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Indoor Air Quality Investigation of Offices in the Food Industry

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ABSTRACT

This paper investigates the quality of air in chosen offices located in the food industry. The parameters including temperature, relative humidity, air velocity, carbon dioxide, carbon monoxide, total volatile organic compound, particulate matter 10 and 2.5 micron and total bacterial counts were measured in three offices within the premises of the industry. The three offices were administrative office, engineer office and screening office. Measurements were carried out for eight hours per day for days chosen in six months. The results were compared with a standard called Industry Code of Practice on Indoor Air Quality 2010 by Department of Occupational Safety and Health, Malaysia. All parameters measured in three offices were complied with the standard except for temperature and air velocity in screening office, which were 27.26 °C and 0.62 m s^{-1} respectively and CO_2 concentration in administrative office, which was 1139.71 ppm. This suggests that the processes in this food industry which might emit PM, VOC were not contributing to the pollutant levels in the offices. The exceeded temperature in screening office was due to the air-conditioner setting and the exceeded air velocity was due to the influence of mechanical fan. The CO_2 was due to the poor ventilation rate that provided insufficient fresh air intake which led to the accumulation of CO_2 in administrative office.

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INTRODUCTION

Few studies show that people tend to spend more than 80% of time in indoor environment [1, 2].Therefore, indoor air environment can be a concern for the people. Indoor air quality study usually measures three types of parameters including physical parameters, chemical parameters and biological parameters. Physical parameters consist of temperature, relative humidity and air velocity. Chemical parameters consist of carbon dioxide (CO_2), carbon monoxide (CO), total volatile organic compound (TVOC), particulate matter 10 and 2.5 micron (PM_{10} and $PM_{2.5}$). Biological parameter consists of total bacterial counts (TBC).

The three physical parameters will determine the thermal comfort condition. The values recommended by Department of Occupational Safety and Health (DOSH) Malaysia in the Industry Code of Practice on Indoor Air Quality 2010 (ICOPIAQ 2010) for physical parameters are 23-26 °C for temperature, 40-70% for RH and 0.15-0.50 m s^{-1} for air velocity. When the thermal comfort condition is not favourable, the building occupants might feel discomfort like too hot or too cold thus affecting the working efficiency. Besides, the undesirable temperature and RH will also affect the growth of bacteria [3].

For chemical parameters, CO_2 acts as a ventilation performance indicator. When the CO_2 concentration is beyond 1000 ppm as suggested as limit of exposure, it indicates that more fresh air intake is needed. For CO, it is a by-product of incomplete combustion using fossil fuels. It can be harmful and causes health effects like headaches, dizziness, vomiting and loss of consciousness when the level is too high. The recommended limit of exposure for CO is below 10 ppm as suggested in ICOPIAQ 2010. TVOC can be emitted from different sources like furniture, cleaning agents, office equipment and others and it can cause effects like exacerbation of asthma and fatigue. ICOPIAQ 2010 recommends a maximum limit of below 3ppm for TVOC exposure. PM_{10} and $PM_{2.5}$ are both small particles exist in the air and can penetrate deeply into our body through respiration. $PM_{2.5}$ could be more harmful than PM_{10} due to its smaller size which allows it to penetrate in depth into alveoli. ICOPIAQ 2010 recommends maximum of 150 µg m^{-3} as limit of exposure for PM_{10} but no recommended limit for $PM_{2.5}$.

For biological parameter, a value above 500 TBC CFU m^{-3} is not acceptable by the ICOPIAQ 2010. It has to be noted that excess of bacterial counts does not

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necessarily imply health risk but serve as an indicator for further investigation. It means that some morphological studies like studying on the gram, shapes and species need to be done to have better understanding on the bacteria. For example, a bacteria called legionella pneumophila can cause Legionnaires' disease which is a building-related illness.

A respectable number of studies about indoor air quality have been conducted so far in different building categories [4-7] except with limited studies in the food industry. Food industry involves the production of food and numerous workers are needed during the manufacturing process. The indoor air quality of an industry can be quite contaminated, depending on the industrial activities. For example, a noodle industry was found to record TBC more than 500 CFU m^{-3} at its warehouse, crushing site and other processing areas [8]. In this particular food industry inspected, certain air pollutants like particulate matter (PM), combustion products, and volatile organic compound (VOC) were found to be emitted and released to the air during processes like raw material conveying, packaging equipment, bulk loadout operations, boilers, lime kilns and others. Meanwhile, offices in this food industry were occupied by workers thus the air quality in offices would be our concern on whether would it be affected by the industrial activities. Besides, a displeased atmosphere of an industrial environment can be linked with employees' health because it was found out that poor indoor air quality is correlated to health-related problems including Sick Building Syndrome [9]. Unhealthy employees will present financial burden to employers and reduce the performance of the industry.

