



Towards healthier dining environments: evaluating indoor air quality in Dubai restaurants

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Abstract

This study investigates the indoor air quality (IAQ) of restaurants in Dubai with a focus on the impact of cooking-related pollutants on the health and comfort of both employees and patrons. Recognizing the release of particulate matter (PM), carbon oxides, and volatile organic compounds (VOCs) during cooking, the study highlights the importance of maintaining healthy IAQ in restaurants. The study includes a detailed case analysis, evaluating current air quality standards, identifying potential pollutants, and assessing their implications. A preliminary assessment, combined with a quantitative inspection of the kitchen and dining areas, set the foundation for a survey conducted among staff and customers. This survey identified key areas of concern and the variables essential for monitoring to maintain IAQ at optimal levels. The study measured parameters such as PM_{2.5}, PM₁₀, temperature, humidity, interior lighting, CO, and total VOCs using appropriate instruments. Results indicated that cooking activities contribute to elevated levels of particulate matter, suggesting a need for enhanced ventilation or air purification systems to ensure a healthy working environment. While some employees reported discomfort during working hours, customer feedback was largely positive, with around 90% expressing satisfaction with the restaurant's IAQ. The findings underscore the importance of continuous monitoring and improvement of IAQ in the hospitality industry to safeguard the well-being of both staff and patrons.

Keywords: Indoor air quality, health and comfort, restaurants, quantitative inspection, Dubai

1. Introduction

Indoor air quality (IAQ) is a significant aspect of public health, especially in places like restaurants where people spend a lot of time. Dubai, a prominent emirate in the United Arab Emirates (UAE), with its distinct environment and fast urbanization, provides unique issues for IAQ in its eating places. Investigating of IAQ in Dubai restaurants has implications not only for consumers' health but also for the well-being of restaurant employees. Poor IAQ has been linked to a variety of health conditions, including respiratory and cardiovascular disorders that are common in the area^[1-3]. The indoor environment of restaurants is often harmed by a variety of factors, including cooking procedures, ventilation systems, and the presence of indoor contaminants. Cooking activities, especially those using gas stoves, may dramatically increase indoor particulate matter (PM₁₀ and PM_{2.5}) and carbon monoxide (CO) levels^[4,5]. Insufficient ventilation exacerbates these problems, resulting in the buildup of dangerous pollutants that may injure both staff and consumers^[6,7]. Furthermore, although open kitchen restaurants are popular for their visual appeal, the closeness of cooking operations to eating areas might result in higher exposure to airborne pollutant^[5,8]. The ramifications of IAQ are particularly obvious in the Dubai, where the environment mandates considerable indoor life owing to severe outside temperatures. According to research, inhabitants spend between 80% and 95% of their time inside, making indoor air quality a major public health risk^[9]. The high incidence of asthma and other respiratory disorders among Emirati children has been connected to indoor air pollutants, emphasizing the critical need for comprehensive IAQ monitoring and control in public areas, especially restaurants^[1,2,10]. The health hazards connected with inadequate IAQ in restaurants are exacerbated by the Dubai's societal dynamics, where eating out is a popular social activity. Effective control systems and ventilation methods are required to reduce these dangers and provide a safe eating environment^[6,7]. The fundamental aim of the study is to investigate the complicated problem of IAQ in Dubai restaurants, taking into account physiological and environmental factors. Given the region's unique climate and high indoor occupancy rates, the research aims to better understand the major elements influencing IAQ in these situations. The study's goal is to improve the health and safety of restaurant consumers and employees by concentrating on better monitoring, improving ventilation, and boosting public awareness.



2. IAQ in Restaurants

2.1 Factors Affecting IAQ

One of the most important aspects influencing IAQ is the rate of ventilation in an environment. Adequate ventilation is critical for reducing indoor pollutants and providing a steady supply of fresh air^[6]. Liu *et al.*^[14] underline the importance of proper airflow arrangement and high-quality fresh air in dramatically lowering indoor pollution concentrations. The modern design concept of minimizing energy use is resulting in tighter, more insulated interior spaces with central ventilation systems^[12-14]. Such surroundings will have a major impact on indoor air quality owing to any ventilation system faults, occupant activities and functions, and the architectural environment of the space. Pollutants distributed in the surrounding air have an influence on interior air quality^[15]. The US Environmental Protection Agency (EPA) identifies sources (internal and external), HVAC design, pollutant routes, and occupants as the primary factors contributing to the development of IAQ concerns. Some of the causes include malfunctioning equipment, building components or furnishings, housekeeping and maintenance operations, tenant activities, polluted outside air, soil gases such as radon, fuel leaks, pesticides, and moisture^[12-14]. The HVAC system is the principal conduit or channel for air movement in buildings, and the distribution of pollutants is impacted by how the air interacts with the building’s components, furniture, and occupants. Individual variations in sensitivity might cause one person to be negatively impacted by an IAQ problem, whereas different persons may respond differently to a same indoor air pollutant or issue^[16]. Table 1 summarizes the classification and health impacts of numerous contaminants in the indoor environment. Climate change is widely recognized as a critical factor influencing IAQ, with consequences for human health and environmental sustainability^[18]. Climate change and IAQ have a complicated connection, with many factors influencing indoor air quality. One of the main effects of climate change on indoor air quality is the transfer of pollutants from the outside to inside surroundings. As outside air quality deteriorates owing to rising temperatures and pollution levels, penetration of harmful contaminants inside buildings becomes an urgent problem^[7,19,20]. Increased indoor air temperature may exacerbate pollution emissions from building materials, chemical processes, and gas-fine particle partitioning. Climate change is causing an increase in heating and cooling demand, necessitating changes in insulating materials, heat protection, and the reduction of open windows and fans^[7]. The variables impacting IAQ in response to climate change can be classified into three major categories: pollutant transmission, emissions from indoor materials, and the partitioning of pollutants between gas and adsorbed phases^[19].

