH	Formaldehyde
NH_3	Ammonia
PM	Particulate matter
SO_2	Sulfur dioxide
NO_2	Nitrogen dioxide
IEQ	Indoor environmental quality
IAQ	Indoor air quality
SAR	Specific sorption rate
$\mu g/m^3$	Microgram per cubic meter
CFU	Colony forming unit
I/O	Indoor/ outdoor ratio
σ	Conductivity of the human brain tissue.
$\|E^2\|$	Magnitude of electric field vector (RMS, root mean square).
pm	Mass density of the human brain tissue
HVAC	Heating, ventilation and air conditioning
ACH	Air exchange rate per hour
gap	Total flow of fresh air introduced into room (m^3/h).
gap.s	Total flow of fresh air introduced into room per person ($m^3/h.p$).
V	Volume of room (m^3).
Np	Number of persons
I_{CT}	Thermal comfort index
I_{CA}	Acoustic comfort
I_{CV}	Visual comfort index
I_{CIA}	Indoor air quality index
Lpi	Average noise level DBA
E	Level of illumination (Lux)
dBA	Decibel
θ	operative temperature-
RFR	Radiofrequency radiation

2. Materials and methods

2.1. Guidelines of sampling

A cross-sectional survey was carried-out at 9 main buildings of a scientific research institute. Field measurements were taken from 132 representative sites (laboratories, administration, training halls and workshops). The sites differ in location, type of work and occupancy density to ensure diversity of indoor/outdoor environment. Environmental measurements were collected indoor/ outdoor, 2 days per week, on Monday-Tuesday, from December to July, during the years 2020-2022.

Real time instruments and integrated samplers were used. Bio-aerosols, PM, HCOH, NH_3, SO_2 and NO_2 were measured using integrated samplers. VOCs, noise, T°C, RH, lighting, air velocity and electromagnetic strength were measured using portable data instruments (short term measurements). The measurements were conducted during the regular daily activities, lasted 4-5 hours, between 10:00 AM - 15:00 PM on a fixed position at a height of 1-1.5m, ~1-2 m away from walls / doors and heating systems.

2.2. Integrated sampling

2.2.1. Microbial aerosols

Two-stage viable cascade impactor sampler (TE-10-160, Tisch Environmental Cleves, OH, USA) was used to collect airborne bacteria and fungi according to NIOSH method 0800 [25] and EN: 13098 [26]. Two consecutive samples were taken during each sampling event, 1-hour between each sample. Trypticase Soya agar (TSA) supplemented with 0.25% cycloheximide and Malt Extract Agar (MEA) supplemented with chloramphenicol [27] were used as culture media for bacteria and fungi, respectively.

Fungal plates were incubated at 25°C for 5-7days. However bacterial plates wereincubated at 28°C and 37°C for 48-72hrs. to grow environmental and mesophilic bacteria,respectively. Positive hole-correction was applied to the raw colony forming unit (CFU) recorded on each plate, and microbial concentration was calculated and expressed as colony forming unit per cubic meter of the air (CFU/m^3).

2.2.2. PM, HCOH, NH_3, SO_2& NO_2

PM was collected on a pre-weighed cellulose nitrate membrane filter (pore size 0.45µm, diameter 25 mm). The samples were obtained using an open face filter holder and pump calibrated to draw 15 L /min over 4 hrs. period. The mass concentration of

PM was gravimetrically calculated and expressed as μg/m^3.

HCOHwas collected using a sorbent of 2, 4 di-nitrophenyhydrazine (2, 4-DNPH) with a constant flow rate of 1 L/ min for ~4 h, and chemically analyzed [28]. NH_3 was also chemically measured using Nessler's reagent and a vacuum pump calibrated to draw 0.5 L/min for ~4 hrs. Sulphanilamide diazotization and West and Gaeke methods were used to analysis NO_2 and SO_2, respectively [28]. Sampling was conducted using glass bubblers, containing 50 ml of 0.1N sodium hydroxide and 0.1M sodium tetra-chloromercurate solutions to determine NO_2 and SO_2, respectively and colorimetrically measured using spectrophotometer (Unicom spectrophotometer model 300).

