The Effect of the Exhaust Fan Position to Indoor

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SEMARAK ILMU PUBLISHING

CFD Letters

Journal homepage:
https://semarakilmu.com.my/journals/index.php/CFD_Letters/index
ISSN: 2180-1363

The Effects of the Exhaust Fan Position to Indoor Air Pollution Distribution in Enclosed Parking Garage

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ARTICLE INFO

Article history:
Received 2 September 2022
Received in revised form 5 October 2022
Accepted 3 November 2022
Available online 1 March 2023

ABSTRACT

Nowadays, lack of space in city center has forced the architects a propose a vertical construction to provide public facility, including the parking garage. Generally, this vertical parking garage has enclosed environment condition, which could be constructed under the building or in the middle of other buildings. This environment causes the parking garage will not have an adequate fresh air circulation or air change rate and gives a more risk due to the accumulation of air pollutants which is emitted from the cars inside. In this research, it observes a simple enclosed parking garage which normally can accommodate six cars. The air pollutant, particularly Carbon Monoxide (CO), from three gasoline cars is extracted by an exhaust fan in a proper location. Two location of exhaust fan are proposed to investigate better air circulation and better air pollutant extraction from the parking garage. The first option (Position of A) installs the exhaust fan near to the parking space units and the other installs the exhaust fan near to the pathway. Each option will follow two worst condition of simulations which are predicted will give a significant impact to Indoor Air Quality (IAQ). Each simulation has to extract the emission from three idle cars with same rate of air circulation of six air change per hour. The results show the influence of air flow pattern to the dispersion of air pollutant. An adequate air flow near to the emission source will cause the increase the maximum of air pollutant concentration. On the other hand, it can minimize the spread of air pollutant dispersion.

Keywords:
Indoor Air Quality; Emission Dispersion; Enclosed Parking

1. Introduction

Nowadays, many big cities face problem of air quality degradation, both in indoor and outdoor environment. The degradation of urban air quality is related to many factors and one of them is the existence of emission sources. City's high population proportionally causes the high population of motorized vehicle. So that's why some researches states motorized vehicle contributes greatly to the degradation of urban air quality [1, 2]. Therefore, many researchers still develop some methods to

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https://doi.org/10.37934/cfdl.15.3.123138

including type of fuel to control the emission. However, changing type of fuel should consider the emission standard which should be fulfilled [3].

On the other hand, the private company and local government builds many high rise building which will blocks the air flow and causes the high air pollutant concentration at some points [4, 5]. In addition, increasing the airflow will cause the energy consumption and emission of greenhouse gas. The other solution to reduce energy consumption is by installing a shading roof to decrease the indoor temperature which is also affected by the airflow [6]. Furthermore, system of heating, ventilating and Air conditioning (HVAC) is one of the main contributors of electricity load on a building [7].

In addition, the high population and lack of free space in a city has forced the private sector and government prefer to build vertical construction including the parking garage. However, this parking garage will have an unclosed environment and will not have a good air circulation which is needed to take out the air pollutant. A good air circulation is very important since the exhaust gas from cold engine, as emission source, will emit a very high concentration of air pollutant especially for parameter of Carbon Monoxide (CO) and Nitrogen Dioxide (NO_2) [8]. Emission of CO in high concentration could risk people health and even a death as consequence of CO Poisoning [9]. As a solution, it can install a Mechanical ventilation device to generate better air circulation. This installation should be well designed to ensure a good Indoor Air Quality (IAQ) and minimize the energy consumption.

Recently the using of Computational Fluid Dynamics (CFD) in designing and predicting the air quality has been increasingly used by many researchers as the increasing of computer performance. This method is capable to predict air pollution in complex situation, various flow and complex geometry [10]. This method has been proved has good agreement compared to the experimental measurement [11]. CFD also provides many turbulences model for various flow condition which the air flow in indoor environment is recommended to use STT k-Ω turbulence model [12]. At the end of the simulation, it could build a prototype, either in full-scale or reduced-scale model, to validate the simulation by experimental measurement. This scale selection of prototype should consider some factors such as cost and size of the measurement device.

In case of air pollution in enclosed room, some researchers have tried to improve the air flow pattern and IAQ by some methods. These methods should pay attention to the emission source and the ventilation condition or the air flow which greatly influence the dispersion [13]. The examples of improvement are by setting the high of exhaust fan [14], setting the direction of jet fan flow [15], setting the variation of on/off operated mechanical ventilation [16], etc. The design should consider the minimum air velocity because the concentration of air pollutant could concentrate at the low-velocity location [17]. In addition, the design should also consider factors of shape and position of the object inside the parking garage [18].

