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# Influence of Outdoor Source on The Variations of Indoor $PM_{2.5}$ Concentration and Its Morphological Properties in Roadside School Environment

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**Abstract:** Particles with aerodynamic diameters equal or less than 2.5 µm, which are known as fine particles ($PM_{2.5}$), are major air pollutants that could seriously impact ambient and indoor air quality. The air quality in school environments less than 500 m away from the roadside is potentially affected by vehicles through exhaust emissions. Thus, the concentrations of ambient and indoor fine particles ($PM_{2.5}$) were measured using a portable outdoor beta-attenuation monitor and an optical indoor direct reading monitor in two naturally ventilated school environments for 8 h during the teaching and learning sessions. In addition, meteorological parameters such as temperature, relative humidity and wind speed were measured under ambient and indoor conditions. $PM_{2.5}$ samples were also collected and morphologically characterised. Pearson's correlation was applied to identify the relationship between the ambient and indoor conditions of $PM_{2.5}$, temperature, relative humidity and wind speed. Results showed that the indoor and outdoor $PM_{2.5}$ in selected schools were varied. The concentration of indoor $PM_{2.5}$ was higher than that of outdoor $PM_{2.5}$ in both schools. Pearson's correlation showed a significant correlation between indoor and outdoor $PM_{2.5}$ in schools A ($p = 0.006$, $r = 0.54$) and B ($p = 0.001$, $r = 0.74$). In addition, ambient temperature, relative humidity and wind speed are the important factors that affect the outdoor concentrations of $PM_{2.5}$.

**Keywords:** fine particles, variation, classroom, indoor and outdoor, natural ventilatio

## 1. Introduction

Particles with aerodynamic diameters equal or less than 2.5 µm, which are also known as fine particles, are air pollutants that can severely harm the respiratory system of humans, especially sensitive groups such as children [1]-[2]. In addition, individuals who are exposed to indoor pollutants are more susceptible than those who are exposed to outdoor air pollutants in the long term [2]. Exposure to high indoor PM, such as $PM_{2.5}$, could increase the risk in acquiring respiratory problems, such as asthma, lung diseases, cardiovascular and cardiopulmonary diseases and premature death [3]-[7]. Children belong to the sensitive groups that spend 90% of their daily lives indoor, such as in school classrooms [8]-[10]. Many studies have determined that children who spend their school sessions in limited space over a period of several hours (6 – 8 hours) per day could be exposed to high concentrations of PM, such as $PM_{2.5}$ [11]-[17]. Young children are more susceptible to air pollutions because they breathe at a higher rate than adults, which is proportional to the growth of tissues, body weight and the immune system [18]-[22].

Malaysia, which is a developing country, has currently experienced rapid development and industrial activities to achieve the developed country status. At the same time, the Malaysian population increases daily and is currently 32.3

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million [23]. Hence, the demand on industrial activities and transportation has also increased to fulfil the daily life requirements. This condition increases air pollution, especially from anthropogenic sources, such as industrialisation and vehicle emissions. Anthropogenic sources, which are mostly from outdoor sources, are considered an important factor that influences the concentrations of indoor air pollutants [19]. In addition, few studies have determined the relationship between indoor and outdoor concentrations of air pollutants [24]-[26]. Agrawal et al. [27] and Gadkan et al. [28] reported that the ambient air in dense urban and suburban areas with buildings and high traffic activities influences the concentrations of indoor air pollutants in indoor environments. Therefore, the present study identified the variations of indoor and outdoor $PM_{2.5}$ concentrations in school environments, determined the influence of outdoor to indoor $PM_{2.5}$ concentrations in school, and identified the morphological properties of indoor and outdoor $PM_{2.5}$ in school.

## 2. Materials and Method

### 2.1 Location of Study Areas

In this study, two schools that are located in Seberang Perai, Pulau Pinang were selected as the study areas, as shown in Fig. 1. The two schools were selected because they are categorised as suburban areas and are located near the roadside, where school A is 31.1 m and school B is 36.6 m away from the roadside. The two schools are located at high-density traffic areas because school A is located at the state road and school B is located at the main federal road based on the road code of the Ministry of Works, Malaysia [29]. Fig. 2 shows the condition during the indoor and outdoor sampling and monitoring of school environment, and the coordinate for each school is provided in Table 1. The monitoring and sampling activities were conducted for 2 days with 8 h/day at each school.

