Dichotomy of Predictor Variables of Indoor Air Quality and Prevailing Public Perception of Green Living Space – A Preliminary Assessment

Hazirah Ab Latib,[a,]* Mohd. Afthar Amir,[b] Kamaruzaman Othman,[b] Jegatheswaran Ratnasingam,[a,]* and Lim Choon Liat [a]

Indoor environmental quality has a profound effect on human health and productivity. In this respect, this study evaluates indoor air quality in terms of its various parameters in sustainably built homes in three different locations. A supplementary study to examine the formaldehyde emission levels from furniture with three different finishes was also undertaken. A questionnaire-based survey was then conducted to evaluate the general public perception of the prevailing indoor air quality in the three locations. The results revealed that temperature, relative humidity, indoor air speed, particulate matter (PM10), CO_2, NO_2, and total volatile organic compounds (TVOC) and formaldehyde (HCHO) readings were not significantly different between the three locations and were below the existing limit allowed for indoor environmental quality. However, the HCHO emission was the highest from furniture with the two-layer coatings, followed by single layer coating, and finally the furniture with the veneer overlay. It was noteworthy that the general public's awareness and knowledge of indoor air quality was relatively poor, except for the tertiary level educated respondents. In this regard, policymakers need to increase the awareness and knowledge of indoor environmental quality among the general public, if non-compliance is to be detected and promptly addressed.

DOI: 10.15376/biores.18.2.3783-3801

Keywords: Indoor environmental quality; Green homes; Formaldehyde; Public perception; Living comfort; Green building policy

Contact information: a: Universiti Putra Malaysia, Faculty of Forestry & Environment, 43400 UPM, Serdang, Selangor, Malaysia; b: Malaysian Timber Industry Board (MTIB), Level 13-17, Menara PGRM, Jalan Pudu Ulu, 56100 Kuala Lumpur, Malaysia;
**Corresponding authors: hazirahlatib@gmail.com; jegaratnasingam@yahoo.com*

INTRODUCTION

The COVID-19 pandemic, since its onset in 2019, has had a major impact on human behavior, as an increasing number of people throughout the world are opting to spend longer hours indoors, and choosing to work from home (D'Alessandro *et al.* 2020; REHDA 2021). In fact, with the imposition of a series of lockdowns in many countries, including Malaysia, people from all walks of life spent nearly 80% of their time indoors compared to 55% prior to the onset of the pandemic. According to the Malaysian Institute of Public Health (2021), almost 95% of the adult population in the country increased their number of hours spent indoors since the onset of the pandemic in 2019, while significant life-style changes have also been observed among the population in both urban and rural areas. According to the REHDA (2021), with increasing number of people spending longer times indoors, the demand for sustainable or green living spaces, better known as green buildings, which offered better indoor environmental quality (IEQ), was expected to increase rapidly.

The Environmental Protection Agency (EPA) of the US defines indoor environmental quality (IEQ) as the quality of the air inside buildings, as represented by concentrations of pollutants and thermal (temperature and relative humidity) conditions affecting the health, comfort, and performance of occupants. The development and urbanization process in Malaysia for the past decades have contributed to an increase of air pollutants in both outdoor and indoor environments. In this respect, the IEQ has now become a key indoor quality criterion that determines the quality of life and comfort level. Inevitably, a clean, healthy, and comfortable indoor environment is a prerequisite to ensure acceptable IEQ, which is vital to avoid health problems (CREA 2022).

The IEQ refers to the nature of conditioned air that circulates throughout the space or work area (DOSH 2018). The IEQ is not only for comfort, which is affected by temperature, humidity, and odour, but it also is related to harmful biological contaminants and chemicals present in the conditioned space (DOSH 2018). The IEQ is defined by characteristics that include indoor temperature, ventilation rates, indoor concentration of carbon dioxide (CO_2), carbon monoxide (CO), particulate matter of less than 10 μm in size (PM10), volatile organic compounds (VOCs), nitrogen dioxide (NO_2), and airborne microbes. On this account, the environment in both workspace and homes must be controlled to a certain degree to provide comfort and health to its occupants (CREA 2022).

Indoor air pollutants come from the outdoors, mechanical ventilation, and air-conditioning (MVAC), building equipment, and furnishing, as well as human activities (CIDB 2019). It has been reported that the four important causes of unacceptable IEQ are inadequate maintenance of heating, ventilation, and air-conditioning (HVAC) systems, a shortage of fresh air intake, a lack of humidity control, and finally, high exposure to pollutants, including particulates and chemicals (ICPIEQ 2010). It has also been found that excessive humidity, lack of fresh air intakes due to lack of ventilation, and uncomfortable level of indoor temperatures are common in many homes in Malaysia, which may exacerbate the problem associated with poor IEQ (ICPIEQ 2010). This condition is further aggravated as Malaysia being in the tropics, has relatively high temperatures and humidity levels throughout the year. Indoor air pollution remains a major environmental health hazard for Malaysians. Despite the relatively small-scale epidemiologic evidence, Malaysian studies have highlighted strong and relatively consistent associations between indoor air pollution and the overall population's respiratory health (Jafari *et al.* 2015; CREA 2022).

Green Building and Indoor Environmental Quality: The Malaysian Perspective

The concept of sustainable and green living space, also referred to as green building, is an outcome of a design philosophy that focuses on increasing the efficiency of resource use, such as energy, water, and materials, while at the same time, reducing building impacts on human health and the environment during the building's lifecycle, through better design, construction, and maintenance. According to the Architects Association of Malaysia (PAM 2019), green building is increasingly important to comply with the Sustainable Development Goals (SDGs) being aggressively pursued by the construction industry in the country. In fact, constructing green buildings is expected to positively improve occupants' health, employee productivity, efficient use of resources, and reduce pollution and waste (PAM 2019). However, the Construction Industry Development Board (CIDB 2019) has also highlighted that most building construction projects in the country are somewhat not in compliance with green building standards, as the cost of construction is the major consideration, which sacrifices sustainability parameters. This is particularly a concern in tropical, humid countries, where air quality control and management pose a challenge.

In Malaysia, green buildings are designed and accredited according to a system called the Green Building Index (GBI). The GBI offers guidance and rating tools for developers to understand and create buildings that align with the efficiency and positive environmental goals of green design. Such buildings have efficient technology that reduces the building's energy intensity by 38%, its water usage by 40%, and its CO_2 emissions by 30%. Although the green building sector is looking up in Malaysia, there is the significant challenge of education and understanding to overcome before this kind of sustainable development can take root on the ground level of all construction (CIDB 2019). Further, building an environmentally sound building and adhering to GBI standards is perceived as being too expensive for many developers. New technologies are costly, as are eco-friendly construction materials and the planning time and staff it takes to put up a truly green building in Malaysia. Developers are stuck in the mind-set of short-term gain, and often resort to cheaper and faster construction as the quickest way to profit, and are reluctant, despite government incentives, to change their way of business and go the extra mile for green building (PAM 2019). Inevitably, as of 2018, only 18% of all new launches of residential buildings were considered as being green buildings (PAM 2019).

