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Assessment and Strategies of Indoor Air Quality for Sustainable City Malls: A Case Study from City Mall in Ajman, UAE

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Abstract: The indoor air quality (IAQ) plays a critical role in public health, comfort, and productivity, particularly in enclosed public places such as shopping malls. Due to the extreme outdoor temperatures in the United Arab Emirates, prolonged indoor occupancy further emphasizes the importance of maintaining a healthy IAQ. The purpose of this study is to evaluate the current state of indoor air quality in Ajman City Mall and investigate its relationship to occupant health and comfort. A series of environmental monitoring and occupant perception surveys was conducted at five key indoor locations: the main entrance, the food court, the retail store, the cinema lobby, and the parking garage. Real-time data of CO_2, $PM_{2.5}$, volatile organic compounds (VOCs), temperature, and humidity were collected over three weeks. In parallel, 50 mall users were interviewed to obtain subjective opinions on IAQ and related symptoms, including fatigue, headaches, and eye irritation. Measurement results show that CO_2 and VOCs concentrations in the food court and parking garage frequently exceed the recommended UAE limits, which were associated with high incidences of discomfort and respiratory symptoms. $PM_{2.5}$ levels in the parking area were identified as a significant health risk, primarily due to vehicle emissions and inadequate ventilation. A statistical analysis included descriptive analytics, time-series visualizations, and linear regression modelling, confirming a strong correlation between elevated CO_2 levels and symptoms of occupants. These findings indicate that IAQ intervention strategies are urgently required in enclosed public spaces. Improvements proposed include improved Heating, Ventilation, and Air Conditioning (HVAC) performance, upgraded filtration systems, and adoption of low-emission materials. As a result of this study, a replicable methodology for the assessment of IAQ was developed. Results emphasize the importance of aligning indoor environmental quality with national standards in order to maintain public health.

Keywords: Air pollution; Ajman-UAE; Climate change; Sustainable city; Indoor air quality; Sustainable buildings

1 Introduction

In densely populated, enclosed spaces, such as shopping malls, indoor air quality (IAQ) is an important component of environmental health and building sustainability. When people spend a significant time indoors, whether working, shopping, or socializing, air quality becomes a critical factor that influences not only physical health but also cognitive function and emotional well-being [1]. Poor IAQ is associated with respiratory diseases, allergic reactions, chronic fatigue, and more severe long-term illnesses [2]. Furthermore, there is increasing evidence that poor IAQ negatively impacts productivity and cognitive function in both employees and customers, affecting the commercial success of retail environments [3, 4]. IAQ has a direct impact on the comfort, performance, and general health of occupants in commercial buildings, such as shopping malls. According to study [1], common indoor pollutants such as particulate matter ($PM_{2.5}$ and PM_{10}), volatile organic compounds (VOCs), carbon dioxide (CO_2), and formaldehyde (CH_2O) contribute to a wide range of health problems. Similarly, Mendell and Heath [3] found that poor ventilation and elevated pollutant concentrations are strongly associated with decreased worker performance and an increased incidence of sick building syndrome (SBS).

Its enclosed infrastructure, large employee base, and high foot traffic daily make Ajman City Mall a suitable case study due to its location in the rapidly developing emirate of Ajman. A regional hub for retail, dining, and entertainment, the mall illustrates both the challenges and opportunities associated with IAQ management in modern commercial architecture. Due to the harsh climate of the United Arab Emirates (UAE), which limits outdoor activities for the majority of the year, malls serve not only as commercial venues but also as locations for social and recreational activities. This increases the duration of indoor exposure and increases the importance of air quality in terms of public health. In terms of developing standards for indoor air quality, the UAE has made significant progress. Dubai Municipality and the UAE Ministry of Climate Change and Environment have both introduced guidelines to mitigate air pollution in public buildings [5, 6]. While enforcement continues to be inconsistent, empirical studies indicate that many indoor spaces, including malls, still report air quality levels that fall below national and international standards [7, 8].

