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Hazard Evaluation of Indoor Air Quality in Bank Offices

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Abstract: IAQ is a crucial factor affecting the health, comfort, and productivity of workers, particularly those working in enclosed spaces like bank offices. This study aimed to evaluate the IAQ of a bank office's operational area and vault by analyzing concentrations of CO_2, TVOC, PM10, and PM2.5, as well as temperature, relative humidity, and air movement. Two different ventilation systems were compared to assess their impact on IAQ. The acquired data were statistically analyzed using mean comparison *t*-tests and hazard ratio analysis. The results revealed that indoor concentrations of PM2.5 and CO_2 significantly contribute to the total hazard ratio, indicating the need to reduce their levels below reference values. The study also found that the ventilation system significantly affects indoor air quality, and concentrations of TVOC, CO_2, PM10, and PM2.5 in the air are considerable. Significantly, the study found that bank offices with split unit air-conditioners had the highest mean CO_2 levels, indicating poor ventilation. Overall, the study reveals that the building, activities, and ventilation in bank offices have a profound influence on IAQ parameters, primarily PM2.5 and CO_2. Further research is required to formulate strategies for enhancing IAQ in these settings.

Keywords: indoor air quality; bank office; indoor air parameters; ventilation

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1. Introduction

Indoor air quality (IAQ) is a well-known threat to human health, causing various health problems that can range from acute to chronic, short-term to long-term [1–3]. Pollutants such as carbon dioxide (CO_2), total volatile organic compounds (TVOCs), and particulate matter contribute to indoor air pollution at varying levels [4–6]. The severity of health symptoms caused by these contaminants depends on the specific pollutant, its concentration, and the duration of exposure [7]. Sick building syndrome (SBS) is a common effect of exposure to these contaminants, characterized by a series of uncomfortable health-related symptoms, including drowsiness, tiredness, a feeling of stale air, eye, nose, and throat irritations, allergies, headaches, fatigue, and other health symptoms [8–11]. Given that IAQ has a significant impact on worker comfort, performance, and well-being, it is an important area of study [3,12,13]. However, despite the large workforce in bank office buildings, there is limited information available about IAQ in these buildings.

Particulate matter PM10, PM2.5, and TVOCs are significant pollutants that harm building occupants' health [14], and their concentrations are influenced by occupant behavior [14–17]. The actions of those occupying a building can increase the release of particulate particles and VOCs from the floor into the air, thus decreasing IAQ. The necessary ventilation rate to achieve an acceptable IAQ level can be assessed by measuring the levels of particulate matter and TVOCs [18].

In Malaysia, the main sources of air contaminants come from land transportation, industrial emissions, and open burning [19]. The average concentration of PM2.5 and PM10 in the Klang valley ambient air is 25 $\mu g/m^3$ and 48 $\mu g/m^3$, respectively [20]. Due to a lack of proper air circulation, most of the outside pollutants are brought indoors, leading to a multiplication of their concentration. Long-term exposure to PM2.5 has been linked to decreased life expectancy and an increased risk of cardiopulmonary mortality. PM2.5 can penetrate deeply into the lungs, irritate and corrode the alveolar wall, and ultimately affect lung function [21]. This underscores the importance of examining the IAQ in the office building.

Indoor concentrations of TVOCs are often higher compared to outdoor levels due to indoor sources [22]. One study found that indoor workplace TVOC values were significantly higher during working hours than at outdoor concentrations [23]. Despite the reported increased levels of TVOCs in indoor environments, there have been limited studies conducted on TVOC concentrations in office buildings. There are hundreds of volatile organic compounds present in indoor air. The use of synthetic construction materials has increased in office buildings due to energy-saving measures, and these materials, such as vinyl flooring, particleboard, sealants, gypsum board, carpet, paint, varnish, and thermal insulation, are significant sources of TVOCs [24]. Furthermore, ventilation systems in office buildings also contribute to the emission of TVOCs. Office equipment such as banknote counters, banknote scanners, laptops, desktop computers, video display terminals, copier machines, carbon paper, copier paper, power cables, and cleaning agents have been identified as sources of TVOCs in the workplace, according to studies [25].

In a country with a hot and humid climate, air conditioning is widely used to achieve comfortable indoor temperatures. The increased usage of air conditioning due to the hot weather is expected to have an impact on the health of occupants [26]. Over the years, the use of air conditioning has risen steadily, and most bank offices use it to create a pleasant indoor environment. Although air conditioning can provide cool air to make an office building comfortable, it can also have significant impacts on IAQ and health [26–28]. For the comfort of the building's occupants, cooling the outside air demands a substantial quantity of energy. Reducing the amount of external air utilized for ventilation can yield substantial energy savings. This compromises the health and comfort of the occupants [29]. Thus, the indoor air quality of office buildings receives considerable attention [30]. In commercial buildings, Seppänen et al. [16] found a significant correlation between CO_2, ventilation rates, and human reaction. They have reported declining health and perceptions of air quality. Datta et al. [31] reported that the average of CO_2 concentration up to 1338 ppm during working hours in office buildings is due to low levels of ventilation. There are several reports from various regions of the world on the indoor air quality of office buildings. In Malaysia, however, there is limited research on IAQ in offices, particularly in bank offices and workplaces [32].

Ventilation is crucial in maintaining good IAQ in office buildings. To keep the air quality in bank office buildings in good condition, air filtration and exchange with outside air is essential. This system must be capable of conditioning the outdoor air before it is introduced into the building. Using this method, the concentration of pollutants in the building can be reduced to a safe level. Split unit air-conditioners are widely used in bank office buildings due to their low cost and ease of installation, operation, and maintenance. However, few studies have investigated the impact of this system on the concentration and dispersion of indoor pollutants [33].

The CO_2 concentration level can be used as a reference for evaluating the efficiency of the air conditioning system and ventilation performance [34]. Elevated CO_2 concentrations due to low air exchange rates can lead to an increase in the concentration of other indoor air pollutants. CO_2, a common gas, is a key indicator of air quality. Measured CO_2 can be used to evaluate the performance of ventilation systems and determine the required minimum amount of outdoor air introduced into the building. Previous studies have shown that with high levels of CO_2, building occupants may complain about drowsiness, tiredness, and a feeling of stale air [34–36].

