KEY FACTORS OF OCCUPANTS' BEHAVIOUR CHARACTERISTICS AND INDOOR AIR QUALITY PERCEPTION ON OCCUPANCY COMFORT IN MULTI-STOREY RESIDENTIAL BUILDINGS IN THAILAND

WARANGKANA JUANGJANDEE, VICKI STEVENSON & ESHRAR LATIF
Welsh School of Architecture, Cardiff University, UK

ABSTRACT
Multi-storey residential buildings in high-density urban areas, especially in a tropical climate like Thailand, tend to suffer poorer indoor environmental quality. Such a significant impact increases the risks of health issues. However, there has been little study exploring the reason and identifying potential solutions. This research tackles the problems of thermal comfort and indoor air quality (IAQ) in multi-storey residential buildings in high-density urban areas (2,400 people/km^2) in Chiang Mai, Thailand (equatorial, winter dry climate). The survey explored occupants' behaviour characteristics in relation to their indoor air quality and comfort perceptions. 482 responses from adult occupants were received (400 responses were required for results to have a 95% confidence level). Cronbach's alpha, Spearman's rank, Pearson correlation coefficient and stepwise multiple regression analysis methods were applied to analyse data; the five key results are summarised as follows: (1) five critical factors for overall comfort satisfaction were identified as temperature, natural lighting, ventilation, room privacy, and humidity (in order of importance); (2) activities which generate moisture (e.g., washing clothes, hanging clothes to dry, cooking) have a strong negative correlation with IAQ perception; (3) factors such as natural lighting and ventilation had a significant positive relationship with IAQ, while humidity and mould had a negative relationship with the IAQ; (4) natural lighting and air freshness were the strongest influences on occupant's humidity comfort; and (5) ventilation and air freshness positively correlate with ventilation comfort, whereas humidity negatively correlated with the comfort (at a significant level). This study proposes design guidelines to improve the comfort. Built environment professionals from Thailand will be consulted on the proposed design, which may assist architects and engineers in generating IAQ improvement for their occupants, achieving indoor comfort.
Keywords: occupants' behaviour, occupancy comfort, multi-storey residential building, surveying, indoor air quality, questionnaire.

1 INTRODUCTION

The rapid increase in multi-storey residential buildings in metropolitan area has caused high-density environment, which has caused an obstruction of wind flow and solar radiation over decades [1], [2]. The obstruction exacerbates both outdoor and indoor thermal comfort, especially in tropical climates [3], [4]. Many studies conducted within the last decade have shown that the limitation of opening due to the obstruction can reduce the change in ventilation flow rate and indoor air quality [5]–[7]. The rising mean internal temperature cause problems with overheating in building [8], which potentially further impacts human health risk [9] and building electricity in cooling load demanded [8]. Additionally, the ineffective building design negatively impacts living comfort by causing difficulties in removing internal moisture. The high intensity of moisture might cause mould growth to risk human health [10]. The moisture-related issues, particularly in tropical climate zones, aggravate residential buildings more than other building types [11].

The problem related to indoor environment quality is defined by the specific occupancy behaviour causing the problems and discomfort. Yan et al. [12] also stated that occupant

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behaviour mainly influences building performance. The behaviour pattern can evolve concerning a mix of sources, i.e., inside-gender, preference, and outside-air temperature, wind speed, building properties [13]. The mix of sources can impact indoor environment conditions. For example, Roetzel et al. [14] investigated that windows are usually opened to improve natural ventilation and enhance fresh air entering the room. However, humid air can also enter the room through the window and crack in a free-running building.

Thus, understanding the occupant's room and behaviour characteristics is crucial for the building evaluation. A survey is one of the methods for obtaining feedback on a building's performance in use after it has been occupied. Xue et al. [15] adopt the Chi-Square and non-parametric test, i.e. Spearman rank coefficient to identify the relationship between occupants' behaviour and luminous comfort in residential buildings; the result indicated that occupants' behaviour significantly influenced luminous comfort. Azimi and Esmaeilzadeh [16] applied Cronbach alpha for internal consistency testing. Yik et al. [11] adopted survey and physical measurement for investigating moisture generation due to various household activities. The researcher mentioned that survey could be applicable to define actual activities and moisture generation in the household. Unfortunately, there have been limited studies on occupants' behaviour with their building context, perception, and comfort.