There is an increased connection between IAQ and public health in recent literature, particularly in the context of asthma aggravation, respiratory disease risk, and reduced cognitive performance associated with pollutants like VOCs and fine particulates [2, 9]. Even CO_2 levels within commonly accepted thresholds can negatively impact decision-making and cognitive performance, suggesting that ventilation has a direct impact on brain activity [4]. Several sources of pollution could be found in Ajman Mall, including cooking emissions in the food court, cleaning products and personal care items sold in retail outlets, and carpets, paints, and furniture that emit VOCs and formaldehyde. Poor air circulation or poorly maintained Heating, Ventilation, and Air Conditioning (HVAC) systems contribute to pollutant build-up, especially in areas with limited natural ventilation, such as the lobby of a cinema or a parking garage. As outlined in the UAE's National Environmental Policy and Vision 2021 [6], there is a need for more research-driven strategies to ensure a healthier indoor environment. This study will provide evidence-based recommendations for policymakers, mall managers, and urban developers in Ajman and beyond to advance the sustainable city agenda through improved indoor environmental quality.

The IAQ plays a critical role in public health, comfort, and productivity, particularly in enclosed public places such as shopping malls. The quality of indoor air is of paramount importance in regions such as the United Arab Emirates (UAE), where climatic conditions require prolonged indoor stays. SBS is associated with poor IAQ. Respiratory ailments, headaches, and fatigue characterize this syndrome [10, 11]. The Ajman Mall is a prominent commercial hub with high occupancy rates and a wide range of activities. It is imperative to assess and ensure optimal indoor air quality to ensure the health and comfort of mall occupants, owing to the mall's enclosed structure and reliance on mechanical ventilation systems.

The objective of this work is to evaluate IAQ in Ajman Mall and its impact on occupant health and comfort. The scope of the work is monitoring and survey activities that were conducted over three weeks in five areas of Ajman Mall, combining environmental data and occupant feedback for IAQ assessment and intervention planning. The following steps were followed.

- Measure CO_2, $PM_{2.5}$, PM_{10}, VOCs, formaldehyde, temperature, and humidity in key mall zones.
- Assess the link between IAQ levels and reported health symptoms.
- Compare pollutant levels with UAE and international standards.
- Propose strategies to improve IAQ in line with sustainable practices.

A combination of environmental monitoring and occupant surveys is used in this study to provide a real-world understanding of IAQ's effects in a busy mall environment. It also assesses how indoor air quality aligns with or diverges from UAE indoor air quality standards and suggests practical solutions. Among these measures are improving HVAC performance, upgrading filtration systems, using low-emission building materials, and raising awareness among stakeholders about IAQ-related risks and solutions. During this study, the current level of indoor air quality at Ajman City Mall was assessed and evaluated to determine how it may impact the health, performance, and productivity of its occupants. As a result of this study, valuable insights were gained into the challenges associated with indoor air quality in high-density commercial settings in the UAE. This research provided facility management and policymakers with information regarding pollutant hotspots and their health implications. Furthermore, the study contributes to the broader discussion on sustainable building practices by emphasizing the integration of IAQ considerations into commercial space design and operation.

2 Methodology

2.1 Study Location

The study was conducted in Ajman Mall, one of the largest and busiest commercial buildings in the Emirate of Ajman, UAE. The mall's geographical location is shown in Figure 1.

Multiple functional zones are present in the mall, including retail outlets, dining areas, entertainment areas, and an underground parking garage with multiple levels. As a result of its high occupancy rates, mechanical ventilation systems, and closed indoor environment, the site is well-suited to evaluate IAQ under different indoor conditions [5]. Based on traffic intensity, activity type, and ventilation conditions, five distinct monitoring locations in the mall were selected, as listed in Table 1.