To meet the standards of occupational safety and health and improve IAQ as outlined in the Industrial Code of Practice (ICOP), there is a need for a thorough evaluation to determine the lacking areas in current research regarding IAQ and its relationship to air emissions, health hazards, and exposure in bank office buildings.

Several variables have been investigated to enhance indoor air quality [37]. When the building's ventilation rate is increased, the quality of indoor air and the prevalence of SBS may improve [37–39]. The exchange rate of air in the workplace is crucial for maintaining air quality and controlling indoor air pollutants. To keep the CO_2 concentration in the low range (1000 ppm), the number of people in the building should align with its design, and to maintain the TVOC levels within the low range, it is necessary to raise the air change rate to meet the minimum requirement set by the ASHRAE 62–1 air change rate standard. Additionally, there is a significantly higher amount of fine particulate matter present in the air outside compared to inside [40].

The aim of this study was to assess the IAQ in bank offices. Sampling was conducted in two types of ventilation systems, the ACMV and split unit air-conditioning system, in both the operation and vault rooms. The indoor air parameters evaluated were CO_2, TVOCs, PM10, PM2.5, and physical parameters, and measurements were taken during working hours in each bank office building. To determine the relative hazard to worker health posed by various bank branches and workplaces, the Total Hazardous Ratio Indicator (THRI) was analyzed.

2. Methodology

2.1. Measurement of IAQ Parameter

The process of measuring IAQ parameters involves evaluating air contaminants present in a building. Air monitoring equipment is used to measure the concentration of air samples and monitor human exposure to indoor pollutants. This equipment can also identify and model the sources of pollutants inside the building. To determine the amount of outside air mixed with recirculated air inside a building, the CO_2 concentration in indoor air is commonly measured [41]. CO_2, a chemical gas produced by humans, is released into the air 100 times more when people exhale than when they inhale [42]. The concentration of CO_2 in an occupied indoor area is an indicator of the amount of outside air entering the building and whether enough outside air is being supplied to dilute indoor pollutants, including CO_2 [43]. According to ICOP [4], the indoor CO_2 concentration should not exceed 1000 ppm for daily 8 h.

The current study aimed to evaluate the IAQ of six banking offices located in Selangor, Kuala Lumpur, and Putrajaya in Malaysia. The selected banks were located at Jalan Rakyat in Brickfields, Kuala Lumpur; Jalan Tangsi in Kuala Lumpur; Jalan Bukit in Bandar Kajang, Kajang, Selangor; Seksyen 9 in Shah Alam, Selangor; Subang Jaya in Selangor; and Precinct 8 in Putrajaya, as depicted in Figure 1. Table 1 provides a description of the bank office buildings. The study was conducted throughout a workday to simulate actual banking operations, taking into account the bank's main areas (operations and vault), activities, occupants, and ventilation system.

From August 2018 to January 2019, indoor air temperature, relative humidity, particulate matter (PM10 and PM2.5), CO_2, and TVOCs were measured in the selected bank offices. The measurements took place from 9.00 a.m. to 4.00 p.m. to reflect the working hours of the bank operations. Additionally, the outside air temperature, relative humidity, and CO_2 were measured for each selected bank office. Malaysia's tropical climate is characterized by a uniform temperature, high humidity, and heavy rainfall, with an average temperature of 26.7 °C per year [44,45].

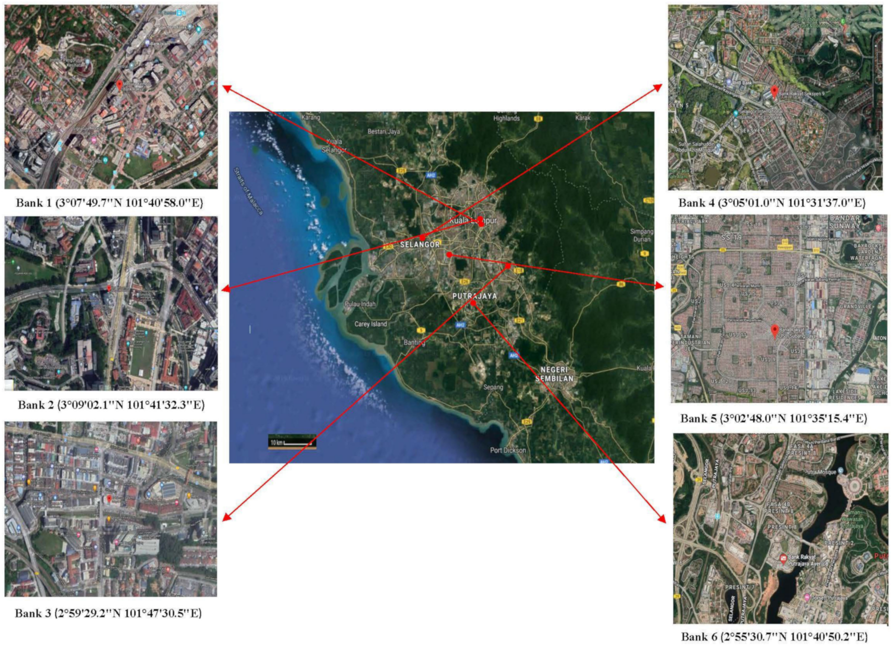

Figure 1. Location of banks.

Table 1. Basic information about investigated bank offices.

Parameter	Bank 1	Bank 2	Bank 3	Bank 4	Bank 5	Bank 6
Location	Brickfield, KL	Jalan Tangsi, KL	Kajang	Seksyen 9, Shah Alam	USJ, Subang Jaya	Putrajaya
Type of building	Ground floor, high rise building	Ground floor, high rise building	2 story commercial building	2 story commercial building	2 story commercial building	3 story commercial building
Year of construction	2014	1982	2008	1996	1996	2015
Ventilation type	ACMV	ACMV	AC	AC	AC	AC
Vault volume [m^3]	22.56	202.37	22.66	39.18	25.14	28.38
Operation Division volume [m^3]	189.70	860.30	149.73	140.50	134.60	193.67
Occupant (min-max)	9–18	8–16	10–26	10–34	6–18	4–22
Environment	Town, High traffic	Town, High traffic	Town, High traffic	Town, Low traffic	Town, Low traffic	Town, Low traffic
Door area [m^2]	4.1	4.1	4.1	4.1	4.1	4.1
Floor type [Operation Division]	Tile & Carpet	Tile	Tile	Tile	Tile	Tile & Carpet
Floor type [Vault]	cement	Carpet	Cement	cement	cement	cement

