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Investigating the air quality index inside two museums in Baghdad City

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Abstract
The study aims to investigate and assess the indoor air quality within two renowned museums situated in Baghdad city, namely the Iraqi National Museum and the Natural History Museum, during the months of October and November 2023. A Temtop device was used to measure the main indoor environmental parameters in these museums, particularly (total volatile organic compounds (TVOC), formaldehyde (HCHO), particulate matter (PM), temperature, and humidity), as well as Air Quality Index (AQI). The average concentrations of different air pollutants measured in both museums were as follows: TVOC was 0.93 mg/m3 and 0.80 mg/m3, HCHO was 0.31 mg/m3 and 0.28 mg/m3, PM2.5 was 57.23 µg/m3 and 52.33 µg/m3, and PM10 was 85.11 µg/m3 and 72.82 µg/m3. The average values of TVOC were within the limits recommended by the World Health Organization (WHO) and Environmental Protection Agency (EPA), which is less than 1mg/m^3. Meanwhile, the average values of the rest of the indoor pollutant concentrations exceeded the recommended limits, which for HCHO is 0.004 mg/m^3 and for, PM2.5 is 35µg/m^{3,} and PM10 is 150µg/m^3, for the daily standard. The average values of indoor air temperature for the two museums were higher than the ASHRAE standards recommended limits. In contrast, Indoor RH is below the recommended limits. As for AQI, it was classified as unhealthy for sensitive groups for both museums.

Keywords: Indoor air quality, museums, exhibits, parameters.

التحري عن مؤشر نوعية الهواء داخل متحفين في مدينة بغداد

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الخلاصة
تهدف الدراسة إلى دراسة وتقييم نوعية الهواء الداخلي في متحفين مشهورين يقعان في مدينة بغداد، وهما المتحف الوطني العراقي ومتحف التاريخ الطبيعي، خلال شهري تشرين الأول وتشرين الثاني 2023. وتم استخدام جهاز تيمتوب لقياس الهواء الداخلي الرئيسي. المعايير البيئية في هذه المتاحف، وخاصة (إجمالي المركبات العضوية المتطايرة (TVOC)، والفورمالديهايد (HCHO)، والجسيمات (PM)، ودرجة الحرارة، والرطوبة)، وكذلك مؤشر جودة الهواء (AQI). كان متوسط تركيزات ملوثات الهواء المختلفة التي تم قياسها في كلا المتحفين على النحو التالي: كان TVOC 0.93 ملغم / م 3 و 0.80 ملغم / م 3، وكان HCHO 0.31 ملغم / م 3 و 0.28 ملغم / م 3، وكان PM2.5 57.23 ميكروغرام / م 3 و

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52.33 ميكروغرام. / م 3، وكان PM10 85.11 ميكروغرام / م 3 و 72.82 ميكروغرام / م 3.
وكان متوسط قيم TVOC ضمن الحدود الموصى بها من قبل منظمة الصحة العالمية (WHO) ووكالة حماية البيئة (EPA)، وهي أقل من 1 ملجم/م3. وفي الوقت نفسه، تجاوز متوسط قيم بقية تراكيز الملوثات الداخلية الحدود الموصى بها، وهي بالنسبة لـ HCHO 0.004 ملجم/م3، و35 PM2.5 ميكروجرام/م3، و150 PM10 ميكروجرام/م3، للمعيار اليومي. وكان متوسط قيم درجة حرارة الهواء الداخلي للمتحفين أعلى من الحدود الموصى بها من قبل معايير ASHRAE. وفي المقابل، فإن الرطوبة النسبية الداخلية أقل من الحدود الموصى بها. أما بالنسبة لمؤشر جودة الهواء، فقد تم تصنيفه على أنه غير صحي للمجموعات الحساسة لكلا المتحفين.

