ORIGINAL ARTICLE

School Indoor Air Quality and Health Risk on the Junior High Schools Students in Depok, Indonesia

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ABSTRACT

Introduction: School environment represents an important microenvironment for students who spend 6–8 hours in classrooms. Indoor air quality is linked to several respiratory diseases in the school age group. This research aims to study indoor air quality of schools at different environmental characteristic and assess its health risks to students.

Methods: This research measured air quality (PM$_{2.5}$, PM$_{10}$, CO$_2$, and HCHO) in three junior high schools and followed by health risk assessment.

Results: This research found that the mean or median level of indoor PM$_{2.5}$ and PM$_{10}$ in all three schools exceeded the standard value with health risks (HQ> 1) for PM$_{2.5}$ in all three schools and PM$_{10}$ in two schools. Whereas carbon dioxide and formaldehyde concentrations were still safe and did not inflict health risks (HQ < 1). The scenario for managing the health risk of PM$_{2.5}$ and PM$_{10}$ exposure was to control the exposure at a safe threshold of PM$_{2.5}$ 0.035 mg/m$^3$; 0.043 mg/m$^3$ and PM$_{10}$ 0.144 mg/m$^3$ for most of the population at normal school time.

Conclusion: It was concluded that the level of indoor particulate matters indicates poor indoor air quality in all three schools at different environmental characteristic and inflicts health risk on students so that the health risk management is required.

Keywords: PM$_{2.5}$, PM$_{10}$, carbon dioxide, Formaldehyde, School health

INTRODUCTION

School is an important microenvironment because school children spend about 6 – 8 hours per day inside school building during weekdays (1,2). Classrooms in school have unique characteristics such as higher density than office room, diversity of student activities, and variety of ventilation systems that affect its indoor air quality (3). In addition, the indoor air quality is also determined by school environmental characteristic such as position to pollutant source and neighborhood activity (4,5). Several studies reported that traffic, industrial activity and biomass burning emit air pollutants to outdoor air that come in through infiltration and inadequate ventilation system and affect indoor air quality of classroom (1,4,6).

Some reports have estimated indoor exposures for children and adults, finding that children are at greater risk from pollutants that accumulate indoors due to higher respiratory frequency, higher physical activity, and the development of their respiratory system (7–9). Several studies have also shown that formaldehyde exposure is associated with symptoms of respiratory diseases such as asthma, wheeze, bronchitis, and lower respiratory tract infection (15–18). In addition, particulate matter also reported to affect lung development while high carbon dioxide concentration is associated with drowsiness, lethargy, and even decrease in learning ability (13,18–20).

Student health is important in academic achievement so that the Indonesian government runs a school health
program but air quality has not obtained significant concern in this program. This research aims to study indoor air quality of schools with different environmental settings and assess its health risks to students. The health risk management would be advised if health risk is estimated in this study. The result of this study may be useful to improve school health program such as conducting air quality monitoring and controlling or improving school’s environmental features.

MATERIALS AND METHODS

Location and Sampling
The location of air quality measurement was ten classrooms and three fields from three junior high schools located in sub-districts with different environmental characteristics namely Cimanggis (school A), Tapos (school B), and Beji (school C) as shown in Fig. 1. School A is on the roadside and surrounded by office, stores and housing complex. School B is in the residential area. School C is located in the city center near busy main road, public transportation terminal and business area. The three schools had characteristics as shown in table I. The classrooms of each school were selected randomly.