Table 1. Indoor air contaminants, sources and related health impacts^[20].

Contaminants	Sources	Health Impacts
Endotoxins	Contaminated humidifiers, stored food wastes, lower ventilation rates	Asthma, reduced lung function
Wetness and mold	Water system leak, food waste	Asthma, upper respiratory illness
Carbon dioxide, Nitrous Oxide particulates, various hydrocarbons	Combustion of solid fuels	Pulmonary cancer, pulmonary diseases
Carbon monoxide	Outdoor air, bio fuels, cigarettes	Headache, nausea, fatigue
Nitrogen Dioxide	Combustion of fossil fuels	Respiratory illness
Formaldehydes (-HCHO)	Internal finishes, cigarette smoke	eye, nose, throat irritation, asthma, bronchitis, and possible carcinogen
VOCs	Cigar smoke, room deodorizers, paints, carpets	Asthma, bronchial hyper-reactivity
Ultra fine particles	Frying and combustion activities	Heart and lung disease

VOCs: volatile organic compounds.

2.2 Standards of IAQ

IAQ guidelines are fundamental to protecting public health and providing a pleasant indoor environment. These criteria are based on scientific research and are intended to restrict exposure to dangerous contaminants, resulting in improved health outcomes for occupants in a variety of contexts, including residential, business, and public areas. Several organizations, including WHO, USEPA, and ASHRAE, have developed standards and threshold values for several IAQ metrics, recognizing IAQ as some multidisciplinary phenomena^[20]. Table 2 and Table 3 list some of the standards recognized by various bodies, as well as the requirements necessary to satisfy Dubai’s green construction laws. Ensuring and improving indoor air quality requires a comprehensive strategy that integrates technology with a variety of critical tactics. Even though there is no single, agreed-upon definition of “good” IAQ, ASHRAE and the USEPA recommend three widely accepted methods for improving IAQ in buildings: managing contaminants at the source, improved ventilation or dilution strategy, and the use of air purifiers^[21,22].

Table 2. Standards for Indoor Air Quality^[17,21,22].

Parameter	WHO	US EPA	ASHRAE	Dubai GBRS
Carbon monoxide	8.6 ppm	9 ppm	6 ppm	9 ppm
Formaldehyde	0.2 mg/m ³	920 µgms/m ³		< 0.08 ppm
Total VOC	200 µgms/m ³	< 200 µgms/m ³	100 µgms/m ³	< 300 µgms/m ³
PM ₁₀	150 µgms/m ³	150 µgms/m ³	150 µgms/m ³	150 µgms/m ³
PM _{2.5}	25 µgms/m ³	35 µgms/m ³	35 µgms/m ³	
Relative humidity	30%-60%	30%-50%	30%-60%	30%-60%

WHO: World Health Organization; US EPA: U.S. Environmental Protection Agency; ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers; Dubai GBRS: Dubai Green Building System; PM: particulate matter; VOC: volatile organic compounds.

Table 3. Standards for indoor air quality with respect to time of exposure as per Dubai Municipality^[23].

Pollutant & Contaminant parameter	Long term exposure		Short term exposure	
	Maximum Value	Average Time	Maximum value	Average Time
Carbon monoxide	9 ppm	8 hours	25 ppm	1 hour
Formaldehyde	0.01 ppm	8 hours	0.08 ppm	30 mins
Total VOC	0.6 mg/m ³	8 hours	3 ppm	30 mins
PM ₁₀	150 µg/m ³	24 hours	100 µg/m ³	1 hour
PM _{2.5}	35 µg/m ³	24 hours	100 µg/m ³	1hour

PM: particulate matter; VOC: volatile organic compounds.

While the WHO global air quality guidelines recommend annual average AQG values of PM_{2.5}, PM₁₀ and carbon monoxide are at 5 µg/m³, 15 µg/m³ and 4mg/m³ respectively to avoid any kind of adverse health impacts to public due to longer exposure^[24].

The findings of this study’s initial investigation will be carefully compared to worldwide IAQ standards as well as the Dubai Green Building Regulations and Specifications. The study’s goal is to examine current IAQ levels in Dubai restaurants by comparing measured IAQ parameters such as particulate matter (PM_{2.5}, PM₁₀), CO, and VOCs to established worldwide norms. Furthermore, the comparison with Dubai GBRS will provide light on how effectively local enterprises adhere to regional sustainability and health requirements, emphasizing areas that may need additional development to safeguard the health and safety of consumers as well as staff members.

