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Monitoring of Outdoor and Indoor Air Particulate Matter (PM_{10}) at Buildings Located in An Industrial District

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Abstract: Particulate matter (PM_{10}) pollution has become a problem of significant impact in many countries and cities due to its dangerous effects on public health and environmental balance. The current study aims to monitor the indoor and outdoor PM_{10} concentrations of the buildings located next to an industrial area that releasing industrial fumes. Three buildings were selected to be investigated. Two factors were considered in the current study, including the outdoor PM10 and wind speed. Response surface methodology (RSM) design was used to identify the relationship between the outdoor and indoor PM_{10} concentration (I/O) through the ANOVA analysis ($P<0.05$). The obtained results of PM_{10} concentrations were showed an acceptable concentration (PM10.In.max= 34 µg.m-3, PM_{10}.Out.max= 77 µg.m-3) compared to the Malaysian standard of Practice (DOSH) and RMAAQG (150 µg.m-3) for the selected areas. The investigation was showed a relationship between PM_{10}.in, PM_{10}.out, and the wind speed with a significant ANOVA factor ($P < 0.05$). The study findings are considered a knowledge contribution of the PM_{10} concentrations on the relationship of indoor and outdoor air quality for building surrounded by factories.

Keywords: PM_{10}, inside, outside, pollution, air, relationship

1. Introduction

Air pollution has always been at the top of the world's environmental issues through the last decades due to its health and global damages associated with respiratory diseases and global warming (Robinson, 2015). Industrial human activities are one of the biggest sources that contribute to the production of a massive amount of air-polluting emissions (Im et al., 2019). Several studies have been shown the appearance of severely degraded air quality status in various industrialized countries. A study has been performed by Han et al., (2018) to assess the air multi-contaminant in 155 cities with a total population of 276 million. The results have been shown that 147 million (51%) have been exposed to over-annual multi-contaminant concentrations than the limited by WHO. Abd Rani et al., (2018) have investigated the air quality from 2010 to 2015 in Malaysia to determine the API trend. The study collected 19,872 air quality station databases in Muar district in Johor. The databases analysis has shown that the air quality reached the emergency level with an estimated API of 663 on 23 June 2013.

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Particulate matter (PM_{10}) is considered one of the dangerous air pollutants that consist of small volatile liquid and solid particles (With a diameter less than 10 microns and 1/7 thickness) and cause many health problems, as they can enter deep into the respiratory system, which may lead to death (Roux et al., 2017). At a time when air pollution has become closely associated with deaths and ecological imbalance, it has become necessary to find deterrent solutions to reduce and regulate dangerous emissions (Schraufnagel et al., 2019). Furthermore, the PM_{10} could contain substantial amounts of elemental carbon, condensed organic compounds, and hundreds of different chemical elements according to their formation sources (Arif et al., 2018; Siciliano et al., 2018). A practical study has been conducted for 114 volunteers in China to investigate the relationship between respiratory tract microbiota health and air pollution (Li et al., 2019). The study has followed the group separation method where the volunteers were separated into three different groups A (35 volunteers exposed to light pollution), B (40 volunteers exposed to moderate pollution), and C (39 volunteers exposed to heavy pollution). The study outputs have recorded a direct correlation between air pollution and impairment of oropharyngeal microbiota (Li et al., 2019).

Buildings are one of the most important aspects of modern life in which most people spend most of their time, which requires designing them according to environmental standards to maintain public health. The indoor air quality of buildings is affected by several factors, including the quality of the outdoor air, the ventilation systems, the number of residents/workers, the indoor activities of the building, and other factors (Leung, 2015). The outdoor and indoor PM differ due to their original sources, where biogenic components play an important role in PM formation (Seibert et al., 2020). Diapouli et al. (2008a) have confirmed the positive correlations between inner and outer air quality in seven schools in Greece. Halek et al. (2009) have recorded the relationship between inner and outer air quality of five different schools in Iran. Both studies indicated that the indoor PM_{10} concentration could be affected by the outdoor concentrations of PM_{10}.