Therefore, this study investigates the offices' air quality within the premises of the food industry by monitoring certain parameters including temperature, RH, air velocity, CO_2, CO, TVOC, PM_{10}, $PM_{2.5}$ and TBC. Then the variations of paramaters which exceeded the suggested limits by ICOPIAQ 2010 are further investigated in line charts.

MATERIAL AND METHODS

Sampling locations

Three offices were chosen within the premises of the food industry which were administrative office, engineer office and screening office. During a walkthrough inspection, the characteristics of three offices including number of occupants, type of ventilation, main equipment and activities being carried out were noted down. The characteristics are presented in Table 1.

Sampling settings

An indoor air quality sampling was carrying out within six months (April to September) in 2016. For the parameters, all were measured for days chosen along the sampling period for 8 hours continuously from 0900 to 1700 except for total bacterial count (TBC). The parameters measured were divided into physical, chemical and biological parameters. Physical parameters including temperature, RH and air velocity; chemical parameters including CO_2, CO, TVOC, PM_{10} and $PM_{2.5}$ and biological parameter including TBC. The sampling instruments were placed about 1 m above floor level in order to align with the breathing level.

TABLE 1. Main characteristics of the sampling stations

Sampling stations	Administrat-ive office (S1)	Engineer office (S2)	Screening office (S3)
Number of occupants	4-16	9-12	3-5
Type of ventilation	Mechanical	Mechanical	Mechanical
Main equipment/ environment	Computers, printers, furniture	Computers, printers, furniture	Computers
Main activities	Carrying out office work	Carrying out office work	Monitoring of screening process

Real-time monitoring

Temperature and RH were measured using HOBO (Model U12-012, Onset). Air velocity was measured using Accusense (Model F900, Degree Control Inc). CO_2, CO, TVOC and $PM_{2.5}$ were measured using EVM Environmental Monitors (Model EVM-7, 3M). The three instruments mentioned above were operating based on real-time monitoring method where the data logging interval was set at one minute. After that, the data was imported out using software.

Gravimetric method

PM_{10} was measured using Minivol Portable Air Sampler (Airmetrics Inc) using gravimetric method. A <10 μm impactor was used to collect airborne particles on glass microfiber filters with 47 mm diameter (GF/A, Whatman) at a flow rate of 5 L/min. The initial and final weight were measured using analytical balance (Model Discovery, Ohaus). The weight of the PM_{10} was calculated by subtracting the initial weight from the final weight and then further transformed into unit in term of weight per volume.

Plate count method

The biological parameter, TBC was measured by Microbial Air Sampler (Model MAS-100 Eco, MBV) using plate counting method. The air was drawn at a rate of 1.67 L/min and impacted on 90-mm Petri dishes containing trypticase soy agar (TSA) twice per day at 10:00 and 15:00 which covered morning and afternoon sessions respectively. The used TSA plates were incubated at 37°C for two days and the concentrations were determined by counting the colony forming units.

RESULTS AND DISCUSSION

Comparison with Malaysia's standard

Table 2 shows the values of nine measured parameters (temperature, RH, air velocity, CO_2, CO, TVOC, PM_{10}, $PM_{2.5}$ and TBC) in administrative office (S1), engineer office (S2) and screening office (S3). The Industry Code of Practice on Indoor Air Quality 2010 (ICOPIAQ 2010) by Department of Occupational Safety and Health Malaysia is also shown in Table 2 for comparison between the standard and the measured values.

TABLE 2. Average concentrations of measured parameters

Sampling locations		Temp, °C	RH, %	Air Velocity, m s^{-1}	CO_2, ppm	CO, ppm	TVOC, ppm	PM_{10}, µg m^{-3}	$PM_{2.5}$, µg m^{-3}	TBC, CFU m^{-3}	
										10:00	15:00
S1	Min	22.42	51.37	0.09	665.00	-	-	12.5	-	4	8
	Max	26.06	70.15	0.87	1497.00	1.0	1.3	45.4	50.0	40	62
	Mean	24.19	60.34	0.19	1139.71	-	0.2	28.7	13.0	20	30
	SD	0.85	3.10	0.05	78.31	-	0.3	11.7	8.1	14	18
S2	Min	25.26	48.53	0.09	453.00	-	-	42.1	6.0	8	2
	Max	28.99	57.54	0.66	743.00	-	0.5	45.4	72.0	20	14
	Mean	25.90	52.95	0.16	593.00	-	-	43.8	26.0	14	8
	SD	0.28	1.91	0.02	8.49	-	-	2.4	5.7	8	8
S3	Min	24.15	44.36	0.09	447.00	-	-	16.7	-	12	10
	Max	29.02	74.16	3.18	965.00	7.0	3.2	91.3	131.0	178	180
	Mean	27.26	51.20	0.62	623.43	0.1	0.6	50.1	22.3	93	85
	SD	1.11	1.84	0.46	51.61	0.4	0.2	24.6	17.3	63	58
	ICOPIAQ	23-26	40-70	0.15-0.50	< 1000	< 10	< 3.0	< 150	-	500	500