2.3. Real time data instruments

VOCs were measured using real time Aeroqual-Series 200 (Aeroqual-USA) and the measurement were expressed as μg/m^3. Noise was measured using Sound Level Meter (model RO-1350- made in Taiwan), located ~1.5 m above the ground level, and no close than 3 m to any reflecting surface. Significant /or accidental anthropogenic noise sources were excluded from themeasurements.The lighting intensity was measured using Light Meter (Light meter-TM-201, made in Taiwan). Noise and lighting levels were expressed as dBAand Lux,respectively. Air and radiant temperatures; relative humidity and air velocity were measured using thermocouple device, thermohygrometer and anemometer, respectively.

Electric and magnetic strength 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 2 min before reading, andthe electrical and magnetic strengths were expressed as V/m and A/m, respectively.

2.4. Specific Absorption Rate

Specific Absorption Rate (SAR) is described as the transfer of energy from electric and magnetic fields to charged particles in an absorber. SAR was estimated at a point on the brain of the absorber and can be determined using equation-1 [29].

$$SAR=\sigma|E^2|/Pm \qquad \text{eq.1}$$

The conductivity (σ) and mass density of human brain tissue (Pm) values for frequencies 900 and 1800 MHz are shown in Table 1 [30].

Table 1. The conductivity and mass density values for 900 and 1800 MHz

Frequency	Conductivity/ohm^{-1} m^{-1}	Mass density/kg/m^3
900	0.7665	1030
1800	1.1531	1030

2.5. Ventilation rate

Ventilation is an essential to eliminate air pollutants from enclosed spaces. Natural or mechanical ventilation may require air conditions and HVAC systems. IAQ is mainly evaluated by calculating ventilation rate. Air exchange rate (ACH) andventilation rate (m^3/h/person) are estimatedduring the work's occupied period using the equations 2 & 3, respectively [31].

$$ACH=\frac{gas}{V} \qquad \text{eq.2}$$

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

3. Results and Discussion

3.1. Microbial air quality

IEQ is influenced by biological,physical and chemical parameters of indoor/outdoor environments. The summary of indoor/ outdoor airborne biological contamination is shown in Table 2 and illustrated in Figure 1. Microbial concentrations significantly varied between locations. Environmental bacteria, mesophilic bacteria and fungi averaged 4450 CFU/m^3 (25th-75th = 2439-5172 CFU/m^3), 887 CFU/m^3 (25th-75th =218-1294 CFU/m^3) and 556 CFU/m^3 (25-75th= 327-634 CFU/m^3) indoors, respectively.

Table 2. Summary of biological parameters at the research buildings

Biological parameter	CFU/m^3							
	Indoor				Outdoor			
	Mean	25th	75th	range	Mean	25th	75th	range
Environ-bacteria	4450	2439	5172	287-19378	5034	2971	5406	1366-15495
Meso-bacteria	887	218	1294	0-4531	814	182	1039	64-4421
Fungi	556	327	634	71-2841	611	350	764	35-1962

I/O ratios of airborne microorganisms were 0.88, 1.09 and 0.9 for the corresponding indicators, respectively. I/O microbial ratios were ≥ 1 at ~13.7% of the total sampling sites, indicating accumulation and proliferation of microorganisms indoor. The results confirmed that outdoor environment was the major contributor of indoor microbial particles (environmentally origin). However mesophilic bacteria-human-related bacteria- were higher indoors as a result of overcrowding and hypoventilation.

Under normal conditions the number of microbial particles indoor is the same as/ or less than that found outdoor. Indoor microbialproliferation and occupant's health problems are closely related, and as a result of global warming environmental bacteria may be modified to be more pathogenic ones.

