ORIGINAL ARTICLE

OCCUPANCY IMPLICATIONS ON INDOOR AIR QUALITY (IAQ) IN SELECTED PRIMARY SCHOOL CLASSROOMS AROUND KUANTAN, PAHANG

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ABSTRACT

The effects of children's exposure on high concentration of airborne pollutants at schools often associated with increased rate of absenteeism, low productivities and learning performances, and development of respiratory problems. Recent studies have found that the presence of occupants in the classroom seems to give major effect towards the elevation of concentration of airborne pollutants in indoors. In order to evaluate and further understand on the significance of occupancy factor on IAQ, this study has been designed to determine and compare the level of selected physical (particulate matter (PM)) and chemical (carbon dioxide (CO_2) and temperature) IAQ parameters and biological contaminants via colony forming unit ($CFUm^{-3}$) for bacteria and fungi inside the selected classrooms during occupied and non-occupied period (first objective). The second objective is to describe the possible sources of airborne pollutants inside the classrooms at the selected primary schools around Kuantan, Pahang. Assessments of physical and chemical IAQ were done by using instruments known as DustMate Environmental Dust Detector and VelociCalc® Multi-Function Ventilation Meter 9565.The data were recorded every 30 minutes for 8 hours during schooldays and weekend at the selected sampling point in the classrooms. For microbial sampling, Surface Air System Indoor Air Quality (SAS IAQ) was used to capture the bacteria and fungi. The data obtained were compared with the established standard reference known as the Industrial Code of Practice on Indoor Air Quality (2010) constructed by the Department of Occupational Safety and Health (DOSH), Malaysia. This study has found that some of the IAQ parameters in the selected classrooms were exceeding the established standards during occupied period in schooldays compared to non-occupied period during weekend. Findings of this study provide the insights for future research including the site selection of school, arrangement of the classrooms and numbers of students per class.

Keywords: *Occupancy, particulate matter (PM), airborne microbes, indoor air quality, primary schools*

INTRODUCTION

Several studies have revealed that the indoor air quality (IAQ) in school is influenced by three main factors; outdoor/surrounding areas, types of ventilation, and occupancy. Most importantly, recent studies found that occupants' presence and activities are the main source and attribution to the deterioration of IAQ in the classroom[1,2,3]. The effects of poor IAQ were known to cause several adverse effects including reducing children's productivity, increasing rate of absenteeism and hospital admission, and development of respiratory problems[4,5]. Failure to immediately control this situation could lead to higher occurrence of undesirable health outcomes and might involve huge cost for treatment purposes.

The issue of increase in pollutants concentration due to occupancy has becomes a subject of interest in schools due to a situation which high pupil density is cramped within very limited classroom space. Furthermore, the fact that children are more susceptible and vulnerable towards airborne pollutants compared to adult due to higher breathing rate relative to their body and immature defence systems also emphasize on its seriousness to further investigate on this matter[6,7]. A number of recent studies have identified multiple factors that deteriorate IAQ in association with human occupancy; including particles build-up, resuspension of deposited particles, infiltration of outdoor sources, and delayed deposition due to various occupants physical activities, accumulation of human by-products via respiration and perspiration, clothes and furniture fragments, skin flakes, hair fragments and other dead or decaying biological materials originated from the human, and also oral and nasal fluids through sneezing, coughing, and talking processes[2,6,8,9,10,11,12.]

In Malaysia, schoolchildren spend about 6 to 7 hours daily in their classrooms. Meaning that, they are exposed to the indoor air condition in the classrooms most of their days. Therefore they deserve the good IAQ for their comfort to learn and to be educated inside the school. Yet, very few studies have examined the IAQ inside the primary school for improvising the environment. Therefore, this study aims to investigate the key aspect of the factor influencing IAQ in the classroom which is occupancy and to examine the

IAQ parameters inside the selected primary schools classroom. Furthermore, hopefully this study is able to identify and describe other possible sources of IAQ contaminants inside the classrooms.

