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Background concentration of indoor air quality in hostel rooms during varying conditions

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Abstract

The indoor air pollutants in student hostel room during eight different conditions were evaluated. One minute interval of TVOC, CO_2, CO, O_3 concentrations, temperature and relative humidity were measured inside a vacant hostel room of Universiti Sains Malaysia. Four fan speeds of 0, 1, 3 and 5 and the installed window being open and close were selected as the basis to determine the condition inside the hostel room. Result suggested that the concentrations of indoor air pollutants were below the maximum permissible values outlined by Industrial Code of Practice on Indoor Air Pollutants except for O_3, with maximum concentration are 576 ppb (TVOC), 666 ppm (CO_2), 4.4 ppm (CO) and 90 ppb (O_3). The hourly trend of TVOC and CO_2 concentrations with peak concentrations were observed in the morning (8 a.m.) due to outdoor traffic emission which greatly influenced the indoor pollutants variation. Meanwhile, O_3 showed some delay in time to reach peak concentrations that were observed at 4 p.m. and 5 p.m. Result indicate that the conditions set up were incapable in the regulation of indoor pollutants variation since these pollutants are more dependent with the source of emission and destruction factors.

1. INTRODUCTION

Indoor air quality (IAQ) is a common but people still not consider it as an issue. This was due to extremely low concentration of various compounds present in the air which was considered neutral to living organisms at very small doses. However, IAQ could pose harmful effects to human health due to the tendency of these air pollutants to impose negative impacts in living organisms. Indoor pollutants can arise from various sources within the interior spaces whereby the sources could originate from the building materials, wall paint, furnishings, or even carried indoors by people entering the room (Vallero, 2008). The common type of IAQ parameters are carbon monoxide (CO), formaldehyde (CH_2O), ozone (O_3), respirable particulates (PM_4), and total volatile organic compounds (TVOC) (DOSH, 2010). These substances were frequently found in indoor air based on numerous scientific studies and field investigations conducted inside homes, office buildings, and schools whereby, their concentrations were sufficient to cause acute or chronic symptoms or illness in individuals (Godish & Fu, 2003).

Another factor which possesses huge influence on indoor air quality is the indoor air and outdoor air exchange rate. There are several ways for air exchange to occur namely from the natural ventilation and mechanical ventilation. Mechanical ventilation is the usage of fans and air-conditioning systems in an enclosed room. Mechanical ventilation gives a significant influence in the concentration of indoor air pollutants in two ways, where at higher air exchange rates, the indoor pollutants are removed. If the pollutant concentration on the outside was high, the air exchange rate will bring the pollutant into the interior of the room. In comparison during lower air exchange rates, the indoor air pollutants released from indoors can contribute to higher indoor air pollutants (IAP) (Vallero, 2008). Besides that, ineffective removal of polluted air due to limited ventilation system in a building could also display signs of "sick building syndrome" (SBS). SBS is defined as a set of sub-clinical symptoms with no identified cause dominated by sensory reactions. Factors that are associated with SBS comprised of the building age, outdoor air flow rate and dampness problems (Gupta et al., 2007). It is presumed that SBS is the cause for health symptoms in students, such as blocked nose and throat, headache, dizziness, sensory discomfort from odors, dry skin, fatigue, lethargy, wheezing and sinus (Burge, 2004).

In present day, hostel rooms are also mechanically ventilated. Usually the hostel rooms will be provided with either a ceiling fan or a wall fan. Normally the number of fans will be around one or two fans depending with the room size. This was because occasionally one fan is enough for one hostel room however a larger room might be provided with two fans. The efficiency of airflow in hostel rooms was crucial for the IAQ regulation in hostel rooms. The main objective of

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this study was to investigate several indoor conditions controlled by fan speed and window in student's hostel room to indoor air pollutants, temperature and relative humidity. Relationship between IAQ and ventilation system was important as the IAQ could affect the student's performance and productivity (Lee et al., 2012). This was because higher levels of indoor air pollution have the tendency to give negative effects to the student's comfort and health (Wyon, 2004).

2. MATERIALS AND METHODS

The sampling was carried out in Desasiswa Lembaran, Universiti Sains Malaysia Engineering Campus (N05º 7086, E 101º 7356), Nibong Tebal, Pulau Pinang (Figure 1). Nibong Tebal located in southern part of Seberang Perai, Penang. Climatically, Nibong Tebal experienced tropical rainforest climate distinguished by high temperature and relative humidity. The layout of the selected hostel room was illustrated in Figure 2. The selected hostel room is located at third floor of the hostel building. The total area of the hostel room was 23.52 m^2 which consists of two celling fans, a window and two ventilation windows to allow airflow in and out of the room. Normally, the hostel room were occupied with three students. However, during the monitoring period, the room was unoccupied in order to measure background concentration of IAQ parameters as well as the meteorological parameters.