1. Introduction

Given that people spend approximately 90% of their time indoors, where they are susceptible to hazardous and toxic pollutants due to inadequate indoor and outdoor air circulation, indoor air quality (IAQ) issues have become a pressing health concern in the field of architecture [1]. Three main elements have been suggested to significantly influence indoor air quality IAQ in homes or businesses [2, 3]: Outdoor air quality, human activity within structures, building and construction materials, tools, and furnishings. Among the primary sources of damage to museum displays is IAQ. Some objects of great importance shown at museums and other historical landmark buildings are old and highly delicate. Hence, regular cleaning is impossible for some of them [4]. Since the validity of the displays depends on conservation procedures, they are also somewhat delicate to administer [5-7]. Over time, this has drawn the interest of academics who have tracked museum internal environments to maintain the displays as best as they could [8-10]. One of the leading causes of damage to displays and adversely influences human health is the combined effect of indoor environment indicators and different contaminants [11]. Maintaining artwork and guaranteeing the comfort of museum staff depend on good indoor air quality. Museums are regarded as historical repositories that serve as a vital link bridging the past, present, and future for nations [12]. Apart from consistent displays, early museums began to offer interpretative services, lectures, and educational activities to improve audience understanding and involvement [13, 14]. In 2007, the International Community of Museums (ICOM) Statutes established that "A museum is a permanent, non-profit institution that is open to the public and serves the interests of society and its development. It acquires, conserves, researches, communicates, and exhibits the tangible and intangible legacy of humanity and its environment for the purposes of education, study, and enjoyment." There are numerous sources of polluted that must be taken into account in the museum environment. One source of pollutants is the outdoor air, which is introduced into the museum environment through Heating, Ventilation, and Air Conditioning (HVAC) systems or exchange through doors and other apertures. interior levels of environmental pollutants are influenced by both interior and outdoor sources, as the World Health Organization (WHO) has stated [15, 16]. Specifically, indoor levels are influenced by high outdoor levels that originate from local traffic or other combustion sources [20]. Pollutants may undergo modifications in both quantity and appearance upon entering the museum. The concentrations and varieties of pollutants will differ significantly based on the location of a museum. Additional contaminants are frequently introduced into a museum during the construction of exhibits and display cases. Within display cases characterized by restricted air exchange, volatile and semi-volatile compounds emanating from construction materials are prone to accumulate [17]. Finally, the museum personnel and visitors who enter museums on a daily basis introduce their own chemicals to an exhibition. For instance, recent investigations into the detrimental effects of third-hand smoke have demonstrated that numerous compounds that are detrimental to human health can be introduced into non-smoking environments through the apparel and skin of smokers [18]. Fragrances, lotions, and other personal-care products can all contribute novel compounds to the museum environment [19]. Various factors, including light, humidity, temperature, biological factors, and pollutants, cause the objects in the museums to degrade over time. These objects are composed of a variety of materials, including metals, textiles, and wood [20, 21].

The objective of this study was to assess the indoor air quality (IAQ) of two Baghdad museums and its consequences for the archeological models of the museums. In these museums, data of indoor environmental parameters including temperature, humidity, indoor particulate matter PM and gaseous pollutants, as well as air quality index (AQI), will be compile to help identify the extent to which elevated indoor air pollution levels might impact the displayed artifacts and the welfare of museum staff members.

2. Materials and methods

The different types of museums include general museums, science and technology museums, history museums, art museums, and national museums. The primary focus of this research is on natural history and natural science museums. First, with an eye on the natural world, is Natural History and Natural Science Museum. Birds, mammals, insects, plants, rocks, minerals, and fossils might all find place in their assembles [22]. Through the lens of public historians, who embrace the intricate and complex facets of history, recognizing that historical experiences do not necessarily align with the national borders that delineate their work, that the nation is not always the center of human experience and culture, the second is National Museum, the concept of which is essentially at odds with the theory and practice of public history [23].

2.1 The Field of Study

This study was performed at two museums in Baghdad district, one in AL-Karkh and one in AL-Rusafa. The first museum (the National Iraqi Museum) represents site (M1) located in AL-Karkh and surrounded with Transportation routes. The (M1) site has Central Laboratories department divided into five divisions (Documentation Division, Chemical Preservation and Devices Division, Organic and Inorganic Division, Casting Division). These divisions are in turn divided into several laboratories (mineral and rock laboratory, clay number laboratory, numismatic laboratory, chemistry laboratory, physics laboratory, biology laboratory) in addition to a store for the preservation and storage of chemicals used in the maintenance of artifacts ,which have different dimensions ranging between (8(length) x 6(width) x 4.3(high))m and (6(length) x 6(width) x4.3(high))m with volume 206.4m^3 and 154.8 m^3 respectively with central ventilation conditions (moderate ventilation). The second museum (The Natural History Museum) site (M2) was in AL-Rusafa surrounded with Transportation routes, It includes several laboratories [Vertebrate Laboratory (includes two sections: the first section Reptiles and Amphibians and the second section Birds and Mammals), Insects and Invertebrates Laboratory, Botanical herbarium Laboratory, Fish Laboratory]. These laboratories have different dimensions ranging between (4(length) x 3(width) x 2.45(high))m and (8(length) x 10(width) x 3.8(high))m with volume 29.4 m^3 and 304 m^3 respectively with source of ventilation is a turbine puller (moderate ventilation).