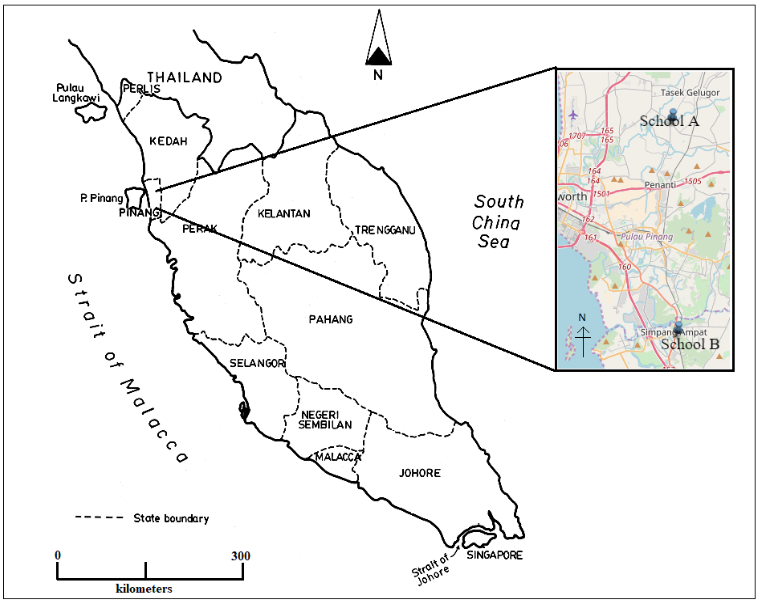



**Fig. 1 - Location of study areas**


a) b)

**Fig. 2 - Sampling and monitoring for a) outdoor and b) indoor (right) $PM_{2.5}$ in one the schools, school A**

**Table 1 - Location of each school located in Seberang Perai, Pulau Pinang**

| School | Coordinate |
|---|---|
| **A** | 5˚29’5.914”N; 100˚29’9.423”E |
| **B** | 5˚16’28.646”N; 100˚28’39.298”E |

## 2.2 Data and sample collection

Air quality sampling and monitoring were conducted in one classroom for each school throughout the school session. The measurements focused on the indoor and outdoor concentrations of $PM_{2.5}$, temperature, relative humidity (RH) and wind speed throughout the school session. For indoor measurement, an optical direct reader (Environmental Sampler, E-sampler) with a flowrate of 2 L/min was used and placed at the back of the classroom at a height of 1.2 m from the floor and 1 m from the windows, door and soft board as recommended by the Department of Safety and Health Malaysia [30] Industrial Code of Practice for Indoor Air Quality 2010 (ICOP 2010). For outdoor measurement, a portable beta-attenuation monitor with a flowrate of 16.7 L/min (E-BAM) was used to measure and filter the $PM_{2.5}$ samples. Pre-calibration was conducted to determine the calibration factor of the two instruments in comparing the indoor and outdoor $PM_{2.5}$ concentrations. The two instruments were simultaneously run at a distance of more than 1 m. Then, the calibration factor was determined for the two instruments by applying a regression analysis, and the value of k-factor was 0.33779.

$PM_{2.5}$ samples were filtered by using a glass fibre filter paper with 47 mm diameter and 2.0 µm pore size (indoor) and a glass fibre filter tape with 2.0 µm pore size (outdoor). For the analysis of morphological properties, the filtered paper was cut into half for indoor, and the filtered paper was first cut with a paper puncher with a diameter of 12 mm for outdoor. Then, the filtered paper was cut into half similar to the filtered paper for indoor by using a disposable scalpel. The morphological properties of the samples were analysed through field-emission scanning electron microscopy (FESEM) coupled with energy dispersive X-ray spectroscopy QUANTA FEG 650, as shown in Fig. 3 [31].

