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Indoor Air Quality Assessment and Influencing Factors of Bacterial Growth in Klang Valley Health Clinics

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ABSTRACT

Introduction: Healthcare-Associated Infections (HCAIs) pose significant challenges to patient safety and public health, particularly in environments with high patient traffic such as health clinics. Inadequate indoor air quality (IAQ) is a well-documented contributing factor to the growth and spread of harmful microorganisms, which can lead to increased morbidity and healthcare costs. Objective: This study investigates the factors influencing bacterial growth in the Waiting Room, Medical Officer Room, and Patient Treatment Room of health clinics located in Klang Valley, Malaysia, with a focus on assessing indoor air quality (IAQ) parameters. Methods: Comprehensive assessments were conducted using industry-standard equipment to evaluate physical, chemical, and biological variables in alignment with the Industry Code of Practice (ICOP) for IAQ (2010). A one-way ANOVA test was utilized to analyze the data collected from three different health clinics, allowing for a comparative analysis of bacterial counts during morning and afternoon sessions. Results: Statistically significant differences ($p<0.05$) in total bacterial counts were observed across the health clinics at different times of the day. A strong positive correlation between carbon dioxide levels and bacterial concentrations was identified in most premises, with exceptions noted in locations using effective cleaning agents. In contrast, ozone (O_3) demonstrated a negative correlation, indicating its potential as a disinfectant that inhibits bacterial proliferation. Conclusion: Bacterial concentrations exceeding ICOP IAQ (2010) standards were detected in the Waiting Rooms of health clinics C2 (morning and afternoon) and C3 (morning). Contributing factors included inadequate ventilation systems, elevated temperatures, low air movement, high occupancy levels, and increased PM10 concentrations. The findings underscore the urgent need for a thorough review of ventilation designs and maintenance protocols to improve indoor air quality. Moreover, emphasis on the use of personal protective equipment (PPE) and strict adherence to safety practices is warranted, as all health clinics recorded Total Volatile Organic Compounds (TVOCs) above acceptable levels, posing potential health risks. These insights are critical for informing policy and practice improvements in healthcare settings.

Keywords: Indoor air quality, Health clinics, Physical parameters, Chemical parameters, Biological parameters.

INTRODUCTION

Healthcare-Associated Infections (HCAIs) continue to present significant complications and challenges globally, leading to increased morbidity, mortality, and substantial healthcare costs.[1,2] (CDC 2025; WHO, 2022). The Centers for Disease Control and Prevention (CDC) is actively monitoring this trend as HCAIs pose a critical public health threat that undermines the quality of medical services and patient safety.[1]

The World Health Organization (WHO) defined HCAI in 2011 as infections acquired by patients during medical care. This definition has evolved to encompass not only hospitalized patients but also those receiving treatment in outpatient clinics, public health venues, medical offices, ambulatory surgical centers, and specialized care facilities.[1,2] HCAIs arise from infectious agents or microorganisms that pose risks to patients. Various pathogens, including bacteria, viruses, protozoa, fungi, and mycobacteria, are implicated in these infections.[1,3]

While traditional focus has been on inpatient hospital environments, the risk of HCAIs in outpatient clinics and health facilities is substantial but often overlooked.[4,5] The scarcity of studies exploring HCAIs in such settings complicates prevention efforts, compounded by inadequate infrastructure and resources supporting infection control in outpatient environments compared to inpatient settings.[6]

Transmission routes of HCAIs include person-to-person contact, contaminated environments, infected individuals, healthcare workers' skin, and shared equipment.[7,8] Factors that facilitate microbial growth encompass temperature, relative humidity, ventilation systems, occupancy levels, and hygiene practices.[9,10] Poor indoor air quality, as highlighted in recent studies, can be a breeding ground for microorganisms and may be mitigated by effective controls of environmental parameters like air movement, humidity, temperature, and cleanliness.[11,12]

Additionally, chemical pollutants such as carbon dioxide (CO_2), carbon monoxide (CO), and formaldehyde are critical indicators of air quality that may influence microbial stability.[13,14] For instance, research demonstrates that elevated CO_2 levels correlate with human activities linked to microbial proliferation through respiratory emissions and skin shedding.[15,16] Furthermore, airborne particulate matter (PM10) serves as both a transport medium for pathogens and a nutrient source for microbial metabolism.[17]

In summary, the interrelation between bioaerosols, environmental pollutants, ventilation, and cleaning practices significantly impacts the level of contamination in health facilities.[18] This research examines the concentrations of physical, chemical, and biological factors by the ICOP IAQ standards (2010)[19] across various patient areas within three health clinics in Klang Valley, Malaysia, to understand their influence on bacterial growth and HCAI prevalence.

