Journal of Energy and Safety Technology

JEST

RESEARCH ARTICLE

Open Access

Assessment of PM_{10} and $PM_{2.5}$ Concentrations at Different Floor Levels of USM Health Campus's Library

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Article History

Received: April 27, 2022 Received in revised form: June 07, 2022 Accepted: June 08, 2022 Published Online: June 30, 2022

Abstract

Library plays an important role in education and research materials especially used by university students. And it is known that university students prefer to spend most of their time in the library. There are multifactorial of high concentration of pollutants in a building, thus library is the best choice in this study to prove it. The purpose of this study is to assess the indoor air quality (IAQ) in library at USM Health Campus, Kota Bharu, Kelantan. The comparison of PM_{10} and $PM_{2.5}$ concentrations between different floor levels of library was determined. This study was also conducted to obtain the relation between PM_{10} and $PM_{2.5}$ concentrations with the number of occupants, temperature, relative humidity and total number of books. Particulate matter concentrations were measured at library by using Handheld 3016 IAQ Particle Counter. The data was collected for eight hours for each floor with five minutes time interval. Based on Kruskal Wallis test, there were significant differences of $PM_{2.5}$ and PM_{10} concentrations between floor levels (p<0.05). Number of occupants was found significant to $PM_{2.5}$ concentrations through Spearman Correlation test (p<0.05). Furthermore, two of environmental factors (temperature and relative humidity) were found poorly significant with PM_{10} and $PM_{2.5}$ concentrations which r-value were less than 0.3 (r-PM_{10}=0.22, r-$PM_{2.5}$=-0.15; r-PM_{10}=-0.17, r-$PM_{2.5}$=0.2). Number of books and different floor surface area of library were obtained as contributing factor which increased PM concentration. In conclusion, cleaning and housekeeping activities in library need to regularly practice to minimize IAQ problems in order to provide a healthier indoor environment.

Keywords: indoor air quality; particulate matter; library; PM_{10}; $PM_{2.5}$.

1.0 INTRODUCTION

Air is the most important component or element that is necessary for human life. Thus, clean air is needed in order to prevent the health effect problems that may arise due to the unhealthy air in the environment. Due to the arising concern on the health effects because of the indoor air quality (IAQ) and the tendency of people to spend more time indoor than outdoor, several studies about indoor air quality were performed [1]. IAQ means quality of air around and within the building or structures which concerned the occupants' health and comfort [2]. Acceptable IAQ is defined as air in which there was no known contamination at harmful level of concentration as determine by cognizant authorities and with a substantial majority (80% or more) of people exposed does not express dissatisfaction [3][4].

One of the indoor air pollutants that may contribute to poor IAQ is particulate matter. Particulate matter is formed of mixture from tiny particles and droplets of liquid [5]. Particulate matter is varying from primary particles and also secondary particles. As for primary particle, it is directly release from the sources while for secondary sources, it is formed based on gases through the reactions of chemicals [6]. Particulate matter could be generated from several sources in which it could come from outdoor or indoor environment.

In general, PM is used as an abbreviation for particulate matter which according to the [7] it is a mixture of solid particles and liquid droplets found in the air. Some of the particles that are normally visible to the naked eyes are found

to be large in size or dark in color; for example dust, dirt, soot, and smoke. While others usually have a very small size and can only be detected using an electron microscope.

Basically, most researchers have found two common major sizes to be the cause of air pollution. It consists of particulate matter of size 2.5 and 10 micrometers, which known as $PM_{2.5}$ and PM_{10}, respectively. According to [7] $PM_{2.5}$ is defined as an inhalable fine particle with a diameter smaller than 2.5 micrometers. Meanwhile, PM_{10} is an inhalable particle with a diameter usually of 10 micrometers and smaller. The size difference between those two has been illustrated as in Figure 1.