2.3 IAQ in Dubai Restaurants

IAQ in Dubai restaurants, considering the region’s unique climate and cultural practices, presents distinct challenges and implications. This study synthesizes existing literature to examine the current state of IAQ in Dubai restaurants, the factors that influence it, and the associated health impacts on both employees and customers. In the Dubai, the primary causes of indoor air pollution in restaurants include culinary operations, insufficient ventilation, and the presence of dangerous chemicals such as VOCs and particle matter. Cooking techniques, especially those that use gas stoves or open flames, are significant contributors to high levels of CO, PM₁₀, and PM_{2.5}. According to research, culinary operations, particularly in open-kitchen restaurants, might result in greater concentrations of these pollutants owing to poor ventilation systems^[4]. Similarly, methods of cooking such as barbecue may increase indoor environmental factors, especially when ventilation is insufficient^[25]. This is particularly relevant in the Dubai, where many eateries use traditional cooking techniques that may not meet current ventilation regulations. In addition to cooking, the design and layout of restaurants can have a significant impact on IAQ. A study on open-kitchen restaurants found that the functional zones within these spaces can result in varying air quality levels, with areas near cooking stations frequently exhibiting higher concentrations of harmful pollutants^[5]. This finding underscores the significance of strategic restaurant design in reducing the buildup of indoor air pollution. Furthermore, the existence of smoking areas in certain places might worsen IAQ difficulties since secondhand smoke adds new dangerous compounds into the atmosphere. According to Jones *et al.*^[26], indoor nicotine and fine particulate matter levels are much greater in venues that allow smoking, providing health concerns to both personnel and consumers. Poor indoor air quality in restaurants has far-reaching consequences, including major health hazards. Indoor air pollution has been linked in studies to respiratory problems, cardiovascular illness, and other health consequences. According to Barakat-Haddad *et al.*^[1], the UAE has a high incidence of asthma and respiratory disorders, which may be aggravated by poor indoor

air quality. This is especially alarming considering that UAE citizens spend a significant amount of time inside, sometimes in settings such as restaurants where air quality may be affected^[9]. The necessity for effective air quality management systems is evident, as noted by Funk *et al.*^[2], who stressed the need of monitoring and managing indoor air pollutants in order to preserve public health. Furthermore, the COVID-19 pandemic has refocused attention on IAQ, since airborne viral transmission has highlighted the need for enhanced ventilation and air quality monitoring in public places, including restaurants. Many studies stressed the importance of indoor air quality in preventing the transmission of infectious illnesses, and advocated for the use of sophisticated monitoring technology in restaurant settings^[27]. In terms of legislative frameworks, the Dubai urgently needs to create and implement rigorous indoor air quality regulations for eateries. Current recommendations may fail to appropriately address the specific constraints given by the local environment and cultural behaviors. underlined the need for awareness programs to educate restaurant owners and employees about the health concerns associated with indoor air pollution and the significance of effective ventilation^[7]. Furthermore, integrating technology, such as IoT-based monitoring systems, might provide real-time tracking of air quality data, allowing for rapid interventions to enhance IAQ^[27]. Poor indoor air quality in restaurants has significant economic repercussions. Establishments with poor air quality may face lower patronage owing to health concerns, reducing their profitability^[6]. Keeping healthy IAQ is necessary for establishing a welcoming dining atmosphere that attracts guests while also protecting the health of restaurant employees^[6]. As a result, investment in air quality improvements should be considered as both a health priority and a smart commercial choice. The study of indoor air quality in Dubai restaurants indicates a complex interaction of elements that contribute to the overall health and safety of these establishments. Prioritizing IAQ allows restaurant owners to improve the dining experience, safeguard public health, and contribute to the general well-being of the community.

3. Methodology

The methodology for this study follows a case study approach, focusing on a restaurant in Dubai selected through purposive sampling. Data collection involved monitoring key air quality parameters such as temperature, relative humidity, CO, PM_{2.5}, PM₁₀, TVOCs, and aldehydes, using air quality sensors strategically placed in dining areas, kitchens, and near ventilation systems. A preliminary inspection and quantitative walk-through were conducted with management approval, assessing the restaurant’s layout, finishes, evidence of dampness or mold, ventilation systems, HVAC layout, open kitchen activities, and exhaust systems. Continuous measurements were taken over a week to capture air quality variations during peak and off-peak hours. Details of indoor air quality lab equipment used for the research are given in [Table 4](#).

Table 4. Details of sensors used for the study.

No	Name	Make & Model No	Specification
1	FP-30 HCHO Detector	RIKEN KEIKI; FP-30	Accuracy- ± 10% of reading or ± 5% of full scale (whichever is greater)
2	Data Logging Heavy Duty Light meter	EXTECH; HD 450	Accuracy- ± (5% rdg + 10 digits)
3	Mini Thermo-Anemometer 45158	EXTECH; 45158	Temperature Accuracy- ± 1 °C Relative Humidity Accuracy- ± 5% of RH
4	Indoor Air Quality Probe	Graywolf	TVOC- Accuracy -1ppbParticulate matter- 0.3 µgms

TVOC: total volatile organic compounds.

