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A FIELD INVESTIGATION OF THERMAL COMFORT PARAMETERS IN GREEN BUILDING INDEX (GBI)-RATED OFFICE BUILDINGS IN MALAYSIA

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ABSTRACT

This field investigation of thermal comfort parameters in Green Building Index (GBI)-rated office buildings employing various façade-shading devices compared thermal performance in terms of four main variables: indoor air temperature, indoor relative humidity, mean radiant temperature, and indoor air velocity. Over five days of fieldwork at each building, the four variables of interest were measured, recorded, and analysed using Excel graphs. The results show that the thermal comfort performance of each building was acceptable within the parameters of the GBI Non-Residential New Construction (NRNC) Tools for Indoor Environmental Quality (IEQ). In general, observed values were good for three of the four thermal parameters: indoor air temperature, indoor relative humidity and mean radiant temperature. However, indoor air velocity fell below the acceptable range as defined by the GBI NRNC Tools. One possible reason for this negative outcome is low air exchange from the air conditioning systems in the selected buildings.

Keywords: Field investigation; GBI; Office building; Thermal comfort

1. INTRODUCTION

Malaysia is classified as having tropical atmospheric conditions that are for the most part consistently hot and humid. The first half of the year is typically sunny while the remaining six months are wet. This hot and humid tropical climate is widely acknowledged as presenting particular challenges for building design (Szokolay, 2008). As a consequence of global warming, the world is facing an increase in outdoor and indoor temperatures. Although climates, living conditions, and societies differ widely across the world, the temperatures that individuals find comfortable in terms of dress, activity, moisture, and air are known to be very similar. To date, however, the construction industry's idea of green building seems to have focused only on finding the "right mechanism" for an environmentally sustainable "final result" (such as energy efficiency or water conservation), with no provision for subsequent appraisal of building execution (Yang, 2012).

The essential purpose of a building is to provide a safe and comfortable place for people to live, work, and communicate (Bessoudo et al., 2010). On that basis, it is appropriate to consider the

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building façade not just as a "wrapper" but as a boundary with fundamental capacities that impact indoor environmental quality and comfort (Drake, 2007). As indoor thermal comfort is commonly determined by the façade's thermal performance (Gratia & Herde, 2004; Liping & Hien, 2007), it seems important to ask how this factor is addressed in the design of mechanical ventilation structures in hot and humid climates like Malaysia. Previous studies have explored this issue from various perspectives. Gagge et al. (1986) discovered that thermal comfort is influenced by the relation between the building and outside conditions. More recently, Cheung et al. (2005) examined the impacts of architectural components on energy consumption in mechanically ventilated buildings and the effects on occupants' performance.

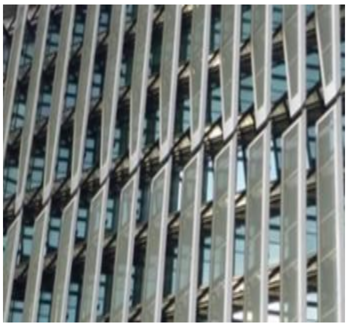
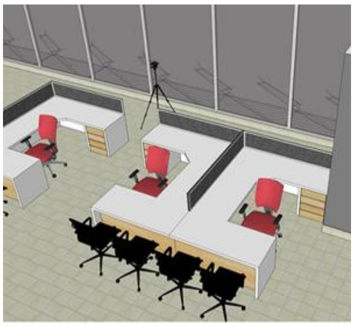
However, despite numerous analyses of how the building envelope affects indoor air quality, few studies have explored the effectiveness of façade structures in hot and humid climates as compared to those in cold climates (Ochoa & Capeluto, 2008). While a range of green building certification systems have been introduced worldwide, one question in particular remains to be clarified: are green building certification schemes as currently applied producing levels of Indoor Environmental Quality that satisfy their occupants (Liang et al., 2013)? In this regard, Gou et al. (2013) called for more research to identify the factors affecting indoor air quality in tropical locations.