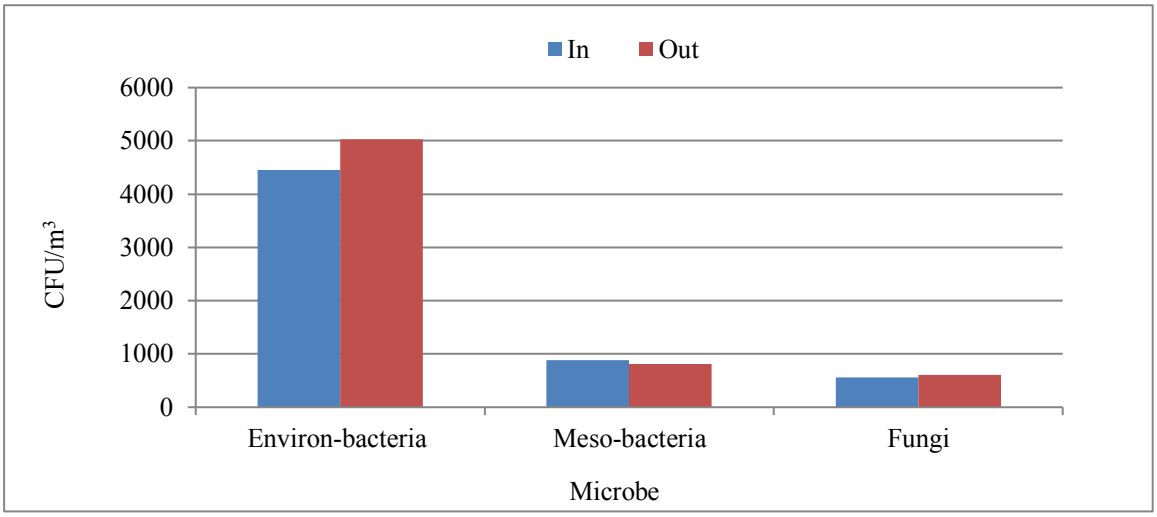

Fig.1. Indoor/outdoor mean concentrations of airborne microbial parameters of building environment

No-acceptable threshold limit values have been established for airborne microorganisms, instead of numerical values critically identify sanitary conditions of the building environment. Airborne bacterial concentrations ≤ 100 CFU/m^3 may be unhealthy to vulnerable people [32], and in the range of 4500-10000 CFU/m^3 has been suggested as upper limit for ubiquitous bacterial aerosols [33]. In the present study airborne bacterial concentrations could be classified as high (≥500 CFU/m^3) in almost locations [34]. Rao et al. [35] reported that bacterial concentration ≤750 CFU/m^3 indicated a building free of bio-contamination, if there were no infectious/or allergenic species. Fungal guidelines are ranged between ≤100 to ≥1000 CFU/m^3 as the upper limit for non-contaminated indoor environment [36]. In the present study fungal concentrations were below the maximum value of 103 CFU/m^3 and 750 CFU/m^3 recommended by the U.S-EPA [36] and the Brazilian standard [37], respectively, but exceeded of 500 CFU/m^3 recommended by the WHO[38].

3.2. Chemical parameters

HCOH, VOCs, NH_3 and PM concentrations averaged 279 µg/m^3, 650 µg/m^3, 218.5 µg/m^3, and 204 µg/m^3 indoors, respectively (Table 3). I/O ratios of VOCs, NH_3 and PM were ≥ 1, suggesting that internal sources were the most contributors of these pollutants. VOCs and HCOH concentrations exceeded the guideline limit value of 300µg/m^3 and 100 µg/m^3-30 min recommended by the German Federal Environment Agency [39] and the WHO [14], respectively, representing a matter of concern. HCOH and VOCs are related to different sources “insulating materials, plywood furniture and cleaners" as well as HCOH is formed through oxidation of VOCs [40].

In the present study the I/O ratios of NH_3 were roughly as the same as indoor and outdoor. However, NH_3 mean concentrations relatively exceeded 200µg/m^3 set as a limit value guideline [41].

PM concentrations were higher indoors than outdoors. No limit value is existed for indoor PM [42], however PM did not exceed the Egyptian's limit value 230 μg/m^3 (24-h) [43]. Higher PM indoor is attributed to dust infiltration, human activity, re-suspension of indoor dust and hypoventilation.

I/O ratios of NO_2 (0.9) and SO_2 (0.97) were ≤ 1 (Table 3). SO_2 and NO_2 pollutants are related to local traffic/ or combustion sources influence indoor levels. Their indoor concentrations are a function of both indoor and outdoor sources. NO_2 concentrations were found in the range of 13–62 μg/m^3 indoors and 24–61 μg/m^3 outdoors [44]. Under normal ventilation conditions I/O ratio may be varied from 0.88 to 1 [45]. NO_2concentrations were found below the guideline limit of 200 μg/m^3/1-h [46] whileas SO_2 exceeded guideline of 40 μg/m^3 for a short-term (24-hour) [47].

