IEQ PERFORMANCE AND OCCUPANTS' SATISFACTION OF A MIXED-MODE VENTILATED SHOPPING MALL IN HOT-HUMID CLIMATE OF MALAYSIA

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ABSTRACT

This study is an evaluation of the IEQ performance and occupants' satisfaction of a selected mixed-mode ventilated Malaysian mall under the following objectives: 1) to evaluate the IEQ performance of the mixed-mode ventilated mall, 2) to study how occupants (shoppers and retailers) of the mall perceive the IEQ factors, and 3) to reveal the effect of the mall's performance on retailers' work activities and shoppers' intention of revisiting the mall. In this study, five measured environmental factors (air temperature, operative temperature, relative humidity, air speed, and CO_2) and five satisfaction factors (thermal comfort, indoor air quality, air movement, workplace/present location, and overall building performance) were evaluated in the case study mall through field measurements and questionnaire survey. The results revealed that although high indoor air temperature and low occupants' thermal satisfaction was recorded, the majority of the retailers still found their work activities enjoyable and the majority of the shoppers would still revisit the mall if given the opportunity. Generally, results from this study will contribute to the knowledge on the advantages of adopting sustainable designs in commercial buildings for improving the indoor environment and general the well-being of occupants. Finally, it will open more opportunities for future IEQ studies to be carried out in hot-humid climatic regions.

Keywords: hot-humid climate, indoor environmental quality, mixed-mode ventilation, shopping mall, thermal comfort

1. Introduction

Today, shopping malls not only compete on their product offerings but also on creating exciting and comfortable mall atmospheres for users (Anning-Dorson et al., 2013). Since the mall's strategy is to attract large number of customers (shoppers) as possible, it is now evident that several motivating factors affects shoppers' behaviour towards a particular mall such as their choice of visiting the mall (Anning-Dorson et al., 2013), and their spending behaviour (Turley and Milliman, 2000; Chebat and Michon, 2003; Chebat et al., 2014). Several studies have attempted to identify these motivating factors, Chebat and Michon, (2003), Michon et al. (2005), Singh and Prashar (2014) identified what they termed "the mall's indoor atmosphere" which constitutes the indoor odour. However, Turley and Milliman (2000)'s "mall's indoor atmosphere" included internal lighting, temperature, and cleanliness. El-Adly (2007) and Khayyambashi and Vahid (2014) identified "thermal comfort" among all other identified factors. Anning-Dorson et al. (2013) included "aesthetic and architectural motivation" which was defined as climatic comfort and elimination of noise pollution. For Malaysians, the "indoor ambiance" and the "interior design" are among the most important factors that influence their stay in a particular mall (Kamarulzaman et al., 2010). All the identified factors affects shoppers' shopping behaviour in terms of the length of time they spend in the mall (Zafar et al., 2007; Kamarulzaman et al., 2010), amount of money spent (Chebat and Michon, 2003; Chebat et al., 2014), the likelihood of them choosing the same mall over again and their overall satisfaction (Chang and Fang, 2012; Chebat et al., 2014). All the above identified motivational factors ("indoor atmosphere", "indoor ambience", "thermal comfort", "indoor odour", etc.) are all indoor environmental condition connected to Indoor Environmental Quality (IEQ). IEQ refers to the quality of a building's environment in relation to the health and wellbeing of those who occupy the space within it (NIOSH, 2014) and it 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). And thermal comfort has been revealed to be one of the most important IEQ factor that affects to workers (Lai et al., 2009) and also specifically inhabitants of retail buildings (Martellotta et al., 2016).

Over the years, building designers have been taking advantage of different technological means to improve the thermal condition in buildings in other for the occupants' thermal comfort to be met. Incorporating natural ventilation to compliment mechanical cooling in buildings is one major mechanism employed to improve occupants' thermal comfort and this practice is referred to as

mixed-mode ventilation (Brager, 2006; Brager et. al, 2007). It offers huge advantages for reducing energy consumption while still maximizing comfort (Deuble and de Dear, 2012; Hamlyn et al., 2012; Huang et al., 2014; Thomas, 2014) and creates exciting atmosphere for occupants as it allows movement between different climatic conditions within the same roof (Federico, 2008). Although this phenomenon of mixed-mode ventilation occurs in some Malaysian shopping malls, no documented IEQ study has been carried out on these types of malls; despite the advantages they can offer with regards to their mixed-mode ventilation properties. Although some IEQ studies have been conducted on shopping malls, few have been reported in a hot-humid climatic region like Malaysia and almost none on mixed-mode ventilated malls. However, these studies are majorly focused on IAQ, visual and acoustic comfort, a few number of studies with an in-depth evaluation of the thermal comfort conditions in malls are Chow and Fung (1995) and Chun and Tamura (1998), these two studies are quite old has recent literature with an in-depth analysis of thermal comfort conditions in the mall can hardly be found. 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 similar comfort temperature in occupants of all three buildings; however, the spread of the occupants' comfort range in the three buildings was significantly different.