The study by CIDB (2019) has shown that green building practices can reduce a building's operating costs by as much as 9%, increase building value by 7.5%, and realize a 6.5% increase in return on investment (ROI). Accordingly, green buildings bring multiple benefits throughout their lifecycle, including using up to 50% less electricity, which inevitably reduces greenhouse gas emissions, recycling construction waste which leads to minimal emissions of toxic substances, and reduce water usage through rainwater harvesting and efficient fittings.

Green building certification in Malaysia is achieved through the adoption of one of the certification schemes available, such as the Green Building Index (GBI), Green Real Estate (GreenRE), Leadership in Energy and Environmental Design (LEED), Green Mark, and Green Star (Darus *et al.* 2009; CIDB 2019). However, the most prevalent green building certification scheme in Malaysia are the GBI and GreenRE. Malaysia's Green Building Index (GBI) is an internationally recognised green building tool founded by the Malaysian Institute of Architects and the Association of Consulting Engineers Malaysia in 2009. Green Real Estate, or GreenRE, is an alternative rating system introduced by the Real Estate and Housing Development Association of Malaysia (REHDA) in 2013. It was developed in collaboration with the Ministry of Energy, Green Technology and Water and other government agencies and statutory bodies such as the Construction and Industry Development Board (CIBD), and the Institute of Engineers Malaysia. According to the GreenRE certification scheme, green buildings are classified according to six criteria, including energy efficiency, indoor environmental quality, sustainable site planning and management, materials and resources, water efficiency and innovation. However, as it stands, this certification scheme pays little attention to the contents and its impact on the IEQ of the buildings (REHDA 2021).

Despite the growing interests in green buildings construction, controlling and managing IEQ is challenging even in such buildings due to the fact that Malaysia is a tropical, hot and humid country (CIDB 2019). In general, the daily temperature profile increases slightly from morning to afternoon, whereas the trend is reversed for relative humidity (RH) with decreasing value as time passes. As a result, the mean temperatures and relative humidity during the day in Malaysia is often higher than the standard stipulated in the Industry Code of Practice of Indoor Air Quality (ICPIEQ), a guideline by the Department of Occupational Safety and Health Malaysia (DOSH). The recommended range for acceptable IEQ is 23.0 °C to 26.0 °C for temperature, and 30% to 65% for RH, but the reportedly higher temperature and RH in the country often cause discomfort to individuals within an indoor environment (ICPIEQ 2010).

Further, the CO_2 concentrations were reported to be higher in urban and commercial work areas, while significantly lower in rural work areas (CREA 2022). The indoor CO_2 levels were positively affected by ventilation systems and the number of occupants, and in the study by CREA (2022), the recommended value of CO_2 exposure, which should not exceed 1000 ppm for an 8-h period, as per the ICPIEQ (2010), is often exceeded primarily due to over-crowded spaces, poor ventilation, and lack of fresh air intake. In contrast, the reported CO_2 concentration for different types of work areas ranges between 2.74 to 6.41, below the recommended value of 10 ppm for an 8-h exposure, in accordance with the ICPIEQ.

Air-borne dust and particulate matter is also a matter of major concern in most Malaysian buildings (Mohd Shafie *et al.* 2022). The presence of respirable particulate matter below 10 µm in size (PM10) in buildings is attributed to the age of the building, the types of flooring, presence of curtains, shelf area, dust from blackboard, and fans. The recommended threshold level for respirable particulates by the ICPIEQ is 150 µg/m^3, and available evidence suggests the concentration of indoor particulate was close to exceeding the recommended value in most buildings, which may explain the high incidence of respiratory-induced ailments within the population (Ratnasingam *et al.* 2012).

Although studies on indoor volatile organic compounds (VOCs) in Malaysia are limited (Jafari *et al.* 2015; CREA 2022), the reports available suggest that the mean concentrations of formaldehyde (HCHO), CO, and total volatile organic compounds (TVOCs) were well below the recommended values of 10 ppm for 8-h of exposure, although in some instances, a few parameters, especially NO_2, were beyond the standard limit. However, in the study by Salthammer (2019), it was found that indoor concentration of VOCs at homes in urban areas was averaging 0.08 µg/m^3, which was higher compared with the homes in rural areas of 0.035 µg/m^3. Although the concentration of VOCs was not positively different between the urban and the rural areas, the variations in concentrations of these sources were suspected contributors to the health symptoms among occupants.

The influence of particulate matter and chemical pollutants on IEQ is a matter of growing concern, as urbanization and transport volume increase throughout the country. Further, with increasing use of wood products for interior decorations apart from furniture, *etc.*, there is a need for increased scrutiny on volatile organic compounds (VOCs) emissions, including formaldehyde, xylene, toluene, benzene, *etc.*, not only from building materials and furniture, but also from carpets and other household materials (Roffael 2006). From another context, the growing environmental concern among the general population also leads to a higher demand for better indoor air quality.

Growing Concern for Formaldehyde Emission

Formaldehyde has been of concern as an indoor air pollutant because it exists in a wide range of products and human exposure to it may result in adverse health effects. The U. S. Environmental Protection Agency (EPA) and the U. S. National Toxicology Program have recently classified formaldehyde as a known human carcinogen. Studies have shown that people exposed to formaldehyde levels ranging from 50 to 100 µg/m^3 for long periods of time are more likely to experience asthma-related respiratory symptoms, such as coughing and wheezing (Ratnasingam *et al.* 2014; Isinkaralar *et al.* 2022). In this respect, the recommended exposure limit (REL) for formaldehyde equal to 0.016 ppm, which might be converted to approximately 20 µg/m^3 (ICPIEQ 2010).

Exposure to formaldehyde is higher indoors than outdoors due to low air exchange rates (Salthammer 2019; Isinkaralar *et al.* 2022). Formaldehyde is released into homes from a variety of indoor sources, *e.g.*, wood products, consumer products, coatings, permanent-press fabrics, insulation materials, combustion appliances, and tobacco products. It may also be formed by the chemical reaction of ozone with VOCs that are present indoors (Salthammer 2019).

Formaldehyde emission from a wood-based panel can be a complicated process, which can be affected by (1) factors related to the materials, such as type of panel, wood species, adhesive, coating, and overlay used for the panels; (2) factors related to the environment, such as temperature, humidity, air velocity, and air exchange rate; (3) factors related to treatment; and (4) factors related to panel fabrication process, such as resin content, moisture content of the panel, and others (Que and Furuno 2007).

Studies have also shown that coatings based on alkyd and amino resins used on floorings, cabinets, and furniture also emit a high concentration of formaldehyde (Wolkoff 1999), depending on the pre-conditioning and thickness of the coating applied. The increasing use of low-VOC coatings, including latex-based coatings and water-based coatings, although deemed to be more environmentally friendly, appears to be another unexpected source of formaldehyde emission in indoor environments (Yu and Kim 2012). Cleaning products often used indoors in buildings have also been found to emit formaldehyde, which is also a major secondary pollutant in the presence of ozone (Wolkoff 1999; Singer *et al.* 2006). Previous studies have also shown alternative methods to reduce formaldehyde emission from wood products in indoor environment (Isinkaralar 2022a,b; Isinkaralar *et al.* 2022).

