THE EFFECT OF VENTILATION AND OCCUPANT ACTIVITIES TOWARDS INDOOR AIR QUALITY IN RESIDENTAL HOUSE FOR FINE PARTICULATE

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Abstract

Indoor air quality is important because it is related to human health. One of the factors that can affect indoor air quality is ventilation and occupant activities. Poor air quality can cause respiratory problems and sick building syndrome. One of the harmful pollutants that affects human health is $PM_{2.5}$. This study aims to evaluate the quality of $PM_{2.5}$ within indoor air against quality standards and determine the ventilation and occupant activities that affect the concentration of $PM_{2.5}$. Primary data sources were obtained by measurements and questionnaires. Eleven houses (11) were sampled on 2 weekdays and 1 weekend. $PM_{2.5}$ concentration measurements were carried out indoors and outdoors. The results were then analysed using multiple linear regression analysis through the SPSS. The concentration of $PM_{2.5}$ indoors and outdoors has a moderate to strong correlation due to window opening activities. Fan usage time has a significant effect on reducing the concentration of fine particulates. The amount of furniture is also one of the factors that increase the concentration of fine particulates. The activity of opening a window has two effects, it can increase or decrease concentration. Further research is needed to observe the window opening to confirm the results of this study.

Keywirds: Air visual pro, fine particulates, indoor air quality, $PM_{2.5}$, ventilation

1. INTRODUCTION

The home environment can be a source of disease and discomfort for residents of the house. Most humans spend about 85-90% of their time in an indoor environment therefore a decrease in air quality can affect human health (Oktaviani & Prasasti, 2016). Beside that, air quality can also impact human productivity (Leung, 2015). Health problems that can be caused include lung diseases such as acute respiratory infections (pneumonia), asthma, COPD to lung cancer, and sick building syndrome (Aurora, 2021). Referring to (World Health organization, 2016) the number of deaths due to air pollution every year reached 8 million people and 54% came from indoor air pollution.

Sources of air pollutants include carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOC), ozone (O_3), heavy metals, and particulates ($PM_{2.5}$ and PM_{10}). The sources of indoor air pollution are related to equipment in the building (carpets, air conditioners, etc.), building conditions, temperature, humidity, air exchange and the behavior of people in the room, such as smoking (Dewi et al., 2021). $PM_{2.5}$ is a pollutant with a very small diameter, which is < less than 2.5 μm. Because of this size, fine particulates can enter the deepest respiratory tract, such as the alveolus. As many as 90.2% of children under five who live at home with high $PM_{2.5}$ levels have ISPA symptoms (Azhar et al., 2014).

The existence of windows as ventilation is very important to maintain air quality in the room. Ventilation as a medium for air circulation, which in ideal conditions of ventilation can ensure clean air conditions in the room. Indoor air pollution can come from outdoor pollution, and motor vehicles can affect the air quality of homes nearby the highways. Through ventilation, indoor spaces can become receptors for a mixture of outdoor pollutants, mainly from vehicular traffic and industrial activities (Bani Mfarrej et al., 2020). Concentrations emitted from higher emission sources have greater dilution and dispersion potential than emission sources close to the ground (Istirokhatun et al., 2016). Exposure to $PM_{2.5}$ concentrations in industrial areas has the most impact on distances from 1 km to 2.5 km (Novirsa & Achmadi, 2012).

The overuses of air conditioning also cause the change of air from outside to inside the room to become optimum when compared to natural ventilation. This can reduce indoor air quality and affect the health of room users. Furthermore the high concentrations of CO_2, NO_2, and $PM_{2.5}$ are also influenced by cooking activities (Yen et al., n.d.). Another study stated that cooking activities have an effect on $PM_{2.5}$ concentrations in living rooms (Liu et al., n.d.).

There is apparent relationship between pollutant sources and the exposure that occurs has an impact on human health. Hence an in-depth study is needed to prevail the effect of ventilation and occupant activities on the concentration of $PM_{2.5}$ in residential houses around industrial area and roadside area.