METHODS

Site selection and description

This study was conducted in government primary schools around Pahang with contrasting background characteristics which are industrial, urban, and rural area. The sites selection was justified on the basis of the location of nearby meteorological monitoring station managed by Department of Environment (DOE), Malaysia. The chosen primary schools were SK Indera Mahkota (SKIM), Indera Mahkota, Kuantan (3°49'07.2"N 103°17'53.0"E), SK Balok Baru (SKBB), Balok, Kuantan (3°57'37.6"N 103°22'52.3"E), and SK Teh (SKT), Batu Embun, Jerantut (3°58'07.6"N 102°21'03.2"E). Walkthrough investigation was conducted in every schools for collection of data regarding its layout design and characteristics, building operation, and also for determination of sampling points. The sampling points were carefully chosen to ensure representative data were collected. Only one classroom has been selected from each schools to minimize interruption to the teaching activities. The sampling sites details from the walkthrough investigation are summarized in Table 1.

Sampling method

The study focus on assessing several pollutants of interest including selected physical and chemical IAQ parameters (PM, CO_2, and temperature) and biological contaminants via colony forming unit ($CFUm^{-3}$) of bacteria and fungi. The sampling campaign has been conducted for total of four days in each school during schooldays and school holidays; representing both during occupied and the absence of school children in the classroom. Generally, the sampling process was conducted for 8 hours duration for every session started from the beginning of school period. The point for sampling has been placed at the back of the classroom, with all the instruments positioned at the height of sitting school children's breathing zone (± 0.75 meter above the floor) and about 1 meter away from the walls and windows.

Physical and chemical IAQ assessments

PM measurement was conducted by using DustMate environmental dust detector by Turnkey Instruments, USA. The instrument applies the light scattering indication method and able to give a continuous and simultaneous indication of various fractions of PM including PM_{10}, $PM_{2.5}$, PM_1 (unit = $\mu g/m^3$). The PM concentrations were recorded continuously for 8 hours duration with one minute data interval. On the other hand, other parameters were measured by using VelociCalc multi-function ventilation meter 9565 by TSI®, USA. CO_2 was measured by using non-dispersive infrared (NDIR) analyser (Model: IAQ Probe 982) while temperature was measured by using hot-wire probe (Model: Thermo anemometer Straight Probe 964). As it was not practical to measure the parameters for 8 hours continuously due to instrumentation limitation, grab sampling technique has been chosen with half-hour measurements conducted at four evenly distributed time slots within the 8-hours duration.

Biological contaminants

SAS IAQ Microbial Air Sampler by PBI International was used to evaluate the microbial air contamination in the classrooms. The surrounding air was aspirated over the media plate and the airborne particles were captured on the agar by impaction. Nutrient agar (NA) was used for bacteria while Potato Dextrose agar (PDA) was used for fungi. Sampling volume of air was set at 100 litres. After the impaction, the agar plate was removed, closed, and sealed before being incubated. Bacteria were incubated at 37 ºC for 24 hours whereas fungi were incubated at 30 ºC for 3-5 days. Colony forming unit (CFU) of bacteria and fungi were counted at the end of incubation period. The samples were triplicated. The number of colonies counted on the plates were adjusted due to probability of more than one particles of microorganisms were impacted at the same site. Therefore, adjusted total microbial counts ($CFUm^{-3}$) were measured by dividing the number of adjusted colonies by volume of air impacted on the agar during sample collection.

Data analysis

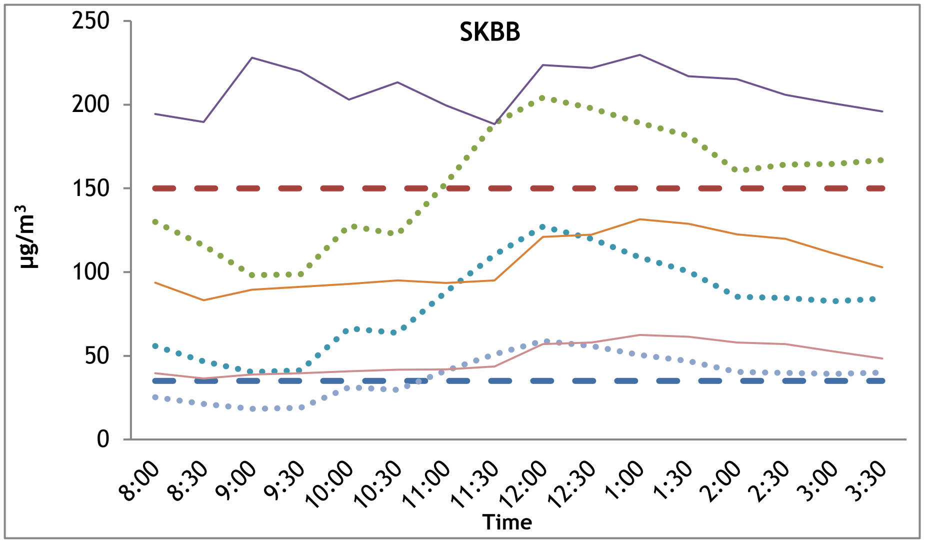
All data analyses were performed by using Statistical Package for Social Sciences (SPSS Version 23.0) and Microsoft Excel 2013. All parameters were analysed by using descriptive statistics. The value of IAQ parameters including PM, CO_2, temperature, and biological contaminants were presented in the form of mean (SD) or average.