Chow and Fung (1995)'s study was particularly on air-conditioned malls in Hong Kong. Three key thermal comfort parameters (indoor air temperature, relative humidity, and air speed) were measured in the occupied zone and subjective evaluation was acquired from shoppers. One limitation of the study is the relatively small number of respondents used, only 5-15 respondents were interviewed in each 84 malls considered in the study. Also, no continuous physical measurement was done; only 4 measurement points were allocated in each mall for taken spot measurement. The results revealed that the shoppers prefer high air speed and they are more comfortable with a mean air temperature of 20-24^{0}C, mean relative air humidity of 50-65% and mean air speed of 0.2-0.4 m/s. Chun and Tamura (1998)'s study, on the other hand, was focused on the comparison of thermal environment and human responses in underground shopping malls and departmental stores in Japan. The result revealed an unstable thermal condition and unstable occupants' psychological evaluation in the underground shopping mall compared to the department store. Also, the neutral temperature recorded in the underground shopping mall becomes colder in winter compared to the department store. It was concluded that the difference in the neutral temperature recorded was due to the fact that the temperature range in winter is very different between the two buildings. Also in this study, very few respondents (11 respondents) were used for the whole study. Therefore, this study aims to fill this knowledge gap by investigating the IEQ performances of a mixed-mode ventilated mall in Malaysia, an evaluation into the occupants' perception (shoppers and retailers) towards the mall's performance was also be carried out. Specifically, the objectives of this study are:
1. To evaluate the IEQ performance of the mixed-mode ventilated mall.
2. To study how occupants (shoppers and retailers) of the mall perceive the IEQ factors.
3. To reveal the effect of the mall's performance on retailers' work activities and shoppers' intention of revisiting the mall.

This study provides a better understanding of occupants' concerns and expectations for their indoor environment and overall satisfaction. It will also inform architects and designers on how different building design features, ventilation strategies, and technologies may affect the building's indoor environment, occupant comfort, and also their satisfaction. The paper first explains the method used in the study, then a description of the case study mall. It then presents and discusses the results of the study. The paper concludes with some recommendations for future research.

2. Method
To fulfil the stated objectives, both objective and subjective measurements were carried out on the case study mall. This case study mall was chosen from a list of identified Malaysian mixed-mode ventilated malls in Ibiyeye et al. (2015) where six presently operating Malaysian malls were identified and grouped based on their design concept. The case study mall operates under 'Zoned' mixed-mode ventilation strategy, and it was chosen particularly because of its size, location, and design concept. All data was collected within the naturally ventilated central space and the chosen respondents were the occupants (shoppers and retailers) within this central space.

2.1 Description of case study mall
This mall is the first phase of a planned four-phase development; it is located in Bandar Baru Bangi, Bangi, Selangor, Malaysia. The mall is surrounded by low buildings, and vegetation and accessible from major roads (Figure 1). The building consists five blocks in total: a block of four-storey shopping unit, four blocks of three-storey shops and office units and a one-level underground car park. All five blocks of retail buildings are positioned around a large naturally ventilated central space and connected to each other (Figure 2). The four-storey shopping unit is enclosed and operates on central air-conditioning system. The blocks of three-storey shop and office units are individually air-conditioned and some, particularly those on the ground floor (mostly restaurants) are naturally ventilated. They are built in such a way that some blocks open directly to the central space and others open directly to the outside (Figure 3 and 4). The central space, on the other hand, is naturally ventilated and covered but at the same time opens at five different ends/entry points (Figure 2). These openings or entry points are very large (7 to 10 meters in width) and extend from the floor to the roof (See Figure 2 and 4).
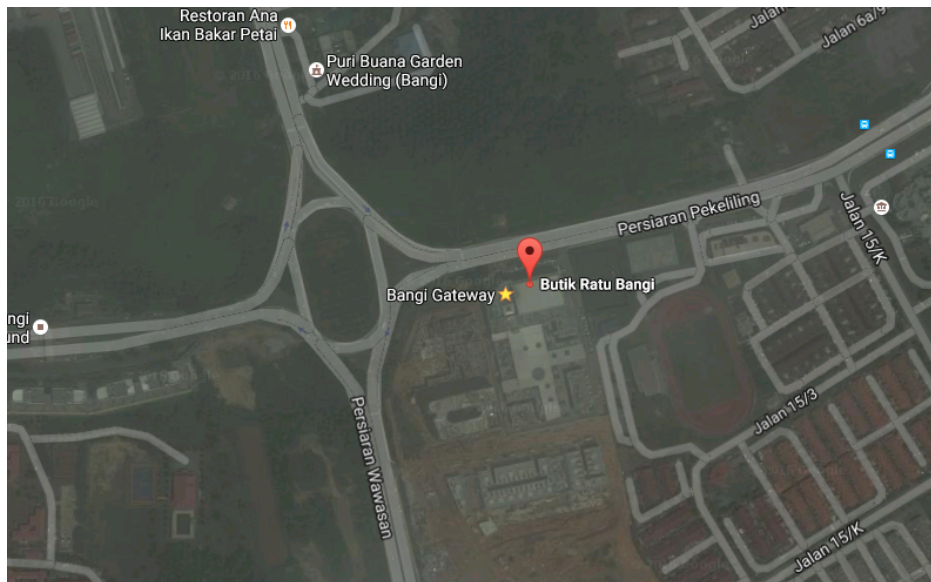
Figure 1. Location of the mall and surrounding areas (Source: Google maps, 2016)

