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Indoor Environmental Quality performance of mixed-mode ventilated shopping malls in hot-humid climatic region

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ABSTRACT

Studies have revealed important roles quality indoor environment plays on human health and productivity; consequently, its influence on certain shopping behavior has also been well spelt out. In other to keep up with the demand for quality indoor environment, new trend has been evolving in the design of Malaysian shopping malls. From fully air-conditioned to newly designed ones that integrate passive ventilation strategies; and as such operating under mixed-mode ventilation system. These passive ventilation strategies are implemented to reduce energy consumption and also to improve the indoor environment within the mall's indoor space. However, the potentials of these designs in terms of their indoor environmental quality (IEQ) performance have not been studied nor have their advantages been revealed. In this study, occupants' thermal perception and IEQ performance was investigated in two mixed-mode ventilated malls selected based on their design concept ('open' and 'enclosed'). Both subjective and objective measurements were carried out in accordance with the ASHRAE performance measurement protocol for commercial buildings. Five IEQ factors (indoor air temperature, operative temperature, relative humidity, air speed, and carbon dioxide concentration level) were evaluated in the two malls. The results revealed that both malls fell below the ASHRAE comfort requirement but majority of the occupants still found the indoor thermal performance acceptable despite the high indoor air temperature recorded. For both malls, high air speed and low humidity level were recorded. However, higher air movement was still preferred by the occupants while the recorded mean carbon dioxide (CO2) concentration was within the recommended level. The 'open' concept mixed-mode ventilated mall proved superior compared to the 'enclosed' concept by providing a more thermally tolerance indoor environment for its occupants. Generally, results from this study contribute to the knowledge on the advantages of adopting sustainable designs in commercial buildings for improving the indoor environment as well as the health and general well-being of the occupants. The study will open more opportunities for future IEQ studies to be carried out in hot-humid climatic regions.

1. Introduction

Malls, due to their large floor area and huge crowd capacity, are not only faced with energy consumption issues but also other issues ranging from social (e.g. tight competition with regards to services and customers' satisfaction) to environmental issues (e.g. indoor environmental quality (IEQ). These issues one way or the other are interwoven and have impacts on the malls' performance as well as users' satisfaction. A typical example of a social issue is the shoppers' motivation for visiting a particular mall. Since the mall's strategy is to attract large number of customers as possible, malls do not only compete with each other in terms of their product offerings but also by creating exciting and comfortable indoor atmospheres for users (Anning-Dorson et al., 2013). The competition and market congestion has led developers and mall management into considering alternative methods in order to build more excitement for their customers. These include the incorporation of various entertainment outlets within the mall such as parks, cinemas, etc. (Rajagopal, 2009).

These entertainment outlets are just a fraction among other factors that attract malls' customers. It is evident that there are several other motivating factors that affect shoppers' behavior towards a particular mall, such as their choice of visiting the mall (Anning-Dorson et al., 2013), and their spending behavior (Chebat et al., 2014). These motivating factors have been identified as "the mall's indoor atmosphere" which constitutes the indoor odour (Michon et al., 2005; Singh and Prashar, 2014), lighting, thermal comfort (Rajagopal, 2009; Khayyambashi and Vahid, 2014), acoustic comfort (Anning-Dorson et al., 2013). According to Rajagopal (2009), a mall's indoor comfort is one of the major factors that draw higher customer traffic to malls.

All of the identified motivational factors are connected to IEQ, which is one of the major issues affecting the general well-being of building occupants in terms of their health and productivity (Heinzerling et al., 2013). Consequently, these factors affect the shoppers' shopping behavior in terms of the length of time they spend in the mall (Zafar et al., 2007; Kamarulzaman et al., 2010), the amount of money they spend (Chebat et al., 2014), the likelihood of them returning to the same mall, and their overall satisfaction (Chang and Fang, 2012; Chebat et al., 2014).

An example of environmental issue faced by malls is the indoor contaminants issue. Since malls are normally located in close proximity to main roads, they are prone to attract contamination from vehicles' exhaust (Li et al., 2013). Furthermore, indoor contaminants emitted by different products and chemicals within the mall can exacerbate the problem of poor indoor air quality (Xu et al., 2014). Previous studies have identified these contaminants, their level of contamination, and the exposure risk they pose to both shoppers and retailers (Li et al., 2013; Amodio et al., 2014; Xu et al., 2014). In Malaysia, adults (18 years above) spend about 48% of their leisure time in shopping malls as shopping constitutes their most popular and affordable form of outing (Zafar et al., 2007). Unarguably, their continuous exposure to indoor contaminants can lead to both short and long-term health effects (Amodio et al., 2014). Since malls generally are huge energy consumers due to their huge lighting load and cooling demand, energy consumption is one additional issue a shopping malls has to face. However, the indoor air quality and occupants' comfort should not be compromise in the pursuit of a building's energy efficiency (Lisa et al., 2015).