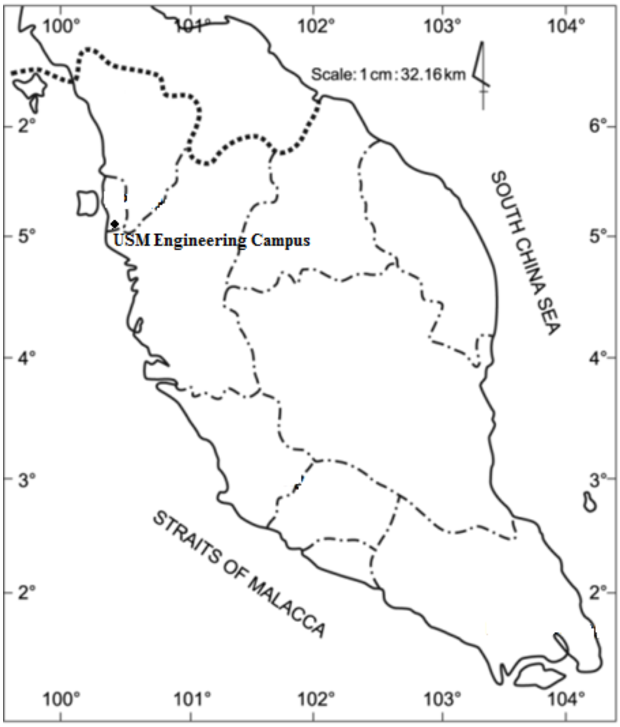

Figure 1: Location of study area at Desasiswa Lembaran, USM Engineering Campus.

The IAQ parameters were collected using WolfSence Indoor Air Quality apparatus, which obtained the readings for the parameters such as ground level ozone (O_3), total organic compound (TVOC), carbon monoxide (CO), carbon dioxide (CO_2), temperature (T) and relative humidity (RH). The sampler was placed at a height of 1 m above the ground in the middle of the room. The procedure was in accordance to the Industry Code of Practice on Indoor Air Quality (2010) where, the minimum number of sampling point for enclosed building with an area lower than 500 m^2 is only 1 and should be placed at the center of the area. The monitoring procedures were carried out continuously between the duration of 21st – 31st January 2017 from 8 a.m. to 7 p.m. at 1 minute interval. The small time intervals were choose to obtain detail data as possible. The conditions of the hostel room was changed each day, with different conditions as shown in Table 1. The two variables changed in the studied room were the fan speed and the condition of the hostel room window being opened or closed.

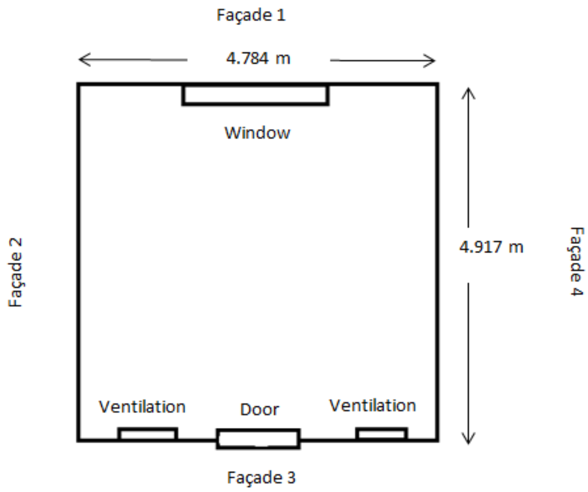

Figure 2: Detail of hostel room in Universiti Sains Malaysia.

Table 1: Experimental setup conditions.

Condition	Fan Speed	Window
C1	0	Open
C2	0	Close
C3	1	Open
C4	1	Close
C5	3	Open
C6	3	Close
C7	5	Open
C8	5	Close

3. RESULTS AND DISCUSSION

3.1. Descriptive statistics

The statistical description of the measured indoor pollutants and meteorological parameters were shown using box and whisker plot in Figure 3. In this study, Industrial Code on Indoor Air pollutants (ICOP, 2010) was used to set minimum standard for selected parameters that will avoid discomfort and/or adverse health effect among the hostel occupants. ICOP normally used as guideline to assess indoor environment of an indoor or enclosed environment served by a mechanical ventilating and air

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conditioning (MVAC) system including air cooled split unit.