Table 3.Summary of chemical parameters at the research buildings

Parameter	μg/m^3							
	Indoor				Outdoor			
	Mean	25th	75th	range	Mean	25th	75th	range
HCOH	279	162	317.6	0-1080	287	193.5	380	0-830
VOCs	650	54	547	9-1568	351.7	58	341	6-1355
NH_3	218.5	66.3	338	0-939	190.7	58	325.5	0-658.8
PM	204	118	238	56.7-757.6	148	102	171	67-280
SO_2	148	9	88	0-1460	152	13	175	12-960
NO_2	77.8	43.8	87	0-350	86	43	102	0-375

3.3. Physical parameters

The summary of physical parameters of the research-building environment is shown in Table 4. Noise values averaged 67 dBA (25th-75th=62-71.6 dBA) indoors and 66.8 dBA (25th-75th= 62.8-72dBA) outdoors. The noise values ≥ 60dBA were measured at ~77.7% of the investigated sites. The background of noise in classrooms should below 35 dBA [48]. Noise level exceeded the Egyptian guidelines (55 dBA) [43]. The high noise level is attributed to the presence of open space and diverse noise sources [49].

The lighting intensity averaged 355 lux (25th-75th=213-465 lux) indoors and 739 lux (25th-75th=135-619 lux) outdoors (Table 4). Lighting values were below the minimum acceptable level ≤ 300 lux at ~ 50% of the investigated sites [50]. The light intensity in the range of 200 - 400 lux was the most favorable in rooms [51]. It is suggested that lighting should be redesigned to achieve optimal environment.Indoor temperature, relative humidity and air velocity ranged between 17.7-35 °C; 30-66.5% and 0-1.4 m/s, respectively (Table 4). This variation is attributed to season, occupant activity, effect of fresh air and heat gain from appliances. Non-significant differences (P≥0.05) were found between indoor and outdoor microclimatic parameters. The acceptable guidelines of temperature are ranged within 23-27 °C [52] and 20-23°C in offices in temperate climate zone [53]. The ASHRAE [54] considered an acceptable RH%range between 30%-60% in office buildings for thermal comfort. Sterling et al. [55] suggested that a mid-range value of 40%-60% RH might be optimal to prevent a number of health issues in buildings. Catalina et al. [23] recommended the range value between 20-60% RH as acceptable around the year. People who spent the majority of their time in conditions of 30%-60% RH experienced 25% less stress than those who spent the majority of their time in drier conditions[56]. In the present study operative temperature and RH% range were found on border levels, representing a matter of concern.

Table 4. The summary of physical parameters at the research buildings

Parameter	Indoor				Outdoor			
	Mean	25th	75th	range	Mean	25th	75th	range
Noise- dBA	67	62	71.6	48-87	66.8	62.8	72	57-78.9
Illumination-lux	355.5	213	465	41-2415	739	135	619	38-4000
T°C	22.9	19.6	24.6	17-35.6	23	19.5	25	17.7-35
RH %	45	39	50	30-66.5	43.5	38.7	48	31-73
Ws- m/s	0.044	0	0	0-1.4	1.1	0.25	4	0-11
Electric field-V/m	29	3.1	29.2	1-242	12	1.6	6	1-118
Magnetic field A/m	65.5	21.9	64.4	0.5-349	208	24.2	180	14.5-1878

The mean readings of air velocity averaged zero, less than the standard limit value recommended between 0.15 to 0.50 m/s indoors [57], causing hypoventilation and accumulating of contaminants. Natural ventilation is insufficient to exchange air appropriately, and mechanical ventilation is critically required.

The electric and magnetic strengths extremely fluctuated regarding field structure at each site, ranging between1-242 V/m and 14.5-1878 A/m, respectively. The mean electric and magnetic fields exceeded some standards for SI agencies (Table 5). Absorption of RFR depends on transmission frequency, power density, distance from the radiating source, one's orientation towards the radiation, size, and mineral and water content of an organism [58].

Table 5. General public and occupational exposure standards/guidelines for SI agencies

Country	Exposure			
	Electric field (V/m)		Magnetic field (A/m)	
	Public	Occupational	Public	Occupational
IRPA, 1984	87	614	0.231	1.6
Italy	20	61	0.05	350
HDFSS, 2002	670	1,500	157	350
ANSI,2002	632	614	1.58	1.58
ArabLaborOrganization,1999	-	10000/day 30000/short period	-	1.59/ day 69.5/short period

SAR values estimated for 900 and 1800 MHz are shown in Table 6. The SAR values were lower outdoors than indoors. Indoor SAR values averaged 0.021 W/kg and 0.009 W/kg for 900 MHz and 1800 MHz, respectively. SAR values were much below the limits allowed by the international boards 1.6 W/kg [59] and 2 W/kg for 1800 MHz [60]. Harmful biological effects may be started to occur in the brain at SARs ≤ 0.001 W/kg [61], increase calcium efflux in human neuroblastoma cells at 0.005W/kg [62], and breaks DNA strand in brain cells of rats at SAR of 0.0008 W/kg [63].