Thus, it is evident that a balance needs to be maintained with regard to energy savings, occupants' comfort, and occupants' health and wellbeing in shopping malls. To attain this balance, shopping malls are encouraged to take advantage of natural ventilation and daylighting within their indoor space to reduce energy load from air-conditioning and electric lightings. In response to this, new design trends have started to evolve in the Malaysian shopping malls; for instance, openings are created within the shopping spaces to admit outdoor air into the indoor environment. Thus, operating on both mechanical and natural ventilation in different spaces within the buildings. This practice of combining natural ventilation and mechanical ventilation in a building is referred to as "mixed-mode ventilation", which offers huge advantages for energy reduction while still maximizing comfort (Hamlyn et al., 2012; Huang et al., 2014).

Despite the social and environmental advantages that mixed -mode type of shopping malls can offer, no documented IEQ study has been carried out on this type of malls in Malaysia so far. Although, some IEQ studies have been conducted on shopping malls, almost none has been carried out in hot-humid climatic conditions. In recent years, IEQ studies in malls focused mainly on IAQ (Li et al., 2013; Amodio et al., 2014; Xu et al., 2014; Hu and Li, 2015; Tao et al., 2015), visual (Al-Jubouri, 2012), and acoustic comfort (Della Crociata et al., 2013; Meng and Kang, 2013). A recent study by Karyono et al. (2015) however, looked into thermal comfort in a naturally ventilated market compared to a naturally ventilated cathedral and museum in Jakarta, Indonesia. The study revealed a different spread in comfort range in the three buildings. This is expected as all compared buildings in the study are not of similar typology.

Therefore, this research aims to fill this knowledge gap by investigating the IEQ performances of two mixed-mode ventilated malls in Malaysia. Specifically, the objectives of this study are: (1) to evaluate and compare the IEQ (thermal comfort and indoor air quality) performances of malls operating on mixed-mode ventilation strategy, (2) to determine the occupants' thermal perception of their indoor environment.

This study provides a better understanding on occupants' expectations and concerns with regard to their indoor environmental conditions. The paper first explains the method used in the study, followed by description of the case study malls. It then presents and discusses the results from both the objective and subjective measurements. The paper concludes with some recommendations for future research.

2. Methods

To fulfil the stated objectives, both objective and subjective measurements were undertaken in accordance with the intermediate measurement level of the ASHRAE/CIBSE/USGBC Performance Measurement Protocols (ASHRAE PMP) (ASHRAE, 2010). ASHRAE PMP is a set of comprehensive protocols laid down for evaluating the performance of occupied commercial buildings. For the ASHRAE PMP intermediate measurement level, the subjective measurement involves 'right-now' thermal comfort satisfaction survey while the objective measurement involves continuous data logging of several IEQ parameters (ASHRAE, 2010).

The two case study malls were chosen from a list of Malaysian mixed-mode ventilated shopping malls as identified in Ibiyeye et al. (2015) where six presently operating Malaysian malls were identified and grouped based on their design concept. Two types of mixed-mode strategy was identified operating in Malaysian malls which are 'concurrent' and 'zoned', however, 'zoned' is the most adopted mixed-mode strategy (Ibiyeye et al., 2015). Both malls chosen for this study operate under 'Zoned' mixed-mode ventilation strategy, and they were chosen particularly because of their size, location and design concept.

All data for the two malls were collected within the naturally ventilated central space and the respondents of the study were the occupants (shoppers and retailers) within this central space.

2.1 Description of case study malls

2.1.1 Shopping mall 1 (SM1)

SM1 is designed as 'enclosed and open air' concept (Ibiyeye et al., 2015) but will be referred to as 'open' concept for the purpose of this study. It is surrounded by vegetation and low buildings and accessible from major roads. It consists of five blocks in total: a block of four-storey shopping unit and four blocks of three-storey shops with office units and a one-level underground car park. All five

