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Occupants' Satisfaction toward Indoor Environment Quality of Platinum Green-Certified Office Buildings in Tropical Climate

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Abstract: The quality of the indoor environment has become a vital component for buildings due to the time spent indoors. To this extent, the performance of the indoor environment is considered as part of the greenery criteria by green rating schemes such as the Green Building Index in Malaysia. This study aims to investigate and assess the quality of the indoor environment of Platinum-certified office buildings in a tropical climate. This research applied a case study approach over two Platinum-certified office buildings. Post-occupancy evaluation is employed integrating full-scale measurement with an occupants' survey. The measurement was carried out from May to August, and 112 questionnaires were retrieved to evaluate occupants' satisfaction with aspects of the indoor environment. Thermal comfort, indoor air quality, acoustic, lighting, furniture, and cleanliness are considered as the main study variables. The findings of full-scale measurement indicated high relative humidity, and low air velocity and illuminance. While occupants reported overall indoor environment quality (IEQ) comfort, a significant correlation of variables was observed. The main sources of dissatisfaction were identified as overcooling around 24 °C, high relative humidity (RH), around 70% RH, glare, and background noise around 51.9 dB. Statistically, a significant difference between occupants' responses to IEQ of two cases was identified, although both buildings are labelled with a Platinum certificate.

Keywords: building performance assessment; indoor environment quality; occupants' satisfaction; post-occupancy evaluation; Green Building Index; tropical climate



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1. Introduction

The quality of the environment inside any building is called indoor environment quality (IEQ) [1]. IEQ has been proven to have a significant effect on occupants' wellbeing, health, comfort, productivity, and behaviour; thus, it has been a vital research area for decades [2,3]. The focus of the research in the field of IEQ has been adapting continuously according to human demands. For instance, poor indoor air quality (IAQ) as one of the IEQ parameters, could lead to sick building syndrome (SBS), which has been acknowledged as a health issue since the 1970s [4]. Later, the focus has become wider, from health issues to occupants' comfort. Various studies have investigated parameters

of IEQ such as thermal quality, IAQ, acoustic quality, lighting quality, etc., concerning occupants' comfort and satisfaction [5–8]. Also, researchers evaluated IEQ, implying that the acceptable ranges of IEQ factors can be varied case by case. Sadick et al. [9] evaluated the importance of IEQ in offices of Ghana with a tropical climate. This study concluded that improving IEQ can positively impact the occupants' productivity. Besides, indoor air temperature is found to be an effective factor in thermal comfort and the perception of IEQ variables of offices located in tropical climates [10]. Another study in the tropical climate of Singapore showed that the most acceptable temperature is 26 °C in offices using ceiling fans [11]. Nematchoua et al. [12] reported that workers' productivity in Cameroon offices dramatically reduced in temperatures above 28 °C.

After the introduction of green buildings, studies attempted to compare IEQ of green buildings with conventional ones [13,14]. A recent comparative study reported that the SBS prevalence was found to be 38.1% and 53.1% in green and conventional buildings, respectively [3]. Also, Lee et al. [15], in a comparative study, investigated satisfaction and health symptoms, reporting higher IEQ acceptance for employees of green offices.

General beliefs are that green buildings are preferred regarding the performance competition against conventional buildings. Some studies claimed that the occupants of green buildings reported higher satisfaction and healthier in comparison to conventional buildings [14]. On the other hand, there are studies that indicated that there is no significant difference in occupants' satisfaction and wellbeing between IEQ of green and conventional buildings [16,17]. MacNaughton et al. [17] used post-occupancy evaluation (POE) to compare occupants' satisfaction between green and conventional buildings. In this study, occupants moved from a conventional to green building, reporting higher IEQ satisfaction from the green building. The result of this experiment indicated that the green building has higher performance for occupants, however, it is not possible to generalise this finding. For instance, Paul et al. [16] reported that there is no significant difference in occupants' satisfaction from IEQ of green and conventional buildings.

A high-performance green building brings higher occupants' productivity, which could be considered as the ultimate economic outcome [18], considering that studies indicated occupants' higher productivity, healthier, less absenteeism, and lower compensation for health insurance and claim returns, resulted from green buildings [19–22]. Moreover, green buildings are known for the energy-saving benefits, which ultimately reduce energy consumption costs.

However, the energy-efficient design approach might have side effects on green building performance. Providing a thermally comfortable environment usually has a direct influence on the energy consumption of office buildings. The majority of office buildings implemented heating, ventilation, and air-conditioning (HVAC) systems to maintain indoor air temperature, typically between 21.5 and 24 °C [23]. Additionally, HVAC systems attributed to about 43% of total energy consumption in US office buildings [24]. Thus, reducing energy consumption by increasing HVAC set points could lead to the uncomfortable indoor thermal condition [25]. Particularly, green office buildings in a tropical climate, where the HVAC system is often the main source of cooling or ventilation in the buildings, could become a challenge [26].

In addition, conflicts within IEQ parameters might occur with an attempt to provide a high-performance building. For instance, a high ventilation rate from a natural ventilation or mechanical system to improve IAQ could contribute to increasing background noise, resulting in acoustic discomfort [27]. This conflict could also happen between thermal comfort and daylight, to provide visual comfort, particularly for green buildings, as presented by Liang et al. [14]. Occupants in this study reported high satisfaction with lighting, but thermal comfort was less satisfactory. This could be due to the application of daylight resulting in higher heat exchange with the indoor environment and the increase in indoor temperature [28]. Application of daylight also associates with an increase in glare, which negatively affects visual comfort [29]. On the other hand, daylight has the potential to reduce energy consumption and provide health benefits [30].

Concerning IEQ influence on health and productivity, the extent of the effect depends on the IEQ variables. As mentioned in the literature, each variable alone impacts occupants in a particular way. Additionally, the quality of the variables can be varied according to building typology. Besides, green or conventional construction methods have shown diverse performances as there is no consensus on which method performs better. Achieving a high-performance IEQ requires periodical assessment to identify and improve sources of IEQ dissatisfaction [31]. Many studies have investigated IEQ, particularly in the European and American countries, to suggest improvements for future constructions. However, according to the literature, a few studies have focused on IEQ, specifically green buildings, in countries located in tropical regions such as Malaysia [32–34]. Particularly in the tropical climate of Malaysia, energy efficiency is one of the key factors to label buildings as green by the Green Building Index (GBI). Indeed, energy efficiency methods applied to green buildings—as mentioned earlier—could negatively impact occupant satisfaction. Thus, IEQ assessment of green-certified buildings is vital to have an insight into the constructions made to meet GBI criteria.

This study, therefore, aims to investigate and assess green-certified building performance regarding IEQ and occupants' satisfaction in the tropical climate of Kuala Lumpur. Additionally, the investigation is narrowed to office buildings with a Platinum Certificate. Another objective of this study is to make a comparison between the IEQ of Platinum GBI-certified office buildings. To achieve the objectives, the main variables are defined as indoor air quality, thermal quality, lighting quality, and acoustic quality. To perform the assessment, a post-occupancy evaluation (POE) was employed with the integration of full-scale measurements and an occupants' survey, leading to a comprehensive IEQ evaluation. Full-scale measurement was performed using environmental loggers monitoring IEQ variables. The occupants' IEQ satisfaction are assessed using a standardised questionnaire survey. Collected data from measurement and occupant surveys are utilised to address IEQ dissatisfaction sources and recommendations to further improve IEQ. To address this, this paper is structured as follows: after the introduction given in Section 1, green building tools in Malaysia will be briefly explained in Section 2. The methods applied to investigate IEQ, including full-scale measurement and occupants' survey, and cases selected for this study will be elaborated in Section 3. This is followed by the presentation of results in Section 4, and these results are discussed in Section 5. Finally, a conclusion and summary will be provided in Section 6.

2. Green Building Certification in Malaysia

The green building introduction required new construction methods that were different in various aspects from the old techniques. By this introduction, the green rating tools were established to evaluate and certify alleged green constructions. The United Kingdom pioneered and established the first green building rating system, known as the "Building Research Establishment Environmental Assessment Method" (BREEAM) in 1990. The United States then established a rating system eight years later in 1998, known as "Leadership in Energy and Environmental Design" (LEED). More countries have conducted the rating system in the following years, such as Australia (Green Star) in 2003 and Singapore (Green Mark) in 2005 [13,35]. Additionally, with a global approach, the WELL Building Standard was introduced in 2013 to exclusively focus on the impact of the building on human wellbeing and health.

The Malaysia Green Building Confederation (MGBC) was introduced in early 2007. It started when a group of consultants, academics, and representatives from the building industry met to initiate a non-profit organisation promoting sustainable buildings in Malaysia [36]. Following this movement, the GBI was established in 2009, which was formulated by the Malaysian Institute of Architecture, or Persatuan Arkitek Malaysia (PAM), and the Association of Consulting Engineers of Malaysia (ACEM) [36]. The green building assessment system was developed particularly to ensure the welfare of the occupants

and the entire environment [37]. Although there are various building assessment tools in Malaysia, GBI is mostly applied to assess green buildings.

GBI assesses buildings through six (6) key criteria, such as Energy Efficiency (EE), Indoor Environment Quality (EQ), Sustainable Site Planning and Management (SM), Materials and Resources (MR), Water Efficiency (WE), and Innovation (IN) [35]. The buildings are assessed and scored between zero (0) to a maximum of 100, and as a result, they are awarded through one of the four categories: (1) Platinum: above 86 points, (2) Gold: between 76 to 85 points, (3) Silver: with 66 to 75 points, and (4) Certified: minimum of 50 points up to 65 points [35]. Hence, according to GBI, any building that achieves a minimum of 50 points in the evaluation process can be called “green”.

GBI has organised buildings in seven (7) categories, such as Non-Residential New Construction (NRNC), Residential New Construction (RNC), Industrial New Construction (INC), Non-Residential Existing Building (NREB), Industrial Existing Building (IEB), Interior (ID), and Township (T). According to the study by Zian et al. [38] in 2019, the energy efficiency criteria is the most widely used in green building assessment systems, followed by water efficiency and innovations. Moreover, about 1/5 of the total points were dedicated to the IEQ in the NRNC, where it was 21 points out of 100. The IEQ of NRNC is evaluated through air quality, thermal comfort, lighting, visual and acoustic comfort, and verification (post-occupancy evaluation) during occupancy [35].