Measurement of air quality parameters (PM$_{2.5}$, PM$_{10}$, CO$_2$ and HCHO) was conducted in May 2018 using several air quality monitoring instruments, namely DustTrak™ II Aerosol Monitor 8532 (PM$_{2.5}$, PM$_{10}$), VelociCalc/Q-Trak 7565 (CO$_2$, CO, temperature, humidity), and Formal Demeter HIV (HCHO). The instruments installed in the middle front of the classroom, at height parallel to student seating position. Each instrument was calibrated on measured point before running a measurement episode (23,24). The measurement was conducted on school hours with each parameter measured for one hour per point (classroom and field) unless formaldehyde that was only measured for 30 minutes per classroom point. The measurement of PM$_{2.5}$ and PM$_{10}$ were not conducted simultaneously due to limited instrument availability. Indoor and outdoor air quality measurements were not conducted simultaneously due to the limited instrument availability. Formaldehyde was measured indoor only. The size of the floor (C) and ventilation (V) of the classroom was also measured using measuring tape. The ventilation size was the opening area of windows during air quality monitoring (25). Closed windows were not measured.

The minimum sample size was calculated using sample size formula for simple random sampling (26). The exposure of poor air quality is associated with abnormal lung function so that be used to approach the proportion of risk group. The proportion of abnormal lung function was based on a study by Kamaruddin (23). The sample size formula was as followed, with 95% confidence, the proportion of risk group (p) was 0.65 and absolute precision (d) was 0.05. Therefore, the minimum sample size (n) in this study was 350. The number of participated students from ten classrooms was 357, met the minimum sample size.

$$n = \frac{Z_{1-\alpha}^2 p (1 - p)}{d^2}$$

A survey was conducted on 357 students from randomly selected ten classrooms of each school to obtain data on body weight, height, and activity patterns that describe the population of junior high school students in Depok. The measurement of weight and height used digital scale and microtoise, while data on activity patterns were collected through questionnaires filled directly by the students.

Data Analysis
Air quality data, anthropometry, and activity patterns were analyzed descriptively to determine mean, median, and normal distribution of data using statistical analysis software. The used median size was in the form of mean or median based on data distribution. Furthermore, the non-parametric Mann Whitney test was used to compare the air quality inside and outside the classroom because not all data were normally distributed even though the data were transformed. Statistical analysis was carried out using SPSS version 22.0.

Health Risk Assessment
Quantitative risk assessment was conducted by referring to the Risk Assessment and Management Handbook 1996. Classrooms air quality data, anthropometric data, and students’ activity data were used to estimate daily intake of PM$_{2.5}$, PM$_{10}$ and carbon dioxide as non-carcinogenic agent; and formaldehyde as carcinogenic agent (27,28). The formula used is as follows:

$$CDI \text{ or } LADD = \frac{C \times R \times t_E \times f_E \times D_E}{W_b \times t_{avg}}$$

Calculation of the non-carcinogenic and carcinogenic daily intake (CDI or LADD, mg/kg/day) using mean or median pollutant concentrations (C, mg/m$^3$) depending on the data distribution. For the daily intake of carbon dioxide and formaldehyde, the concentration value of ppm is converted to mg/m$^3$ with the ideal gas equation at a measured temperature. While the rate of inhalation (R) uses the inhalation rate value of 11-16 years old, which are 15.7 m$^3$/day (29). Junior high schools in Depok apply school time (t_E, hour/day) 6 hours/day, 5 days/week. Based on the 2017/2018 academic calendar set by the West Java Provincial Education Board are obtained 218 days/year of school days including the exam days which is then deducted by the average of absence day according to the survey of student activity patterns so that the frequency of exposure (f_E, day/year) is obtained. In addition, students also conducted extracurricular activities after the normal 6 school-hours so then the calculation of the daily intake was also
conducted based on the average time and frequency of extracurricular activities in the classroom. Duration of exposure ( was based on the compulsory junior high school education for three years. Subsequently, it was divided by the value of student weight (Wb, kg) and the average daily period of carcinogenic exposure (DE x 365 day/year). Therefore, the daily intake value is the amount of normal daily intake (CDIn or LADDn) and additional daily intake (CDIt or LADDt).