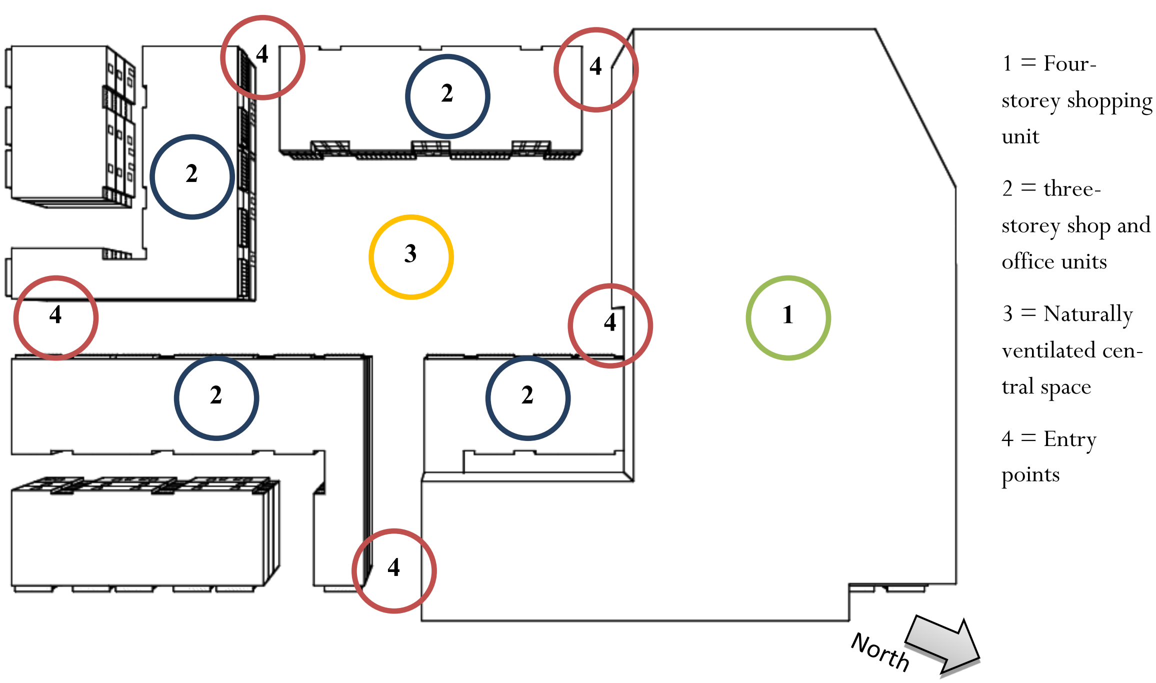

Figure 1: *Blocks arrangement in SM1*

Figure 2: *Exterior (left) and interior views (right) of SM1*

blocks of retail buildings are positioned around a large naturally ventilated central space and connected to each other (see Figure 1). The naturally ventilated central space is covered but at the same time opens at five different ends. These openings or entry points are very large (7 to 10 meters in width and extended from the floor to the roof).

Furthermore, the roof of the central space is created higher than the roofs of the surrounding retail buildings, leaving large gaps or openings in between. Within the central space, giant ceiling fans are installed in strategic locations to improve the air circulation. Figure 2 shows the exterior and interior views of SM1.

2.1.2 Shopping mall 2 (SM2)

SM2 was designed as ‘enclosed’ concept mall (Ibiyeye et al., 2015) and just like SM1, it is also surrounded by vegetation and low buildings, mainly residential and industrial buildings. It is also accessible from major roads. The building is a four-storey shopping unit integrated with retail and office units. This mall is enclosed and provided with a huge naturally ventilated central courtyard (see Figure 3) which is provided with water bodies acting as cooling effect. Similar to SM1, SM2 also have entry points leading to the central courtyard but these entry points are narrower than SM1’s and do not open through all floors. Instead, they are just the same height as a door way and

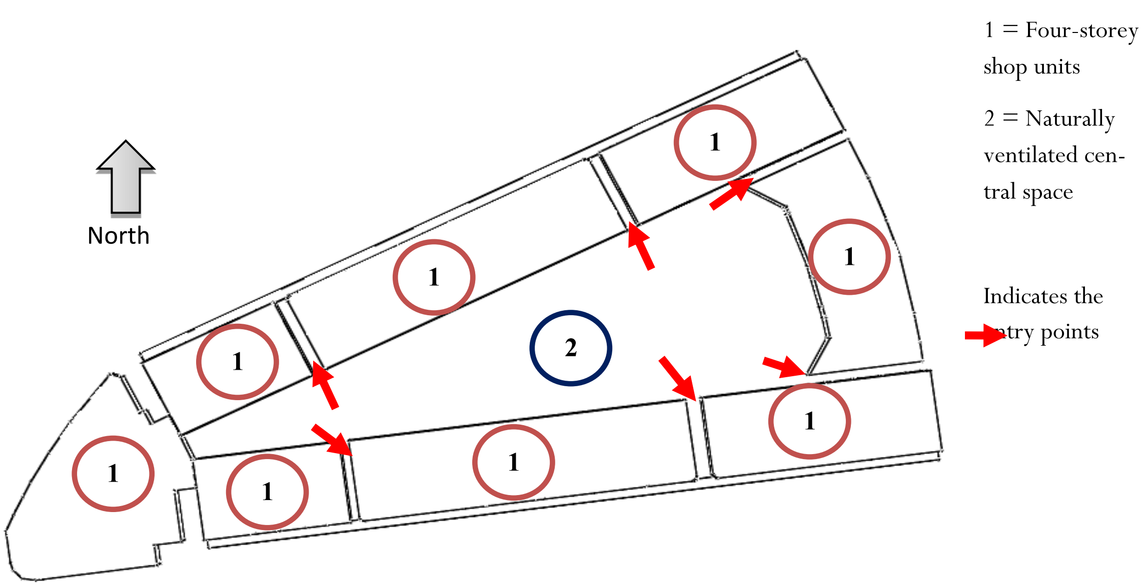

Figure 3: *Blocks arrangement in SM2*

Figure 4: *Exterior (above) and interior views (below) of SM2.*

accessible only through the ground floor.

All around the top most part of the central courtyard is provided with wide openings for ventilation and daylighting purposes (see Figure 4b). And just like in SM1, giant fans are also installed within this central courtyard. The general descriptions of both malls are shown in Table 1.