RESULTS AND DISCUSSION

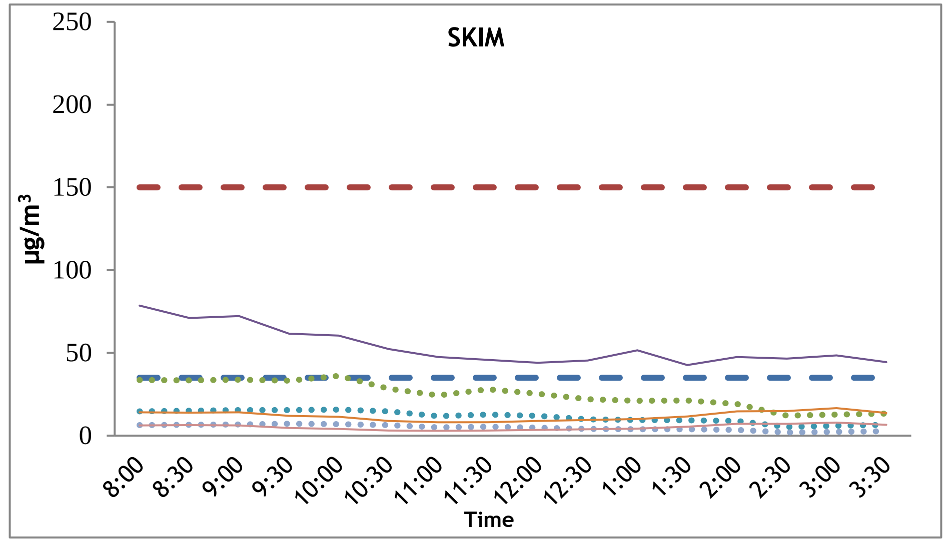
It should be noted that this study was intended to approach the issues of IAQ from the perspective of occupancy as one of the main contributing factors in influencing the concentration of pollutants in indoors. Up to now, the study on its effects toward the IAQ is not abundantly studied compared to other factors like outdoor and anthropogenic sources. In order to discuss onto the matter of impacts of occupancy towards the indoor environment, school and classroom characteristics had been investigated properly in order to record any other possible contributing factors that may influence the indoor level of parameters. The details are as in Table 1.

Table 1 – Overview of the selected primary schools characteristics

Characteristics	SKIM	SKBB	SKT
Class dimension	Area: 63.64 m^2 Volume: 190.91 m^3	Area: 63.19 m^2 Volume: 195.89 m^3	Area: 65.49 m^2 Volume: 219.39 m^3
Level	1^{st} floor	1^{st} floor	2^{nd} floor
Windows	4	5	4
Doors	2	2	2
Ceiling fans	3	3	3
Ventilation system	Natural	Natural	Natural
Table & chair	Press wood	Press wood	Press wood
Board	White board/marker pen	White board/marker pen	White board/marker pen
Cupboard/cabinet	Press wood	Press wood	Press wood
Building age	> 10 years	> 10 years	> 10 years
Building material	Concrete	Concrete	Concrete
Background location	Residential area	Industrial area	Background area
Traffic condition	Heavy traffic during the beginning and end of school sessions	Heavy traffic on peak hours	Light traffic condition on most times
School operation	Two sessions	Single session	Single session
Number of occupants	~28 (morning session) ~34 (afternoon session)	~36	~31



(a)