This study investigates the critical factors of occupants' behaviour characteristics and indoor air quality perception on occupancy comfort in a multi-storey residential building in Chiang Mai, Thailand. Furthermore, this study visualises the satisfactory and environmental performance of the residential buildings with occupants living in. The online questionnaire constituted multiple-choice and Likert scale questions. The occupants are encouraged to select the most relevant answer about general background, occupants' behaviour, and physical environment, through the multiple-choice questions. Then, the participants rate their room's environmental perception through Likert scale questions.

2 METHODOLOGY

2.1 Sampling and questionnaire design

Chiang Mai is selected as a case study. Chiang Mai is a tropical savanna climate (Aw) located in the north of Thailand. Chiang Mai is the fifth largest population city across Thailand, with a population density above 1,200 people per km^2 in the urban area [17].

This survey was carried out from February to May 2021. One criterion applies to the participants; only adults (age range 18–60) live in the multi-storey residential buildings in Chiang Mai. The minimum number of necessary samples to meet the desired statistical constraints (confidence level with 95%) is 400 from the Chiang Mai metropolitan population of 190,199 people [18], only those living in multi-storey residential buildings. Yamane's formula for calculating sample size is:

$$\text{Sample size (n)} = N/(1 + N(e\text{^}2)), \quad (1)$$

where n, N, and e are the sample size, population size and level of precision, respectively [19]. Simple random sampling was conducted to select two districts (clusters) in Chiang Mai metropolitan. Then, the investigation used the cluster sampling method with Thai census data sources, who live in multi-storey residential buildings in Chiang Mai, for choosing samples. The questionnaire invited approximately 4,000 people to participate because the average online questionnaire response rate is approximately 10%–15% of sample [20]. 482 completed surveys were obtained, meeting the requirement to have a 95% confidence level in the results.

The questionnaire has been approved by the ethics group in Cardiff University.

The questionnaire was divided into five parts. The first part is general information of participant. Part 2 considered the physical living environment. Part 3 considered occupancy indoor activity, including cooking, and washing clothes characteristics. The questions in parts 1 to 3 were multiple choice. Part 4 included questions about the participants' perceptions towards IAQ. The questions required the residents to answer on a nine-point scale. Part 5 considered the satisfactory level of the participants with the environment in their rooms.

2.2 Data analysis methods

All data were analysed via SPSS 27.0. For reliability measuring, Cronbach's alpha was used to assess the internal consistency of tested items [21], such as occupants' comfort questions and satisfaction with indoor air quality levels.

Descriptive analysis was used to evaluate general information of occupants, while inferential statistics was used to analyse the relationship between occupants' room perception and satisfaction. In order to investigate the relationship between two variables, Spearman's rank correlation was applied to measure the monotonic association (between ordinal scales) [22], while Pearson correlation was performed to measure the linear relationship (between ratio/interval scales) [23]. Both Pearson and Spearman correlation coefficients are measured on a scale varying between –1 and 1. The correlation coefficient greater than zero signifies a positive relationship, while the value less than zero indicates a negative relationship. Zero value means no correlation [24]. For the Likert scale, a correlation value close to –1 or 1 indicates a strong relationship. The correlation data having the coefficient value either lower than –0.5 or higher than 0.5 were then tested by multiple regression. Multivariance regression analysis was to identify the most significant variables influencing the outcome.

3 RESULTS AND ANALYSIS

This study used Cronbach's alpha coefficient for estimating internal consistency of occupants, indoor air quality scale and comfort in the survey. Cronbach's alpha of nine comfort questions were all above 0.60, which can be considered as good internal consistency and strong correlation in questionnaire items.

3.1 Demographic analysis of survey participants

50.8% of the respondents were female, 44.6% were male, 3.9% preferred not to answer, and 0.6% were other. Over half of respondents (60.8%) were students. For ownership, most of the participants were tenants (95%), while 5% were room owners. In terms of occupied periods, the participants commonly spent time in their rooms between 8–12 hours and 12–16 hours during the weekend (see Fig. 1).