2.2 Subjective measurement

The general subjective IEQ performance metrics required at the intermediate level was the results of occupants' 'right-now' thermal comfort survey conducted to investigate the occupants' thermal sensation and comfort, thermal acceptability, and thermal preference. The occupants' (i.e. shoppers and retailers) present activity level and clothing worn were also simultaneously surveyed. The respondents were asked to indicate the specific time that the questionnaire was filled out. This allowed for the physical condition of the space at that specific point in time to be noted and the necessary subjective responses to be matched with the physical instrumental measurements (Della Crociata et al., 2012). The questionnaire is divided into five sections as explained below.

2.2.1 Occupants' background survey

The first section requested information about the occupants' demographic characteristics such as age, nationality, and gender. Specifically among retailers, they were also asked to indicate their work position held. Respondents were further asked to indicate their period of

Table 1: *Description of the case study malls*

Mall's ID	Description						
	Location	Opening Year	Floors	Total built-up area (sq. ft.)	Develop-ment type	Concept	Ventilation mode
SM1	Bangi	2013	3-4	675,000	Office and retail	Open	Mixed-mode
SM2	Shah Alam	2011	4	700,000	Office and retail	Enclosed	Mixed-mode

stay in the mall, and the frequency of their visits (for shoppers only).

2.2.2 Thermal sensation and comfort

This section aimed to determine respondents' thermal responds and comfort level. A seven-point scale ranging from cold to hot (-3 = cold, -2 = cool, -1 = slightly cool, 0 = neutral, +1 = slightly warm, +2 = warm, and +3 = hot) was assigned to measure respondents' thermal sensation. While, respondents' thermal comfort was measured on a six-point scale of 'very uncomfortable' to 'very comfortable' (1 = 'very uncomfortable', 2 = 'uncomfortable', 3 = 'just uncomfortable', 4 = 'just comfortable', 5 = 'comfortable', and 6 = 'very comfortable').

2.2.3 Thermal acceptability

Questions under this section were designed to measure how acceptable occupants found their present thermal condition. The thermal acceptability scale is usually in a binary response form of 'acceptable' or 'not acceptable', with a question such as "is the thermal environment acceptable?" However, for more powerful statistical analysis, a continuous scale is more preferred (ASHRAE, 2010). Therefore, for this study, a continuous scale of 'clearly unacceptable' to 'clearly acceptable' (1 = 'clearly unacceptable', 2 = 'just unacceptable', 3 = 'just acceptable', and 4 = 'clearly acceptable') was used (CBE, 2015).

2.2.4 Thermal preference

This section aimed to reveal what occupants prefer with regards to the indoor the condition. Respondents were asked to indicate their preference in terms of thermal state and air movement. For the occupants' thermal state, the question "right now, would you prefer to be" was posed and respondents were asked to choose from three options: 'warmer', 'no change', and 'cooler'. For air movement, respondents were required to choose from three options: 'more air movement', 'no change', and 'less air movement'.

2.2.5 Clothing and activity

The last section asked about the clothing worn and activity levels of the respondents. Generally, in field surveys, clothing and metabolic levels need to be estimated to allow indices such as PMV to be calculated and occupants are normally asked about their clothing and activity to aid this estimation (ASHRAE, 2010). For this study, respondents were asked to choose from a list of clothing and activities (as listed in ASHRAE, 2004) to best describe their present clothing and activity level.

2.3. Objective measurement

The performance metrics required at the intermediate level for IEQ building performance are data logging of selected IEQ parameters, such as: indoor air temperature, operative temperature, relative humidity, air speed, and carbon dioxide (CO2) concentration level. Continuous monitoring of physical data was necessary in order for the local conditions to be known and also for specific condition to be ascertained at the time each "right-now" survey was taken. For this study, 5 minutes logging interval was set for all measured IEQ parameters; however, due to instrument constraint, CO2 measurement was taken every 15 minutes in each case study mall.

2.4 Data collection process

Both objective and subjective measurements were carried out within the natural ventilated central space of both malls. Measurement positions and location were in line with the ASHRAE standard 55, i.e. they were made in occupied zones of the mall and were taken sufficiently away from the boundaries of the zone and from any surfaces to allow for proper circulation around the sensors. Also, sensors were stationed at a level of 48 inches (1.1 m) above the floor for standing position (ASHRAE, 2004). Both DeltaOHM HD32.3 and HOBO Datalogger were used for this purpose. The DeltaOHM HD32.3 had connecting sensors for recording the air speed, globe thermometer temperature, ambient temperature, and relative humidity, while the HOBO Datalogger could accurately record readings of air temperature and humidity.