Several studies have investigated the PM_{10} concentrations at the UTHM university campus. Samuri, (2005) has recorded a PM_{10} concentration of 222.22 µg/m³ at the UTHM entrance which exceeded the recommended concentration at the Malaysian Ambient Air Quality Guidelines -2015 (RMAQ) and the National Ambient Air Quality Standards (NAAQS) (150 µg/m³). However, in 2016 R. Mohamed et al., (2017) have recorded moderated concentrations of PM_{10} at the UTHM university campus that ranged between 58 and 114 µg/m³ (<150 µg/m³). The indoor air quality of the UTHM university campus buildings was in accordance with the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), RMAQ, and NAAQS (R. Mohamed et al., 2017). Among all the conducted studies, there was a lack of identifying the relationship between the inner and outer PM_{10} concentration in the UTHM campus buildings. The current study was aimed to measure the indoor and outdoor PM_{10} concentrations and identify the relationship between them in the campus of UTHM university located in the industrial area to assess the health risks for university residents.

2. Methodology

2.1 Study Area

The current study was aimed to investigate the air quality at the University Hussein Onn Malaysia (UTHM) campus vicinity of industrial areas at Parit Raja, the southern part of Malaysia. The industrial zone contains processing data, industrializing of electrical apparatus, producing and processing wood, fabricating the corrugated carton, and manufacturing of packaging materials. Three different zones at the UTHM campus were specified for the investigation process based on their distance from the industrial zone. The selected zones were included Kolej Kediaman Tun Dr. Ismail hostel (KTDI) (700 m far from the industrial zone), Faculty of Civil and Environmental Engineering (FKAAB) (800 m), and UTHM Library (900 m) (Figure 1).

The three selected areas consist of several facilities that are ventilated by ventilation systems or/and natural ventilation. The nearest location selected in this study was the KTDI Student hostel, which was chosen to assess the public health risk of the industrial zone. The KTDI hostel is ventilated by means of natural ventilation and ventilation systems. The FKAAB faculty contains many facilities, including offices, light and heavy laboratories that require natural ventilation almost daily. The UTHM library consists of four floors with a total floor area of 16,000 square meters closed and an open central space in the middle (avoided in this study as it is considered an outside space). The library was targeted in this study because it is above the surface ground and has a large number of daily access, which may be affected by wind speed and outdoor PM10 factors.

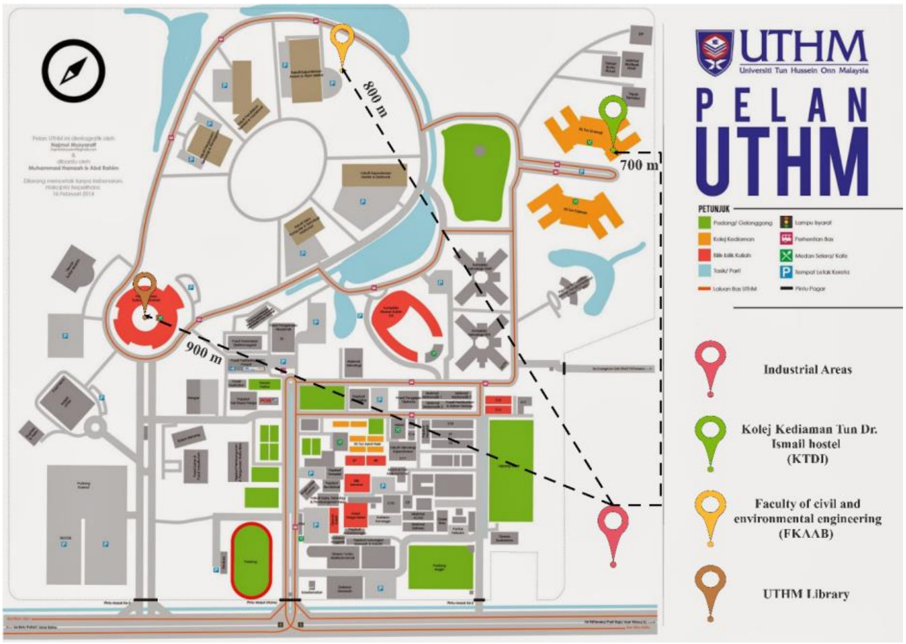

Fig. 1 - Sampling location and their distance from industry (source of the original map: FIESKOM UTHM)

3. Monitoring and Sampling

The indoor and outdoor PM_{10} concentrations of the selected zones were monitored using the E-Sampler Particulate Matter (PM_{10}) with a flow rate of 2 $L.min^{-1}$. A data logger was employed to record the data within a sampling period of 24 hrs. Wind speed was measured by the E-Sampler. The Indoor and outdoor PM_{10} were recorded along the weekday and the weekend through installing the E-samplers in each zone.