3.2 Physical environment

Most of the participants (30%) lived in seven floors building, while approximately 19% of the participants were evenly distributed between four, five and six floor buildings. 78% of the participants occupied on the 1st, 2nd and 3rd floor. The occupants of shorter buildings

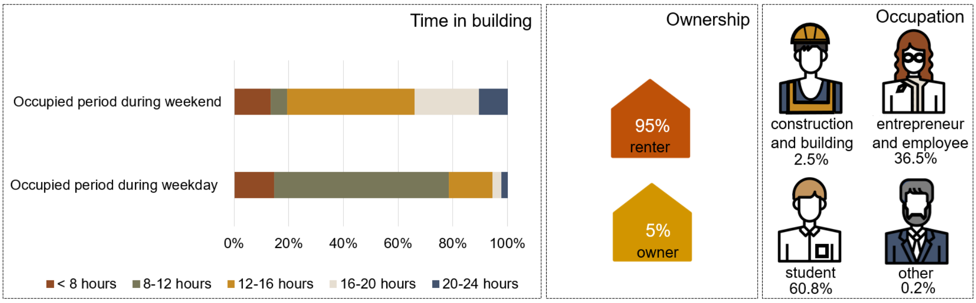

Figure 1: Demographic characteristics of participants (© Warangkana Juangjandee, 2022).

(one, two or three floors) tended to live on the 1st floor. Greater than 60% of participants lived in buildings located 0–6 m away from the nearest nearby building. In addition, almost half of the participants' room openings faced north. For building plan and room location, over 90% of the respondents lived in double load corridor buildings and over 70% of their rooms' locations were at the middle of the building. Most responders reported rooms comprising of one bedroom, one bathroom and one balcony. Three typical room types were defined in relation to location of WC. The proportion of people living in these room types (along with room sizes) is shown in Fig. 2. Over half of the respondents lived in room sizes ranging from 21 to 30 m^2. For room size range from 8–20 m^2 to 21–30 m^2, there is an even distribution of participants' room types. For example, the 21–30 m^2 size range has approximately 16% of Type A, 23% of Type B and 23% of Type C.

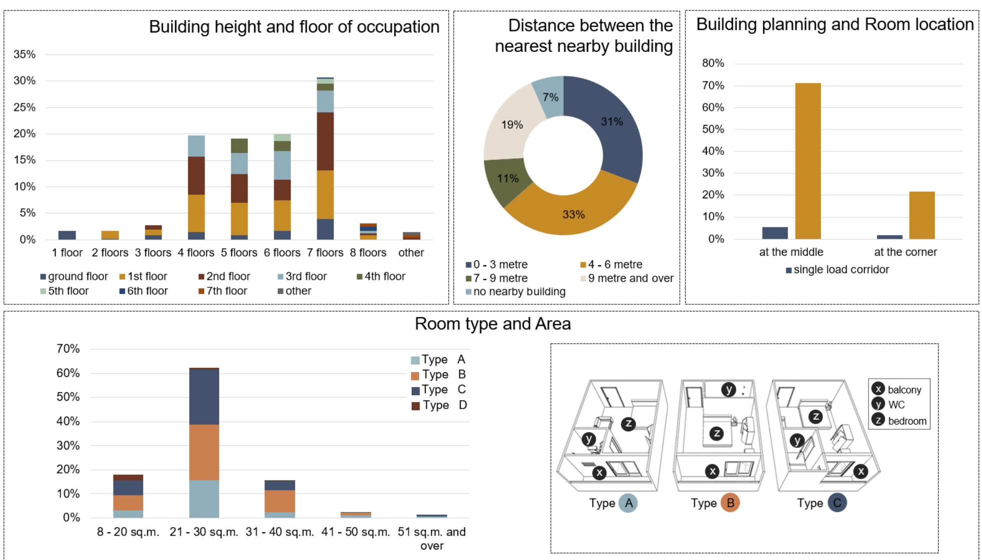

Figure 2: Physical environment (© Warangkana Juangjandee, 2022).