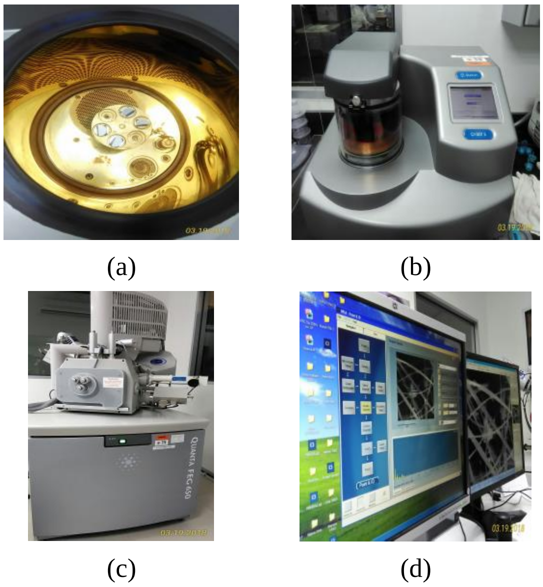



**Fig. 3 - Field-Emission Scanning Electron Microscopy QUANTA FEG 650 (a) samples of $PM_{2.5}$ were allocated in the vacuum (b) Vacuum Quarta (c) Field-Emission Scanning Electron Microscopy QUANTA FEG 650 (d) Identification of shape for $PM_{2.5}$**

## 2.3 Statistical Analysis

In this study, the indoor and outdoor $PM_{2.5}$ concentrations and meteorological parameters (temperature, RH and wind speed) were continuously measured at 15 min intervals in which the particle samples are well filtered. All the data were arranged in a spreadsheet and statistically analysed using MS Excel 2007 and IBM Statistical Package for Social Science (SPSS Version 16.0, USA). Pearson’s correlation was performed by applying a bivariate correlation analysis, which is an important approach used to evaluate the relationship between the variables [32]-[34]. The relationship strength between indoor and outdoor $PM_{2.5}$, temperature, RH and wind speed was determined based on Pearson’s correlation coefficient, which can be expressed in Eq. (1). The strength of relationship was referred to the Guildford’s Rule of Thumb [35], as shown in Table 2.

$$r = \frac{\sum\left(X-\bar{X}\right)\left(Y-\bar{Y}\right)}{\sqrt{\left(X-\bar{X}\right)^2\left(Y-\bar{Y}\right)^2}} \quad (1)$$

where: r = Pearson's correlation coefficient, X = x variables, Y = y variables, $\bar{X}$ = sample mean for x variables and $\bar{Y}$ = sample mean for y variables

**Table 2 - Correlation coefficient by Guildford's Rule of Thumb**

| Size of Correlation | Interpretation |
|---|---|
| 0.90 to 1.00 (-0.90 to –1.00) | Very high positive (negative) correlation |
| 0.70 to 0.90 (-0.70 to -0.90) | High positive (negative) correlation |
| 0.50 to 0.70 (-0.50 to -0.70) | Moderate positive (negative) correlation |
| 0.30 to 0.50 (-0.30 to -0.50) | Low positive (negative) correlation |
| 0.00 to 0.30 (0.00 to -0.30) | Little if any correlation |

## 3. Results and Discussion

### 3.1 Variations of $PM_{2.5}$, Temperature, Relative Humidity and Wind Speed for Indoor and Outdoor in School

Table 3 and Table 4 show the variations of indoor and outdoor concentrations of $PM_{2.5}$, temperature, RH and wind speed in schools A and B. The two schools experienced higher indoor $PM_{2.5}$ concentrations than outdoor $PM_{2.5}$ concentrations. In school A, the average indoor concentration was 58±11 μg/m$^3$ and the average outdoor concentration was 32±10 μg/m$^3$. In school B, the average $PM_{2.5}$ concentrations for indoor and outdoor were 71±22 and 36±9 μg/m$^3$, respectively. For the average indoor concentration of $PM_{2.5}$, schools A and B experienced high concentrations that exceed the 35 μg/m$^3$ limit recommended by ASHRAE Standard 62.1-2010 [36]. The outdoor concentrations of $PM_{2.5}$ did not exceed the 50 μg/m$^3$ limit of Malaysia Ambient Air Quality Standard-Interim 2 (MAAQS-IT-2). The temperature ranges were 27.3–30.9 °C for indoor school A and 24.5–33.3 °C for outdoor school A. Meanwhile, the indoor temperature range of school B was 29.1–33.0 °C, which exceeds the 23–26 °C and 25.0–35.2 °C indoor and outdoor temperature limits recommended by ICOP 2010, respectively. The RH in the two schools was within the range recommended by ICOP 2010 (40%–70%). The relative indoor and outdoor humidity of school A were 51%–71% and 39%–68%, respectively. The indoor and outdoor RH ranges for school B were 48%–51% and 48%–78%, respectively. Meanwhile, the average wind speed in all schools was within the limit of 0.15–0.50 m/s inside the classroom.