Daily intake value of PM$_{2.5}$, PM$_{10}$, and carbon dioxide would be used to calculate the risk level of non-carcinogenic (HQ) exposures. Daily intake value of formaldehyde was used to calculate the risk level of carcinogenic (ECR) exposures. The risk level was calculated using following formula:

Non-carcinogenic risk:

$$ HQ = \frac{CDI}{RfC} $$

Carcinogenic risk:

$$ ECR = LADD \times IUR $$

The risk level (HQ) calculation of non-carcinogenic health impact through the inhalation pathway was carried out on the exposure to PM$_{2.5}$, PM$_{10}$, carbon dioxide, and formaldehyde by comparing the daily intake to the estimated value of exposure that did not provide health impact. For the inhalation pathway, this value was called reference concentration (RfC), which could be obtained from NOAEL, LOAEL, or benchmark concentration along with uncertainty factor. The RfC value for PM$_{2.5}$, PM$_{10}$, carbon dioxide and formaldehyde were not available in the IRIS list. The researchers used annual guideline value that was derived based on the default value of exposure factors for adult individual recommended by U.S. EPA in 2014 and Exposure Factors Handbook 2001 to obtain a safe reference for daily intake. The guideline value used is the annual (long term) guideline value of PM$_{2.5}$ (primary guideline 0.012 mg/m$^3$, secondary 0.015 mg/m$^3$) and PM$_{10}$ (0.05 mg/m$^3$) based on National Ambient Air Quality Guidelines (NAAQS) U.S. EPA in 1997 and 2012, carbon dioxide (1000 ppm) from American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Guideline 62.1-2016 recommendation, and 30 minutes formaldehyde guideline value (0.08 ppm) based on World Health Organization (WHO) in 2010 (30). The reference value of the safe intake used was PM$_{2.5}$ 0.002 mg/kg/day and 0.003 mg/kg/day, PM$_{10}$ 0.009 mg/kg/day, carbon dioxide 338.51 mg/kg/day, and formaldehyde 0.019 mg/kg/day. The risk level of carcinogenic exposure (ECR) is calculated for formaldehyde exposure using the value of Inhalation Unit Risk (IUR) was 1.3 x 10$^{-8}$ mg/m$^3$ (31).

If the HQ exceeded one, it is estimated that the level of PM$_{2.5}$, PM$_{10}$, carbon dioxide, and formaldehyde exposure inflict non-cancer effects to the students. Similarly, if the ECR exceeded one, it is estimated that the level of formaldehyde exposure inflict cancer effects to the students.

This research was approved by the ethic board of Universitas Indonesia, Faculty of Public Health, Universitas Indonesia (No.: 458/UN2.F10/ PPM.00.02/2018) and the respondent’s parents by signing the informed consent sheet.

**RESULTS**

**Indoor Air Quality**

The three schools have characteristics as shown in table I and Fig 1 with the highest percentage of ventilation to the size of classroom (% V/C) in school C. According to Regulation of Health Minister of Republic of Indonesia No. 1429/2006 on Guidelines of Health School Environment (Permenkes RI No. 1429/2006), the percentage of ventilation opening to room area should be 20%. The result of air quality measurement in table II shows the concentration of exposures at each school. The highest value of PM$_{2.5}$ was in school B with a median of 0.119 mg/m$^3$ for indoor air and a mean of 0.144 mg/m$^3$ for outdoor air. The lowest was at school C with a median of 0.056 mg/m$^3$ for indoor air. While the PM$_{10}$ indoor and outdoor was found to be highest at school C with a mean of 0.229 mg/m$^3$ and median of 0.218 mg/m$^3$, respectively. The lowest concentration of indoor PM$_{10}$ was measured at school B with a median of 0.071 mg/m$^3$ and outdoor PM$_{10}$ at school A with a mean of 0.065 mg/m$^3$. The highest value of carbon dioxide concentration indoor and outdoor was found in school B (556 ppm indoor, 270 ppm outdoor) followed

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**Table I: School and Classroom Characteristics**