Note: (-) represents the concentrations below the detectable limit.
ICOPIAQ represents Industry Code of Practice on Indoor Air Quality (DOSH Malaysia, 2010)

Temperature

For temperature, the measured values were 24.19 °C, 25.90 °C and 27.26 °C for S1, S2 and S3 respectively. Among the three sampling locations, S3 had the highest average temperature and it slightly exceeded the limit with a difference of 1.26 °C. Since S3 was mechanical ventilated with air-conditioner therefore this might be due to the AC settings. AC settings should be set correctly in order to maintain the temperature in acceptable range and ensure the thermal comfort.

Air velocity

For air velocity, the measured values were 0.19 m s^{-1}, 0.16 m s^{-1}, and 0.62 m s^{-1} for S1, S2 and S3 respectively. S3 also recorded the highest air velocity and slightly exceeded the limit with a difference of 0.12 m s^{-1}. This was due to the sampling spot was situated nearby a mechanical fan. A mechanical fan supplies high velocity air to its surrounding.

Carbon dioxide (CO_2)

For CO_2, the measured values were 1139.71 ppm, 593.00 ppm and 623.43 ppm for S1, S2 and S3 respectively. Among three sampling locations, S1 recorded the highest CO_2 concentration at 1139.71 ppm and had exceeded the limit with a difference of 139.71 ppm. The poor ventilation might be the cause of the high CO_2 concentration. The other research that measured higher CO_2 levels in other building categories suggested that poor ventilation could be the reason [10-12]. Poor ventilation occurs when the fresh air intake is insufficient and might further lead to the accumulation of CO_2 in that particular space.

Relative humidity (RH)
For RH, the measured values were 60.34%, 52.95% and 51.20% for S1, S2 and S3 respectively.

Carbon monoxide (CO)
For CO, S1 and S2 recorded values under detectable limit whereas S3 recorded 0.4 ppm.

Total volatile organic compound (TVOC)
For TVOC, S2 recorded value under detectable limit whereas S1 and S3 recorded 0.2 ppm and 0.6 ppm respectively. Low CO and TVOC were recorded due to the absence of combustion process and possible TVOC sources like solvents and cleaning agents in the sampling locations.

Particulate matter 10 micron (PM_{10}) and 2.5 micron ($PM_{2.5}$)
For PM_{10} and $PM_{2.5}$, S1 recorded 28.7 µg m^{-3} and 13.0 µg m^{-3} respectively; S2 recorded 43.8 µg m^{-3} and 26.0 µg m^{-3} respectively and S3 recorded 50.1 µg m^{-3} and 22.3 µg m^{-3}. Generally, the values for $PM_{2.5}$ would usually be lower than PM_{10}. Studies suggest that $PM_{2.5}$ can pose more consequential health effects than PM_{10} due to $PM_{2.5}$ can penetrate deeper into smallest airways and alveoli [13]. The PM_{10} values recorded for three locations were far lower than 150 µg m^{-3} which suggested as limit of exposure.

Total bacterial counts (TBC)
For TBC at 10:00 and 15:00, S1 recorded 20 CFU m^{-3} and 30 CFU m^{-3} respectively; S2 recorded 14 CFU m-3 and 8 CFU m^{-3} respectively and S3 recorded 93 CFU m-3 and 85 CFU m^{-3}. The low levels of TBC recorded can be explained with the low RH recorded. Studies suggest that when RH is maintained between 40-60%, the growth of bacteria can be suppressed better than low or high humidity [3].

Overall, measured values of CO, TVOC, PM_{10}, and TBC (10:00 and 15:00) were all within the limits set by ICOPIAQ in all three offices. This suggests that the processes in this food industry like raw material conveying, packaging equipment, bulk loadout operations, boilers, lime kilns and others which might emit PM, VOC were not contributing to the pollutant levels in the offices.