Observational data, such as customer occupancy, cooking activities, and ventilation types, were recorded, and interviews with managers were conducted to gather insights into air quality management practices. A diagnostic survey among staff was also conducted to assess whether prolonged exposure to the indoor environment affected the health of kitchen and housekeeping staff. Additionally, a 5-point Likert scale survey was administered to diners to evaluate their comfort levels in the dining area. The Likert survey and quantitative air quality measurements were analyzed to assess the overall indoor environment quality. The results were compared with international (WHO, ASHRAE) and Dubai air quality standards. Descriptive and inferential statistics were used to interpret the data. Ethical considerations included informed consent and confidentiality, and recommendations for improving the restaurant’s indoor environment were provided to align air quality with standard guidelines.

4. Case Study

This case study focuses on a modern East-Asian fine dining restaurant situated within a 5-star hotel in Downtown Dubai, UAE ([Figure 1](#)). The restaurant offers a sleek and sophisticated environment, reflecting contemporary Asian design and culinary practices. With a seating capacity of over 200 guests, it caters to a diverse clientele, offering separate dining areas for business lunches, family meals, and a bar lounge, each tailored to enhance the dining experience. The restaurant features a unique dual-kitchen setup: an open kitchen, where non-cooking dishes are prepared in full view of diners, adding an interactive element to the ambiance, and a closed, fully functional kitchen that handles the preparation of the elaborate Pan-Asian menu. This setup allows for efficient service

while maintaining a high level of cleanliness and organization. As shown in Figure 2 and Figure 3, the restaurant, known for its vibrant and upscale environment attracts a wide variety of guests, from hotel visitors to locals seeking premium dining experiences. The combination of elegant interiors, a well-designed layout, and an extensive menu showcasing Asian culinary art makes this restaurant an ideal candidate for assessing indoor air quality in a high-traffic, high-end dining environment. The case study not only aims to evaluate the restaurant's air quality but also provides insights into how various dining areas, kitchen designs, and customer activity may influence the overall indoor environment. Figure 4 illustrates the sampling locations selected for the IAQ parameter measurements.

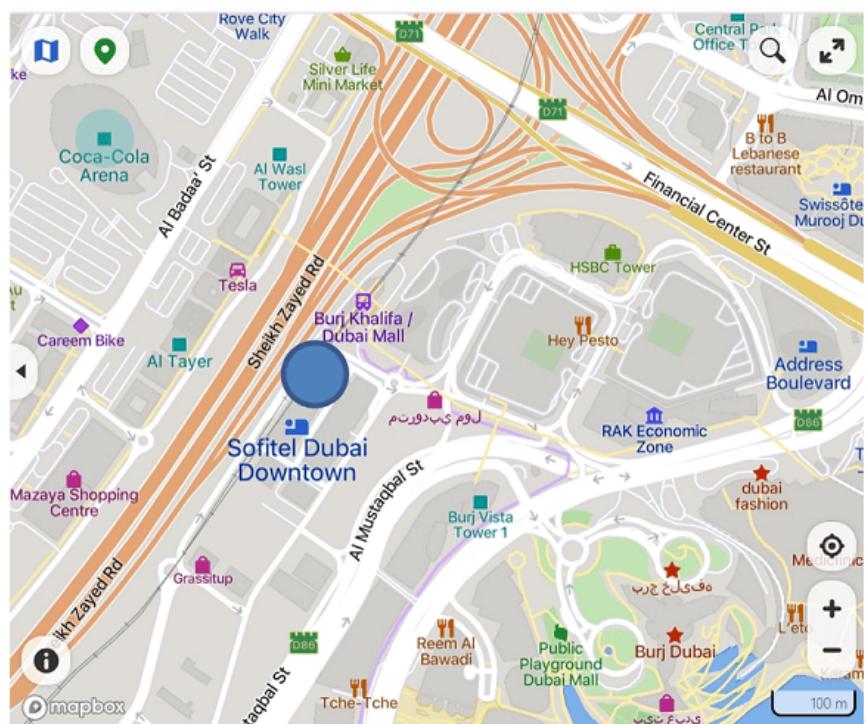


Figure 1. Location of the restaurant (Lat 25.20052, Long.55.26904). Source: (Map carta, 2024).



Figure 2. Interior shot for the dining area in the restaurant.



Figure 3. Interior shot for the entrance and bar lounge area of the restaurant.