One of the major challenges in reducing formaldehyde exposure to humans is the lack of awareness of the potential health risk posed by formaldehyde among the general public (Abdullah *et al.* 2019). To reduce formaldehyde exposure, the Malaysian Timber Industry Board (MTIB) formulated and implemented the 'Guidelines on Formaldehyde Emission from Wood-Based Panels' in 2023, which aims to reduce formaldehyde emission from non-compliant imported, as well as locally produced wood-based panels, which are harmful to human health. The permitted levels of formaldehyde in indoor spaces in Malaysia is set at 0.1 ppm (100 µg/m^3) as stated by the ICPIEQ. This guideline is touted to be in line with the international guidelines set by the World Health Organization (2018), as model measurements (in test chambers) of formaldehyde emissions from different wood and wood-based products, as well as from paints, carpeting, *etc.*, have shown high and variable levels (Que and Furuno 2007). Nevertheless, information about the influence of different wood-based panels, finishing materials, and overlaying materials on formaldehyde emission from furniture and wood products in indoor spaces is limited, as alluded in the report by CREA (2022) and Ratnasingam *et al.* (2023). This is mainly because a lot of parameters must be considered, as offices vary in size, equipment, occupant number, as well as the type of activities they are designated for, *etc*.

In a study on VOC emission in wood products consumed in the domestic market, it was found that 59% of the products did not comply with the existing VOC, including the formaldehyde emission levels (PAM 2019; Agarwal *et al.* 2021; Kumar *et al.* 2023). This trend may adversely affect the prevailing IEQ in buildings, including green buildings, which affects the healthy living of the occupants in the long term. This is a concern for not only housing developers, but also home buyers, as the limited reports on IEQ within green buildings are impacting home buyers' sentiments, regarding living comfort (REHDA 2021). Therefore, a study was undertaken to evaluate IEQ, formaldehyde emission levels, and the prevailing public perception of IEQ in green buildings. The results of this study should provide an insight into the current state of IEQ in green building in Malaysia and to make the necessary recommendations for improvements of the IEQ to comply with standards, in line with the Sustainable Development Goals (SDGs).

EXPERIMENTAL

Part I – Measurements of IEQ Parameters in Homes

Selection of Experimental Sites

According to the Real Estate and Housing Developers Association (REHDA) report of 2021, the typical green home in Malaysia is usually sized 190 m^2 (or 1900 ft^2), with rooms normally of 28 m^2 (or 280 ft^2) in size. It is constructed primarily from environment- friendly materials, with passive ventilation and cooling incorporated into its design. A room in such homes usually has a twin-panel window of 1.2 m^2 (12 ft^2) in opening to facilitate air exchange, and it is usually equipped with a ceiling fan. The height of the room (floor to ceiling) is usually 3.0 m (10 feet). With the assistance of the REHDA, three green homes were randomly selected at three different locations, of varying housing density and number of occupants to obtain a fair representation of living conditions. The location for the study was identified based on the REHDA database of sustainably constructed homes. The chosen locations for the study were within Kelang Valley, namely in Serdang (high density), Cyberjaya (medium density), and Sepang (low density). The rooms chosen for the experimental measurements of IEQ, in each of the three houses were similar in size and characteristics, which represented the typical living space in green homes. The walls in these homes were given a fresh coat of standard emulsion paint in 2022, the flooring was tiled neatly, and the ventilation frequency was reportedly 7 times per hour in the room. The rooms had a single adult occupant each, furnished with old furniture, including a single bed, a study desk, a chair, and a twin-door wardrobe, which were more than 10 years old. These rooms were classified as being compliant to a green living space as defined by the CIDB (2019).

Measurements of indoor environment quality

Eight parameters were recorded during the field measurements of IEQ in the rooms, in the three locations. The IEQ data collected included four physical parameters (air temperature, relative humidity, air velocity, and particulate matter, PM10) measured over a period of 14 days, with measurements of air temperature and relative humidity made on an hourly basis from 06.00 hours to 18.00 hours throughout the period. Air velocity and particulate matter, PM10, were measured twice a day within the room. Measurements of the physical parameters were taken using the TSI IEQ-Cal meter (GEOTECH, Denver, CO, USA), attached to a portable data logger, which recorded the air temperature, relative humidity, air velocity, and particulate matter PM10, data.

The four chemical parameters, specifically nitrogen dioxide, carbon dioxide, total VOCs, and formaldehyde were measured using a 4 in 1 Meter Kit, TSI IEQ-Cal (GEOTECH, Denver, CO, USA). The chemical parameters were measured throughout the 14 days period, thrice per day, at 8.00 am, 12.00 noon, and 6.00 pm. To increase accuracy and reliability, all measurements were professionally taken by technicians from the company UT Environmental Services. The captured data were collated and compiled in a portable data-logger for further analysis.

Influence of furniture on formaldehyde emissions

To evaluate the emission of VOCs and formaldehyde from furniture, the three experimental rooms were refurnished with a new wardrobe made up of medium-density fiberboard, after one month of initial measurements. Two of the wardrobes were finished with standard urea-based coating used commonly for furniture (one with a single layer of coating, while the second had received two layers of coating), while the third wardrobe was finished with veneer overlay. The coating material used had a solid content of 34%, and the dry film thickness of each coating layer was 125 µm, while the veneer overlay used was a 0.35 mm thick rubberwood veneer. One wardrobe was installed in each room where measurements of formaldehyde were made, immediately after installation, and monitored daily for a 30-day period. Subsequent measurements were made at day 45, 60, 75, and 90 to observe the trend in emission levels. Measurements were taken by technicians from the company UT Environment services, using the 4 in 1 Meter Kit, TSI IEQ-Cal, and the captured data stored in a data-logger for further analysis.

IEQ data analysis

The captured data were extracted from the data logger and transformed into an EXCEL spreadsheet for further analysis using the IBM Statistical Package for Social Sciences (SPSS) Version 23 software (IBM Corp., Redmond, WA, USA). The IEQ physical and chemical parameters were averaged and transformed into graphical illustrations to clearly show the trends in variations observed throughout the study period, for the three experimental locations. The Anderson-Darling test was used to confirm the normality of the data variables. The Kruskal-Wallis test was performed to compare the level of IAP parameters between the three sites, with $p < 0.05$ set as the significant level.

Part II – Public Perception of IEQ

Sample population

In the second part of the study, the general public perception of the IEQ was evaluated in the three locations where the physical measurements were made, using a structured questionnaire. The total number of randomly selected respondents in each location was 100, and they were interviewed with the assistance of staff of the REHDA.