A crucial problem of air pollution inside the parking garage is emission from idling car. In idling condition, a catalytic converter cannot convert some hazardous compounds, particularly Carbon Monoxide (CO), into Carbon Dioxide (CO_2). Normally, catalytic converter has low efficiency of CO conversion in low temperature and the efficiency will be increased along with the increasing of temperature [19]. According to research, a gasoline car emits may emits CO with the concentration of 1 % in the first minute of idling and it gradually reduces the CO concentration as the increase of engine and catalytic converter temperature [20].

Considering these factors, it needs to study a proper position of mechanical ventilation device which optimally take out the air pollutant from enclosed parking garage. By placing this device in a proper position, it hopes that the exhaust fan can maintain the Indoor Air Quality even in various worst conditions.

2. Method

This study investigates the dispersion of air pollutant in enclosed parking garage. There are two option positions of exhaust fan, near to parking space area (Position A) and near to the path way (Position B). Then each position of exhaust fan is tested with two conditions of idling cars position in CFD simulation in order to evaluate the performance of the device in maintaining the Indoor Air Quality (AIQ). Overall, the parking garage has length, width, and high are 18 m, 13 m, and 3.5 m respectively. For the capacity, it normally can accommodate six cars, which the parking space located at the middle of four columns. Dimension of the parking garage and the options position of exhaust fan is shown in Figure 1:

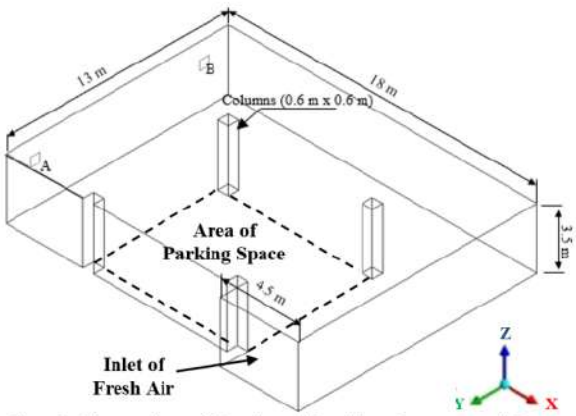
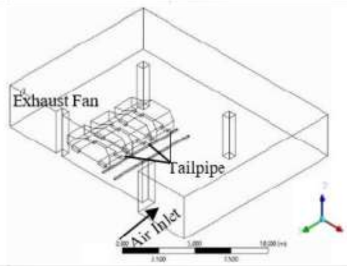
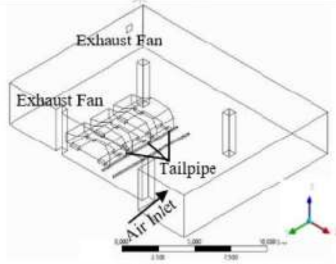


Fig. 1. Dimension of Enclosed Parking Garage and Two Options of Exhaust Fan Position (A and B)

As the emission source, it places some simple car models with length, width and height of 4.2 m, 1.7 m, and 1.7 m respectively. The car model emits an exhaust gas through the tailpipe located 0.3 m from the floor. In order to create adequate air circulation inside the parking garage, it will install an exhaust fan which is able to adsorb fresh air with rate of six Air Change per Hour (ACH) or 1.67213 kg/s with air quality as shown in Table 1. The air compositions are mainly obtained from Universal Industrial Gases, Inc, meanwhile the air pollutants (CO and NO_2) are obtained from related studies. Each position of exhaust fan is tested with two worst conditions, they are emission from three cars facing the exhaust fan (Model of A-1 and Model of B-1) and the other are three cars backing the exhaust fan (Model of A-2 and Model of B-2) as shown in Figure 2.

Table 1
Prediction of the fresh air quality

Parameter	Value
Nitrogen (N_2)	74,0534%
Oxygen (O_2)	22,7645%
Argon (Ar)	1,2607%
Carbon Dioxide (CO_2)	0,0442%
Carbon Monoxide (CO) [21]	2,0 ppm
Nitrogen Dioxide (NO_2) [21]	0,02 ppm
Moisture (H_2O) [22]	1,87700%
Total	100.0000%