The questionnaire survey and all monitoring processes were carried out in both case study malls within the month of March on weekends (Saturdays and Sundays) since malls are generally more visited during the weekends (Hu and Li, 2015; Hassan et al., 2015). And the whole data collection process was carried out within the period of 11 AM – 5 PM. At the end of the survey, a total of 156 completed questionnaires were collected in SM1 and 154 in SM2. Questionnaire forms that were excluded from the analysis were those that were poorly filled out as well as responses from retailers with less than 4 months of occupancy and shoppers with less than 4 months of repeated visits to the

Table 2: *Descriptive statistics of all measured physical factors.*

Malls' ID	IEQ Factors	Air Temperature (ºC)	Operative Temperature (ºC)	Relative Humidity (%)	Air Speed (m/s)	CO_2 (ppm)
SM1	Mean	33.52	34.33	43.11	0.89	437.88
'open' concept	Std. Dev.	±0.39	±0.79	±1.63	±0.20	±22.05
	Minimum	32.45	33.20	40.35	0.42	413.00
	Maximum	34.36	36.70	46.59	1.42	478.00
SM2	Mean	33.12	33.51	49.35	0.65	438.24
'enclosed' concept	Std. Dev.	±0.77	±0.89	±3.55	±0.11	±19.90
	Minimum	31.58	31.80	43.24	0.41	397.00
	Maximum	34.27	35.08	60.32	0.95	491.00

studied malls (Khalil and Husin, 2009; Jamaludin et al. 2014). Eventually, a total of 144 and 145 responses from SM1 and SM2 respectively were used for the analysis. The obtained data were analysed using SPSS software version 21 and excel spreadsheet. Relevant statistical analyses were carried out to achieve the study's objectives.

3. Results and discussion

3.1 Results from objective measurement

Table 2 represents the descriptive statistics of all measured physical factors in each studied mall. The recorded air temperatures in both malls were generally high. This is an expected observation since the monitored area in both malls is primarily naturally ventilated, although higher air temperature and air speed were recorded in the 'open' concept mall (SM1) compared to the 'enclosed' one (SM2). This could be due to the fact that the 'open' concept mall is more opened and exposed to the outdoor and also provided with wide open entry points compared to those found in the 'enclosed' mall. The wide open entry points are easy and direct link to incoming breeze and contribute to heat gain through direct penetration of sunlight.

The average CO2 levels in the two malls were low and well below the maximum concentration level of 1000ppm, as stated in the Malaysia code of practice on indoor air quality (DOSH, 2010). This indicates that the natural ventilated zone of the mixed-mode ventilated malls is less contaminated with CO2. This is understandable since there is provision for free air circulation between the outdoor and indoor in both malls, thus facilitating high air ventilation rates (Yamamoto et al., 2010; Marr et al., 2012). Moreover, high ventilation rates have been revealed to improve IAQ and reduce contaminations caused by various indoor contaminants (Zuraimi and Tham, 2008; Fisk et al., 2009).

3.1.1 Performance comparison between the two malls

A Mann-Whitney U test (non-parametric equivalent of independent sample t-test) was conducted to compare the performances of the two malls. Table 3 shows the comparison between the two malls. The result reveals no significant difference in air temperature and CO2 performances between the two malls. However, a significant medium-sized difference in performance is evident for operative temperature and air speed while a significant large-sized difference in performance was recorded for relative humidity. This indicates that SM1 performs better than SM2 with regard to indoor relative humidity and air speed. Whereas SM2 performs better than SM1 with regard to indoor operative temperature.

Table 3: *Mann-Whitney U test: comparison between both malls*

Pair wise comparison		Air Temp. (ºC)	Operative Temp. (ºC)	Relative Humidity (%)	Air Speed (m/s)	CO2 (ppm)
SM1 - SM2	Sig.	0.223	0.017*	0.000*	0.000*	0.834
	Effect size	-	0.22 Medium	0.81 Large	0.38 Medium	-

*Significant at .05
Effect size: r=Z/√n, where Z = Standardised test statistics and n = the number of cases
r = 0.10 (**small effect**); r = 0.30 (**medium effect);** r = 0.50 (**large effect**) **(Cohen, 1988)**

Table 4 *Prevailing outdoor weather data for monitoring days*

Malls/ stations		Air temperature (^{0}C)	Relative humidity (%)	Wind speed (m/s)	Wind direction (degrees)
SM1/MM	Mean	33.5	50.0	1.2	180
Petaling-Jaya station (5th & 6th March)	Minimum	31.7	42.0	0.7	020
	Maximum	34.9	59.0	1.8	360
SM2/MM	Mean	33.3	53.0	2.7	230
Subang station (12th & 13th March)	Minimum	31.2	47.0	1.1	050
	Maximum	35.1	71.0	5.4	350

3.1.2 ASHRAE Standard 55-2013 psychrometric chart

The mean prevailing outdoor temperature for the period of data collection was sourced for the calculation of the adaptive model for the two mixed-mode ventilated malls and these were obtained from relevant meteorological stations. Two weather stations nearest to the case study malls were chosen for this purpose. The nearest weather station to SM1 is Petaling Jaya Meteorological station, which is about 31.9km away. While the nearest weather station to SM2 is Subang Meteorological station, which is about 11.4 km away. Weather data such as hourly recorded data of temperature, relative humidity, air speed and direction were sourced. Subsequently, the mean, minimum, and maximum values were calculated (Table 4). The psychrometric chart for both case study malls was generated using the free online CBE comfort tool developed based on work at the Center for the Built Environment, University of Berkley (Tyler et al., 2016). The tool allows users to determine whether a certain combination complies with ASHRAE 55 by inputting relevant comfort parameters.