Questionnaire design

The questionnaire consisted of a combination of both open- and closed-ended types of questions and was divided into four sections: 1) demographic background, 2) awareness of IEQ, 3) knowledge on existing policy on IEQ, and 4) recommendations. In this study awareness is defined as the person's state of knowing about IEQ and its effect on health, as a result of personal or family members' experience. Assessments were made on the basis of respondents choosing the IEQ parameters that had an effect on them. In section 3, knowledge was assessed based on whether respondent has read or heard about IEQ standard and policy framework, using a dichotomous response (yes/no). The respondents were assessed on their understanding of basic concepts of IEQ, identifying the main parameters of concern, and associated symptoms and health effect if subjected to poor IEQ, using dichotomous responses (true/false and yes/no). A further set of questions was posed to the respondents to seek their awareness of green homes and its benefits. The draft questionnaire was designed based on previous studies (Ratnasingam *et al.* 2010, 2012; CREA 2022). After several discussions with representatives of the DOSH, CIDB and REHDA, it was sent to two experts in social science for content validation. After necessary corrections and amendments were made, a pre-test survey using randomly selected 15 respondents was conducted to check for question clarity and the timing of respondents answering the questions. Necessary corrections and amendments on the pre-test study were made accordingly before the questionnaire was used for data collection.

Data analysis

Descriptive statistics were computed for continuous variables, and some of the results were represented using graphical charts. To assess the level of awareness and knowledge of IEQ, the percentage of correct answers was ranked as good (65% to 100%), fair (40% to 64%), and poor (< 40%). The Kruskal-Wallis H test was used to establish the IEQ knowledge of the respondents with their demographic background.

RESULTS AND DISCUSSION

The results of this study are presented in two parts.

Part I: IEQ Measurements

Figures 1a and 1b show the average temperature and relative humidity recorded in the three locations throughout the study period. Figure 2 shows that average air velocity recorded at the study sites, while Fig. 3 reflects the concentration of particulate matter PM10 at the study sites throughout the study period. It is apparent that the average temperature and relative humidity at the three locations were within acceptable range in the early mornings until 11:00 am and from 4:00 pm onwards throughout the study period. Peak temperature and relative humidity, exceeding the recommended range of 23 to 26 °C in temperature, and relative humidity ranging from 40% to 70% were recorded consistently at 12.00 noon. However, these readings were in line with the data reported in the Metrological Department's Weather Report (2021) for the duration. The recorded air velocity was consistently within the stipulated range of 0.15 m/s to 0.50 m/s as per the ICPIEQ.

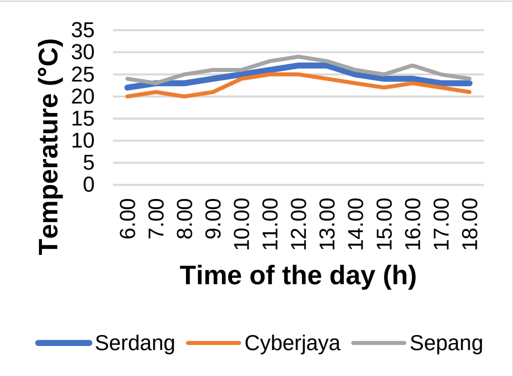

Fig. 1. a: Average daily temperature

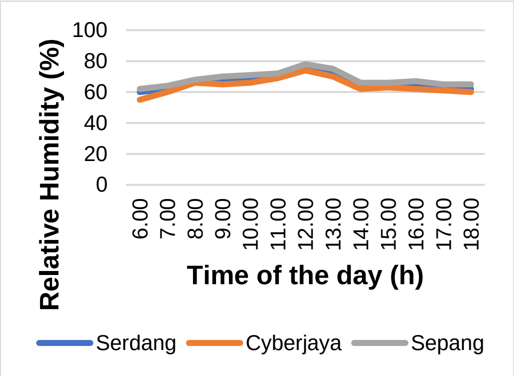

Fig. 1. b: Average daily RH

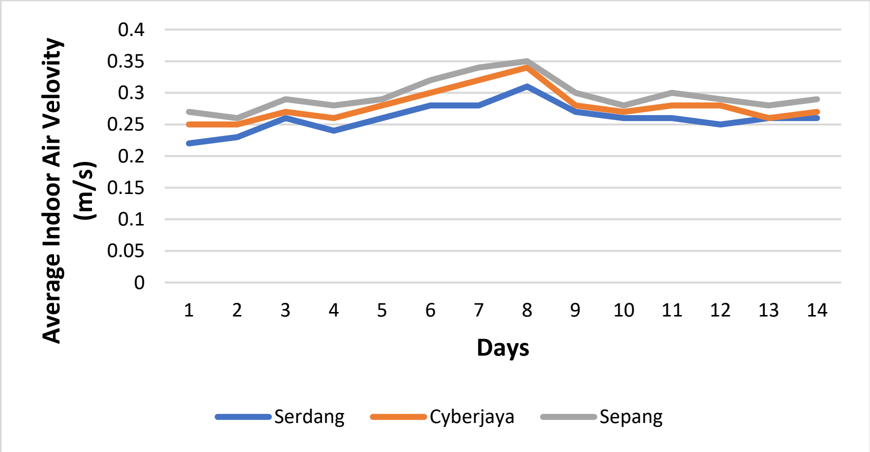

Fig. 2. Average indoor air velocity

In terms of the particulate matter concentration, PM10, the concentration in Serdang was the highest followed by Cyberjaya, and the lowest recorded in Sepang (Fig. 3). The differences in PM10 concentration recorded in the three study sites may be attributed to the differences in population density and also the intensity of economic activities, which has been shown to positively impact particulate matter concentration in the environment (Stefanowski 2018). However, the values recorded in all three sites were below the stipulated limit of 0.15 mg/m^3 of particulate matter below 10 µm in size, or also known as respirable particulate matter, as stated by the ICPIEQ.

Malaysia being a tropical, humid country, is not spared the variations in global weather patterns as a result of global climate change, resulting in turbulent weather patterns. According to a recent report, a higher temperature variation is to be expected, and fluctuating levels of relative humidity may become common, leading to uncomfortable IEQ in many parts of the country, especially in areas with high building density (MET Malaysia 2021). It has also been implied that temperature and relatively humidity are usually the primary contributory factors for the poor comfort level in buildings and homes, often due to poor fresh air-intake, poor ventilation, and lack of air-conditioning (WHO 2018), which in turn contributes to fatigue and low productivity of the occupants. In this context, it is imperative that better natural air exchange is facilitated through improved building design, while at the same time, this will also contribute towards reducing the concentration of indoor particulate matter concentration.