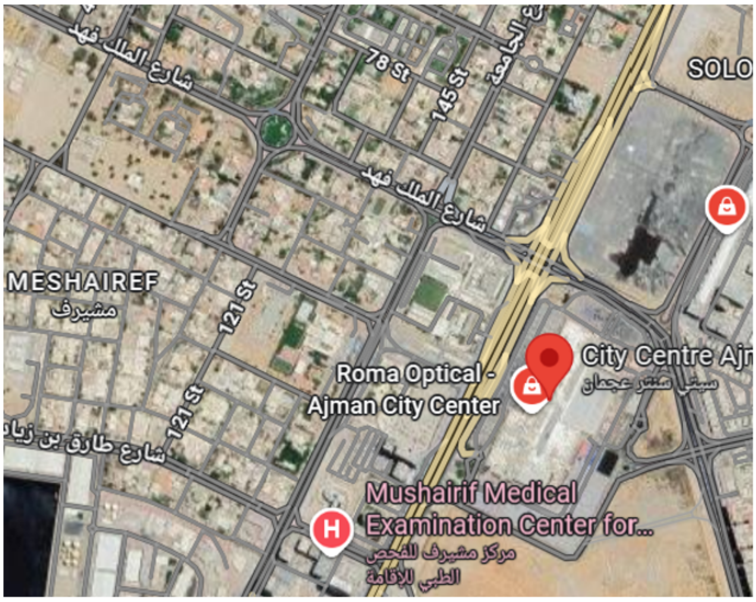

Figure 1. Location of the Ajman mall in the city center of the Emirate of Ajman

Table 1. Locations of measurements in the mall

Location	Description
Main entrance	Outdoor-to-indoor air transition zone
Food court	High traffic with significant cooking emissions
Retail store	Enclosed space with customer presence and HVAC impact
Cinema lobby	Low ventilation, prolonged occupancy
Parking garage	Vehicular emissions and airborne dust

2.2 Data Collection

In order to assess the IAQ conditions at Ajman City Centre Mall, a three-week real-time monitoring campaign was conducted. Throughout five critical indoor zones, 30-minute intervals were recorded: the main entrance, the food court, the retail store, the cinema lobby, and the parking garage. Based on expected pollutant variations, occupant density, and ventilation dynamics, these areas were selected. The monitored environmental parameters included:

- Temperature (°C)
- Relative humidity (%)
- Carbon dioxide (CO_2, ppm)
- Volatile organic compounds (VOCs, $\mu g/m^3$)
- Particulate matter ($PM_{2.5}, \mu g/m^3$)

IAQ parameters were monitored using high-precision instruments to ensure accurate and reliable measurements. The TSI Q-Trak Plus 7575 was employed to record CO_2 concentration, temperature, and relative humidity, while the TSI AeroTrak 9110 was utilized to measure $PM_{2.5}$ and VOCs. These instruments were selected for their proven precision, reliability, and compliance with international IAQ monitoring standards [1, 12]. Data collection was conducted at three distinct periods, morning, afternoon, and evening, to capture occupancy-related variations in pollutant concentrations and HVAC system performance.

Table 2 presents a representative dataset from five monitored zones within the mall on 01 May 2023, illustrating real-time fluctuations in temperature, humidity, CO_2, VOCs, and $PM_{2.5}$ levels. Notably, CO_2 concentrations in the parking garage exceeded the recommended threshold of 1,050 ppm, indicating inadequate ventilation during peak occupancy periods.

An analysis of descriptive statistics was conducted in order to interpret the overall trends and variability during the monitoring period. The mean, median, standard deviation, and range were calculated for each parameter across all recorded sessions. Table 3 summarizes these statistics by highlighting key pollutant concentrations and their fluctuation patterns in the mall environment. Based on these results, a comparative analysis was conducted with national and international indoor air quality standards, and a correlation analysis was conducted with occupant health survey data.

Table 2. Sample IAQ measurements at Ajman mall (01/05/2023)

Location	Date	Time	Temperature ($^\circ$C)	Relative Humidity (%)	CO_2 (ppm)	VOCs ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)
Main entrance	01/05/2023	10: 00	22.5	48	750	200	10
Food court	01/05/2023	12: 00	24	52	950	350	20
Clothing store	01/05/2023	14: 00	23	50	800	220	12
Cinema lobby	01/05/2023	18: 00	23.5	51	850	250	15
Parking garage	01/05/2023	20: 00	24.5	53	1050	400	25

Table 3. Summary statistics for IAQ parameters (all locations)

Parameter	Mean	Median	Standard Deviation	Minimum	Maximum
Temperature ($^\circ$C)	23.5	23.5	0.5	22.5	24.5
Relative humidity (%)	50.2	50	1.5	48	53
CO_2 (ppm)	850	850	100	750	1050
VOCs ($\mu g/m^3$)	250	250	75	200	400
$PM_{2.5}$ ($\mu g/m^3$)	15	15	5	10	25

2.3 Advanced Analysis of IAQ Parameters: Actionable Insights and Metrics

The data presented in Table 2 and Table 3 were further analyzed, and an advanced interpretation of the collected IAQ data will be developed by applying cumulative risk metrics, environmental comfort indicators, and correlation-based indices.