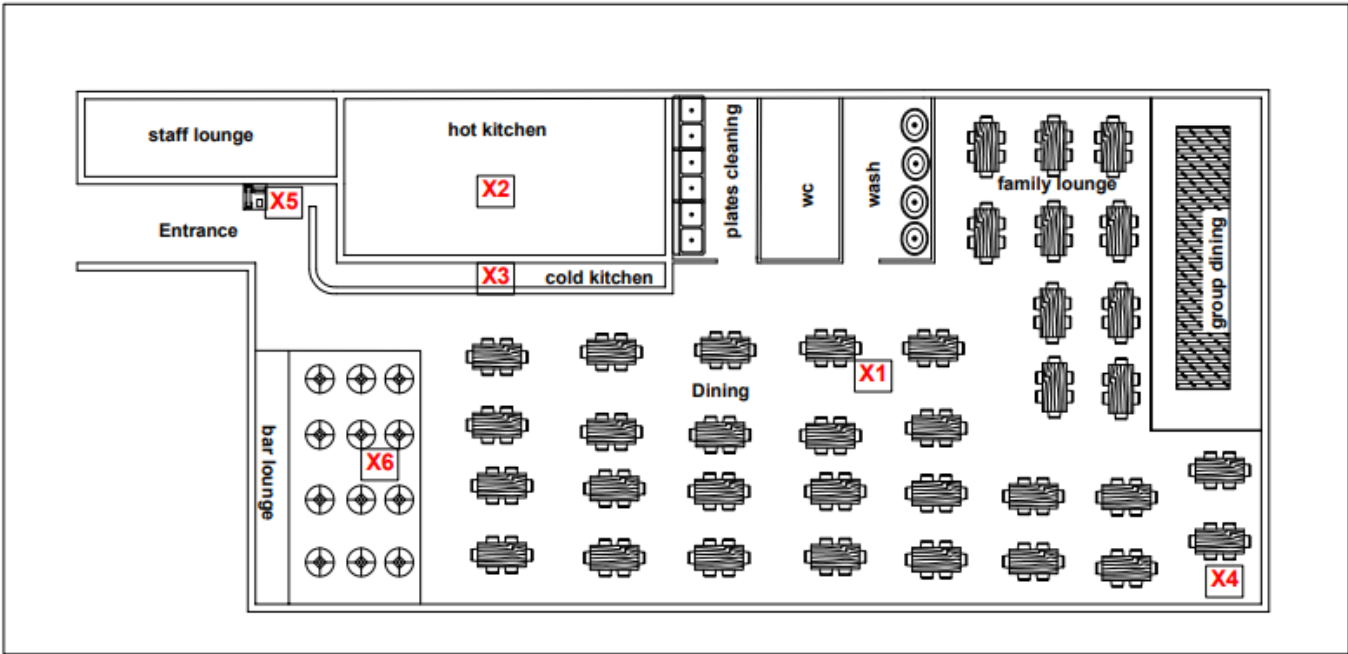


Figure 4. Layout of the restaurant (X refereeing to the position of the sensors).

5. Results and Discussion

A preliminary investigation and quantitative walk-through inspection were conducted at the restaurant with management’s permission during the last week of January 2024. Observations were made on various aspects, including the general layout, finishes, floor and walls for any signs of dampness or mold, natural ventilation systems, HVAC layout, open kitchen activities, and the kitchen’s equipment and exhaust system. Following this, a diagnostic survey was carried out among the staff to determine whether prolonged exposure to the restaurant’s indoor environment was causing them any discomfort.

Regarding environmental quality, the survey results, illustrated in Figure 5, revealed that the primary concern among the staff was insufficient lighting (62.5%), followed by poor air circulation (31.3%), together accounting for approximately 93.8% of the responses on

environmental quality. Furthermore, the survey results shown in Figure 6 indicate that the most common health-related concern among the staff was eye and nose irritation (43.8%), while breathing difficulties (37.5%) and other unspecified difficulties (37.5%) were the second most prevalent health impact symptoms.

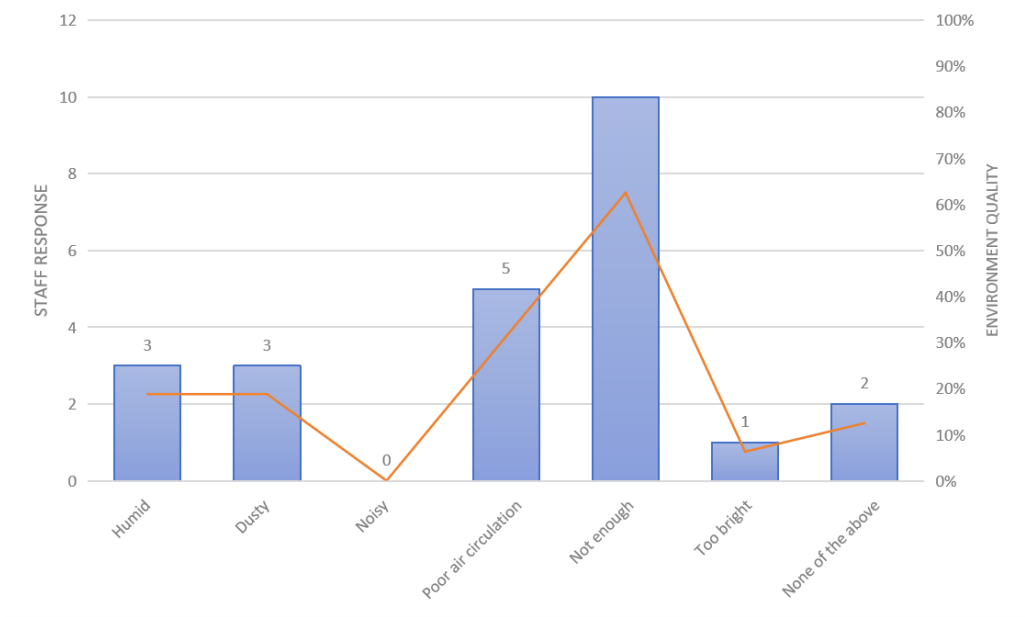


Figure 5. Responses on environment quality.