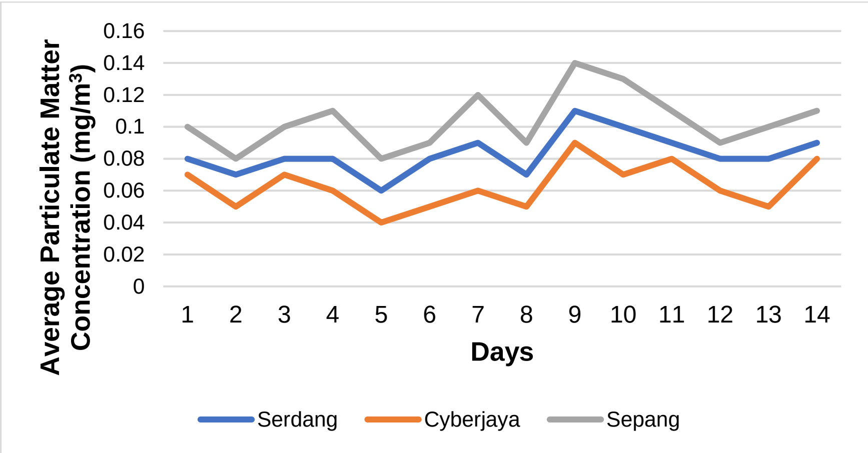

Fig. 3. Average particulate matter (PM10) concentration in study sites

In terms of the chemical emissions, the concentration of CO_2 throughout the study period was recorded to be in the range of 645 to 748 ppm (Fig. 4a). No significant statistical differences were noted among the three different study locations, as all the study sites had a similar number of occupants. Normally, respiration activity from humans is the major source of CO_2 within a confined space, with acceptable air exchange through a window opening. According to the ICPIEQ, the concentration of CO_2 is recommended as 1000 ppm for continuous 8-h of exposure in an area, and the recorded values in the three sites were below the threshold value stipulated in the guideline. Based on this result, CO_2 emission levels were considered safe in the three sites. In contrast, the average NO_2 emission levels in the three sites were markedly lower than the value stipulated in the Malaysian Ambient Air Quality Guideline (2018) of 0.075 ppm. The recorded values of NO_2 that ranged from 0.018 to 0.044 ppm in the three sites clearly suggest that NO_2 emission is very low, to pose any health threat to the occupants (Fig. 4b). NO_2 is often a pollutant arising from transport fumes, and such fumes may find entry into indoor spaces if the buildings are close to high traffic areas and construction sites (Nakos and Athanassiadou 2006).

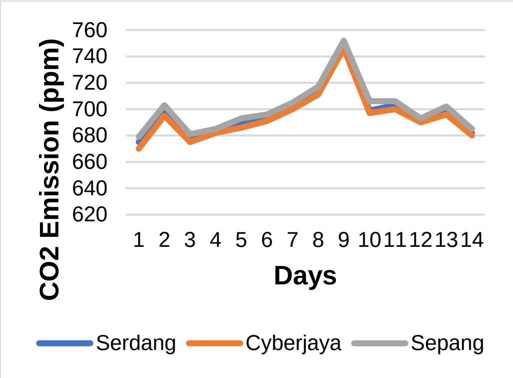

Fig. 4. a: Average CO_2 emission

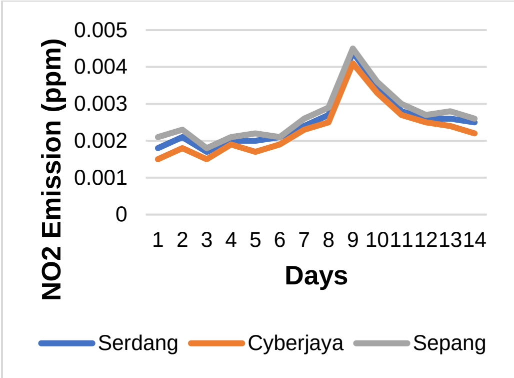

Fig. 4. b: Average NO_2 emission

The concentration of TVOCs from the three study sites ranged from 0.12 to 0.19 ppm, which was below the 3.0 ppm on an 8-h time-weighted average, as stipulated in the ICPIEQ. In contrast, the formaldehyde concentration in the three study sites, which ranged from 0.01 ppm to 0.03 ppm, were below the limit value of 0.1 ppm for an 8-h time-weighted average (Fig. 5), as per the ICPIEQ. Therefore, it is apparent that under most circumstances, TVOCs and formaldehyde emissions in most building spaces were low, and below the threshold value set in the indoor air quality guideline. A similar observation was also made in the report that suggests that TVOCs levels were decreased in new buildings after a period of 7 days onwards, with proper ventilation and air exchanges (Park and Ikeda 2006).

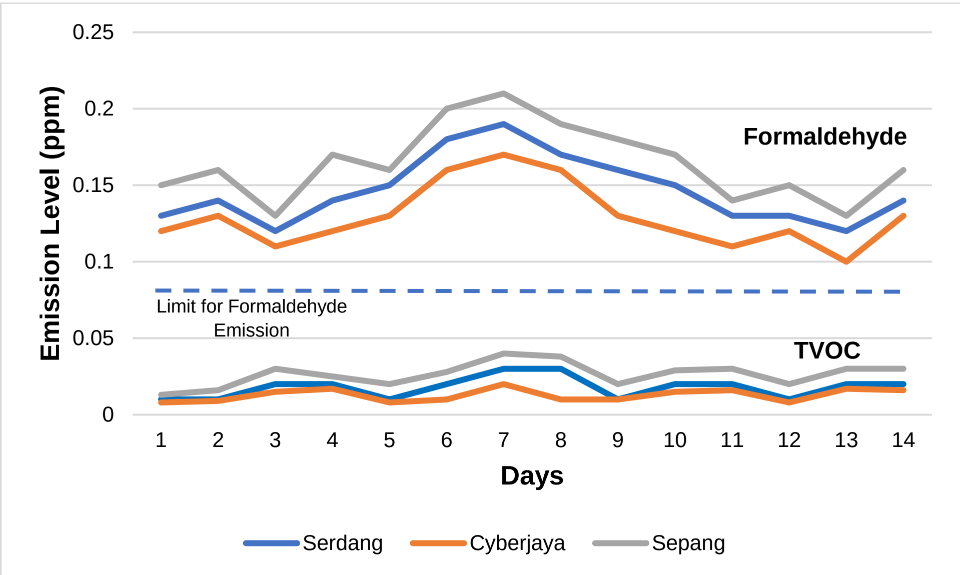

Fig. 5. Average formaldehyde and TVOC emission in study sites

The Kruskal-Wallis H test conducted on the data set for CO_2, NO_2, TVOC, and HCHO concentration in the three sites, did not reveal any significant differences between them ($\chi^2(2) = 6.05$, $p = 0.071$), clearly suggesting that chemical parameters of the IEQ is comparable in the three locations.

Measurements of formaldehyde emission from furniture

The results of formaldehyde emission captured immediately after the installation of the wardrobe with three distinct finishes, in the three rooms, is shown in Fig. 6. It is apparent that the wardrobe with the veneer overlay showed the lowest emission level, followed by the wardrobe finished with the single layer of urea-based coating. The highest emission level of formaldehyde was recorded from the wardrobe finished with two layers of urea-based coating. It is worth mentioning that the wardrobe with the veneer overlay had relatively low emission levels, *i.e.*, between 0.07 ppm to 0.05 ppm in the first three days after installation, and thereafter the value was reduced significantly to 0.04 ppm and lower. In contrast, the wardrobe finished with the single layer of urea-based coating had a higher level of emission of 0.48 ppm on the first day, and gradually decreasing to 0.41 ppm after day three, and thereafter reducing further. However, the formaldehyde emission level from the wardrobe with two layers of urea-based coating was the highest at 0.73 ppm on the first day, and gradually reduced to 0.59 ppm after four days, and thereafter diminishing further.