2.2 Detection of indoor particulate matter (PM2.5, PM10), gaseous pollutant concentrations

To accurately determine indoor air quality at the two study sites (M1, M2), a specific monitor/detector device called Temtop was used. This laser particle multi-functional detector, model LKC-1000S+ (US), with Display mode: TFT color LCD screen designed in California -Assembled in China. Adoption of the laser particle sensor and high-precision electrochemical formaldehyde, it is capable of measuring several important air quality parameters and directly transforming the concentration of pollutants in the air into visual data. The concentrations of (PM) are reported in (µg/m³), and gaseous pollutants in (mg/m³).

2.3 Monitoring of Air Quality Index (AQI)

The Temtop device continuously measures and updates the AQI in real-time, displaying the readings on the built-in screen. In addition, it mentions the Air Quality Index (AQI) value, which indicates whether the environmental air quality is healthy or unhealthy.

2.4 Measurement of Temperature and Humidity

Due to its portable design, the monitor Temtop device is simple to transport between different locations and put in an environment that needed testing, and then the monitor`s system automatically detected the temperature in Celsius (°C) and humidity in percentage (%). The monitor operates within the temperature range of 0-50C° and humidity range of 0-90% RH at atmospheric pressure condition of 1 ATM.

3. Statistical Analysis

In the present work, the data were expressed as the mean value ± SE (Standard Error) applying the program The Statistical Analysis System- System- SPSS (2012), which was used to identify the influence of many elements in study parameters. At P value (0.05), the LSD test (Analysis of Variance-ANOVA) was applied with the least significant difference.

4. Results and Discussion

4.1 Particulate Matter (PM2.5, PM10) and Number of particles in the Iraqi National Museum (M1) and the Natural History Museum (M2)

According to the data presented in Table 1, upon comparing the two museums with respect to PM2.5, PM10, and the number of particles, it was observed that the Iraqi National Museum (M1) exhibited the highest level of particulate matter (PM2.5) with a maximum value of 57.23 ± 2.64µg/m³, whereas the Natural History Museum (M2) recorded the lowest value of 52.33 ± 0.92µg/m³ for PM2.5. The maximum value of particulate matter (PM10) was recorded in M1 as 85.11 ± 3.93µg/m³, while the minimum value was 72.82 ± 1.36µg/m³ in M2. The maximum value of Number of particles was 6633.08 ± 263.30 per/L in M1, while the minimum value was 6142.80 ± 79.91per/L in M2. There are significant differences in the P value ($P<0.05$) of PM10. That means the Natural History Museum is less polluted in PM10 than the Iraqi National Museum. On the other hand, there were no significant differences in the P value ($P>0.05$) of PM2.5 and the Number of particles recorded between the two museums. The higher concentrations of the mean value of PM10 for M1 compared to M2 may be returned to using gypsum and white cement in producing gypsum pieces. They also use liquid and powder paints such as silicon carbide powder and thinner to paint these pieces. This may be due to the proximity of the museum building from transportation routes, resulting in heavy traffic, especially on weekends, and the use of scraping and drilling machines to clean, polish, and maintain archaeological models before displaying them in the museum exhibition.

The United States Environmental Protection Agency (EPA) states that the suspended particles PM2.5 threshold allowed not to affect human health has been set at 12µg/m^3 for the multiannual average and 35µg/m^3 for daily variations; also, for PM10, the daily standard is 150µg/m^3 [24]. The mean PM2.5 and PM10 concentration values for both museums constantly exceed the acceptable Threshold Limit Value (TLV). Furthermore, the World Health Organization (WHO) specified 25 µg/m^3 as the permissible TLV for a 24-hour PM2.5 exposure [15]. Starting from the opening of the museum's operation hour to the end of the museum's operation hour, the PM2.5 concentration for both case studies continually exceeded the allowable TLV, according to the results consistent with a previous study [25]. Generally, an urban environment in which the concentration of PM is kept up to (10–15)µg/m^3 is regarded as an immaculate environment suited for human health and the integrity of displays [26]. Based on this standard, the air quality in neither of the museums can be deemed suitable. WHO claims several sources of particles linked to natural sources and human activity exist, including infrastructure, manufacturing, landfills, building sites, agricultural areas, and vehicle use [27]. It has been shown that organic vapors produce most of the particle development in many mediums from a source of organic precursor gases. One might conclude that the city of a molecule has to be more volatile the smaller the particles are [28].