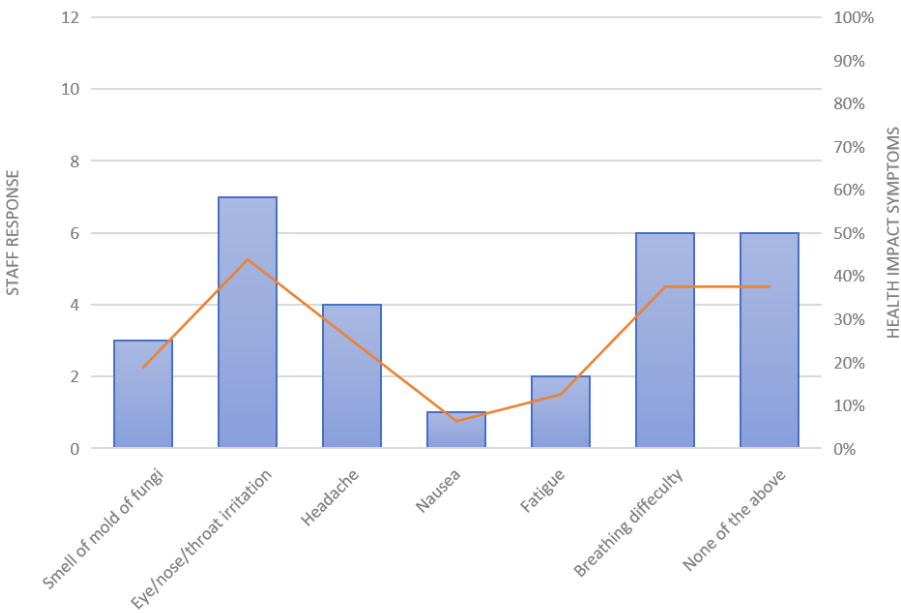


Figure 6. Responses on health impact symptoms.

Based on insights from the diagnostic survey, indoor environmental parameters such as interior lighting, temperature, relative humidity, CO, PM_{2.5}, PM₁₀, TVOC, and aldehydes were measured using instruments including FP-30 HCHO detector, HD450 light meter, Thermo-Anemometer 45158, and GrayWolf indoor air quality probe. The sampling locations were strategically selected to obtain representative samples from all IAQ hotspots within the restaurant. These locations, labeled as X1 to X6, are marked in Figure 4. Observations were recorded during off-peak hours (1:00 PM to 3:00 PM) on a weekday (T1) and peak hours (8:00 PM to 10:00 PM) on a weekend (T2). The summarized results are presented in Table 5 and Table 6 below.

The Air Quality Index (AQI) was used as a reference to assess the indoor environment. The AQI is a standard measure for daily reporting of air quality, reflecting the short-term health effects of air pollution. To protect public health, national air quality standards

have been established for five major air pollutants, for which the EPA calculates the AQI: ground-level ozone, particulate matter concentrations (PM_{2.5} and PM₁₀), carbon monoxide, sulfur dioxide, and nitrogen dioxide^[28].

Table 5. IAQ parameter measurements during off-peak hours (T1).

Parameters	Observed values at different locations in the restaurant during T1							Dubai GBC Threshold
	Unit	X1	X2	X3	X4	X5	X6	
Temperature	C	24	26	24	24	24	24	≤ 25
Relative Humidity	%	60	65	60	60	60	60	30-60
Light	lux	92	450	165	260	163	260	≥ 220-Rest ≥ 550-Kitchen
Formaldehyde	ppm	0.01	0.008	0.01	0.005	0.003	0.0065	≤ 0.08
PM _{2.5}	µg/m ³	30	47	28	29	22	22	≤ 35
PM ₁₀	µg/m ³	47	174	43	43	34	32	≤ 150
CO	ppm	1	1	1	1	2	2	≤ 9
TVOC	mg/m ³	0.022	0.016	0.022	0.012	0.012	0.012	≤ 0.3

IAQ: indoor air quality; PM: particulate matter; CO: carbon monoxide; TVOC: total volatile organic compounds; GBC: Green Building System.

Table 6. IAQ parameter measurements during peak hours (T2).

Parameters	Observed values at different locations in the restaurant during T2							Dubai GBC Threshold
	Unit	X1	X2	X3	X4	X5	X6	
Temperature	C	24	26	24	24	24	24	≤ 25
Relative Humidity	%	50	65	50	50	50	50	30-60
Light	lux	92	450	158	128	160	159	≥ 220 -Rest ≥ 550-Kitchen
Formaldehyde	ppm	0.007	0.008	0.007	0.007	0.006	0.007	≤ 0.08
PM _{2.5}	µg/m ³	26	123	35.5	22	40	23	≤ 35
PM ₁₀	µg/m ³	36	187	47	38	65	49	≤ 150
CO	ppm	2	2	2	2	2	2	≤ 9
TVOC	mg/m ³	0.015	0.016	0.017	0.015	0.014	0.024	≤ 0.3

IAQ: indoor air quality; PM: particulate matter; CO: carbon monoxide; TVOC: total volatile organic compounds; GBC: Green Building System.