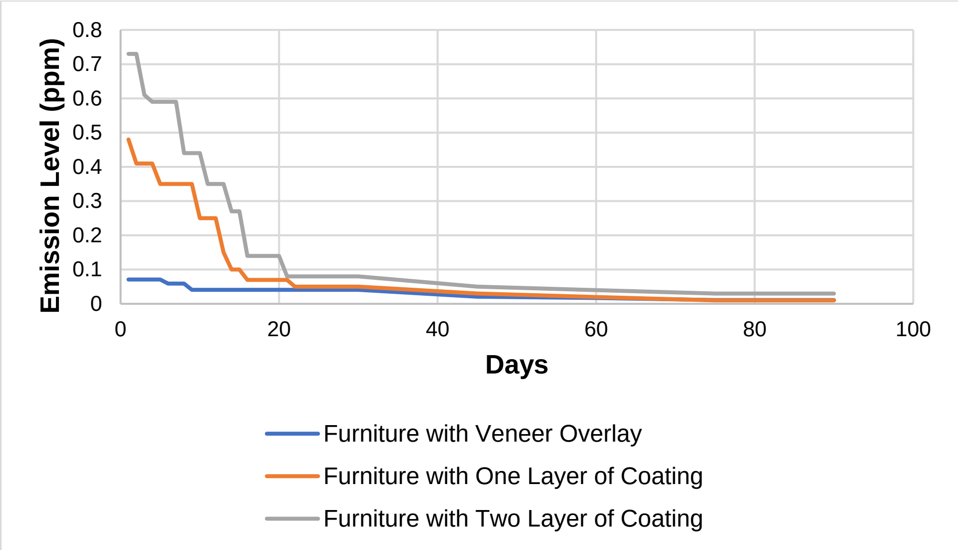

Fig. 6. Comparative formaldehyde emission from furniture with different finishes

As shown in Fig. 6 the formaldehyde emission levels from all three wardrobes with different finishes diminished over time. It was apparent that the reduction in emission level was facilitated by improved ventilation and fresh air-exchanges in the measurement rooms (Yu and Kim 2010). The results of this study provide evidence in support of the argument that formaldehyde emission levels from wood-based panels decrease over time, and if the furniture is manufactured from an aged wood-based panel, the expected formaldehyde emission level will be low. Further, formaldehyde emission levels were higher from urea-based coatings, in which thicker layers of coating showed higher emission levels (Ulker *et al.* 2021). Further, proper ventilation and better fresh air-exchange not only facilitates formaldehyde exposure levels in buildings but may offer a more economical and business-friendly proposition to manufacturers of furniture who are increasingly under pressure to use to low-emission level wood-based panels, which costs more (Yu and Kim 2012).

The Kruskal-Wallis H test conducted on the formaldehyde emission recorded from the three different wardrobes clearly showed significant difference ($\chi^2(2) = 5.9$, $p = 0.039$), highlighting that formaldehyde emission from coatings is higher than emission from wood-based panels, as reported previously by Sarika *et al.* (2020).

Part II: Public Perception of IEQ

A total of 300 respondents participated in the survey, and the demographic background of the respondents is shown in Table 1. It is apparent that the respondents represented the spectrum of socioeconomic status of the population in the Klang Valley, as reported in the Population Census Report 2020 (DOSM 2021).

Table 1. Demographic Characteristics of Respondents

Demographic Characteristics		Serdang	Cyberjaya	Sepang
Gender	Male	47	54	59
	Female	53	46	41
Age (year)	20 to 30	35	39	28
	31 to 45	31	35	35
	46 to 60	34	26	37
Education Level	Primary	21	11	26
	Secondary	31	38	41
	Tertiary	48	51	33
Marital Status	Single	44	58	37
	Married	56	42	63
Smoking Status	Non-Smoker	38	39	27
	Current Smoker	62	61	73

The Kruskal-Wallis H test conducted showed no statistically significant difference between the demographic characteristics of the respondents of the survey in the three locations ($\chi^2(2) = 8.11$, $p = 0.59$).

In part two of the survey, the responses from the respondents are shown in Fig. 7 where 62% of the respondents had relatively poor awareness of the IEQ and the related matters. It was worth mentioning that the higher the education level of the respondents, the higher is their degree of awareness of IEQ (Fig. 8). A similar result was also reported by Ratnasingam *et al.* (2020), who found a strong correlation between IEQ awareness and the level of education of the respondent.

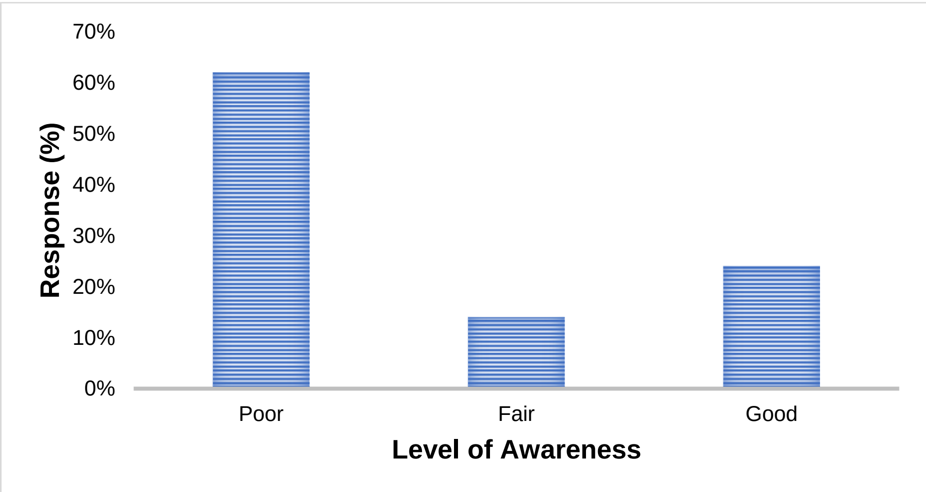

Fig. 7. Level of awareness of IEQ among respondents

In part three of the survey, the results were comparable to that of the level of awareness of IEQ. The knowledge level of IEQ among respondents was as shown in Fig. 9. The results showed that the majority of respondents (61%) had poor knowledge of the existence of related laws and regulations governing IEQ in the country. Further, only 23% of the respondents had good knowledge of the many factors affecting IEQ, while 31% of the respondents had good knowledge of the relationship between IEQ and the incidence of health issues among building and home occupants (Figs. 10 and 11).