It is generally accepted that green building techniques can provide superior indoor conditions that enhance wellbeing, prosperity, and efficiency. When properly applied, these techniques ensure more comfortable and advantageous working conditions. For that reason, the present study investigates the execution of NRNC GBI-rated buildings in Malaysia and the effects on indoor thermal comfort. While the study does not question GBI accreditation, it seeks to evaluate the execution of these provisions in the post occupancy period in terms of how green façade-shading devices help to fulfill criteria for indoor thermal comfort.

2. METHODOLOGY

The criteria for inclusion in the study were that the target case must be an office building (full or semi-government) rated by GBI Malaysia in either Kuala Lumpur or Putrajaya, Malaysia. Fieldwork measurements commenced in April 2016 and were completed in May 2016. These were conducted on weekdays during normal office hours (between 9.30 am and 4.30 pm). In one case, regulations and requests from persons in charge meant that equipment set up could only commence at 9.00 am and had to be completed by 5 pm each day. In all of the case study buildings, air conditioning and lighting for all spaces were in normal daily operation during the measurement procedure. In addition, all of the office spaces selected for fieldwork measurement were used for normal administrative work, involving everyday office tasks such as typing, reading, discussion, and telephone calls. Measurements included indoor air temperature, relative humidity, air velocity, and heat transfer through the building façade, as well as outdoor physical variables that included solar radiation, outdoor air temperature, and outdoor relative humidity. Using a BABUC-A data logger at a height of 1.0 meter above floor level on a west-facing facade, readings for each variable were taken at 30-minute intervals. The operating hours of the selected green building influenced this decision, and this is one of the study's limitations. The four GBI-rated office buildings chosen for the study are described in Table 1 below, with reference to the inclusion criteria.

Table 1 Case study buildings

Case Description	Façade	Measurement Area
1. *Building A* Location: Putrajaya GBI Rating: Platinum No. of Storeys: 7 Measurement Location: 6th floor (West Facing Façade) Facade: Double Glazing/ Tilting Façade Shading: Self-Shading (Slanting Design) *Air Conditioning System set at 24°C		
2. *Building B* Location: Putrajaya, GBI Rating: Gold No of Storeys: 12 Measurement Location: 6th floor (West Facing Façade) Façade: Curtain Wall (Low e) Shading: Vertical-Fin Perforated Panel *Air Conditioning System set at 24°C		
3. *Building C* Location: Kuala Lumpur, GBI Rating: Gold No of Storeys: 33 Measurement Location: 6th floor (West Facing Façade) Facade: Curtain Wall (Low e) Shading: Horizontal Shading *Air Conditioning System set at 24°C		
4. *Building D* Location: Kuala Lumpur, Malaysia GBI Rating: Platinum No of Storeys: 37 Measurement Location: 6th floor (West Facing Façade) Facade: Slanting Facade (Low e) Shading: Vertical- and Horizontal-Fin Steel Frame *Air Conditioning System set at 24°C		

The equipment used in the study is described in Table 2.

Table 2 Measuring equipment

BABUC A:	
Instrument	Parameters
Air Temperature Sensor (Pt100 output) BST 101	Indoor Air Temperature (°C)
Psychrometer Sensor (Pt100 output)	Indoor Relative Humidity (%)
Black Globe Radiant Temperature Sensor (Pt100 output) BST 131	Mean Radiant Temperature (W/m^2)
Globe Radiant K 601 012	Solar Radiation Intensity (Wh/m^2)
Individual Equipment:	
Instrument	Parameters
Extech Thermo Hygro Anemometer (3-in-1)	Outdoor Air Temperature (°C) & Outdoor Relative Humidity (%)
Extech Hotwire Thermo Anemometer with Datalogger	Air Velocity (m/s)