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 providing lighting and ventilation (Figure 4). Some retail kiosks are positioned within the large central space, and it is worth noting that some shops (particularly the naturally ventilated restaurants) in this mall are opened directly into the naturally ventilated common space thereby benefiting from the natural ventilation. Within the central space, giant ceiling fans are installed in strategic locations to improve the air circulation.
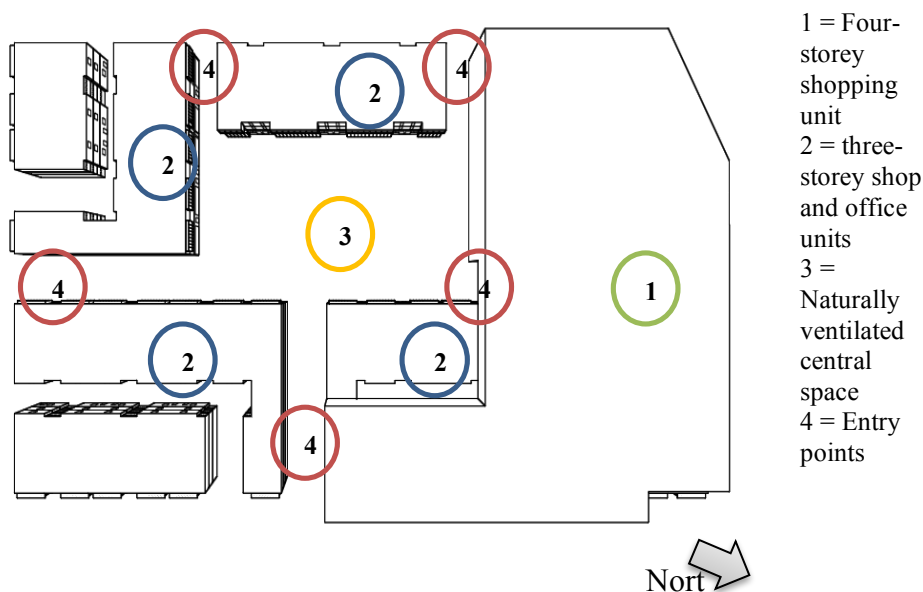

1 = Four-storey shopping unit
2 = three-storey shop and office units
3 = Naturally ventilated central space
4 = Entry points

Figure 2. Blocks arrangement in the mall

Figure 3. Outside view of the mall

Figure 4. Interior view of the mall. A and B shows the large openings between the roofs. C and D show two of the large open ends leading to the courtyard.

2.2 Objective measurement

Continuous monitoring of physical data was done of five measured environmental factors (indoor air temperature, operative temperature, relative humidity, air speed, and CO2). For this study, 5 minutes logging interval was set for all measured parameters; however, due to instrument constraint, CO_2 measurement was taken every 15 minutes in the case study mall.

2.3 Subjective measurement

The subjective measurement involves survey questions consisting of evaluation of different factors which includes occupants' background survey (i.e., gender, age, etc.), thermal satisfaction (indoor temperature), indoor air quality satisfaction (indoor perceive odour), indoor air movement satisfaction, present location/workplace satisfaction, and overall building performance satisfaction. The questionnaire was divided into five sections and it took around 5 to 7 minutes for a respondent to fill the questionnaire. Each satisfaction factor was evaluated using a 7-point satisfaction scale (7: very satisfied, 4: neutral, 1: very dissatisfied) followed by branching questions for occupants that falls within the dissatisfied group, this is done in other to identify the sources of discomfort. The questionnaire was translated into the local language (Bahasa Melayu) for easy understanding and comprehension and at the end, a bilingual (Bahasa Melayu and English) was used to accommodate foreign

respondents that do not understand the local language. A detailed description of each section of the questionnaire is given in the following subsections (2.3.1 – 2.3.5).

2.3.1   Occupants' background survey

Questions under this part were to obtain information about occupants' demographic characteristics such as age, nationality, gender, and work position held (for retailers). Respondents were further asked to give information on the period of their stay in the mall and frequency of visit (for shoppers).