### 3.2 Influence of Outdoor $PM_{2.5}$ and Meteorological Parameters on Indoor $PM_{2.5}$ in School Environment

The influence of outdoor concentrations on indoor concentrations was identified in the two schools. Pearson's correlation analysis revealed a significant correlation between indoor and outdoor $PM_{2.5}$ concentrations ($p = 0.006$; $r = 0.542$) in school A. In addition, indoor temperature ($p = 0.001$; $r = -0.630$) and RH ($p = 0.001$; $r = 0.643$) significantly influenced $PM_{2.5}$ concentrations. Ambient $PM_{2.5}$ in school A was significantly influenced by temperature ($p = 0.000$; $r = -0.831$), RH ($p = 0.000$; $r = 0.859$) and wind speed ($p = 0.000$; $r = -0.873$), as shown in Table 5. Pearson's correlation analysis also showed a significant correlation between the indoor and outdoor $PM_{2.5}$ in school B ($p = 0.001$, $r = 0.74$). In addition, ambient temperature and RH significantly influenced the $PM_{2.5}$ concentrations, where the p-values were 0.009 with $r = 0.521$ for temperature and $PM_{2.5}$ and 0.008 with $r = -0.528$ for RH and $PM_{2.5}$, as shown in Table 6.

Based on Pearson's correlation in school A and B, the correlation was categorised as a moderate correlation between indoor and outdoor $PM_{2.5}$. This finding is similar to that reported by Yang et al. [34], who determined that the relationship between indoor and outdoor of $PM_{2.5}$ for classroom is significant with moderate relationship ($r = 0.5287$). Latif et al. [26] and Guo et al. [37] also found a significant correlation between the indoor and outdoor $PM_{2.5}$ in school. This condition is due to the infiltration of outdoor particles from vehicles and industrial emissions. Furthermore, the area of openings, such as door and windows, act as important factors for outdoor particles to be infiltrated [38]-[40].

However, the relationship of ambient temperature, RH and wind speed with outdoor $PM_{2.5}$ can be classified in the range of moderate to strong category. Meteorological parameters, such as temperature, RH and wind speed, act as important factors, which is similar to the findings of Tecer et al. [41], Tai et al. [42], Wang et al. [43] and Ching-Hui et al. [44].

**Table 3 - Descriptive statistics of indoor $PM_{2.5}$, temperature, relative humidity and wind speed in schools A and B**

| School | Descriptive Statistic | $PM_{2.5}$ (µg/m$^3$) | T (˚C) | RH (%) | WS (m/s) |
|---|---|---|---|---|---|
| A | Max | 80 | 30.9 | 71 | 0.6 |
| | Min | 42 | 27.3 | 51 | 0.3 |
| | Avg | 58 | 28.6 | 64 | 0.4 |
| | SD | 11 | 1.3 | 7 | 0.1 |
| B | Max | 116 | 33.0 | 51 | 0.6 |
| | Min | 41 | 29.1 | 48 | 0.3 |
| | Avg | 71 | 31.1 | 49 | 0.4 |
| | SD | 22 | 1.3 | 1 | 0.1 |

**Table 4 - Descriptive statistics of outdoor $PM_{2.5}$, temperature, relative humidity and wind speed in schools A and B**

| School | Descriptive Statistic | $PM_{2.5}$ (µg/m$^3$) | T (˚C) | RH (%) | WS (m/s) |
|---|---|---|---|---|---|
| A | Max | 46 | 33.3 | 68 | 1.8 |
| | Min | 21 | 24.5 | 39 | 0.7 |
| | Avg | 32 | 28.0 | 56 | 1.1 |
| | SD | 10 | 3.2 | 10 | 0.3 |
| B | Max | 46 | 35.2 | 78 | 1.8 |
| | Min | 23 | 25.0 | 48 | 0.5 |
| | Avg | 36 | 29.4 | 65 | 1.0 |
| | SD | 9 | 3.9 | 12 | 0.3 |