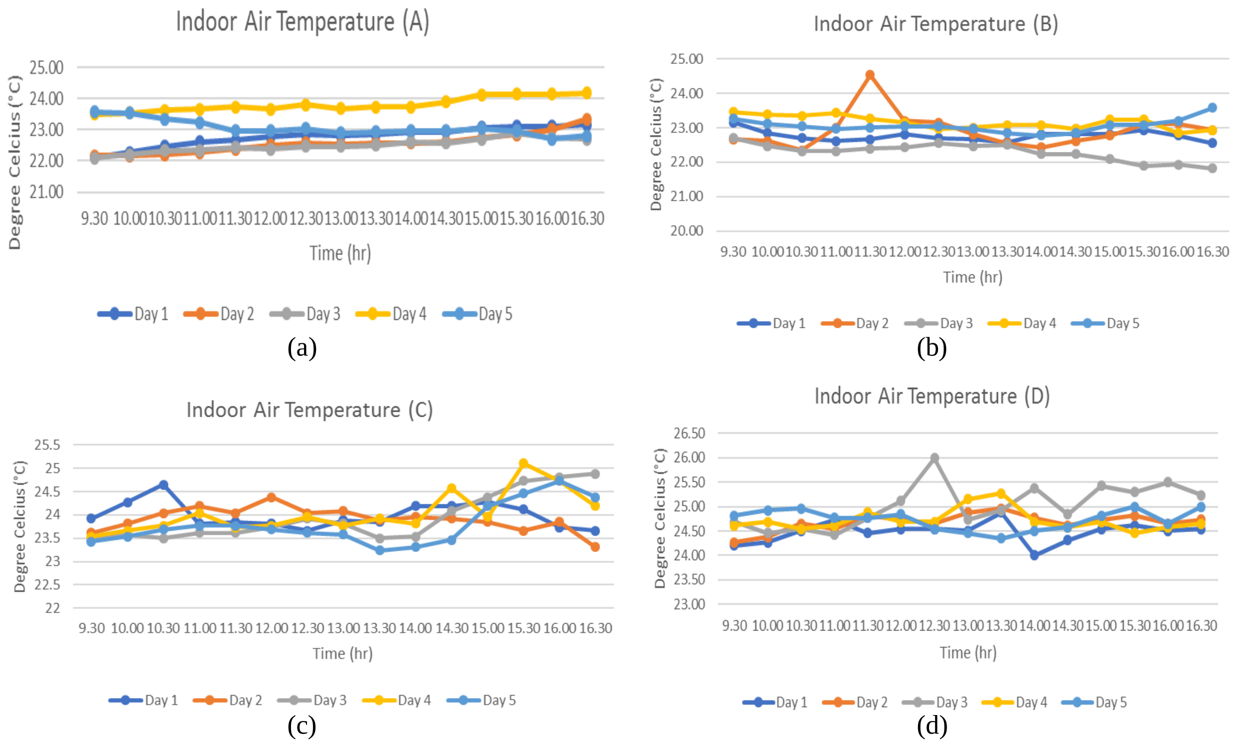
3. RESULTS AND DISCUSSION

3.1. Thermal Comfort Performance Analysis

The study originally focused on seven Indoor Environmental Quality (IEQ) variables: (1) Air Temperature; (2) Relative Humidity; (3) Mean Radiant Temperature; (4) Air Velocity; (5) Acoustic (Background Noise); (6) Visual (Illumination); and (7) Indoor Air Quality (IAQ). The fieldwork measurements also included related outdoor variables such as Outdoor Air Temperature, Outdoor Relative Humidity, Solar Radiation, and Outdoor Air Velocity, using correlation analysis to assess the contribution of each building's façade shading properties and design to IEQ. Differences between the case study buildings were assessed using Kruskal-Wallis H and post-hoc Mann-Whitney U tests for analysis of variance. The study focused on thermal comfort performance in each case, based on measurement of Air Temperature, Relative Humidity, Mean Radiant Temperature and Air Velocity. Correlations and analysis of variance are not discussed here, but these will be included in a future publication.

3.1.1. Indoor air temperature

Figure 1a shows five days of indoor air temperature measurements for Building A, which is located in Putrajaya, Malaysia. A steady pattern of indoor air temperature was observed, with the exception of the fourth day of observation, when the pattern differed. The graph indicates that the average indoor temperature ranged from 22°C to almost 25°C; the highest indoor air temperature of 24.19°C was recorded at 4.30 pm on the fourth day of observation. Figure 1b shows a regular pattern of indoor air temperature for Building B, with relatively little variation over the five-day observation period. Building B's consistent temperature exceeded 24°C only on the second day of observation; this increase is consistent with the increased mean radiant temperature value shown in Figure 4b. In relation to Building C, Figure 1c indicates a regular pattern of fluctuation in indoor air temperature for the five-day observation period, ranging between 23°C and almost 25°C. However, air temperature exhibits an irregular pattern over the five-day measurement period, with a highest value of 25.11°C recorded at 3.30 pm on the fourth day of observation. Finally, Figure 1d shows indoor air temperature values for Building D, ranging from 24°C to about 26°C. Indoor temperature increased dramatically at 12.30 on the third day of measurement. Based on these data, Building A exhibits the steadiest indoor air temperature pattern for the five-day observation period.