Variations of temperature, air velocity and CO_2 over time
Figure 1, 2 and 3 show the variations of temperature, air velocity and CO_2 respectively over the time. Only these three variations of parameters were shown instead of all parameters because these three parameters were not complied with the standard of ICOPIAQ 2010.

For the temperature, three offices show no obvious fluctuation along the sampling hours as shown in Figure 1 due to they were all mechanical ventilated which the temperature was controlled by the AC. The temperature at S3 was above 26°C as suggested by standard for the whole eight hours of monitoring.

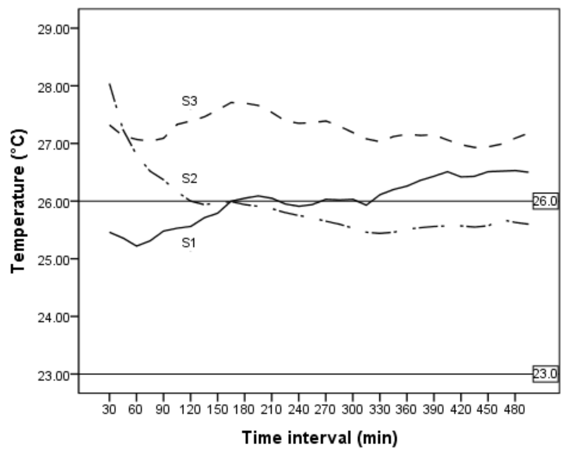

Figure 1. Variation of temperature at S1, S2 and S3

As shown in Figure 2, air velocity at S1 and S2 shows stable trend along the sampling hours. For S3, air velocity fluctuates due to the influence by mechanical fan.

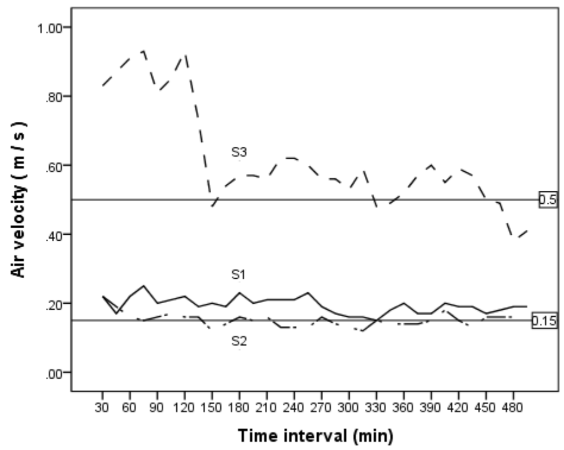

Figure 2. Variation of air velocity at S1, S2 and S3

For CO_2, S1, S2 and S3 were all mechanical ventilated with AC. As shown in Figure 3, S2 and S3 showed low and stable CO_2 along the sampling hours. However for S1, it was observed that CO_2 increased when workers started occupying the office (from 30 to 270 minutes interval) and decreased when they left for break (from 270 to 330 minutes interval). CO_2 rose again when the workers reoccupied office (from 330 to 480 minutes interval) and reached the maximum at end of working hours (480 minutes interval). When people present in an area, they exhale out CO_2 while they are breathing. The CO_2 tends to accumulate to higher concentration if poor ventilation rate is provided.