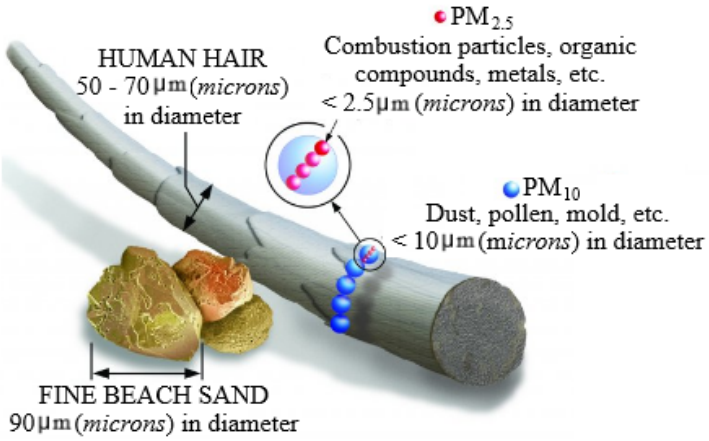


Figure 1. Saiz comparison of PM particles [7]

Particulate matter could poses health effects towards human. Various study stated that particulate matter may trigger the respiratory systems and asthma problems [5] [8]. It also could prompt adverse health effects for instance premature deaths and mortality of infants and other parts of susceptible population [9]. The studies from [10] found that there are several building characteristics and indoor factors in dwelling can affect occupants' health when they exposed to dampness and inadequate ventilation. It is supported with [11] which also found that the presence of furniture and dampness in indoor environments was associated with respiratory problem such as asthma and also allergic disease. In addition, an indoor air quality study that focused on health risk assessment at university library in India found the highest chances to get lifetime cancer among the occupants [12].

On the other hand, [13] reported that there are parameter changes during the day and in different room of the several university libraries around Bartin, Turkey. The same result reported by [14] which found higher pollutant concentration in the morning hours and vary significantly ($p < 0.05$) among the different floors of the central library of Indian Institute of Technology Roorkee, India. As in Malaysia, a study in 2018 was conducted in a four-storey library building at the Engineering Campus, Universiti Sains Malaysia found that inadequate distribution of fresh water is one of the factors that need to be considered when the third floor of the building shows pollutant readings exceed the Malaysian guidelines [15]. All those factors indicate the importance of risk assessment on air quality in the library which known as a focal place for university students to do a variety of activities.

Thus, this study was conducted in Perpustakaan Hamdan Tahir (PHT), focused on two different size of particulate matter since it was known as major indoor air pollutants. Therefore, to give a healthy and clean environment to the occupants in PHT, a study regarding indoor air quality particularly in particulate matter need to be carried out. The findings from this study can be used as a good reference to other libraries.

2.0 METHODOLOGY

2.1 Study Design

This study is categorized as cross sectional study. It is an observational study that was carried out at one time or within the short period of time [16]. In general, cross sectional study is used to determine the relationship between the factor and the outcome [17]. As for this study, it was used to identify the relationship between the contributing factors (number of occupants, relative humidity, temperature, and number of books) and the concentration of selected particulate matters ($PM_{2.5}$ and PM_{10}) in the library.

2.2 Sampling Location

This study was conducted at Perpustakaan Hamdan Tahir (PHT) that was located at Universiti Sains Malaysia (USM), Health Campus in Kota Bharu, Kelantan. Due to the semester break, PHT was selected as a monitoring location since it was the only university libraries in Kelantan that opened during that time. This study covered all three floor level in PHT and each level have different service and function. The ground floor was mainly used as a relaxing area as it has a large resting space, besides the media service department also can be found there. As for the first floor, it has been set as the main area for this library. This main area included counter for students to borrow books, computer room and reading area. Meanwhile, on the second floor it consists of multipurpose rooms and reading area.