(a) (b)

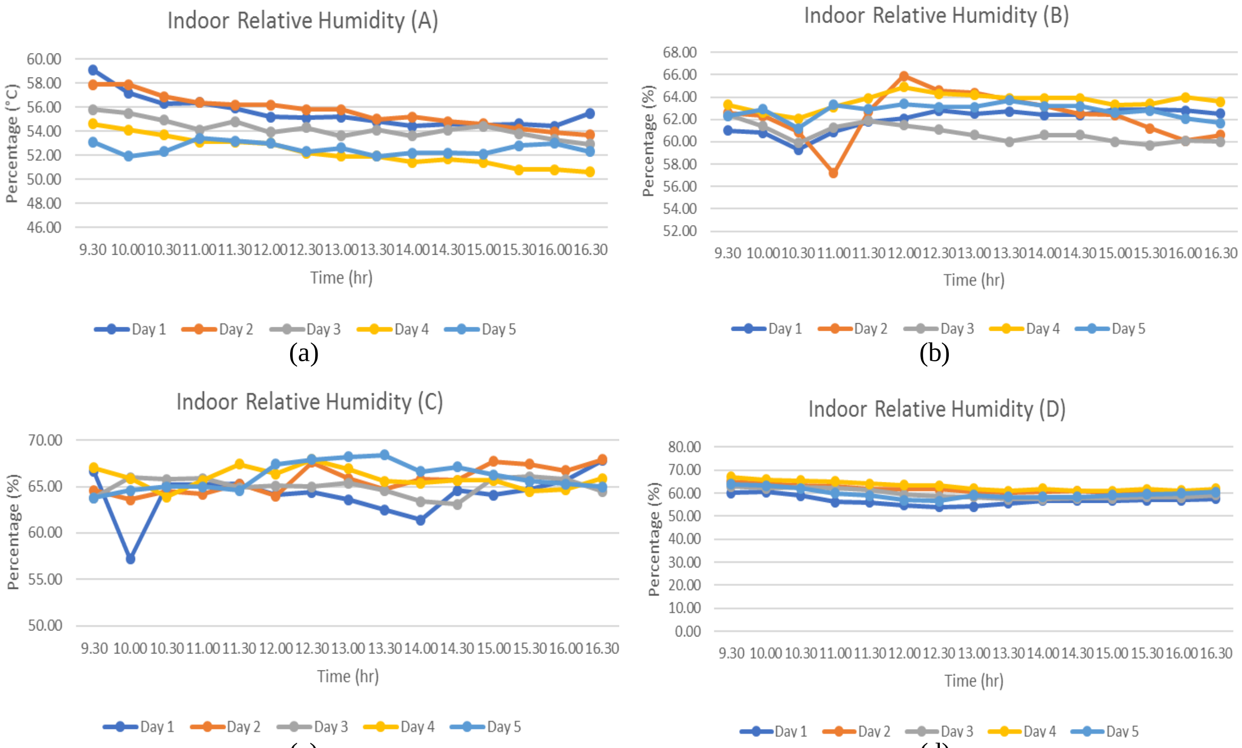
(c) (d)

Figure 1 Indoor air temperature: (a) Building A; (b) Building B; (c) Building C; (d) Building D

3.1.2. Indoor relative humidity

Figure 2a shows the variation of relative humidity in Building A, which remains within the acceptable range of structure-relative moistness specified in MS 1525. In general, the five-day perceived estimate of indoor relative humidity drops quickly until 4.30 pm, with indoor moistness ranging from 50% to 59% for the entire period of observation. Figure 2b shows the variation in relative humidity for Building B, which is again within the acceptable range specified in MS 1525. Indoor relative humidity drops quickly at 10.30 to 11.00 on the second day, ranging from 56% to 66% over the period of observation. Figure 2c indicates the range of relative stickiness for Building C, which again falls within the range of plan-relative dampness specified in MS 1525.