2.3.1 Cumulative pollutant index (CPI): Identifying high-risk zones

Eq. (1) was developed to quantify the total indoor air pollution burden at each monitored location. CO_2, VOCs, and $PM_{2.5}$ are three key indicators of IAQ that have well-documented effects on respiratory health and cognitive performance [13, 14]:

$$\mathrm{CPI} = \mathrm{CO_2}\ (\mathrm{ppm}) + \mathrm{VOCs}\ (\mu g/m^3) + \mathrm{PM_{2.5}}\ (\mu g/m^3) \tag{1}$$

As a result of this approach, zones with a high cumulative exposure risk can be quickly identified. As such, it is consistent with the integrated pollutant burden assessment model adopted in recent IAQ studies [15, 16]. In Table 4, the CPI scores calculated for each of the five monitored locations within Ajman Mall are presented.

According to Table 4, the parking garage had the highest cumulative pollutant burden (CPI = 1475), followed by the Food Court (CPI = 1320). In general, these values are higher than those associated with occupant discomfort and potential adverse health outcomes [14]. Interventions in these areas may include increasing air exchange rates, installation of air purifiers, and reduction of idling (e.g., updating cooking hoods).

Table 4. CPI by zone

Location	CO_2(ppm)	VOCs ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	CPI
Main entrance	750	200	10	960
Food court	950	350	20	1320
Clothing store	800	220	12	1032
Cinema lobby	850	250	15	1115
Parking garage	1050	400	25	1475

2.3.2 Health, performance, and productivity assessment

A structured survey was conducted to assess how occupants perceive IAQ at Ajman City Mall, and how it might affect their health, comfort, productivity, and satisfaction. The mixed-methods approach enables a more holistic understanding of the mall's environmental performance. The survey targeted both visitors and employees, collecting information on demographics, exposure patterns, symptom frequency, work satisfaction, and attitudes toward indoor air quality. The integration of quantitative and qualitative feedback complements sensor-based data in evaluating Sick Building Syndrome and cognitive health in indoor environments [4, 14].

2.4 Method for Data Collection

A questionnaire-based survey was conducted in conjunction with technical air quality monitoring to understand how IAQ affects people inside the Mall. IAQ was explored to determine how it influences health symptoms, comfort, work productivity, and overall satisfaction. A convenience sampling method, commonly used in exploratory environmental health studies, was used to select 50 participants. As these two groups represent the main types of indoor occupants with different levels of exposure, the population included both mall visitors (70%) and mall employees (30%):

- Visitors represent short-term exposure patterns.
- Employees provide insight into long-term IAQ effects.

To ensure a representative range of responses, the survey was distributed at different times of the day across all mall zones.

2.4.1 Questionnaire design

In total, 19 questions were asked, combining multiple-choice, Likert scale, and open-ended formats, as detailed in Table 5 and Table 6. The questions were designed to assess factors related to health, IAQ perception, or occupant satisfaction.