3. Methodology

This study utilised a post-occupancy evaluation (POE) method to investigate occupants’ satisfaction toward the existing implementation of green design concepts for the office buildings in Malaysia. POE is a widely acceptable systematic method to investigate building performance through occupants’ feedback [31,39]. Many believe that this method is the most effective and the best systematic technique of investigation to explore and examine the mutual interaction between the building and the occupants’ needs [40–42]. Particularly for office buildings, many studies emphasised the occupants’ assessment role in measuring the performance of the workplace [43–45]. Findings from POE can bring suggestions to form an alternative basis method for any construction or renovation in the future; therefore, it could amend and influence design codes, standards, and decisions [40,46]. Although some studies have only used survey to assess and investigate IEQ [14,47], POE in this study utilised occupants’ survey integrated with full-scale measurement [31]. This is to comprehensively evaluate the IEQ of the Platinum-certified office buildings. IEQ is evaluated according to the following criteria: indoor thermal environment (thermal comfort, temperature, humidity), IAQ (ventilation, carbon dioxide (CO₂), volatile organic compounds (VOCs)), lighting (daylight, artificial light, glare), acoustic (sound insulation), furniture, and maintenance (cleaning).

3.1. Case Study

As mentioned earlier, the purpose of this study is to investigate the IEQ of Platinum-certified office buildings in Kuala Lumpur. GBI categorizes buildings into separate groups, and the NRNC category includes buildings with functions such as governmental agencies, office buildings or towers, malls, galleries, factories, etc. Besides, buildings to be certified as Platinum must obtain the maximum points from various rigorous criteria. Since green construction is a new growing concept in Malaysia, only limited buildings have been able to integrate sustainable technologies and methods that successfully obtained the Platinum certificate. According to the latest GBI report in December 2020, the buildings awarded a Platinum certificate represent less than 4% of all the certificates issued in NRNC [48]. For this study, however, considering office functionality within the NRNC category, two cases are identified with a Platinum certificate located in Klang Valley [48]. Also, to achieve the study objective, the building must be in the operational phase for more than two years. These Platinum certificate office buildings are named buildings A and B. Building A is a government agency and building B is the headquarters of a private company.

The unique construction of the buildings incorporates various sustainable applications, such as utilisation of daylight, roof light, daylight reflectors, artificial light sensors, passive design strategies, green roof, sustainable materials, photovoltaic panels, rain harvest system, recyclable materials, etc. Table 1 represents the key features of these buildings.

Table 1. Key data for case study buildings A and B.

	Building A	Building B
No. stories	8 + 2	9
Green landscape area	3600 m ²	-
Structure	Steel-reinforced concrete (SRC)	Steel-reinforced concrete (SRC)
Facade finishes	Double glass curtain wall	Double glass curtain wall
Access to public transport	Bus	Bus
Air conditioning system	Air Handling Unit (AHU), Fans	Underfloor Air Distribution (UFAD)
Roof vents	Yes	-
Lighting type	Fluorescent	Fluorescent, Personal LED
Window to wall ratio (WWR)	About 60%	About 55%
Window blind, roller shade, fixed shading system	Yes	Yes
Interior separators	Medium-density fiber-board (MDF) and glass	Medium-density fiber-board (MDF) and glass
Exterior shades	No	No
Atrium	Yes	No
Courtyard	No	Yes
Employees/Occupants	80–100	60–100
Year of GBI certificate	2014 (validated until 2019)	2014 (validated until 2020)

Case study building A is located in Putrajaya, whereas case study building B is located in Shah Alam, both within Kuala Lumpur. Buildings A and B have been in operation since 2010 and 2014, respectively. Each floor of the buildings is dedicated to a few departments, except for parking and the ground floor. Within each department, employees are involved in sedentary activities, such as typical office tasks like writing, reading, computer typing, and occasional walking within the workstations and rooms. There is no significant heat emission from body activities. To carry out office tasks, the majority of employees work within open-plan offices, and the minority in private rooms, making the open-plan offices the main work areas in buildings. Also, the seminars and meetings are held in conference rooms. Generally, the occupants' appearance was observed to be trousers, long sleeve or short sleeve shirts, socks, and shoes. The clothing value of the occupants was 0.5 to 0.7 clo during the investigation.

Building A has an 11,473 m² net floor area and 14,230 m² gross floor area, with 75% floor efficiency (Figure 1a). Building B includes a 14,087 m² net floor area and 33,798 m² gross floor area (Figure 1b). Buildings A and B accommodate up to 400 and 250 occupants, respectively. For building A, a combination of a radiant cooling system with pipes embedded in the concrete slabs and an air handling unit (AHU) with fans has been employed to provide thermal comfort. Building B maintains thermal comfort with an underfloor air distribution (UFAD) system. Raising the floor to provide ventilation and distributing conditioned air through vents or diffusers into the indoor environment is known as UFAD. Both buildings have utilised a centralised ventilation system, with no occupant control over temperature or air velocity. In a tropical climate, thermal comfort significantly impacts occupants' satisfaction, thus, due to the centralised system, buildings should be investigated as one unit [14,49,50]. The facade of both buildings is mainly constructed by a glass curtain without any operable window for occupants.

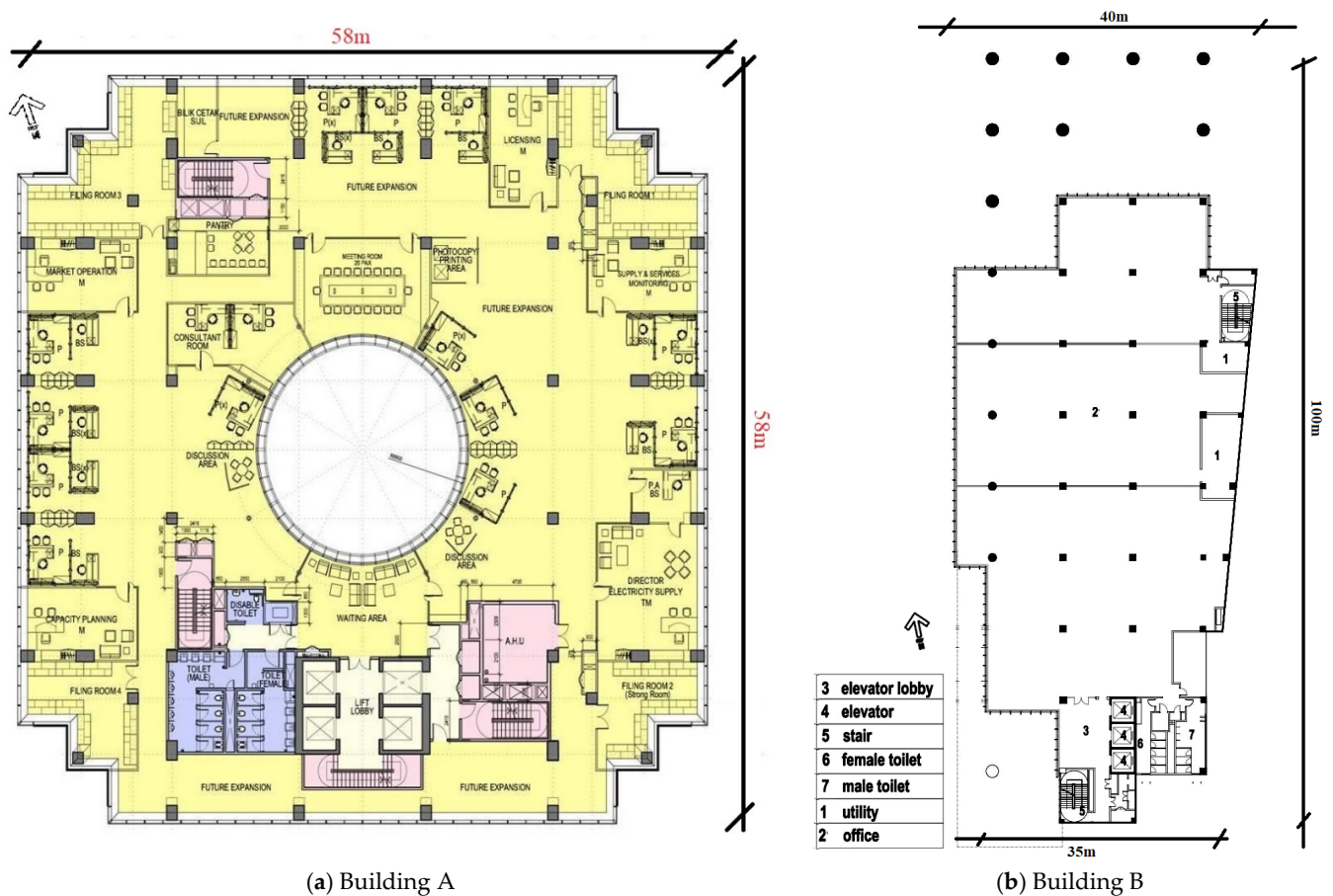


Figure 1. Plan layout of buildings.

3.2. Occupants' Satisfaction Survey

This study implemented a questionnaire survey to subjectively investigate IEQ satisfaction of green-certified office buildings. This would allow quantifying the subjective opinions. In this regard, the latest version of the Building Use Studies (BUS) questionnaire, specialised for non-domestic buildings in a tropical climate, was employed. BUS is a structured questionnaire with several versions depending on the building's typology, study design, and microclimate. The original questionnaire survey and database was established in 1985 because of the working group which tried to cover the surveying of 4300 office workers in 50 buildings in the United Kingdom in response to the SBS. The questionnaire has been constantly updated and modified to reduce the flaws, hence different sections of the questionnaire have been changed [51]. This standard questionnaire has been used to evaluate over 850 buildings worldwide up to 2021 [52]. This questionnaire uses a seven (7)-point satisfaction scale to evaluate various aspects of the building performance, but the "perceived productivity" was measured with a nine-point scale.

As is the norm for short-term POE, the survey was conducted one time on-site [3,31,43,47], where occupants were informed of the survey 24 h in advance. The questionnaires were distributed to occupants by the start of working hours and collected by the end of working hours on the same day. Table 2 presents a summary of the collected data.

