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A FIELD STUDY OF INDOOR AIR QUALITY IN A TROPICAL REFECTORY

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ABSTRACT

A refectory is the building area in educational institutions where meals and beverages are served. Since these areas are often occupied by a large number of students and staff during mealtime, the provision of good indoor air quality (IAQ) is of utmost importance. To supplement the available information about conditions of indoor air in many building areas which have been reported in other studies and to identify the levels of indoor air parameters (IAPs) in a Malaysian refectory, a field study has been carried out in a local university using electronic environmental monitoring sensors and questionnaire survey and the results are reported in this paper. The mean air temperature and concentration level of the carbon dioxide gas were found to be higher than the acceptable ranges stipulated in both DOSH and ASHRAE IAQ standards, while other IAPs were generally within the recommended levels. The split air-conditioning units, albeit installed near the dining zones of the refectory, were found to be inefficient at removing the occupant heat gain during peak hours and provided very limited ventilation effectiveness since there is no fresh air intake for this type of air conditioner. High prevalence of sick building syndrome (SBS) was also found in this building area, possibly due to the high occupancy levels. Increased ventilation with the aid of exhaust fans and retrofitting of the existing air conditioning system to a centralised one were required to lower the CO_2 level as well as removing other airborne contaminants.

Keywords: *Refectory, educational institutions, indoor air quality (IAQ), indoor air parameters (IAPs), field survey, ventilation*

INTRODUCTION

Given the fact that human spend most of their time indoors (Klepeis et al., 2001), a good indoor environment is essential to maintain the comfort, safety and health of building users. Therefore, many experimental studies on indoor air quality (IAQ) and occupant comfort conditions in offices, laboratories, classrooms and other building spaces have been carried out since decades back (Ehsanol et al., 2012; Asadi and Hussein, 2014; Travers and Vogl, 2015; Yousef et al., 2013; Kwong et al., 2014; Rawi et al., 2014). Some of the main parameters that affect indoor air conditions are air temperature, ventilation rate, humidity level and concentration levels of both chemical and biological air pollutants, which would in turn affect human comfort, productivity and learning ability (Kumar and Fisk, 2002; Kosonen and Tan, 2004; Karimipanah et al., 2007; Yu et al., 2009, Frontczak and Wargocki, 2011). As most modern buildings are well insulated and tightly sealed for the protection of occupants, the use of mechanical ventilation equipment to reduce concentration levels of pollutants become inevitable in various places around the world (Lin & Chen, 2014; AIHA, 2015) and the importance of ventilation towards controlling the concentrations and exposures released by indoor sources was also reported (Nazaroff, 2013). However, some previous works had identified the prevalence of sick building syndrome (SBS) in air-conditioned spaces at which some health related issues and dissatisfaction towards the existing IAQ were reported by the occupants (Mui et al., 2011; McGill et al., 2015). Sekhar and William (2004) specifically noted that air supply volume, location of supply and return air plenums, space design and heat sources had significant impact on IAQ in tropical buildings. Besides, old malfunctioning air conditioning system was found as one of the major reasons for poor IAQ in buildings (Hirshberg, 2011).

A refectory or cafeteria is a dining area located within academic institutes with several unique features compared to other building areas: it is usually designed to accommodate a large number of consumers during peak periods (recess and meal time) of a typical academic session and the occupants are generally exposed to a higher level of air pollutants in this area, as cooking is considered as a major source of producing indoor pollutants in the form of exhaust particles (Sofuoglu et al., 2015). Lee et al. (2001) found that the air contaminant levels were significantly higher at locations where cooking activities were held, and different cooking methods may have different impact on the quality of indoor air. The environmental conditions in the kitchen had been found to be closely related to the respiratory symptoms of the workers (Svendsen et al., 2003). Therefore, setting up partitions to separate the cooking area with other zones has been found to be effective in preventing the spread of the air particles generated by cooking (Zhao et al., 2010). Besides, the effectiveness of the mechanical ventilation systems installed at a food centre in a tropical country was studied and poor thermal environments were identified in several locations (Wong et al., 2006). A more recent study has found that the equipment used in the cafeteria often contributed to the increase of heat gain, which may lead to thermal discomfort among occupants (Zainuddin et al., 2014). Although the abovementioned studies have pointed out the issue related to IAQ in the eateries, the current information on the indoor air conditions in tropical refectories is lacking, which proposed that more work in this field of study is required.

Since indoor contaminants are among the many factors that lead to poor IAQ, experimental studies on IAQ often focus on determining the levels of important indoor air parameters (IAPs) and also the occupants' opinion. This paper examines issues related to indoor air conditions in the main refectory of a local academic institute. The major indoor air parameters (IAPs) were measured in a series of field measurements and occupant perception of their immediate surroundings were also studied. Based on the results obtained from field surveys, recommendations were made for the improvement of indoor air conditions in this building type.