CO_2 concentration levels play a crucial role in evaluating indoor ventilation performance. CO_2 serves as an indicator of air quality in inadequately ventilated spaces, as its presence is directly proportional to the quantity of fresh air that enters a room through ventilation systems and openings. TVOC levels were measured using the MiniRAE 2000

Model PGM-7600 Organic Vapor Monitor from RAE Systems (San Jose, CA, USA). The particulate matters PM10 and PM2.5 were measured by the DustTrak DRX Aerosol Monitor 8534 from TSI (Dallas, TX, USA). The CO_2 levels were measured by the IAQ Meter Fluke 975 Air Meter from Fluke (Everett, WA, USA) and the QUEST AQ5000 Air Quality Monitor from QUEST (Brooklyn, NY, USA). The instruments were set to log data at 5-min intervals, positioned at a height of 1 m above the floor, near the employees in the operation division and bank vault, as shown in Figure 2 [4]. Occupant data were collected during the measurement period.

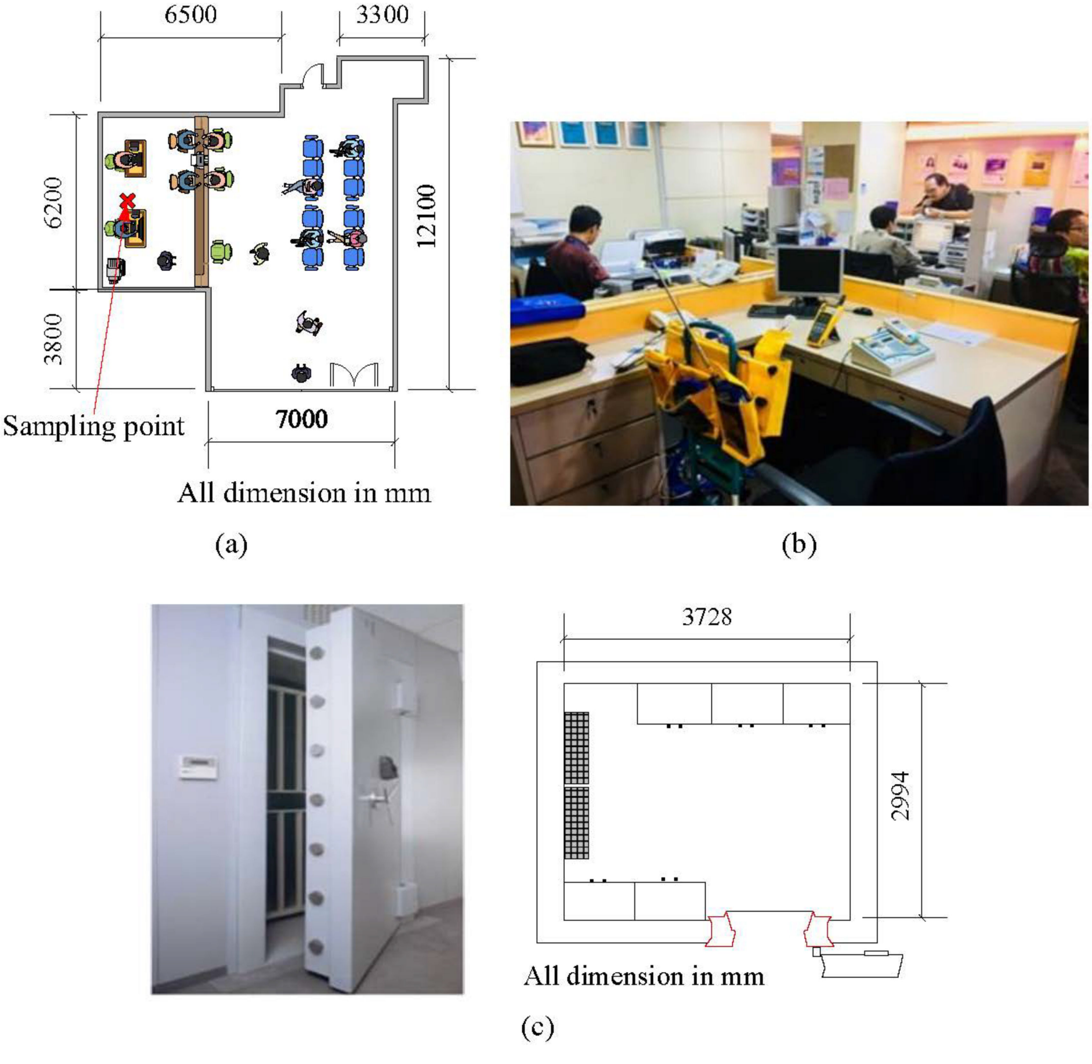

Figure 2. Location of sampling. (**a**) Floor plan bank 3 (operation division). (**b**) Photo of sampling equipment (**c**) view and floor plan bank 3 (vault).

2.2. Hazard Ratio Analysis

The total hazard ratio (THR) is a statistical measure used in analysis to assess the risk of hazard exposure between two groups or a reference level over a certain period. Essentially, the THR is the ratio of the hazard rates in both groups, which indicates the relative risk of exposure to indoor air pollutants. When the THR is 1, it suggests that exposure levels are lower compared to the reference standard. Conversely, a THR greater than 1 indicates a higher risk of exposure beyond allowable limits, while a THR less than 1 indicates that the exposure and risk are below the allowable limits.

In this study, the THR is a measure used to evaluate the exposure of workers to different air pollutants. This is done by comparing the daily air concentrations of the pollutants to their corresponding inhalation limits, which are also known as reference concentrations. The reference concentrations used in this study were 3000 ppb for TVOCs, 25 μg/m^3 for PM2.5, and 1000 ppm for CO_2.

To calculate the hazard ratio (HR) for each pollutant and the total hazard ratio for each bank (THR_{Bank}), Equations (1) and (2) were used. Equation (1) calculates the HR for each pollutant by dividing the measured average concentration by the reference concentration. Equation (2) calculates the THR_{Bank} by summing the HRs for each pollutant [31,46,47]:

$$HR_i = \frac{C_i}{RfC_i} \quad (1)$$

$$THR_{Bank} = \sum HR_i, \quad (2)$$

where C_i is the measured average concentration and RfC_i is the reference concentration.