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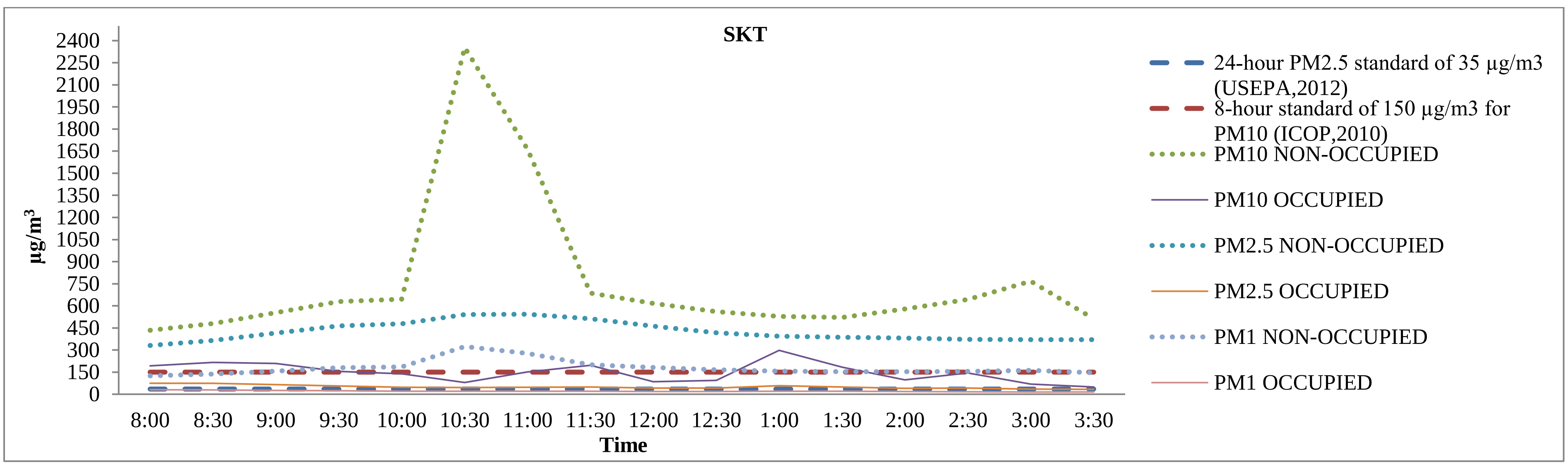
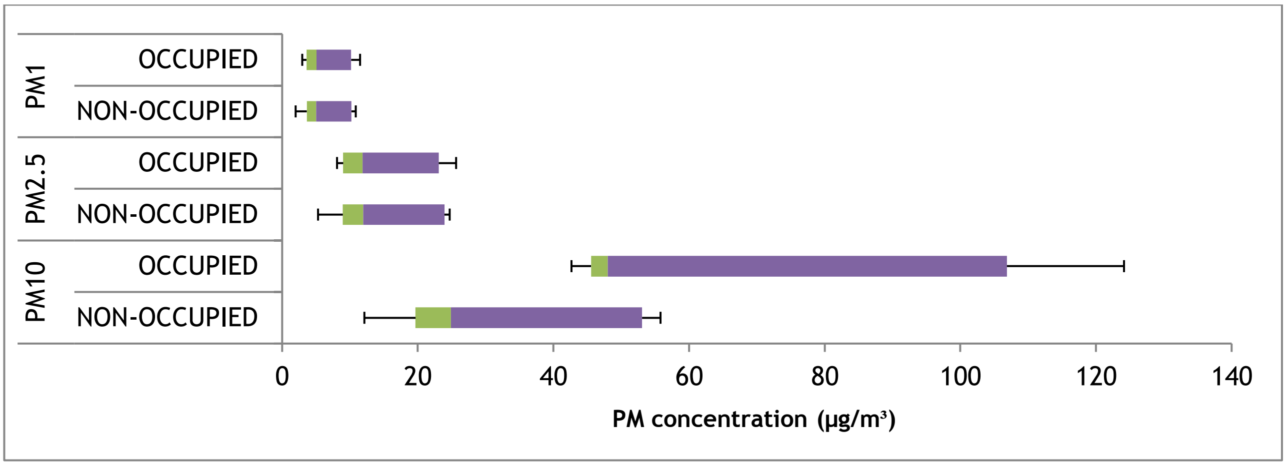
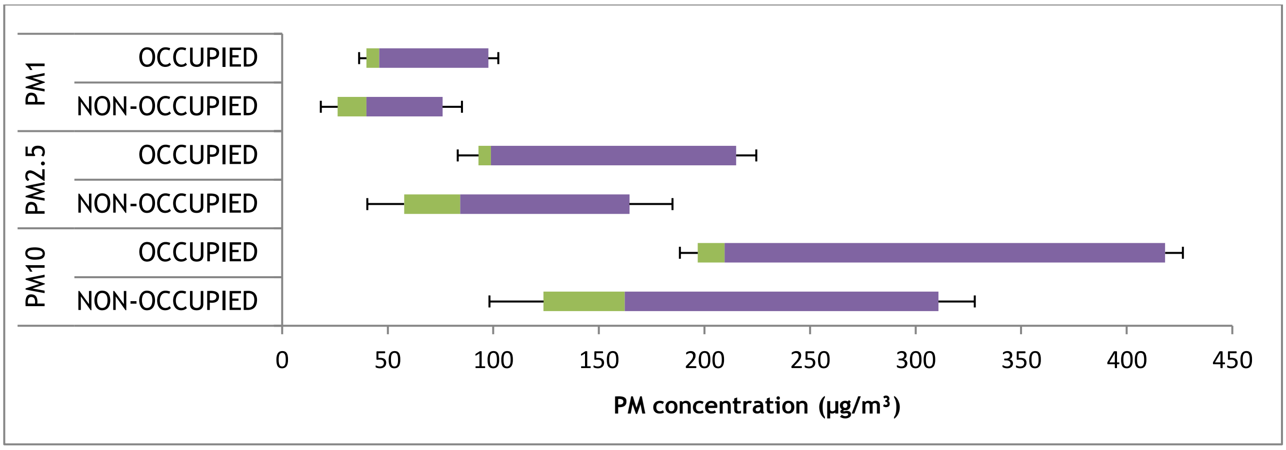


