Impact of high particulate event on the indoor and outdoor fine particulate matter concentrations during the Southwest monsoon season

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Abstract. Haze event, also known as the high particulate event (HPE) normally occurs during the Southwest monsoon season due to the high concentrations of atmospheric particulate matters including PM$_{2.5}$ which are majorly caused by anthropogenic activities such as open forest and biomass burning. The impact of haze, not only on ambient air but also indoor environment, elevates with the emission of particulate matters from local transportation and industrial sources. Polluted indoor environment could impose adverse effects towards the occupants, particularly those categorized in the sensitive group. School children are among the sensitive group whom spend the majority of their time indoors, especially in school classroom and home. The present study aims to determine the indoor/outdoor ratios of PM$_{2.5}$ during non-HPE and HPE. The concentrations of indoor and outdoor PM$_{2.5}$ were measured continuously using a direct optical monitor (E-Sampler) and portable environmental beta-attenuation monitor (E-BAM) respectively for 24 hours. The findings revealed that the I/O ratio during HPE (0.35) was higher than the non-HPE (0.26). The Pearson correlation analysis exhibited a significant relationship ($p < 0.01$) between the indoor and outdoor PM$_{2.5}$ concentrations with a strong correlation ($r = 0.75$). Therefore, it is evident that the outdoor concentrations of PM$_{2.5}$ during HPE inflicted a significant impact on the indoor environment of naturally ventilated classroom due to the high I/O ratio in comparison to non-HPE, in addition to the less practical design of the classroom (open system).

Keywords: children, health effects, indoor/outdoor ratio, PM$_{2.5}$, school

1. Introduction
Haze episodes have been recorded to affect several countries in the Southeast Asia (Singapore, Malaysia, Indonesia, Brunei Darussalam, and Thailand) since 1982 [1]. [2] stated that the major contributor to this problem is the transboundary pollution due to uncontrolled biomass burning. Haze events mostly take place during the dry season, which is also known as the Southwest monsoon (from June to September) [3], and the haze impacts aggravate with the low recorded rainfall during this season [4]. Recently, haze has become an annual event in the Southeast Asia region especially in Indonesia, Malaysia, and Singapore [5, 6, 7, 8]. This phenomenon occurs upon the gathering of high-
level air pollutants originated from various anthropogenic activities such as peatland and wood burning, transportation, and industrialization [8, 9, 10]. Particulate matter (PM) has become the main focused parameter in a haze evaluation, where the Malaysia Air Pollution Index (API) is invariably dependent on the PM$_{2.5}$ (particles with aerodynamic diameters of less than 2.5 μm) and PM$_{10}$ (particles with aerodynamic diameters of less than 10 μm) concentrations [11, 12, 13]. A previous study exercised the term ‘high particulate event’ (HPE) to define this condition [13]. HPE has become a major concern due to its adverse impacts towards the human health, including complications in children respiratory system (i.e. upper respiratory zone infection and asthma) and conjunctivitis [5, 14]. In this matter, teaching and learning sessions are also affected whereby schools are encouraged to close due to the very unhealthy and hazardous air quality during HPE based on the API record [11]. In addition, economic sectors are also influenced by HPE due to the output cutback particularly in manufacturing, construction, and tourism earnings [8]. Outdoor air pollution in school environment should be taken as a serious matter because of its detrimental effects on school children who are still vulnerable and less resilient towards polluted air. [15, 16] reported that relationship between the indoor and outdoor PM$_{2.5}$ concentrations in a school environment significantly existed. Infiltration process is one the transportation mechanism that could transport the outdoor PM$_{2.5}$ into indoor environment, thus contributing to its suspension especially in naturally ventilated classrooms wherein windows and doors are left open throughout the school session in order to encourage ventilation. However, during HPE, such ventilation system is inappropriate since particulate matter, typically the PM$_{2.5}$ could be transported to a long distance and suspended for an extended period in the atmosphere. The Ministry of Education (MOE) Malaysia has enforced the closure of schools when the API reaches very unhealthy (101-200) and hazardous (above 300) levels in order to avoid risks to school children and teachers [17, 18]. Most school classrooms in Malaysia practice a mix-mode ventilation system (natural ventilation with mechanical aids i.e. fans), that is also exposed to outdoor PM$_{2.5}$ infiltration. Consequently, school children may suffer from visibility problem, difficulty in breathing, and other respiratory problems during HPE. [19, 20, 21] found that ventilation system gives significant impacts on the infiltration of outdoor air pollutants including PM$_{2.5}$ into indoor. Thus, the aim of present study is to find out the ratios of indoor/outdoor PM$_{2.5}$ concentrations during non-HPE and HPE.