For the two mixed-mode ventilated malls, the adaptive model was used and the inputted comfort parameters were mean operative temperature, mean prevailing outdoor temperature, and air speed. This was in response to various studies that indicated that the natural ventilation zones in a mixed-mode ventilated building could be treated as a purely natural ventilated space (Honnekeri et al., 2014; Luo et al., 2014; Rupp and Ghisi, 2014). Figures 5 and 6 show the psychrometric charts for the two mixed-mode ventilated malls SM1 and SM2 respectively.

Although there is a difference in performance between the two malls with regard to indoor operative temperature, relative humidity and air speed, it can be noticed that none of the two case study malls complied with the ASHRAE standard 55 for thermal comfort in an occupied space during the monitoring period (11am – 5pm). This result supports many studies that have revealed that naturally

Figure 5: *Psychrometric chart for SM1*

Figure 6: *Psychrometric chart for SM2*

ventilated buildings in high temperature regions fall below the ASHRAE comfort zone (Nicol and Humphreys, 2002; Cândido et al., 2010; Toe and Kubota, 2013; Kumar, 2015). This was due to the fact that occupants of these buildings used different adaptive measures (e.g. change clothing or use alternative means to achieve comfort like opening the windows) to adapt themselves to their thermal environment. As a result, they could comfortably accommodate a wide range of temperature.

3.2 Survey results

3.2.1 Demographic characteristics

Occupants' information was investigated to analyse their demographic characteristics. Table 5 represents the characteristics of a total of 289 respondents from the two case study malls. The mean age of respondents was 27.38 years, with the minimum and maximum age of 17 and 61 years respectively. Retailers in the two malls had the personal means of control in their workplaces and the two most popular means of control were ceiling and potable fans (see Figure 7). In both case study malls, majority of the respondents were females and also Malaysian citizens and the two main positions held by the retailers were 'sales assistant' and 'managerial/supervisor' positions (Figure 8). In both malls, the average period of occupancy for retailers was twelve (12) months and their average period of stay in their workplace per day was 10.38 hours. However for shoppers, the average of their visitation was 11.49 months (i.e. on average a shopper had been visiting the mall for the past 11.49 months). Also, the average period a shopper spent in the mall was 3.5 hours. Comparatively, this is far less than the average period the retailer spent in his/her workplace. With regard to the activity rates and clothing worn by shoppers and retailers, the mean metabolic rate in both case study malls was 1.24 met while the mean clothing value was 0.56 clo.

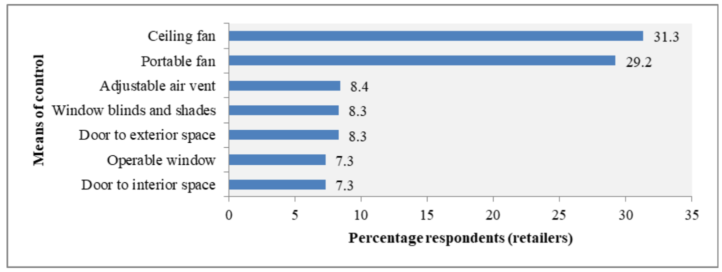

Figure 7: *Retailers' means of control in both malls*

3.2.2 Thermal sensation and comfort votes

Table 6 shows the distribution of thermal sensation and comfort votes across the two case study malls. It can be seen in Table 6 that in both malls, respondents mostly felt 'slightly warm'; however, majority of them still felt 'just comfortable' with their thermal environment. After the thermal comfort scales were grouped into two categories (uncomfortable and comfortable), majority of respondents in SM1 found their thermal condition comfortable (65.3%) while, majority in SM2 (50.3%) found their thermal condition uncomfortable.

3.2.3 Thermal acceptability and preference votes

Table 7 shows the distribution of thermal acceptability votes in both case study malls. It can be seen in Table 7 that majority of the respondents fall under 'just acceptable' category and clearly, very few respondents accepted their

Table 5 *Respondents' attributes*

Variables		SM1	SM2
Sample size		144	145
Means of control		yes	yes
Type of respondents	Shoppers	99	100
	Retailers	45	45
% Gender	Female	70.8	62.8
	Male	29.2	37.2
% Nationality	Malaysian	92.4	95.2
	Foreigner	7.6	4.8
Age in years (N = 289)	Mean	27.38	
Average period of occupancy (months)	Retailers (n = 90)	12.0	
Average period of visiting (months)	Shoppers (n = 199)	11.49	
Average period of stay in workplace per day (hours)	Retailers (n = 90)	10.38	
Average hours spend in a mall per visit (hours)	Shoppers (n = 199)	3.5	
Average clothing value (clo)		0.56	
Average activity rate (met)		1.24	
	SD	8.73	
	Maximum	61.0	
	Minimum	17.0	