Table 1: The mean ± SE of particle matter (PM2.5, PM10), and the Number of particles in the Iraqi National Museum (M1) and the Natural History Museum (M2).

Place	**particle matter 2.5 PM2.5 (µg/m³)**	**particle matter PM10 (µg/m³)**	**Number of particles** per/L
M1	57.23 ± 2.64	85.11 ± 3.93	6633.08 ± 263.30
M2	52.33 ± 0.92	72.82 ± 1.36	6142.80 ± 79.91
p-value	P > 0.05	P < 0.05	P > 0.05

4.2 Total Volatile Organic Compound (TVOC), Formaldehyde (HCHO), Temperature (Temp) and Relative Humidity (RH) in the Iraqi National Museum (M1) and the Natural History Museum (M2)

Based on the results shown in Table 2, the maximum value of TVOC was recorded at 0.93 ± 0.09mg/m³ in the Iraqi National Museum (M1), while the minimum value was 0.80±0.15 mg/m³ in the Natural History Museum (M2). In addition, the maximum value of HCHO in M1 was 0.31±0.05 mg/ m^3, and the minimum value was 0.28±0.07mg/m³ in M2. The minimum value of RH was recorded at 34.47±0.30 % in M1, and the maximum value was 40.39±0.23% in M2. The temperature measurements showed a maximum value of 28.24 ± 0.24 degrees Celsius (°C) in M1, while the minimum value was recorded at 25 ± 0.0 °C in M2. The results showed no significant differences in P value (P>0.05) of TVOC and HCHO between both museums. This may be due to the two museums' use of acids, alcohols, and formaldehyde in cleaning, polishing, and maintaining archaeological models and fogging and preserving insects and animals. Artist resins can be reactive or non-reactive when making art pieces using resin and silicon rubber components in M1. The non-reactive variety is hazardous as, mixed, they emit volatile organic compounds (VOCs) after a chemical reaction and would leach over time. This compromises the environment as well as health [22].

Furthermore, the use of dyes diluted with the solvent material Nitro Cellulose Thinner (NCT) prior to their application in painting artworks contributes to an increase in the levels of Total Volatile Organic Compounds (TVOC) and formaldehyde (HCHO). Nitro

Cellulose Thinner is an industrial solvent containing different organic chemical substances known to constitute chemical pollutants in the environments where they are used. Moreover, the leakage of NCT during storage and transportation might not only cause safety problems but also negatively affect the environment [29]. Paint thinner is considered a household hazardous waste; hence, it should never be thrown into the drain. Moreover, improper disposal of it could contaminate the nearby surroundings [24, 30].

For M2, they use citric acid in tanning the skins of large animals, using formaldehyde, pesticides (Sevin, Ragon, Pif paf) in the restoration and the conservation of insects, and the use of some materials in the embalming of animals such as Borax salt ($Na_2B_4O_7.10H_2O$) for drying the skin of animals. Wood, plastic, or rubber products can also naturally release TVOC and HCHO or include polyurethane foam, paints, synthetic adhesives, and oils [31]. Higher interior temperatures cause more diffusion and evaporation of VOC from the surface to raise the VOC emission [32]. Although people mostly experience the negative effects of TVOC and HCHO, the displays are also vulnerable to damage because of too high concentrations of these chemical substances [33]. Due to the notable influence of external factors [34], TVOC concentration tends to increase closer to windows where temperature and humidity levels are typically elevated compared to other areas of the room. The World Health Organization (WHO) states in its Air Quality Guidelines for Europe– Second Edition that the permissible TVOC concentration level is less than 1 mg/m^3 [35]. Consequently, both museums fall below the reasonable limits for TVOC. Indoor VOC concentrations are usually 5–10 times greater than outside levels [36]. Regarding formaldehyde concentration (HCHO), both museums have exceeded the recommended minimum risk of inhalation for human health of 0.004 mg/m^3 set by the Agency for Toxic Substances and Disease Registry (ATSDR), quoted by the United States Environmental Protection Agency (EPA) [37]. Furthermore, the WHO advised short-term exposure as a safe limit for HCHO of 0.1 mg/m^3 [35]. Therefore, exposure to those high levels at a rate of 5-8 hours a day, i.e. (35-56) hours a week, is enough to harm employees and exhibits. Moreover, formaldehyde levels were linked with building age; this trend was not seen for VOC concentrations [38]. Type of ventilation system and flat positioning connected with formaldehyde concentrations [39].