*Note: Max = Maximum, Min = Minimum, Avg = Average, SD = Standard Deviation, T = Temperature, RH = Relative humidity, WS = Wind speed

**Table 5 - Pearson's correlation between indoor and outdoor $PM_{2.5}$, temperature, relative humidity and wind speed in school A**

| | $PM_{2.5}$ | | T | | RH | | WS | |
|---|---|---|---|---|---|---|---|---|
| | I | O | I | O | I | O | I | O |
| **a** | 1 | 0.54** | 0.63** | 0.65** | 0.64** | 0.66** | 0.35 | 0.67** |
| **b** | 0.54** | 1 | 0.73** | 0.83** | 0.76** | 0.85** | 0.49* | 0.87** |

**Table 6 - Pearson's correlation between indoor and outdoor $PM_{2.5}$, temperature, relative humidity and wind speed in school B**

| | $PM_{2.5}$ | | T | | RH | | WS | |
|---|---|---|---|---|---|---|---|---|
| | I | O | I | O | I | O | I | O |
| **a** | 1 | 0.74** | 0.08 | 0.09 | 0.12 | 0.08 | 0.12 | 0.37 |
| **b** | 0.74** | 1 | 0.52** | 0.52** | 0.17 | 0.53** | 0.44 | 0.06 |

For Table 5 and Table 6:
Note a = $PM_{2.5}$_In; b = $PM_{2.5}$_Out; I = indoor; O = outdoor
**.Correlation is significant at the 0.01 level (2-tailed)
*.Correlation is significant at the 0.05 level (2- tailed)

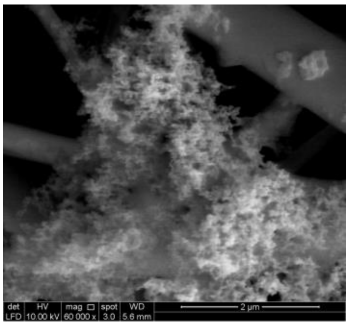
### 3.3 Morphological Properties of Indoor and Outdoor $PM_{2.5}$ for Indoor and Outdoor

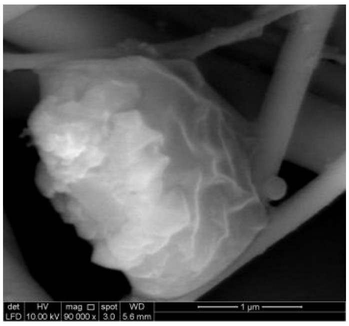
Fig. 4(a) and Fig. 4(b) show the micrographs from high-resolution FESEM of fine particles from outdoor sources. Fig. 4(a) shows the small clustered agglomerate soot, which are typical soot particles, that is carbon aggregates emitted from vehicles [31], [45]. Fig. 4(b) shows the cluster shape of particles from anthropogenic sources. Outdoor particles are mostly in spherical shape and have smooth surfaces produced from anthropogenic sources, such as combustion at high temperature [4]. Fig. 4 (c) and Fig. 4(d) show the flaky shape of particles identified from indoor samples, which is similar to the finding of Jan et al. [46].

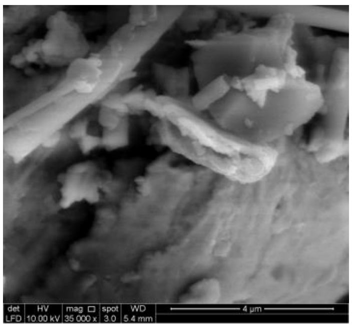
Fig. 5 shows the micrograph for indoor and outdoor PM2.5 in school A. Fig. 5(a) shows the small clustered agglomerate soot mainly emitted from vehicle emissions [31], [45]. Fig. 5(a) shows the high-resolution FESEM micrograph with the percentage of each element of indoor particles. As shown in the pie chart in Fig. 5(a), the elements that exist in the particles are O, Si, Na, C, Ca, Mg and Al. The size range is O > Si > Na > C > Ca > Mg > Al for indoor particles in school A. Fig. 5(b) shows the outdoor particles with flaky shapes that are rich with oxygen, carbon and silica. In addition, other elements, such as Na, Al, K and Ca, are found. The trend of elements is O > C > Si > Na > Al > K > Ca.