Figure 3c shows the rapid fall in indoor relative humidity at 10 am on the first day of observation. In Building C, indoor humidity ranges from 57% to 68% over the observation period. Finally, Figure 2d captures the range of relative mugginess for the MITI Building, which is again within the acceptable range of structure-relative moistness specified in MS 1525. In general, Figure 2d shows a steady level of indoor relative moistness throughout the five-day period, ranging from 54% to 68% for the observation period. Based on the data in Figure 2, Building D exhibits the steadiest levels of indoor relative humidity.



(a) (b)

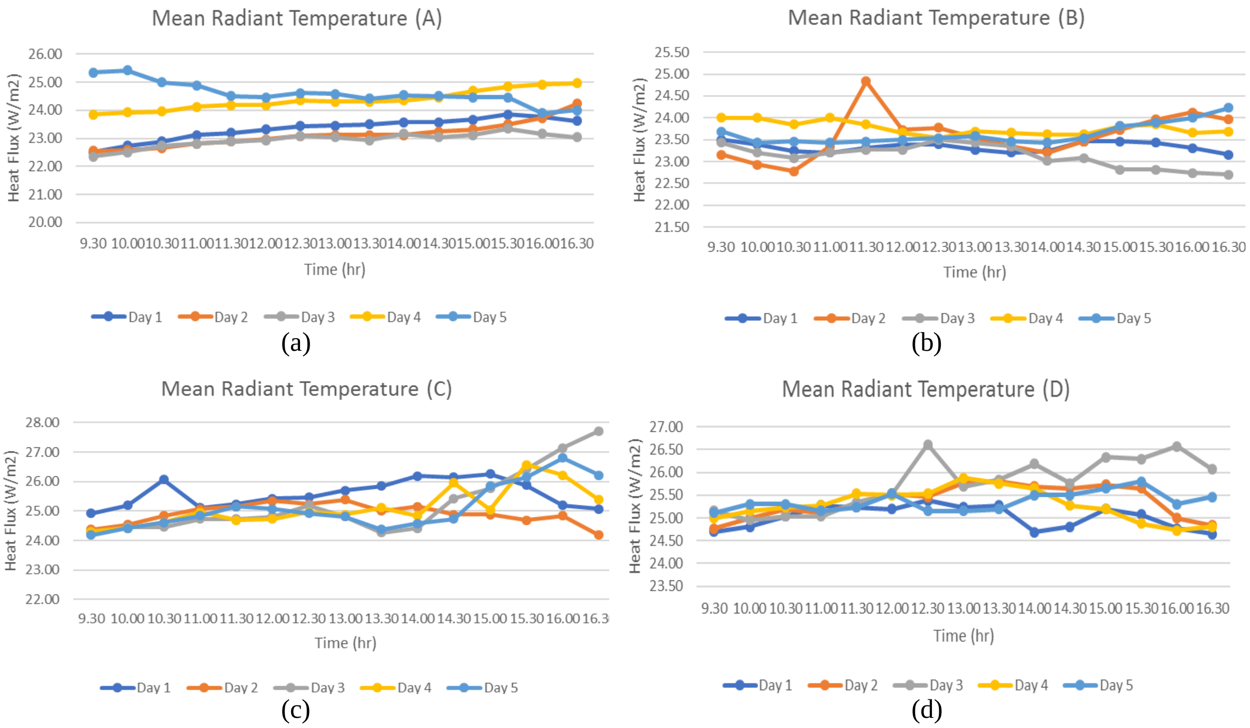
(c) (d)

Figure 2 Indoor relative humidity: (a) Building A; (b) Building B; (c) Building C; (d) Building D