<table>
<thead>
<tr>
<th>School</th>
<th>Mean V/C (%)</th>
<th>Regulation of Minister of Health RI (Permen-kes RI) No. 1077/2011</th>
<th>Environmental Characteristics</th>
<th>Classroom Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>14.50</td>
<td>In the middle of residential area. Cemented floors and field and paved courtyard.</td>
<td>Fan, wooden table, wooden chair, white-board, and marker.</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>29.65</td>
<td>On the side of the busy main road. A business area in the city center. Cemented floors and courtyard.</td>
<td>Fan, wooden table, wooden chair, white-board, and marker. One class with carpet.</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 1: The junior high school A, B, and C were located in sub-districts of Depok, with different environmental characteristics. School A (Cimanggis) was on the roadside, surrounded by offices, stores and houses. School B (Tapos) was in the residential area. School C (Beji) was in the city center, adjacent to busy main road and business district. Source: Google Earth, accessed on Mar 2, 2019.

Table II: Indoor Air Quality of School A, B and C

<table>
<thead>
<tr>
<th>Parameter &amp; Location</th>
<th>School A</th>
<th>School B</th>
<th>School C</th>
<th>Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (±SD)/ Median (IQR)</td>
<td>Mean (±SD)/ Median (IQR)</td>
<td>Mean (±SD)/ Median (IQR)</td>
<td>NAAQS U.S. EPA 1997, WHO air quality guidelines, Government Regulation of Republic of Indonesia No.41/1999</td>
</tr>
<tr>
<td><strong>Temperature(°C)</strong></td>
<td>Indoor 30.76 ± 1.43, Median 29.54</td>
<td>29.54 ± 1.25, Median 29.98</td>
<td>0.46, Median 36.43</td>
<td>18-30</td>
</tr>
<tr>
<td></td>
<td>Outdoor 37.03 ± 1.31, Median 33.53</td>
<td>33.53 ± 0.36, Median 36.43</td>
<td>0.88, Median 36.43</td>
<td>40-60</td>
</tr>
<tr>
<td><strong>Humidity (% Rh)</strong></td>
<td>Indoor 68.83 ± 8.07, Median 73.09</td>
<td>73.09 ± 6.16, Median 69.31</td>
<td>4.23, Median 69.31</td>
<td>0.035, 24 hours</td>
</tr>
<tr>
<td></td>
<td>Outdoor 39.81 ± 5.58, Median 52.71</td>
<td>52.71 ± 1.17, Median 44.63</td>
<td>3.45, Median 44.63</td>
<td>0.012 - 0.015, 1 year</td>
</tr>
<tr>
<td><strong>PM$_{2.5}$ (mg/m$^3$)</strong></td>
<td>Indoor 0.113 ± 0.015, Median 0.119</td>
<td>0.120, Median 0.056</td>
<td>0.020, Median 0.020</td>
<td>0.012 - 0.015, 1 year</td>
</tr>
<tr>
<td></td>
<td>Outdoor 0.053 ± 0.003, Median 0.144</td>
<td>0.012, Median 0.057</td>
<td>0.009, Median 0.009</td>
<td>0.012 - 0.015, 24 hours</td>
</tr>
<tr>
<td><strong>PM$_{10}$ (mg/m$^3$)</strong></td>
<td>Indoor 0.188(0.127), Median 0.071</td>
<td>0.017, Median 0.229</td>
<td>0.058, Median 0.058</td>
<td>0.015 - 0.1, 1 year</td>
</tr>
<tr>
<td></td>
<td>Outdoor 0.065 ± 0.003, Median 0.087</td>
<td>0.010, Median 0.120</td>
<td>0.023, Median 0.120</td>
<td>0.015 - 0.1, 24 hours</td>
</tr>
<tr>
<td><strong>CO$_2$ (ppm)</strong></td>
<td>Indoor 408.741 ± 75.276, Median 572.446</td>
<td>170.169</td>
<td>368.040</td>
<td>0.15, 24 hours</td>
</tr>
<tr>
<td></td>
<td>Outdoor 250.813 ± 20.961, Median 268.04</td>
<td>250.000</td>
<td>250.000</td>
<td>0.15, 24 hours</td>
</tr>
<tr>
<td><strong>CO (ppm)</strong></td>
<td>Indoor 0.000 (0.000), Median 0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.00, 8 hours</td>
</tr>
<tr>
<td></td>
<td>Outdoor 0.0200(0.010), Median 0.0200</td>
<td>0.030</td>
<td>0.030</td>
<td>0.02, 1 hour</td>
</tr>
<tr>
<td><strong>Formaldehyde (ppm)</strong></td>
<td>Indoor 0.0200(0.010), Median 0.0200</td>
<td>0.030</td>
<td>0.030</td>
<td>0.08, 30 minutes</td>
</tr>
<tr>
<td></td>
<td>Outdoor 0.0200(0.010), Median 0.0200</td>
<td>0.030</td>
<td>0.030</td>
<td>0.10, 30 minutes</td>
</tr>
</tbody>
</table>