Table 2. Questionnaire parameters.

Category	Question
Background information	Age, Sex, Years of working in the building, Type of the working office
Satisfaction with building design	Cleaning, Furniture
Satisfaction with IEQ parameters	Overall comfort, Perceived health, Perceived productivity Overall thermal comfort, Temperature, Temperature stability Overall air quality, Air humidity, Air freshness, Odour Overall noise, Noise from colleagues, Noise from other people, Other noise inside, Noise from outside Overall lighting, Natural light, Glare from sun and sky, Artificial light, Glare from light

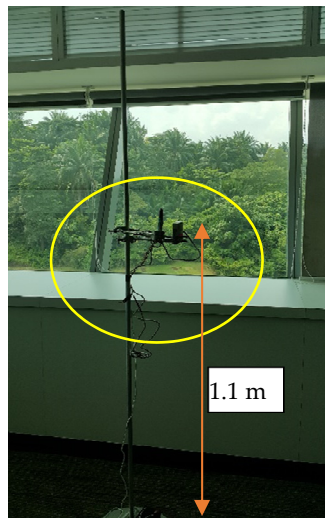
3.3. Full-Scale Measurement of the Indoor Environment

Full-scale measurement or objective measurement was performed to monitor IEQ in the study. This aided to provide a holistic perspective of the circumstances occupants responded to in the questionnaire survey. Additionally, full-scale measurement integrated with a survey would create a platform to identify and improve any potential source of IEQ dissatisfaction [31,53]. The parameters for monitoring were air indoor temperature (T_a), relative humidity (RH), air velocity (m/s), CO₂ concentration, TVOC concentration, illumination level, and indoor sound pressure level (SPL). Also, regarding mean radiant temperature, the difference between the indoor air temperature and mean radiant temperature is negligible under moderate outdoor conditions. Thus, the mean radiant temperature can be assumed equal to the indoor air temperature [54–56].

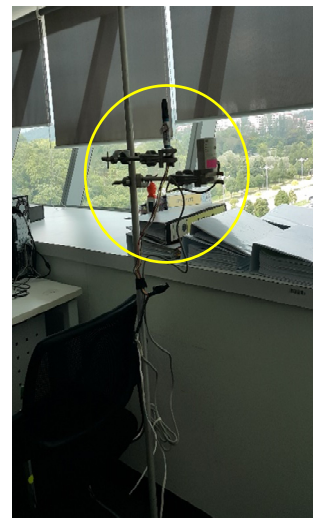
Kuala Lumpur is located between latitude 3.12 °N and longitude 101.55 °E, with a 13:11 solar noon. The daily climate is hot and humid, which is fairly consistent throughout the entire year, with minor temperature fluctuation [57]. Considering the stability of the outdoor microclimate throughout the year, the full-scale measurement was carried out from May to August 2019, which could be extended to the yearly data. Monitoring IEQ was performed with five-minute intervals of data logging, limited to operational days, and working hours 8:00 to 18:00 of the buildings.

Table 3 illustrates the specification of equipment used for full-scale measurement. Ten sets of equipment were used to collect environmental data. Each floor, starting from the first floor, was divided into zones—rooms without occupancy were excluded—and loggers were impended to monitor the zones for seven working days. This helped to monitor occupied spaces in a sequence covering floors and buildings.

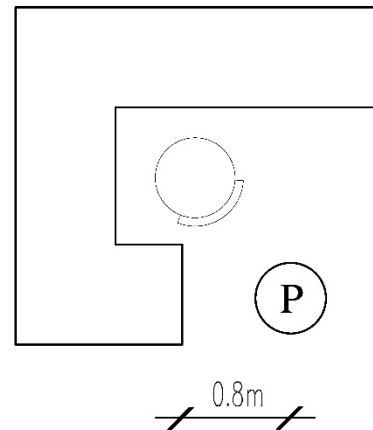
The environmental loggers attached to portable poles (Figure 2a,b) in the height of 1.1 m above the finished floor (level of sedentary activities), as suggested by ISO 16000-1 [58], close to occupants, 0.3 m. For the horizontal distribution of measurements, the devices were positioned approximately 0.8 m away from the devices and walls (Figure 2d) to avoid radiative temperature. This permitted simulation exposure of occupants to indoor air near the breathing zone when seated. Furthermore, portable light meters were placed on the working desk of the occupants to measure the lighting level (Figure 2c). This was to record a realistic approximation of the illumination received by occupants. A daily average of each parameter (121 data points) was generated for the period of measurement to present buildings' indoor environment conditions.



(a): Air temperature, air velocity, RH measurement



(b): Portables poles with loggers

(c): Illuminance, CO₂, TVOC measurement

(d): Sample of poles' location close to workstation

Figure 2. Demonstration of equipment installed to monitor indoor environment quality (IEQ).**Table 3.** Specifications of equipment for physical measurement of indoor environment parameters.

IEQ Parameter	Environmental Sensor	Range and Accuracy
Air temperature	HOBO-U12-012 ¹ , Onest	−20 to 70 °C, accuracy ±0.35 °C, from 0 to 50 °C,
Relative humidity		±2.5%, 3.5% maximum, from 10% to 90% RH
Air velocity	T-DCI-F900-S-O ¹ , Onest	Accuracy greater than 10% of the reading or ±0.05 m/s or 1% full-scale
Illuminance	TM-203 Datalogging ² , TENMARS	20 to 200 K Lux, ±3%
Sound pressure level	Solo 1092 01dB-METRAVIB ² , ACOEM	20 to 137 dB (A) class 1, or 30 to 137 dB (A) class 2
Carbon dioxide	98,123 J ² , MIC	0 to 50 PPM with a resolution of 1 PPM, ±30 PPM + 5% of reading
TVOCs	98, 519 ² , MIC	0–50 PPM with 0.01 PPM resolution, ±30 PPM + 5% of reading,

¹ Sensor was tested for accuracy in a pilot study. ² Sensor was calibrated before the monitoring in the laboratory of the Faculty of Built Environment, University of Malaysia.

3.4. Questionnaire Respondents

Completed questionnaires were considered for the final analysis to have more accurate results. A total of 174 questionnaires were distributed, of which 112 valid questionnaires were retrieved, with a response rate of 64%. According to Cochran [59], the sample size and response rate comes with a 94% confidence level. Among the responses, 57 (50.9%) were completed by males and 55 (49.1%) were completed by females, 47 (42%) of the respondents reported age under 30 years and 65 (58%) reported age 30 or over. Further details on the distribution of the respondents, including respondents from each building, work experience in the building, and type of the work office are summarised in Table 4.

Table 4. Background and demographic information of valid respondents.

		Building A	Building B	Total
Sex	Female	30	25	55
	Male	29	28	57
Age	Under 30	21	26	47
	30 and above	38	27	65
Work experience in building	Less than a year	20	20	40
	A year or more	39	33	72
Type of the work office	Normally occupied by 1	16	8	24
	Shared with 1 other	1	0	1
	Shared with 2–4 others	6	22	28
	Shared with 5–8 others	16	15	31
	Shared with more than 8 others	20	8	28

4. Results

As explained in Section 1, the POE approach in this study integrated a survey with full-scale measurement to investigate IEQ performance of study buildings. Collected data during full-scale measurement are utilised to report a daily average of the variables and questionnaire survey to quantify occupants' responses.

4.1. Full-Scale Measurement of the Indoor Environment

The results from the full-scale measurement of buildings have been presented to make a comparison between the study outcomes, recommendations, and standards. Figure 3 presents the mean and variance of the parameters such as air temperature (T_a), relative humidity (RH), air velocity, CO_2 concentration, illuminance level, and sound pressure level (SPL) for buildings A and B. T_a was observed to be in a similar range for both buildings, as for building A, T_a ranged from 23.3 to 24.6 °C with a mean of 24.2 °C, and T_a for building B ranged from 23.6 to 24 °C, with mean of 23.8 °C (Figure 3a). T_a for building B has a lower variance in comparison to building A. Lower mean T_a and low variance of T_a contributed to higher unconfortable and neutral sensation mean vote from occupants for building B. It seems that both buildings have tried to maintain operation temperature (T_o) around 24 °C, an appropriate range according to MS 1525 [60]. Malaysian standard MS 1525 [60] recommend dry bulb temperature to be in a range of 24 to 26 °C, with a minimum of 23 °C for office buildings. The level of monitored RH is significantly different for buildings A and B, ranging from 58% to 64.5% with a mean of 60%, and 72% to 78.5% with a mean of 72.4%, respectively (Figure 3b). RH level for building B is above the recommended range by MS 1525 [60], which is recommended to be in the range of 50% to 70%. Particularly, the RH level is recommended not to exceed 70% [60]. The main reason for the high RH level in building B in comparison to building A was due to the quality of the HVAC system to maintain the indoor RH level, as natural ventilation or operable windows are not included in both buildings. This in compliance with Aziz, Sumiyoshi [61], who implied that the implementation of normal air handling units is unable to adequately dehumidify the indoor environment in the tropical climate of Malaysia.