3.1.3. Mean radiant temperature

Figure 3a shows the five-day measurements of heat transfer into Building A. A fluctuating pattern of solar radiation was observed throughout the week, especially on the last two days of observation, where heat flux into the building rose above 25 W/m^2 as recorded from 9.30 to 10.30 on the fourth day of measurement. In general, solar heat transfer intensity varied throughout the day as a result of variation in cloud cover. Heat flux into the building fluctuated from 22 to almost 25 W/m^2 between 9.30 and 4.30 each day. Figure 3b shows five-day measurements of heat transfer into Building B. A regular pattern of solar radiation was observed throughout the week other than on the second day of observation, when heat flux into the building rose to almost 25 W/m^2 at 11.30. Solar heat transfer intensity fluctuated throughout the day because of the variation in cloud cover. Heat flux into the building fluctuated from 22 to nearly 25 W/m^2 between 9.30 and 4.30 each day.

Figure 3c shows the five-day measurements of indoor heat transfer for Building C. An unvarying pattern of heat flux was observed throughout the week. Heat flux intensity entering the building through its facade fluctuated during the day because of the variation in cloud cover, ranging from 24 to nearly 28 W/m^2 between 9.30 and 4.30 each day. The highest indoor heat transfer intensity of 27.72 W/m^2 was recorded on the third day of observation at 4.30. Finally, Figure 3d shows a regular pattern of indoor heat transfer during the week for Building D. Heat transfer into the building through the facade fluctuated throughout the measurement day because of the variation in cloud cover and inconsistent weather conditions throughout the five-day observation. Heat flux ranged from 24 W/m^2 to about 27 W/m^2. The maximum heat flux entering the building during the five days was recorded as 26.61 W/m^2 at 12.30 on the third day of observation. Based on the mean radiant temperature graphs for each building, Building A shows a steady pattern for the five-day measurement period.



(a) (b) (c) (d)

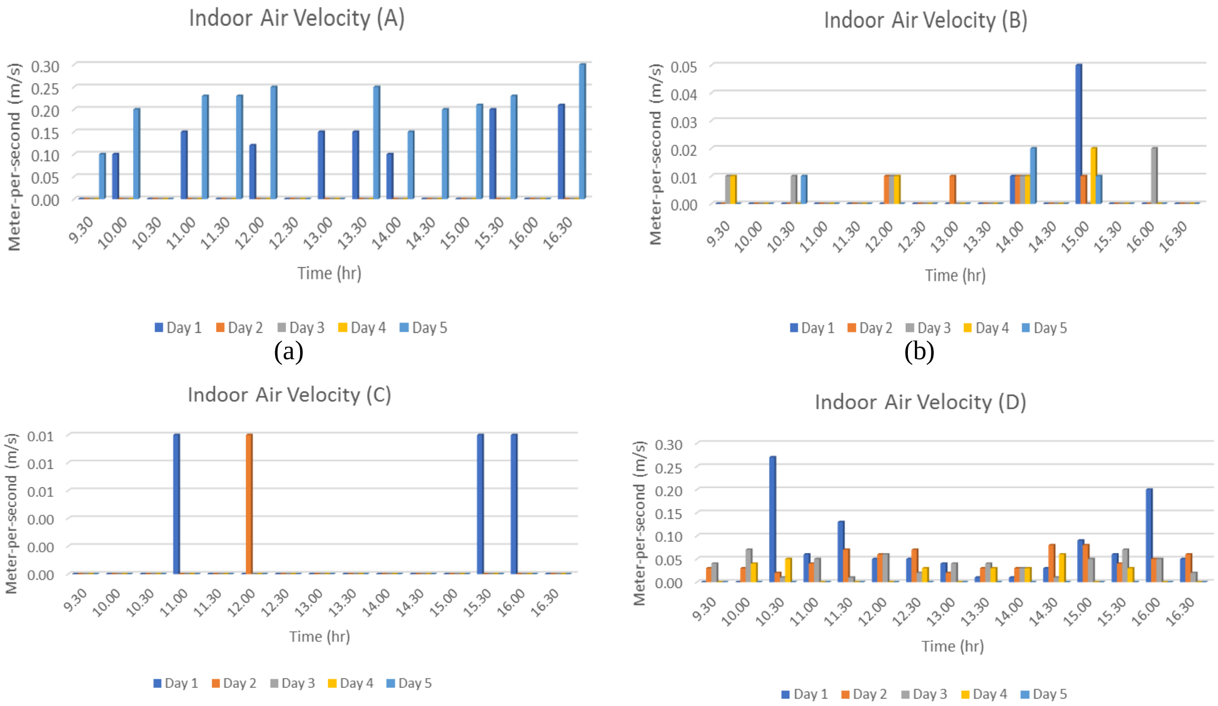
Figure 3 Mean radiant temperature: (a) Building A; (b) Building B; (c) Building C; (d) Building D