DESCRIPTION OF THE REFECTORY UNDER STUDY

The selected refectory is a part of the administrative building of a local university, which is conveniently sited at the heart of the campus. It provides a diverse catering service to over 200 students and staff at one time. The building layout is a multi-concept plan and is divided into two sections – the air-conditioned indoor area where the kitchen, food serving stations and eating areas were located and the naturally ventilated outdoor space where independent stalls were set up. The main area of the building is concentrated on the right side, which is the indoor section. The dining area consists of both indoor and outdoor areas, circulating the row of food stalls and catering serving counters. Other services like cleaning and kitchen are placed indoors. The semester opening hours of the refectory are from 8.00 am to 5.00 pm and served breakfast, lunch and evening meals. The main entrance is located at the right side of the building. Besides, there are two sub-entrances located between the indoor and outdoor sections of the building, but only one is accessible. Although ceiling mounted air conditioners are available in the refectory, not all units are switched on during the air sampling period. Three windows are located near to the entrance doors and were kept closed throughout the field survey due to the use of air conditioners. The indoor environment of the refectory is shown in Figure 1. Since this academic institution is a public one, smoking within its compound is strictly prohibited.

Figure 1: Indoor environment of the refectory under study

METHODOLOGY

The methodology of this study (as presented in Figure 2) was developed based on the recommendations in IAQ standards and guidelines. In this work, only the IAPs at the interior (air-conditioned) part of the refectory were measured as that was the area where cooking activities were carried out and most of the consumers were seated. A pilot study was first carried out to identify the existing air conditions in the refectory. After that, four measuring points at the dining areas were selected so as to identify the levels of IAPs at different locations, as highlighted in Figure 3. Two of the measuring points (L1 and L4) were nearer to the entrance doors while the remaining points (L2 and L3) were more confined.

Two indoor environmental standards were referred to in this work – ASHRAE Std 62.1 (2016) and DOSH ICOP (2010). ASHRAE Std 62.1 (2016) specifies minimum ventilation rates and other measures intended to create an indoor environment with acceptable IAQ for the occupants and this standard has been widely used by mechanical consulting engineers, building contractors, architects and government agencies worldwide. For instance, this standard specifies that the concentration of interest of the Carbon Monoxide (CO) gas is 9 ppm (8-hour observation period) and Carbon Dioxide (CO2) level in indoor rooms should be controlled below 700 ppm. A sample questionnaire form is attached together with the code so that industrial hygienists/ building engineers can use it freely to assess the quality of air in the interior spaces. On the other hand, DOSH ICOP (2010) is a code of practice introduced by the Department of Occupational Safety and Health, Malaysia to ensure that workers and building occupants are protected from poor IAQ conditions that could adversely affect their comfort, safety and well-being which would in turn lower their productivity. The acceptable ranges of IAPs are listed in this code of practices, as shown in Table 1.

In this work, four IAQ monitoring instruments - Direct Sense-IAQ, VOC meter, HCHO sensor and handheld CO-CO_2 meter were used to measure the IAPs with an 8-hour observation period The instruments were positioned at approximately 1.0 meter above the floor level at the selected measuring points from 9 am to 5 pm daily during the field survey period, following the requirements stated in the standards mentioned above. A questionnaire survey was carried out concurrently to assess the perceptions of consumers towards their immediate surroundings. Consumers were selected randomly in this case study as it was difficult to determine the occupancy duration of each individual, but the majority of the respondents were those who had just finished their meals and those who were standing up waiting to pay for their dishes. Field data were checked and compiled daily for analysis purposes.