Table 5. Questionnaire features

Question	Purpose	Analysis	Hypothetical Results
Visitor or employee	Differentiate visitor and employee responses for targeted analysis	Calculate the percentage of visitors vs. employees	Visitors: 70%, Employees: 30%
Age	Understand if IAQ perceptions vary by age	Group responses by age brackets and use ANOVA for IAQ perception differences	Under 18: 10 %, 18–24: 20%, 25–34: 30%, 35–44: 20%, 45–54: 10%, 55–64: 5%, 65+: 5%
Gender	Analyze gender-based differences in IAQ perceptions	Compare responses by gender using chi-square tests	Male: 50%, Female: 45%, Prefer not to say: 5%
Frequency of visits	Assess exposure frequency	Calculate visit frequencies and correlate with IAQ symptoms	Daily: 15%, Weekly: 40%, Monthly: 30%, Less than once a month: 15%
Hours spent per visit	Understand the duration of exposure	Calculate average hours spent and correlate with IAQ symptoms	Less than 1 hour: 10%, 1–2 hours: 30%, 2–3 hours: 40%, 3–4 hours: 15%, More than 4 hours: 5%
Areas spent the most time	Identify areas of IAQ concern	Rank areas by selection frequency and cross-tabulate with IAQ symptoms	Food court: 40%, Clothing stores: 30%, Entertainment areas: 20%, Other: 10%
Symptoms experienced	Identify common health symptoms	Calculate symptom frequency and use chi-square for demographic associations	Headache: 30%, Fatigue: 25%, Respiratory irritation: 20%, Eye irritation: 15%, Allergic reactions: 10%, None: 50%
Frequency of symptoms	Assess symptom frequency	Calculate symptom occurrence distribution	Never: 20%, Rarely: 30%, Sometimes: 25%, Often: 15%, Always: 10%
Impact of IAQ on experience	Gauge visitor perception of IAQ	Calculate the percentage of 'Yes,' 'No,' and 'Unsure' responses	Yes: 60%, No: 20%, Unsure: 20%

Table 6. Questionnaire structure

Q No.	Question	Reason for Question	Type
1	Are you a: Visitor / Employee	To differentiate between visitor and employee responses for targeted analysis	Multiple Choice
2	Age: Under 18 / 18–24 / 25–34 / 35–44 / 45–54 / 55–64 / 65+	To understand if IAQ perceptions vary by age group	Multiple Choice
3	Gender: Male / Female / Prefer not to say	To analyze gender-based differences in IAQ perceptions	Multiple Choice
4	How often do you visit Ajman Mall? Daily / Weekly / Monthly / <Once a month	To assess the frequency of exposure to the mall's indoor environment	Multiple Choice
5	Hours spent per visit: <1 / 1–2 / 2–3 / 3–4 / >4 hours	To understand the duration of exposure to the indoor environment	Multiple Choice
6	Areas you spend most time in (select all): Main entrance / Food court / Clothing / Electronics / Entertainment / Parking / Other	To identify areas where IAQ may be a concern based on the presence	Multiple Choice + Open-Ended
7	Symptoms experienced (select all): Headache / Fatigue / Respiratory irritation / Eye irritation / Allergic reactions / None	To identify health symptoms associated with IAQ	Multiple Choice
8	Frequency of symptoms: Never / Rarely / Sometimes / Often / Always	To assess how often health symptoms occur	Multiple Choice
9	Does air quality affect your overall experience? Yes / No / Unsure	To gauge perception of IAQ's impact on visitor experience	Multiple Choice
10	Duration working in Ajman Mall: < 6 months / 6 m–1 y / 1–3 y / 3–5 y / >5 y	To understand the length of exposure for employees	Multiple Choice
11	Primary work area: Main entrance / Food court / Clothing / Electronics / Entertainment / Parking / Other	To identify areas where IAQ may affect employees	Multiple Choice + Open-Ended
12	Weekly working hours: <20 / 20–30 / 30–40 / >40	To assess the extent of employee exposure	Multiple Choice
13	Employee symptoms (select all): Headache / Fatigue / Respiratory irritation / Eye irritation / Allergic reactions / None	To identify health symptoms among employees	Multiple Choice
14	Frequency of symptoms: Never / Rarely / Sometimes / Often / Always	To assess the frequency of symptoms among employees	Multiple Choice
15	Does air quality affect your productivity? Yes / No / Unsure	To gauge the perceived IAQ impact on productivity	Multiple Choice
16	Job satisfaction (1–10 scale)	To measure satisfaction and correlation with IAQ	Scale
17	Would improving air quality increase satisfaction/productivity? Yes / No / Unsure	To assess the perceived benefits of IAQ improvement	Multiple Choice
18	Describe any experiences or concerns regarding air quality	To gather qualitative IAQ feedback	Open-Ended
19	Suggestions for improving air quality	To collect improvement ideas from occupants	Open-Ended

3 Results and Discussion

3.1 IAQ Data Analysis

Five zones within the Ajman City Centre Mall were monitored in real time. Figure 2 shows pollutant concentrations and thermal comfort variables, with CO_2 levels peaking in the cinema lobby (1050 ppm) and food court (950 ppm). $PM_{2.5}$ levels were highest in the parking garage (53 g/m^3), and VOCs were elevated in both the parking garage and food court, indicating the need to improve ventilation in both areas.