2.3 Sampling points

The total floor area for each floor in PHT was less than a 3000 m^2. The total area for ground floor was 900.48 m^2. While for the first and second floors were 2161.16 m^2 and 1891.01 m^2, respectively. Figure 2(a) – (c) shows the floor plans for each level at PHT.

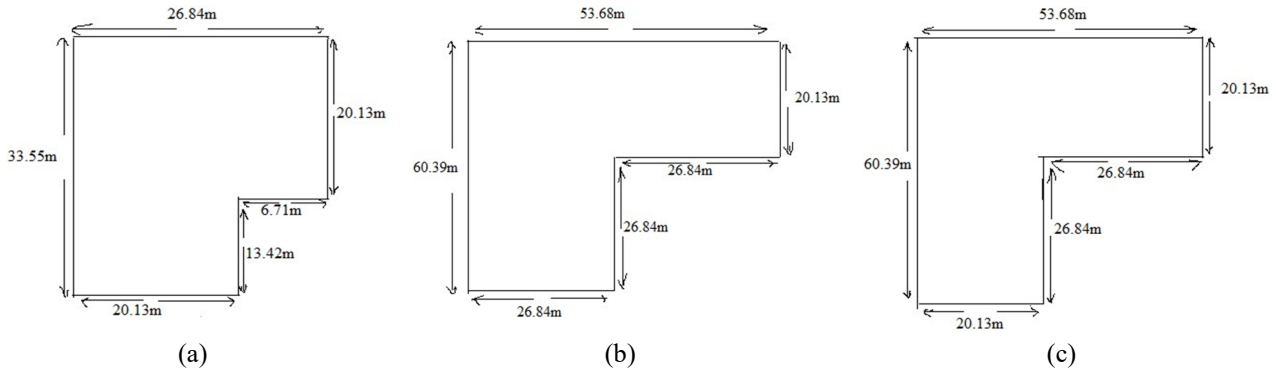


Figure 2(a). Floor plans for (a) ground floor; (b) first floor; and (c) second floor of PHT

As followed by the requirement given by [16], the minimum number of sampling points for each floor level in PHT was considered as one point (refer to Table 1).

Table 1. Minimum number of sampling point recommended for indoor air quality samplings [16]

Total floor area (served by MVAC system)(m^2)	Minimum number of sampling points
<3,000	1 per 500 m^2
3,000 - <5,000	8
5,000 - <10,000	12
10,000 - <15,000	15
15,000 - <20,000	18
20,000 - <30,000	21
≥30,000	1 per 1,200 m^2

2.4 Sampling instruments

Instrument that was used in this study was named as Handheld 3016 IAQ Particle Counter. It was used to measure the concentration of particulate matter (PM_{10} and $PM_{2.5}$) in the library. It also can displays temperature and relative humidity data. Tripod was used to place and support the Handheld 3016 IAQ Particle Counter. It was also used to provide static measurement for Lighthouse Handheld IAQ Particle counter in order to standardize the height of the Handheld IAQ Particle Counter. The standard high to place the instrument was at 110 cm height from the floor [16]. The modification checklist from Industrial Code of Practice on Indoor Air Quality 2010 (ICOP) was used to get the information regarding contributing factor which related to poor IAQ in that library. There are five contributing factors involved which are number of occupants, relative humidity, temperature and number of books.

2.5 Sampling method

The data monitoring of PM concentrations were carried out for five consecutive days which is from Sunday until Thursday at every floor of the library. Each floor was continuously monitored for ten days. The monitoring started from 9.00 am until 5.00 pm at the same spot for each floor with five minutes time interval. During data collection, the Lighthouse Handheld 3016 IAQ was positioned as guided by [16]. It was located 2 m away from the stairs and must not interfere with occupants from the reading area. The sampling point was located at the area that had minimal disturbance of work activities. The equipment was also placed at height 110cm from the floor. After positioned the instruments at the selected point, the Lighthouse Handheld 3016 IAQ was setup before let it running for eight hours continuously.