MATERIALS AND METHODS

Study Design and Setting

This study was conducted across three health clinics situated in the Klang Valley, Federal Territory of Kuala Lumpur: C1, C2 and C3. The exploration focused on three specific areas within each clinic: the Waiting Room, Medical Officer Room, and Treatment Room.

Sampling Points

A total of nine sampling points were established, with three designated sampling points per health clinic. The selection of these sampling points was guided by the metrics outlined in the Indoor Quality Management (ICOP IAQ) standards (2010), which emphasize the significance of spatial representation across the premises.

Measurement of Parameters

Physical Parameters

The physical parameters measured included:

- Temperature: Ambient air temperature was recorded.
- Relative Humidity (Rh): The moisture content in the air was assessed using a hygrometer.
- Air Movement: The air velocity within the designated rooms was measured, indicating ventilation effectiveness.

Chemical Parameters

The chemical parameters monitored were:

- Ozone (O_3): Measured using Aeroqual Series 500.
- Total Volatile Organic Compounds (TVOC):

Assessed with Aeroqual Series 500.

- Carbon Dioxide (CO_2): Monitored using the Tetra 3 Crowcon.
- Carbon Monoxide (CO): Measured with the Tetra 3 Crowcon.
- Particulate Matter (PM10): Determined using Tetra 3 Crowcon.
- Formaldehyde (CH2O): Concentration measured with the Formaldemeter.

Measurements of both physical and chemical parameters were conducted during two time slots, morning and afternoon, using direct reading methods. Data were collected at each sampling point three times, with each measurement taken in five-minute intervals over a total period of 15 minutes, providing robust replication of readings across different times of the day.

Microbial Analysis

The assessment of total bacterial counts was executed using the Quick Take 30 sampler. This involved the exposure method utilizing duplicate Trypticase Soy Agar (TSA) media, which served to culture bacteria present in the air samples. Following the exposure, the developed colonies were counted using the Galaxy 230 Colony Counter, software integrated from WIGGENS GmbH.

Statistical Analysis

Data analysis was performed using IBM SPSS Statistics version 26.0 software. The mean differences in physical, chemical, and biological parameters among the three health clinics (C1, C2 and C3) were evaluated using One-Way ANOVA. This statistical approach ensured a comprehensive understanding of variations in environmental parameters across different health clinic settings and time periods.

RESULTS AND DISCUSSION

IAQ parameter readings at health clinics (C1, C2 and C3)

The data on mean values and standard deviations for physical (temperature, relative humidity, and air movement), chemical (formaldehyde [CH_2O], carbon dioxide [CO_2], carbon monoxide [CO], total volatile organic compounds [TVOC], and particulate matter [PM10]), and biological (total bacterial count [TBC]) parameters are summarized in Tables 1 and 2.