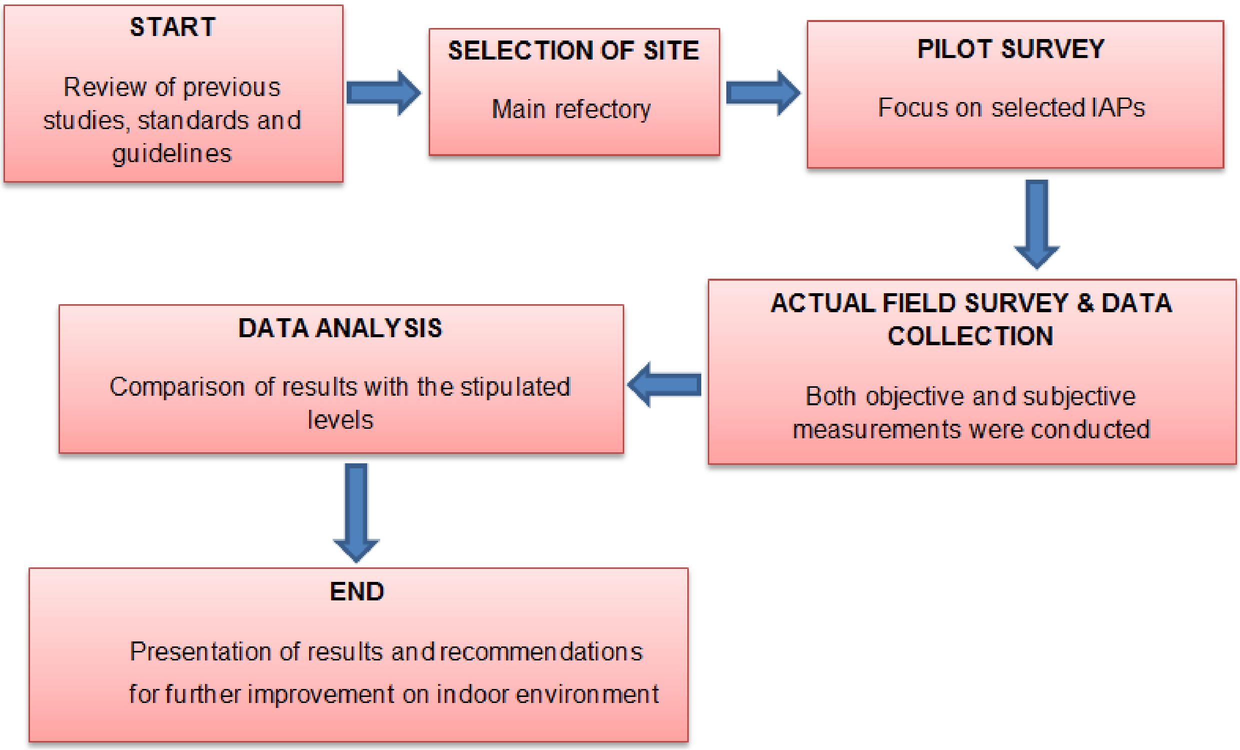

Figure 2: Methodology flow chart

Table 1: Major indoor air contaminants and threshold limit values (DOSH ICOP, 2010)

Indoor Air Contaminants	**Acceptable Limits** ppm[3]	mg/m[3]
Chemical Contaminants		
CO	10	-
TVOCs[1]	3	-
HCHO[2]	0.1	-
Particulate Matter (PM)	-	0.15
Ventilation performance indicator		
CO_2	*C1000	

*Ceiling limit that shall not be exceeded at any time
[1]Total Volatile Organic Compounds
[2]Formaldehyde
[3]parts per million