(c)

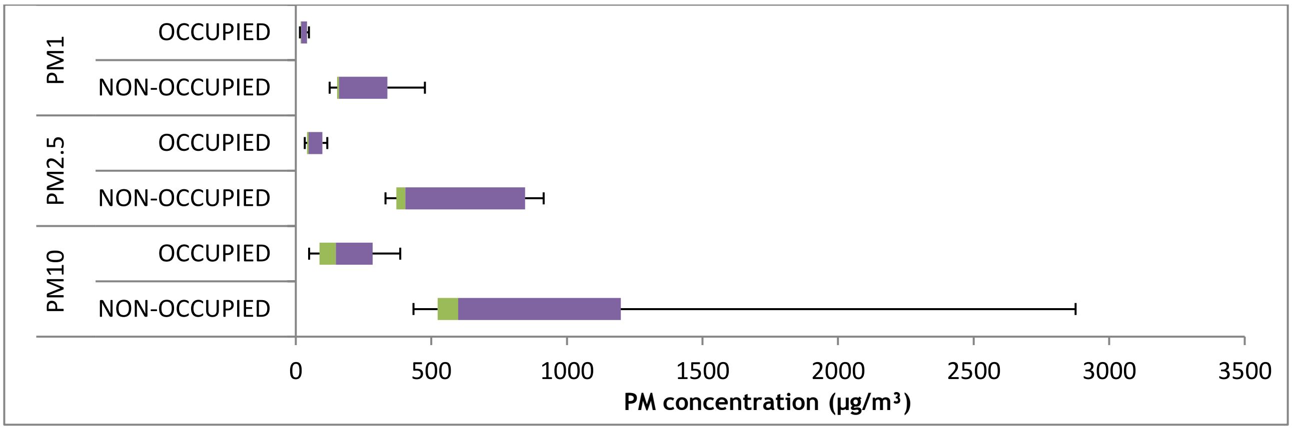
Figure 1: Diurnal variation profile (hourly) for indoor PM in naturally ventilated classrooms during occupied and non-occupied period.



a) SKIM



b) SKBB



c) SKT

Figure 2: Box-and-Whisker plot for PM_{10}, $PM_{2.5}$ and PM_1 based on 8-hours duration inside the classroom.

Physical and Chemical IAQ parameters

Particulate Matter (PM)

Figure 1 shows the 8-hours concentration of PM in the selected classrooms during the occupied and non-occupied period. In addition, to better visualize the distribution of PM, the data were also presented in the form of Box-and-Whisker plot as shown in figure 2. Since the selected schools representing different background location, the magnitude of PM concentration was noticeably different between each other possibly due to the impact of outdoor environment. However, in terms of comparison due to the effects of occupancy towards the concentration of PM, exclusion has been made on the data from SKT as the data obtained for the non-occupied period was affected by serious episode of haze. Hence, very high PM concentrations were observed as in figure 1(c). On the other hand, it was found that the concentrations of PM_{10} and $PM_{2.5}$ in SKBB and SKT during occupied sessions were exceeding the standard limit of ICOP 2010 provided by DOSH, Malaysia and guidelines provided by United States Environmental Protection Agency (U.S. EPA).

