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$PM_{2.5}$ and PM_{10} Concentrations at Indoor and Outdoor in Industrial Area

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ABSTRACT
This study examines the total concentration of particulate matter (PM) in Banjaran, an industrial sub-district located in the south of Bandung. Sampling was conducted using the gravimetric method with a mini particle counter measuring instrument, known as CEM DT-96. Sampling was carried out at a house and a school in 24-hours and five days of working hours. The results show that concentration of PM either during indoor or outdoor condition can be affected by activity, air temperature, air relative humidity, air ventilation area, and particulate deposition rate. In addition, air quality for industrial area was categorized as unhealthy. It is due to PM concentrations exceeding air pollution quality standards as highlighted by Environmental Protection Agency.

KEYWORDS
$PM_{2.5}$
PM_{10}
Indoor
Outdoor
Industrial-Area

INTRODUCTION

Banjaran is a sub-district located in the south of Bandung. It is one of the most densely populated industrial area in Indonesia. As an industrial area, there are various kinds of factories such as paper-making factories, textiles, pharmaceuticals, beverage products, processed food, etc. As a result, trees are rarely found. A part from that, horse carts are allowed as a means of transportation and horse manure is also allowed to just fall onto the streets. These factors will result in bad air pollution which later create a negative impact on humans who live around it.

The World Health Organization (WHO) reported that there are seven million peoples die worldwide every year due to air pollution [WHO, 2019]. One type of air pollution is particulate matter (PM). Air pollution particulate matter is dispersed material in the air, whether solid or liquid, which is larger than a molecule (0,002 μm^3) and smaller than 500 μm^3 (Wark et al., 1998).

There is a high correlation between the indoor and outdoor air PM because ventilation system in high-rise buildings utilize fresh air from outdoor (Kuo and Yi, 2019). Outdoor environmental

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conditions have an impact on increasing the concentration of air pollutants in a building. The number of working factories and vehicles that pass in front of buildings and in surrounding settlements can be a source of pollutants for outdoor air or ambient air. This is because the pollutants produced from combustion in the factory production process, and the vehicle internal combustion engine are discharged into the free air. The concentration of PM in outdoor is also influenced by the wind direction (Contini et al., 2011). Besides that is exacerbated by the existence industrial activities increase PM emissions, which can make people around them unhealthy (Chiari et al., 2006). The objective of this study is to find factors that can influence PM concentrations in indoor and outdoor air and compare the measurement of PM concentrations with the EPA-US (Environmental Protection Agency – United State) air pollution quality standard.

METHODS

Building Location Description

The study was conducted in a school and a house with six different measuring conditions. The measuring conditions are indoor house without air conditioning (A/C) (living room), indoor school with A/C, indoor school without A/C, outdoor house, outdoor school and near the street. The location of sampling is focused on the school; therefore the location of the house was chosen close to the existence of the school being study.