2. Materials and Methods

2.1. Description on sampling site

The monitoring of indoor and outdoor concentrations of PM$_{2.5}$ was performed at a school located in Johan Setia, Klang at coordinate 2°58'42.54"N, 101°29'24.25"E. The study area is surrounded by agricultural area known as Green Revolution with an area of 4000 acre [22], and several residential areas. The classrooms are ventilated with a mix-mode system (i.e. natural ventilation with a mechanical aid; fans) where each classroom is set-up with louver windows and two doors. The selected classroom for PM$_{2.5}$ monitoring which is located in the second floor was occupied by Standard 5 primary school children in the morning and Standard 3 children in the evening school session. The distance between the agricultural area and the school was in the range of 0.5 – 5 km radius (red circle). Figure 1 illustrates the location of the sampling site in Johan Setia, Klang.
2.2. Data monitoring for indoor and outdoor PM$_{2.5}$

Measurement of indoor and outdoor PM$_{2.5}$ concentrations was conducted continuously in non-HPE and HPE for 24 h with 1 min interval during the Southwest monsoon season (July and August 2019). The PM$_{2.5}$ measurement was carried out for durations of 2 days (48 hours) and 6 days (144 hours) for non-HPE and HPE respectively. A direct optical monitor (E-sampler) was allocated in the assigned classroom (indoor). Meanwhile, for outdoor evaluation, samples of PM$_{2.5}$ were collected and measured using an environmental beta attenuation monitor (E-BAM).

2.3. Variations of PM$_{2.5}$ concentration, meteorological parameter, and I/O ratio analysis

Descriptive statistic was performed to determine the minimum, maximum, mean, and standard deviation values for indoor and outdoor concentrations of PM$_{2.5}$ during non-HPE and HPE. In addition, the I/O ratio was implemented to identify the fraction of outdoor PM$_{2.5}$ that penetrates into the indoor classroom area [23, 24, 25, 26]. This analysis is also supported by [27] whom utilized the I/O ratios in the determination of relationship between indoor and outdoor particles.

2.4. Pearson correlation analysis for indoor and outdoor PM$_{2.5}$ relationship

The linear relationship between the two variables was analyzed using the Pearson correlation analysis. The Pearson correlation coefficient ($r$) could be classified into three types, namely positive correlation, negative correlation, and no correlation. A positive correlation indicates a directly proportional relationship between two variables whereas a negative correlation represents an indirectly proportional relationship wherein if the factor (x) increases; the other variable (y) will decrease. No correlation on
the other hand demonstrates a condition of no influence between the variables (x) and (y). Correlation coefficient (r) is used to determine the strength of correlation between variables in the range between -1 and +1 as shown in Table 1 [28, 29]. The Guildford’s Rule of Thumb that established by Guildford [29] is referred in order to determine the strength of linear relationship [28].

\[
r = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}}
\]

Where \( r \) = coefficient for Pearson correlation, \( X \) = outdoor PM\(_{2.5}\) concentration, outdoor meteorological variables; \( Y \) = indoor PM\(_{2.5}\) concentration, indoor meteorological variables; \( \bar{x} \) = average for outdoor PM\(_{2.5}\) concentration, outdoor meteorological variables; and \( \bar{y} \) = average for indoor PM\(_{2.5}\) concentration, indoor meteorological variables.

### Table 1. Range of correlation coefficient by Guildford’s Rule of Thumb (Dominick et al., 2012; Guilford, 1973)

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

### 3. Results and Discussion

#### 3.1. Variations of indoor and outdoor PM\(_{2.5}\) concentrations and meteorological parameters

Table 2 shows the variations of 24 h-averaged indoor and outdoor PM\(_{2.5}\) concentrations and meteorological parameters recorded during the non-HPE and HPE. As expected, the mean indoor and outdoor PM\(_{2.5}\) concentrations ± standard deviation during HPE (of 60.40 ± 23.83 \(\mu\)gm\(^{-3}\) and 21.10 ± 10.01 \(\mu\)gm\(^{-3}\) respectively) were higher than those during the non-HPE. The outdoor mean PM\(_{2.5}\) concentration in HPE exceeded the limit set by the United State of Environmental Protection Agency (USEPA) and Malaysian Ambient Air Quality Standard (MAAQS) of 35 \(\mu\)gm\(^{-3}\) and 50 \(\mu\)gm\(^{-3}\) respectively [11, 30]. The indoor PM\(_{2.5}\) concentration is therefore influenced by indoor activities as well as the infiltration of outdoor air [31]. In comparison to other studies conducted during the Southwest monsoon season [32, 33, 34, 35], the outdoor PM\(_{2.5}\) concentrations obtained in this study were much higher (28.5 – 51.2\%). The indoor temperatures (Temp.) were found higher during HPE (30.60°C) and non-HPE (30.20°C), compared to outdoor temperatures of 27.85°C and 29.06°C respectively. This condition might be due to the low humidity and rainfall events during the Southwest monsoon season [36]. Meanwhile, during HPE, the relative humidity (RH) was revealed higher compared to the non-HPE, of 76.60% and 74.32% for indoor and outdoor humidity accordingly.
Table 2. Variations of 24 h-averaged indoor and outdoor PM$_{2.5}$ concentrations and meteorological parameters recorded during non-HPE and HPE