Table 6. SAR values estimated from for 900 and 1800 MHz

Environment	W/kg	
	SAR-900 MHz	SAR-1800 MHz
Indoor	0.012	0.03
Outdoor	0.009	0.013

3.5. IEQ index simulation

IEQ index is calculated basing on 4 parameters include "thermal comfort index (I_{CT}), acoustic comfort index (I_{CA}), visual comfort index (I_{CV}) and indoor air quality index (I_{CIA}) [19]. These indices affect occupant's comfort and building energy consumption. I_{CT} is calculated basing on operative temperature (eq. 4) as following:

$$I_{CT}=\begin{cases}\theta \le 21.5; Ith = 28.57\theta - 514\\ \theta \ge 24.5; Ith = 28.57\theta + 800\end{cases} \quad \text{eq. 4}$$

I_{CA} is calculated basing on measured level of noise and 60 dBA is considered the maximum comfortable level (eq. 5).

$$I_{CA}= -3.33.Lpi +200 \quad \text{eq.5}$$

I_{CV} is calculated using lighting level (eq. 6).

$$I_{CV} = 0.33.E \quad \text{eq.6}$$

Different categories of IAQ influence ventilation rates (e.g., ventilation per m^2 floor area, ventilation per person and /according to CO_2 level), [31]. I_{CIA} is determined depending on airflow (eqs7-9). The mechanical ventilation is used to introduce fresh air indoor, and natural ventilation (opened doors/ windows) is generally insensible (air velocity 0- 1.4 m/s).

$$I_{CIA} = 3.125.qap.s - 12.5 \quad \text{eq.7}$$

$$qap.s = \frac{qap}{Np} \quad \text{eq.8}$$

$$qap= ACR \times V \quad \text{eq.9}$$

I_{IEQ} is calculated basing on the previously mentioned indices (eq.10) [17].

$$IEQ - index = \frac{(ICT + ICA + ICV + ICIA)}{4} \quad \text{eq .10}$$

This module could be used to determine IEQ of the research-building environment, since research buildings are as the same as educational ones. IEQ limits, classes and star rating were previously published [19]. Mapping of the IEQ index of the investigated locations is illustrated in Figure2.

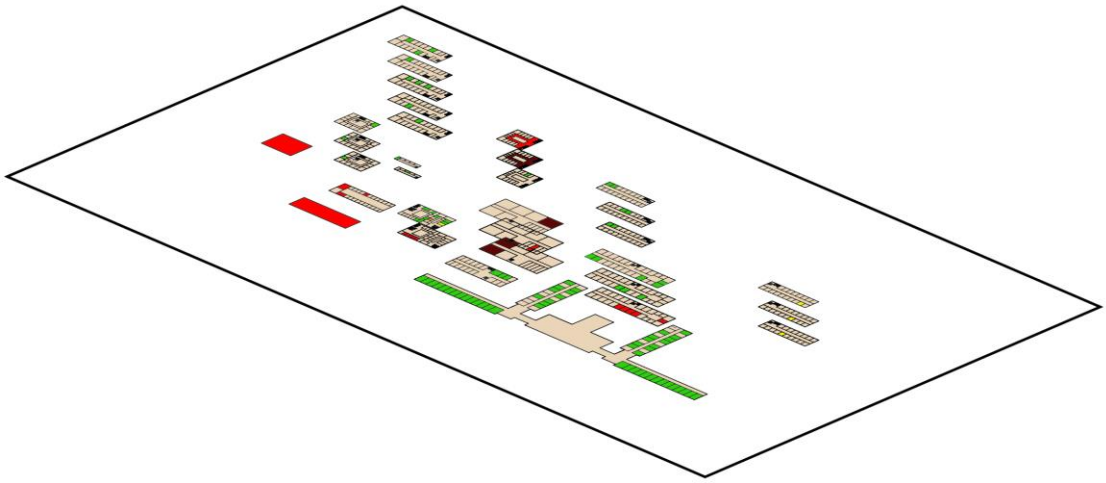

Fig 2.The map showing IEQ classes of the investigated research buildings

It can be concluded that 80.6% of the sites had acceptable IEQ, however ~ 14.56% of the investigated sites had low rating (classes D-E) and need a priority for improvement.