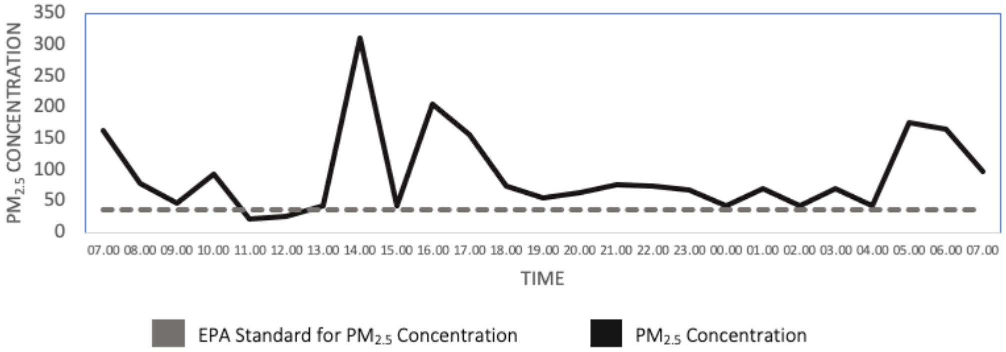
Sampling Method

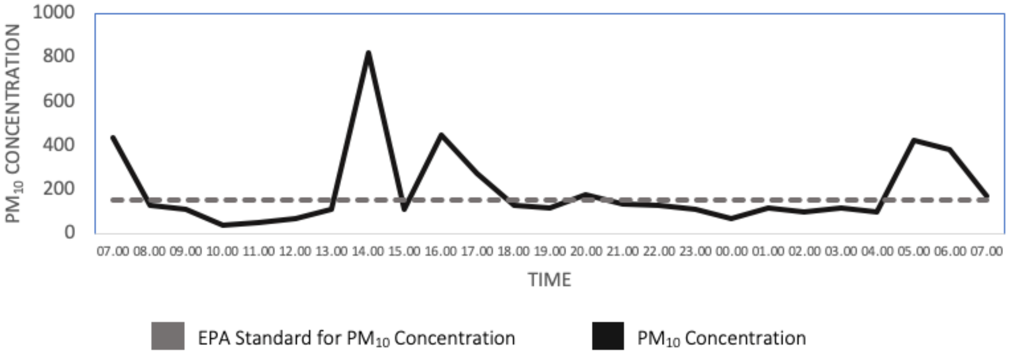
The direct-reading instrument used to measure particle size and concentrations was a CEM Instrument DT-96. The machine has the ability to measure particle sizes of 10 and 2.5 µm, air relative humidity, and air temperature. It uses a gravimetric method, where the concentration is determined from the result of reducing weight of the sample in a fine filter with the weight of empty fine filter. Measurements on the instrument are carried out for 15 seconds. Sampling periods were divided into two categories, which are for 24 hours at one of the measuring points outdoors and for five days with nine hours for each day starting at 7:00 AM until 3:00 PM at each measurement points.

RESULT AND DISCUSSION

Condition of the measurement area for 24-hours

Figure 1 and 2 show PM concentrations of outdoor (near the road) condition in industrial areas with a measurement time span of every an hour, for $PM_{2.5}$ and PM_{10} respectively. A part from that, a 24-hour averaging for a $PM_{2.5}$ concentration of 96 and a PM_{10} concentration of 201 were obtained. In fact, EPA provides a threshold or quality standard for outdoor air pollution of 35 for the concentration of $PM_{2.5}$ and 150 for the concentration of PM_{10} (EPA, 2016).





Air quality index (AQI) is used as earlier indicator to avoid excessive level of PM. In other words, AQI is used to alerts everyone so that PM at harmful level can be prevented. Consequently, AQI can protect everyone from being exposed to harmful level of PM if earlier prevention action can be taken. AQI is calculated as in equation (1), where:

$$AQI = \left[\frac{(PM_{obs} - PM_{min}) \times (AQI_{max} - AQI_{min})}{(PM_{max} - PM_{min})}\right] + AQI_{min} \qquad (1)$$

Where PM_{obs} is observed 24-hour average concentration in μg/m^3, PM_{max} is maximum concentration of AQI color category that contains PM_{obs}, PM_{min} is minimum concentration of AQI color category that contains PM_{obs}, AQI_{max} is maximum AQI value for color category that corresponds to PM_{obs}, and AQI_{min} is minimum AQI value for color category that corresponds to PM_{obs}.

By using equation (1), AQI value for $PM_{2.5}$ concentration of 172 which considered as unhealthy category (red code) was obtained. It means for group with sensitive peoples who have a respiratory or heart disease, the elderly and children, are the groups most at risk. That increased aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; increased respiratory effects in general population.

Meanwhile for PM_{10} concentration, AQI value of 124 was obtained which reflects to unhealthy condition for sensitive group category (orange code). It means for group with sensitive peoples who have a respiratory or heart disease, the elderly and children, are the groups most at risk. That increasing likelihood of respiratory symptoms and aggravation of lung disease, such as asthma. As a result, people with respiratory or heart disease, the elderly and children should avoid prolonged exertion.

Factors that affect indoor air PM concentrations

From the measurements carried out for five days in an industrial-area, one of the days that has the minimum and maximum PM concentration was taken. Figure 3 shows a graph of the $PM_{2.5}$ concentration on a day, by comparing the minimum and maximum $PM_{2.5}$ concentration values. Figure 4 shows a graph of the PM_{10} concentration on a day, by comparing the minimum and maximum PM_{10} concentration values. The reason of PM concentrations showing the minimum or maximum PM concentrations on a certain day is due to various factors. These factors are the influence of activity, wind speed and direction or daily vehicle intensity is different.

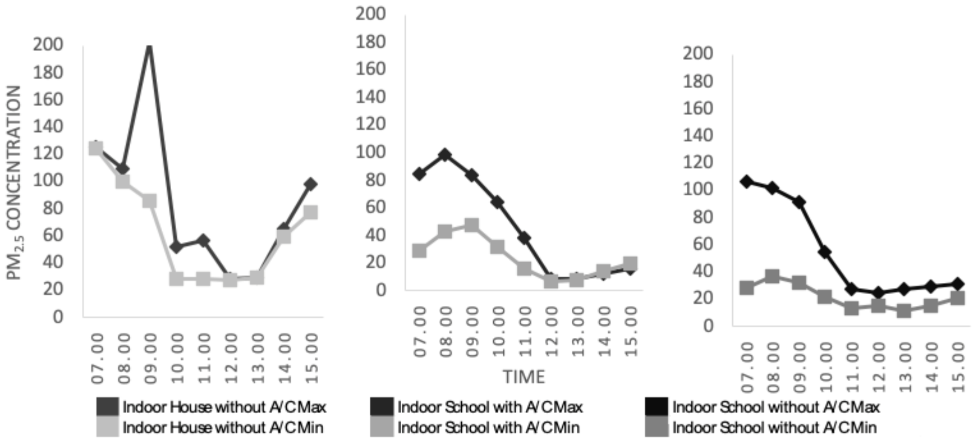


Figure 3. Comparison of maximum and minimum concentration values for $PM_{2.5}$ concentration at three different indoor sites