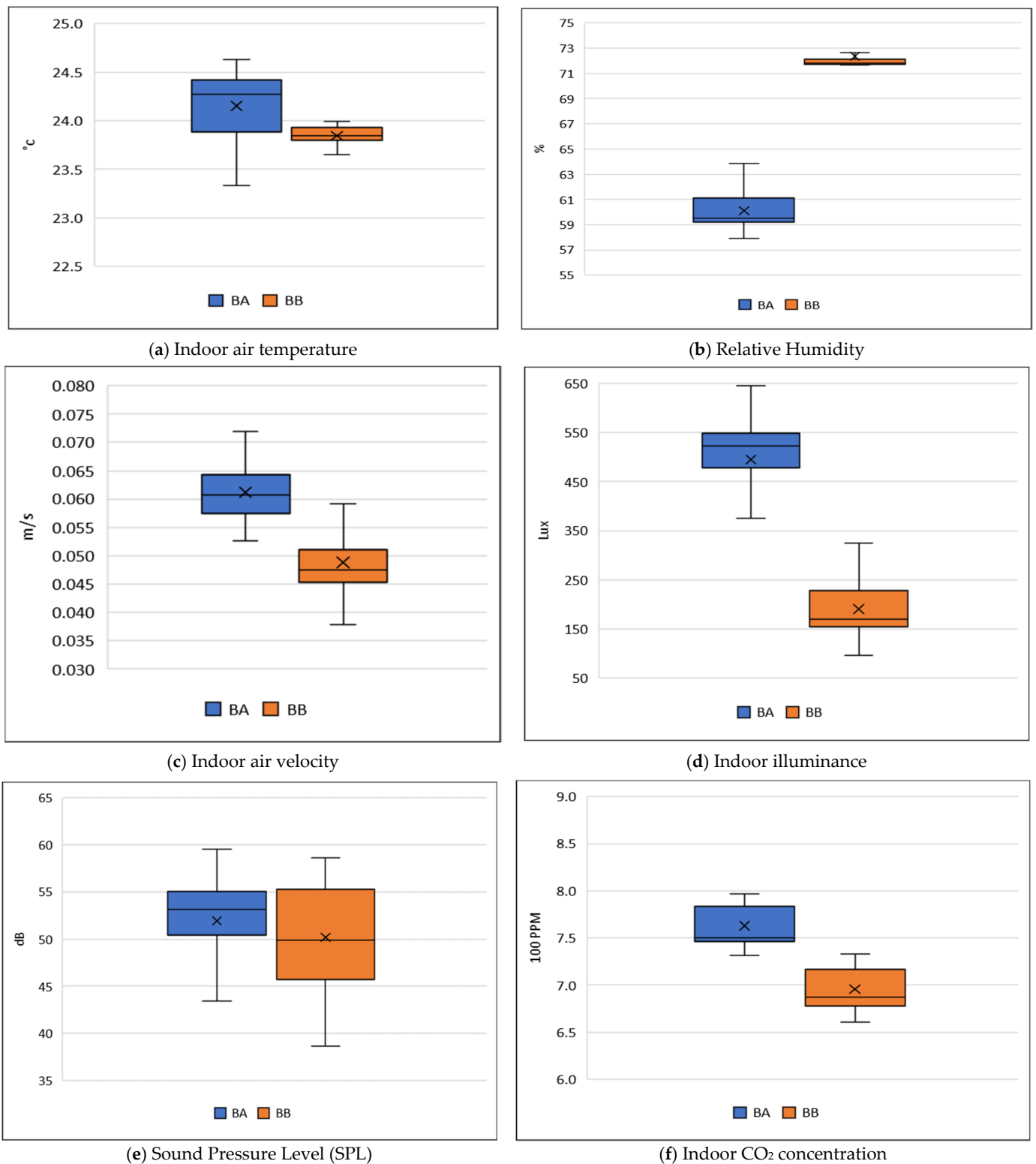


Figure 3. Distribution of IEQ parameters for building A (BA) and building B (BB).

Air velocity for both buildings is observed to be similar and considered below the recommended range (0.15–0.50 m/s) by MS 1525 [60]. Air velocity for building A ranged from 0.05 to 0.07 m/s, with a mean of 0.06 m/s, and ranged between 0.04 and 0.07 m/s with a mean of 0.05 m/s for building B (Figure 3c). The main reason for low air velocity within building A was observed to be due to the location of vents in the top of the rooms and over the corridors, which resulted in low air velocity around the breathing area of occupants.

Building B is equipped with adjustable vents to distribute air from the underfloor; however, it was observed that most of the vents adjacent to workstations were closed by occupants, resulting in low air velocity near the breathing area of a seated person. The main reason for occupants to close the vents was found to be the cool air temperature, as higher air velocity can extend the level of coolness feeling for the occupants.

The illuminance level for building B is significantly lower than building A. It was in the range of 95 to 325 lux with a mean of 191 lux for building B. In parallel, building A provided illuminance in the range of 375 to 646 lux, with a mean of 494 lux (Figure 3d). In this regard, various standards and studies suggested that acceptable illuminance for a normal office work should be between 500 and 1000 lux [62,63]. In addition, the average minimum daylight available in Kuala Lumpur is above 10,000 lux, from 10 a.m. to 6 p.m. [57]. Thus, both buildings have tried to utilise daylight as the main source of lighting. It was observed that occupants sitting near the window received a high illuminance level from daylight. To control the level of illuminance, blinds were used by occupants sitting near the window to reduce the intensity of daylight. However, this action resulted in dim spaces within a range from the window, in which occupants suffered from low-level daylight and luminance level. To diminish this issue, occupants were provided with task lighting in building B and an atrium is applied in the design of building A. Particularly, task lighting significantly enhances the individual's visual quality, although the indoor environment is dim. This is supported by the illuminance level being very low, although the occupants reported overall comfort from light quality in building B. In addition to the distance of the window within the inner part of the building, the daylight was trapped by workspaces with high-level partitions before reaching the inner workspaces, resulting in dim spaces for inner parts.

Regarding background noise from outdoors, buildings were located near the street. Additionally, the neighbourhood buildings and transportation density are observed to be lower for building B. However, the study buildings are fully air-conditioned with no operable windows, which significantly reduces noise penetration. SPL is similar for both buildings and ranges from 43.45 to 59.55 dB, with a mean of 51.9 dB, and 38.65 to 58.65, with a mean of 50.2 dB, for buildings A and B, respectively (Figure 3e). Mui and Wong [64] reported that the neutral SPL for aural comfort in typical air-conditioned offices should be between 45 and 70 dB, with a mean of 57.5 dB. Mean CO₂ was detected to be 763 and 695 ppm for buildings A and B, respectively (Figure 3f). CO₂ lower than 1000 ppm is considered harmless [65]. No vestige of TVOC was detected in both buildings, with 0 ppm measured.

A similar AC management scheme is applied to both buildings A and B. This scheme activates AC only during operation hours of the office building (8 a.m. to 6 p.m.). Besides, the buildings mainly included open-plan office workstations as well as a few private rooms, conference rooms, and storage spaces.

Given the typical office work of the occupants, such as sedentary activities, there are no significant indoor heat gains from occupants' activities. Personal fans were observed to be used by occupants in both buildings, particularly for private rooms, which could be a sign of low indoor air velocity.

Another issue that should be considered is the tropical climate of Malaysia, which directly influences the indoor thermal condition. Malaysia is located in the equatorial region of South East Asia between 1° N and 7° N, and longitude 0° and 119° E [57]. Kuala Lumpur as a base location for this study is located between the latitude of 3.12° N and longitude of 101.55° E, with a 13:11 solar noon [57]. The daily climate in Malaysia is described as hot and humid, which is consistent throughout the entire year, and the heavy rain comes during monsoon seasons. The average dry bulb temperature is around 26.92 °C for the entire year. The highest dry bulb temperature fluctuation happens around 14:00 to 18:00 [57]. The effect of this fluctuation was observed in the samples collected during the monitoring period, in which around 14:00 to 16:00, the mean air temperature of the indoor environment was at the crest. Moreover, it was observed that relative humidity

started to peak by the start of the operation hour of the buildings, then it declined to a lower percentage after the start of the HVAC system to maintain relative humidity; however, building B presented a very high RH level.

4.2. Occupants' Satisfaction with Indoor Environment Quality

Despite the high RH and low illuminance for building B, findings from measuring indoor environment parameters show general compliance with standards such as MS 1525 [60] for both buildings. However, the findings cannot speculate occupants' comfort from IEQ. Thus, the occupants' IEQ feedback would give a better perspective.

The data from the questionnaire survey were analysed individually to make a comparison between IEQ of buildings and to correlate the results of the measurements with the findings of the survey. To perform the statistical analysis, responses to "5, 6, 7, or +1, +2, +3" transformed into a "comfortable" category and "1, 2, 3, or -3, -2, -1" into the "uncomfortable" category. Figure 4 shows the frequency of the occupants' responses to the overall IEQ comfort. As indicated in the results, about 91.5% of occupants were comfortable with the overall IEQ of building A, and only 3.8% of occupants were uncomfortable with the IEQ of building B (Figure 4). Despite the high neutral percentage (43.40%) of occupants for building B, generally, both green buildings were able to deliver an indoor environment condition to meet occupants' needs and fulfil their satisfaction. A comparison between buildings A and B indicates a high ratio of occupants in the "comfortable" category for building A (91.5% to 52.8%). The mean scores for buildings A and B are 1.66 and 0.58, which is another index to indicate higher satisfaction from building A's performance.

Besides occupants' satisfaction from overall IEQ, IEQ variables were assessed and analysed. As shown in Figure 5, occupants' satisfaction was analysed using frequency distribution over 'overall thermal comfort', 'overall indoor air quality', 'overall noise quality', 'overall lighting quality', 'furniture quality', and 'cleaning quality'.