Table 6: *Distribution of thermal sensation and comfort votes*

Thermal sensation	Cold (-3)	Cool (-2)	Slightly cool (-1)	Neutral (0)	Slightly warm (+1)	Warm (+2)	Hot (+3)
SM1	0	0.7%	4.2%	36.8%	37.5%	15.3%	5.6%
				78.5%			
SM2	0	0	4.8%	38.6%	45.5%	10.3%	0.7%
				88.9%			

Comfort	Very uncomfortable	Uncomfortable	Just uncomfortable	Just comfortable	Comfortable	Very comfortable
SM1	2.8%	10.4%	21.5%	56.3%	8.3%	0.7%
		34.7%			**65.3%**	
SM2	1.4%	11.7%	37.2%	45.5%	4.1%	0
		50.3%			**49.6%**	

thermal condition (7.6% and 0.7% respondents in SM1 and SM2 respectively). In addition, as shown in Table 8, majority of the respondents in both malls preferred a ‘cooler’ thermal environment (76.4% and 80.0% for SM1 and SM2 respectively). Furthermore, most of them preferred more air movement within the indoor environment (Table 9).

3.2.4 Assessment of acceptability by various scales

In accessing occupants’ thermal acceptability, various scales are being developed, namely,1) the middle three scale (-1, 0, +1) of the ASHRAE thermal sensation scale, 2) direct thermal acceptability votes, and 3) percentage responses that falls in the ‘no change’ category of the thermal preference scale (Kwok and Chun, 2003; Wong and Khoo, 2003). By equating the central three categories of the ASHRAE thermal sensation scale with the impression of acceptability, 78.5% and 88.9% (see Table 6) of the occupants of SM1 and SM2 respectively were assumed to be satisfied with the thermal condition. With this, the ASHRAE’s 80% thermal acceptability criterion was almost met in SM1, while this criterion was met in SM2.

Table 7: *Distribution of acceptability votes*

	Clearly unacceptable	Just unacceptable	Just acceptable	Clearly acceptable
SM1	2.1%	16.7%	73.6%	7.6%
	18.8%		**81.2%**	
SM2	2.8%	23.4%	73.1%	0.7%
	26.2%		**73.8%**	

Table 8: *Distribution of temperature preference*

	No change	warmer	cooler
SM1	22.2%	1.4%	76.4%
SM2	18.6%	1.4%	80.0%

Table 9: *Distribution of air movement preference*

	No change	Less air movement	More air movement
SM1	30.6%	1.4%	68.1%
SM2	24.8%	4.1%	71.0%

The direct votes of acceptability for SM1 and SM2 were 81.2% and 73.8% respectively (See Table 7). The direct vote of acceptability in SM1 was higher than the central three categories of the ASHRAE thermal sensation scale. This shows that there are people who voted beyond the center three categories in SM1 but still find their environment acceptable. On the contrary, the direct votes of acceptability in SM2 was lower than the central three categories of the ASHRAE thermal sensation scale; hence, it is an indication that there are people who voted within the center three ASHRAE categories in SM2 and yet find their environment unacceptable. This result pattern shows that not all respondents that votes within the middle votes of the ASHRAE thermal sensation scale find their thermal environment comfortable. Similar pattern was observed in Kwok and Chun (2003); Wong and Khoo (2003); Daghigh et al. (2009); hence, it is sensible to argue that people in the tropics voting in the extreme categories of the ASHRAE scale may not necessarily be experiencing thermal discomfort.

Compared to the other two modes of acceptability assessment, the thermal preference scale appears to be the most stringent measure of thermal acceptability, with only 22.2% and 18.6% of the respondents in SM1 and SM2 respectively indicating that they preferred no change (See Table 8). These findings clearly show that different measures of acceptability can produce generally different results.

Even though SM2 performed better than SM1 with regard to the indoor operative temperature, the psychrometric chart indicates that none of the two case study malls complied with the ASHRAE standard 55 for thermal comfort in an occupied space during the monitoring period. However, the survey reveals that SM1 fulfilled the ASHRAE's 80% thermal acceptability (while using the direct votes of acceptability). In the case of SM2, the ASHRAE's 80% thermal acceptability was almost met. Once again, this results confirm the wide spread believe that people in the hot climatic condition who occupy naturally ventilated spaces can adapt to wide and higher range of indoor temperature changes.

3.2.5. Occupants' thermal neutrality

Griffiths (1990) proposed a method in which the comfort temperature can be computed from a small data sample. Griffiths made the assumption that the increase in temperature for each scale point on the thermal sensation scale was effectively 3 ^{O}C for a seven-point scale (i.e., 1 = cold, 2 = cool, 3 = slightly cool, 4 = neutral, 5 = slightly warm, 6 = warm, and 7 = hot) as the case in this study. This indicates that for each thermal sensation vote away from neutral, he subtracted or added 30C from the actual temperature at the time to obtain the neutral temperature (Nicol et. al, 2012). Griffiths (1990) thus deduce the neutral temperature (Tc) from indoor air temperature (Ti) and the corresponding thermal sensation votes in this relation:

$$Tc = Ti + 3\,(4 - C)$$

Where Tc represents the neutral temperature; Ti represents the indoor air temperature that corresponds with the time each respondent vote on the thermal sensation scale; C represents the respondents' thermal sensation votes.