4. Conclusions

The indoor building environment influences occupant's well-being, energy consumption and climate challenge. VOCs, HCOH, SO_2, noise and light were not consistent with the standards. I/O ratios of microbial aerosols and VOCs exceeded ≥1 at ~ 14% of the investigated sites, since indoor sources were the most contributors. PM concentrations were roughly higher indoor, confirming infiltration and building-up of dust. SAR values did not exceed the ICNIRP limit values; however damages in cells and tissue could be started to take place at low value (0.001W/kg). The I_{IEQ} is an appropriate tool to determine IEQ rating and green building requirements. Checking environmental parameters values against numerical standards/guidelines is critically needed. Further research is needed to understand IEQ by integrating other environmental parameters such as electromagnetic radiation and pathogenic microorganisms.

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Credit author statement

Abdel Hameed A.A: conceptualization-writing original draft-investigation-writing-review, supervision. **Saeed Y. & El-Gendy S. A**.: investigation- methodology-formal analysis-data creation. **Hassan S. K**.: investigation-methodology-data creation.

References:

[1] L. Pérez-Lombard,J. Ortiz, C. Pout, A review on buildings energy consumption 11 information, Energy Build. 40(3) (2008) 394-398.

[2] International Energy Agency, Global Status Report: Towards a Zero-Emission, Efficient and Resilient Buildings and Construction Sector; United Nations Environment Programme: Nairobi, Kenya, 2018.

[3] H.Abdulaali, I.M.S.Usman, M.M. Hanafiah, M.J. Abdulhasan, M. T. Hamzah, A. A. Nazal, Impact of poor indoor environmental quality (IEQ) to inhabitants, health, wellbeing and satisfaction, Int. J of Advanced Science and Technology 29 (4s) (2020) 1284-1296.

[4] S.A. Ghita, T. Catalina, Energy efficiency versus indoor environmental quality in different Romanian countryside schools, Energy Build. 92 (2015) 140–154, https://doi.org/10.1016/j.enbuild.2015.01.049.