| Parameter                          | Mean (μgm$^{-3}$) | Standard Deviation | Min. | Median | Max. |
|------------------------------------|-------------------|--------------------|------|--------|------|
| **Indoor**                         |                   |                    |      |        |      |
| PM$_{2.5}$ Concentration (μgm$^{-3}$) | 9.70              | 4.68               | 2.63 | 9.75   | 19.00 |
| Temperature (°C)                   | 30.60             | 0.89               | 28.80| 30.65  | 31.90 |
| Relative Humidity (%)              | 72.20             | 6.70               | 58.75| 75.30  | 81.35 |
| Wind Speed (ms$^{-1}$)             | 0.68              | 0.43               | 0.30 | 0.43   | 1.51  |
| **Outdoor**                        |                   |                    |      |        |      |
| PM$_{2.5}$ Concentration (μgm$^{-3}$) | 37.50             | 13.90              | 16.50| 34.00  | 59.5  |
| Temperature (°C)                   | 29.06             | 2.83               | 25.70| 28.05  | 34.10 |
| Relative Humidity (%)              | 67.30             | 12.07              | 44.80| 72.68  | 81.50 |
| Wind Speed (ms$^{-1}$)             | 0.75              | 0.39               | 0.34 | 0.61   | 1.50  |
| **HPE**                            |                   |                    |      |        |      |
| PM$_{2.5}$ Concentration (μgm$^{-3}$) | 21.10             | 10.01              | 11.10| 19.14  | 46.30 |
| Temperature (°C)                   | 30.20             | 1.04               | 28.75| 30.35  | 31.85 |
| Relative Humidity (%)              | 76.60             | 6.68               | 64.40| 78.10  | 84.75 |
| Wind Speed (ms$^{-1}$)             | 0.69              | 0.41               | 0.31 | 0.42   | 1.43  |
| **Outdoor**                        |                   |                    |      |        |      |
| PM$_{2.5}$ Concentration (μgm$^{-3}$) | 60.40             | 23.83              | 27.82| 53.50  | 105.20|
| Temperature (°C)                   | 27.85             | 2.73               | 24.80| 26.90  | 32.80 |
| Relative Humidity (%)              | 74.32             | 10.86              | 54.40| 78.10  | 85.63 |
| Wind Speed (ms$^{-1}$)             | 0.87              | 0.54               | 0.32 | 0.56   | 1.76  |

*Note: Min.: Minimum; Max.: Maximum*

3.2. Comparisons between HPE and non-HPE variations for indoor and outdoor PM$_{2.5}$ concentrations

Figure 2 presents the diurnal 24 h-averaged indoor and outdoor PM$_{2.5}$ concentrations recorded during HPE and non-HPE at the study area. The trend for both non-HPE and HPE was similar but different in magnitude. PM$_{2.5}$ in HPE exhibited a higher level of concentration compared to the non-HPE for both indoor and outdoor PM$_{2.5}$. During HPE, the maximum indoor and outdoor PM$_{2.5}$ concentrations were recorded in the early morning as 46.30 μgm$^{-3}$ (12 a.m.) and 105.20 μgm$^{-3}$ (1 a.m.), respectively. Even though it clearly occurred during HPE, there was an expected increase in biomass burning activities from the existing local agricultural area that induced the PM$_{2.5}$ generation. In fact, biomass burning is one of the main anthropogenic sources for PM$_{2.5}$ origination as reported by [8]. This scenario is also linked to the haze episodes occurring in the Southeast Asia (SEA) region particularly during the Southwest monsoon season (between June and September). [37, 38, 39] reported that during HPE, high densities of biomass fire and wildfire hotspots were identified at several sampling locations in Klang Valley.
3.3. Ratio of indoor to outdoor PM$_{2.5}$ concentrations