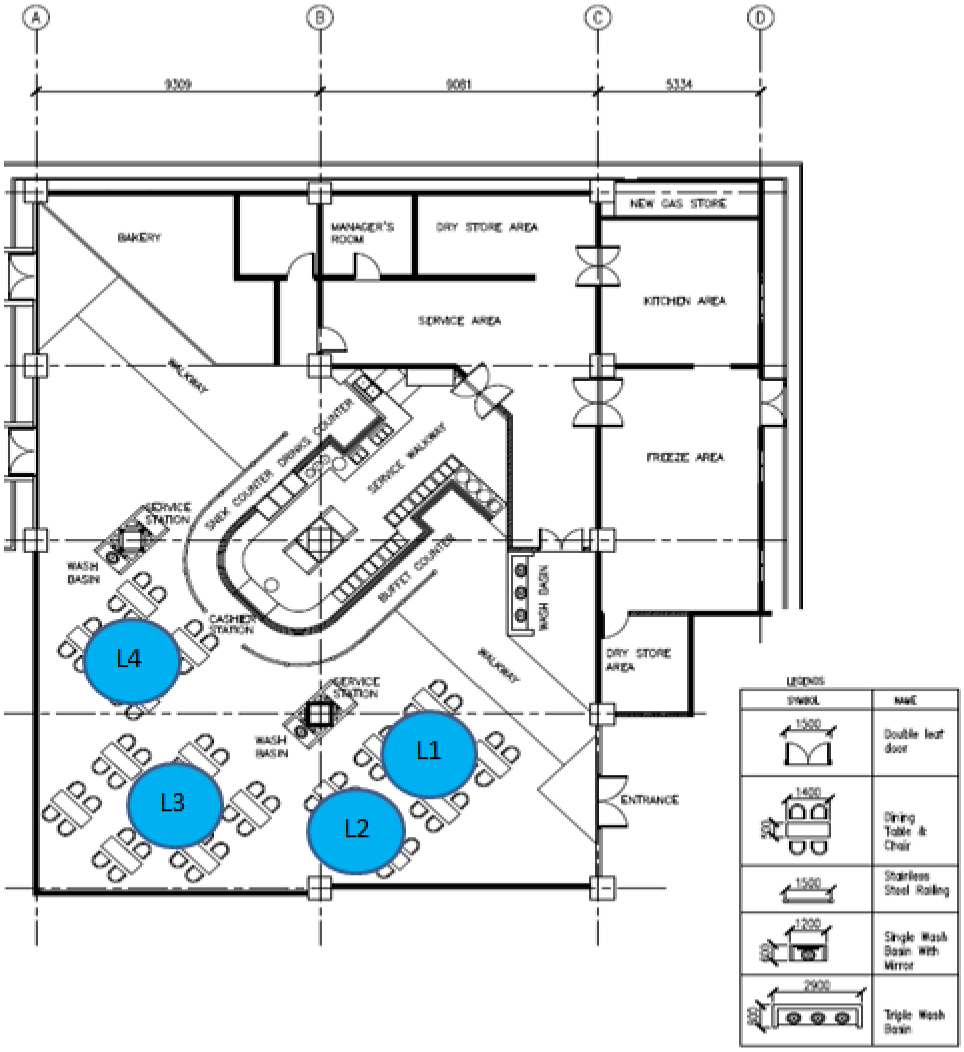

Figure 3: Locations selected for data collection

RESULTS AND DISCUSSION

Physical Measurements

The measurement of IAPs was carried out in September to October 2016 in the main refectory of an educational institution in Malaysia. Each day of the field survey was dedicated to one measuring location (as shown in Figure 3) and no repetition of measuring work at the same location was performed in this work. The measurements targeted CO, CO_2, HCHO, VOCs, air temperature, air velocity and relative humidity levels only.

Carbon Monoxide

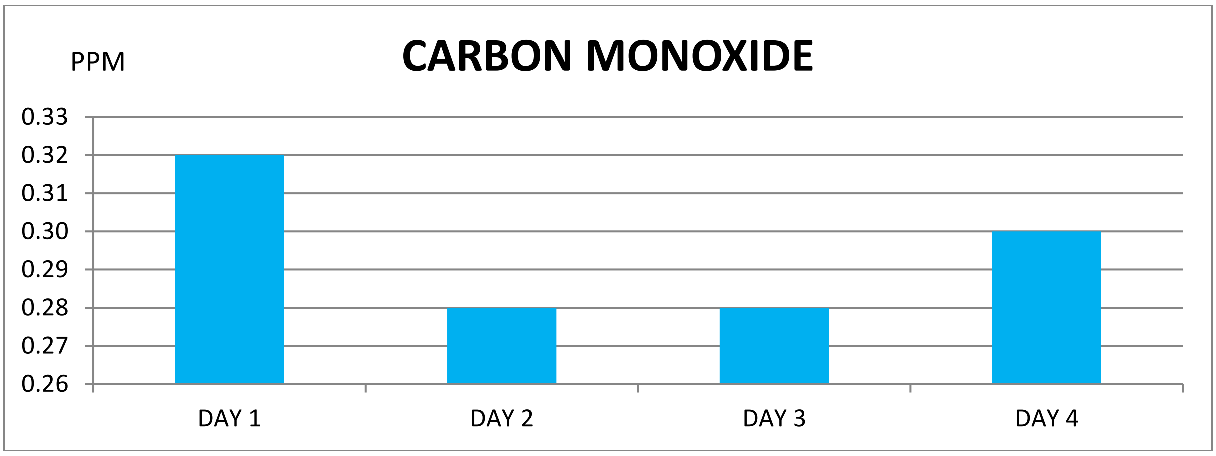

Figure 4: Mean concentration levels of Carbon Monoxide in the refectory

CO is the by-product of incomplete combustion. Figure 4 presents the measured CO concentration levels during the air sampling period. It can be seen that occupants at location 1 of the refectory were exposed to the highest mean CO concentration level of 0.32 ppm, while slightly lower CO levels were recorded at other locations, ranging from 0.28 ppm to 0.30 ppm. This finding shows that the level of CO concentrations in the refectory was within the acceptable range stipulated in both ASHRAE Std 62.1 (2016) and DOSH ICOP (2010) and one of the reasons for this was that there were no barbecue style cooking and food boiling near to the measuring points, as these two cooking methods can generate a substantial amount of this harmful gas (Lee et al., 2001). Besides, the parking area for the university staff was not located nearby and thus the indoor area was not affected by the exhaust gases produced by automobiles. The only food station that sells grilled sizzling food was located at the exterior part of the refectory, which was quite a distance away from the measuring points.