Table 1: IAQ parameter readings in the morning at health clinic C1, C2 and C3

Health Clinic		C1			C2			C3		
/ Location		PO1	PO2	PO3	PO1	PO2	PO3	PO1	PO2	PO3
Parameter	Standard Value (ICOP IAQ	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
Temp (°C)	23.0-26.0	24.7±1.815	22.9±0.377	23.0±0.118	27.2±0.849	25.7±0.165	26.4±0.047	28.5±0.071	28.3±0.330	29.3±0.330
Rh (%)	40-70	63.9±9.145	60.9±0.165	68.5±4.761	58.7±4.148	55.3±1.980	55.6±2.687	60.2±2.003	58.1±1.532	58.9±1.815
AM (ms^{-1})	0.15-0.50	0.10±0.002	0.10±0.004	0.11±0.002	0.08±0.033	0.12±0.000	0.11±0.007	0.08±0.007	0.12±0.019	0.10±0.002
CH_2O (ppm)	0.1	0.05±0.003	0.05±0.003	0.11±0.003	0.18±0.006	0.36±0.025	0.05±0.006	0.03±0.003	0.02±0.003	0.00±0.000
CO_2 (ppm)	1000	1166±337.815	1274±240.258	640±188.090	2186±319.875	2275±164.049	1905±394.794	2508±308.103	1304±104.416	2155±16.971
CO (ppm)	10	0.1±0.024	0.2±0.141	0.1±0.070	3.0±1.485	4.4±0.141	2.3±0.825	3.6±0.212	2.2±0.118	3.2±0.259
PM_{10} (mg/m^3)	0.15	0.01±0.001	0.01±0.002	0.11±0.119	0.04±0.003	0.04±0.001	0.27±0.316	0.07±0.022	0.02±0.002	0.03±0.013
O_3 (ppm)	0.05	0.00±0.001	0.00±0.001	0.07±0.010	0.00±0.000	0.00±0.000	0.00±0.000	0.00±0.000	0.00±0.000	0.00±0.000
TVOC (ppm)	3.0	77.0±15.886	130.0±4.196	92.5±76.721	340.3±145.903	2832±68.354	426.2±257.198	621.9±230.705	317.1±14.991	581.7±27.624
TBC (cfu/m^3)	500	261.6±4.172	41.0±5.374	89.2±2.687	592.2±8.344	211.0±8.344	228.4±3.818	648.8±6.364	52.2±5.515	337.6±4.950

*Signifikan pada nilai p<0.05

PO1, Waiting Room; PO2, Medical Officer Room; PO3, Treatment Room; Temp, Temperature; Rh, Relative Humidity; AM, Air Movement; CH_2O, Formaldehyde; CO_2, Carbon Dioxide; CO, Carbon Monoxide; PM10, Particulate Matters; O3, Ozone; TVOC, Total Volatile Compounds; TBC, Total Bacterial Count.

Table 2: IAQ parameter readings in the afternoon at health clinic C1, C2 and C3

Health Clinic / Location		C1			C2			C3		
Parameter	Standard Value (ICOP IAQ 2010)	PO1	PO2	PO3	PO1	PO2	PO3	PO1	PO2	PO3
		Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
Temp (°C)	23.0-26.0	22.6±0.071	23.0±0.071	23.0±1.084	28.7±3.536	25.6±0.141	26.3±0.259	27.5±0.353	28.2±0.589	28.4±0.236
Rh (%)	40-70	60.0±0.094	60.3±0.684	61.8±2.192	53.3±5.704	51.0±2.263	51.5±3.771	55.0±0.189	55.7±0.919	54.5±0.636
AM (ms^{-1})	0.15-0.50	0.11±0.012	0.12±0.024	0.12±0.002	0.11±0.033	0.13±0.014	0.11±0.009	0.11±0.024	0.15±0.059	0.13±0.009
CH_2O (ppm)	0.1	0.05±0.003	0.04±0.003	0.11±0.003	0.18±0.006	0.36±0.025	0.05±0.006	0.03±0.003	0.02±0.003	0.00±0.000
CO_2 (ppm)	1000	1312±19.092	1143±233.341	663±24.513	1791±160.749	1643±73.539	1428±181.282	1041±178.662	533±64.347	747±2.357
CO (ppm)	10	0.1±0.141	0.0±0.024	0.0±0.000	1.5±0.024	1.2±0.519	0.9±0.448	1.5±0.283	1.0±0.165	1.6±0.330
PM_{10} (mg/m^3)	0.15	0.09±0.006	0.09±0.000	0.07±0.028	0.03±0.004	0.04±0.008	0.03±0.005	0.01±0.006	0.01±0.001	0.01±0.002
O_3 (ppm)	0.05	0.00±0.000	0.00±0.001	0.01±0.001	0.00±0.000	0.00±0.002	0.00±0.000	0.00±0.000	0.07±0.065	0.00±0.000
TVOC (ppm)	3.0	95.5±14.260	111.4±14.401	102.4±75.448	174.2±16.499	732.8±584.259	229.8±91.641	184.8±0.306	103.8±68.707	234.4±74.246
TBC (cfu/m^3)	500	189.6±5.657	62.6±6.647	45.5±2.333	550.6±8.344	88.0±1.697	108.4±7.495	239.1±3.677	43.2±4.666	209.4±3.536