2. METHODS

Research preparation consists of several stages including preparing the Air Visual Pro sampling tool, making questionnaires and determining the research location. Questionnaires were also conducted to determine occupant activities that could affect indoor air quality. Measurement of $PM_{2.5}$ concentration was carried out indoors and outdoors at the same time. The concentration measurements were carried out for 5 houses located on the roadside and 6 houses around the industrial area. $PM_{2.5}$ concentration was measured with Air Visual Pro every 10 minutes for 1 x 24 hours on 3 days. Air Visual Pro can accurately record pollutant concentrations in real time. This portable device is capable of measuring air quality both indoors and outdoors using artificial intelligence and high-accuracy laser sensors (Govindaraj & Arpita Sarkar, 2021). Airvisual Pro detects fine and ultrafine (up to 0.3 micron) particulate pollution, CO_2, temperature, humidity in the indoor environment. In this study, Air Visual Pro was intended to measure $PM_{2.5}$ concentration, temperature, and humidity. The location of the sampling point is placed in a room that is center point of occupant activity. The device is placed in a safe location and does not interfere with occupant activities. The device is placed at a height of ± 1-1.5 m from the floor to represent inhalation by humans.

Several variables were examined during interviews to capture how these variables affect the pollutants concentration. The variables consisted of indoor conditions and inhabitants activities, as explained in **Table 1.**

Table 1. Variables in the model input

Variables	Explanation
Humidity (%)	Humidity affects pollutant's reaction and activities also affect humidity. The relationship between humidity and pollutant's concentration will be measured
Temperature (ºC)	These data were collected from the device
Wide window opening percentage (100 = 100%, 50 = 50%, 25 = 25% dan 0 = window closes)	Percentage of window openings. Larger the window opening is expected to increase the air exchange.
Window opening (1= when window opens, 0= window closes)	It is expected that when the window is open, it will allow pollutants tranfer to the outside environment. Respondent states in the questionnaire the time in which he/she opens the window(s) every day.
Number of ACs	The higher number of air conditioners are expected to increase the fine particykate filtration.
Number of fan	More fans is expected to increase airflow and move fine particulates out of the room.

Variables	Explanation
AC time on (1= when AC on, 0= AC off)	When the air conditioner is turned on, the air in the room is renewed and the air conditioner has a filter that can filter out fine particulates.
Fan time on (1= when fan on, 0= fan off)	When the fan is turned on the air flow in the room increased and so that it is expected to move fine particulates out of the room.
Exhaust fan time on ((1= when Ex-fan on, 0= Ex-fan off)	When the exhaust fan is turned on, fine particulates will flow out of the room.
Number of bedrooms	More bedrooms are assumed to be associated with higher particulate and Total Suspended Particulate concentrations in the room.
Cleaning frequency (x times/week)	House cleaning activities can reduce fine particulates. Greater frequency of house cleaning is expected to reduce fine particulates.
Cooking fuel (1= using LPG, 0= using another fuel)	Types of occupant fuels such as Liquefied Petroleum Gas, biogas, electric stoves, and natural gas have different effects in increasing fine particulates when cooking.
Cook time (1= cooking, 0= not cooking)	The combustion process of the cooking activity produces fine particulates.
Smoking activity (1= Smoking, 0= not smoking)	Smoking activity is a combustion process that is a source of fine particulates.
Amount of furniture	Furniture is expexted to increase fine particulates, especially when human activities occur. Fine particulates can stick to the surface of the furniture and accumulate.

Results obtained from $PM_{2.5}$ concentration measurement are then assessed using Pearson correlation test through SPSS. The pearson correlation test aims to determine the relationship between indoor and outdoor concentrations due to window opening activities. Multiple linear regression analysis is used to obtain the effect between variables and $PM_{2.5}$ concentration. Multiple linear regression is an analysis that has more than one independent variable.