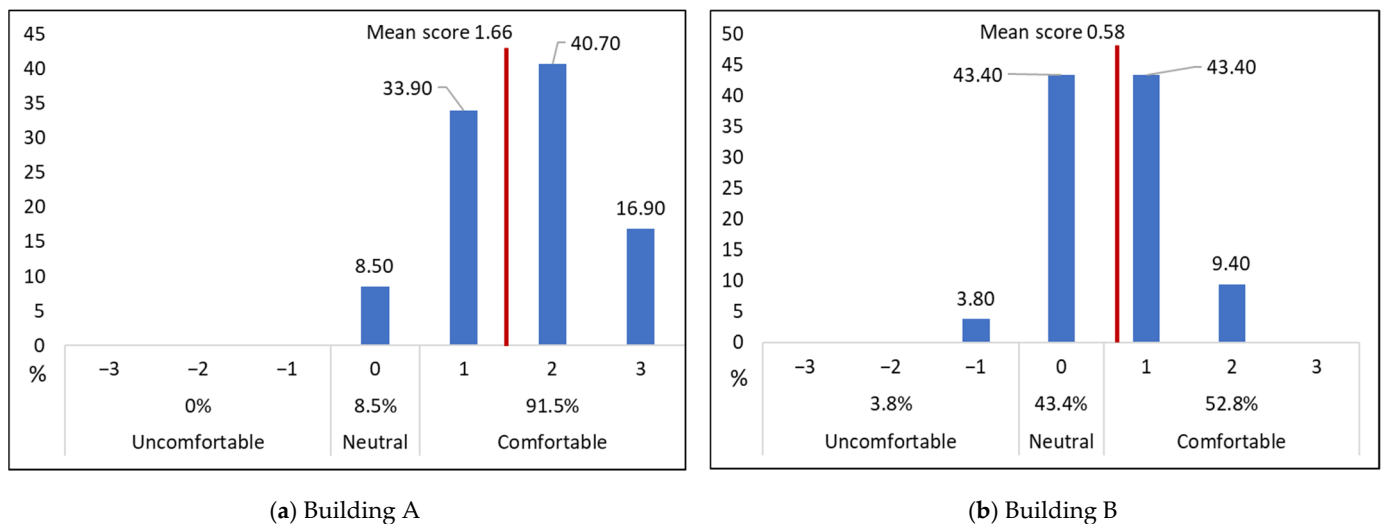
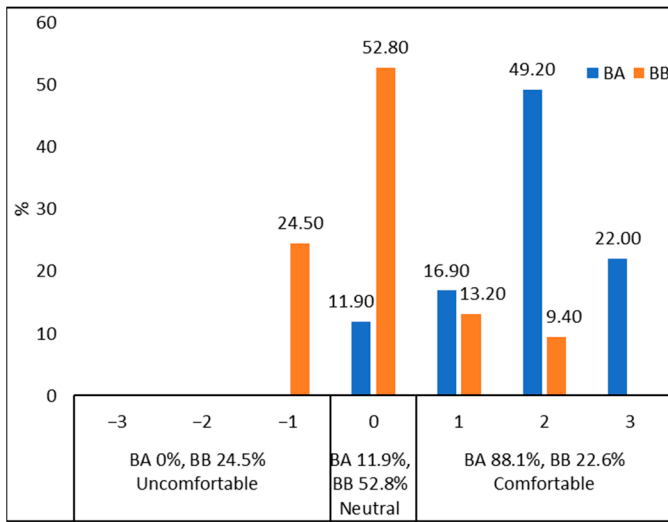
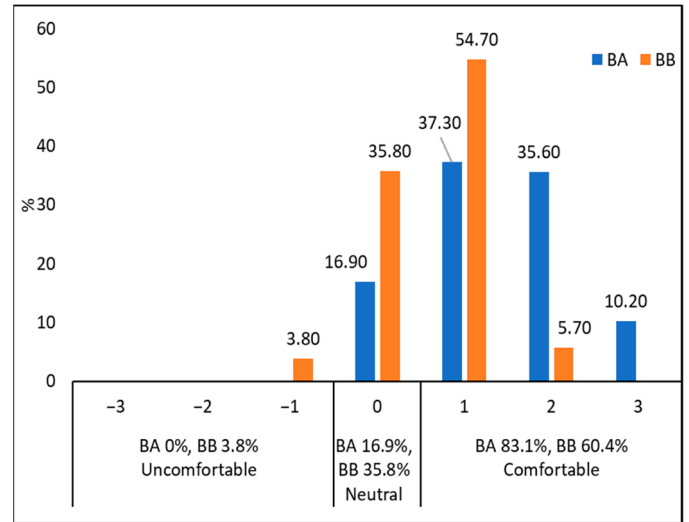


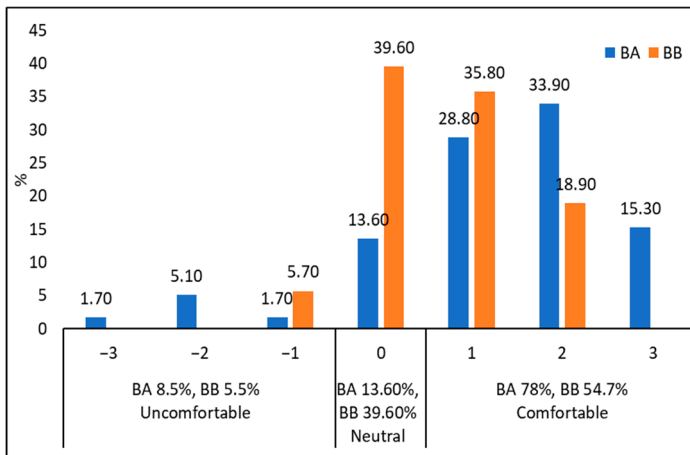
Figure 4. Frequency distribution of occupants' vote for overall comfort.



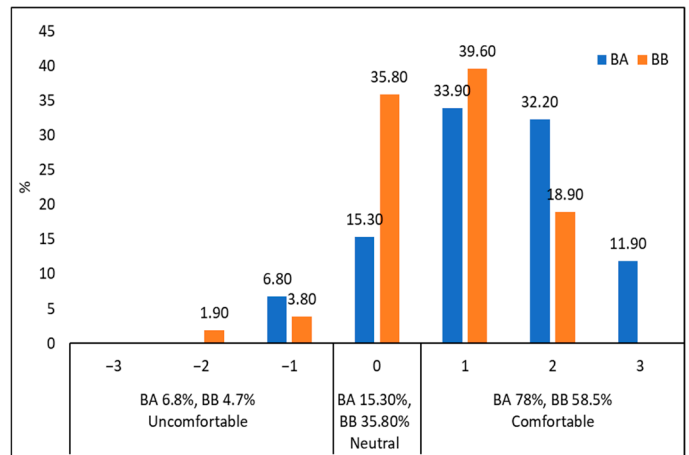
(a) Overall thermal comfort



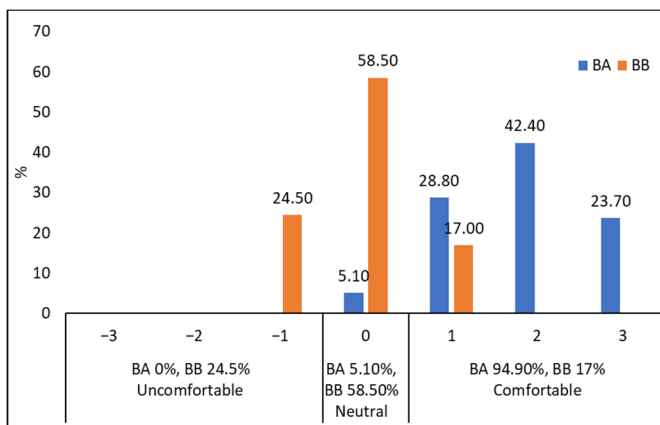
(b) Overall air quality



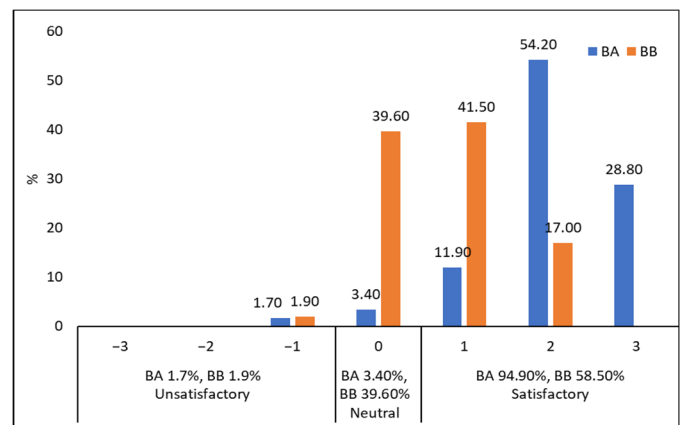
(c) Overall noise



(d) Overall lighting quality



(e) Furniture quality



(f) Overall cleaning quality

Figure 5. Frequency distribution of occupants' votes over IEQ parameters.

Satisfaction from overall thermal comfort is measured using a seven-point scale from uncomfortable to comfortable. This gives an overview of the portion of the occupants satisfied with thermal comfort. The finding indicated that 88.1% of respondents reported overall thermal comfort for building A, but 22.6% of respondents reported overall thermal comfort for building B. There is no thermal comfort dissatisfaction report of building A, whereas 24.5% of thermal comfort dissatisfaction was observed for building B (Figure 5a).

ASHRAE Standard 55 [66] suggests a minimum of 80% satisfaction for acceptable thermal comfort, in which building B fails to meet the condition.

Responses to the overall air quality could be triggered by factors such as air velocity, humidity, temperature, and indoor pollutants [67,68]. Regarding the air quality, 83.1% and 60.4% of occupants reported comfort for buildings A and B, respectively. Only a minority of occupants (3.8%) of building B reported dissatisfaction from IAQ (Figure 5b). The high relative humidity level (mean of 72.4% RH) of building B is observed to be the major reason for less satisfied occupants of building B in comparison to building A. The overall noise satisfaction for buildings A and B is observed at 78% and 54.7% and minority dissatisfaction at 8.5% and 5.5%, respectively (Figure 5c). For overall lighting quality, 78% and 58.5% of occupants reported satisfaction for buildings A and B, respectively. A minority of occupants, 6.8% (building A) and 4.7% (building B), reported dissatisfaction with overall lighting quality (Figure 5d). Although the mean indoor environment illuminance level in building B was measured to be low (190.88 lux), the application of task lighting increased the occupants' satisfaction for overall lighting. Another significant factor of indoor environment quality is furniture, which contributes to the occupants' overall IEQ comfort. Furniture for buildings A and B were reported to be 94.90% and 17% comfortable, respectively. However, 24.5% reported uncomfortable furniture for building B (Figure 5e). The cleanliness satisfaction of buildings A and B were reported as 94.90% and 58.50%, respectively. Dissatisfaction from cleanliness was reported as being minor, as 1.7% and 1.9% for buildings A and B, respectively (Figure 5f). Generally, most occupants reported satisfaction for the overall quality of parameters, which is aligned with the overall comfort. However, it should be noted that a significant group of occupants reported neutral from "overall IEQ" as well as parameters of IEQ, where any changes in the indoor environmental quality could push them to comfort, or in a worse-case scenario, to the uncomfortable range.