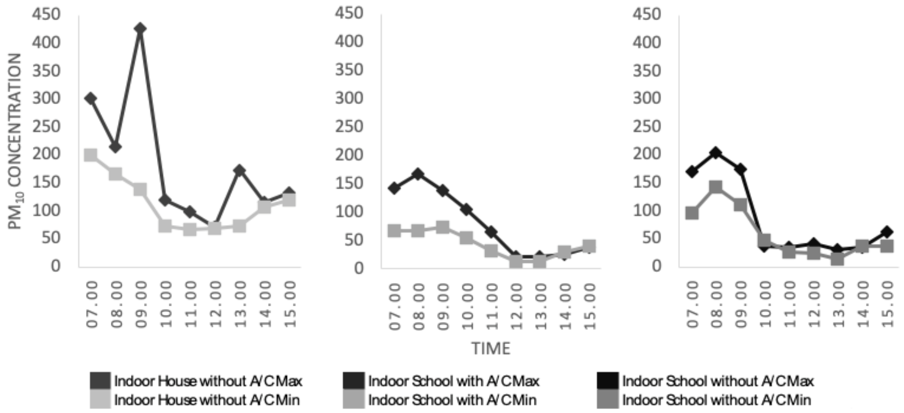


Figure 4. Comparison of maximum and minimum concentration values for PM_{10} concentration at three different indoor sites

Factors that affect outdoor air PM concentrations

From the measurements carried out for five days in an industrial-area, one of the days that has the minimum and maximum PM concentration was taken. Figure 3 shows a graph of the $PM_{2.5}$ concentration on a day, by comparing the minimum and maximum $PM_{2.5}$ concentration values. Figure 4 shows a graph of the PM_{10} concentration on a day, by comparing the minimum and maximum PM_{10} concentration values.

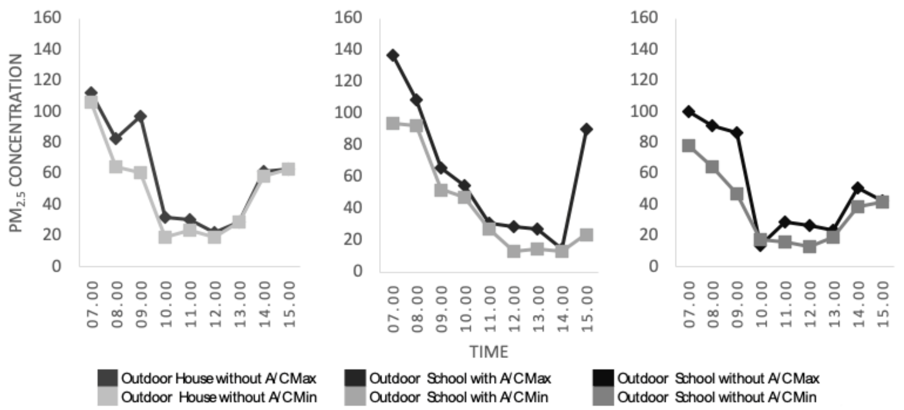


Figure 5. Comparison of maximum and minimum concentration values for $PM_{2.5}$ concentration at three outdoor sites indoor sites

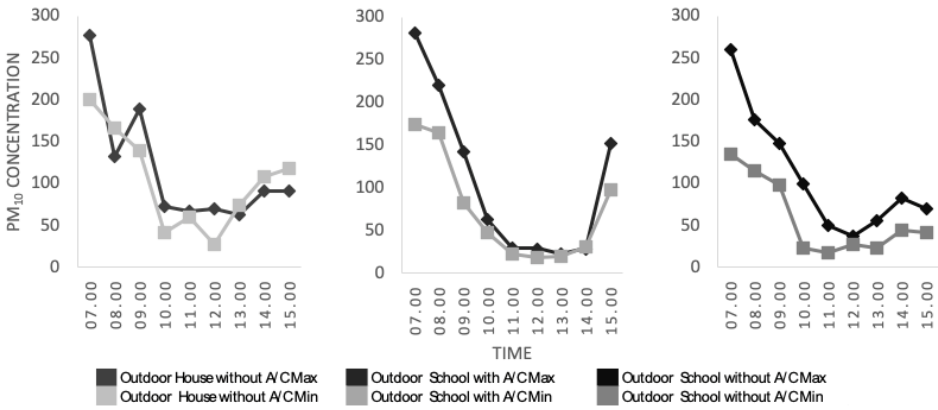


Figure 6. Comparison of maximum and minimum concentration values for PM_{10} concentration at three outdoor sites