Box and whisker plot in Figure 3 (a) illustrated variations of indoor TVOC concentrations during different conditions. TVOC is defined as a group of wide range of organic chemical compound which is present in ambient air or emission. TVOC is also defined by the World Health Organization (WHO) as a set of agents (toluene, xylene) with a melting point below room temperature and a boiling point in the range of 50 - 260°C (Jokl, 2000). Result suggested that the minimum and maximum concentration of TVOC are 209 ppb (C5) and 576 ppb (C1), respectively with the average concentration for every condition lies in between 270 – 382 ppb. The maximum concentrations measured were still below the permissible value outlined by Industrial Code on Indoor Air pollutants of 3000 ppb. Meanwhile, the C8 showed lowest variation in TVOC concentration with the standard deviation value of 33.03 ppb. Result clearly indicated that the concentration of TVOC were higher during conditions with open window compare to close window even though the fan speed was unchanged. The mean concentration of TVOC during fan speed of 0 for condition C1 and C2 are 69.95 ppb and 47.19 ppb, for fan speed 1 for condition C3 and C4 are 53.82 ppb and 42.78 ppb, for fan speed 3 for condition C5 and C6 are 63.15 ppb and 59.56 ppb and for fan speed 5 for condition C7 and C8 are 49.21 ppb and 33.03 ppb. Even though, the TVOC concentration is usually higher in the indoors than outdoors due to the wide range of products present indoors, it seems that the outdoor source of TVOC is more prominent in regulating TVOC concentration inside the hostel room. Meanwhile, the indoor source of TVOC usually comes from the everyday household products such as paints, varnishes, apart from the use of cleaning and cosmetic products. However, the indoor source of TVOC could be lower in the hostel room since students were absent during the monitoring period.

Figure 3(b) illustrated variation of indoor CO_2 concentrations in the hostel room. Result showed that variations in CO_2 concentrations were in the range of 404 to 666 ppm relatively low compare to ICOP value at 10000 ppb, with small variations between different conditions set in the hostel room. These small variations can be justified by low standard deviation value for each condition which is between 14.47 ppm (C5) to 32.97 ppm (C3). According to Putra and Chandra (2015), CO_2 is one of the commonly used indicators in indoor environment, whereby people are the main contributor of CO_2 and serves as the main determinant for acceptable ventilation system in an enclosed space. This is because CO_2 was the main fluid waste produced by people in buildings through respiration and combustion process. Based on The European Standard, the upper limit of indoor CO_2 concentration was set as concentrations not exceeding 800 ppm, which indicated that the level of CO_2 in the hostel room was much lower than the limit set.

In contrast with CO_2, the carbon monoxide (CO) is a poisonous, colorless, odorless and tasteless gas which was very harmful to the human health (Pires et al., 2008). Carbon monoxide is produced by incomplete combustion of carbonaceous fuels such as wood, petrol, coal, natural gas and kerosene (Kampa and Castanas, 2008). The descriptive statistics of CO concentration measured in the hostel room were illustrated using box and whisker plot in Figure 3(c). Result suggested that the concentration of CO was lower in the hostel room which ranged between 0.4 to 4.4 ppm, whereby the highest concentration was measured during C6. The measured concentrations were relatively low as compared to recommended Malaysia Ambient Air Quality Guidelines (RMAAQG) at 30 ppm. RMAAQG value was used for CO since ICOP not listed CO as one of the significant pollutants for indoor environment. The obtained result was probably due to the fact that the hostel room is situated quite far from main road which was recognised as the main contributor to ambient CO concentration. Elminir (2005) justified that 85 to 95 % of the total CO concentration in Cairo, Egypt may come from vehicle exhausts and generally occur in areas with heavy traffic. Even though, the hostel room located in Nibong Tebal was also hosted by a few industrial facilities, the effect is minimal due to low concentration detected in this study.

Ground level ozone (O_3) is another important indoor air parameter and the descriptive statistic of the pollutant in the hostel room was illustrated in Figure 3(d). Due to the fact that O_3 is a secondary pollutant which was produced in the ambient air resulted from photochemical reactions, O_3 is very responsive towards the variations of its precursors such as nitrogen oxide (NO_x) and volatile organic compounds (VOCs). The availability of the precursors will determine the rate of photochemical reactions which subsequently control the concentration of O_3 in the air. Result suggested that the concentration of O_3 in the hostel room were in the range of 0 to 90 ppb. The maximum concentration recorded on C6 with 90 ppb and C7 with 70 ppb were surpassing the allowable value by ICOP at 50 ppb. Zero concentration was recorded during C4, while most of the time during C3 monitoring, O_3 was at zero concentrations except once in between 8 to 9 a.m. According to Weschler (2000), variations in indoor O_3 was highly dependent with the outdoor ozone concentration, the rate at which indoor air is exchanged with the outdoor air, indoor sources of ozone, the rate at which ozone is removed by indoor surfaces and the reactions between ozone and other chemicals in the air.