*Signifikan pada nilai p<0.05

PO1, Waiting Room; PO2, Medical Officer Room; PO3, Treatment Room; Temp, Temperature; Rh, Relative Humidity; AM, Air Movement; CH_2O, Formaldehyde; CO_2, Carbon Dioxide; CO, Carbon Monoxide; PM10, Particulate Matters; O3, Ozone; TVOC, Total Volatile Compounds; TBC, Total Bacterial Count

In the Waiting Room of C1, all IAQ parameters complied with the accepted limits of the ICOP IAQ (2010) standards, except for air movement, which recorded values of 0.10±0.002 ms^{-1} in the morning and 0.11±0.012 ms^{-1} in the afternoon, and CO_2 levels, which were 1166±337.815 ppm in the morning and increased to 1312±19.092 ppm in the afternoon. Additionally, TVOC concentrations were measured at 77.0±15.886 ppm in the morning and 95.5±14.260 ppm in the afternoon.

In the Medical Officer Room, while air movement was recorded at 0.10±0.004 ms^{-1} in the morning and 0.12±0.024 ms^{-1} in the afternoon, CO_2 levels were found to be 1274±240.258 ppm in the morning and 1143±233.341 ppm in the afternoon, along with TVOC levels at 130.0±4.196 ppm in the morning and 111.4±14.401 ppm in the afternoon, all of which exceeded the standard ranges. The Patient Treatment Room showed better compliance, with air movement at 0.11±0.002 ms^{-1} in the morning and 0.12±0.002 ms^{-1} in the afternoon, while TVOC levels were within acceptable limits at 92.5±76.721 ppm in the morning and 102.4±75.448 ppm in the afternoon.

Conversely, the Waiting Room in C2 exhibited total deviations in six IAQ parameters from the established standards: air movement (0.08±0.033 ms^{-1} in the morning and 0.11±0.033 ms^{-1} in the afternoon), temperature (27.2±0.849°C), formaldehyde (0.18±0.006 ppm), CO_2 (2186±319.875 ppm in the morning and 1791±160.749 ppm in the afternoon), TVOC (340.3±145.903 ppm in the morning and 174.2±16.499 ppm in the afternoon), and TBC (592.2±8.344 cfu/m^3 in the morning and 550.6±8.344 cfu/m^3 in the afternoon).

In the Medical Officer Room at C2, four parameters were also outside standard limits, notably air movement (0.12±0.000 ms^{-1} in the morning and 0.13±0.014 ms^{-1} in the afternoon), formaldehyde (0.36±0.025 ppm), CO_2 (2275±164.049 ppm in the morning and 1643±73.539 ppm in the afternoon), and TVOC (2832±68.354 ppm in the morning and 732.8±584.259 ppm in the afternoon). Similarly, in the Patient Treatment Room, four IAQ parameters failed to meet the standards: air movement (0.11±0.007 ms^{-1} in the morning and 0.11±0.009 ms^{-1} in the afternoon), temperature (26.4±0.047°C in the morning and 26.3±0.259°C in the afternoon), CO_2 (1905±394.794 ppm in the morning and 1428±181.282 ppm in the afternoon), and TVOC (426.2±257.198 ppm in the morning and 229.8±91.641 ppm in the afternoon).

In comparison, the Waiting Room of C3

reported five IAQ parameters not complying with ICOP IAQ standards (2010): air movement (0.08±0.007 ms^{-1} in the morning and 0.11±0.024 ms^{-1} in the afternoon), temperature (28.5±0.071°C in the morning and 27.5±0.353°C in the afternoon), CO_2 (2508±308.103 ppm in the morning and 1041±178.662 ppm in the afternoon), TVOC (621.9±230.705 ppm in the morning and 184.8±0.306 ppm in the afternoon), and TBC (648.8±6.364 cfu/m^3 in the morning).