There were several step in setting up the lighthouse Handheld 3016 IAQ. First, the instrument was positioned in the environment to be measured. The protective cap was removed from the inlet tube. If using the isokinetic probe provided, install probe by connecting probe to the instrument inlet tube found on the top of the instrument. The included temperature and relative humidity probe can be attached to read environmental data. Then, the on and off switch on the left side of the unit was turned on and the "start up" was displayed on the screen. After that, the main screen was appeared and on the touch screen, the start button was pressed to start the instrument. The pump is initially turned on when the indicator with "starting" button displayed. The indicator with the word "counting" then appeared on the display screen when the Handheld was started to count the particles. The data then was saved automatically in the instrument and it was transferred to the computer to be interpreted.

2.6 Statistical Analysis

The data was analyzed using Microsoft Excel and Statistical Package Social Sciences (SPSS) version 22. There are two test were involved in this study which are Kruskal Wallis and Spearman Correlation tests. According to the normality test, it was found that the data for PM concentrations and all contributing factors were not normal (the p value were found less than 0.05). In order to compare the concentration of particulate matter (PM_{10} and $PM_{2.5}$) between floors in the library, Kruskal Wallis test was used. Kruskal Wallis test is known as non-parametric test which is used for determining whether three or more independent samples come from populations with identical distributions [18]. In this case, the library's level were acted as independent variables, while $PM_{2.5}$ and PM_{10} represent as dependent variables. The main purpose of using this test is to test the significance of PM concentration between floors. However, multiple comparisons will inflate type 1 error. Thus, Bonferrroni's correction needs to perform. The requirement for Bonferroni's correction is multiply p value with number of pairs and refer each respective pairs calculated p value with alpha set as 0.05. All test were 2-tailed and significance level was set at $p<0.05$.

Moreover, in order to find the factors that associate with the increasing concentration of particulate matter (PM_{10} and $PM_{2.5}$) in the library, Spearman Correlation test was used. Spearman Correlation test is also a non-parametric test that was used to find the relationship between two numerical variables. To obtain the relationship between two variables, the presence of association, p value was calculated. If p value is more than 0.05, then null hypothesis was accepted. In this case, this test was used to obtain the correlation between contributing factors and the concentration of particulate matter.

3.0 RESULTS AND DISCUSSION

3.1 Descriptive statistic

The minimum, maximum and mean values of PM concentration at ground, first and second floors were summarized in Table 2. The highest mean value of $PM_{2.5}$ concentration was recorded at the second floor of the library (3.74 $\mu g/m^3$), while the maximum value is 16.62 $\mu g/m^3$ recorded at ground floor. Otherwise, both the highest mean and maximum values of PM_{10} concentration was recorded at the ground floor with 11.20 $\mu g/m^3$ and 407.67$\mu g/m^3$, respectively.

Table 2. Minimum, maximum and mean value of PM concentration for each floor

PM concentration	Floor	Minimum ($\mu g/m^3$)	Maximum ($\mu g/m^3$)	Mean ($\mu g/m^3$)
$PM_{2.5}$	Ground floor	1.27	16.62	3.48
	First floor	1.98	11.63	3.56
	Second floor	0.72	10.10	3.74
PM_{10}	Ground floor	2.26	407.67	11.20
	First floor	2.65	51.18	5.38
	Second floor	1.24	18.26	4.69