2.3. Evaluation of the Results

To evaluate the results, descriptive statistical analysis and mean comparison *t*-tests were performed using IBM SPSS Statistics 26. Descriptive statistical analysis was performed for each bank office to assess the level of IAQ parameters, including CO_2, TVOCs, PM10, and PM2.5. Mean comparisons of IAQ-parameter measurements between bank offices, sampling locations, and ventilation types were carried out using *t*-tests for CO_2, TVOCs, PM10, and PM2.5 concentrations.

3. Results

3.1. IAQ Parameters at Bank Vault

This research was conducted following the guidelines provided by the Industrial Code of Practices for Indoor Air Quality 2010 (ICOP) published by the Malaysian Department of Occupational Safety and Health [4]. The study measured IAQ parameters in various bank vaults and compared them based on different types of ventilation systems.

As shown in Table 2, the results showed that in four bank vaults (banks 3, 4, 5, and 6) that used split air-conditioning units, the concentration of CO_2 exceeded the ceiling limit set by the ICOP [4]. The mean CO_2 levels were found to be 1560, 1465, 1093, and 1399 ppm, respectively. However, the bank vault that used ACMV-type ventilation had lower average CO_2 levels below 1000 ppm. The mean CO_2 levels in banks 1 and 2 were 920 ppm and 640 ppm, respectively. The concentration of PM10 in the bank vaults with AC-type ventilation was higher compared to those with ACMV-type ventilation. The highest PM10 concentration was recorded in bank 6, with 35.12 μg/m^3, while the maximum PM10 concentration was recorded in bank 3, reaching 60 μg/m^3.

The TVOC levels measured in all bank vaults were within the standard level set by the ICOP [4], ranging from 35 to 666 ppb. However, bank 2 recorded a higher level of TVOCs, which was 607.7 ppb, exceeding the standard set by WHO at 500 ppb, which may cause symptoms of SBS among occupants.

Regarding the temperature inside the bank vaults, as in Table 3, the results showed that the temperature levels in the bank vault with ACMV-type ventilation ranged from 23.2 to 28.8 °C, while those with AC-type ventilation ranged from 22.5 to 29 °C, exceeding the standard range of 22 to 26 °C set by the ICOP [4]. The environment inside the bank vault was relatively hot compared to the outside environment. In the end, the levels of relative humidity that were measured in every bank vault varied between 38.4% and 59.3 %RH. Bank 4 had the lowest mean recorded at 39.95%RH, while the highest mean was observed at 51.49 %RH.

Table 2. Concentration of IAQ parameter at vault.

Ventilation Type IAQ Parameter	Bank 1 ACMV				Bank 2 ACMV				Bank 3 AC				Bank 4 AC				Bank 5 AC				Bank 6 AC				Reference Standard
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	
CO_2 (ppm)	920.1	143.2	744	1128	640.9	18.35	615	700	1560	205.6	1050	1877	1465	168.4	1102	1716	1093	135.8	934	1399	1027	72.14	784	1112	1000 ppm (ICOP/ASHRAE)
PM2.5 (µg/m^3)	7.23	2.41	4.00	13.00	12.06	1.29	10.00	17.00	27.44	10.48	15.40	57.70	26.72	2.89	21.00	37.00	18.72	1.90	16.00	25.00	30.63	6.67	20.00	45.00	25 µg/m^3 (WHO)
PM10 (µg/m^3)	8.28	2.60	5.00	15.00	13.00	1.30	11.00	18.00	29.17	10.30	17.00	60.00	30.62	2.40	25.00	39.00	21.48	1.40	19.00	27.00	35.12	7.30	26.00	49.00	150 µg/m^3 (ICOP)
TVOC (ppb)	1113.2	16.46	58	133	607.7	38.76	525	666	118.9	30.39	68	185	160.4	35.08	114	229	187	34.95	35	237	143	18.83	58	159	3000 ppb (ICOP)
Temperature	28.09	0.829	24.3	28.8	27.44	0.683	23.2	27.7	27.9	0.922	24.2	29	26.34	0.907	22.5	27.3	27.05	0.538	24.3	27.5	27.04	0.858	23.2	28.1	23–26 °C
RH (%RH)	42.91	1.55	40	49	49.62	1.35	46.5	55	51.7	1.67	50	58.1	39.95	1.52	38.4	48.7	51.49	1.55	49.1	59.3	41.99	2.27	40	55.1	40–70% RH
Air Movement (m/s)	0.01	0.05	0	0.02	0.005	0.018	0	0.1	0.012	0.027	0	0.1	0.001	0.004	0	0.02	0.002	0.006	0	0.03	0.014	0.004	0	0.15	0.15–0.5 m/s

ACMV: Air conditioning and Mechanical Ventilation System; AC: Split unit Air-Conditioner; ICOP: Industrial Code of Practices on Indoor Air Quality 2010; ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers; WHO: World Health Organization.

Table 3. IAQ parameters for different types of ventilation in bank vaults.

IAQ Parameter	Ventilation Type ACMV Average	Min	Max	AC Average	Min	Max
CO_2 (ppm)	780.48	615	1128	1286.23	784	1877
PM2.5 (μg/m^3)	9.64	4.00	17.00	25.88	15.40	57.70
PM10 (μg/m^3)	10.64	5.00	18.00	29.10	17.00	60.00
TVOC (ppb)	360.46	58	666	152.34	35	237
Temperature	27.76	23.2	28.8	27.08	22.5	29.0
RH (%RH)	46.26	40	55	46.28	38.4	59.3
Air movement (m/s)	0.003	0.00	0.10	0.007	0.00	0.15

ACMV: Air conditioning and Mechanical Ventilation System; AC: Split unit Air-Conditioner.

The provided information pertains to the study of CO_2 concentration patterns in a bank vault over a specific time-period. The findings are presented in Figure 3, which depicts a time-series plot of CO_2 levels at a 5-min interval.