94.1% and 69.2% of the participants had wood for room doors and furniture, respectively. Over half of the respondents' rooms had concrete as a material of wall and ceiling. 80.9% of the voters occupied rooms that had tile as a flooring material. Plastic was a toilet door material of around 56% of the respondents. Referring to the different material porous structure, each material has different thermal properties, which will affect ventilation, moisture transport and heat transfer in building (see Fig. 3).

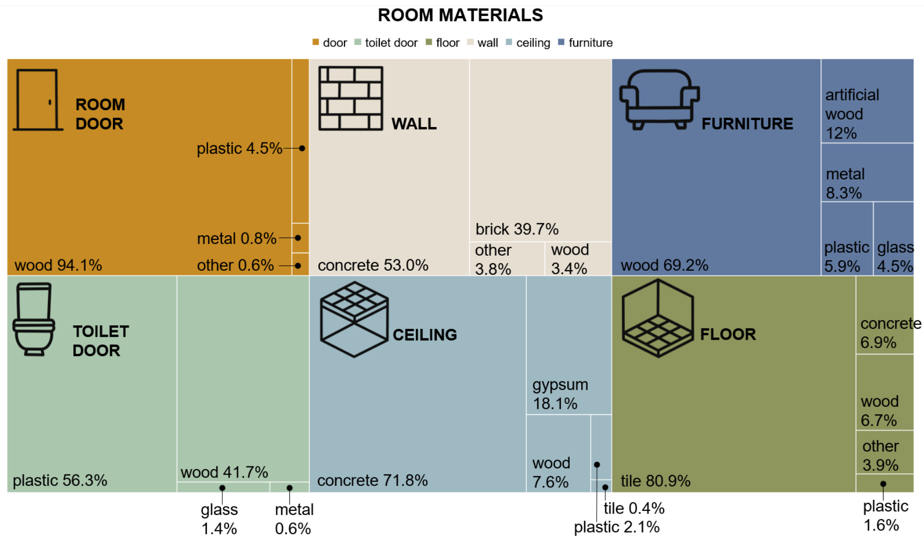

Figure 3: Treemap of occupants' room materials (© Warangkana Juangjandee, 2022).

3.4 Indoor air quality perception level scale and occupants' satisfaction

Fig. 4 presents occupants' indoor air quality perception levels, in which the temperature (a1), natural lighting (a2) and air humidity (a3) perception levels are exhibited in diverging stack bar charts; the air freshness (b1), ventilation (b2) and mould (b3) perception levels are shown in stacked bar charts.

The respondents were asked to rate their seasonal temperature perceptions. In summer, the percentage of participants indicating temperature perception of "excessively hot" is four times higher during summer than winter. This is likely to be attributable to seasonal temperature variations as the summer is approximately 5°C hotter than winter in Chiang Mai. The average outdoor temperature in summer ranges from 26.4°C to 32.0°C.

The natural lighting perception was divided into two purposes: the lighting for general and working purpose. Approximately 50% of the respondents perceived natural lighting rather dark for general purpose. Moreover, over 60% of the participants felt that the natural lighting for working purposes was not bright enough. Over half of participants responding to air humidity and ventilation report "excessively humid" and "not significant", respectively. Over half of the participants reported stale air in their rooms. The surface with the relative humidity exceeding 80% can support gemination of various mould spores. In addition, in warm, humid air within the building, the excess moisture on the surface can be accumulated as condensation, which can be a risk of construction damage. The percentage of mould growth in the room can represent the actual room environment. 55.2% of the