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + \dots + b_kX_k \quad (1)$$

Equation (1) represents the regression model.

Y : variable that explains the concentration of $PM_{2.5}$
a, b : the regression coefficient
X_1, X_2, X_3, X_k : the independent variable

3. RESULTS AND DISCUSSION

Good indoor air quality is characterized by a concentration that fillfil the quality standard threshold. Ambient air quality standard is based on Lampiran VII Peraturan Pemerintah No 22 Tahun 2021 in 24-hour measurement, which is 55 μg/m^3. The following are the results of the evaluation of $PM_{2.5}$ concentrations in houses located in industrial and roadside area which are measured for 24 hours, as seen in **Table 2.**

The results showed that the air quality in houses around industrial area unit 2 to 6 is polluted by $PM_{2.5}$. The greatest $PM_{2.5}$ contamination was found in unit 6 on weekday-2 at 88.45 μg/m^3. Unit1 showed good air quality for 3 days of measurement, and on weekday-2 showed the lowest $PM_{2.5}$ level of 22.34 μg/m^3. While in the roadside area, the concentration of $PM_{2.5}$ in units 4 and 5 is higher than other units. The greatest $PM_{2.5}$ contamination was found in unit 4 on weekday-1 at 61.57 μg/m^3 and house 5 on weekday-2 at 89.69 μg/m^3.

Table 2. Average $PM_{2.5}$ concentration in 24 hours

Unit	Day of sampling	Industrial area				Roadside area			
		Indoor		Outdoor		Indoor		Outdoor	
		$PM_{2.5}$ Concentration (μg/m³)	Result	$PM_{2.5}$ Concentration (μg/m³)	Result	$PM_{2.5}$ Concentration (μg/m³)	Result	$PM_{2.5}$ Concentration (μg/m³)	Result
	weekday-1	43.62	Good	55.06	Bad	28.08	Good	35	Good
1	weekday-2	22.34	Good	25	Good	44.28	Good	51.83	Good
	weekend	45.4	Good	55.82	Bad	19.55	Good	22.59	Good
	weekday-1	60.82	Bad	52.47	Good	43.36	Good	48.38	Good
2	weekday-2	61.23	Bad	63.06	Bad	30.58	Good	34.58	Good
	weekend	55.5	Bad	48.88	Good	43.43	Good	50.7	Good
	weekday-1	53.64	Good	61.05	Bad	29.74	Good	35.9	Good
3	weekday-2	50.06	Good	54.25	Good	26.22	Good	32.29	Good
	weekend	60.04	Bad	70.83	Bad	37.34	Good	44.26	Good
	weekday-1	35.1	Good	39.98	Good	61.57	Bad	62.37	Bad
4	weekday-2	66.52	Bad	71.41	Bad	34.08	Good	36.49	Good
	weekend	58.25	Good	68.34	Bad	40.3	Good	44.28	Good
	weekday-1	50.86	Good	60.99	Bad	55.8	Bad	55.32	Bad
5	weekday-2	63.96	Bad	76.52	Bad	89.69	Bad	93.79	Bad
	weekend	64.81	Bad	75.2	Bad	40.75	Good	42.59	Good
	weekday-1	59.88	Bad	62.48	Bad				
6	weekday-2	88.45	Bad	69.38	Bad				
	weekend	72.39	Bad	83.69	Bad				

The results of the data obtained for each house are in the form of indoor $PM_{2.5}$ concentration and outdoor $PM_{2.5}$ concentration. By identifying the results of the questionnaire regarding window opening hours, the effect of ventilation as a medium for air exchange can be analyzed from outside and inside the house. The results of the pearson correlation test in the form of correlation coefficients in open and closed window conditions can be seen in **Table 3.**