<table>
<tr><th>Description of Simulations</th><th>Position of A
Exhaust Fan installed near to parking space</th><th>Position of B
Exhaust Fan installed near to pathway</th></tr>
<tr><td>1. Three idling Vehicles facing the exhaust fan</td><td>
</td><td>
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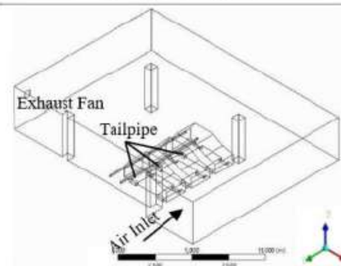
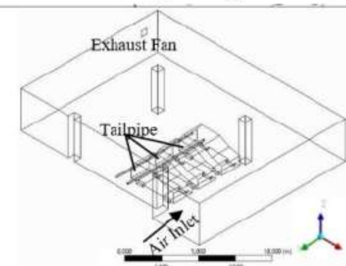
<tr><td>2. Three idle Vehicles backing the exhaust fan</td><td>
</td><td>
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Fig. 2. Four models to examine the effect of exhaust fan installation on position of A and B

The exhaust gas disperses inside the parking garage and affects the CO and NO_2 concentration. Concentration of CO and NO_2 is determined based on a study by Pielecha *et al.*, as shown in Table 2. In this idling condition, cars are predicted consumes fuel of 90 ml/min and it will emit exhaust gas of 1,76281 g/s when the air fuel ratio is set to 14.7. Calculation to predict exhaust gas concentration uses the mass balance of burning process. On burning process, all components of Carbon and Hydrogen in fuel reacts with oxygen contained in air and form CO_2, H_2O, and CO while some components of nitrogen and oxygen in air form NO_2. Based on the mass balance calculation, there is little oxygen do not react with fuel and calculated as the remain oxygen content in the exhaust gas. The prediction of exhaust gas as shown in Table 2.

Table 2
Prediction of Exhaust Gas quality

Parameter	Value
Flow Rate	1.76281 (g/s)
Nitrogen (N_2)	69.34846 %
Oxygen (O_2)	0.55741 %
Argon (Ar)	1.18069 %
Carbon Dioxide (CO_2)	18.71159 %
Carbon Monoxide (CO)	1.00000 %
Nitrogen Dioxide (NO_2)	0.02000 %
Moisture (H_2O)	9.18185 %
Total	100.0000%

Having collecting all data of boundary condition, it uses Ansys Fluent to simulates all the models. In order to ease the creating of mesh and attaining the convergence, shape of the cars is simplified but they still have dimension similar to a popular mini-van Indonesia. The mesh is created with default size of 144 mm, but the size near to the wall is minimized to 25 mm. Since these simulations have purpose to predict the emission dispersion, the simulations use species transport model with the concentration of each species is set to as shown in Table 1 and Table 2. Finally for the viscous model, all the simulations use viscous model of shear Stress Transport (SST) k-Ω since all models have some obstacles which have walls and also create adverse pressure gradient. In post processing, the air pollutant concentrations have to be compared to environmental threshold. In this process the unit of mass fraction is convert from percentage to $\mu g/Nm^3$.

The exhaust fan is acting as the outlet and taking out the air with mass-flowrate of 6 air change per hour (ACH) or 1,67231 kg/s. These models have four inlets which consists of one main inlet and three tailpipes of the cars. The main inlet is set as inlet vent and consist of some substances which the concentrations are shown in Table 1. Meanwhile the tailpipes are set as mass-inlet which the flowrate and concentration of substances is shown in Table 2. In order to investigate the proper location of exhaust fan, it observes three different surface levels (z-axis) based on the height of human breath as shown in Figure 3. Each level shows the area of human breath, they are breath level of infants on stroller (y = 0.7 m), breath level of kids (y = 1.1 m, it assumes the average height of kids are 1.2 m), and breath area of adults (y = 1.5 m, it assumes the average heigh of adults are 1.6 m), [23].

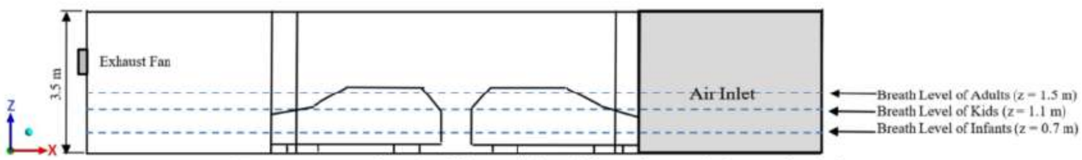


Fig. 3. Various levels of breath level for infants, kids, and adults

3. Results and Discussion

Four CFD Simulations conducted to predicts the air flow and the IAQ (CO and NO_2 concentration) inside the garage. Figure 4 shows the streamline air flow inside the parking garage. This figure also shows the dispersion one of the air pollutants (CO) at the level of tailpipe (z = 0.3 m). Based on the figure, the exhaust gas, contained much higher concentration of CO, flows away the outlet of tailpipe and change it direction when it meets the air flow. When the exhaust gas meets the air flow, it will diffuse with the air and the air pollutant concentration will be decreased significantly.