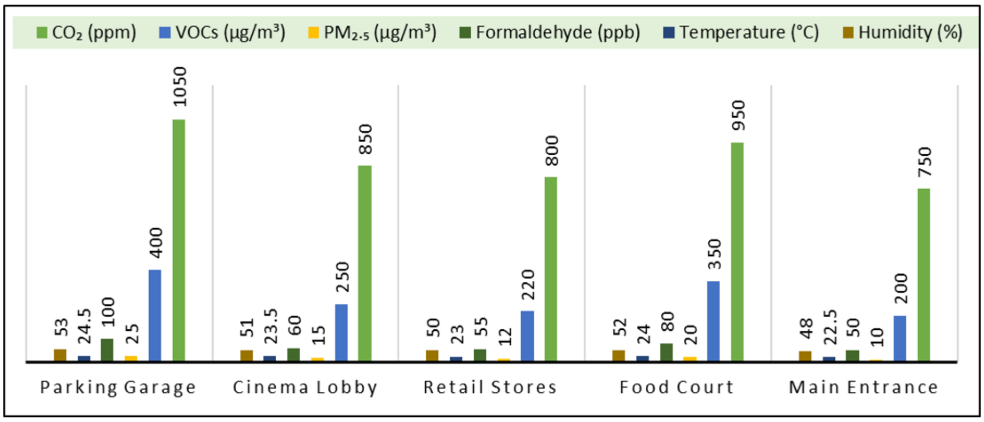

Figure 2. Measurement results of pollutant concentration and thermal comfort data

3.2 Occupant Survey Analysis

The key observations concluded from the analysis are as follows.

- Throughout the parking garage, CO_2 levels exceeded 800 parts per million, peaking at 1050 parts per million. This exceeds the UAE guideline of 1000 parts per million, indicating poor ventilation [4, 5].
- Cooking fumes and vehicle exhaust contribute to the highest levels of VOCs in the food court and parking garage, which ranged from 200 to 400 grams per cubic meter.
- Both the food court and parking garage had formaldehyde concentrations that exceeded the recommended 80 parts per billion thresholds, due to emissions from building materials and adhesives [15].
- In the parking garage, $PM_{2.5}$ levels reached a peak of 25 g/m^3, exceeding the UAE's limit, but still posing a long-term respiratory risk [14, 17, 18].

Figure 3 shows that 41% of respondents reported experiencing health symptoms linked to IAQ. The most common were headaches (30%), fatigue (25%), and respiratory irritation (20%). More than half (59%) reported no symptoms, highlighting varied exposure effects.

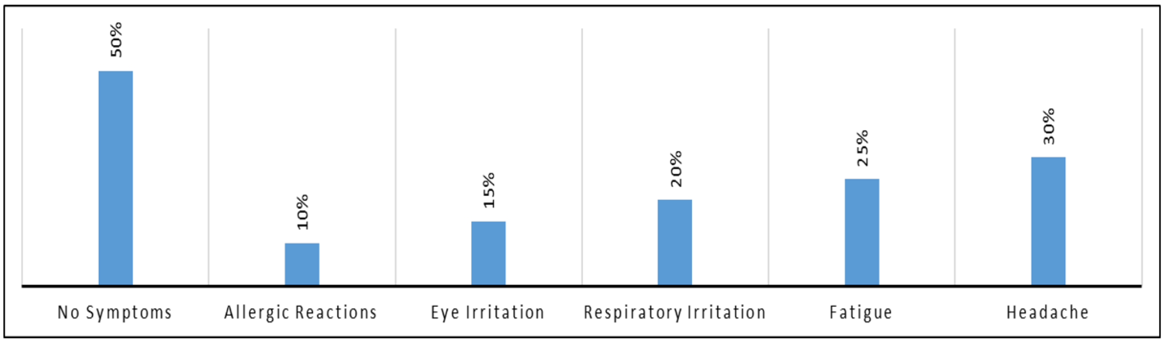

Figure 3. Reported health symptoms by respondents

3.3 Compliance with UAE IAQ Standards

Despite short-term exposure, 50% of respondents experienced at least one IAQ-related symptom.