However, the above relationship is based on the theoretical relationship between comfort parameters obtained in a climate chamber study. This relationship was therefore criticised and the equation was revised thus:

$$Tc = Ti + 2\,(4 - C)$$

Therefore, equation (2) was used to calculate the neutral temperature for the three case study malls. The average value for each parameter in each case study mall was used.

For the SM1 ('open' concept mall), by using the above formula, we found Tc = 31.93 ^{O}C. Similarly, for the SM2 ('enclosed' concept mall), Tc = 30.59 ^{O}C.

In the 'open' concept mall thermal neutrality was found to be 31.93 ^{O}C, indicating that users of the 'open' concept mall could tolerate higher indoor air temperature compared to users of the 'enclosed' concept mall.

In summary, despite the higher indoor temperature recorded, the 'open' concept mall can still provide its occupants with a more thermally comfortable indoor environment compared to the 'enclosed' concept mall. This is evident in the high percentage of occupants who voted comfortable and found their indoor thermal condition as acceptable. Also, the occupants' high indoor temperature tolerance as demonstrated in their thermal neutrality. To some degree, the reasons why the occupants of both malls are expected to be tolerant of high indoor temperature are twofold: 1) considering the fact that the studied spaces in both malls are naturally ventilated and 2) occupants in both malls are provided with means of personal control mainly by ceiling and portable fan. As indicated by Djamila et al. (2013), the acceptance of high thermal condition by occupants of naturally ventilated spaces can be explained by the relationship that exist between them and their means of control. Occupants' adaptive ability can escalate primarily due to the excessive dependence on the use of fans to relieve thermal discomfort and as supported by Nicol (2004), indoor temperature above 30 ^{O}C can be tolerated by occupants if fans are used as a means of improving their thermal condition.

Despite the similarities between both malls in terms of them been naturally ventilated and the provision of personal control, the 'open' concept still proved superior to the 'enclosed' concept mall. The high indoor temperature tolerance as demonstrated by the occupants in the 'open' concept mall could be further explained by the high recorded indoor air speed. The average air speed recorded in the 'open' concept mall was higher than the 'enclosed' concept by 0.24 m/s. According to Nicol (2004), air movement is an essential factor in determining comfort in hot-humid climate so much so that an increase in air velocity above 0.1 m/s can significantly raise the comfort temperature.

Despite the higher indoor air speed advantage that the 'open' concept mall has over the 'enclosed' one, majority of its occupants still prefer higher air movement. This is similar to the observation from a study on subjects in naturally ventilated spaces under hot-humid climatic condition by Cândido et al. (2008) where even under air speed above 0.5 m/s majority of the respondents still demanded for increased air movement. This can be explained by an argument from Szokolay (1997) who confirmed that under a hot thermal condition, indoor air speed of 1 m/s would be considered pleasant by occupants as comfort could be achieved through psychological cooling effect enhanced by the evaporation of sweat from the skin surface. Szokolay further added that an indoor air speed of 1.5m/s would be considered more acceptable. Unfortunately, none of the two mixed-mode ventilated mall succeeded in attaining this stated air speed values.

4. Conclusion

This paper has revealed the IEQ performances of two mixed-mode ventilated malls by conducting both objective and subjective measurements. From the objective measurement results, the two malls recorded high indoor air temperature range. However, for the CO2 concentration, the two malls performed well as their CO2 values are within the recommended range. Both malls recorded high air speed values but the recorded air speed in the 'open' concept mall is higher compared to that recorded in the 'enclosed' concept mall. From the subjective measurement, the results have revealed that both malls fell below the ASHRAE comfort requirement. Yet, thermal acceptance in both malls was high with higher acceptance for the occupants in the 'open' concept mall. Although the recorded air speed was high for both malls, majority of the occupants still preferred higher air movement. Furthermore, occupants' neutral temperature for the 'open' concept mall was significantly higher than the neutral temperature for the 'enclosed' concept mall.

In conclusion, an 'open' concept mixed-mode ventilated mall can potentially provide its occupants with a more thermally tolerant indoor environment due to the higher indoor air movement advantage compared to an 'enclosed' concept mall. This study has been able to prove that for natural ventilated spaces, the air movement is very essential in elevating occupants' thermal condition. Therefore, mixed-mode ventilated malls should ensure that their indoor spaces receive adequate air movement within their natural ventilation zones by adopting a more open design that allows for direct and close link to the outdoor. By allowing easy exchange of air, required air movement for body cooling will be established within the indoor space.

This study was only carried out in two case study malls in Malaysia located within the state of Selangor and the federal territory of Kuala Lumpur and as such, not a representative of all shopping malls operating in Malaysia. Further study is recommended to include malls from other locations in Malaysia and also incorporate a larger number of survey respondents.

This study provides a better understanding on occupants' expectations and concerns with regard to their indoor environmental conditions. The results can potentially be used to help designers in creating malls that are more efficient in resources and also safer and healthier for people and the environment.

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