2.3.2   Thermal satisfaction

Questions under this part were those formulated to establish the occupants' perception of the indoor temperature within their present location (for shoppers) or their workplace (for retailers). Specifically, respondents were requested to rate their level of satisfaction on seven point scale of 1 to 7 (1 representing 'very unsatisfied' to 7 representing 'very satisfied'). In addition to this, retailers were asked to indicate any means of control accessible to them within their workplace. Generally, respondents that rate their satisfaction level on the 'unsatisfied' scale were further requested to point out the specific reasons for their dissatisfaction and also to choose from a list of different related factors that best describe their source of discomfort. Furthermore, shoppers were asked if based on their perceived thermal condition they will visit the particular mall again and retailers were asked if they enjoy their work activities based on their perceived thermal condition. This is necessary to know the magnitude the effect of thermal perception has on shoppers' preference of a particular mall and the significant it has on retailers work activities.

2.3.3   Air quality satisfaction

Similar to thermal satisfaction, questions under this part were formulated to establish occupants' perception of the air quality within their present location (for shoppers) or their workplace (for retailers). Respondents were also requested to rate their level of satisfaction with the air quality on the same seven-point scale of 1 to 7. And again those that rate their satisfaction level on the 'unsatisfied' scale were further requested to point out the specific reasons for their dissatisfaction and also to choose from a list of different related factors that best describe their source of discomfort. Shoppers were also asked if based on their perceived air quality condition they will visit the particular mall again and retailers were asked if they enjoy their work activities based on their perceived air quality condition.

2.3.4. Air movement satisfaction

Similar to thermal satisfaction and air quality, in this section, respondents were requested to rate their level of satisfaction with the air movement within their present location (for shoppers) or their workplace (for retailers) on the same seven-point scale of 1 to 7. Also, shoppers were also asked if based on the perceived air movement they will visit the particular mall again and retailers were asked if they enjoy their work activities based on the perceived air movement.

2.3.5.   Overall building performance satisfaction

In this section, respondents were asked to rate the overall satisfaction level of their present location (for shopper) or workplace (for retailers) and also to rate the overall building performance based on the combined effects of the previously evaluated factors (thermal perception, air quality, and air movement) both on a 7 point scale of 1 representing 'very unsatisfied' to 7 representing 'very satisfied'. The last question in this part of the questionnaire was an open-ended question which provided respondents the opportunity to express additional opinions and comments regarding their present location/workplace and the building in general.

2.4.   Data collection process

Both objective and subjective measurements were carried out within the naturally ventilated central space in the case study mall. The questionnaire survey and all monitoring processes were carried out in the case study mall on a weekend (Saturday and Sunday) within the month of March since malls are generally more visited during the weekends (Klinmalee et al., 2009; Hu and Li, 2015). All data collection process was done from 11 AM to 5 PM. A minimum total of 150 questionnaires (100 shoppers and 50 retailers) were intended to be collected in the case study mall. However, at the end of the survey a total of 156 filled questionnaires were collected and out of this, 144 responses was analysed (after responses have been filtered to omit poorly filled and incomplete questionnaires). 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. Measurement positions and location are in line with the ASHRAE standard 55, i.e: measurements were made in occupied zones of the mall and are taken sufficiently away from the boundaries of the zone and from any surfaces to allow for proper circulation around the sensors. Also, sensors are stationed at a level of 48 inches (1.1 m) from the floor for the standing position (ASHRAE, 2004).

3.   Results and discussion

3.1 Objective measurement

Figure 5 - 8 represent the plot of all measured physical factors (indoor air temperature, operative temperature, relative humidity, air speed and CO2) against time in the case studied mall. Figure 5 shows a slight increase in the air temperature and operative temperature value from around noon till 4:00 PM when the air temperature starts to drop. Unlike the measured air temperature and operative temperature, the humidity value in the mall started to drop around noon and then rose again around 4:00 PM (See Figure 6). Figure 7 represents the measured air speed in m/s, high air speed value was recorded (mean). Figure 8 shows that CO_2 mall stayed below 500ppm.

Generally, the recorded indoor air temperature and air speed (mean: 33.52 ^{0}C and 0.89 m/s respectively) are high and this is an expected observation since the monitored area in the case study mall is primarily naturally ventilated. This could also be due to