The results obtained provide evidence that indoor occupancy produces a significant effect towards the concentration of PM. It has been suggested that these PM either from indoor or outdoor classrooms may cause allergic and other undesired health problems due to their possible toxicity and carcinogenicity properties[8]. However, the factor of occupancy seems to affect PM differently between different size fractions. It appears from the results that the concentration of PM_{10} was obviously related with the presence of children and their activities whereas finer particles shown otherwise, as the relationship are unclear and subtle. This outcomes are in lines with earlier literatures which stated that human presence and their related activities were an important sources in contributing the concentration of PM_{10} but unlikely to give effects on finer particles fractions[8,13]. Our results have confirmed the previous finding which mentioned that $PM_{2.5}$ and PM_1 behave differently from PM_{10}, in concordance to the factor of occupancy. Furthermore, the idea of PM concentration was affected by the level of occupancy proved by the fact that classes with higher number of occupants possessed higher level of PM concentration.

In addition, it was observed in the results that higher levels of PM were noticed in the beginning of school period as children started to occupy the classroom. The increased in PM concentration might be due to activities of the children such as walking and running which possibly will resuspend the deposited PM or from infiltration of outdoor particles which attached to the occupants while entering the classroom. Another clear effects of occupants' activities toward the PM concentration can be seen in Figure 1(b), which the PM concentration suddenly increased when students doing the cleaning routine. Then the PM remains suspended in the air for a long time before being deposited back. Thus, this results was in a good agreement with the conclusion made in previous study, which mentioned indoor concentrations were strongly influenced by activities and movement of occupants which may allow resuspension of previously deposited particles or their delayed deposition or settling[14].

Table 2 - Temperature and CO_2 concentration during non-occupied and occupied period

School	Session	Temperature (°C)		CO_2 (ppm)	
		Non-Occupied	Occupied	Non-Occupied	Occupied
Standard	Acceptable range (ICOP 2010)	23-26		C1000	
SKIM	S1	**26.8 ±1.2**	**26.7 ±1.6**	363 ±10	344 ±34
	S2	**29.8 ±0.5**	**27.9 ±2.3**	310 ±9	310 ±16
	S3	**31.9 ±0.2**	**29.9 ±0.7**	294 ±8	298 ±17
	S4	**31.7 ±0.5**	**30.8 ±0.4**	298 ±2	289 ±3
SKBB	S1	**28.1 ±0.3**	**27.3 ±1.4**	336 ±7	322 ±17
	S2	**30.2 ±0.5**	**28.7 ±2.0**	306 ±15	302 ±41
	S3	**31.7 ±0.4**	**30.1 ±1.2**	293 ±6	275 ±10
	S4	**32.0 ±0.3**	**30.2 ±1.4**	294 ±6	270 ±30
SKT	S1	**26.1 ±0.8**	25.8 ±1.0	384 ±6	388 ±75
	S2	**27.2 ±1.5**	**28.1 ±1.0**	307 ±30	303 ±17
	S3	**30.0 ±0.5**	**31.0 ±1.2**	282 ±17	268 ±12
	S4	**31.0 ±0.9**	**32.2 ±1.0**	272 ±24	245 ±1

***Notes**: Temperature and CO_2 are presented in mean (SD). Exceeded values are shown in bold*

The results of temperature and CO_2 from the selected primary schools are summarized in table 2. Our finding revealed that most of the temperatures in the school either during occupied and non-occupied exceeded ICOP 2010 acceptable limit. This is expected because during the sampling days were done during dry season/southwest monsoon whereby Pahang experienced fewer total amount of rainfall and less frequency of wet days during the southwest monsoon compared to northeast monsoon[15]. However, control measurement should be implemented to ensure the temperature of the classroom is within the acceptable limit. With the normal situation where pupils sitting close to each other, high temperature might cause discomfort and fatigue to them.

In this study, as a whole the concentrations of CO_2 were below acceptable limit during occupied and non-occupied period. Even though CO_2 is the by-product of human respiration, from the graph above the human occupancy has no effect toward CO_2 concentration during occupied period. This is might due to the natural ventilation system in all classrooms which allows fresh air supply to enter the classrooms. Fresh air needed to dilute the CO_2 inside the classroom. It is important to make sure fresh air supply for each student is sufficient so that the school children can learn comfortably in the classroom. It has been suggested that high concentration of CO_2 may lead to symptoms like headache and fatigue. In the same way, higher level of CO_2 may lower productivity in the schoolchildren[10].