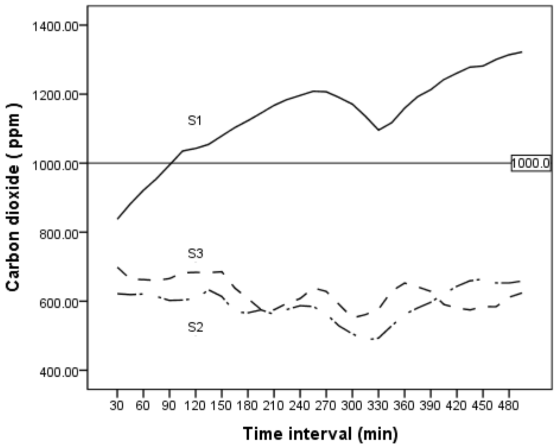

Figure 3. Variation of CO_2 at S1, S2 and S3

Pearson correlation matrix of measured parameters in three offices

Table 3 shows the Pearson correlation matrix of measured parameters for S1, S2 and S3. Temperature was found to be negatively correlated to RH (p-value < 0.01). There are studies which discovered the negative correlations between temperature and RH [14, 15]. CO_2 was found to be negatively correlated to temperature (p-value < 0.01) and positively correlated to RH (p-value < 0.01). TVOC was positively correlated to temperature (p-value = 0.03) and air velocity (p-value = 0.01) and negatively correlated to RH (p-value = 0.02). For PM, although both PM_{10} and $PM_{2.5}$ were positively correlated to temperature and negatively correlated to RH and CO_2, only PM_{10} were having significant correlations (p-value = 0.01; 0.02; 0.02). Negative correlations between PM and RH agree with the findings in some studies [16, 17]. Strong positive correlation was observed between PM_{10} and $PM_{2.5}$ (p-value < 0.01) because these two are both particles suspended in air but only with different sizes. TBC (10:00) was negatively correlated to RH (p-value = 0.01) and positively correlated to temperature (p-value < 0.01) and TVOC (p-value < 0.01). TBC (15:00) was positively correlated to air velocity (p-value < 0.01), TVOC (p-value < 0.01) and TBC (10:00) (p-value = 0.04). A study by [18] established positive correlation between air velocity and airborne bacteria while a study by [19] found no significant correlation between these two parameters.

TABLE 3. Pearson correlation matrix of measured parameters for S1, S2 and S3

	Temp	RH	Air velocity	CO_2	CO	TVOC	PM_{10}	$PM_{2.5}$	TBC (10:00)	TBC (15:00)
Temp	1	-0.84^{**}	0.40	-0.78^{**}	0.38	0.55^{*}	0.60^{*}	0.38	0.64^{**}	0.26
RH		1	-0.44	0.90^{**}	-0.24	-0.58^{*}	-0.57^{*}	-0.39	-0.63^{**}	-0.33
Air velocity			1	-0.38	0.47	0.65^{**}	0.13	-0.08	0.48	0.83^{**}
CO_2				1	-0.13	-0.49	-0.59^{*}	-0.45	-0.44	-0.33
CO					1	0.23	0.01	0.19	0.20	0.28
TVOC						1	0.15	-0.18	0.72^{**}	0.71^{**}
PM_{10}							1	0.77^{**}	-0.02	-0.09
$PM_{2.5}$								1	-0.28	0.36
TBC (1000)									1	0.52^{*}
TBC (1500)										1

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

CONCLUSION

Parameters measured like CO, TVOC, PM_{10}, and TBC (10:00 and 15:00) in three offices were all complied with the standard (ICOPIAQ 2010) except for temperature and air velocity in screening office (S3), which were 27.26 °C and 0.62 m s^{-1} respectively and CO_2 concentration in administrative office (S1), which was 1139.71 ppm. This suggests that the processes in this food industry like raw material conveying, packaging equipment, bulk loadout operations, boilers, lime kilns and others which might emit PM, VOC were not contributing to the pollutant levels in the offices. In screening office, the high temperature was probably due to the AC settings and the high air velocity was due to the influence of nearby mechanical fan. For high CO_2 concentration in administrative office, it happened due to the poor ventilation was provided.

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Persian Abstract

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چکیده

این مقاله کیفیت هوا را در دفاتر انتخاب شده در صنایع غذایی بررسی می کند. پارامترهای شامل دما، رطوبت نسبی، سرعت هوای، دی اکسید کربن، منوکسید کربن، ترکیب کل آلی فرار، ذرات ۱۰ و ۲٫۵ میکرون و کل تعداد باکتری ها در سه دفاتر درون صنعت اندازه گیری شد. سه دفاتر دفتر اداری، مهندسین و دفاتر اسناد رسمی بودند. اندازه گیری ها برای هشت ساعت در روز برای روز انتخاب شده در شش ماه انجام شد. نتایج به دست آمده توسط استاندارد ایمنی و بهداشت حرفه ای صنعت مالزی در سال ۲۰۱۰ با استاندارد کیفیت صنعت هوا در محیط داخلی مقایسه شد. تمام پارامترهای اندازه گیری شده در سه دفاتر استاندارد با توجه به دمای و سرعت هوا در دفاتر غربالگری مطابقت داشتند که به ترتیب ۲۷٫۲۶ درجه سانتیگراد و ۰٫۶۲ متر بر ثانیه و غلظت CO2 در اداره اداری بود که ppm ۱۱۳۹٫۷۱ بود. این نشان می دهد که فرآیندهای موجود در این صنایع غذایی که ممکن است PM، VOC را انتشار دهند، به سطوح آلاینده در دفاتر کمک نمی کنند. درجه حرارت بیش از حد در دفاتر غربالگری به دلیل تنظیم هوا تهویه مطبوع بود و سرعت بیش از حد هوا به علت تأثیر فن مکانیکی بود.