Measurement of indoor and outdoor air quality was conducted in different hours but the same day, so it was assumed to represent the outdoor air quality along the measurement of the same day. The value of I/O ratio > 1 in table III shows that certain parameters were found to be higher at indoor. The value PM$_{2.5}$, PM$_{10}$, and CO$_2$ indoor concentration ratio to the outdoor was found more than one at school A (I/O PM$_{2.5}$, 2.13; PM$_{10}$, 2.89; CO$_2$ 1.64) and was statistically and significantly different. The ratio of indoor PM$_{2.5}$ and PM$_{10}$ concentration to outdoor at school B and C was not more than one, not statistically and significantly for school C. The value of indoor carbon dioxide ratio to the outdoor in all schools by A and C. The formaldehyde central tendency was substantially the same between the three schools. The highest formaldehyde value of 0.025 ppm was found in school C. The mean of indoor temperature at school A (30.67 °C) was slightly higher than school B, and C. While the highest mean of indoor humidity was at school B (73.09% Rh). In Table II, the measured parameters is compared against several guidelines i.e. National Ambient Air Quality Guidelines (NAAQS) U.S. EPA, WHO air quality guidelines, Government Regulation of Republic of Indonesia No.41/1999 on Environmental Management (PP RI No. 41/1999), Regulation of Health Minister of Republic of Indonesia No. 1077/2011 on Guidelines Air Sanitation in House (Permenkes RI No. 1077/2011).
Table III: Ratio of Indoor to Outdoor Air Quality

<table>
<thead>
<tr>
<th>Parameter</th>
<th>School A</th>
<th>School B</th>
<th>School C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I/O</td>
<td>p value</td>
<td>I/O</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>2.13</td>
<td>0.000$^a$</td>
<td>0.83</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>2.89</td>
<td>0.000$^b$</td>
<td>0.82</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>1.63</td>
<td>0.000$^b$</td>
<td>2.14</td>
</tr>
</tbody>
</table>

Mann-Whitney Test

Indoor and outdoor air quality significantly different at $p < 0.05$

was more than one and statistically and significantly different.

Assessment of Non-Carcinogenic and Carcinogenic Health Risks

The risk assessment was conducted for three academic years of exposure to the junior high schools’ students therefore the calculation of daily intake values based on anthropometric data and activity patterns of the respective group. The daily intake (CDI or LADD) was calculated by adding up normal daily intake (CDIn or LADDn) and additional daily intake (CDIe or LADDDe), as shown in table IV. Normal daily intake describes intake during normal school hours while additional daily intake describes intake during extracurricular activities after normal school hours. The normal and additional daily intake used anthropometric data according to the results of survey by 357 students as respondents consisted of 157 males (44%) and 200 females (56%) with weight median of 46 kg, age 10-17 years from grade seven to nine of junior high school. Inhalation rate of the students is 15.7 m$^3$/day, based on the inhalation rate of children aged 11-16 years old (29).

Based on the survey, a median of absence day was 2 days/year that reduce the number of normal school days (218 days/year), so that the frequency of exposure (fEn) was 216 days. The duration of exposure (DE) was three years according to the academic period of junior secondary. The extracurricular activity in the classroom took a median of 0.75 hour/day (tEe), 1 day/week. It was assumed that students carried out activities for 30 weeks/year outside the exam weeks so that they can get 30 days/year of extracurricular activity (fEt).