Similarly, the Medical Officer Room at C3 was found to have four parameters exceeding the acceptable standard ranges: air movement (0.12±0.019 ms^{-1} in the morning), temperature (28.3±0.330°C in the morning and 28.2±0.589°C in the afternoon), CO_2 (1304±104.416 ppm in the morning), and TVOC (317.1±14.991 ppm in the morning and 103.8±68.707 ppm in the afternoon). Lastly, the Patient Treatment Room also revealed four IAQ parameters beyond the standard limits, with air movement recorded at 0.10±0.002 ms^{-1} in the morning and 0.13±0.009 ms^{-1} in the afternoon, temperature reaching 29.3±0.330°C in the morning and 28.4±0.236°C in the afternoon, CO_2 measuring at 2155±16.971 ppm in the morning, and TVOC at 581.7±27.624 ppm in the morning and 234.4± 74.246 ppm in the afternoon.

Overall, significant non-compliance with ICOP IAQ standards was observed across all three health clinics, primarily related to air movement, CO_2 levels, and TVOC concentrations. The findings highlight critical areas for improvement in maintaining acceptable indoor air quality in health clinics, emphasizing the need for regular monitoring and implementation of effective ventilation and air quality management strategies to safeguard the health of both patients and healthcare providers.

Comparison of IAQ Parameter Readings (Mean) in the Morning and Afternoon between Health Clinic C1, C2 and C3

The mean differences in physical, chemical, and biological parameters were evaluated using the One-Way ANOVA test for both morning and afternoon sessions, focusing on measurements such as temperature, relative humidity (Rh), air movement, formaldehyde (CH_2O), carbon dioxide (CO_2), carbon monoxide (CO), total volatile organic compounds (TVOC), particulate matter (PM10), and total bacterial counts (TBC) across the Waiting Room, Medical Officer Room, and Treatment Room in health clinics C1, C2 and C3. The results are presented in Tables 3, 4, and 5.

Table 3: Comparison of IAQ parameter readings (mean) in the morning & afternoon between the Waiting Room at health clinic C1, C2 and C3

	Morning					Afternoon				
Health Clinic /Parameter	C1 Mean±SD	C2 Mean±SD	C3 Mean±SD	F	p	C1 Mean±SD	C2 Mean±SD	C3 Mean±SD	F	p
Temp (°C)	24.7±1.815	27.2±0.849	28.5±0.071	5.495	0.099	22.6±0.071	28.7±3.536	27.5±0.353	5.008	0.111
Rh (%)	63.9±9.145	58.7±4.148	60.2±2.003	0.416	0.693	60.0±0.094	53.3±5.704	55.0±0.189	2.222	0.256
AM (ms^{-1})	0.10±0.002	0.08±0.033	0.08±0.007	0.306	0.757	0.11±0.012	0.11±0.033	0.11±0.024	0.022	0.979
CH_2O (ppm)	0.05±0.003	0.18±0.006	0.03±0.003	688.625	0.000	0.05±0.003	0.18±0.006	0.03±0.003	688.625	0.000
CO_2 (ppm)	1166±337.815	2186±319.875	2508±308.103	5.766	0.094	1312±19.092	1791±160.749	1041±178.662	14.913	0.028
CO (ppm)	0.1±0.024	3.0±1.485	3.6±0.212	9.436	0.051	0.1±0.141	1.5±0.024	1.5±0.283	37.608	0.008
PM_{10} (mg/m^3)	0.01±0.001	0.04±0.003	0.07±0.022	13.163	0.033	0.09±0.006	0.03±0.004	0.01±0.006	8.144	0.061
O_3 (ppm)	0.00±0.000	0.00±0.000	0.00±0.000	-	-	0.00±0.000	0.00±0.000	0.00±0.000	-	-
TVOC (ppm)	77.0±15.886	340.3±145.903	621.9±230.705	5.105	0.108	95.5±14.260	174.2±16.499	184.8±0.306	29.994	0.010
TBC (cfu/m^3)	261.6±4.172	592.2±8.344	648.8±6.364	1486.570	0.000	189.6±5.657	550.6±8.344	239.1±3.677	2076.812	0.000

*Signifikan pada nilai p<0.05

Temp, Temperature; Rh, Relative Humidity; AM, Air Movement; CH_2O, Formaldehyde; CO_2, Carbon Dioxide; CO, Carbon Monoxide; PM_{10}, Particulate Matters; O_3, Ozone; TVOC, Total Volatile Compounds; TBC, Total Bacterial Count