A total of sixty samples were collected from indoor and outdoor the selected places. Samples were collected under similar weather conditions (Temp= 28-30 ºC, Humidity= 47-50 º). Therefore, some effecting factors were neglected in this study. Sample collection was designed for 90 days to ensure avoiding operation errors. The maximum daily record of PM_{10} was used to assess the highest risk level in the study areas.

3.1 Indoor/Outdoor (I/O) Ratio

The relationship study of the I/O ratio is one of the most used methods to identify the link between the PM_{10} concentrations outside and inside buildings. In the current study, the I/O ratio was calculated to identify whether there is an effect of the building external PM_{10} concentrations on the internal PM_{10} at UTHM using the following equation (Chen & Zhao, 2011):

$$I/O\ Ratio = \frac{C_{in}}{C_{out}} \quad (Eq.1)$$

C_{in} refers to the PM_{10} concentration indoor, and C_{out} refers to the PM_{10} concentration outdoor.
According to Diapouli et al. (2008b), the percentage of I/O is denoted by *I/O ≥ 1 < I/O*, which is interpreted as mentioned in Table 1.

Table 1 - Description of indoor/outdoor (I/O) ratio

I/O Ratio	Disscrption
I/O > 1	Indoor pollution (PM_{10}) is more than outdoor pollution, which is related to several factors as the facility activities or the low functions of the Air Conditioning (HVAC) system
I/O = 1	The emissions level indoor and outdoor buildings are equal, which is commonly found in the natural ventilation places
0.3< I/O <1	This range indicates that 30 to 100% of outdoor emissions infiltrate into the buildings
I/O < 0.05	The indoor emissions are low and perfect, and there are no effects of the outdoor emissions.

3.2 Statistical Analyses

The collection of samples was by the direct method as it is impossible to control the influencing factors that depend on weather conditions. Design Expert 11.1.2.0 software was employed (through the historical data option) to analyze the recorded data and identify the indoor and outdoor PM_{10} concentration relationship through the ANOVA test and response surface methodology (RSM). Wind speed and outdoor PM_{10} concentration were entered as independent factors, while the indoor PM_{10} concentration was entered as a response. Quadratic ANOVA model was used to identify the effect of outdoor PM_{10} and wind speed on indoor PM_{10} with a significant factor of $P<0.05$.

I/O ratio was determined to investigate the infiltrating of the outdoor PM_{10} and assess the risk level of the buildings.

4. Results and Discussion

The outdoor PM_{10} concentration and wind speed were calculated and considered as influencing factors of the indoor PM_{10}, which was considered as a response. The I/O ratio was determined to verify the effect validity of outdoor PM_{10} on indoor PM_{10}. An investigation of the indoor and outdoor PM_{10} was performed and compared with the recommendations of RMAAQS and DOSH standards to assess the PM_{10} risk level at the UTHM campus.

4.1 Indoor and Outdoor PM_{10} Concentrations and the I/O Ratio

The collected samples showed different concentrations of PM_{10} in each location, where the KTDI zone was recorded the largest indoor and outdoor PM_{10} estimated by 15-34 $\mu g.m^{-3}$ and 47-77 $\mu g.m^{-3}$ respectively (Table 2). It was observed that the maximum indoor concentration of PM_{10} was at an outdoor concentration value of 74 $\mu g.m^{-3}$ and a wind speed of 1 $m.s^{-1}$, which indicates the effect of the wind speed. The I/O ratio of the KTDI showed an over-moderated infiltration of PM_{10} into buildings (0.32- 0.53), which indicates the presence of issues related to ventilation or distance. Zhou et al., (2017) have reported that natural ventilation and the absence of adequate ventilation systems degrade the indoor air quality of buildings and increase the impact of outdoor emissions.