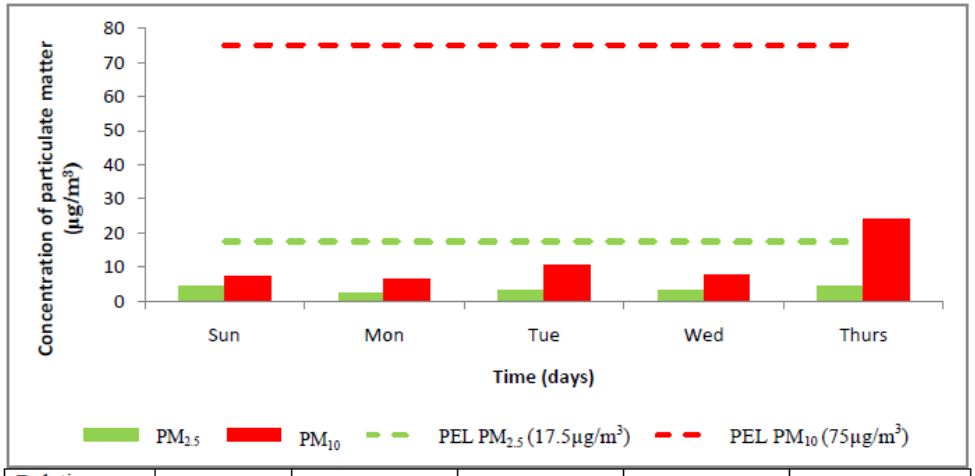
Both maximum PM concentration readings at the ground floor were found above the recommended limit. This is due to the activities that were carried out at that floor. According to [19], one of the factors that led to the increase in contaminants level was human activity. In this case, several book shelves were brought in and placed at the ground floor.

Basically, particles tend to accumulate at the surface of book cover when they do not get cleaned over the long term. It was then results of dispersion of the particles to the air (which known as dust) during books transferred activities. Dust from books can be spread anywhere when library staff or a person carry the books [20]. Thus resulted the high PM concentrations reading.

Furthermore, the other factor of higher PM concentration readings was due to the vacuuming activities that were carried out at certain days. This activities were included cleaning the book shelves, carpets and furniture. As the vacuuming activity started, the readings of PM especially PM_{10} were increased rapidly and then slowly decreased after this activity was finished. The vacuuming activities can trigger the released of large concentrations of antigens through mechanical disturbance of settled dust. It also can be emit through vacuum itself [21].

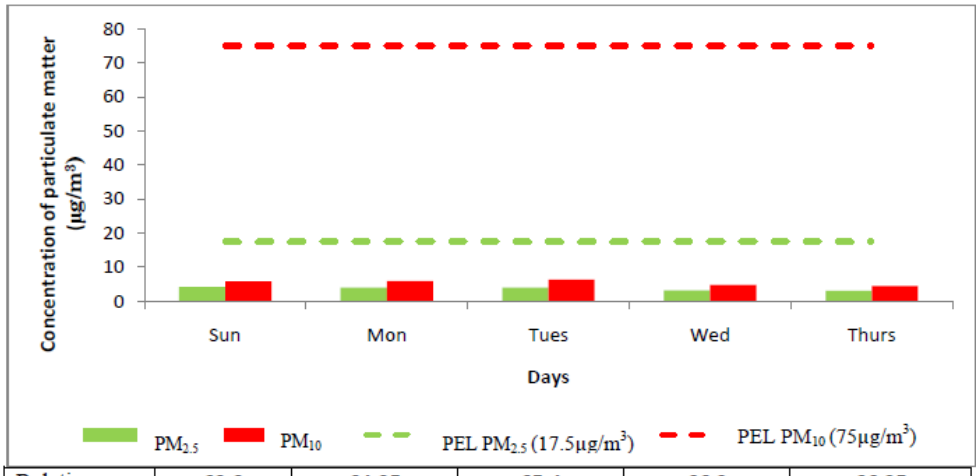
3.2 Average concentration of particulate matter ($PM_{2.5}$ and PM_{10})

The average concentrations of particulate matter readings including their relative humidity and temperature for each floor of PHT were presented in Figure 3(a)-(c). Permissible Exposure Limits (PEL) for PM_{10} and $PM_{2.5}$ were referred to the recommendation given by Environmental Protection Aagency (EPA). According to [22], the indoor PEL for PM_{10} and $PM_{2.5}$ was stated at 50% or less than the PEL of outdoor concentrations. Thus, the limit of IAQ that were recommended for $PM_{2.5}$ was 17.5µg/m^3 meanwhile for PM_{10} was 75µg/m^3.