Table 4: Comparison of IAQ parameter readings (mean) in the morning & afternoon between the Medical Officer Room at the health clinic C1, C2 and C3

Health Clinic /Parameter	Morning C1 Mean±SD	C2 Mean±SD	C3 Mean±SD	F	p	Afternoon C1 Mean±SD	C2 Mean±SD	C3 Mean±SD	F	p
Temp (°C)	22.9±0.377	25.7±0.165	28.3±0.330	153.343	0.001	23.0±0.071	25.6±0.141	28.2±0.589	107.581	0.002
Rh (%)	60.9±0.165	55.3±1.980	58.1±1.532	7.253	0.071	60.3±0.684	51.0±2.263	55.7±0.919	19.953	0.018
AM (ms^{-1})	0.10±0.004	0.12±0.000	0.12±0.019	1.609	0.335	0.12±0.024	0.13±0.014	0.15±0.059	.438	0.681
CH_2O (ppm)	0.05±0.003	0.36±0.025	0.02±0.003	340.015	0.000	0.04±0.003	0.36±0.025	0.02±0.003	340.015	0.000
CO_2 (ppm)	1274±240.258	2275±164.049	1304±104.416	14.575	0.029	1143±233.341	1643±73.539	533±64.347	18.691	0.020
CO (ppm)	0.2±0.141	4.4±0.141	2.2±0.118	483.907	0.000	0.0±0.024	1.2±0.519	1.0±0.165	8.197	0.061
PM_{10} (mg/m^3)	0.01±0.002	0.04±0.001	0.02±0.002	246.949	0.000	0.09±0.000	0.04±0.008	0.01±0.001	22.135	0.016
O_3 (ppm)	0.00±0.000	0.00±0.000	0.00±0.000	-	-	0.00±0.000	0.00±0.000	0.07±0.065	2.464	0.233
TVOC (ppm)	130.0±4.196	2832±68.354	317.1±14.991	2883.250	0.000	111.4±14.401	732.8±584.259	103.8±68.707	2.258	0.252
TBC (cfu/m^3)	41.0±5.374	211.0±8.344	52.2±5.515	448.456	0.000	62.6±6.647	88.0±1.697	43.2±4.666	34.712	0.008

*Signifikan pada nilai p<0.05

Temp, Temperature; Rh, Relative Humidity; AM, Air Movement; CH_2O, Formaldehyde; CO_2, Carbon Dioxide; CO, Carbon Monoxide; PM_{10}, Particulate Matters; O_3, Ozone; TVOC, Total Volatile Compounds; TBC, Total Bacterial Count

Table 5: Comparison of IAQ parameter readings (mean) in the morning & afternoon between the Treatment Room at the health clinic C1, C2 and C3

Health Clinic /Parameter	Morning C1 Mean±SD	C2 Mean±SD	C3 Mean±SD	F	p	Afternoon C1 Mean±SD	C2 Mean±SD	C3 Mean±SD	F	p
Temp (°C)	23.0±0.118	26.4±0.047	29.3±0.330	480.164	0.000	23.0±1.084	26.3±0.259	28.4±0.236	33.713	0.009
Rh (%)	68.5±4.761	55.6±2.687	58.9±1.815	8.062	0.062	61.8±2.192	51.5±3.771	54.5±0.636	8.688	0.056
AM (ms^{-1})	0.11±0.002	0.11±0.007	0.10±0.002	5.333	0.103	0.12±0.002	0.11±0.009	0.13±0.009	1.480	0.357
CH_2O (ppm)	0.11±0.003	0.05±0.006	0.00±0.000	387.050	0.000	0.11±0.003	0.05±0.006	0.00±0.000	387.050	0.000
CO_2 (ppm)	640±188.090	1905±394.794	2155±16.971	13.399	0.032	663±24.513	1428±181.282	747±2.357	81.518	0.002
CO (ppm)	0.1±0.070	2.3±0.825	3.2±0.259	20.629	0.018	0.0±0.000	0.9±0.448	1.6±0.330	11.962	0.037
PM_{10} (mg/m^3)	0.11±0.119	0.27±0.316	0.03±0.013	.760	0.541	0.07±0.028	0.03±0.005	0.01±0.002	6.706	0.078
O_3 (ppm)	0.07±0.010	0.00±0.000	0.00±0.000	1.100	0.438	0.01±0.001	0.00±0.000	0.00±0.000	420.250	0.000
TVOC (ppm)	92.5±76.721	426.2±257.198	581.7±27.624	5.149	0.107	102.4±75.448	229.8±91.641	234.4±74.246	1.718	0.318
TBC (cfu/m_3)	89.2±2.687	228.4±3.818	337.6±4.950	606.313	0.000	45.5±2.333	108.4±7.495	209.4±3.536	43.339	0.006