The calculation of non-carcinogenic risk health of PM$_{2.5}$

Table IV: Daily Intake of Non-Carcinogenic and Carcinogenic Exposures in Three Years

<table>
<thead>
<tr>
<th>Effect &amp; Exposure</th>
<th>School A</th>
<th>School B</th>
<th>School C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal School Hours</td>
<td>Normal &amp; Extracurricular Hours</td>
<td></td>
</tr>
<tr>
<td>Non-carcinogenic</td>
<td>Wb = 46kg</td>
<td>Wb = 35.5kg$^c$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wb = 46kg</td>
<td>Wb = 35.5kg$^c$</td>
<td></td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>0.006</td>
<td>0.006</td>
<td>0.003</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>0.010</td>
<td>0.004</td>
<td>0.012</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>0.011</td>
<td>0.004</td>
<td>0.013</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>3.705E+01</td>
<td>5.056E+01</td>
<td>3.345E+01</td>
</tr>
<tr>
<td>Carcinogenic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Formaldehyde</td>
<td>1.175E-03</td>
<td>1.242E-03</td>
</tr>
</tbody>
</table>

DISCUSSION

Indoor Air Quality

Indoor PM$_{2.5}$ and PM$_{10}$ in school A were considerably high and exceeded the guideline of 24-hours and annual of WHO, NAAQS U.S. EPA, PP RI No. 41/1999, and Permenkes RI No. 1077/2011. By considering the environmental characteristics of school A, indoor PM$_{2.5}$ and PM$_{10}$ might be sourced from outdoor such as traffic emission, not cemented school yard, or particulate matters attached to students (32,33). However, school A had the lowest concentration of outdoor PM$_{2.5}$ and PM$_{10}$ among all schools. The low outdoor PM$_{2.5}$ and PM$_{10}$ might be caused by rain that occurred a day before the measurement at school A, so that it was expected to dissolve mainly outdoor PM$_{2.5}$ and PM$_{10}$ but not much affect indoor air. In addition, it is reported that high indoor concentration of PM$_{2.5}$ and PM$_{10}$ were associated with less or inefficient deposited particles removal or room cleaning and inadequate ventilation causing accumulation of the particulate matters (34). The average V/C % of school A was found below the guideline value of 20% according to Permenkes RI No. 1077/2011. The particulate matters might be trapped in the classroom, not much affected by the rain on previous
day. Resulting in, school A had highest I/O ratio for PM$_{2.5}$ and PM$_{10}$ among all schools. This research did not record meteorological condition but several studies reported that meteorological conditions such as the wind and rain could reduce the concentration of particulate matters (9,35). However, the level of outdoor PM$_{2.5}$ exceeded the guideline of 24-hours and annual of WHO, NAAQS U.S. EPA, and annual of PP RI No. 41/1999. The level of outdoor PM$_{10}$ exceeded the guideline of 24-hours and annual of WHO. Government Regulation of Republic of Indonesia and was U.S. EPA are more loose on the guideline of annual level of PM$_{10}$ than WHO. The measurement of particulate matters level in school B, which was located in the residential area, showed high indoor and outdoor PM$_{2.5}$. The level of indoor and outdoor PM$_{2.5}$ was the highest among three schools. Meanwhile, indoor and outdoor PM$_{10}$ of school B was relatively low. Biomass burning and cooking are the main source of PM$_{2.5}$ pollutants in the residential areas (6,33). Besides that, soil particles from not cemented yard around the school leads to a high concentration of indoor PM$_{2.5}$ in school located in the residential area (6,34). The indoor concentration of PM$_{2.5}$ and PM$_{10}$ at school B was lower than outdoor leaded to lower I/O ratio than school A and C. This might indicate modest source of indoor particulate matters or good classroom cleanliness despite inadequate ventilation. The average V/C % of school B was found below the guideline value of 20% according to Permenkes RI No. 1077/2011. However, the level of indoor and outdoor PM$_{2.5}$ in school B exceeded the value guideline of 24-hours and annual of WHO, NAAQS U.S. EPA, PP RI No. 41/1999, and Permenkes RI No. 1077/2011. The level of outdoor PM$_{10}$ exceeded the guideline of 24-hours and annual of WHO.