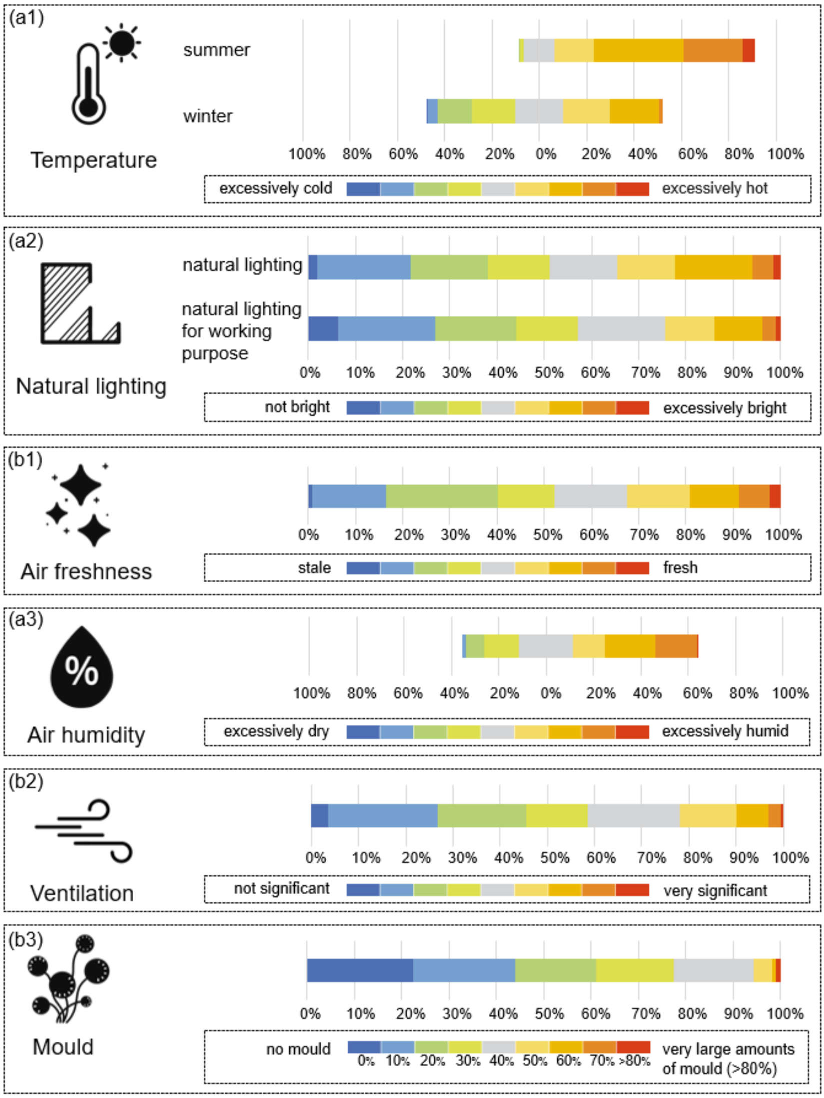

Figure 4: Indoor quality perception level (© Warangkana Juangjandee, 2022).

respondents had mould happening on between 10% and 30% of their rooms' surface areas, whereas a further 20% of the respondents had mould occurring on more than 40% of the rooms' surface.

For occupant satisfaction, the proportion of participants who agreed with the statements are shown to the right of the zero line in the bar chart, while the participants who disagreed are shown to the left (in Fig. 5). Across the categories, approximately 30% of respondents gave a neutral response, while the average satisfaction response was roughly 20%. However, a considerable number of votes indicated dissatisfaction. The percentage of dissatisfaction in natural lighting, temperature, location and room size was over 40%, while the dissatisfaction was 38% and 28% in room humidity and natural ventilation, respectively.

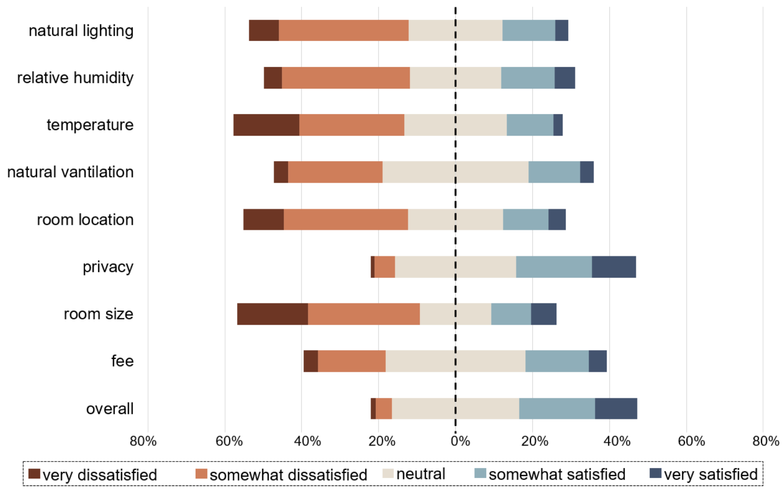

Figure 5: Occupants'satisfaction (© Warangkana Juangjandee, 2022).