the fact that the mall is opened and exposed to the outdoor and also provided with wide open entry points. These wide open entry points are easy and direct link to the incoming breeze and as well could contribute to heat gain through direct penetration of sunlight. CO_2 concentration level (mean: 437.88 ppm) in the mall was low and well below the maximum concentration level of 1000ppm as stated in the Malaysia code of practice on indoor air quality (DOSH, 2005). This is an indication that since there is provision for free air circulation between the outdoor and indoor in the natural ventilated zone of a mixed-mode ventilated mall, less CO_2 contamination level is expected. As the free exchange of air facilitates high air ventilation rates (Yamamoto et al., 2010; Marr et al., 2012) and this, in turn, improves IAQ and reduce contaminations caused by various indoor contaminants (Guo et al., 2008, Zuraimi and Tham, 2008; Fisk et al., 2009).
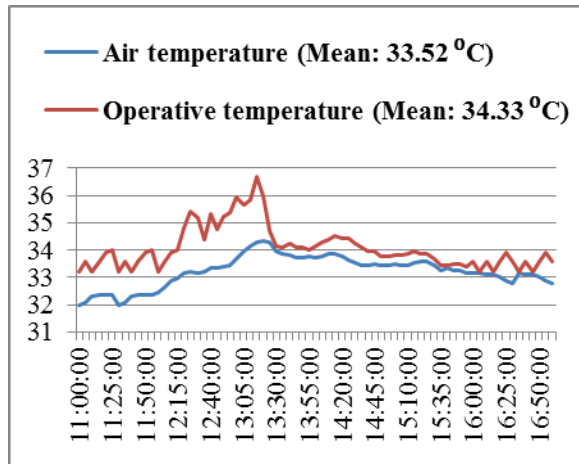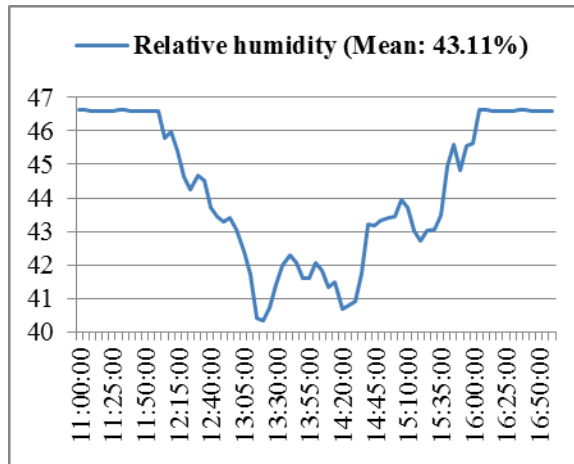

Figure 5. Measured air temperature
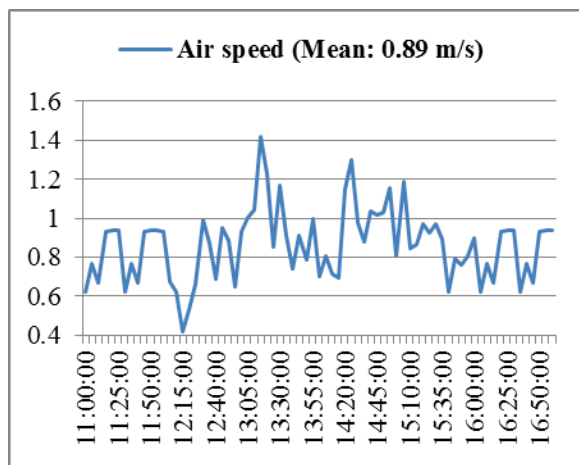

Figure 6. Measured relative humidity

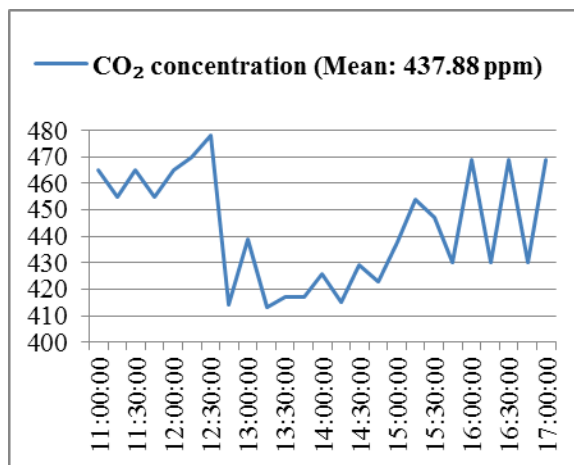Figure 7. Measured air speed

Figure 8. Measured CO_2 level

3.2. Survey results
2.3.4   Demographic characteristics

Occupants' information was investigated to analyse their demographic characteristics. Table 1 represents the characteristics of a total of 144 respondents (99 shoppers and 45 retailers) from the case study mall. Furthermore, the two most popular means of control retailers employ in their workplaces were the ceiling and portable fans. While the two main positions held by the retailers in the case study mall were 'sales assistant' and 'managerial/supervisor' positions.

Table 1. Respondents' demographic characteristics

Variables

Means of control		yes
Type of respondents	Shoppers	99
	Retailers	45
% Gender	Female	70.8
	Male	29.2
% Nationality	Malaysian	92.4
	Foreigner	7.6
Average period of occupancy (months)	Retailers (n = 45)	12.0
Average period of visiting (months)	Shoppers (n = 99)	11.49
Average period of stay in workplace per day (hours)	Retailers (n = 45)	10.38
Average hours spent in a mall per visit (hours)	Shoppers (n = 99)	3.5
Age in years (N = 437)	Mean	27.38