FKAAB faculty recorded a lower concentration of PM_{10} than KDTI, estimated by13-32 $\mu g.m^{-3}$ for the indoor and 47-72 $\mu g.m^{-3}$ for the outdoor. It is clear that the presence of PM_{10} infiltration in FKAAB buildings is due to the daily natural ventilation of the laboratories located on the ground floor. The decrease in indoor and outdoor PM_{10} concentration represents the appropriate ventilation systems, and the distance from the source could be another factor. The I/O ratio was shown low to moderate effect of the outdoor PM_{10} on indoor PM_{10} rated between 0.22 to 0.47 (Table 2).

UTHM library was the least polluted zone compared to other zones, where it recorded the lowest concentrations of indoor PM_{10} (7-28 $\mu g.m^{-3}$) and outdoor PM_{10} (46-66 $\mu g.m^{-3}$). In the context of the KTDI zone, the highest indoor concentration of PM_{10} was recorded at an outdoor PM_{10} concentration of 60 $\mu g.m^{-3}$ and wind speed of 1 $m.s^{-1}$, which explains the significant effect of wind speed. It is expected that the reduction in the PM_{10} concentration in the library zone is due to several reasons, including the distance, the location of the library, wind direction, and advanced ventilation systems. The I/O ratio indicates the presence of infiltrating of the outdoor PM_{10}, which affected the indoor air quality (Table 2).

Table 2 - Sampling values, their effects and relationship

Sample location	*Sample No.*	*Outdoor PM_{10} (*) ($\mu g.m^{-3}$)*	*Wind Speed (*) ($m.s^{-1}$)*	*Indoor PM_{10} (#) ($\mu g.m^{-3}$)*	*RMAAQS and DOSH standards ($\mu g.m^{-3}$)*	*I/O ratio*
Tun Dr. Ismail hostel (KTDI)	1	1.7	47	15	150	0.32
	2	1.6	50	21		0.42
	3	2	51	27		0.53
	4	1.4	53	26		0.49
	5	1.4	55	28		0.51
	6	1.2	62	29		0.47
	7	1.1	66	31		0.47
	8	1	74	34		0.46
	9	0.7	76	31		0.41
	10	0.6	77	30		0.39
Faculty of Civil and Environmental Engineering (FKAAB)	11	1.8	45	10		0.22
	12	1.6	47	13		0.28
	13	1.6	49	19		0.39

	14	1.4	51	23	0.45
	15	1.3	53	24	0.45
	16	1.4	55	26	0.47
	17	1.2	62	28	0.45
	18	1	66	30	0.45
	19	0.9	68	30	0.44
	20	0.9	72	32	0.44
	21	1.4	46	7	0.15
	22	1.5	47	10	0.21
	23	1.3	49	16	0.33
	24	1.2	51	20	0.39
UTHM Library	25	1.1	53	23	0.43
	26	1.1	57	26	0.46
	27	1	60	28	0.47
	28	0.8	62	26	0.42
	29	0.6	64	26	0.41
	30	0.8	66	27	0.41

(*) Factors
(#) Response

4.2 Relationships between Indoor PM_{10}, Outdoor PM_{10}, and the Wind Speed

ANOVA quadratic model was performed to investigate the outdoor PM_{10} and wind speed effects on indoor PM_{10}. The ANOVA model was significant (p-value <0.05) with R^2 of 0.92 and R^2 adj of 0.90 (Table 3). The ANOVA analysis displayed a linear effect of the wind speed and outdoor PM_{10} on indoor PM_{10} ($p< 0.05$). The indoor PM_{10} was also affected quadratically (indirect effect) by the outdoor PM_{10} ($p<0.05$). ANOVA analysis Summarized the collected data and indicated a strong influence of the specified factors. The model was judged using the diagnostic scheme (Figure 2), where the scheme showed a satisfactory agreement between the actual and the predicted values of the model. The actual maximum record of the indoor PM_{10} was 34 $\mu g.m^{-3}$, while the predicted value was 32 $\mu g.m^{-3}$.