The level of indoor PM$_{2.5}$ and PM$_{10}$ in school C exceeded the guideline of 24-hours and annual of WHO, NAAQS U.S. EPA, PP RI No. 41/1999, and Permenkes RI No. 1077/2011. Similar to the school A, the measurements at school C was performed after a rainy day but with different result. The rain was estimated to dissolve PM$_{2.5}$ so that it was measured low but still left high PM$_{10}$. The level of indoor and outdoor PM$_{10}$ was the highest among three schools and exceeded the guideline of 24-hours and annual of WHO, NAAQS U.S. EPA, PP RI No. 41/1999, and Permenkes RI No. 1077/2011. However the level of outdoor PM$_{2.5}$ and PM$_{10}$ was statistically not different to indoor and exceeded the compared guidelines. The location of school C was on the side of the main highway in the city center. High particulate matters could be sourced from heavy traffic that infiltrates school building. Traffic activity becomes one of the sources of indoor and outdoor PM$_{10}$ due to fuel burning from motorized vehicles (32,33). A research on indoor PM$_{10}$ reported that highway dust was a major component and associated with the high level of indoor PM$_{10}$ (32). The chemical components of particulate matters could be analyzed further so that it can indicate the source of indoor and outdoor PM$_{10}$ (4,32).

EPA studies indicate that indoor levels of pollutants may be two to five times higher than outdoor levels (3). Other study in Poland reported I/O ratio of particulate matters was 0.8 to 5.6 in school during day time with the level of particulate matters exceeded the WHO air quality guidelines (2). Whereas a study in tropical schools found I/O ratio of PM$_{10}$ was above one and its level also exceeded the WHO air quality guidelines (32). The I/O ratio above one indicates higher indoor particulate matters. In this study, the I/O ratio of PM$_{2.5}$ and PM$_{10}$ was 0.82 to 2.89 and the level of PM$_{2.5}$ and PM$_{10}$ exceeded various guidelines. These studies showed that air quality in school environment requires significant attention since school age children spend about 6-8 hours per day in this microenvironment.

The median of indoor and outdoor carbon dioxide all schools did not exceed the guideline of Permenkes RI No. 1077/2011 and ASHRAE Guideline 62.1-2016. The level of carbon dioxide concentration in school A and B was higher than school C. The high carbon dioxide in the might be due to the ventilation factor. The average V/C % of school A and B was below the guideline value of 20% according to Permenkes RI No. 1077/2011. Indoor carbon dioxide concentration is related to several factors, i.e. occupant activity, room density, and length of occupancy. In addition, the size, number, position and type of ventilation affect the concentration of carbon dioxide in the classroom air using natural ventilation (36,37). The 30-minutes concentration of formaldehyde in all schools did not exceed the guideline value of WHO and Permenkes RI No. 1077/2011. Formaldehyde in classrooms might be sourced from markers, furniture tables and wooden chairs, or painted wall which are observed at the time of measurement. Assessment of Non-Carcinogenic and Carcinogenic Health Risk

This research estimated that the exposure of PM$_{2.5}$ in classroom led to non-cancer health problems to the students. PM$_{2.5}$ exposure is considered more dangerous risk factor than PM$_{10}$ because of the smaller particle size that enters the lungs and consist more toxic materials. Short-term exposure to PM$_{2.5}$ is associated with a number of respiratory health effects such as development of chronic respiratory diseases; reduced lung function; increased hospital visits and emergencies for respiratory diseases such as asthma, coughing, wheezing and shortness of breath and development of cardiovascular disease (17,38). Short term exposure might be reversible but long term exposure associated with greater health effect such as chronically reduced lung growth and function, cardiopulmonary and lung cancer mortality (17,18,39). Long term exposure to PM$_{2.5}$ is stronger risk factor of mortality than PM$_{10}$ (17). Studies reported the exposure of PM$_{2.5}$ at school environment was associated
with asthma or asthma-like symptoms and airway inflammation on students (1,12).