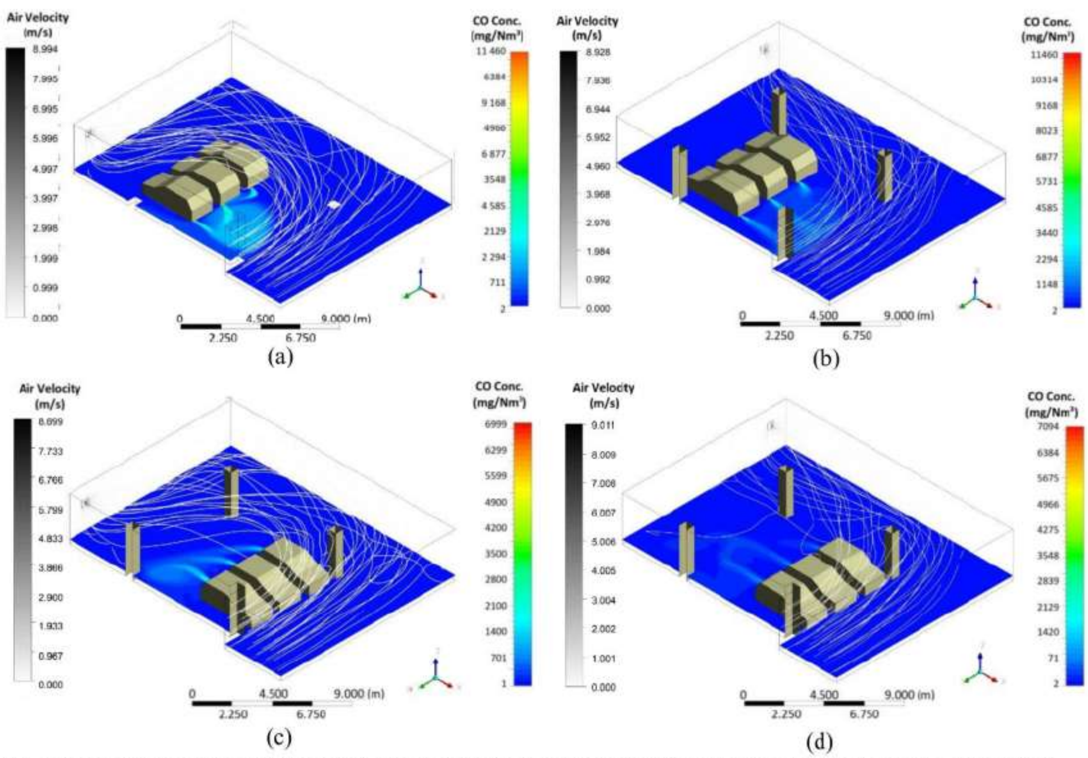


Fig. 4. Streamline of the air flow and dispersion of air pollutant (CO) at the level of Tailpipe (z = 0.3 m) (a) Exhaust fan placed on Position of A and cars are facing the exhaust fan (b) Exhaust fan placed on Position of B and cars are facing the exhaust fan (c) Exhaust fan placed on Position of A and cars are backing the exhaust fan (d) Exhaust fan placed on Position of B and cars are backing the exhaust fan

Figure 5 shows the contour of air velocity at breath level of infants on stroller, kids and adults (z = 0.7 m; z = 1.1 m; and z = 1.5 m). Meanwhile Figure 6 and Figure 7 show the contour of CO concentration and NO_2 concentration respectively at the three levels of breath. When comparing the air pollutant concentration (Figure 6 and Figure 7) to air velocity (Figure 5), it can see the relationship between air flow and air pollutant concentration at any point inside the parking garage. Generally, CO and NO_2 disperse, diffuse with air, and move follow the air flow. Based on the figures, they show that the higher concentration of CO and NO_2 is occurred at level 0.7 m which is located near to the emission source. This concentration gradually decreases as the increase of distance to emission source. For more clear information related to the air quality at any position, it puts some 1 x 1 m grids.