A comparison between the frequency of IEQ parameters contributed to 'uncomfortable' and 'neutral' for buildings A and B is demonstrated in Figure 6. 'Uncomfortable' is determined based on the ratio of the votes '−3 to −1' to the total responses. In building A, 'stuffy air' is the top dissatisfaction source underlying 'uncomfortable' and 'neutral' that is indicated by around 61% of occupants. This agrees with 'humidity' as the top dissatisfaction source for building B, with more than 81% of responses. This is followed by 'glare from sun and sky' with 59.3% of responses and 'cold' with 77.4% of responses for buildings A and B, respectively. 'Cold', 'other noise inside', 'noise from colleagues', 'smelly air', 'humid', 'too much natural light', 'temperature varies during the day', and 'noise from other people' are the third to eighth parameters in sequence for building A, with considerable percentages. For building B, 'temperature varies during the day', 'smelly air', 'stuffy air', 'too much natural light', and 'glare from sun and sky' are the third to fifth parameters, with more than 40% for 'uncomfortable' and 'neutral' responses. For building A, 'too little artificial light', 'dry', and 'warm' were addressed by less than 20% of occupants. 'Noise from other people', 'other noise inside', 'noise from outside', 'too little artificial light', 'dry', and 'warm' were addressed by less than 20% for building B.

High percentages of occupants voted 'uncomfortable' and 'neutral' for 'overall thermal comfort' (total 77.4%, Figure 5a). It can be explained by issues such as 'high humidity' and 'cold temperature' (Figure 6) as the main sources of uncomfortable thermal quality. 'Too much glare from sun and sky' and 'too much natural light' (Figure 6) are the main sources for 22.1% of occupants who did not vote 'comfortable' for 'overall lighting' (Figure 5d). 'Stuffy air' is also the main reason for 16.9% of 'neutral' votes to the overall air quality of building A, whereas 'smelly air' and 'stuffy air' are the main causes for 39.6% of votes in building B. Finally, 'noise from colleagues' is the main reason for occupants 'uncomfortable' or 'neutral votes' for both buildings (Figures 5 and 6).

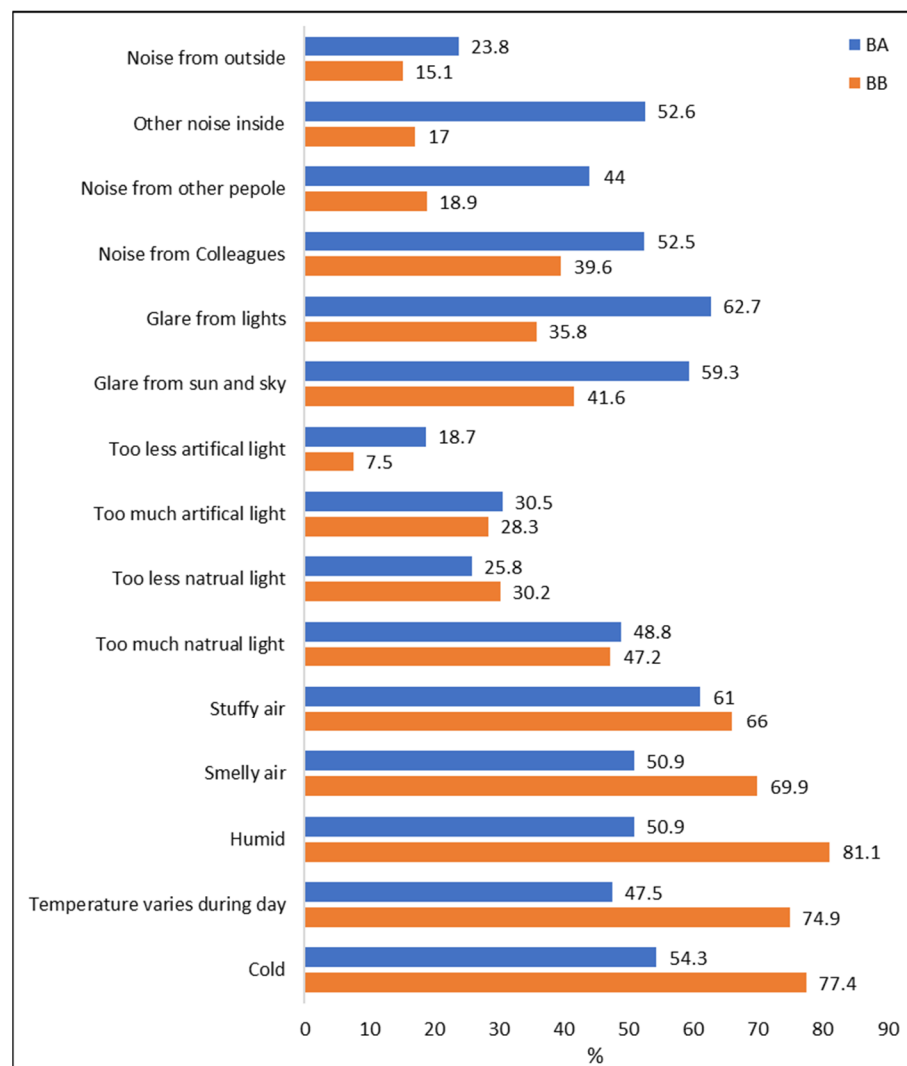


Figure 6. Comparison between the frequency of votes to the IEQ parameters contributing to uncomfortable and neural sensation.

Productivity is defined as “... the ability of people to enhance their work output through increases in the quantity and/or quality of the product or service they deliver”, by Leaman et al. [69]. Since it is difficult to achieve a meaningful evaluation of the productivity or work output, a self-report of productivity evaluation is suggested, known as “perceived productivity” [69]. Similarly, feeling healthy in the buildings has been self-reported and evaluated in the POE studies [70–72]. To measure perceived productivity and health, therefore, occupants were asked in the questionnaire survey to self-report IEQ impact on perceived productivity and health. For productivity, a nine-point scale measurement was used, as productivity decreased by 1: −40% or more, 2: −30%, 3: −20%, 4: −10%, 5: 0%, and productivity increased by 6: +10%, 7: +20%, 8: +30%, 9: +40% or more for IEQ. Also, occupants reported feeling healthier or less healthy in the questionnaire (seven-point scale, with 1 as less healthy to 7 as healthier) in the buildings to measure perceived health. The measuring scale was transformed into −4 to +4 from 1 to 9 for productivity and −3 to 3 from 1 to 7 for health. Also, votes over −4 to −1 were considered as less productive and +1 to +4 as more productive, as well as −3 to −1 as less healthy and 1 to 3 as healthier. Figure 7 demonstrates the responses’ frequency distribution for perceived productivity and health: 86.40% and 45.30% of occupants reported being more productive in buildings A and B respectively, whereas only 18.9% of respondents reported decreased productivity in building B (Figure 7a). Similar to the perceived productivity,

67.80% and 62.30% of respondents reported feeling healthier, with only a minority reporting less healthy, 10.2% and 11.30% for buildings A and B, respectively.

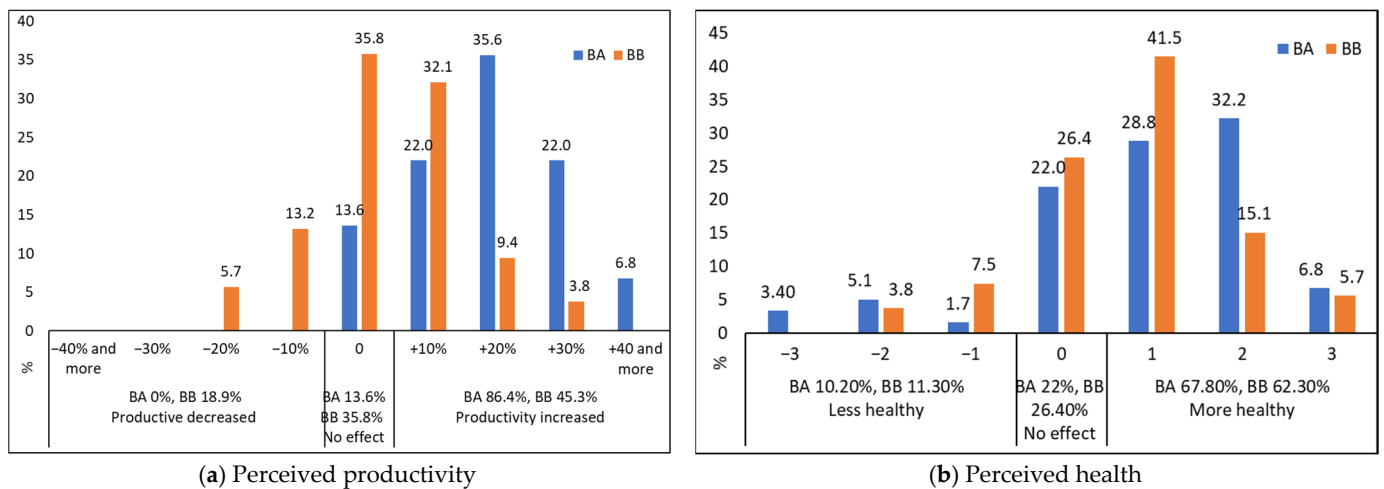


Figure 7. Frequency distribution of perceived health and productivity.

4.3. Variation in Satisfaction between Buildings A and B

To statistically make a comparison between occupants' mean vote of buildings A and B for variables such as comfort, thermal, IAQ, noise, lighting, furniture, cleanliness, productivity, and health, an independent sample *t*-test was used. This test statistically compares the significant difference between the means of two groups [73]. This test has also been used to make a comparison between IEQ mean votes of green and non-green buildings [14]. For this study, to conduct the independent *t*-test and compare the mean between two Platinum-certified office buildings, IBM SPSS statistical package version 24 was employed. As shown in Table 5, the mean vote for all the concerned parameters, overall comfort, perceived productivity, and health is higher for building A. *t*-test results also indicate that statistically, there is a significant difference ($p < 0.05$) for the mean vote of the parameters, except for perceived health. As mentioned above, both buildings are evaluated by GBI and certified as Platinum. However, occupants' mean votes over IEQ parameters indicate a significantly better IEQ for building A in comparison to building B. The mean score of 'cleanliness' (2.05) for building A is the highest mean among all the parameters for both buildings, whereas the mean of -0.7 for 'furniture' of building B is the lowest mean vote. Furniture is the sole parameter with a negative mean value, indicating unsatisfactory furniture quality of building B. Besides, all the mean values for building A are around 1 to 2, highlighting the perception of slightly satisfied or satisfied, whereas mean values for building B are mostly between around 0.5 to 0.75, which stays in the neutral range, except the 'furniture', with a negative value.