Fig. 6(a) and Fig. 6(b) show the micrographs from high-resolution FESEM of fine particles from outdoor sources in school B. Fig. 6(a) shows the small clustered agglomerate soot, and Fig. 6(b) shows the irregular shape particles from outdoor sources. Fig. 6(c) shows the soot particles and Fig. 6(d) shows the flaky shape particles that are present inside the classroom. Fig. 7(a) shows the high-resolution FESEM micrograph with the percentage of each element of indoor particles that consist of elements, such as C, O, Na, Al and Si. The dominant element is in the order of C > O > Si >Na > Ca > Mg and Al. Fig. 7(b) shows the percentage of elements that consist the outdoor particles for school B, which is the order of O > Si > C> Na > Al.

The results on morphological properties of outdoor particles in schools A and B show the existence of soot particles and biological and irregularly shaped particles. Soot particles are usually obtained from incomplete combustion processes, such as vehicle emissions with diesel engines, gas burners, coal-fired power plants, domestic heating and biomass burning [47]-[50]. Biological shape particles are usually obtained from biological sources, such as trees and flowers for landscape purposes near the school area [31]. The morphological properties of indoor particles in schools A and B consist of soot particles and irregularly shaped particles. The indoor morphological properties of school B show that soot particles also exist inside the classrooms similar to outdoor particles. This condition shows the influence of outdoor sources on the indoor concentrations in school B [45].


(a) outdoor


(b) outdoor


(c) indoor

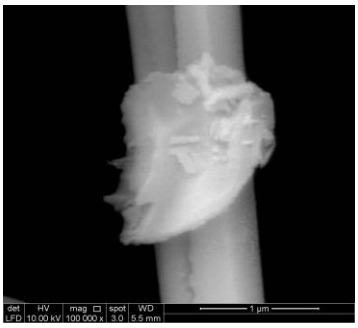
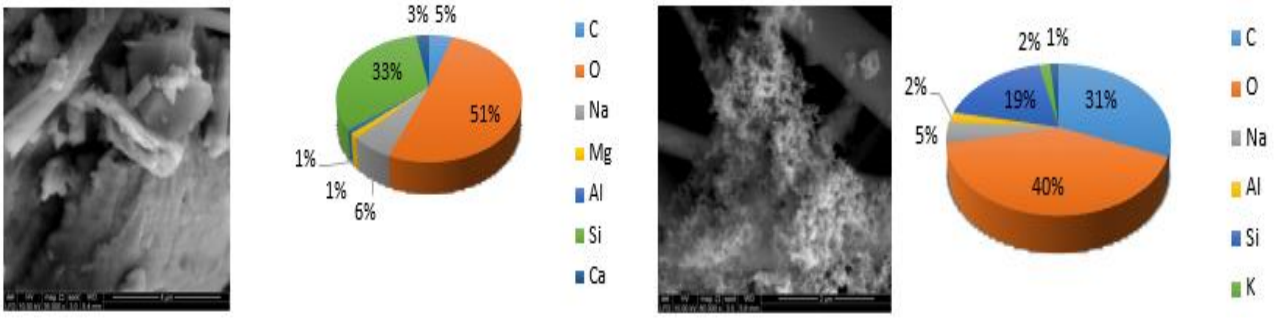
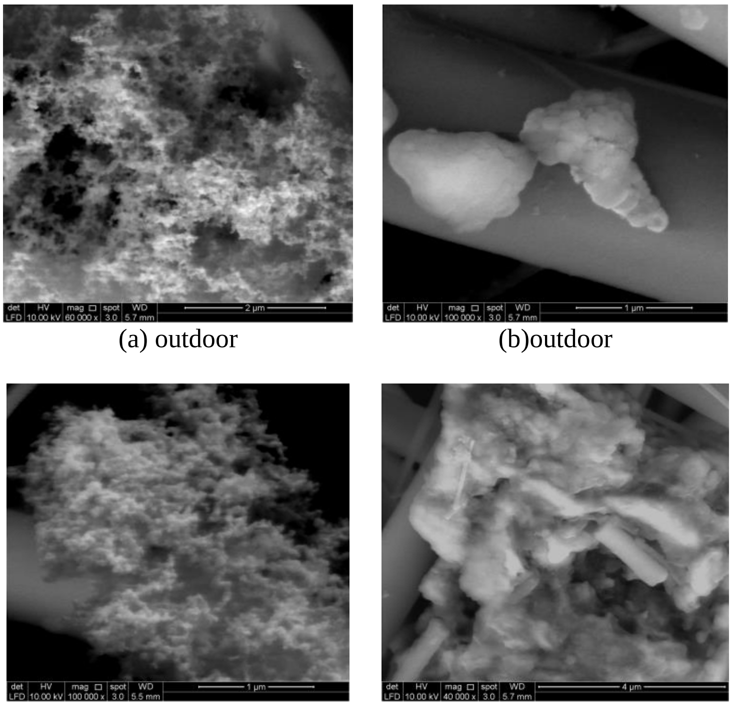