Carbon Dioxide

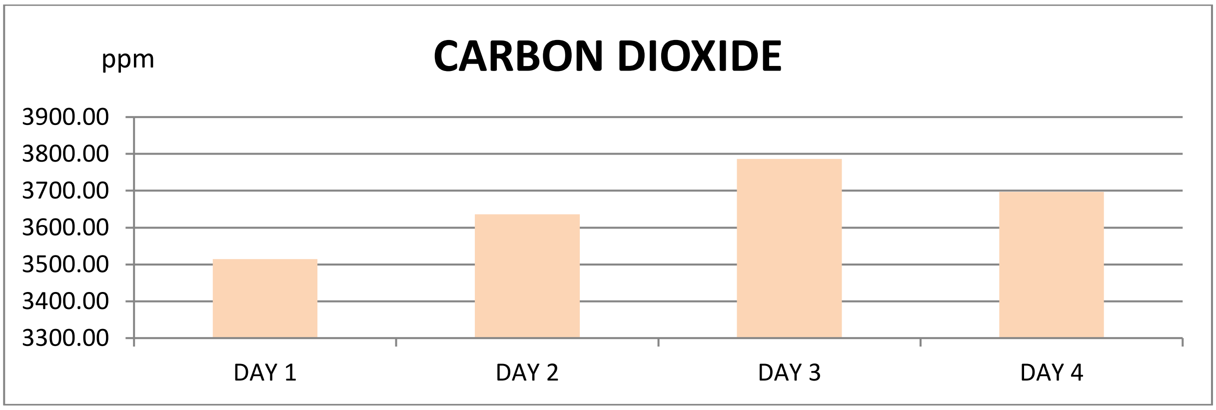

Figure 5: Mean concentration levels of Carbon Dioxide in the refectory

From Figure 5, the highest mean concentration level of CO2 was found at location 3 of the refectory, where a concentration level of 3787 ppm was recorded. The concentration levels of this greenhouse gas at other locations were also high, ranging from 3514 to 3697 ppm. According to ASHRAE Std 62.1 (2016) and DOSH ICOP (2010), the level of carbon dioxide should not exceed 1000 ppm so as to ensure that the majority of people entering a space will be satisfied. This finding reflects the field survey outcome reported by Lee et al. (2001), which also found that the CO2 level of restaurants in Hong Kong exceeded the threshold limit specified in the local IAQ guideline. Among the factors that lead to this elevated CO_2 level were the high occupancy during meal time and insufficient ventilation, since the current air conditioning system only circulated the indoor air without any provision of fresh air. Hence, the proposed mitigation strategies include providing higher ventilation rates by retrofitting the air conditioning system into a centralised one to allow fresh air to be supplied to the inner dining areas

(Location 2 and 3) and allowing more openings to be made in the refectory to enhance natural ventilation especially at location 1. The site observation showed that exhaust fans can be installed in the wall area between location 3 and 4 to enhance the contaminant removal effectiveness. A previous work has also concluded that the loss of occupant productivity in office buildings was often affected by the level of airflow rate (Kosonen and Tan, 2004).

Volatile Organic Compounds (VOCs)

VOCs are chemical contaminants that are emitted by several indoor sources like paints, aerosol sprays, cleansers, air fresheners, sealants, adhesives, partition boards and office equipment. Many sources have reported that VOCs can easily enter the air and cause various SBS, which include headache, shortness of breath, nausea, dry and watery eyes, flu-like symptoms and others. During the field measurement, the readings of the electronic sensor showed no sign of this indoor gas within the refectory. The main reason for this was that this location was unlike office spaces where large numbers of equipment are available. The only possible sources of VOCs were the detergents used for floor and table cleaning, which were only carried out after operating hours and no measurement was held. Moreover, this area has been in use since the past decades and there was no recent renovation or repainting of the interior walls.

Formaldehyde (HCHO)

HCHO is a type of VOC and is widely used in manufacturing domestic products, such as furniture and other household items due to its abundance and low cost (Hirshberg, 2011). New building materials and household equipment often emit HCHO gas at different rates. In this study, a separate handheld electronic sensor was used to measure the HCHO level because of the limitation of the VOC meter, which used a photoionisation detector (PID) that was not able to detect HCHO gas. Similar to the VOC, it was found that the HCHO level was significantly lower than the prescribed value in DOSH ICOP (2010). Most of the time the samples were below the equipment detection limit. The level of HCHO measured in the refectory was within the range of 0 – 0.01 ppm, which is negligible. Therefore, it can be concluded that both VOCs and HCHO levels were generally very low in the refectory and do not pose any major health threat to the occupants.