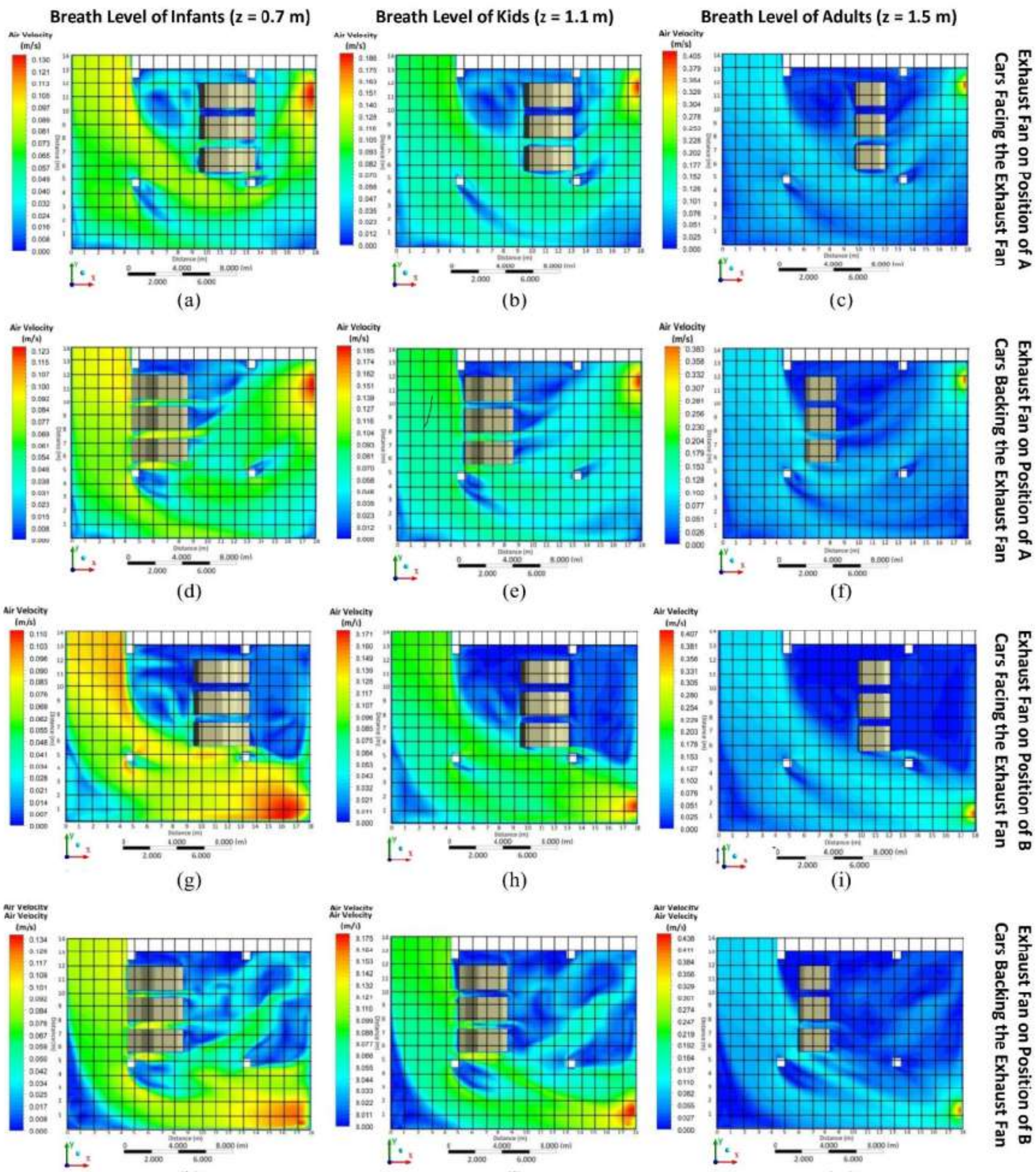


Fig. 5. Contour of air velocity (a) Model of A-1 at z = 0.7 m (b) Model of A-1 at z = 1.1 m (c) Model of A-1 at z = 1.5 m (d) Model of A-2 at z = 0.7 m (e) Model of A-2 at z = 1.1 m (f) Model of A-2 at z = 1.5 m (g) Model of B-1 at z = 0.7 m (h) Model of B-1 at z = 1.1 m (i) Model of B-1 at z = 1.5 m (k) Model of B-2 at z = 0.7 m (l) Model of B-2 at z = 1.1 m (m) Model of B-2 at z = 1.5 m