Headaches and fatigue were the most commonly reported symptoms and were strongly correlated with areas with high CO_2 and VOC concentrations (e.g., food court and theatre lobby).

Those exposed for longer periods (30–40 hours/week) reported higher symptom frequency and lower job satisfaction (average score: 6.8/10).

A number of studies have demonstrated that IAQ has both measurable and perceived effects on comfort, productivity, and well-being [4, 19]. Comparison of the current findings with the UAE standard, shown in Table 7, indicates that the food court and parking garage consistently exceed thresholds for multiple pollutants, warranting urgent intervention.

Table 7. Comparison of IAQ measurements with UAE standards

Pollutant	Mall Range	UAE Standard	Compliance Status
CO_2 (ppm)	750–1050	$\leq$1000	Non-compliant in the parking garage
VOCs (μg/m^3)	200–400	$\leq$300	Exceeded in the food court and parking garage
$PM_{2.5}$(μg/m^3)	10–25	$\leq$25	Compliant, but borderline in parking
Formaldehyde (ppb)	50–100	$\leq$80	Exceeded in the food court and parking garage

4 Recommendations

Based on the data collected and occupant feedback, the following strategies are recommended:

- Enhancement of the ventilation efficiency by installation of CO_2 sensors with demand-controlled ventilation to automatically adjust airflow in congested areas.
- Air filtration systems with HEPA filters for PM control and activated carbon filters for VOC removal.
- Use of Sustainable Low-Emission Materials by replacing high-emission paints, adhesives, and furniture with certified low-VOC materials.
- Regular HVAC maintenance to ensure ducts and filters are cleaned and replaced regularly, especially in high-traffic and high-emission areas.
- Occupant Awareness Campaigns by promoting understanding of IAQ importance among employees and encouraging safe practices (e.g., reducing idle engine time).

5 Conclusions

According to this study, the IAQ within Ajman City Mall varies significantly across functional zones. The food court and parking garage are consistently exhibiting elevated levels of CO_2, VOCs, and formaldehyde. The findings demonstrate a strong correlation between pollutant concentrations and reported symptoms such as headaches, fatigue, and respiratory irritation. By evaluating both physical measurements and perceived health impacts, the research offers novel contributions. The study examines hydrocarbon-based indoor pollutants originating from common building materials and cleaning products that are of particular relevance to the petroleum industry. The article emphasizes the significance of energy-efficient HVAC systems, sustainable materials, and enhanced ventilation strategies for indoor environments in petroleum-producing regions. A future research study should investigate seasonal variations, cumulative exposure impacts, and the implementation of smart IAQ monitoring systems to support continuous environmental management in both public and industrial buildings.

Author Contributions

Conceptualization, Y.O.K. and A.S.K.D.; methodology, Y.O.K.; software, K.M.A.; validation, Y.O.K., K.M.A., and A.S.K.D.; formal analysis, Y.O.K. and A.S.K.D.; investigation, K.M.A.; resources, Y.O.K.; data curation, K.M.A. and A.S.K.D.; writing, original draft preparation, Y.O.K., K.M.A., and A.S.K.D.; writing, review and editing, K.M.A., and A.S.K.D.; visualization, K.M.A.; supervision, A.S.K.D.; project administration, Y.O.K. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Nomenclature

IAQ	Indoor air quality
$\mathrm{CO_2}$	Carbon dioxide
CO	Carbon monoxide
$\mathrm{PM_{2.5}}$	Particulate matter (2.5 microns)
$\mathrm{PM_{10}}$	Particulate matter (10 microns)
VOCs	Volatile organic compounds
$\mathrm{CH_2O}$	Formaldehyde
SBS	Sick building syndrome
HVAC	Heating, Ventilation, and Air Conditioning