Table 5. Comparison of IEQ parameters between buildings A and B.

IEQ Parameter	Building A	Building B	<i>p</i> -Value ^a
Overall comfort	1.66	0.58	0.000 ^b
Overall thermal comfort	1.81	0.07	0.000 ^b
Overall air quality	1.39	0.62	0.000 ^b
Overall Noise	1.25	0.68	0.009 ^b
Overall lighting	1.27	0.70	0.003 ^b
Furniture	1.85	−0.75	0.000 ^b
Overall cleaning quality	2.05	0.74	0.000 ^b
Perceived productivity	1.86	0.38	0.000 ^b
Perceived health	0.92	0.74	0.449

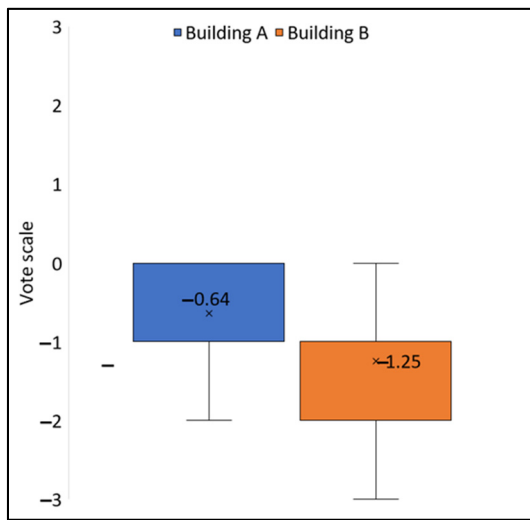
^a Two-tailed *t*-test was employed to compare the mean score between buildings A to B over IEQ parameters.

^b Highlights the statistical significance of test result at a level of $p < 0.05$.

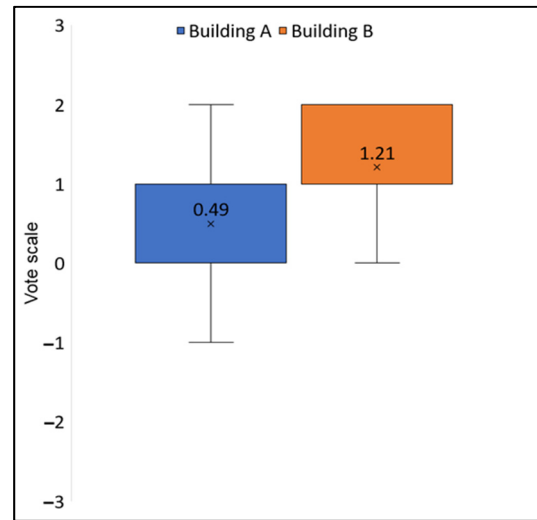
5. Discussion

There are many studies focused on assessing the quality of the indoor environment [74]. Findings of the assessment can be used to improve buildings' performance [53]. This study focused on the IEQ assessment of the Platinum-certified office buildings in Kuala Lumpur. As mentioned in Section 1, to obtain a GBI certificate, office buildings should be assessed by GBI through six categories, including IEQ. According to assessment results, buildings could be awarded one of four different certificates, with Platinum being the best award. This indicates that the IEQ of the Platinum-certified office buildings should be of a high quality compared to non-certified buildings. Concerning all six GBI assessment criteria, however, IEQ could be negatively influenced. This makes it essential to assess IEQ of Platinum-certified office buildings.

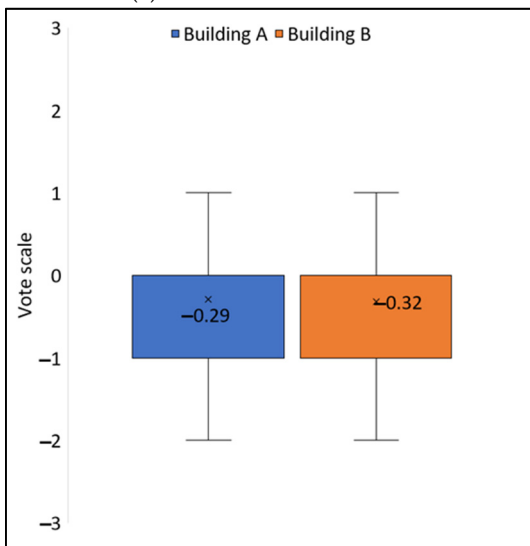
To perform the assessment, the IEQ variables were investigated through full-scale measurement and an occupants' survey. Figure 8 shows the distribution of occupants' votes over thermal sensation, dry–humid air, stuffy–fresh air, and smelly–odourless air. These variables are measured with a seven-point scale. ASHRAE [66] suggests a seven-point scale with $-3 = \text{Cold}$ to $+3 = \text{Hot}$. The mean vote between -0.5 to $+0.5$ is considered as a neutral thermal feeling [66]. Mean votes out of the suggested neutral range are considered as uncomfortable thermal sensation, which leads to a high rate of dissatisfied occupants from thermal comfort. The TSV means for occupants of buildings A and B are -0.64 and -1.25 (equivalent to slightly cool), respectively (Figure 8a). TSV for both buildings is out of the suggested neutral range [66], indicating an uncomfortable cool thermal sensation. This indicates the overcooled indoor environment. Cheung, Schiavon [47] also suggested an overcooled indoor environment as one of the major contributors to occupants' dissatisfaction in green-certified office buildings in Singapore, with a tropical microclimate. As summarised in Table 6, the air temperature of 24.2 and 23.8 °C are the sources for the thermal sensation mean vote. Association of thermal sensation mean vote with the air temperature of the buildings suggests that to have a neutral thermal sensation mean vote, a higher air temperature is required. This complies with Malaysian standard MS 1525 [60], that suggested a minimum of 24 °C for dry bulb temperature of the indoor environment of office buildings. Buonocore et al. [75] suggested an optimised air temperature of 26 °C to have thermal comfort and energy efficiency for air-conditioned faculties in a hot and humid climate. Besides, office air temperature was suggested to be set at 28 °C and with low clothing value for occupants, which resulted in energy-saving and thermal satisfaction [76]. Aghniaey et al. [77] suggested that office air temperature should be increased to 26 °C to have less than 10% PPD. In compliance with the literature, this study also found that air temperature around 24 °C is one of the major sources of thermal dissatisfaction.



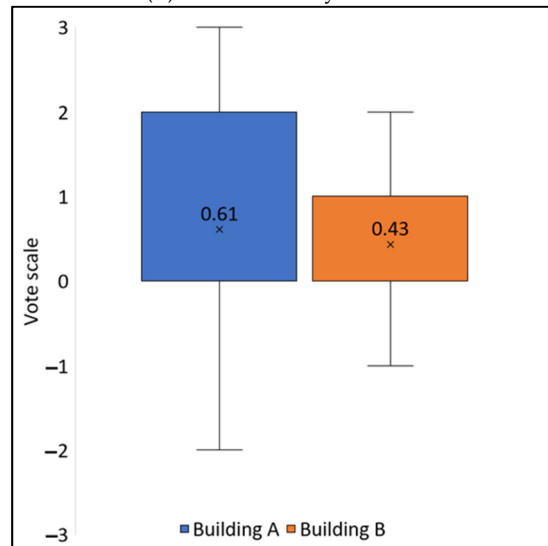
(a) Thermal sensation vote



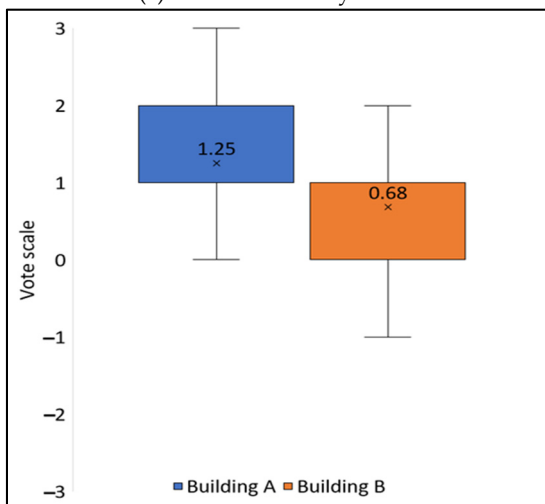
(b) Indoor air: dry-humid



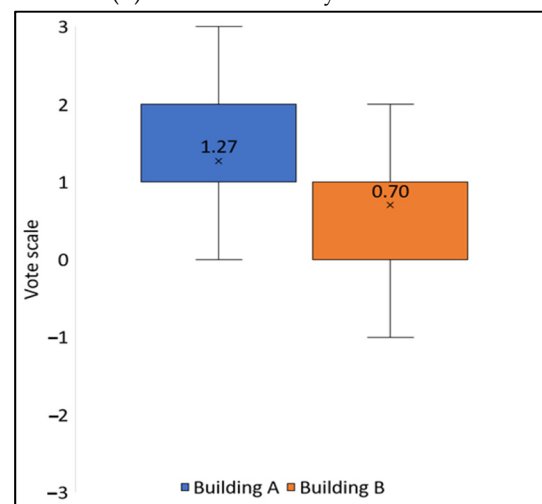
(c) Indoor air: stuffy-fresh



(d) Indoor air: smelly-odourless



(e) Indoor noise unsatisfactory-satisfactory



(f) Indoor lighting unsatisfactory-satisfactory

Figure 8. Distribution of occupants' votes.

The humidity levels of 60% (building A) and 72.4% RH (building B) (Table 6) have resulted in the occupants' mean votes of 0.49 (equivalent to neutral) and 1.21 (equivalent to slightly humid) for buildings A and B, respectively (Figure 8b). Malaysian standard MS 1525 [60] suggests a maximum RH lower than 70%. However, according to the occupants' mean vote, RH around 60% also seems to be at the edge of occupants' tolerance, in which lower RH for higher satisfaction should be considered. The circumstance of building B (72.4% RH) led temperature and humidity to be the main concerns and sources of dissatisfaction. Aziz, Sumiyoshi [61] suggest the usage of a Dual Air Handling Unit system to control indoor humidity around 50% and achieve energy efficiency goals. In alignment with this study, Ravindu et al. [78] found that high humidity is the main IEQ dissatisfaction source for a LEED Platinum-certified factory in a tropical microclimate. It should also be considered that thermal parameters such as air temperature and relative humidity have a relationship with each other, in which higher air temperature results in lower relative humidity and vice versa [57]. This is because warm air can contain more water vapour than cool air [57]. The low difference of air temperature (around 0.4 °C) for buildings A and B is not a significant factor and contributes to around a 12% difference in RH level.