3.5 Relationship between indoor air quality scale and occupants' satisfaction

This section used two steps to examine the relationship between indoor air quality perception and occupant satisfaction. Firstly, Pearson's correlation coefficient was applied to define the strength of any linear relationship between two variables. Secondly, multiple regression was used to determine the main contributing factors in the relationship between variables.

The occupants' satisfaction involved two primary aspects, which are the physical environment and indoor air quality perception. Table 1 presents all the factors which have a correlation significant at the 0.01 level to indoor air quality scale. The relationship between human behaviour and indoor quality rating was estimated via Spearman correlation, while the Pearson's correlation was applied to assess the relationship between ratio scale, e.g., building height and natural lighting perception. Referring to Cohen rules, a correlation coefficient (reported as the statistic r) of 0.1 refers to a weak correlation, 0.3 means a moderate correlation and 0.5 means a strong correlation. The p-value (quoted under significant (2-tailed) at the 0.01 level ($p < 0.01$)) is significant if the value is between 0.001 to 0.010, which also indicates 99% confidence levels. The p-value between 0.010 to 0.050 will be considered significant at 95% confidence level [26].

Human behaviour characteristics such as cooking, washing clothes, and hanging clothes for drying had a strong significant correlation ($p < 0.01$) with indoor air quality perception. For example, the washing characteristic had a solidly negative correlation with the mould rating scale, which concludes mould is likely to increase if washing activities happen in the room. The correlations between the physical environment and indoor air quality scale were also strong, with significant at the 0.01 level. The coefficients between the distance from the participant's building to the nearby building were 0.509 with natural lighting, 0.530 with fresh air scale, and 0.542 with ventilation scale. This can signify that such a positive relationship had large strength of association because the coefficients were above 0.5. However, the distance between the participant's building and a nearby building was

Table 1: Spearman and Pearson correlation coefficient of human behaviour characteristic, physical environment and indoor air quality perception scale.

<table>
<tr><td colspan="3">Spearman correlation</td><td colspan="3">Pearson’s correlation</td></tr>
<tr><td rowspan="4">Cooking characteristic</td><td>Air freshness</td><td>–.510**</td><td rowspan="4">Cleaning frequency</td><td>Humidity satisfaction</td><td>–.212**</td></tr>
<tr><td>Air humidity</td><td>.563**</td><td>Temperature satisfaction</td><td>–.245**</td></tr>
<tr><td>Ventilation</td><td>–.504**</td><td>Room privacy satisfaction</td><td>–.157**</td></tr>
<tr><td>Mould level</td><td>.499**</td><td>Overall satisfaction</td><td>–.318**</td></tr>
<tr><td rowspan="4">Washing characteristic</td><td>Air freshness</td><td>.582**</td><td>Room size</td><td>Room size satisfaction</td><td>.566**</td></tr>
<tr><td>Air humidity</td><td>–.670**</td><td rowspan="2">Building tall</td><td>Natural lighting</td><td>–.363**</td></tr>
<tr><td>Ventilation</td><td>.548**</td><td>Natural lighting for working purpose</td><td>–.368**</td></tr>
<tr><td>Mould level</td><td>–.617**</td><td rowspan="6">Distance between the building and nearby building</td><td>Natural lighting</td><td>.509**</td></tr>
<tr><td rowspan="5">Cloth hanging characteristic</td><td>Air freshness</td><td>.364**</td><td>Natural lighting for working purpose</td><td>.478**</td></tr>
<tr><td>Air humidity</td><td>–.433**</td><td>Air freshness</td><td>.530**</td></tr>
<tr><td>Ventilation</td><td>.374**</td><td>Air humidity</td><td>–.601**</td></tr>
<tr><td>Mould level</td><td>–.411**</td><td>Ventilation</td><td>.542**</td></tr>
<tr><td></td><td></td><td>Mould level</td><td>–.417**</td></tr>
</table>

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

negatively correlated with the air humidity air scale. The result indicates that greater distance between the participant’s building and nearby building can influence the air humidity perception in a room.