Box and whisker plots of indoor temperature and relative humidity during varying conditions inside the hostel room are showed in Figure 3 (e) and Figure 3 (f), respectively. The recorded temperature inside the hostel

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room ranged between 26 - 32.9ºC in which both minimum and maximum temperature was recorded during C5. During the monitoring period, the temperature shows small variation with mean temperature around 28.01 to 30.40ºC and standard deviation around 1ºC. Result suggested that the conditions set up by controlling the fan speed and open/close the window had insignificantly regulated the indoor temperature as the measured temperature surpassing ICOP recommend range of 23 - 26 ºC. The natural factors such as rainfall and wind were more dominant in determining the indoor as well as outdoor temperature. Similar trends were also been observed in variations of the indoor relative humidity due to the fact that relative humidity was closely related to temperature. Most of the time, relative humidity ranged between 60 – 80%, which lies in the normal range of relative humidity in Malaysia as well the recommended ICOP range of 40 – 70%.

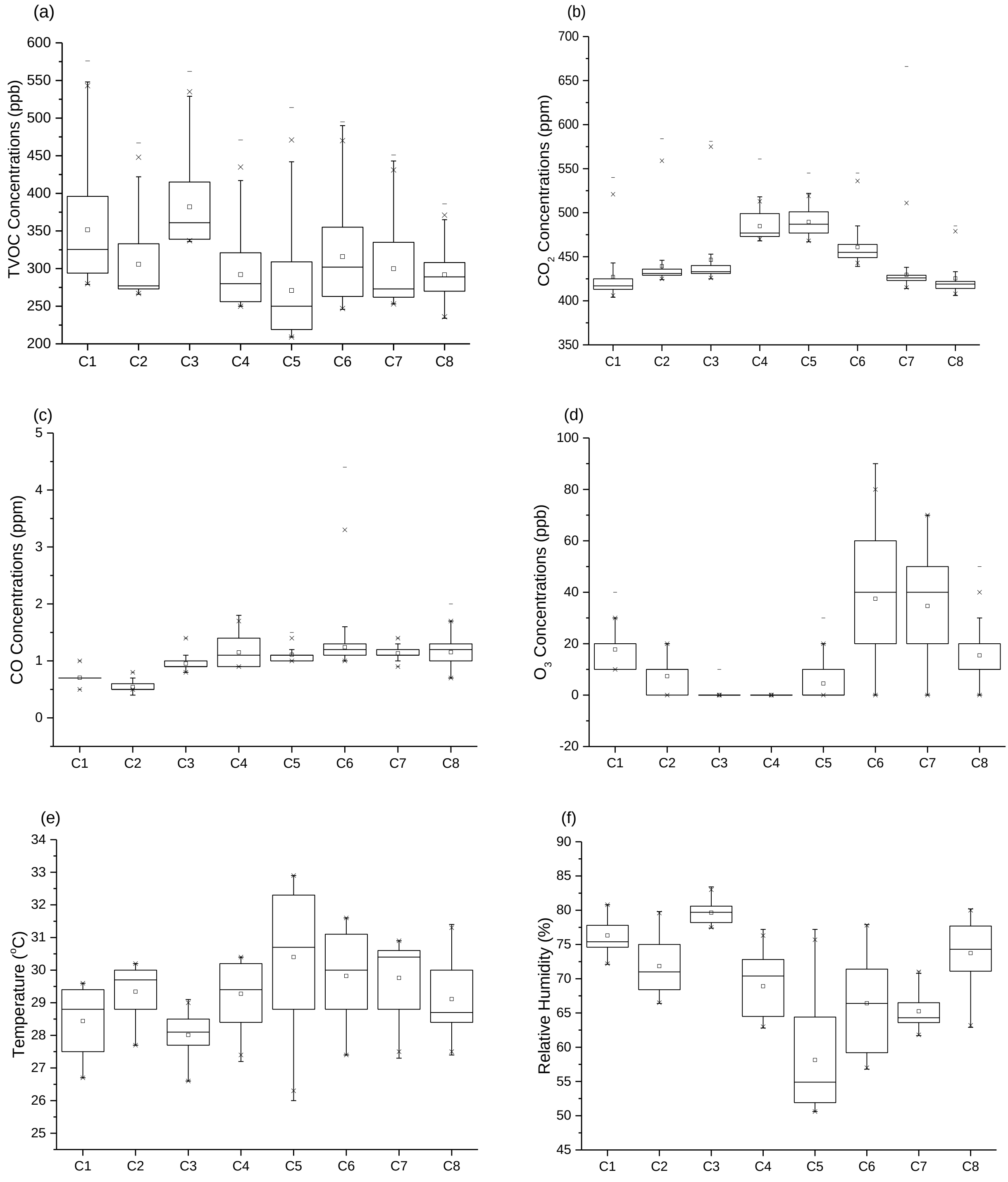

Figure 3: Box and whisker plots of indoor (a) TVOC; (b) CO_2; (c) CO; (d) O_3 concentrations; (e) temperature and (f) relative humidity in the hostel room.