(d) indoor

**Fig. 4 - High resolution of FESEM of outdoor (a) soot aggregated and (b) biological particles while for indoor (c) and (d) are irregular shapes in school A**




(a) (b)

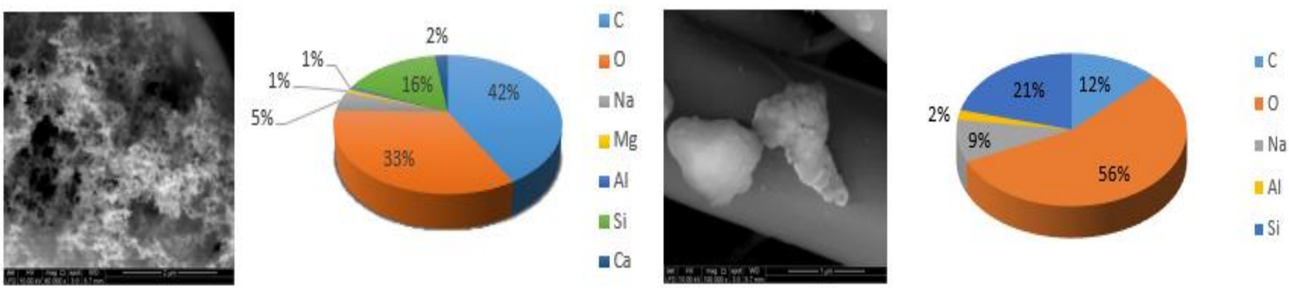
**Fig. 5 - High resolution of FESEM micrographs with percentage of each element in for (a) indoor and (b) outdoor in school A**



(a) outdoor (b)outdoor

(c) indoor (d) indoor

**Fig. 6 - High resolution of FESEM of outdoor and indoor in school B. 6 (a) soot particles (b) irregular shape for outdoor and 6 (c) soot particles (d) irregular shape of indoor particles in school B.T**




(a) indoor (b) outdoor

**Fig. 7 - High resolution of FESEM micrographs with percentage of each element for (a) indoor and (b) outdoor in school B**

## 4. Conclusion

The concentrations of outdoor and indoor $PM_{2.5}$ varied. The indoor concentration was contributed by outdoor sources. Then, the trapped and resuspended concentrations were due to students' activities. Pearson's correlation analysis revealed a significant correlation between indoor and outdoor $PM_{2.5}$ in schools A and B. This finding is also supported by a similar type of particles (i.e. soot particles) for indoors and outdoors in school B. The morphological characteristics were also identified for indoor and outdoor $PM_{2.5}$ in schools A and B, which are soot, irregularly shaped and biological particles. The dominant elements are O and C for indoor and outdoor particles in both schools. In addition, ambient temperature, RH and wind speed are the important factors that influence the outdoor $PM_{2.5}$ concentrations in schools

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