Concerning the temperature (°C) and RH, M1 recorded the highest significant differences at P value ($P<0.05$) compared to M2. Unlike temperature, M1 recorded the lowest significant differences at Pvalue ($P<0.05$) in RH compared to M2. This is possibly a return to the fact that M1 has more oversized windows overlooking the museum's outdoor courtyards, so the heat and sunlight enter them more than M2, whereas the last one has minor or no windows. In addition, the use of resin and Nitro Cellulose Thinner also causes an elevation in temperature when used to manufacture art pieces because of the emission of fumes due to their organic components.

Given that humidity and temperature are inversely correlated, a rise in temperature will cause relative humidity to drop. The air will so grow drier and vice versa. Consequently, in M1, the humidity is lower. The daily variance cannot be more than two °C and the temperature should be kept at an average value of 20 °C (±1–2 °C) according to ASHRAE criteria [40, 41]. Regarding the RH, values between 45% and 60% are also approved, even if the ideal is set at an average value of 50% (±3%).
The average temperature in M1 and M2 was 28.24 °C, 25°C respectively, 8.24 °C, 5°C above the situation regarded optimal. Unlike temperature, the average values of RH are below the suitable conditions for the two studied museums. The average temperature

during the investigated period mostly conforms to the set criteria, so the current findings were not unlike those of a previous study. Unlike temperature, the average values of RH surpass the suitable condition set for every examined hall [33].

Table 2: The mean ± SE of Total Volatile Organic Compound (TVOC), Formaldehyde (HCHO), Relative Humidity (RH), and Temperature (Temp) in (°F, °C) in the Iraqi National Museum (M1) and the Natural History Museum (M2).

Place	Total Volatile Organic Compound TVOC (mg/m3)	Formaldehyde HCHO (mg/m^3)	Relative Humidity RH(%)	Temperature Temp Celsius (°C)
M1	0.93 ± 0.09	0.31 ± 0.05	34.47 ± 0.30	28.24 ± 0.24
M2	0.80 ± 0.15	0.28 ± 0.07	40.39 ± 0.23	25.0 ± 0.0
P value	P > 0.05	P > 0.05	P < 0.05	P < 0.05

4.3 Air Quality Index (AQI) in the two museums

According to the result mentioned in Table 3, the mean of AQI in the Iraqi National Museum (M1) was recorded as 131.59± 3.04, and in the Natural History Museum (M2) was 137.77 ± 1.19. There are no significant differences in AQI's P value ($p<0.05$). That means both museums have an increasing level of PM2.5. Introduced by the EPA in the USA, the Air Quality Index is a tool meant to gauge air pollution levels [42]. Reporting daily air quality, the Air Quality Index shows that air pollution increases with the increase in air quality, raising health issue concerns [42, 43]. Since PM2.5 is readily available and regarded as the most harmful air pollution influencing human health, the Air Visual Series tracks AQI using PM2.5 data to determine AQI levels [44-46]. The United States Environmental Protection Agency (EPA) asserts that any test result exceeding 9.0µg/m3 (USA AQI 50) can pose a threat to human health. The AQI converts concentrations for fine particles to a number on a scale from (0-500). Good is the classification for an AQI value between 0 and 50, moderate for a value between 51 and 100, unhealthy for sensitive groups for a value between 101 and 150, unhealthy for a value between 151 and 200, very unhealthy for a value between 201 and 300, and hazardous for a value between 301 and 500. As a result, the two museums are classified as unhealthy for sensitive groups by the Environmental Protection Agency.

Table 3: The mean ± SE of the Air Quality Index (AQI) in the Iraqi National Museum (M1) and the Natural History Museum (M2).

Place	Air Quality Index AQI
M1	131.59 ± 3.04
M2	137.77 ± 1.19
Probability	P > 0.05

Conclusions

This paper evaluates the indoor air quality within two museums located in Baghdad. The concentration of PM2.5, PM10, and number of particles, TVOC, HCHO, and AQI were measured in these museums. The average concertation of TVOC for M1 and M2 was within the limits recommended by WHO and EPA. In contrast, the average values of the rest of the indoor pollutant concentrations exceeded the recommended limit. AQI was unhealthy for sensitive groups, consistent with EPA. The average values of indoor air temperature for M1 and M2 are higher than the range recommended by ASHRAE standards. In contrast, Indoor RH is below the recommended range.

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