Table 3 - ANOVA analysis of the factors and response

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1362.10	5	272.42	55.71	< 0.0001	significant
A-Wind Speed	58.39	1	58.39	11.94	0.0021	
B-Outdoor PM_{10}	214.40	1	214.40	43.84	< 0.0001	
AB	2.93	1	2.93	0.5987	0.4466	
A^2	2.23	1	2.23	0.4552	0.5063	
B^2	21.54	1	21.54	4.40	0.0466	
Residual	117.37	24	4.89			
Lack of Fit	114.87	22	5.22	4.18	0.2109	not significant
Pure Error	2.50	2	1.25			
Cor Total	1479.47	29				

The results indicated that there is a strong relationship between the indoor, outdoor concentrations of PM_{10} and wind speed. Figure 3 shows that the higher the outdoor concentration of PM_{10}, the higher the indoor PM_{10} concentration. However, there was a slight effect of the wind speed on the indoor PM_{10}. Pallarés et al., (2019) have conducted a study to investigate the indoor and outdoor concentration of the PM_{10} of 7 primary schools in different environments. The study aimed to compare indoor and outdoor PM_{10} and assess the sources of indoor and outdoor emissions. The authors have confirmed that outdoor activities have increased the indoor PM_{10} level. Ścibor et al., (2020) have studied the PM_{10} and $PM_{2.5}$ concentrations under different weather conditions. The study found an increase of 10% of the indoor concentrations during the weather changes under similar conditions. The previous results are consistent with the current study results, summarizing the relationship between wind speed and indoor and outdoor concentrations of PM_{10}.

The normal plot presented by the software was added to provide normal probability plots for the studentized residuals for the indoor PM_{10} concentration in this analysis to ensure the convergence of the actual values and the approximate values provided by the software (Figure 4). The normal probabilities of studentized residuals are distributed for the internal concentration of PM_{10}, which in turn gives a predictive plot indicating that if the remaining points follow a normal distribution, they will be distributed on the midline line.

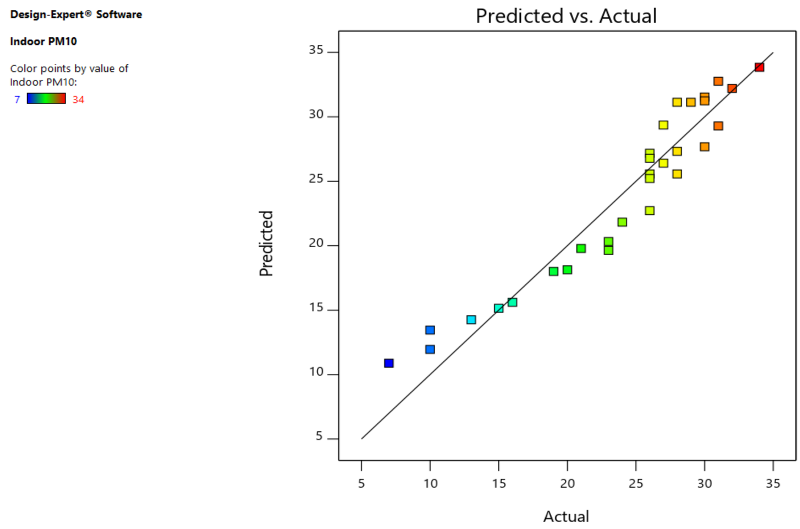

Fig. 2 - The actual and predicted values obtained by the Design Expert software for the indoor PM_{10}