The assessment of the exposure of PM₁₀ in this research estimated non cancer health risk to the students. Short-term exposure to PM₁₀ may be related to respiratory health and hospital visits and emergency units for cardiopulmonary related diseases. A study in Brazil showed that daily respiratory hospital admissions for children and adolescents in Sao Paulo increased with PM₁₀ level (40). Whereas, studies at school environment found the exposure of PM₁₀ at was associated with asthma-like symptoms and lung function disorder on students (1,12). Various long-term exposure toxicology studies indicate that PM₁₀ is contaminated with heavy metals and other pollutants such as polycyclic aromatic hydrocarbons (PAHs) that can directly enter the body through inhalation, skin and oral contact so as to increase the risk of cardiovascular and respiratory diseases, and lung cancer (4,32,41). Furthermore, health risk could be assessed based on the chemical composition of particulate matters.

Level of PM₂.₅ and PM₁₀ concentration that exceeds the guideline values may lead to health risk (HQ > 1) and requires risk management. The most possible control scenario is to control the concentration of PM₂.₅ and PM₁₀ so that the daily intake value is lower than the RfC. School hour and academic year are associated to the quality of education and student achievement, not to be modified. Based on the tenth percentile of student body weight, 35.5 kg and the normal school hour without additional activities, a safe threshold of PM₂.₅ is 0.035 mg/m³; 0.043 mg/m³ and PM₁₀ 0.144 mg/m³. This concentration is higher than the set guideline value and safe for 90% of the population only during normal school hours. Controlling the concentration of particulate matters can be performed by regular room cleaning to reduce the accumulation of particulate matters, regulating ventilation opening to the class area to meet the guideline, the use air purifier in the classroom, and school location should not adjacent to pollutant sources such as roads or industries.

Risk studies on the exposure of indoor carbon dioxide estimated no health effect to the students. In addition, 1000 ppm recommendation value is related to the formation of body odor that disrupts the comfort of room occupants and does not have a serious effect on health (2,34). A research in Portugal using a 984 ppm reference value reported that high CO₂ exposure is statistically related to the student concentration (36).

Low formaldehyde exposure in all schools was estimated to not provide non-carcinogenic and carcinogenic health effect. The exposure of 0.1 to 0.5 ppm formaldehyde through the inhalation pathway causes irritating effect on the eyes and nasal passages, neurological effects, and an increased risk of asthma or allergies (21). Meanwhile, carcinogenic health effect on humans, ATSDR 1989 classified formaldehyde as group B1 or possibly carcinogen because of limited evidence for the incidence of human cancer.

CONCLUSION

The pattern of particulate matters among the three schools was different which might be related to each school environmental characteristic and meteorological condition. However, the level of PM₂.₅ and PM₁₀ at three schools located in different environmental settings exceeded various short-term and long-term guidelines which indicates indoor poor air quality and inflicts a risk level of HQ > 1 for junior high school students. While the concentration of carbon dioxide and formaldehyde exposure was still in accordance with the applicable guideline values. The risk management scenario of PM₂.₅ and PM₁₀ exposure is required by controlling the concentration level of PM₂.₅ and PM₁₀ throughout school hour. Controlling the particulate matters could be done by regular room cleaning to reduce the accumulation of particulate material, the provision of air purifier, periodic air quality monitoring, regulating ventilation opening to classroom area to fit guideline values, and improving school locations or environmental settings by not being close to pollutant sources such as roads or industries. Furthermore, this research could be improved by conducting longer and simultaneous air quality monitoring and advanced health assessment method, counting in meteorological condition and epidemiological study to find the association between exposure levels and student health status.

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