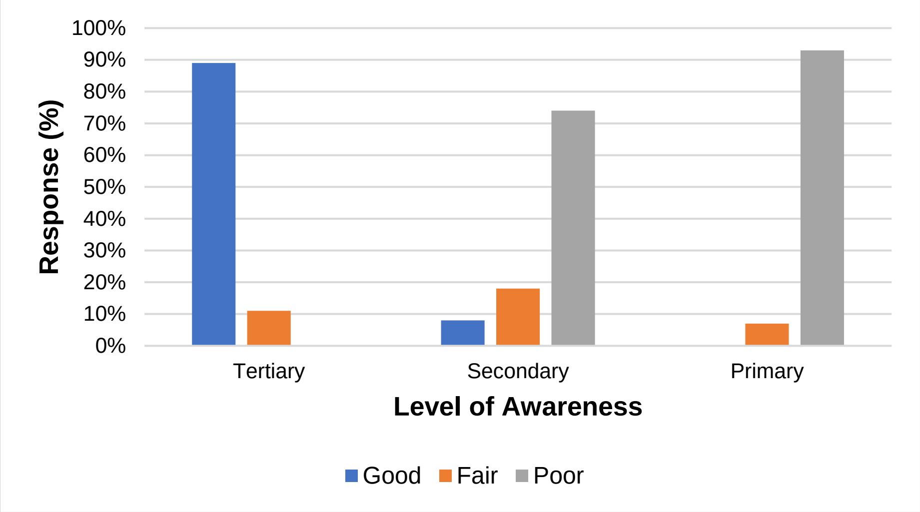

Fig. 8. Level of awareness of IEQ in relation to education level

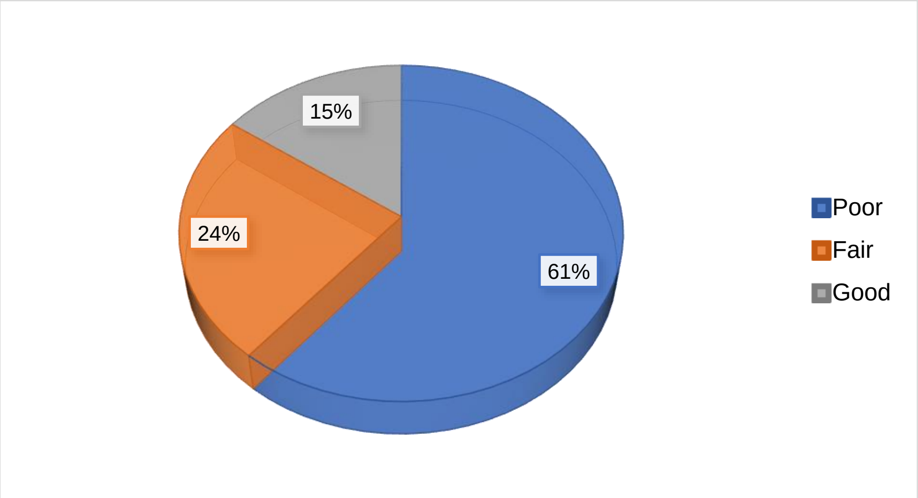

Fig. 9. Knowledge on IEQ laws and regulations

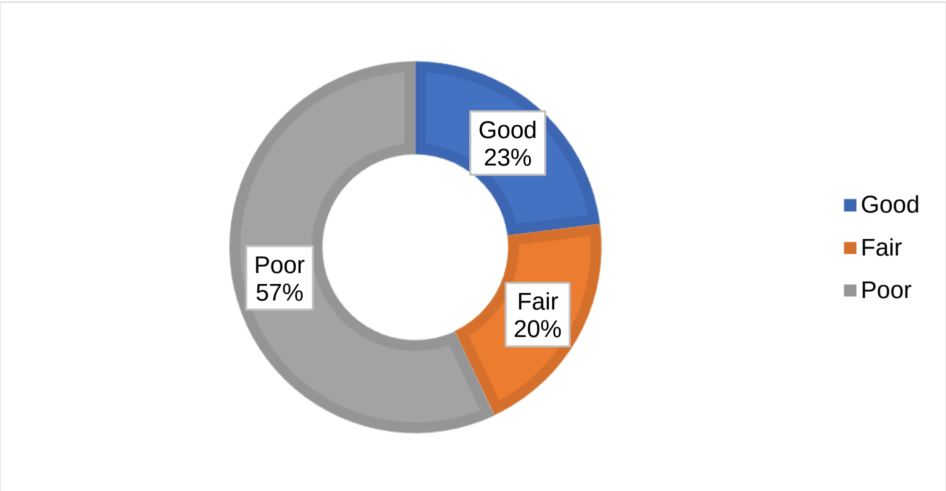

Fig. 10. Knowledge on parameters affecting IEQ and comfort level

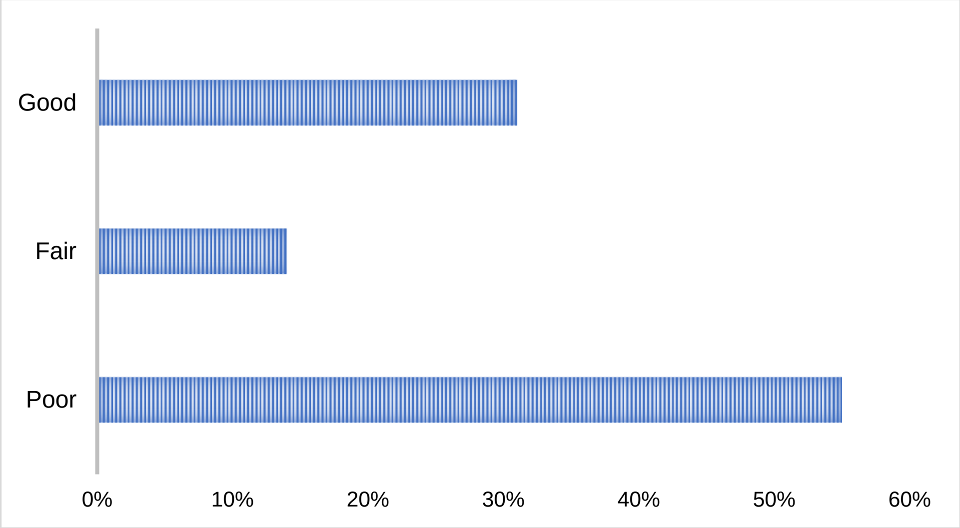

Fig. 11. Knowledge on the relationship between IEQ and health issues

The final part of the survey had noteworthy revelations of the status and adoption of IEQ standards in buildings and homes. A total of 96% of the respondents indicated that most buildings and homes were not designed for comfort living, often due to poor ventilation and lack of fresh air-exchange. The respondents also acknowledged that the hot and humid weather in the country does little favor to living comfort, and it aggravates the poor comfort level in homes. Unfortunately, they did not realize that poor comfort and the prevailing IEQ compromises the health of the occupants, and to improve building comfort, remedial measures, such as installation of air-conditioning, air circulation devices, *etc.* that increase the operational cost of buildings and homes are often taken into consideration during the building construction (CIDB 2019).