3.2.2 Satisfaction votes

Figure 9 shows the percentage responses of respondents' (both shoppers and retailers) perception of all five measured parameters: thermal satisfaction (TempSAT), indoor air quality satisfaction (IAQSAT), air movement satisfaction (AMSAT), present location/workplace satisfaction (PL/WPSAT), and overall building performance satisfaction (BuildPerfSAT). The 'satisfied' groups are those that fell in the three higher categories of the rating scale (i.e. scale 5, 6 and 7), the 'dissatisfied' groups are those that fell in the three lower categories of the rating scale (i.e. scale 1, 2 and 3), and the 'neutral' groups are those that rated their satisfaction on the rating scale '4'. Figure 9 shows that large percentage of respondents are generally not satisfied with the indoor air temperature compared to the other four factors where the percentage of respondents that are satisfied exceeds the percentage of dissatisfied respondents. However, high of respondents still feel neutral towards all measured satisfaction factors, these respondents are neither satisfied nor dissatisfied with the indoor condition within their present location or workplace. It can be noticed in Figure 9 that although a large percentage of respondents are not satisfied with the indoor thermal condition, the majority of the respondents still feels that the indoor condition of their present location/workplace and the overall building performance are still satisfactory. An inquiry into the reasons for dissatisfaction in the dissatisfied respondents with regards to indoor temperature reveals that the major source of discomfort is the discomfort of the 'incoming sun' followed by the feeling of low air movement (Figure 10). This is expected has the skylights that provide daylighting into the naturally ventilated central space are direct sources of heat penetration. For indoor air quality, the major cause of dissatisfaction in the dissatisfied respondents is the perceived discomfort from tobacco smoke (Figure 11).
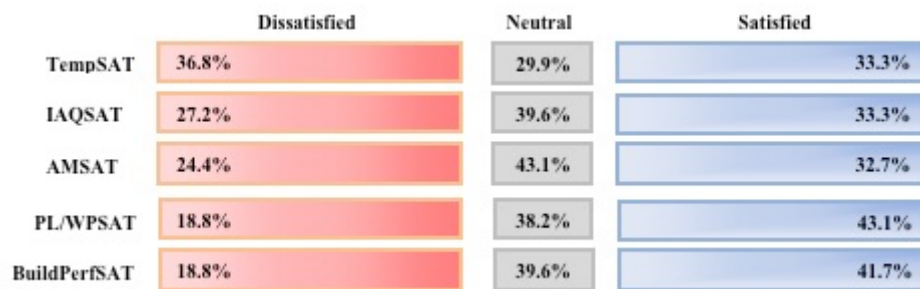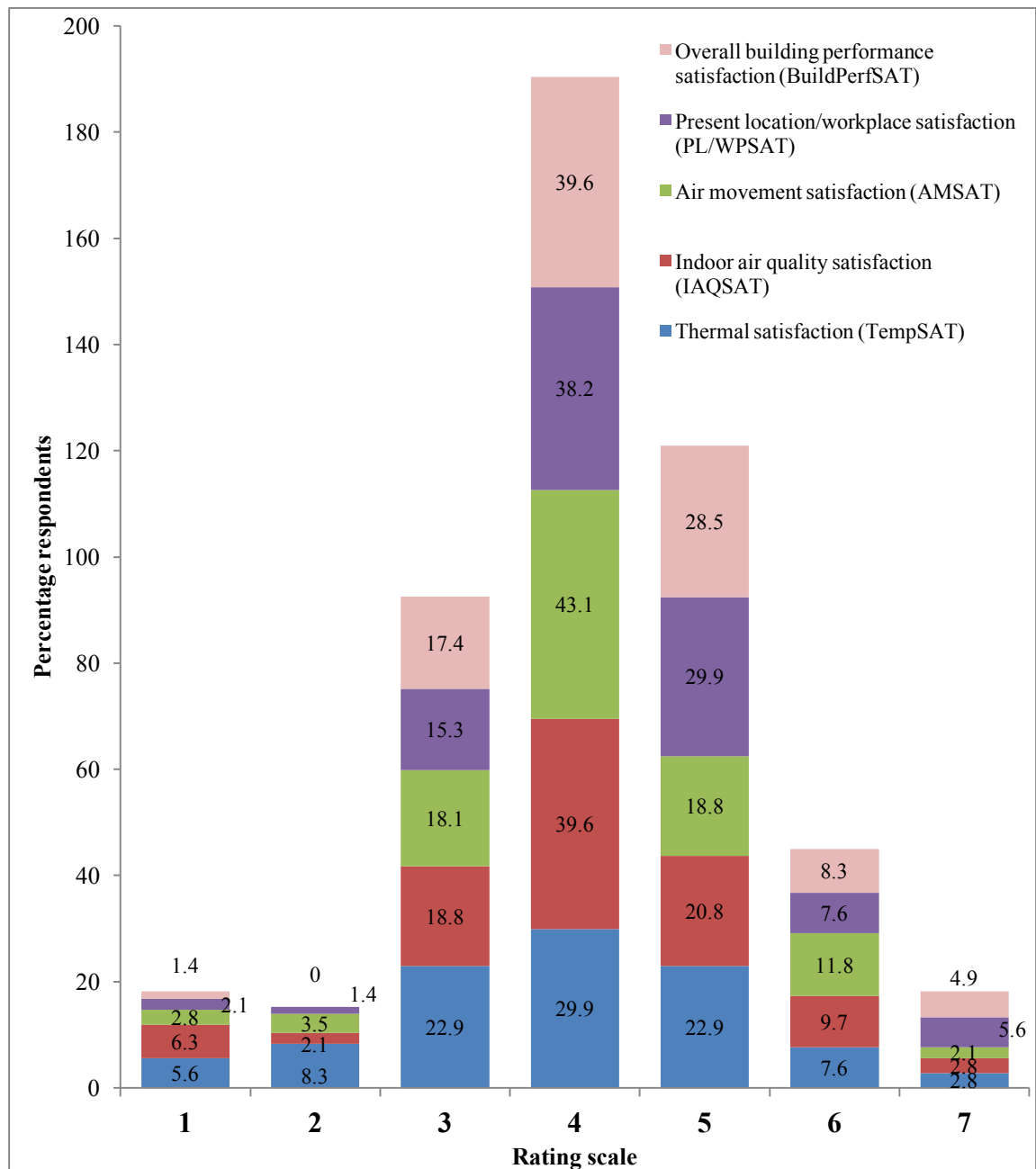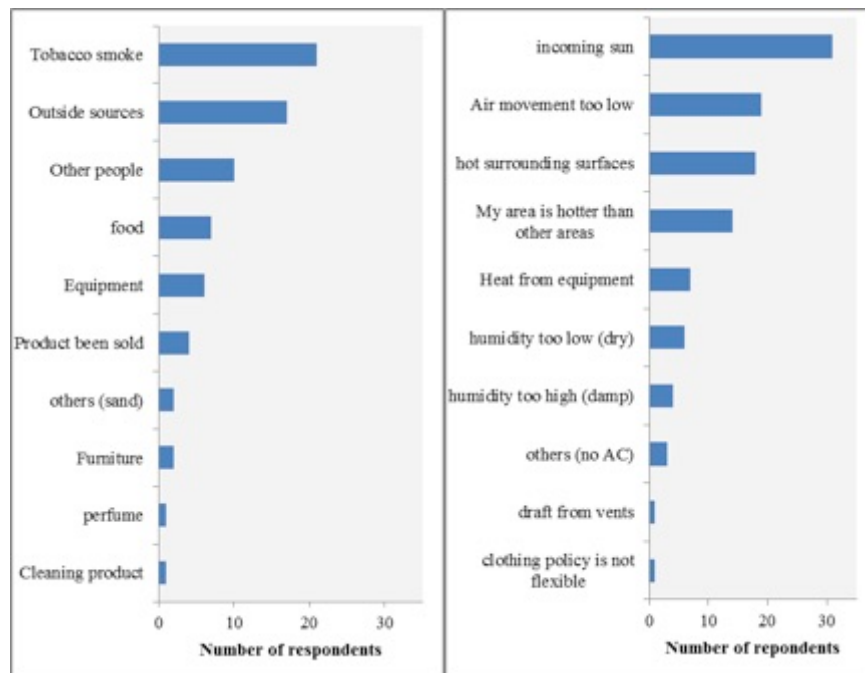
**Figure 9.** Satisfaction votes for all measured factors