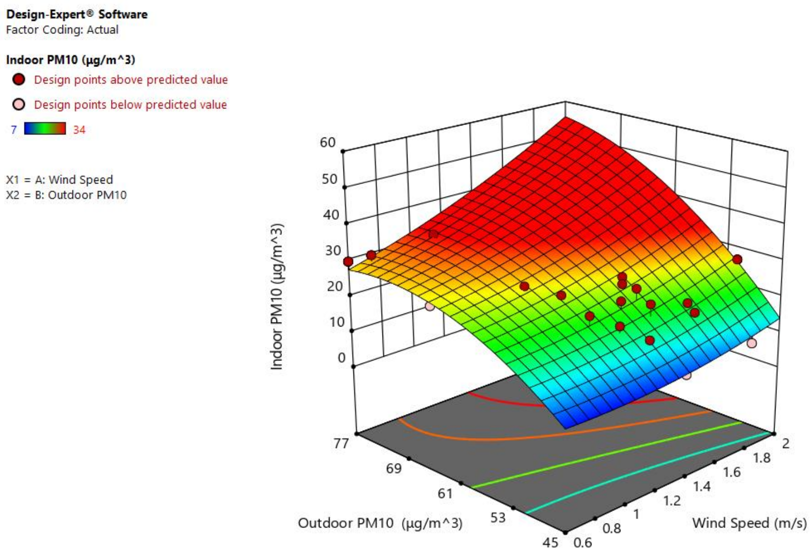

Fig. 3 - Response surface methodology of the relationship between indoor PM_{10}, outdoor PM_{10}, and the wind speed

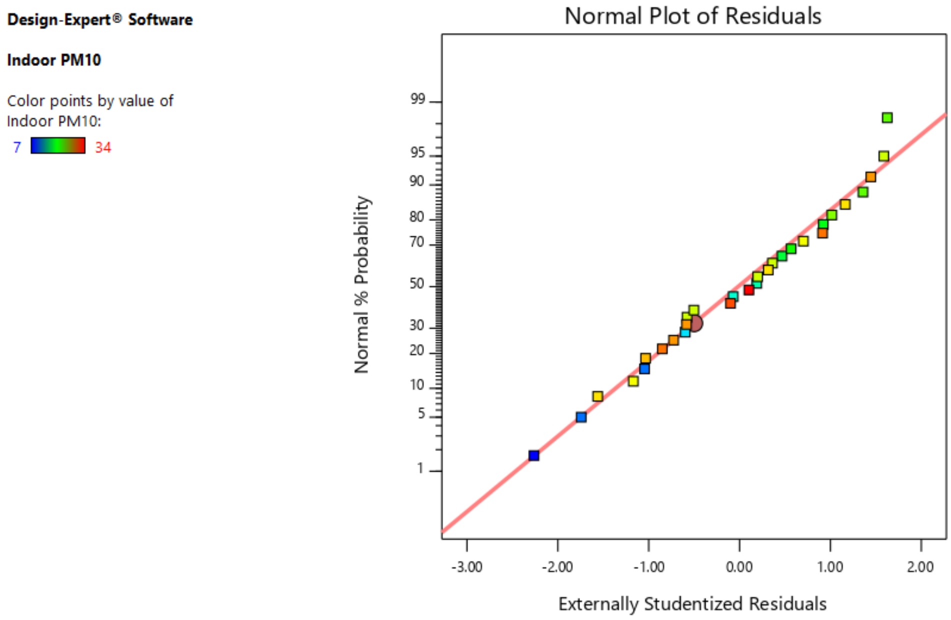

Fig. 4 - The normal plot of the studentized residuals

5. Conclusion

The study aimed to assess the indoor concentrations of PM_{10} for three buildings on the UTHM university campus located near an industrial area and identify the effects of wind speed and the outdoor PM_{10} concentration on indoor PM_{10}. The study was showed a strong relationship between indoor PM_{10}, wind speed, and outdoor PM_{10}. Samples results indicated that there is also a relationship between the zone distance, wind direction, and the concentrations of PM_{10} at the UTHM campus. Moderate to a high concentration of PM_{10} was reported from the outdoor samples (45-77 µg.m-^{3}), while the indoors samples were recorded low to moderate concentration of PM_{10} (7-34 µg.m^{3}). All results showed that the concentrations of PM_{10} were within the permissible and recommended range in DOSH and RMAAQG standards. However, the authors were considered that the monitored concentrations pose a slight risk to public health for the long term. This study is recommended to investigate the effect of many other factors, including wind direction, temperature, distance, humidity, weather conditions, and others on the indoor and outdoor concentrations of PM_{10} inside the UTHM university campus, which will provide a roadmap for the required technologies for preventing the PM_{10} spreading indoors.

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