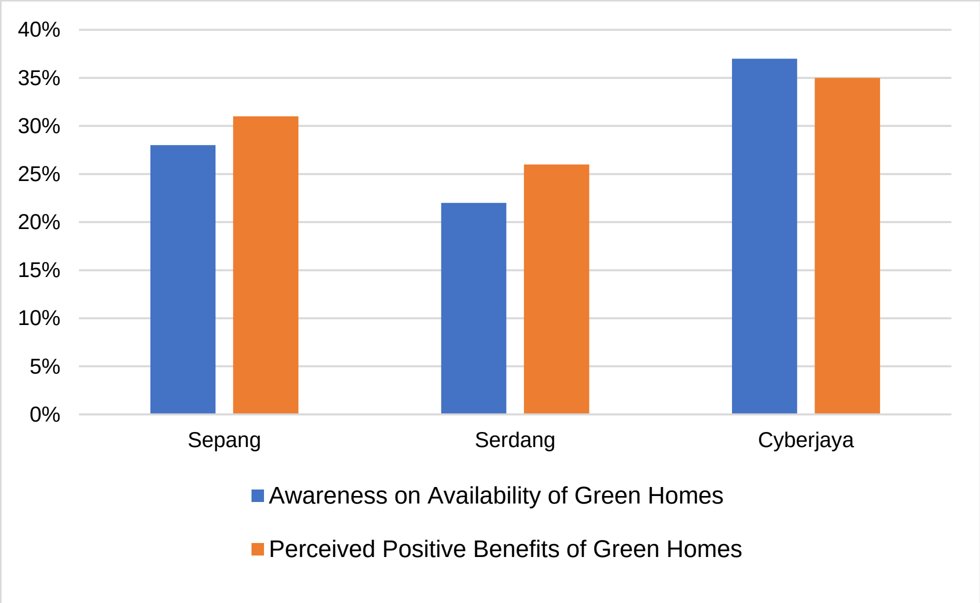

Fig. 12. Degree of awareness among respondents

This is confirmed by the respondents who appear to be unaware of the green homes and their benefits (Fig. 12), as a majority of them did not perceive the IEQ in such a home as being significantly different than that of traditional homes. In this respect, it is timely as echoed by the report on CREA (2022), which clearly underlined the need to reexamine the Building By-Laws and Codes at the Local Council levels to improve building design and construction, so as to improve living comfort and prevailing IEQ in homes and buildings in the country.

IMPLICATIONS OF THE RESULTS

The results of the study suggest that the IEQ in sustainably constructed or green homes are comparable to those of traditional homes (CIDB 2019). Traditional homes are characteristically less spacious (i.e., typical room will be 20 m^2 or 200 ft^2 in floor space, with a ceiling height of 2.4 m and a single panel window). In this respect, the temperature, relative humidity, and indoor air velocity recorded do not necessarily improve the living comfort of the occupants in these homes (Suhaida *et al.* 2013; Mohd Sahabuddin and Gonzalez-Longo 2019). The poor air ventilation and lack of fresh air intake necessitates the use of ceiling fans, to provide the minimum comfort level, which in turn, increases the operational cost. Previous studies by Pang *et al.* (2007) and Mohd Sahabuddin and Gonzalez-Longo (2019), demonstrated that the failure to respond to the problem of poor indoor air quality can bring adverse impacts on human health and productivity. Meanwhile, Building Related Illnesses (BRI) are closely related to prevailing poor IAP, and the impact of such poor building practices. In fact, with the growing concern for the Environment, Social and Governance (ESG) compliance, in line with the SDGs, such consideration will become increasingly important when designing and constructing homes and buildings in the future (Marques *et al.* 2020; Mannan and Al-Ghamdi 2021; Ratnasingam *et al.* 2023). The sick building syndrome (SBS) describes a situation in which building occupants experience acute health and/or comfort effects that appear to be linked to time spent in a particular building, but where no specific illness or cause can be identified (DOSH 2010).

The predictor variables levels of the IEQ in this study also suggest that although most of the levels were below of ICPIEQ (2010), the lack of awareness and knowledge about the importance of IEQ suggest that the general population may not be aware of above limit exposure levels, which may compromise their living comfort and overall health. What is apparent is that the respondents of the survey are also ignorant of the parameters that affect IEQ, and the prevailing poor living comfort is perceived to be attributed to weather phenomenon, rather that the design and construction of the homes, that affects the IEQ.

The air quality in a home or building is determined by indoor air quality, which in turn is affected by ventilation efficiency as well as the volume of air exchanged with outdoor air. According to the report by CREA (2022), the most likely cause of poor indoor air quality is poor building design and its maintenance, the presence of contaminants, and insufficient ventilation. It has been shown that ventilation is crucial to dilute the concentration of pollutants indoors (Kim *et al.* 2011). On the other hand, air contaminants from the outside air may also be brought into the building through the ventilation system. The ASHRAE Standard No. 62 for natural and Mechanical Ventilation suggests the minimum air exchange rate of 20 cfm/person, which will reduce the pollutants levels to acceptable limits.

Studies by Böhm *et al.* (2012), Barria (2016), and CREA (2022) state that a person's perception of comfort is determined by one's metabolic heat production, heat loss to the environment for physiological adjustments, and their body temperatures. Further, factors like temperature, humidity, air movement, personal activities, and clothing influence a person's heat loss to the environment. It has been reported that the acceptable ranges of temperature and relative humidity inside the office environments are 23 to 26 ºC and 40 to 70%, respectively (ICPIEQ 2010).

In this respect, it is imperative that the design and construction of buildings in the country be re-examined to ensure that the green building concepts are incorporated so that improved living comfort can be achieved. Traditional building design and construction of the past may no longer be viable on the basis of cost, as the general population becomes increasingly conscious of the need for improved living comfort and higher indoor air quality (Ratnasingam *et al.* 2023). In terms of controlling and managing VOCs and formaldehyde emissions indoors, the authorities would need a wholesome approach, rather than a ‘knee-jerk’ guideline, which is insufficient to contain the problem, and in turn has an adverse impact on the wood products manufacturing industry. In the final analysis, achieving good building design, construction, and indoor air quality are integral parts that warrants a wholesome approach.

Likewise, the benefits of increasing the utilization of wood products and wooden building members, such as laminated veneer lumber (LVL), glulam, and cross laminated timber (CLT) is grossly limited in the country. Apart from the excessive cost factor, the issues related to durability and fire resistance remain to be resolved by the relevant authorities, which need to grant building permissions (Ab Latib *et al.* 2019). Although wooden buildings have been proven to be more environmentally friendly, less energy demanding, and achieving a significant improvement in IEQ, such building constructions have a long way to go in the country, without the necessary building authorities’ approvals and incentives from the government to off-set the prevailing high cost involved.

CONCLUSIONS

1. This study evaluated the Indoor Environmental Quality (IEQ) parameters in certified green homes, in three different locations of varying densities and found no significant differences between the sites.
2. The IEQ measurements correspond with the readings captured from previous studies in traditional homes, suggesting that improvements in design and construction must be undertaken to improve the prevailing IEQ.
3. The formaldehyde emission from furniture with the two-layers of coating was the highest, suggesting that any regulatory measures to reduce formaldehyde emission from furniture must resort to a complete approach, rather than solely focusing on the wood-based panel materials.
4. The overall public perception of the IEQ reveals that awareness and knowledge of IEQ is low among the general public, and awareness and information dissemination programs must be intensified to educate the general public of the IEQ and its tolerance level.

ACKNOWLEDGEMENTS

The assistance of REHDA in implementing this study is much appreciated. The partial financial support from Putra Grant (No. 9649900) of Universiti Putra Malaysia is also acknowledged.

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Article submitted: January 26, 2023; Peer review completed: March 4, 2023; Revised version received and accepted: April 4, 2023; Published: April 14, 2023.
DOI: 10.15376/biores.18.2.3783-3801