The overall satisfaction had significant relationship ($p < 0.01$) with indoor quality scale including temperature, ventilation, humidity, and mould level. In Table 2, humidity satisfaction increased if the room has higher natural lighting, greater fresh air, less wet air, more ventilation, and less mould level. Additionally, higher fresh air, less wet air, more ventilation and slight mould level enhance ventilation satisfaction level. Most of the satisfaction categories (except location) had significant association with overall satisfaction (p-value < 0.1).

After the correlation analysis, the strong significant relationship is analysed stepwise by multiple regression for further finding the main factors on occupants’ satisfaction. Regression is a statistical technique to model the relationship between a single dependent variable and multi-independent variables. For estimating the coefficients in the regression equation, unstandardised value (B) shows the influence of independent variables on occupants’ satisfaction. The larger value of B is considered as the larger influencer on such a dependent factor. p-value is the significance level of the regression, and t-value is used to measure a coefficient’s standard error, in which t-value closing to zero indicates the low reliability of the predictive power on its coefficient [27]. Occupant’s satisfaction was determined as the dependent variable, and other significant factors were set as independent variables.

Most independent variables of humidity satisfaction are significant at 0.05 level (p-value < 0.05), except natural lighting for working purpose. Natural lighting ($B = 0.146$, $t = 3.948$) and air freshness level ($B = 0.143$, $t = 4.849$) are principal influences on humidity satisfaction at 99% confidence levels, respectively. Natural lighting relates to humidity

Table 2: Pearson correlation of indoor quality perception scale and occupants' satisfaction.

Pearson's correlation			Pearson's correlation		
Natural lighting satisfaction	Temperature in winter	–.438**	Ventilation satisfaction	Air freshness	.737**
	Temperature in summer	–.218**		Air humidity	–.701**
	Natural lighting	.783**		Ventilation	.781**
	Natural lighting for working purpose	.757**		Mould level	–.605**
Humidity satisfaction	Natural lighting	.688**	Room privacy satisfaction	Natural lighting	.536**
	Natural lighting for working purpose	.650**		Natural lighting for working purpose	.533**
	Air freshness	.688**		Air freshness	.544**
	Air humidity	–.621**		Air humidity	–.500**
	Ventilation	.666**		Ventilation	.575**
	Mould level	–.645**	Overall satisfaction	Temperature in winter	–.529**
Temperature satisfaction	Temperature in winter	–.515**		Temperature in summer	–.352**
	Temperature in summer	–.550**		Natural lighting	.579**
	Air freshness	.493**		Natural lighting for working purpose	.582**
	Air humidity	–.339**		Air freshness	.622**
	Ventilation	.540**		Air humidity	–.490**
	Mould level	–.342**		Ventilation	.644**
				Mould level	–.482**

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

satisfaction because natural lighting can influence human subjective thermal perception from the psychological perspective [28]. Moreover, more natural lighting can associate with more solar radiation, which also effects human thermal perception. The relationship between natural lighting for working and humidity satisfaction is statistically significant at 0.5 level (p-value > 0.5). Natural lighting for working purpose is not able to predict or influence on humidity satisfaction, while other factors have influenced on the humidity satisfaction with significant at 0.05 level (p-value < 0.05).

Three factors influencing the ventilation satisfaction. Ventilation level is a major factor (B = 0.265, t = 9.861, p-value < 0.001), following by air humidity perception level (B = –0.205, t = –8.708, p-value < 0.001) and air freshness (B = 0.133, t = 5.469,p-value < 0.001), respectively.

The main influence of room privacy satisfaction is ventilation rate (B = 0.190, t = 4.118, p-value < 0.001). Air humidity and air freshness perception level are minor factors on the satisfaction. Ventilation perception correlates to privacy satisfaction because rooms with more privacy can open their rooms' opening and then benefit to more ventilation in rooms. However, natural lighting in general and for working purpose are not statistically significant because p-values are greater than significant level (0.05).