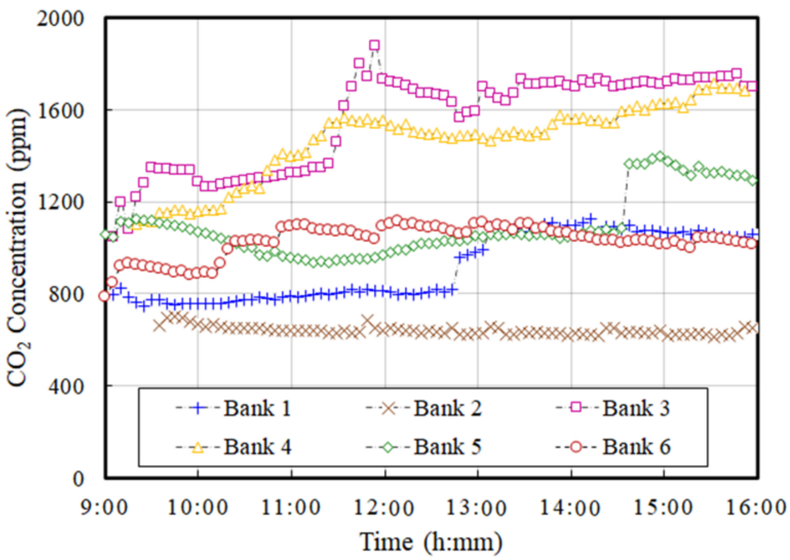

Figure 3. Time-series plot of CO_2 in bank vault, each point at 5-min interval over the study period.

Upon analyzing the graph, it becomes evident that the majority of the CO_2 concentration patterns observed have shown an upward trend. The concentration of CO_2 at bank 2 remained relatively constant and within the range of 600–700 ppm. However, bank 3 experienced the highest concentration of CO_2, with a peak value of 1800 ppm.

3.2. IAQ Parameters at Operation Area (Teller Counter)

Tables 4 and 5 present measurements of IAQ parameters in the banking division, including CO_2 levels, temperature, and relative humidity. According to the data, four banking operations exceeded the limit value established by the ICOP for CO_2 levels [4]. These operations used split air conditioning and were identified as bank 3, 4, 5, and 6, with average CO_2 levels of 1315, 1743, 1328, and 1232 ppm, respectively. On the other hand, the location that used ACMV recorded an average CO_2 concentration below 1000 ppm, which was lower compared to split air-conditioned banking offices.

Table 4. Concentration of IAQ parameters at operation divisions.

Ventilation Type IAQ Parameter	Bank 1 ACMV				Bank 2 ACMV				Bank 3 AC				Bank 4 AC				Bank 5 AC				Bank 6 AC				Reference Standard
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	
CO_2 (ppm)	925.6	96.59	709	1050	620.5	26.85	577	753	1315	107.6	1105	1523	1743	180	1296	1956	1328	74.63	1190	1472	1232	101.8	951	1522	1000 ppm (ICOP/ASHRAE)
PM2.5 (µg/m^3)	16.87	2.62	12.00	22.00	8.09	2.61	1.00	15.00	53.05	1.21	49.00	56.00	51.01	4.62	41.00	59.00	39.59	4.12	29.00	46.00	31.69	6.80	22.00	44.00	25 µg/m^3 (WHO)
PM10 (µg/m^3)	18.45	2.70	13.00	24.00	9.34	2.90	4.00	17.00	54.68	1.50	51.00	55.00	54.90	5.00	52.00	54.00	42.64	4.30	30.00	49.00	35.84	7.30	25.00	49.00	150 µg/m^3 (ICOP)
TVOC (ppb)	538.8	23.75	430	570	22.32	3.366	18	30	139.6	10.47	121	165	167.9	13.6	151	200	157.8	13.82	97	179	223	25.47	84	268	3000 ppb (ICOP)
Temperature	23.72	0.23	22.7	24.2	19.98	0.5	19.2	21.7	20.3	1.414	18.4	23	20.44	1.752	18.9	25.1	22.49	0.282	22.1	23.6	20.86	0.421	20.1	21.5	23–26 °C
RH (%RH)	50.64	0.199	50.2	50.9	60.45	0.46	59.9	61.7	52.27	1.737	44.4	49.7	55.83	1.258	52.6	58.6	52.85	1.699	50.5	59.6	51.48	1.029	49.8	53.7	40–70% RH
Air Movement (m/s)	0.124	0.013	0.11	0.17	0.079	0.013	0.05	0.11	0.152	0.055	0.09	0.31	0.06	0.03	0	0.12	0.057	0.007	0.05	0.09	0.015	0.007	0	0.03	0.15–0.5 m/s

ACMV: Air conditioning and Mechanical Ventilation System; AC: Split unit Air-Conditioner; ICOP: Industrial Code of Practices on Indoor Air Quality 2010; ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers; WHO: World Health Organization.

Table 5. IAQ parameters for different types of ventilation at bank operations.

IAQ Parameter	ACMV Average	ACMV Min	ACMV Max	AC Average	AC Min	AC Max
CO_2 (ppm)	773.05	577	1050	1404.40	951	1956
PM2.5 (µg/m^3)	12.48	1.00	22.00	43.84	22.00	59.00
PM10 (µg/m^3)	13.90	4.00	24.00	47.02	25.00	55.00
TVOC (ppb)	281	18	570	172	84	268
Temperature	21.6	19.2	24.2	21.0	18.4	25.1
RH (%RH)	55.5	50.2	61.7	53.1	44.4	59.6
Air movement (m/s)	0.101	0.05	0.17	0.071	0.00	0.31

ACMV: Air conditioning and Mechanical Ventilation System; AC: Split unit Air-Conditioner.

Bank 3 had the highest concentration of PM10, measuring 55.00 µg/m^3, while bank 4 had the highest mean concentration of PM10 at 54.9 µg/m^3. The highest mean PM2.5 level was found in bank 3, which measured 53.05 µg/m^3, while the highest PM2.5 level in bank 4 was 59.00 µg/m^3. The concentration of PM10 was below the standard level of 150 µg/m^3, but the concentration of PM2.5 exceeded the standard level of 25 µg/m^3.