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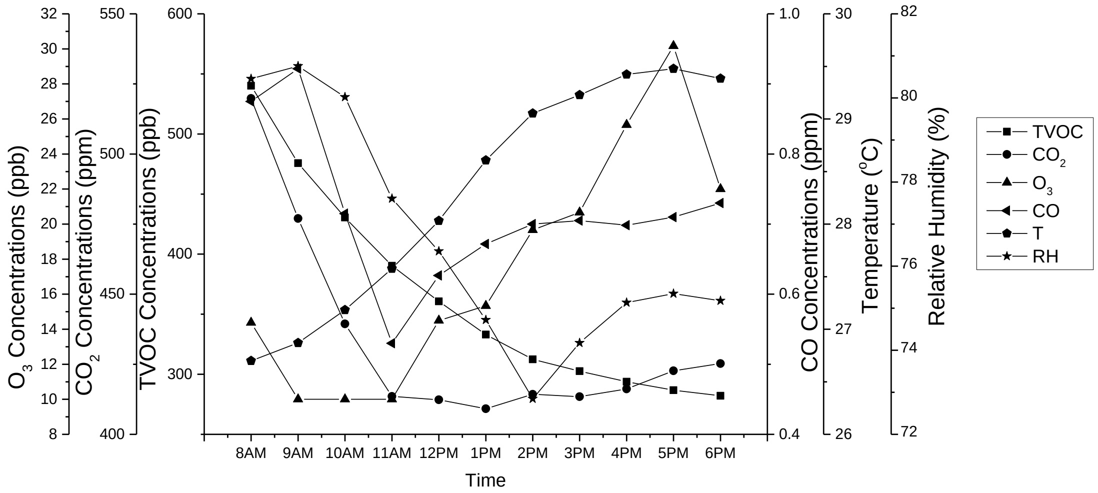
3.2. Hourly variations of indoor air pollutants parameters

Variations in indoor TVOC, CO_2, CO, O_3 concentrations, temperature and relative humidity in the hostel room during C1 to C8 were showed in Figure 4. Result suggested that TVOC showed consistent trend in all conditions except for C8. High TVOC concentrations were normally measured in the morning (8 a.m.) and the concentrations gradually decrease towards the evening. Result also showed that the degree of decrement in TVOC concentration is higher during morning (8 to 11 a.m.) compared to in the afternoon and evening. During evening, the variation of TVOC was very small and close to none in C2, while in C3 small variations occurred earlier which was recorded at 12 p.m. For C8, normal trends were observed up to 2 p.m., however, the concentration TVOC increased about 40 ppb after 3 p.m. and reached second peak at 4 p.m. before gradually decreased once again. Yurdakul et al. (2017) also reported similar finding and briefly explained that high morning TVOC concentration was due to high morning traffic density. They explained that both traffic density and TVOC concentrations decreased as the day advances. Other than decrement in traffic density, decrease in TVOC concentration were also contributed by higher photochemical reactions rate which convert TVOC into ground level ozone. As discussed earlier, the concentration of TVOC during open window conditions (C1, C3, C5 and C7) were significantly higher than the concentration during close window condition (C2, C4, C6 and C8). The result was due to the effect of permitted outdoor pollutant which had entered the hostel rooms through the open window. According to De Nevers (2000), an enclosed space with no or close window only allowed about 0.5 air changes per hour. However, the rate of air changes was proven to be significantly improved with existence or increments in the number of window.

C1



C2

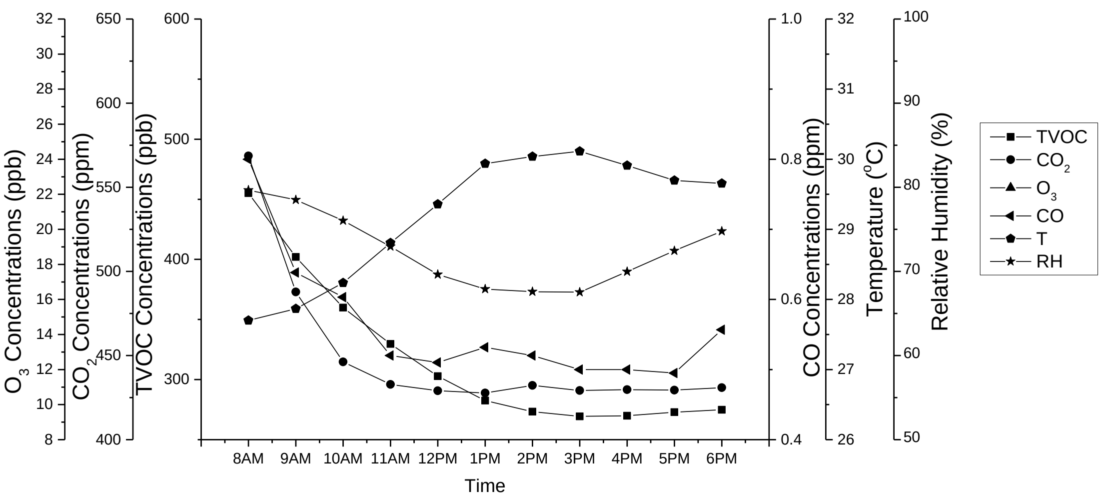


Figure 4: Continued.