The multi-linear regression was calculated to predict the overall satisfaction based on indoor their environmental satisfaction. The coefficient of regression is shown in Table 3. Temperature satisfaction is a major influence on overall satisfaction (B = 0.199, t = 6.163, p-value < 0.001). Natural lighting (B = 0.172, t = 4.803, p-value < 0.001) and ventilation satisfaction (B = 0.159, t = 4.426, p-value < 0.001) are the second and third influences on the overall satisfaction, respectively.

Table 3: Coefficients of regression for overall satisfaction.

Dependent variable	Independent variable	Unstandardized coefficients (B)	t	p-value
Overall satisfaction	(Constant)	0.896	9.907	0.000
	Natural lighting satisfaction	0.172	4.803	0.000
	Humidity satisfaction	0.080	2.358	0.019
	Temperature satisfaction	0.199	6.163	0.000
	Ventilation satisfaction	0.159	4.426	0.000
	Room privacy satisfaction	0.153	6.251	0.000

4 DISCUSSION

Physical environment, such as distance between occupants' building and nearby buildings and building height, affects indoor air quality perception. For example, occupants are likely to perceive inadequate natural lighting and low natural ventilation when another building is located between 0–3 m from their buildings. In contrast, the occupants perceive air rather humid when there is a smaller distance between the occupant's building and nearby building. Referring to Yan et al. [12] and Foster and Oreszczyn [29], occupants in a building with a short distance between nearby buildings tend to keep privacy by keeping the blind down, which can block natural ventilation entering the room. Based on the result of the study, it is suggested that buildings having short distance to nearby buildings should be designed whereby the building or building system for maintaining privacy and also sustaining an adequate indoor air quality of living.

Occupant activities generating moisture content in the room, such as cooking, washing and hanging cloth for drying, influence the occupants to perceive stale air, high humid air, low ventilation and high level of mould occurring. An earlier survey by Yik et al. [11] and Zemitis et al. [30] stated that moisture is generated in residence from occupant not only via internal occupant's body but also by various household activities such as cooking, clothes hanging, clothes washing etc. Occupancy activities, room function, usage duration and frequency cause different level of moisture generation in room. For example, 2,000–3,000 g, 1,500 g, 500 g per day for cooking, drying clothes indoor and washing clothes respectively [25]. In tropical region, the building should be dedicatedly designed by minimizing indoor moisture accumulation. However, from the survey results (Fig. 4), most building materials are porous materials, such as wood door, brick wall and wood furniture, that are susceptible to moisture damage.

Relationship between indoor air quality scale and occupants' satisfaction found that temperature satisfaction is the primary influence on overall satisfaction. The result confirms Tanabe et al. [9] mentioned that temperature affects human mental and body perception. In addition, a high ventilation flow, adequate natural lighting, and low air humidity are also crucial to achieving room satisfaction (see Table 2). Poor natural ventilation is reported as a significant challenge to residential occupancy, which increases the chance of indoor mould growth and increases sick building syndromes [31]. The limitation of natural lighting in buildings can affect occupants' visual and atmosphere perception [32]. !

5 SUMMARY

The survey was analysed by statistical method. The conclusions about the factors influencing occupants' indoor environmental quality perception and their satisfaction are listed below:

1. The most popular physical environment of participants' rooms will be used as a base case in CFD simulation in further steps, such as type B of room planning, room materials, and building height.
2. Occupant indoor air perception has a significant influence on room satisfaction. The occupants' ventilation satisfaction is mainly influenced by ventilation, air humidity and air freshness perception, respectively. The humidity satisfaction is also determined by those perceptions as well as indoor air quality perception of natural lighting and mould level.
3. The environmental satisfaction of natural lighting, humidity, temperature ventilation and room privacy are the five key factors of the overall comfort satisfaction. In such vital factors, temperature satisfaction is the primary factor of the overall satisfaction, followed by natural lighting and ventilation, respectively.

The study examines the data influencing occupants' satisfaction to be a guideline for developing a design to improve occupants' ventilation room and achieve room satisfaction, especially in the tropical climate.

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