Table 3. Correlation between open and closed window

Unit	Industrial area		Roadside area		Sig
	window opens	window closes	window opens	window closes	
	Coefficient	Coefficient	Coefficient	Coefficient	
Unit 1	0.917	0.951	0.956	0.949	0.000
Unit 2	0.916	0.287	0.622	0.822	0.000
Unit 3	0.837	0.844	0.954	0.903	0.000
Unit 4	0.961	0.935	0.946	0.960	0.000
Unit 5	0.538	0.767	0.913	0.888	0.000
Unit 6	-	0.89	-	-	0.000

Pearson correlation test produces a coefficient with a range of 0-1. The coefficient value close to 0 means that the relationship between the two variables is getting weaker, on the contrary if the coefficient value is close to 1, it means that there is a stronger relationship between the two variables. The results of the Pearson correlation test in table 3 showed that all houses have a significant positive relationship (p-value <0.05).

Units 2 and 4 around the industrial area showed that the effect of windows when they are open is greater than when they are closed. This means that if there is an increase in the outdoor $PM_{2.5}$ concentration when the window is open, the indoor $PM_{2.5}$ concentration will also increase. The 1st, 3rd, and 5th unit in the same area have less than ideal conditions, the correlation test results when the windows are closed showed a greater indoor and outdoor relationship than when the windows are open. units 2 and 4 the roadside area showed that the effect of windows when they are closed is greater than when they are open. At the time of observation, unit 2 and unit 4 had vents. The vent is a continuous medium for the entry and exit of air. This is one of the factors that results in a higher correlation coefficient when the window is closed. Moreover, the correlation coefficient when the window is closed is higher because of other factors that make the $PM_{2.5}$ concentration increase even though the window is closed. (Zhang et al., 2018) stated that particulate infiltration resulted in worse indoor pollution. $PM_{2.5}$ concentrations penetrate more easily into the room through cracks or leaks in buildings than PM_{10} because it has a smaller particle diameter (Drzymalla & Henne, 2019). It is also influenced by meteorological factors at night where the air temperature tends to lower than during the day. The low temperature makes the air density higher than the air above it so that there is no upward convection flow which causes an increase in concentration because it accumulates near the ground surface.

The effect of variable X on Y was carried out by statistical analysis with multiple linear regression tests. Multiple linear regression test was run with SPSS application for the independent variable (X) which had fulfilled the multicollinearity test and $PM_{2.5}$ concentration (Y). The regression results obtained are in the form of coefficient values which can be seen in **Table 4.**

Table 4. Multiple linear regression estimates for $PM_{2.5}$

Variabel	Industrial Area		Roadside Area	
	Coeff	t-value (sig)	Coeff	t-value (sig)
(Constant)	-127.31	-2.56 (0.01)	27.87	0.831 (0.406)
Humidity (%)	3.368	12.656 (0.00)	1.16	6.242 (0.000)
Temperature (°C)	-2.103	-1.915 (0.05)	-6.55	-8.865 (0.000)
Number of ACs	11.841	12.956 (0.00)	-	-
Number of fans	-3.239	-4.825 (0.00)	-15.94	-9.712 (0.000)
Number of bedrooms	-	-	16.33	6.740 (0.000)
Window opening (1= when window opens, 0 = window closes)	-8.26	-5.205 (0.00)	15.60	5.500 (0.000)
Wide window opening persentase (100 = 100%, 50 = 50%, 25 = 25% dan 0 = window closes)	-	-	-0.169	-4.007 (0.000)
AC time on (1= when AC on, 0= AC off)	-7.56	-4.315 (0.00)	6.529	5.137 (0.000)
Fan time on (1= when fan on, 0= fan off)	-7.959	-5.088 (0.00)	-11.72	-8.020 (0.000)
Exhaust fan time on ((1= when Ex-fan on, 0= Ex-fan off)	-10.824	-3.621 (0.00)	-	-
Cleaning frequency (x times/week)	-2.941	-10.621 (0.00)	-	-
Cooking fuel (1= using LPG, 0= using another fuel)	3.423	11.928 (0.05)	-	-
Cook time (1= cooking, 0= not cooking)	6.732	3.539 (0.00)	-5.111	-3.022 (0.003)
Smoking activity (1= Smoking, 0= not smoking)	24.156	8.282 (0.00)	-13.35	-3.244 (0.001)
Amount of furniture	2.755	8.474 (0.00)	4.865	9.650 (0.000)