Air Temperature

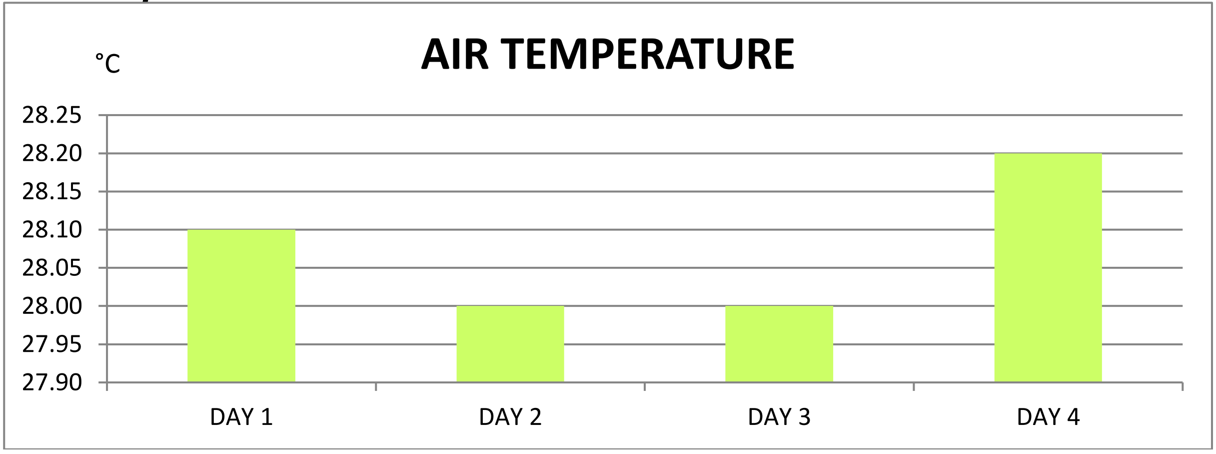

Figure 6: Measured mean air temperature

Good distribution of air flows in buildings is important for overall IAQ improvement (Clements-Croome et al., 2008). The range of air temperature in the refectory is presented in Figure 6. It was identified that the warmest place within the refectory was at location 4, at which an average temperature of 28.2 ^{o}C was measured. On the other hand, location 2 and 3 had the lowest mean temperature where the mean air temperature at both locations was about 28.0 ^{o}C. The results also showed that the air temperature was higher than the recommended temperature range of 23 – 27°C in DOSH ICOP (2010), which may cause thermal discomfort among occupants. It was found that some of the air conditioning units were not functioning properly during the field survey, where an increase of air temperature was observed during peak hours. Therefore, there was need to retrofit the existing air-conditioning units in the refectory to provide a lower supply air temperature, especially at the dining areas. This suggestion was echoed by the results of a previous study, which proposed the use of additional air-conditioning unit to improve the thermal environment in an air-conditioned cafeteria (Zainuddin et al., 2014).

Relative Humidity

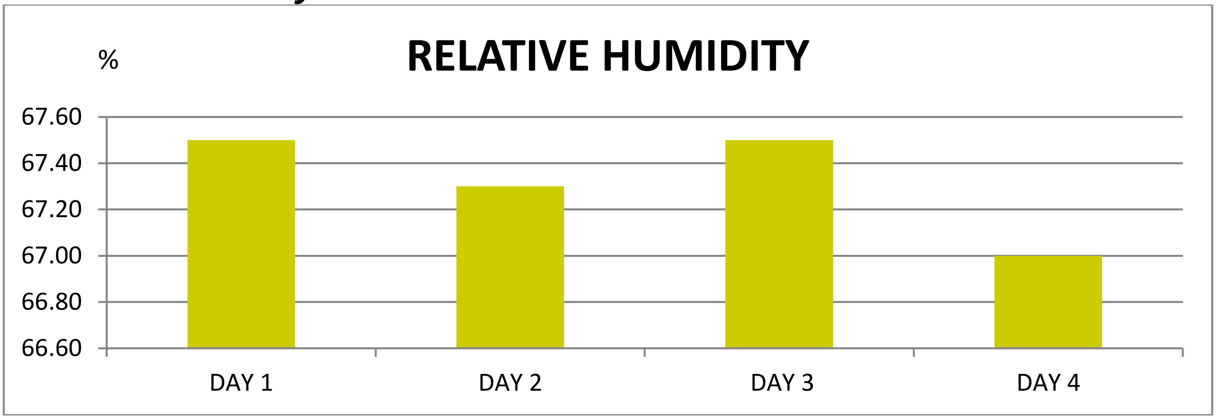

Figure 7: Measured mean relative humidity in the refectory

Occupants are often the main source of the increase of humidity levels in enclosed rooms due to both respiration and perspiration of the human body. Based on the data presented in Figure 7, the mean relative humidity level did not vary much and was within the range of 67.0 to 67.5%. This finding indicates that the relative humidity level in the refectory was within the acceptable range stipulated in DOSH ICOP (2010). Actually, this outcome was rather expected as the occupancy rate during each survey was about the same and during peak hours, almost all seats were taken up by the consumers.