Biological contaminants

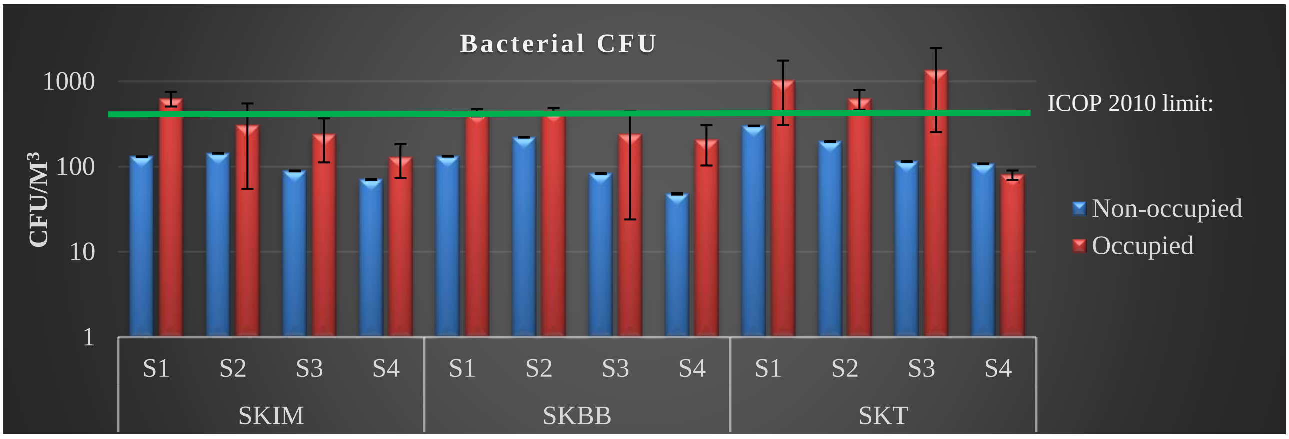


Figure 3: Bacterial CFU in the classrooms during non-occupied and occupied period. Green line indicated the acceptable limit by ICOP 2010

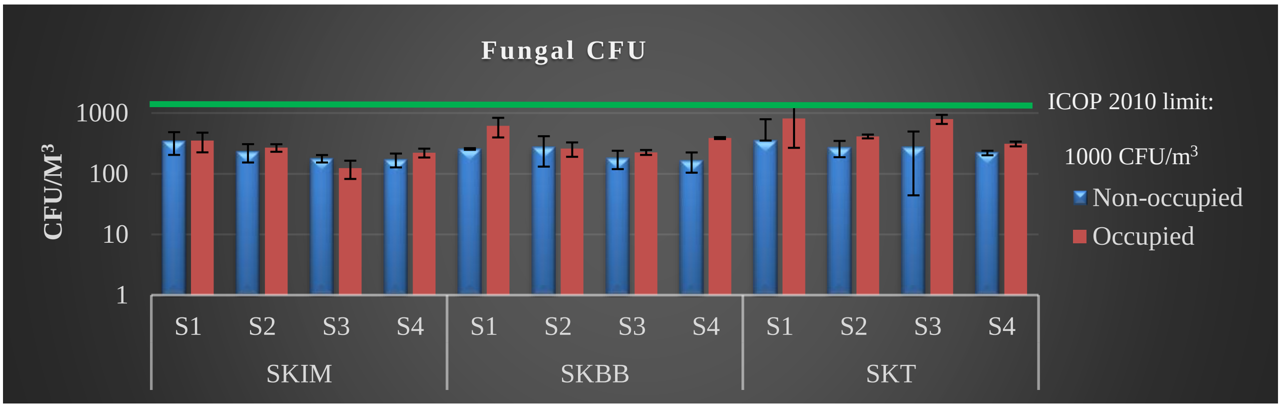


Figure 4: Fungal CFU in the classrooms during non-occupied and occupied period. Green line indicated the acceptable limit by ICOP 2010