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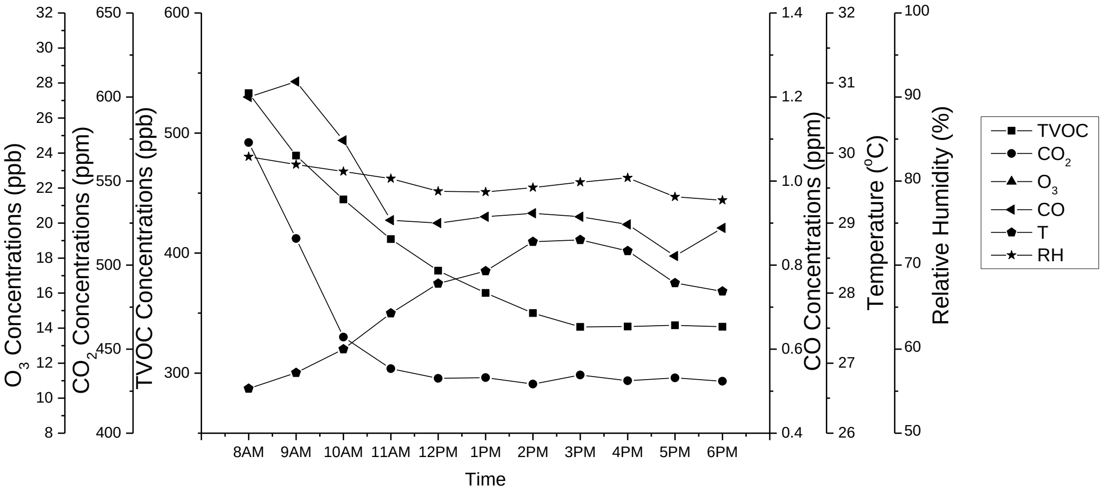
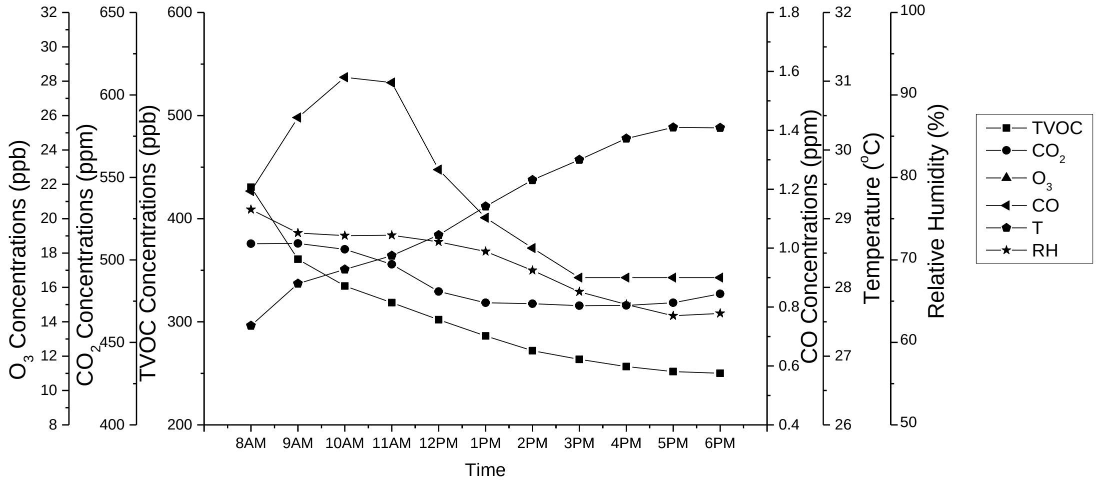
C3