Measurements of TVOC ranged from 18–570 ppb, which was below the standard level of 3000 ppb set by the ICOP [4]. However, bank 1 recorded a TVOC level higher than the standard level set by the WHO of 500 ppb [48]. The temperature was also measured at both banks, with the ACMV-type of ventilation ranging from 19.2–24.2 °C and the AC-type ranging from 18.4–25.1 °C. All temperature levels were outside the standard range set by ICOP of 22–26 °C, and at times, the environment inside the bank felt cool as it was below 22 °C. The RH was measured at 44.4–61.7% RH, which was within the standard range set by ICOP of 40–70% RH.

Figure 4 displays a time-series plot of CO_2 concentration levels at the area of operation division at a 5-min interval throughout the study duration. The majority of the CO_2 concentration levels increased over time, with bank 2 measuring within the range of 600–700 ppm. The highest CO_2 level was found in bank 4, peaking at 1956 ppm. There was a significant difference in the CO_2 level between the ACMV- and AC-types of ventilation banks, with the AC-type recording a comparatively higher level of CO_2 exceeding 1000 ppm.

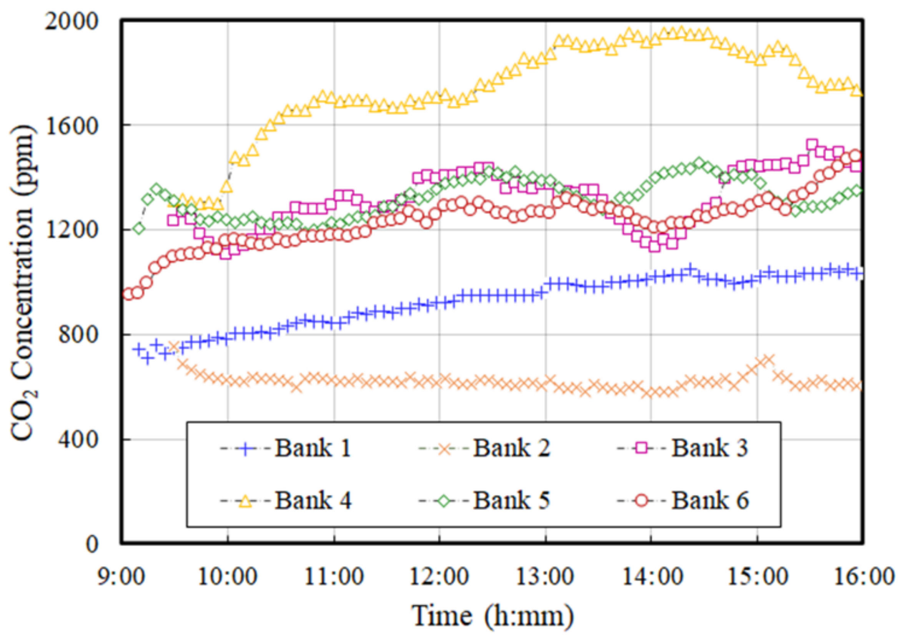

Figure 4. Time-series plot of CO_2 in operation divisions, each point at 5-min interval over the study period.

3.3. PM10 Indoor/Outdoor Ratio (I/O)

A study was conducted to measure PM10 concentration simultaneously indoors and outdoors of six different bank offices using direct reading equipment. Figures 5 and 6 shows the average I/O ratio values for PM10. Bank 5 had the highest ratio values for PM10, ranging from 0.16 to 1.02, indicating that indoor PM10 concentration was lower compared to outdoor concentration, resulting in I/O ratios below 1.0. Four bank offices had I/O ratios close to unity, indicating significant outdoor sources of PM10. The lower I/O ratio was obtained for bank 1 and 2 because the air coming into the building was filtered, resulting in a lower concentration of PM10 compared to outside.

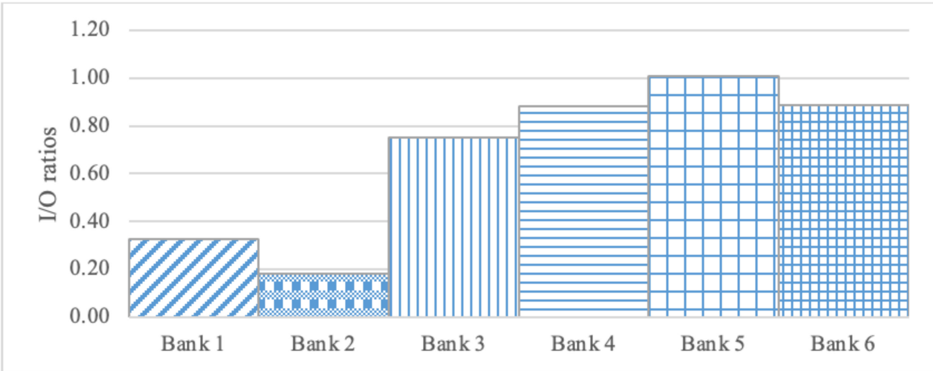

Figure 5. Indoor/Outdoor (I/O) ratio value for PM10 at six different bank offices.

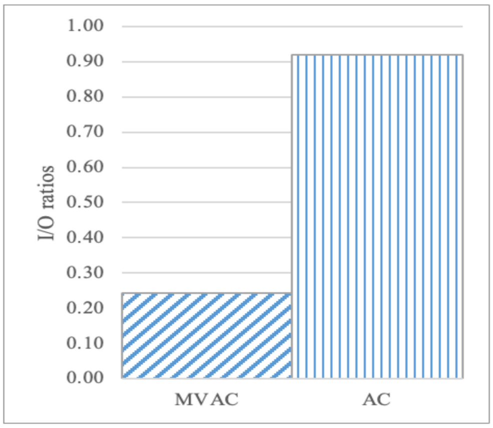

Figure 6. Indoor/Outdoor (I/O) ratio value for PM10 by type of ventilation offices.

The group of bank offices that used ACMV systems had lower I/O ratio values compared to those using AC systems. The average I/O value for group AC and ACMV were 0.92 and 0.24, respectively. Bank 5 had an I/O ratio above 1.0 (1.02), indicating a higher PM10 concentration indoors compared to outdoors due to the combination of outdoor sources and the effect of resuspension of particles. Bank 2 had the lowest I/O ratio of 0.16, indicating a lower PM10 concentration indoors compared to outdoors and other bank offices, possibly due to higher ventilation rates and lower occupancy.