[5] N. Fransson, D. V¨astfjall, J. Skoog, In search of the comfortable indoor environment: a comparison of the utility of objective and subjective indicators of indoor comfort, Build. Environ. 42 (5)(2007) 1886–1890.
[6] B. Cao, Q. Ouyang, Y. Zhu, L. Huang, H. Hu,G. Deng, Development of a multivariate regression model for overall satisfaction in public buildings based on field studies in Beijing and Shanghai, Build. Environ. 47 (2012) 394–399.
[7] V.V. Sakhare, R.V. Ralegaonkar, Indoor environmental quality: review of parameters and assessment models, Archit. Sci. Rev. 57 (2)(2014) 147–154.
[8] D. Y. C. Leung, Outdoor-indoor air pollution in urban environment: Challenges and opportunity, Front. Environ. Sci.2 (2015) 69.
[9] Y. Al horr, M. Arif, M.Katafygiotou, A.Mazroei, A. Kaushik, E. Elsarrag, Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature, Int. J. Sustain. Built Environ. 5(2016) 1-11.
[10]S.A.Altomonte, J. Allen,P.M.Bluyssen, G. Brager, L. Heschong, A. Lorder, S. Schiavon, J.A. Veitch, L.Wang, P. Wargocki, Ten questions concerning well-being in the built environment, Build. Environ. 180 (2020) 106949.
[11] ASHRAE-55, Thermal environmental conditions for human occupancy, https://www.ashrae.org/technical-resources/bookstore/thermal-environmental-conditions-for-human-occupancy, 2013(accessed 20 .9. 2022).
[12] Kang S, Ou D, Mak CM. The impact of indoor environmental quality on work productivity in university open-plan research offices. Build Environ 2017; 124:78–89.
[13] C. Wang, Y. Si, H. Abdul-Rahman, L. C. Wood, Noise annoyance and loudness: Acoustic performance of residential buildings in tropics, Building Services Engineering Research &Technology 36 (6) (2015) 680-700.
[14] WHO, Guidelines for indoor air quality; selected pollutants. World Health Organization, Geneva, 2010.
[15]I. Mujan, D.Licina, M. Kljajić, A.Čulić, A.S. Anđelković, Development of indoor environmental quality index using a low-cost monitoring platform, J. of cleaner Prod.312(2021) 127846.
[16] ACGIH, Bioaerosols: Assessment and control, American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio,1999.
[17]K. J.Heo, C. E. Lim, H. B. Kim, B. U. Lee, Effects of human activities on concentrations of culturablebioaerosols in indoor air environments, J. Aerosol Sci. 104 (2017) 58–65. doi: 10.1016/j.jaerosci.2016.11.008.
[18] T. Mihai, V. Iordache, Determining the indoor environment quality for an educational building, Energy Procedia. 85(2016)566 – 574.
[19] T.Catalina, V. Iordache, IEQ assessment on schools in the design stage, Build. Environ. 49 (2012)129-140.
[20] L. C. R.Salis, M. Abadie, P. Wargocki, C. Rode, Towards the definition of indicators for assessment of indoor air quality and energy performance in low-energy residential buildings, Energy Build. 152(2017) 492–502. https://doi.org/10.1016/j.enbuild.2017.07.054.
[21] J. Kim, R.de Dear, Nonlinear relationships between IEQ factors and overall workspace satisfaction, Build. Environ. 49(2012) 33-40.
[22] M. Frontczak, R. Andersen. Wargocki, Questionnaire survey on factors influencing comfort with indoor environmental quality in Danish housing, J. of Build. Environ. 50 (2012)56–64.
[23] T. Catalina,V. Iordache, A. Ene, Experimental assessment of the indoor environmental quality in an educational facility, RevistaRomana de InginerieCivila, Numarul 3 (2013).
[24] P.V. Dorizas, M. Assimakopoulos, M. Santamouris, A holistic approach for the assessment of the indoor environmental quality, student productivity, and energy consumption in primary schools, Environ.Monit. Assess. 187(2015) 259–277. https://doi.org/10.1007/s10661-015-4503-9.
[25] NIOSH method 0800, NIOSH Manual of Analytical Methods, 1998.
[26] EN: 13098, Workplace atmospheres-guidelines for measurement of airborne microorganisms and endotoxins, Brussels, Belgium: European Committee for Standardization,2000.
[27] C. Mouli, S. Mohan, S.Reddy, Assessment of microbial (bacteria) concentrations of ambient air at semi-arid urban region: influence of meteorological factors, Appl. Ecol. Environ. Res. 3 (2005) 139-49.
[28] R.M. Harrison, R.Perry, Handbook of air pollution analysis,second ed., Chapman and Hall, London, New York, 1986.
[29] Om P. Ghandi, Biological effects and medical applications of electromagnetic Energy, Prentice Hall, Englewood Cliffs, NJ.1990.
[30] A. K. Dhami, Study of electromagnetic radiation pollution in an Indian city, Environ. Monit. Assess. 184(2012) 6507–6512.
[31] EN:15251, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics, Thermal Environment, Lighting and Acoustics, AFNOR: Paris, France, 2007.
[32] ACGIH, Guidelines for the assessment about aerosols in the indoor environment, American

Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1989.
[33] A. Nevälainen, Bacterial Aerosols in Indoor Air (Dissertation), National Public Health Institute, Helsinki, Finland, 1989.
[34] CEC, Indoor air quality & its impact on man: Biological particles in indoor environments, Commission of European Communities, Report 12, Cost Project 613, EUR.14988 EN,1993.
[35] C. Y.Rao, H. A.Burge, J. C. S. Chang, Review of quantitative standards and guidelines for fungi in indoor air, J. Air Waste Manag. Assoc. 46 (1996) 899-908.
[36] US-EPA (United States Environmental Protection Agency) National Ambient Air Quality Standards, 2004, http://www.epa. gov/air/criteria.html.(accessed 12.12 2022).
[37] C. Ross, J.R. Menezes, T.I. Svidzinski, U.Albino, G. Andrade, Studies on fungal and bacterial population of air-conditioned environments, Braz. Arch. Biol. Technol. 47 (2004) 827–835.
[38] WHO, Regional Publications European Series, No. 31: Indoor Air Quality: Biological Contaminants; Report on a WHO Meeting; World Health Organization, Copenhagen, Denmark,1988.
[39] German Federal Environment Agency,Guide values I and II, German committee on indoor guide values [www Document], 2018. Accessed 2.11.2023.https://www.umweltbundesamt.de/en/topics/health/commissions.Working.groups/ German.Committee.on. indoor.guide. values.
[40] W.W. Nazaroff, C.J. Weschler, Cleaning products and air fresheners: exposure to primary and secondary air pollutants, Atmos. Environ. 39 (2004) 2841-2865.
[41] GB/T 18883, Indoor Air Quality Standard, National Standard, 2002. https://www.chinesestandard.net/PDF.aspx/GBT18883-2002 (accessed 18.1.2023).
[42] EPA, U. Border 2012, US Mexico Environmental Program, IndicatorsReport, 2010, Tech. Rep. 2012, http://www.epa.gov/usmexicoborder/docs/BorderIndicatorsReportApril2006.pdf.
[43] EEAA, Egyptian Environmental Affair Agency, Environmental protection law, No. 4, Maddi, Cairo, Egypt, 1994.
[44] D. Kotzias, K. Koistinen, S. Kephalopoulos, et al. The INDEX project. Critical appraisal of the setting and implementation of indoor exposure limits in the EU. Ispra, European Commission Joint Research Centre, 2005.
[45] P. Blondeau, V. Iordache, O. Poupard, D. Genin, F. Allard. Relationship between outdoor and indoor air quality in eight French schools. Indoor Air, 2005, 15:2–12.
[46] WHO, World Health organization (2010), Guidelines for indoor air quality; selected pollutants. Geneva.
[47] WHO global air quality guidelines.Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide.World Health Organization 2021.
[48] European Standard EN-15251, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics, Thermal Environment, Lighting and Acoustics, AFNOR: Paris, France, 2007.
[49] S Kang, C. Ming Maka, D. Ou, Y. Zhang. The effect of room acoustic quality levels on work performance and perceptions in open-plan offices: A laboratory study. Applied Acoustics 201 (2022) 109096.
[50] BS EN 12464-1, Light and lighting - Lighting of workplaces – Part I, indoor workplaces, British Standards Institution, 2011.
[51] N. Krawczyk and L. Debska, indoor environment, lighting conditions and productivity in the educational buildings. Civil and Environmental Engineering, (2022), DOI: 10.2478/cee-2022-0055
[52] D.Norbäck, An update on sick building syndrome,Curr.Opin.Allerg.Clin.Immunol,9 (1) (2009) 55-59.
[53] Indoor Temperature,The National Board of Health and Welfare SOSFS, 15 (M, in Swedish), 2005.
[54] ASHRAE, Ventilation for acceptable indoor air quality. American Society of heating Refrigerating and Air -Conditioning Engineers, 1989.
[55] E.M. Sterling, A. Arundel, T.D. Sterling, Criteria for Human Exposure to Humidity in Occupied Buildings, ASHRAE Transactions, 91 (1B), (1985) 611-622.
[56] J. Razjouyan, H. Lee, B. Gilligan, C. Lindberg, H. Nguyen, et al., Well built for wellbeing: Controlling relative humidity in the workplace matters for our health, Indoor Air 30 (1) (2020) 167-179.
[57] M. A. Sulaiman, W.Z. Wan Yusoff, W.N. Wan Kamarudin, Evaluation of indoor environmental quality (IEQ) on dense academia universitiTun Hussein Onn Malaysia, Int. J of Sci. and Res. Publ., 3 (1) (2013) 1-5.
[58] B. B. Levitt,H. Lai, Biological effects from exposure to electromagnetic radiation emitted by cell tower base stations and other antenna arrays, Environ. Rev. 18 (2010) 369–395.
[59] FCC, Federal Communications Commission, Evaluating compliance with FCC guidelines for human exposure to radiofrequency electromagnetic fields. OET Bulletin 65.Federal Communications

Commission Office of Engineering & Technology, Washington, DC, 1997.
[60] ICNIRP, International Commission on Non-Ionizing Radiation Protection, Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz), Health Phys. 74(1998)494–522.
[61] C.D. de Pomerrai, H. David, J. Allan, I. Duce, M. Mutwakil, D. Thomas,P. Sewell, J. Tattersall,D. Jones, Non-thermal heat-shock response to microwave, Nature, cell biology 405 (2000) 417-418.
[62] S. K.Dutta, B.Ghosh, C. F.Blackman, Radiofrequency radiation-induced calcium ion efflux enhancement from human and other neuroblastoma cells in culture, Bioelectromag10(2) (1989) 197–202.
[63] K. K. Kesari, J.Behari, Fifty-gigahertz microwave exposure effect of radiations on rat brain, Appl. Bioch. Biotech.158 (1) (2009)126–139.