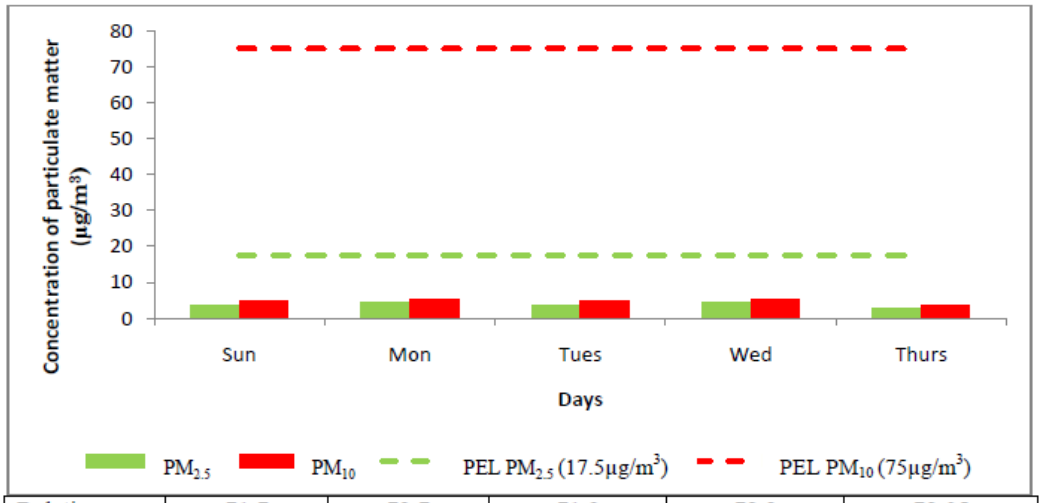
Relative humidity (RH) (%)	63.8	62.85	61.2	61.6	60.55
Temperature (^{0}C)	26.1	26.2	26.25	26.35	26.2

Figure 3(a). Average concentration of PM at ground floor



Relative humidity (RH) (%)	62.3	64.25	65.4	66.3	66.25
Temperature (^{0}C)	23.0	22.45	22.2	22.25	22.05

Figure 3(b). Average concentration of PM at first floor



Relative humidity (RH) (%)	71.7	73.7	71.9	72.3	73.05
Temperature (0C)	23.35	23.55	23.6	23.45	23.45

Figure 3(c). Average concentration of PM at second floor

The concentrations of both sizes of particulate matter in each floor level of PHT were found not exceed the limits as recommended by EPA. As a routine, each floor level of PHT was cleaned early in the morning by the workers everyday before the library was opened to the visitors. Periodic cleaning and housekeeping were the main reasons of the low mean readings of particulate matter concentration and did not exceed the PEL. According to [23], the frequency of vacuuming is recommended once or twice a week. As per recommended, throughout this study the vacuum cleaning was carried out about twice a week in PHT. The vacuum cleaning was done on the carpets and seats that were made of fabric. It also conducted on the bookshelves at each floor level. As a result, it helped the PM concentrations to not accumulate and reduced the potential to exceed the limit for both PM concentrations. Otherwise, books itself produces particles that influenced the distribution of particulate matter in library. Books at the shelves need to be regularly cleaned to prevent the dust from books were accumulated [24].

3.3 Differences of Particulate Matter ($PM_{2.5}$ and PM_{10}) Concentrations between Floors

From Kruskal Wallis test, the *p* values for particulate matter concentration ($PM_{2.5}$ and PM_{10}) were less than 0.05, respectively. It was rejected the null hypothesis and shows that there was a significant difference for these variables. Based on Table 3, PM concentrations for each floor were significantly different, except for $PM_{2.5}$ concentration between first and second floors.