C4



C5

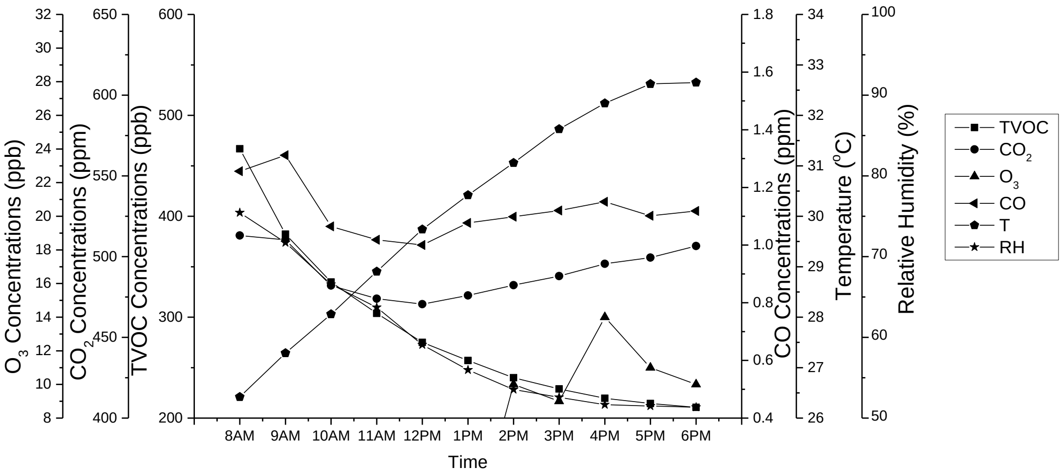


Figure 4: Continued.

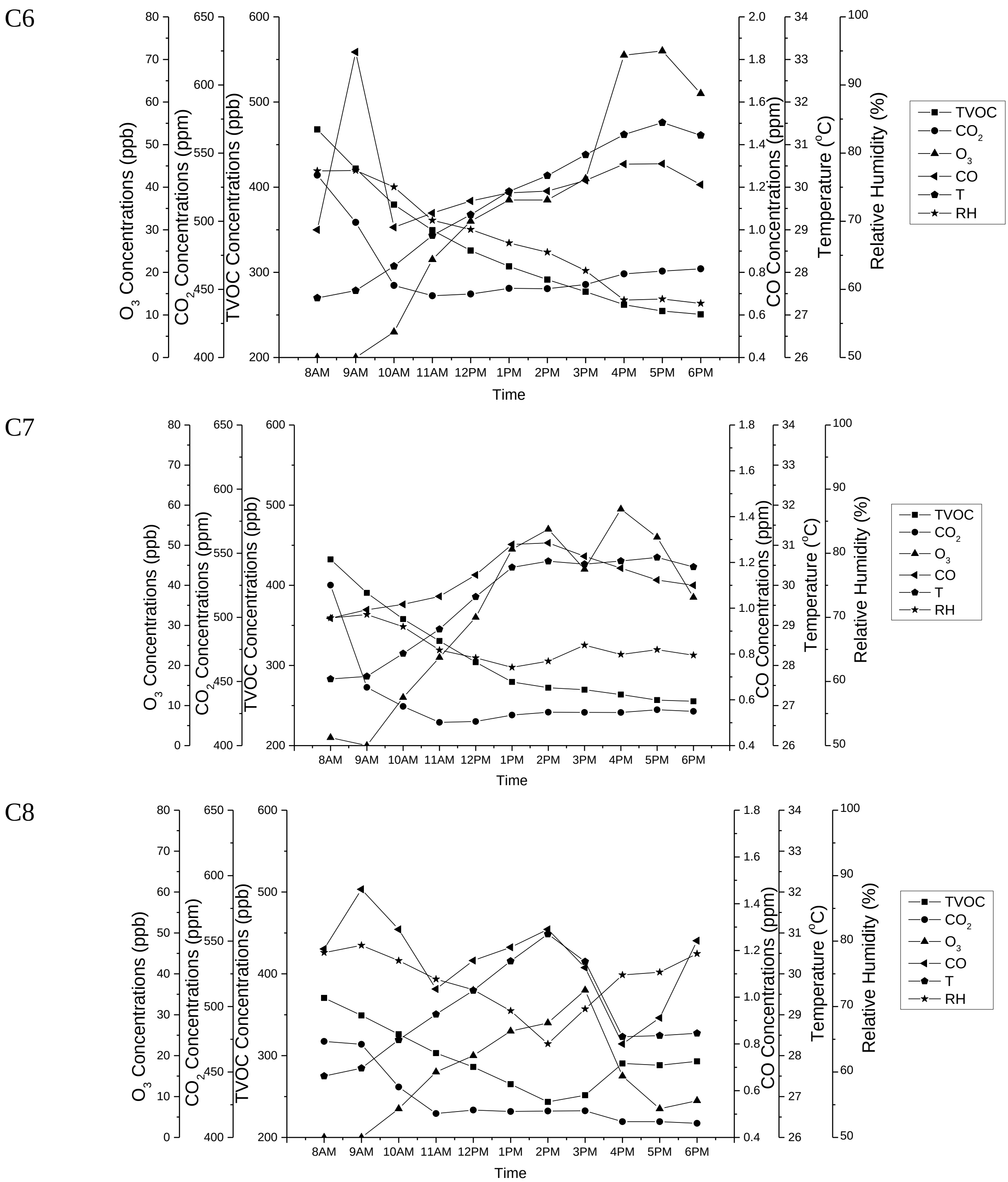


Figure 4: Variations in indoor TVOC, CO_2, CO, O_3, temperature and relative humidity in hostel room during all conditions.