The measurement results during the two time periods, T1 and T2, indicate that the kitchen area is experiencing high relative humidity and elevated levels of PM_{2.5} and PM₁₀, which exceed the Dubai GBC thresholds. This is expected due to the nature of cooking activities, which are the primary source of moisture in the kitchen. Boiling, steaming, frying, and other cooking methods release significant amounts of water vapor, increasing the relative humidity. Additionally, inadequate ventilation may contribute to the inability to effectively remove excess moisture, further raising humidity levels. The use of gas stoves in the kitchen can also release PM_{2.5} and PM₁₀, adding to the particulate matter in the air, which may impact other areas of the kitchen, such as the serving area (Cold kitchen), and entrance area. It is also noticeable that the concentrations of particulate matter in the hot kitchen increase by more than 150% during peak time activities. Although the concentrations of other parameters fluctuate, they remain within the threshold limits. Furthermore, the lighting levels in both the dining and kitchen areas are below the Dubai GBC thresholds. This could be intentional, possibly due to interior design choices aimed at creating a specific atmosphere or aesthetic. The calculated AQI values and corresponding color categorization for each sampling location are presented in Table 7. The chart indicates that the restaurant overall has moderate indoor air quality. However, the cold kitchen and the reception area, which is located nearby, fall into the orange category, while the hot kitchen is classified as unhealthy according to the indoor air measurements observed during this study. The primary factor contributing to these classifications is the elevated concentrations of PM_{2.5}.

Table 7. AQI values for the sampling locations inside the restaurant.

Sampling Station	Sampling Location	AQI calculated		AQI Colour	
		T1	T2	T1	T2
X1	Restaurant Area	89	80	Moderate	Moderate
X2	Hot Kitchen	129	186	Unhealthy /sensitive groups	Unhealthy
X3	Cold Kitchen	84	101	Moderate	Unhealthy /sensitive groups
X4	Under AC duct	87	72	Moderate	Moderate
X5	At Reception Desk	72	112	Moderate	Unhealthy /sensitive groups
X6	At Bar Lounge	72	74	Moderate	Moderate

AQI: air quality index.

In addition to measuring IAQ parameters during the first and second quantitative assessments, a customer survey was conducted, and the responses were analyzed. The survey targeted a sample size of 66, representing 33% of the restaurant’s full capacity. An Indoor Air Quality questionnaire was created using a Likert scale, and a QR code for the survey was distributed to customers to gather their feedback on the restaurant’s indoor environment. A 5-point Likert scale analysis was used to interpret customer responses, revealing that customers were generally satisfied with the indoor environment of the restaurant. The findings from the Likert scale questions were analyzed using the mean, standard deviation, and weighted average, as described in Eq. (1). The results are presented in Table 8 show that the standard deviation ranged from 0.77 to 1.52^[29] indicating moderate variation in customer opinions. The reliability analysis conducted using Jamovi yielded a Cronbach’s α value exceeding 0.7, confirming the reliability of the survey. The descriptive statistics of the 66 responses received from diners shows mean values ranging from 3.24 to 4.29, with 90% of the responses close to 4, indicating general satisfaction with the restaurant’s indoor environment opinions^[30].

Table 8. AQI values for the sampling locations inside the restaurant.

Survey question	Rank/Range	Scale	Mean	SD
Have you ever encountered any discomfort due to the IAQ while dining at the restaurant such as coughing or irritation	Disagree (2)	1.80-2.60	2.40	1.52
Do you think the quality id indoor air can influence your overall enjoyment of dining here	Agree (4)	3.41-4.20	4.20	0.82
Should restaurants prioritize the maintenance of high IAQ	Strongly Agree (5)	4.21-5.00	4.29	0.81
Do you think the restaurant should regularly inspect or test to ensure optimal IAQ	Strongly Agree (5)	4.21-5.00	1.63	0.83
The air inside the restaurant feels fresh and clean	Strongly Agree (5)	4.21-5.00	4.37	0.80
I detect disagreeable smells with the restaurant	Disagree (2)	1.80-2.60	2.09	1.23
The temperature inside the restaurant is comfortable	Agree (4)	3.41-4.20	4.09	1.02
I feel that the humidity level inside the restaurant is appropriate	Agree (4)	3.41-4.20	3.97	0.91
The restaurant has adequate ventilation to keep the air fresh	Agree (4)	3.41-4.20	4.09	0.77
I notice visible dust or particles suspended in the air inside the restaurant	Disagree (2)	1.80-2.60	2.03	1.00
I think the restaurant lighting is sufficient for good dining experience	Agree (4)	3.41-4.20	3.71	1.34
Overall, I am satisfied with the IAQ of the restaurant	Strongly Agree (5)	4.21-5.00	4.26	0.77

AQI: air quality index; IAQ: indoor air quality.

$$W = \frac{\sum_{i=1}^n \omega_i X_i}{\sum_{i=1}^n \omega_i} \quad (1)$$

Where: W = weighted average, n = number of terms to be averaged, ω_i = weights applied to x values, X_i = data values to be averaged.