3.1.4. *Air velocity*

Figure 4a shows the estimated effect of Building A air movement estimated at 1 m above floor level at five different locations. Figure 4a shows normal air velocity as ranging from 0.00 m/s to 0.25 m/s. Figure 4b shows the estimated effect of building air movement at 1 m above floor level at five different points for Building B, indicating that normal air movement ranged from 0.00 m/s to 0.05 m/s.

Figure 4c shows the estimated effect of building air movement for the five-day period at 1m above floor level at five distinct points in Building C. The absence of air speed readings indicates that there is no air movement from the third day onward. The normal air speed for Building C ranges from 0.00 m/s to 0.01 m/s. Finally, Figure 4d shows the estimated building air speed at 1 m above floor level at five distinct points in Building D over the five days, ranging from 0.00 m/s to 0.27 m/s. Aside from the first day reading of 0.27 m/s at 10.30, this is very low in relation to ASHREA's baseline of 0.25 m/s. Taking everything into account, the general effects of indoor air speed are low by comparison with ASHREA's baseline of 0.25 m/s and the MS 1525 range of 0.15 to 0.50 m/s. This effect may be due to low air exchange from the air conditioning system in all of the selected buildings.

Table 3 outlines the implications of thermal comfort readings for the four buildings.
Building A: Based on these data, it can be inferred that thermal comfort is acceptable for the occupants of Building A with slight improvement of air movement.
Building B: Thermal comfort condition is considered satisfactory for occupants of Building B, but significant improvements should be made to enhance air movement.
Building C: Thermal comfort is considered adequate, but again, improvements are needed to improve air movement.
Building D: The parameters indicate that thermal comfort in Building D is considered satisfactory, requiring slight improvement to enhance air movement.



(a) (b)

(c) (d)

Figure 4 Indoor air velocity: (a) Building A; (b) Building B; (c) Building C; (d) Building D

Table 3 Thermal comfort findings

Thermal Comfort Parameter	Reference (as in Table 3)	Outcome Building A	Outcome Building B	Outcome Building C	Outcome Building D	Results Indicator
Indoor Air Temperature	23°C to 26°C	22–25°C	21–25°C	23–25°C	24–25°C	Within Range (Good)
Indoor Relative Humidity	55% to 70%	50–59%	56–66%	57–68%	54–68%	Within Range (Good)
Mean Radiant Temperature	Not exceeding 50 W/m^2	22–26 W/m^2	22–25 W/m^2	24–25 W/m^2	24–27 W/m^2	Within Range (Good)
Indoor Air Velocity	0.15–0.50 m/s	0.00–0.25 m/s	0.00–0.05 m/s	0.00–0.01 m/s	0.00–0.27 m/s	Below Range (improvement required)

In conclusion, it can be said that the results in Table 3 indicate that these structures have met the planning and development requirements of GBI Malaysia under the NRNC Tools category. The findings align with past research by Yau (2011) on thermal comfort and IAQ. However, Yau (2011) did not take account of all the parameters of IEQ in the selected green office building.

4. CONCLUSION

Based on these findings, it may be concluded that Buildings A and B have achieved the requisite IEQ thermal comfort criteria for recertification after five years. Buildings C and D were found worthy of conclusive accreditation from GBI Malaysia. These findings also confirm that IEQ falls within the stipulated GBI range for green office buildings in a hot and humid climate like Malaysia thanks to various double-glazing provisions for façade shading. While a couple of parameters were not fully met, indoor conditions in these buildings are nevertheless considered adequate as benchmarks for green office buildings in Malaysia and South-East Asia.

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