PM concentrations are small matter that can float in the air before finally falling to the ground. The rate of deposition for PM concentration can be calculated using the Stokes law (De Nevers, 1995), where:

$$V_t = gD^2 \frac{(\rho_{part} - \rho_{fluid})}{18\mu} \tag{2}$$

Where V_t is particle velocity (m/s), g is the earth gravitational force (9,81 m/s^2), D is particle diameter (m), ρ_{part} is particle density (2000 kg/m^3), ρ_{fluid} is density of fluids (1,2 kg/m^3) and μ is air viscosity ($1{,}8 \times 10^{-6}$ kg/m.s). From the Figure 5 and Figure 6, the concentration of PM in outdoor also has a concentration of PM which is directly proportional or relatively the same so that, from the data of this comparison, it is found that the outdoor measurement points anywhere shows the same value. This happens because the velocity of the soft particles (fine) or the concentration of PM is very slow. Using equation (2), the deposition rate for $PM_{2.5}$ and PM_{10} concentrations take 43.8 and 63 minutes to cover just one meter, respectively. Therefore, the dispersed soft particulates can hover in the air for quite a while.

Comparison of the correlation between the indoor and outdoor PM Concentrations

Figure 7 shows a graph of the maximum values of $PM_{2.5}$ concentration on a day, by comparing the indoor and outdoor $PM_{2.5}$ concentrations at six measurement points. Figure 8 shows a graph of the maximum values of PM_{10} concentration on a day, by comparing the indoor and outdoor

PM_{10} concentrations at six measurement points. The horizontal axis in the Figure 5 and Figure 6 show the measurement time starting from 7:00 AM until 3:00 PM. According to Figure 7 and Figure 8, PM concentrations at indoor was higher, as compared to PM concentrations at outdoor. This occurs due to the air outdoor that can move easily, in contrast to indoor air which is limited by space.

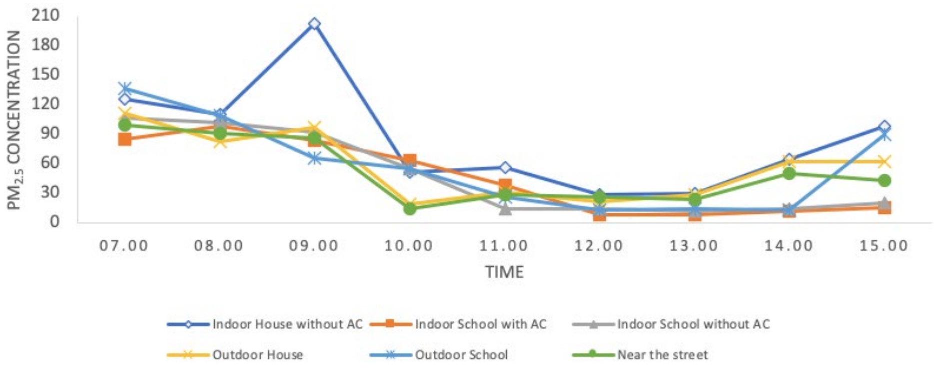


Figure 7. Comparison of maximum values of $PM_{2.5}$ concentration in both indoor and outdoor air on a day

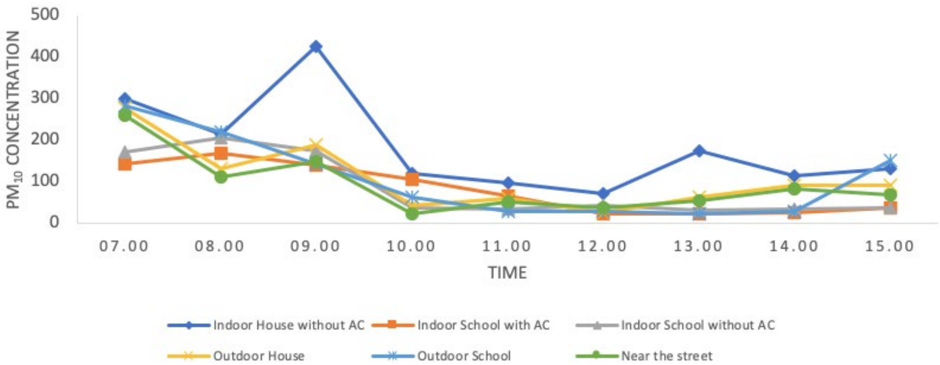


Figure 8. Comparison of maximum values of PM_{10} concentration in both indoor and outdoor air on a day

CONCLUSION

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