Result illustrated that variation in indoor CO_2 concentrations also showed almost similar trends to TVOC concentrations which was characterized by high concentration in the morning. The CO_2 concentrations also gradually decreases as the day advances however, the minimum concentrations were measured in between 12 to 2 p.m. before slightly increased when approaching evening. Variation in hourly CO_2 concentrations were not affected by changes of either fan speed or window being open or close. According to Murayama et al. (2016), the CO_2 concentration starts to decrease rapidly after sunrise, reaches the minimum in the afternoon, rapidly increases after sunset and reaches the maximum at midnight. The reported trends was also been observed in this study even though the monitoring had only been carried out until 5 p.m. This diurnal variation was strongly affected by biological activities such as photosynthesis and respiration near the hostel room (Murayama et al., 2016). Plant photosynthesis increase CO_2 uptake causing reduction in CO_2 concentration, while increase in CO_2 may due to human/soil respiration as well as the industrial emission.

Unlike the consistent variation showed by TVOC and CO_2, the variation of indoor CO concentrations inside the hostel during different conditions was inconsistent

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especially during C4 and C7. The CO variations during C1, C2, C3, C5, C6 and C8 were characterized by two distinctive drops in concentration. The first drop was observed in morning around 10 to 11 a.m., while the second drop was around 5 p.m. Zhang and Smith (2003) stressed that combustion of fuel and tobacco were identified as the main CO sources in indoor environment. Other sources listed by WHO (2010) such as combustion from cooking and heating including poorly installed and maintained ventilated cooking and heating appliances and incense burning for religious ritual were quite not significant with the studied hostel room environment and been eliminated from the possible sources. Since, the hostel room located in the university area was quite far from the major roads, the impact from fuel combustion in vehicle is less significant in controlling the CO variation, thus contributed to inconsistent variations as observed from the result.

Result also suggested some inconsistency in indoor O_3 variations. Relatively low concentrations were observed during all conditions, with zero concentrations observed during C3 and C4. However, the finding from this study was in line with facts outline by De Nevers (2010). De Nevers (2010) reported that indoor O_3 concentrations is generally less than outdoor concentrations due to chemical properties of the pollutant. Ozone is a chemically active compound which has the tendency to react with almost any solid surface. Consequently, the reactions had presumably destroyed the indoor O_3 and maintained it at low concentrations. The observed trend also differ with typical ambient O_3 diurnal trends which normally showed low concentration during morning and nighttime, while peak concentration is reached at afternoon or early evening around 12 to 2 p.m. (Awang et al., 2015). Result suggested that, O_3 concentrations reached the peak concentration at around 4 p.m. which were 2 hour delay from the reported typical ambient diurnal trends. However, O_3 variation during C8 in exhibited clearer variations with peaks concentrations reached at 3 p.m.

4. CONCLUSION

This study had analyzed the indoor concentrations of TVOC, CO_2, CO and O_3 measured in student hostel room during eight different conditions controlled by fan speed and window. The study showed that the concentration of air pollutants inside the hostel room was still below the maximum permissible values outlined by Industrial Code of Practice on Indoor Air Pollutants except for O_3. The maximum concentrations of TVOC, CO_2, CO and O_3 measured in student hostel room were 576 ppb, 666 ppm, 4.4 ppm and 90 ppb, respectively. The result of box and whisker plot indicated that the set up conditions were incapable in regulating the variation of the studied indoor air pollutants except for TVOC. Result clearly indicated that the concentration of TVOC were higher during conditions with open window compared to close window even with the fan speed unchanged. The diurnal trends of TVOC and CO_2 concentrations showed some consistency with the concentration of pollutants observed during morning (8 a.m.), while the minimum concentration were recorded at 5 p.m. for TVOC and at 12 to 2 p.m. for CO_2. Meanwhile, the peak concentrations for O_3 were recorded after delay about 1 to 2 hour compared to typical variations which was normally observed for O_3 in ambient air. In overall, the data revealed that the concentrations of indoor air pollutants in hostel room are at good level with minimal risk towards student's health. Since, this study was carried out to investigate background conditions and have been performed during the absence of student's, further studies by involving students could lead to deeper understanding on this issue. The involvement of students will aid in understanding the effect of human activities towards variations of indoor air pollutants.

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