Air Velocity

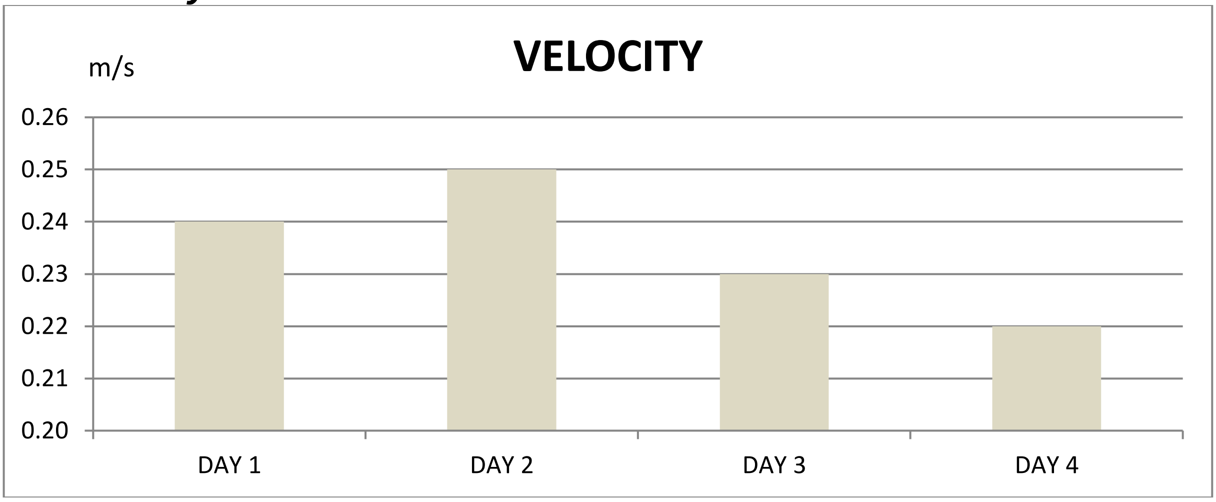

Figure 8: Mean velocity rates in the refectory

The air velocity in the refectory was within the acceptable range of 0.22 to 0.25 m/s, as shown in Figure 8. Referring to the IAQ standards, this range of air velocity was sufficient to provide a comfortable environment for the occupants and may compensate for the high air temperature during peak hours of a day. However, it should be noted that the air velocity near the food serving stations was not recorded in this case study since the placement of measuring equipment may obstruct the consumers' queue for picking up food and to make payment. The architectural design of the refectory, which had a very narrow queuing path, had also limited the locations available for measurement.

Questionnaire Survey

The occupant perception of the indoor environmental conditions was studied in this work using questionnaire survey. Questionnaires were distributed during the peak hours only where almost all seats in the refectory were occupied. A total of 53 responses was collected throughout the field survey. The outcome of the questionnaire survey is tabulated in Table 2.

Table 2: Subjective response to indoor environment in the refectory

IAPs		ASHRAE 7-scale Point							
		-3	-2	-1	0	1	2	3	
Indoor Temperature	Cold	0%	0%	0%	33%	51%	16%	0%	Hot
Relative Humidity	Dry	0%	0%	46%	22%	32%	0%	0%	Wet
Air Movement	Still	0%	28%	43%	29%	0%	0%	0%	Draughty
Air Quality	Smelly	0%	31%	59%	10%	0%	0%	0%	Odourless

As shown in Table 2, most of the respondents found that their immediate surroundings were slightly warm, which concurs with the physical measurement results and therefore the air-conditioning supply air temperature should be lowered. The votes on relative humidity perception focused on the three centre categories of the scale, which was somehow expected because of the small variation of this IAP. As for the air movement, a large number of the respondents, especially those who were seated or standing near to the food serving stations, opined that the air was too still even when the air velocity was generally within the acceptable range stated in the IAQ standards. One of the obvious reasons for this was the crowded environment during peak hours, which directly resulted in restricted air movement. Furthermore, the vendor had to make sure that some of the food to be served while warm due to both hygienic and consumer preference purposes. Therefore, increasing the ventilation rate near the food stations may not be appropriate in this case. Other than that, the general perception of air quality also demonstrated the need for more air movement, since the majority of the votes regardless of the respondents' seating position was placed on the less desirable side of the comfort scale. Many of the respondents were seen either queuing or sitting close to each other because of the limited seats available in the refectory. Based on the findings obtained, the use of commercial electric fan can be considered at locations where low air velocities were measured so as to enhance the cooling effect, especially during lunch break where a sudden increase in occupancy level was observed. Besides, enhanced ventilation can be made through making more openings at the fenestration of the building, which allows more infiltration of outdoor air since people in the tropics were found to be more adapted to the warmer environment if more ventilation is available (Khedari et al., 2006).