**Figure 10.** Respondents reason for being dissatisfied with the thermal condition

Figure 11. Respondents reason for being dissatisfied with the air quality condition

3.2.3. Retailers' work activities and Shopper's willingness to revisit the mall

For three of the subjectively measured satisfaction factors (thermal, indoor air quality, and air movement satisfaction), retailers were asked to indicate if they enjoy their work activities based on each perceived indoor factors. Those retailers that believed they do not enjoy the work activities based on the perceived indoor condition answered 'no' while those that felt that despite the indoor condition, they are still able to enjoy their work activities answered 'yes'. They were also required to rate the level in which their productivity has been affected in relation to their workplace environmental condition based on the combined effects of those mentioned factors. This was recoded on a scale of 1 to 7 (with 4 being the middle value). Figure 12 shows percentage number of retailers who felt that their work activities were negatively affected by the indoor factors (i.e. they do not enjoy their work activities due to their perception of the indoor factors). Similarly, shoppers were asked to indicate based on their perception of the above three mentioned factors if they will visit the mall again. Those shoppers that believed that their perception of the indoor condition would not hinder them from revisiting the mall answered 'yes'. While those that felt that their perception of indoor condition would hinder them from revisiting the mall answered 'no'. Figure 13 shows percentage number of shoppers who felt that their perception of the indoor condition will not allow them to revisit the mall. Figure 12 reveals that the indoor air quality condition has the most negative effect on retailers' work activities (44.4% of retailers not enjoying their work activity) while the air movement condition has the least effect on their work activities (37.8% of retailers not enjoying their work activity). Also, the average productivity level of retailers recorded is 4.04. This productivity level is above the middle value (i.e. on average, the retailers are productive despite their workplace environmental condition). Figure 13 shows that majority of the shoppers are not disappointed shoppers (i.e. few percentage of shoppers are disappointed) by the indoor condition experienced in the mall and they would still love to revisit this same mall again. These results are in line with studies that reveals that certain IEQ condition affects workers' productivity (Heinzerling et al., 2013). And also, these condition influences shoppers willingness to revisit a particular mall (Chang and Fang, 2012; Chebat et al., 2014).
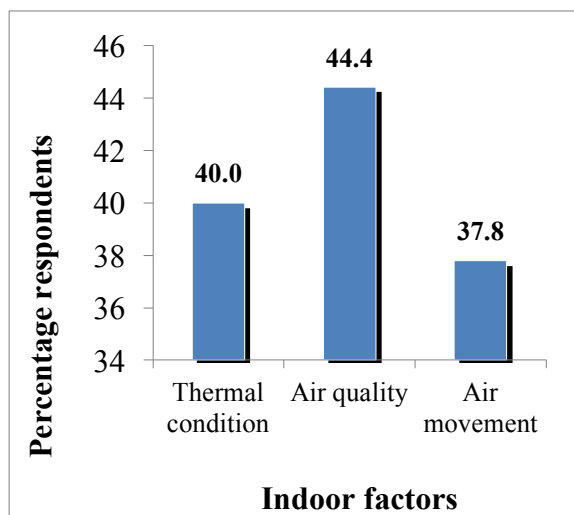
Figure 12. Percentage retailers that do not enjoy their work activities based on the perceived indoor condition
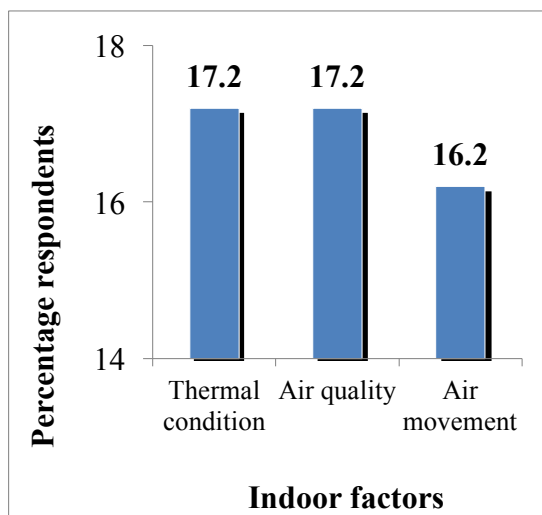
Figure 13. Percentage shoppers that would not revisit the mall based on the perceived indoor condition.

3.2.4 General comments

95.7% of respondents that commented give a comment/complaint related to the building's performance, the remaining 4.3% only commented on the issue related to the business transaction carried out in the mall (i.e. the need for more restaurants). Of the respondents that commented related to the building's performance, 50.0% requested for air-conditioning to be installed within the natural ventilated zone of the mall. 36.3% complained that the space is too hot mostly in the afternoons. However, 9.1% suggested that ventilation could be improved by installing more giant fans in the natural ventilated zone of the mall. While 4.5% believed that the roof needs to be upgraded and improved to prevent the penetration of direct sun into the natural ventilated zone.

4   Conclusions and recommendation for future studies

This study reveals the IEQ performance and occupants' satisfaction level of a selected mixed-mode ventilated Malaysian mall. Five measured environmental factors (air temperature, operative temperature, relative humidity, air speed, and CO_2) and five satisfaction factors (thermal comfort, indoor air quality, air movement, workplace/present location, and overall building performance) were evaluated in the case study mall through field measurements and questionnaire survey. From the field measurement, high indoor air temperature and air speed were recorded and generally, the CO_2 concentration level in the mall was very low. Low percentage of satisfaction with the indoor thermal condition was recorded from the occupants, however the majority of the occupants are still satisfied with the other four satisfaction factors (indoor air quality, air movement, workplace/present location, and overall building performance). Their dissatisfaction with the indoor thermal condition was majorly caused by the discomfort from the incoming sun and the feeling of low air movement while dissatisfaction with the indoor air quality condition was majorly caused by the discomfort from tobacco smoke. These feelings of discomfort and dissatisfaction affect retailers' work activities in the mall. With the air quality condition having the most negative effect on retailers' work activities and the air movement condition with the least effect. Despite all the negative feelings, retailers' productivity levels in the mall are above the average showing that the retailers are still productive despite their workplace environmental condition. Similarly, the majority of shoppers that visited the mall were satisfied with their experience and would consider revisiting the mall. This study was only carried out in one case study mall located within the state of Selangor, Malaysia, further study is recommended to include malls from other locations in Malaysia and also incorporate a larger number of survey respondents. Furthermore, studies should be conducted to investigate another indoor pollutant aside the one studied in this paper (CO2).

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