Table 3 displays the mean I/O ratio of PM$_{2.5}$ concentrations during non-HPE and HPE. The mean I/O ratio for PM$_{2.5}$ during HPE (0.35) was higher compared to the non-HPE (0.26), where both ratios were less than 1.00. This indicates that the outdoor concentrations were very high due to the HPE in addition to the existing biomass burning activities near the school area. [31] found that I/O ratio increases with increasing quantity of people indoor, intensity of activities, and outdoor PM$_{2.5}$ concentration levels. During the non-HPE, the open systems such as windows and doors were opened for ventilation purpose, but this condition did not contribute in the dilution of indoor PM$_{2.5}$ concentration.

| Measurement Duration | Indoor (mean ± s.d.) | Outdoor (mean ± s.d.) | I/O ratio |
|----------------------|----------------------|-----------------------|-----------|
| Non-HPE (24 hr)      | 9.70                 | 37.50                 | 0.26      |
| HPE (24 hr)          | 21.10                | 60.40                 | 0.35      |

*Note: HPE: high particulate event; s.d.: standard deviation; I/O: indoor/outdoor ratio

3.4. Pearson correlation of indoor and outdoor PM$_{2.5}$ concentrations and meteorological parameters

Table 4 exhibits the relationships among the indoor and outdoor PM$_{2.5}$ concentrations and other meteorological parameters, where all correlation coefficients ($r$) were significant ($p < 0.01$). Strong correlations were observed between the PM$_{2.5}$ with indoor variables (RH and wind speed (WS)) and outdoor variables (PM$_{2.5}$, RH, Temp., and WS), with $r$ values in the range of 0.70 - 0.79. Positive correlations were recorded between the indoor PM$_{2.5}$ and indoor RH, and also between indoor PM$_{2.5}$ with outdoor PM$_{2.5}$ and RH. Meanwhile, negative correlations were found between PM$_{2.5}$, Temp., and RH, for both indoor and outdoor environments. [40] in their study revealed the rationale behind the negative correlation is due to the mixing height factor, where the dispersion rate of particles towards the upper part of the atmosphere during high temperatures reduces the amount of PM particles.
Table 4. Correlations among indoor and outdoor PM$_{2.5}$ and meteorological parameters

| Location | Parameter | Indoor | Outdoor |
|----------|-----------|--------|---------|
| Indoor   | PM$_{2.5}$ | 1      | PM$_{2.5}$ | 1 |
|          | RH        | 0.70   | RH      | 0.79 |
|          | Temp.     | -0.45  | Temp.   | -0.77 |
|          | WS        | -0.74  | WS      | -0.76 |
| Outdoor  | PM$_{2.5}$ | 0.75   | 0.74    | 0.72 |
|          | RH        | 0.79   | 0.94    | 0.77 |
|          | Temp.     | -0.77  | 0.77    | 0.58 |
|          | WS        | -0.76  | -0.81   | 0.58 |

*PM$_{2.5}$: Fine particles; RH: relative humidity; Temp.: temperature; WS: wind speed. Correlation is significant at 0.01 confident level (2-tailed).

4. Conclusion

As a conclusion, the average percentages of indoor and outdoor PM$_{2.5}$ concentration were higher during HPE compared to non-HPE by 54% and 37.9% respectively. In addition, the average outdoor PM$_{2.5}$ concentration after 24 h in HPE exceeded the permissible limit as recommended by the United State of Environmental Protection Agency (USEPA) (35 μgm$^{-3}$) and Malaysian Ambient Air Quality Standard (MAAQS) (50 μgm$^{-3}$). The trend for both non-HPE and HPE was similar but different in magnitude. The PM$_{2.5}$ concentration during HPE was higher compared to the non-HPE for both indoor and outdoor environments. Beside the evident HPE effect, an expected increase in biomass burning activities from the existing agricultural area in the vicinity of the selected study area was also considered. The mean I/O ratio for PM$_{2.5}$ concentration during HPE (0.35) was higher compared to the non-HPE (0.26), demonstrating the dispersion of PM$_{2.5}$ from outdoor sources towards the indoor environment. This condition was supported by the strong correlation between indoor and outdoor PM$_{2.5}$ concentrations thus indicating a significant influence from outdoor sources due to HPE and also the existing biomass burning activities near the school area. The findings from this study revealed the infiltration of outdoor PM$_{2.5}$ into indoor environment specifically in naturally ventilated classroom located even at a high floor level. The exceeding concentrations of PM$_{2.5}$ especially in outdoor environment is significantly alarming and immediate enforcement of open burning activities prohibition should be taken by the authorized bodies. Furthermore, the redesigning of classrooms especially the open system (windows and doors) should be considered by architects and engineers in order to provide a conducive study environment particularly for school children.

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