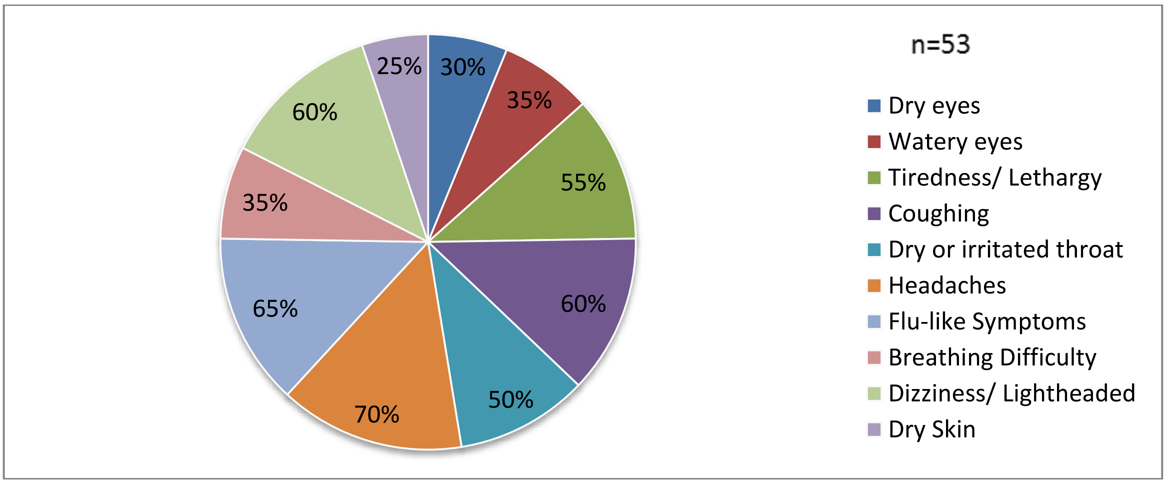

Figure 9: SBS experienced by respondents

The percentage of SBS encountered by the respondents in the refectory is presented in Figure 9. The respondents were allowed to choose more than one SBS that they were experiencing in the questionnaire form. The answers obtained showed that 70% of the respondents had experienced headache symptoms at least once during their visit to the refectory. Besides, 65% of them had also experienced flu-like symptoms, especially those who had chosen to sit at Location 2 and 3. Other symptoms include coughing and dizziness (60%), fatigue (55%), dry or throat irritated (50%), watery eyes and shortness of breath (35%), dry eye (30%) and dry skin (25 %) were also reported by the respondents. Such high percentages of occupant discomfort have demonstrated that the indoor environment was below satisfactory level and thus mitigation plans were required. Similar results were enunciated in other IAQ studies conducted locally, where the IAQ levels of selected office buildings in Malaysia did not meet the occupants' expectations (Kamaruzzaman and Sabrini, 2011) and the importance of using mechanical ventilation systems to improve IAQ was suggested (Sofian and Ismail, 2012). Although dilution of indoor contaminants by increasing the ventilation rate is the most common and practical approach, but this may result in higher operating cost of the buildings and hence further efforts on identifying this cost implication is needed. Since this work only focused on the four major air pollutants stated in DOSH ICOP (2010), more work is required to identify the concentration levels of other harmful gases as well as particulate matters in such food centres in Malaysia which are usually fully enclosed and cooled via mechanical means. There is also a need to conduct more detailed studies on the occupant perception of indoor air conditions, especially in building areas where high occupancy levels are anticipated.

CONCLUSION

Conditions of indoor air conditions play a significant role in governing human comfort, safety and health. The IAQ of a refectory in a local university has been assessed in this work. Measurements of the IAPs were carried out during an academic session in 2016 using IAQ sensors and questionnaire survey. The following conclusions were made based on the analysis of results:

i. The mean CO_2 concentration level was found to be higher than the ceiling limit, while the concentrations of CO were within the acceptable range stipulated in the local IAQ guidelines. This directly suggests the need for providing higher ventilation rates in the refectory under study, especially at the seating areas. A more detailed study targeting the ventilation effectiveness of such space can be considered.
ii. The concentration levels of other harmful air contaminants were found to be lower than the concentration ranges recommended in DOSH ICOP (2010). However, it should be noted that only the HCHO and VOC concentrations were measured. The concentration levels of other harmful gases, which include both biological contaminants and dust particles, were not considered in this work.
iii. The measured air temperature was slightly higher than that of the recommended comfort range. In order to create a more pleasant indoor environment, it was suggested that the supply air temperature can be lowered during peak hours of a day. Besides, although the air velocity was within the acceptable range, an increased ventilation rate could reduce the concentration levels of greenhouse gases in the refectory.
iv. From the subjective questionnaire survey, a significant proportion of the respondents were dissatisfied with the IAP levels and votes were directed towards hot environment, insufficient ventilation and poor air quality. This was possibly due to the crowded environment during peak hours, the need to preserve food temperature and insufficient dining spaces within the refectory.
v. The high prevalence of SBS in this study showed that the indoor air conditions need to be improved by introducing corrective actions such as retrofitting the existing air-conditioning system, allowing more openings to be made, using pedestal and exhaust fans at air stagnant areas and others. More work is needed to identify the presence of other harmful gases in the refectory which may affect the comfort and health of occupants.

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