The partial test (T) indicates that the significance value is less than 0.05 (5%). This means that each variable X has a significant influence on the Y variable. A positive regression coefficient value means that the variable X can increase the concentration of $PM_{2.5}$, while a negative value can reduce the concentration of $PM_{2.5}$. The correlation of most fine particles is related to the relative humidity level. Temperature and relative humidity depend on outdoor climatic conditions, because buildings have natural ventilation. Increasing pressure and decreasing temperature can increase $PM_{2.5}$ (Papanastasiou et al., 2011). Humidity and temperature have an inverse relationship. When the temperature increases and the humidity decreases, the indoor air conditions become drier and the ultrafine particles increase after the PM evaporates (Shrestha et al., 2019). Changes in temperature caused by an activity can last longer than the activity itself, thus affecting indoor air quality even after the activity ends (Lin et al., 2017). High temperatures cause the density of the air on the earth's surface to be lower than the air above and cause air upward convection flow which carries various pollutants, causing a lower pollutant concentration (Elaeis et al., 2013).

Indoor pollution levels are determined by ventilation rates, air mixing patterns, and concentration gradients, as well as source location and contaminant characteristics (Kukadia et al., 2025). Open windows can generally renew the air by swapping the air between indoor and outdoor, but the regression results showed the difference between the two locations. Houses located on the roadside area showed that when the windows were open there was an increase in the concentration of $PM_{2.5}$. This is because the results of the questionnaire showed that the occupants of the house mostly opens the windows in the morning and evening. This time is the peak traffic hour. The number of vehicles at peak hours can increase pollutants so that opening windows longer has the potential to make pollutants outside the room enter the room so that pollutant concentrations increase. In addition, the percentage of window openings is related to the quality of indoor air. Statistical results explain that if the percentage of window opening width increases, the $PM_{2.5}$ concentration decreases. Increased ventilation openings can result in a reduction of particulates (Prakash, 2018).

The addition of the number of air conditioners with the use of air conditioners in homes around industrial areas showed an inversely proportional value. A similar case was found in a study conducted by (Syafei et al., 2020), linking that air filters in air conditioners are not effective at filtering fine particulates. The use of air conditioning in homes on the roadside area can increase $PM_{2.5}$. This can be caused by dust accumulating in the filter and evaporator of the air conditioner (Cheung & Jim, 2019).
Number of fan, fan usage, and exhaust fan usage significantly decreased $PM_{2.5}$. These results are in line with research conducted (Syafei et al., 2020). The fan can accelerate the wind speed so that it can spread indoor pollutants (Putri et al., 2016). Wind speed is inversely proportional to pollutant concentration. The faster the wind moves, the pollutants will also spread more quickly so that the concentration decreases. The use of an exhaust fan in the sampling house is placed in the kitchen to help move pollutants out of the room.

Cooking activity at homes in industrial areas can increase $PM_{2.5}$. These results are linear with research (Wallace et al., 2003) that cooking increases particle pollution by 3.7 $\mu g/m^3$ and can increase by about 3.5 $\mu g/m^3$ due to frying activity. However, cooking activities at houses on the roadside actually reduce the concentration of $PM_{2.5}$. This is possible due to other factors that cause the concentration of $PM_{2.5}$ to decrease, such as opening windows while cooking and the location of the kitchen which is outside the room. (Fakinle et al., 2019) stated that the use of LPG compared to solid fuels makes a significant contribution to reducing air pollutants. (Klasen, E.M., Wills et al., 2015) stated that biomass fuels contributed the most to pollution, due to incomplete combustion. (Sun & Wallace, 2021) have also proven that the frequency and duration of cooking, as well as the cooking method significantly affect the increase in $PM_{2.5}$. This study does not discuss further about it.