Table 3. *p* value for PM concentrations for each floor

PM Concentration	Floors	*p* value*
PM_{10}	Ground floor vs First floor	0.001
	Ground floor vs Second floor	0.001
	First floor vs Second floor	0.001
$PM_{2.5}$	Ground floor vs First floor	0.001
	Ground floor vs Second floor	0.001
	First floor vs Second floor	2.871

*Significant difference at $p<0.05$, post hoc with Bonferroni's correction

The mean concentration of PM at the ground floor was the highest compared to the first and second floor. However, referring to Table 3 there was no significant difference of $PM_{2.5}$ concentration between first and second floor. The movement of human can lead to the difference of PM concentration in each floor. Indoor activities including room occupancy can lead to particle resuspension [25] as it were used differently.

This study was carried out during the study week and examination week for students in USM Health Campus. This condition was associated with the increasing of PM concentrations reading as the number of occupants is higher than the normal day due to the preparation of examination. There are two reasons of higher readings: number of occupants and high rate of infiltration [26] [13]. Normally, the PM concentration was higher when the library was crowded as in line with monitoring activities that were done during study week and examination week. Furthermore, the infiltration rate was higher due to outdoor PM which is leak to indoor environment. This happen when there are huge difference of temperature between indoor and outdoor environment especially when it is cold which will increased the pressure from outside to inside either naturally or mechanically. As stated before, ground floor was used as relaxing area. Instead of filled with the books, ground floor was equipped with other furniture materials such as carpets and fabric seats that can increase the PM concentration. The difference of PM concentrations on each floor also influence by the floor surface area. According to [27], the floor surface area and PM_{10} were related. Through this study, it was found that every floor has different floor surface area which the smallest floor surface area was found at the ground floor, followed by second and first floors, respectively.

The difference of PM concentration between floors also influenced by relative humidity and temperature factors. When temperature increased, the particles tend to disperse in environment [28] [13]. Based on the results, the highest mean concentration of PM was at the ground floor corresponding with the average temperature. According to [28], the deposition of particles increased when humidity increased. When relative humidity increased, PM concentration will be low as those particles will settle down in cool environment. This shows that the difference of PM concentration was influenced by different relative humidity on each floor.

3.4 Correlation between the Number of Occupants and Particulate Matter (PM_{10} and $PM_{2.5}$)

Referring to Table 4, it was shown that there was positive relationship exists for $PM_{2.5}$ concentrations. The correlation also shows that there was a very weak correlation among them. Through the analysis, the *p* value for PM_{10} was more than 0.05 which indicated to accept null hypothesis. Moreover, there was no significant correlation between the number of occupants and PM_{10} concentrations.

Table 4. Correlation between number of occupants with particulate matters concentrations ($PM_{2.5}$ and PM_{10})

PM Concentrations	Number of Occupants	
	r	*p* value*
$PM_{2.5}$	0.12	0.001
PM_{10}	-0.02	0.250

*Significant correlation at $p<0.05$; statistical test- Spearman Correlation test

As known, the study was carried out starting from the study week, examination week and continues with the semester break. The attendances of occupants (normally students) were high at the beginning of this study but slowly decreased towards the end.

Moreover, the activities such as walking and sitting triggered the increasing indoor concentrations of PM greater than 1 µm in the residency of California [29]. Number of occupants in building can cause the increasing of recorded particulate matter reading. It is because the occupants have the tendency to bring in particles into the building. According to [30], the effects of indoor activities that resuspended particles in range 2.5-10µm was including dusting, vacuuming and vigorously walking. The estimation of resuspension rates of deposited PM from normal human activity was done by using steady-state materials balance model for indoor concentration of PM. A mathematical relationship was determined between the size and resuspension rate from normal activity [31].