Table 6. Summary of results from measurement and survey of IEQ parameters.

IEQ Parameter		Occupants' Vote Mean Score		Measurement Results		First Three Main Sources of Dissatisfaction	
		BA	BB	BA	BB	BA	BB
Thermal comfort quality	Temperature	−0.64	−1.24	24.2 °C	23.8 °C	☑	☑
	Air: dry–humidity	0.49	1.20	60%	72.4%	-	☑
	Air velocity	-	-			-	-
Indoor air quality	Air: stuffy–fresh	−0.29	−0.32	0.06 m/s	0.05 m/s	☑	
	Air: smelly–odourless	0.61	0.43			-	-
Noise quality		1.25	0.68	51.9 dB	50.2 dB	-	-
Lighting		1.27	0.70	494 lux	191 lux	☑	-

Low rate of air velocity (0.06 and 0.05 m/s for buildings A and B respectively, see Table 6) in both buildings resulted in occupants reporting stuffy air with a mean of −0.29 and −0.32 for buildings A and B, respectively (Figure 8c). Particularly, stuffy air was found to be one of the main sources of dissatisfaction for building A. Occupants' mean votes are positive for smelly–odourless air (0.61 and 0.43), indicating a neutral feeling for air freshness. Based on the findings for air quality variables, higher air velocity is required to have fresher air and be more odourless. In line with this study finding, low air velocity is also found to be a major contributor to occupants of the office buildings in Singapore [47]. To improve the air quality and thermal satisfaction, a higher air velocity rate is suggested. Melikov et al. [68] implied that an increase in the air velocity can widen occupants' acceptance level for humidity up to 60% and temperature up to 26 °C, however, an increase in the air velocity did not reduce the SBS symptoms, but the replacement of a clean and fresh air did. This study also concluded that improved air velocity is more critical for hot and humid conditions [68].

Regarding acoustic quality, both buildings have a similar result to a typical office building within a range of 45 to 70 dB. The SPL for building A was determined to be around 51.9 dB (Table 6), which resulted in occupants' mean vote of 1.25 (equivalent to slightly satisfactory) (Figure 8e). SPL of 50.2 dB for building B comes with occupants' mean vote of 0.7 (equivalent to slightly satisfactory). Under the noise circumstances of both buildings, lower SPL is suggested for higher satisfaction. Particularly, the reduction of noises from colleagues is critical, as it was one of the main dissatisfaction sources in this study, as well as findings from Banbury et al. [79]. Menadue et al. [80] indicated that noise satisfaction is higher in the non-Green Star office buildings compared to Green

Star-certified office buildings. Also, Lee [81] indicated that acoustic quality in open-plan offices with high cubicle stations is lower than private rooms or shared rooms in LEED-certified office buildings. Passero et al. [82] suggested the use of divider panels between the cubicles/workstations and high sound-absorber materials for the roof finishing to improve the acoustic quality of the open-plan offices. Virjonen et al. [83] also indicated that SPL could be as low as 39 dB in open-plan office buildings with a robust acoustic design plan, whereas Hongisto et al. [84] implied that typical open-plan offices show an SPL range between 50 and 60 dB.

Regarding the lighting, the desk surface illuminance level of 493.84 lux (Table 6) in building A comes with occupants' mean vote of 1.27 (equivalent to slightly satisfactory). Building B presented with 190.88 lux as a desk surface mean illuminance level, which resulted in an occupants' mean vote of 0.70 (equivalent to slightly satisfactory) (Figure 8f). Cheung, Schiavon [47] reported that electrical and natural light quality is among the IEQ factors with high satisfaction in commercial buildings in Singapore. Although the mean surface illuminance level is low in building B, task lighting has improved overall light satisfaction. This is inconsistent with Lim et al. [85] findings indicating that task lightning and daylight combined can improve visual comfort for paper works as well as saving energy. However, to have higher light satisfaction, a range of 500 to 1000 lux is suggested for the indoor visual comfort, for which both buildings failed to meet the minimum range, particularly building B. Also, ceilings with indirect lens types are suggested to increase visual comfort [86]. The same study also recommends a surface illuminance level of 406 to have the highest satisfaction in office buildings. It should be mentioned that due to the green constructions, both buildings have tried to maximise daylight application. For building A, it was observed that parts of the building in the middle distance from window to atrium seemed dim. For building B, it was observed that windows were mostly covered with blinds by occupants sitting near the window to avoid glare from the sun and sky, and this action blocked the daylight from penetrating to spaces with distance from the window. Also, glare is reported to be the main source of dissatisfaction for both buildings. Similar to this, Kwong [87] reported dissatisfaction from sky glare as well as usage of blinds to control the daylight near the windows. Discomfort due to glare is found to be a typical source of dissatisfaction for green buildings, as was supported by Hirning et al. [29]. To control the discomfort from glare, Luo et al. [88] suggested the application of automated shading control for the blinds.

Relationship between Overall IEQ Comfort and IEQ Variables

The relationship of full-scale measurement with a survey is discussed, and results indicated temperature and relative humidity to be among the primary sources of dissatisfaction (Figure 6). To statistically investigate the relationship between overall comfort and IEQ variables, thus, Pearson's correlation coefficient was employed. As shown in Table 7, all the variables were correlated with the overall comfort at a statistically significant level ($p < 0.001$). The lowest Pearson correlation coefficient value is the noise quality, whereas the thermal comfort shows the highest value. The importance of the thermal comfort impact on overall comfort was also reported by Liang et al. [14], who investigated IEQ of green office buildings in the tropical climate of Taiwan.

Table 7. Pearson correlation between overall IEQ comfort and IEQ variables.

Overall Comfort	Thermal Comfort	Indoor Air Quality	Noise	Light	Furniture	Cleaning
Pearson correlation coefficient	0.625 **	0.467 **	0.329 **	0.455 **	0.552 **	0.486 **
<i>p</i> -value	0.000	0.000	0.000	0.000	0.000	0.000

** Correlation is significant at the 0.01 level (2-tailed).

6. Conclusions

The green building movement has altered the construction industry to promote sustainable construction, requiring unique methods of building design. This movement led to the establishment of organisations around the world to systematically evaluate and certify potential buildings as green. However, energy-saving has become the main focus of majority research on green building, with minority studies focusing on occupants' satisfaction with the quality of the indoor environment. Thus, this study has focused on the limited research from IEQ of the GBI Platinum-certified office buildings, to investigate IEQ performance and occupants' satisfaction. In this regard, the IEQ of the selected case studies was evaluated by the utilisation of post-occupancy evaluation as well as full-scale measurement. The primary findings of this study include:

- The onsite monitoring of indoor environment parameters indicates general compliance of parameters with international standards as well as Malaysian standards. However, RH and illuminance level, particularly for building B, were found to be out of the suggested range of the standards.
- The results of the questionnaire survey indicated a general comfort (a mean score of 1.66 on a 7-point scale, -3 to $+3$) from overall IEQ for building A and a neutral feeling for occupants of building B (mean score of 0.58).
- Regarding the parameters of IEQ, the majority of occupants reported a comfortable or neutral feeling for overall thermal comfort, overall IAQ, overall acoustic, overall lighting, furniture comfort, and cleanliness.
- Most occupants reported being more productive and healthier in the buildings.
- Sources of dissatisfaction were identified to be cool air temperature and high relative humidity, especially with an extreme condition for building B. Besides, low air velocity resulted in stuffy or smelly air, which was reported to be another main source of dissatisfaction. Glare and noise from colleagues were also found to be the main sources of dissatisfaction.
- Finally, although both buildings have been awarded Platinum certificates, the results of the *t*-test show a statistically significant difference between the mean vote of occupants' for IEQ variables, with higher satisfaction from building A.

Findings from this study provide a holistic view of the IEQ performance of the GBI Platinum-certified office buildings in a tropical climate. Limited office buildings obtained GBI Platinum certificates due to the robust and strict GBI criteria. Thus, the findings of this study can be generalised to the GBI-certified office buildings, particularly results related to the IEQ dissatisfaction sources. This is because NRNC buildings should follow the criteria posed by GBI for obtaining the certificate. Given that the cases of this study have been evaluated with the highest points and certified as Platinum, the IEQ of the future constructions looking to obtain a GBI certificate or already certified office buildings should have the same dissatisfaction sources as this study highlighted. Thus, the findings of this study can be applied to further improve national and international guidelines in green construction, particularly for the tropical climate of south-east Asia. This would help to move to a more sustainable and satisfactory indoor environment. This could be achieved by further studies on how to diminish sources of occupants' dissatisfaction. Also, for additional investigation, a comparison study between IEQ of GBI office buildings with other green rating tools such as LEED or Green mark should be performed. Besides, the findings of this study indicated that more investigations on thermal quality are needed to design a thermally comfortable indoor environment.

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List of Abbreviation

Nomenclature

a	Indoor Air (Ambient)
CO ₂	Carbon Dioxide Concentration (PPM)
T	Temperature (°C)
V	Air Velocity (m/s)

Acronyms

ACEM	Association of Consulting Engineers of Malaysia
AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BREEAM	Building Research Establishment Environmental Assessment Method
BUS	Building Use Studies
EE	Energy Efficiency
GBI	Green Building Index
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
IEB	Industrial Existing Building
IEQ	Indoor Environment Quality
INC	Industrial New Construction
LEED	Leadership in Energy and Environmental Design
MGBC	Malaysia Green Building Confederation
MR	Materials and Resources
NRNC	Non-Residential New Construction
PAM	Persatuan Arkitek Malaysia
POE	Post-Occupancy Evaluation
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
RNC	Residential New Construction
SBS	Sick Building Syndrome
SM	Sustainable Site Planning and Management
SPL	Sound Pressure Level
TSV	Thermal Sensation vote
UFAD	Underfloor Air Distribution
VOCs	Volatile Organic Compounds
WE	Water Efficiency
WELL	WELL Building Standard
WWR	Window to Wall Ratio

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