*Signifikan pada nilai p<0.05

Temp, Temperature; Rh, Relative Humidity; AM, Air Movement; CH_2O, Formaldehyde; CO_2, Carbon Dioxide; CO, Carbon Monoxide; PM_{10}, Particulate Matters; O_3, Ozone; TVOC, Total Volatile Compounds; TBC, Total Bacterial Count

In the Waiting Room, no statistically significant mean differences ($p>0.05$) were observed for temperature readings (morning, p=0.099; afternoon, p=0.111), relative humidity (morning, p=0.693; afternoon, p=0.256), air movement (morning, p=0.751; afternoon, p=0.315), CO_2 (morning, p=0.094), CO (morning, p=0.051), PM10 (afternoon, p=0.061), and TVOC (morning, p=0.108). However, statistically significant mean differences ($p<0.05$) were identified for CH_2O (morning, p=0.000; afternoon, p=0.000), TBC (morning, p=0.000; afternoon, p=0.000), CO_2 (afternoon, p=0.028), CO (afternoon, p=0.008), PM10 (morning, p=0.033), and TVOC (afternoon, p=0.010) across the three health clinics. Notably, the highest concentrations of CH_2O in both morning and afternoon (0.18±0.006 ppm), as well as CO_2 (1791±160.749 ppm) and TBC (550.6±8.344 cfu/m³) in the afternoon, were detected at C2. In contrast, C3 recorded the highest TVOC level (184.8±0.306 ppm) in the afternoon and TBC (648.8±6.364 cfu/m³) in the morning. It's worth noting that the afternoon readings of CO and PM10 did not exceed the ICOP IAQ 2010 standards across all health clinics.

In the Medical Officer Room, significant mean differences ($p<0.05$) were observed for all IAQ readings among the health clinics, with exceptions for relative humidity (morning, p=0.071), air movement (morning, p=0.335; afternoon, p=0.681), CO (afternoon, p=0.061), ozone (O3, afternoon, p=0.233), and TVOC (afternoon, p=0.252) as shown in Table 4. The highest values recorded were for CH_2O (0.36±0.025 ppm for both morning and afternoon), CO_2 (2275±164.049 ppm in the morning and 1643±73.539 ppm in the afternoon), and TVOC (2832.0±68.354 ppm in the morning; 732.8±584.259 ppm in the afternoon), all observed at C2. Interestingly, the highest temperature reading was recorded at C3 (28.3±0.330°C in the morning; 28.2±0.589°C in the afternoon). In contrast to the results in the Waiting Room, CO (morning) and PM10 (morning and afternoon) levels in the Medical Officer Room remained within the acceptable ICOP IAQ 2010 standards.

Significant differences ($p<0.05$) were also found in the Patient Treatment Room for temperature (morning, p=0.000; afternoon, p=0.009), CH_2O (morning, p=0.000; afternoon, p=0.000), CO_2 (morning, p=0.032; afternoon, p=0.002), CO (morning, p=0.018; afternoon, p=0.037), and TBC (morning, p=0.000; afternoon, p=0.006) between all health clinics. The highest temperature readings were measured at C3 (29.3±0.330°C in the morning; 28.4±0.236°C in the afternoon), followed by C2 (26.4±0.047°C in the morning; 26.3±0.259°C in the afternoon). Notably, the temperature readings at C1 (23.0±0.118°C in the morning; 23.0±1.084°C in the afternoon) did not exceed the standard range. Additionally, the CH_2O levels at C1 were slightly above the acceptable limit at 0.11±0.003 ppm for both morning and afternoon measurements.