3.5 Correlation between the Temperature and Humidity with PM Concentrations

There was association between temperature and relative humidity with $PM_{2.5}$ and PM_{10} concentrations (Table 5). The *p* value was found less than 0.05 indicates that the null hypothesis was rejected. However, the relationship between the temperature and humidity was very weak due to *r* values that were less than 0.3.

Based on the previous study, the temperature has an influence on concentration particulate matter. The airborne particles concentration increased with high temperature meanwhile low relative humidity will slow down the airborne particles concentration [32]. From this study, it was found that the average reading for temperature at ground floor was 26.22 ± 0.58^{0}C. It shown that, the higher the temperature, the higher the particulate matter concentration. The increasing of temperature with small surface area will leads to the increasing of PM concentration.

Table 5. Correlation between the temperature and relative humidity with concentrations of particulate matter ($PM_{2.5}$ and PM_{10})

Factors	PM concentrations	r	*p value
Temperature	$PM_{2.5}$	-0.15	0.001
	PM_{10}	0.22	0.001
Relative Humidity	$PM_{2.5}$	0.20	0.001
	PM_{10}	-0.17	0.001

*Significant correlation at $p<0.05$, statistical test- Spearman Correlation test

PM_{10} concentration is positively correlation with temperature while $PM_{2.5}$ has inverse correlation with temperature. $PM_{2.5}$ was decreased when the temperature was increased. According to [33], when temperature rises, particulate matter concentration significantly decreased. It was due to intense radiation that heats city base surface. It was proved by the particulate matter concentration which have a very weak association with temperature as indicated by the coefficient correlation (r= 0.22, r= -0.15).

$PM_{2.5}$ was positively correlated while; PM_{10} was negatively correlated with relative humidity. Relative humidity was inversely correlated with PM_{10} due to the effects of humidity on coalescence and settling of suspended particles. It happens when the atmospheric moisture helped the particles to stick together and becoming heavier particles before they fall down [34].

3.6 Limitation of Study

This study was conducted during study and examination weeks. The number of occupants was found to be small compared to the teaching and learning weeks. This is because most of the students went back to their homes during the study week while during examination weeks, they prefer to do the revision in their hostel rooms. Thus, it is suggested to conduct future study regarding this topic within teaching and learning weeks in order to find the difference between those conditions.

4.0 CONCLUSION

First, this study was able to assess the indoor air quality in PHT at USM Health Campus in Kota Bharu, Kelantan. According to the findings, average PM_{10} and $PM_{2.5}$ concentrations did not exceed the recommended limit given by EPA. It proved that IAQ in PHT was in a good condition. Good air quality in PHT influenced by the cleaning and housekeeping activities that were continuously done from time to time.

Second, this study was also able to determine the PM_{10} and $PM_{2.5}$ concentrations in PHT. The pattern of PM concentrations at each floor level in PHT was almost the same. The concentrations of PM were higher in the morning due to cleaning activities before it dropped. Based on the findings, the PM concentration was higher on certain days due to the activities conducted in PHT on that day. The highest reading was recorded due to the activities such as transferring books and vacuuming activities that were carried out on bookshelves and carpets at the ground floor.

Third, this study was conducted in order to compare the concentration of PM between floor levels in PHT. Based on Kruskal Wallis test, it is shown that there were significant differences between ground, first and second floor for PM_{10} concentration. It was due to the high number of occupants and activities performed at each floor. The difference of floor surface area in PHT also contributed to the differences of PM concentration. Ground floor was found to have smallest floor surface area in which recorded with the highest PM concentration.

Lastly, this study was done to obtain the factors that associates with the concentration of PM at PHT. It was found that there were several factors that can affect $PM_{2.5}$ and PM_{10} concentration in PHT. The factors were including number of occupants, relative humidity, temperature, and number of books.

Acknowledgements

This research was partially supported under Universiti Sains Malaysia (USM) short-term grant 304/PPSK/61312133. We thank for everyone who assists, and comments that greatly in order to improve the manuscript.

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