Pearson correlations analysis showed a significant correlation between indoor and outdoor PM10 concentrations at each bank location. Banks 1 and 2 had weak correlation coefficients of r^2 = 0.36, $p < 0$, while banks 3, 4, 5, and 6 had strong correlations with r^2 = 0.36, $p < 0$. Bank 4 did not show a significant correlation, possibly due to sources of PM10 other than outdoor air, such as activities and occupancy levels, which could lead to resuspension of deposited particles. Bank 4 had the highest number of occupants among the bank offices.

Pearson correlations analysis revealed a significant correlation between indoor and outdoor PM10 concentrations at each bank location. Banks 1 and 2 had a weak correlation coefficient of $r^2 = 0.36$, $p < 0$ and $r^2 = 0.36$, $p < 0$, respectively. Banks 3, 4, 5 and 6 had strong correlation with $r^2 = 0.36$, 0.36, 0.36 and 0.36, $p < 0$, respectively. Bank 4 had no significant correlation. This is because the source of particles was not only due to outside air. It also may be due to the sources of variables such as activities and number of occupants and indirectly it could cause the resuspension of deposited particles. Bank 4 recorded the highest number of occupants in the bank office.

3.4. Total Hazard Ratio Indicator

Table 6 indicates the hazard ratio in the bank vault. The total HR of CO_2, TVOC, PM10, and PM2.5 was significantly lower for all bank office buildings in the bank vault area. Total HRTVOC was significantly higher for the bank 2 vault which used the ACMV system compared to other locations studied in the bank office. The floor of this area has been furnished with carpet and a significant number of files and papers are placed in an open cabinet.

Table 6. Hazard ratio in the bank vault.

Location	Type	CO_2	HR TVOC	PM10	PM2.5	THR
Bank 1	ACMV	0.92	0.04	0.06	0.29	1.30
Bank 2	ACMV	0.64	0.20	0.09	0.48	1.41
Bank 3	AC	1.56	0.04	0.19	1.10	2.89
Bank 4	AC	1.46	0.05	0.20	1.07	2.79
Bank 5	AC	1.09	0.06	0.14	0.74	2.04
Bank 6	AC	1.03	0.05	0.23	1.23	2.54
Total		6.70	0.44	0.92	4.91	12.97

ACMV: Air-Conditioner and Mechanical Ventilation System, AC: Split unit air-conditioner, HR: Hazard ratio, THR: Total hazard ratio; Mean of the data measured from 9.00 a.m. to 5.00 p.m. at an interval of 5 min at each sampling point for CO_2, TVOC, PM10 and PM2.5.

Table 7 indicates the calculation of the hazard ratio at the operation area. In the bank 4 operation area, the HR of CO_2 was much higher. Average THRAC was significantly higher in bank 3 (3.85), bank 4 (4.21), bank 5 (3.25), and bank 6 (2.81) relative to bank 1 (1.90) and bank 2 (1.01). This is due to considerably higher $HRCO_2$, HRPM10, and HRPM2.5 levels at the bank office that utilized AC systems, as compared to other banks that utilized ACMV systems.

Table 7. Hazard ratio in operation areas.

Location	Type	CO_2	HR TVOC	PM10	PM2.5	THR
Bank 1	ACMV	0.93	0.18	0.12	0.67	1.90
Bank 2	ACMV	0.62	0.01	0.06	0.32	1.01
Bank 3	AC	1.32	0.05	0.36	2.12	3.85
Bank 4	AC	1.74	0.06	0.37	2.04	4.21
Bank 5	AC	1.33	0.05	0.28	1.58	3.25
Bank 6	AC	1.23	0.07	0.24	1.27	2.81
Total		7.16	0.42	1.44	8.01	17.03

ACMV: Air-Conditioner and Mechanical Ventilation System, AC: Split unit air-conditioner, HR: Hazard ratio, THR: Total hazard ratio; Mean of the data measured from 9.00 a.m. to 5.00 p.m. at an interval of 5 min at each sampling point for CO_2, TVOC, PM10 and PM2.5.

4. Discussion

4.1. CO_2 Concentration

The average CO_2 concentration outside the bank office buildings of bank 1, bank 2, bank 3, bank 4, bank 5, and bank 6 during the sampling period was 545, 514, 510, 560, 550, and 540 ppm, respectively. The average CO_2 concentration of outside air was found to be uniform with a value of 536.5 ppm. The study revealed that the average CO_2 concentration in banks 3, 4, 5, and 6 was much higher than the recommended standard. However, the average CO_2 concentration inside the bank offices of bank 1 and bank 2 was within the recommended limit, indicating that their ventilation systems were performing well and providing an adequate supply of outside air to dilute the CO_2 concentration. The results showed that the ACMV systems were able to provide good indoor air quality by reducing CO_2 levels and improving ventilation, while split unit air-conditioners were not as effective.

The CO_2 concentration in bank offices was found to vary based on several factors. Banks 1 and 2 had lower CO_2 levels compared to the other banks evaluated due to their ventilation systems. The ACMV-type of ventilation in banks 1 and 2 allowed for a sufficient supply of outside air to dilute the CO_2 concentration, while the split unit air-conditioner systems in banks 3, 4, 5, and 6 resulted in a higher concentration of CO_2. The increase in CO_2 levels was also influenced by the rise in the number of visitors in the bank offices, which was highest in the afternoon. The frequency of opening the entry doors and the lower staff density in banks 1 and 2 also contributed to lower CO_2 levels. The proximity of the bank building to a busy road and the type of ventilation, building, and environment also played a role in the CO_2 concentration. The results showed that the concentration of CO_2 inside the bank offices was higher during business hours, reaching a peak level in the afternoon and declining before office hours began in the morning. The results suggest that the performance of the ventilation systems, the number of visitors, and the proximity of the bank to busy roads can impact the CO_2 concentration in bank offices.

4.2. PM10 and PM2.5

The study found that the PM10 and PM2.5 concentrations were significantly higher in banks 3, 4, 5, and 6 compared to banks 1 and 2, which utilized split unit air-conditioners. For all the locations sampled, the PM10 concentration was recorded within the standard limit set by ICOP [4], while the PM2.5 level exceeded the guideline value set by WHO [48]. The results showed a significant difference in the average PM10 and PM2.5 concentrations between bank offices that used ACMV and split unit air conditioning systems.