Poor indicators were found in houses with smoking activity which could increase the concentration of particulate pollution by 37 $\mu g/m^3$ (Wallace et al., 2003). (Tunno et al., 2015) revealed that smoking in homes near the Pittsburgh Industrial Estate increased $PM_{2.5}$ concentrations by 8. $\mu g/m^3$ in the dry season and 17.12 $\mu g/m^3$ in the winter. Different from the house on the roadside, smoking activity results in reducing the concentration of $PM_{2.5}$

(Vardoulakis et al., 2020) stated that indoor activities, one of which is smoking, can increase $PM_{2.5}$ concentrations. This is the opposite of the regression results. Based on the results of interviews and questionnaires, in unit 2 the condition of the building has a vent so that cigarette smoke in the room can escape through the hole. Unlike unit 4, smoking is carried out outdoors so that cigarette smoke can be spread directly without entering the room.

The frequency of house cleaning reduces the concentration of $PM_{2.5}$ by 0.005 µg/m^3 (Syafei et al., 2020). House cleaning activities produce emissions (Gola, M., Settimo & Capolongo, 2019). Fine particulates in the air can stick to furniture surfaces and can accumulate. Furniture surfaces can play a role in increasing the concentration of $PM_{2.5}$ (Buczyńska et al., 2014). The regression results showed that if the number of furniture is increased by 1 unit, the concentration of $PM_{2.5}$ will increase by 2,755 µg/m^3.

The coefficient of the variable number of bedrooms is positive. If the number of rooms increases then the concentration of $PM_{2.5}$ increases. This can happen because the number of rooms increases, the number of furniture in the house will increase so that $PM_{2.5}$ can increase. In addition, this can happen due to other causes. The addition of the amount of furniture can increase the concentration of $PM_{2.5}$ (Shinohara & Hiroko, 2021) stated that dust on the surface of walls, shelves, and furniture significantly increases the concentration of $PM_{2.5}$ and PM_{10}. Human activities such as cleaning and sitting on furniture can produce $PM_{2.5}$ in the room (Ferro, A.R., Rooyal & Lynn, 2004). This occurs because particulates are suspended by human mobility. When particulate resuspension occurs, the concentration of $PM_{2.5}$ increases. In addition, the number of furniture in the room makes the air movement more limited.

Simultaneous test results (F) in industrial and roadside areas have a significance value of less than 0.05. This explains that individually or simultaneously variable X has a significant effect on variable Y. The results of the multiple linear regression test obtained an R square value for industrial and roadside areas which are 0.352 and 0.338, respectively. Which means that all X variables explain the effect on the P $PM_{2.5}$ concentration by 35.2% and 33.8%.

4. CONCLUSIN

This article discusses ventilation factors and occupant activities that can affect $PM_{2.5}$ concentrations indoors in industrial area and roadside area. This study showed that there was a correlation between indoor and outdoor concentrations caused by window opening activities. High concentrations of pollutants from outdoors can enter the room through vents or cracks in buildings which are a factor in causing increased indoor concentrations. The results of the regression model prove that human activities are factors that cause an increase in indoor pollutants. It can be concluded that humidity, temperature, number of fans, usage of fans, and amount of furniture significantly affect $PM_{2.5}$ concentrations. The effect of the variable number of air conditioners, exhaust fan usage, frequency of house cleaning, and cooking fuel were found in houses located in industrial areas. While the number of rooms and the percentage of window openings affect the concentration of $PM_{2.5}$ in houses in roadside areas. We also found that the variables of open windows, use of air conditioning, cooking activities, and smoking activities in homes living in the two areas had an inverse effect.

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