Referring to the bar graph above (figure 3), the bacterial CFU in SKIM (S1) and SKT (S1, S2 and S3) were exceeded bacterial CFU acceptable limit set by DOSH. This is might due to the schoolchildren activities during the sampling days. They were just come back from the field and their activities outside classroom may bring soil or other materials inside the classroom with them. The materials might contain sources of microbes and consequently increase the indoor microbes. Furthermore the occupants themselves are known as the sources of microbes and the microbes nutrients too (the occupants' skin flakes are the example of source of microbes' nutrients). While in SKT the bacterial CFU were higher than acceptable limit might be due to the haze episode that occurred during the sampling days. During the haze episode, the PM concentration was also increased and because of that factor, the bacterial CFU also increase because there are nutrients can be found in the PM[10]. As can be seen in the graph above (figure 4), the fungal CFU also showed the same trend as bacterial CFU. The higher fungal CFU were recorded during occupied period. This is in accordance with almost all previous studies that found that human occupancy and activities influenced indoor microbes. As the schoolchildren activities might shed PM from their school uniform or suspending settled dust that can be the origin of the fungal[16]. Therefore higher numbers of fungal CFU were expected during occupied period. For both bacterial and fungal CFU, the highest CFU was recorded in SKT followed by SKBB and SKIM. It is worth taking note that the experiment that were done during haze episode especially during sampling days in SKT. So, for that reason the bacterial and fungal CFU were higher in SKT compared to the other two primary schools[17]. In their study, they found that bacterial and fungal CFU were higher during haze days. In addition, more allergic and infectious genera can be found during the haze episode. Considering this factor, more precautious steps need to be taken in order to avoid or reduce the potential health risk posed by microbes during the haze episode especially for schoolchildren.

CONCLUSION

In summary, occupancy plays an important role in influencing the IAQ in indoors. As some of the parameters like PM, temperature, and bacterial CFU exceeding the level of acceptable limit during occupied time, an immediate preventive measurement should be implemented in order to provide a safe and conducive learning environment. Administrative control such as limiting the maximum number of occupants in each classroom and improving its arrangement could provide a better comfort for the children. Besides, hygienic practices like regular cleaning to remove pollutants and proper body cleaning after outdoor activities would be good in reducing airborne pollutants. In addition, health screening especially related to respiratory system also highly suggested to the children for early detection and prevention from any adverse effects due to IAQ. Good control on IAQ at schools could prevent undesirable outcomes especially related to children's health.

ETHICAL CONSIDERATIONS

Ethical approval and permission have been obtained from Ministry of Education (MOE), Pahang State Department of Education, and IIUM Research Ethics Committee (IREC) prior to data collection. Other issues that may cause any misconducts or conflict of interest also been observed by the authors.

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SUPPLEMENTARY INFORMATION

Parameter		Standards					Location/session					
							Non-occupied			Occupied		
		ICOP	ACGIH	WHO	MAAQS	ASHRAE	SKIM	SKBB	SKT	SKIM	SKBB	SKT
PM	PM_{10} (µg/m^3)	150	C1000	20 (1 yr) 50 (24 h)	50 (1 yr) 150 (1 24 h)	50	25	154	761	54	209	148
	$PM_{2.5}$ (µg/m^3)	-	C3000	10 (1 yr) 25 (24 h)	35 (1 yr) 75 (24 h)	15	11	82	425	12	106	50
Physical & Chemical Parameters	Temperature (°C)	23-26	-	-	-	-	30	31	29	29	29	29
	RH (%)	40-70	-	-	-	-	72	72	78	74	79	74
	Air Velocity (m/s)	0.15-0.50	-	-	-	-	0.19	0.18	0.37	0.64	0.28	0.22
	CO (ppm)	10	25	-	10 (8 h)	9 (8 h)	0	0	1	0	0	0
	CO_2 (ppm)	C1000	5000	-	-	-	316	307	311	310	292	301
CFU	Bacterial CFU/m^3	500	-	-	-	-	109	121	181	325	329	774
	Fungal CFU/m^3	1000	-	-	-	-	231	218	277	241	372	584

C: Ceiling limits **8 h:** 8 hours averaging time **1 yr:** 1 year averaging time **24 h:** 24 hours averaging time

ICOP 2010 : Industry Code of Practice Indoor Air Quality 2010, Department of Occupational Safety and Health (DOSH), Malaysia
ACGIH : American Conference of Governmental Industrial Hygienists
WHO : World Health Organization
MAAQS : New Malaysian Ambient Air Quality Guidelines, Department of Environment (DOE), Malaysia
ASHRAE : American Society of Heating, Refrigerating, and Air-Conditioning Engineers