Although employees reported some discomfort during working hours, most customers responded positively, with around 90% expressing satisfaction with the restaurant's indoor air quality. This difference in perception may be due to the shorter duration of customers' exposure to the restaurant environment compared to employees. Observations and analyses have categorized the overall restaurant environment as moderate, with the area near the cold kitchen deemed unhealthy for sensitive individuals. The primary cause of these categorizations is the presence of particulate matter, an invisible pollutant. Therefore, mitigation measures are necessary. Insufficient ventilation can lead to the accumulation of PM emissions from cooking, allowing them to spread from the kitchen into the dining area. This aligns with findings by Chang *et al.*^[8] who emphasized that high-capacity ventilation systems are crucial in commercial kitchens for the safety of both staff and patrons. Moreover, the threshold values given by Dubai Green Building code and Health and Safety department of Dubai municipality are considering a maximum observation time of 24 hours only. The employees at a workplace are exposed to the environmental conditions continuously on all working days. While considering the health and safety of them, average annual values need to be taken into consideration. The observed values for the particulate matter concentrations are much greater than the recommended global annual average values of 5 $\mu\text{g}/\text{m}^3$ for $\text{PM}_{2.5}$ and 15 $\mu\text{g}/\text{m}^3$ for PM_{10} by the World Health Organization. This further explains the difference in opinion of the employees and customers of the restaurant in the indoor comfort levels and demands the maintenance and monitoring of air quality parameters for the well-being of the employees. Since restaurants in urban areas typically operate in enclosed spaces with regulated ventilation systems, the location is unlikely to impact the research findings. However, it is recommended to implement open-air dining areas and avoid live frying or barbecue counters wherever feasible to further improve air quality. It is recommended to assess ventilation rates and air purifier needs for both kitchen and dining areas before opening to the public. Installing air quality sensors at critical points and raising awareness among staff on continuous monitoring is essential. Authorities should also include indoor air quality monitoring alongside food safety checks to ensure a healthy restaurant environment.

6. Conclusion

This study explored the IAQ of a modern restaurant in Dubai, focusing on the impact of cooking-related pollutants on the health and comfort of both employees and patrons. The study aimed to address the complex issue of IAQ in Dubai restaurants, considering both physiological and environmental factors. Given the region's unique climate and high indoor occupancy rates, the study sought to identify the key elements affecting IAQ in these settings. Despite the restaurant providing a seemingly comfortable dining experience with clean interiors and no visible discomforts, the study found that particulate matter concentrations exceeded threshold limits. This resulted in elevated AQI values, placing the restaurant environment mostly in the moderate air quality category. The open kitchen area and nearby locations were found to be unhealthy for sensitive individuals, particularly during peak hours. Assessing IAQ in restaurants remains challenging, as ambient atmosphere and interior design can influence perceptions. While customers generally reported satisfaction, staff responses aligned with measurements indicating significant IAQ issues, particularly in the kitchen, that warrant further investigation and should be addressed in regulations. Several architectural and mechanical solutions can be implemented to mitigate these problems, such as enhancing ventilation in the hot kitchen, using air purifiers in the dining area, and increasing interior lighting for an improved dining experience and employee well-being. Additionally, incorporating indoor plants as a mitigatory measure and regularly monitoring the effectiveness of ventilation systems and IAQ parameters are recommended to achieve more improvement of IAQ in the hospitality industry to protect the health and well-being of both staff and patrons. The lack of available drawings and specifications for the ventilation systems limited the scope of this study, preventing an examination of the effects of increased ventilation rates and alternative ventilation systems. Moreover, the absence of air quality sensors within the restaurant and restrictions on the duration for which measuring instruments could be used hindered continuous monitoring. These factors represent significant limitations of the study. The findings from the study have the potential to help create effective air quality improvement techniques, ultimately increasing the health and safety of both restaurant consumers and personnel. The study also intends to influence public policy and increase awareness of the relevance of IAQ in eating venues, eventually contributing to the construction of healthier indoor spaces in the emirate of Dubai.

Declarations

Authors contribution

Biju P: Conceptualization, Data collection, field measurements, methodology, analysis and interpretation of results, writing, editing and drafting manuscript.

Sheta W: Conceptualization, methodology, analysis and interpretation of results, editing and drafting manuscript.

Saumer B: Conceptualization, data collection, field measurements.

Conflicts of interest

The authors declare no conflicts of interest.

Ethical approval

According to the relevant research ethics standards, this article does not require approval from an ethics committee because the survey is anonymous and does not involve the collection of personal identities or sensitive information.

Consent to participate

Before participating in the survey, all respondents were informed of the purpose of the study and the use of the questionnaire, and all gave their consent.

Consent for publication

Not applicable.

Availability of data and materials

The data could be obtained from the corresponding author upon request.

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