Similarly, the highest morning CO_2 concentration was observed at C3 (2155±16.971 ppm), followed by C2 (1905±394.794 ppm), while the readings at C1 (640±188.090 ppm) did not surpass the standard threshold. In the afternoon, the CO_2 levels reached 1428±181.282 ppm at C2 exceeded the acceptable range, whereas C1 (663±24.513 ppm) and C3 (747±2.357 ppm) remained within limits.

Overall, significant variations in IAQ parameters were identified across the three health clinics. Although many readings conformed to the ICOP IAQ standards, several critical parameters, particularly CH_2O, CO_2, and TBC, demonstrated readings that exceeded acceptable limits in various locations. These findings underscore the need for continuous monitoring and potential interventions to improve air quality, ensuring a safer environment for both patients and healthcare providers. The results highlight specific areas requiring attention, particularly in the Medical Officer and Patient Treatment Rooms, where further investigations into air quality management practices could be beneficial to meet established standards consistently.

DISCUSSION

The assessment of indoor air quality in Klang Valley health clinics revealed notable variations in physical and chemical parameters across different spaces and times of day. Measurements of temperature, relative humidity, and air movement were compared with the Malaysian Industry Code of Practice on Indoor Air Quality (ICOP IAQ, 2010), which provides guidance for maintaining healthy indoor environments.

Temperature readings frequently exceeded the recommended range of 23–26°C, particularly in waiting areas at C2 and C3, where morning and afternoon values were consistently high. By contrast, C1 showed lower temperatures in the afternoon, which fell within the acceptable standard. These findings suggest that occupancy patterns, combined with limited cooling capacity, play a key role in shaping indoor thermal conditions.

Air movement was also found to be insufficient in most areas, remaining below the recommended threshold of 0.15 m/s. Poor air circulation can lead to stagnant environments, which not only increase temperature but also encourage the accumulation of airborne microorganisms. Only in the Medical Officer Room at C3 were air movement readings within acceptable limits, highlighting the overall inadequacy of ventilation systems in these clinics.

Chemical pollutants presented a mixed picture. While CO, PM10, and ozone levels generally complied with ICOP standards, both carbon dioxide (CO_2) and total volatile organic compounds (TVOCs) were consistently elevated. CO_2 concentrations often exceeded 1,000 ppm, particularly during morning sessions when patient numbers were higher, reflecting inadequate ventilation. TVOC levels also surpassed limits, with spikes observed during patient care and cleaning activities, underscoring the impact of disinfectant use and hand sanitizers on indoor air chemistry.

Interestingly, the relationship between pollutants and microbial concentrations was complex. Higher CO_2 levels often corresponded with increased bacterial counts, consistent with the influence of occupancy and human activity. However, in some instances, such as at C1 in the afternoon, bacterial levels decreased despite elevated CO_2 and TVOC values, likely due to the use of cleaning agents and disinfectants that temporarily suppressed microbial growth.

Taken together, these findings highlight the interplay between thermal comfort, ventilation, chemical exposures, and microbial loads in health clinics. Exceedances in temperature, poor air circulation, and elevated CO_2 and TVOC levels point to systemic ventilation challenges that compromise indoor air quality. Addressing these issues through improved design, maintenance, and operational practices is essential to ensure healthier, safer environments for both patients and healthcare staff.

CONCLUSION

The assessment of airborne bacteria levels across different clinic spaces revealed notable varia-tions between rooms and measurement times. Significant differences ($p<0.05$) in TBC levels were observed in the Waiting Room, Medical Officer Room, and Patient Treatment Room during both morning and afternoon sessions. The highest concentrations were generally detected in C3 and C2, while C1 consistently recorded the lowest levels. Interestingly, despite a higher number of patients in the morning, bacterial growth at C1 was suppressed, which may be attributed to lower temperature conditions that limited microbial activity. In contrast, the elevated readings at C3 and C2 reflected the combined influence of heavier occupancy, higher temperatures, and inade-quate ventilation. Overall, bacterial growth in the clinics was driven by environmental and opera-tional factors, particularly temperature, crowding, ventilation efficiency, air movement, and the presence of particulate matter such as PM

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Conflict of Interest

The author(s) do not have any conflict of interest.

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