Banks 3, 4, 5, and 6 were equipped with split unit air-conditioning systems, while banks 1 and 2 were equipped with central air conditioning (ACMV) systems. Split unit air conditioning was found to have reduced air circulation within the building compared to central air conditioning. The ACMV systems in banks 1 and 2 allowed for better air circulation, due to the outdoor air that entered through the air intake. The PM10 and PM2.5 concentration was similar at all four sites, and significantly lower in bank 6 than in the other bank offices. The concentration of PM10 and PM2.5 was found to be different between the operation division and bank vault sampling locations in bank offices with ACMV ventilation. A high PM10 concentration was observed in the bank vault, attributed to banking operations and proximity to the entrance door. In contrast, bank 3 showed a substantially higher PM10 concentration. This is likely due to reduced air circulation in the bank offices with split unit air-conditioners, leading to PM10 and PM2.5 entrapment and raising their concentration. There appears to be a correlation between PM10 and PM2.5 levels and ventilation performance, with air exchange rate, deposition rate, and penetration factors having a big effect on indoor PM2.5 concentration [49,50]. The operation of bank offices was found to contribute to the concentration of PM10 and PM2.5, which may negatively impact worker health and comfort.

4.3. TVOC Concentration inside Building

The concentration of total volatile organic compounds (TVOC) in indoor air can provide insight into air quality [51,52]. The Department of Occupational Safety and Health, Malaysia has established a standard for indoor TVOC levels [4]. The database of TVOC levels in Malaysia is limited, with typical levels around 0.3 ppm or lower in various indoor environments. The TVOC levels in the six bank office buildings were generally low, except for bank 1 with a carpeted floor. Bank 2 had the lowest TVOC concentration (22.32 ppb), while bank 1 had the highest (538.78 ppb). High air exchange rates and the absence of carpet flooring in bank 2 may have contributed to the lower TVOC levels [53]. Computers, printers, and photocopiers in the bank offices may also be a source of TVOCs.

A time-series analysis of TVOC levels in various bank offices found that the concentration of TVOCs in offices with air conditioning and ventilation systems decreased from morning to afternoon. The use of air fresheners and bank operations may have contributed to the increase of TVOC levels in the offices. Previous research has shown that these products can raise TVOC levels in poorly ventilated spaces [54]. The early morning increase in TVOC levels in all locations may be due to the buildup of overnight concentration and the reduction in banks 1 and 2, where air exchange dilutes TVOC generation. Banks 3, 4, 5, and 6 show little reduction in TVOC levels due to limited exchange of outside air. The presence of people and air infiltration may have diluted the TVOC concentration within the offices. Bank 1 had the highest concentration of TVOCs (538.78 ppb), possibly due to carpet flooring and lower air exchange rate compared to bank 2. Despite being lower than the ICOP level of 3000 ppb, the TVOC concentration was still significant in all bank offices. The high level of TVOCs in bank 2's vault was attributed to the use of carpet flooring. There have been studies that have identified TVOC emissions from human activity [55], indoor office buildings [56], universities [57], homes, schools [58], and workplaces [59].

Outdoor vehicle emissions have been identified as significant sources of TVOCs, including gas leaks from air conditioning systems [60]. Previous research has also reported on the impact of office equipment on TVOC levels, including indoor air pollutants emitted by such equipment [61,62]. Temperature, humidity, and other environmental conditions can influence the concentration of TVOCs [63]. Son et al. [64] found a negative correlation between the air exchange rate and the concentration of certain VOCs in indoor air. There were typical sources of TVOCs in bank offices that emitted considerable amounts of TVOCs. Identification of sources and provision of sufficient ventilation contribute to the lowering of TVOC concentration.

4.4. Physical Parameter

Thermal comfort and IAQ are greatly impacted by physical parameters such as temperature, relative humidity, and air movement. While the temperature in most bank operation areas was below the minimum standard of 22 °C, all the bank vaults had a temperature above 26 °C. The relative humidity in the bank's ACMV and split unit air-conditioning systems were generally within the standard range. However, the air movement in these systems did not reach the minimum required flow of 0.15 m/s.

4.5. Total Hazard Ratio Indicator

The total indoor air contaminant hazard ratio (HR) at each bank office location was calculated using the standard concentration threshold level for a duration of 8 h, based on the bank's normal operation. In the area of operation division at banks 3, 4, 5 and 6, the CO_2 HR was significantly higher compared to banks 1 and 2. The operations division's total HR for PM2.5 and CO_2 was significantly higher than other indoor air pollutants at six different bank locations. However, the CO_2 HR was significantly high at bank 4. The average THRAC at banks 3, 4, 5, and 6 (3.53) was significantly higher compared to bank 1 and bank 2 (1.46). This is due to the significantly higher $HRCO_2$, HRPM10, and HRPM2.5 of the bank offices that used split unit air-conditioning systems compared to other bank offices that used ACMV systems. THR values were higher at all study sites than previously reported levels in office environments [31] and schools in Italy [65].

At all bank office locations, the total HR of CO_2, TVOC, PM10, and PM2.5 was significantly lower in the bank vault. This suggests that employees in the operation area are more exposed to air pollutants, particularly in banks that use split unit air conditioning systems. The total HRTVOC at the bank 2 vault was significantly higher compared to other locations measured. This may be due to the presence of a carpeted floor and open file cabinets in the vault, which can trap and release indoor air pollutants.

5. Conclusions

The unique environment of bank offices poses a risk to the health and productivity of bank employees. This study analyzed various indoor air quality factors such as TVOC, CO_2, PM10, PM2.5, relative humidity, temperature, and air movement in bank offices. The results showed that the concentration of these contaminants is significant and that the type of ventilation in the bank building has a major influence on IAQ. The high levels of PM2.5 and CO_2 measured exceeded reference standards and were associated with internal sources, ventilation, filtration of outdoor air, and bank office activity. The study also highlights the need for a risk evaluation of specific VOCs and the importance of reducing PM2.5 and CO_2 levels promptly in bank offices. This research highlights the importance of maintaining optimal indoor air quality in bank offices to ensure the safety and productivity of bank employees.

Study Limitation

Research was carried out in selected bank offices in Malaysia and only seven major indoor air parameters stipulated in the Department of Occupational Safety and Health (DOSH) code of practice were measured.

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