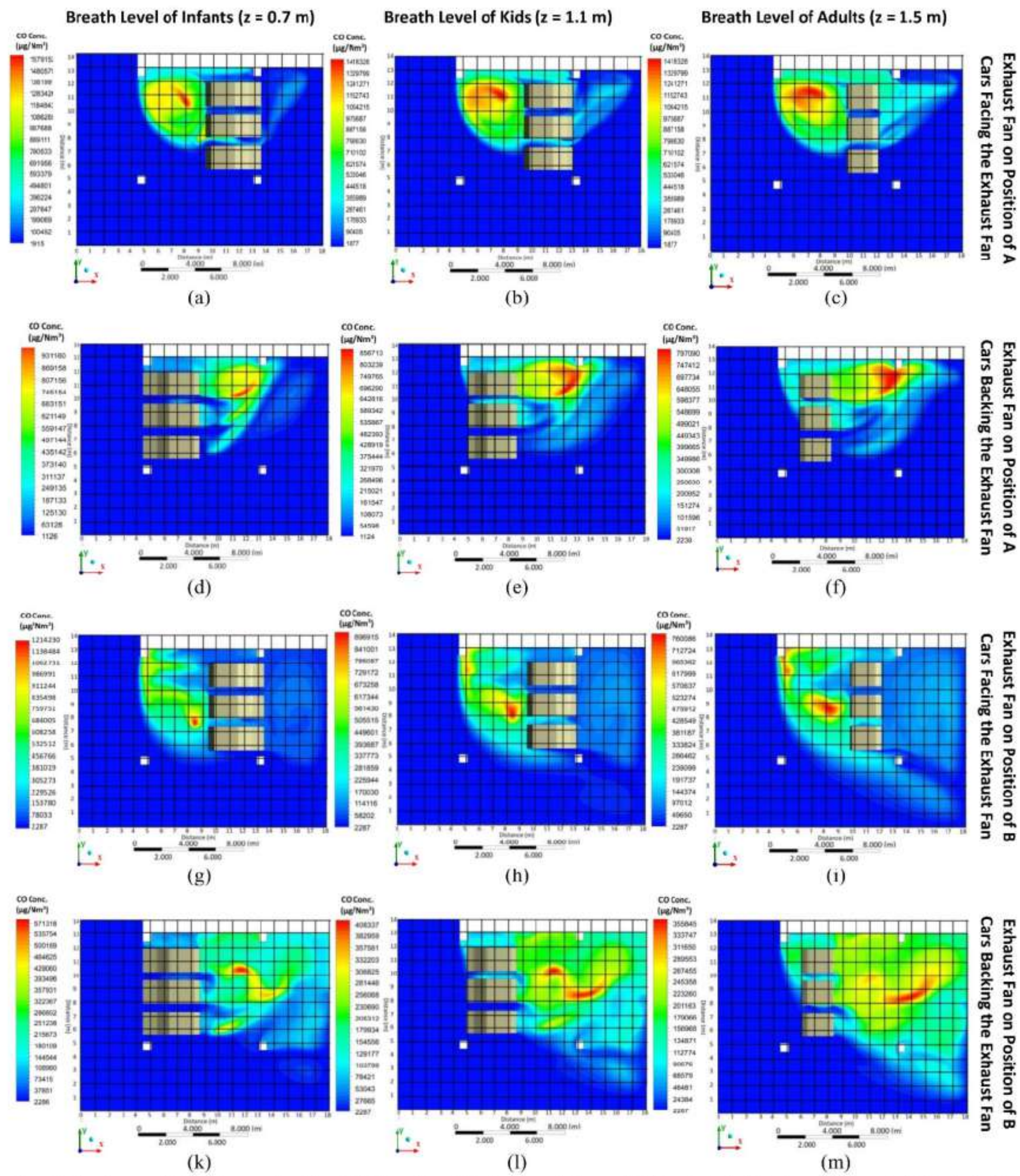


Fig. 6. Contour of CO Concentration (a) Model of A-1 at z = 0.7 m, (b) Model of A-1 at z = 1.1 m (c) Model of A-1 at z = 1.5 m (d) Model of A-2 at z = 0.7 m (e) Model of A-2 at z = 1.1 m (f) Model of A-2 at z = 1.5 m (g) Model of B-1 at z = 0.7 m (h) Model of B-1 at z = 1.1 m (i) Model of B-1 at z = 1.5 m (k) Model of B-2 at z = 0.7 m (l) Model of B-2 at z = 1.1 m (m) Model of B-2 at z = 1.5 m

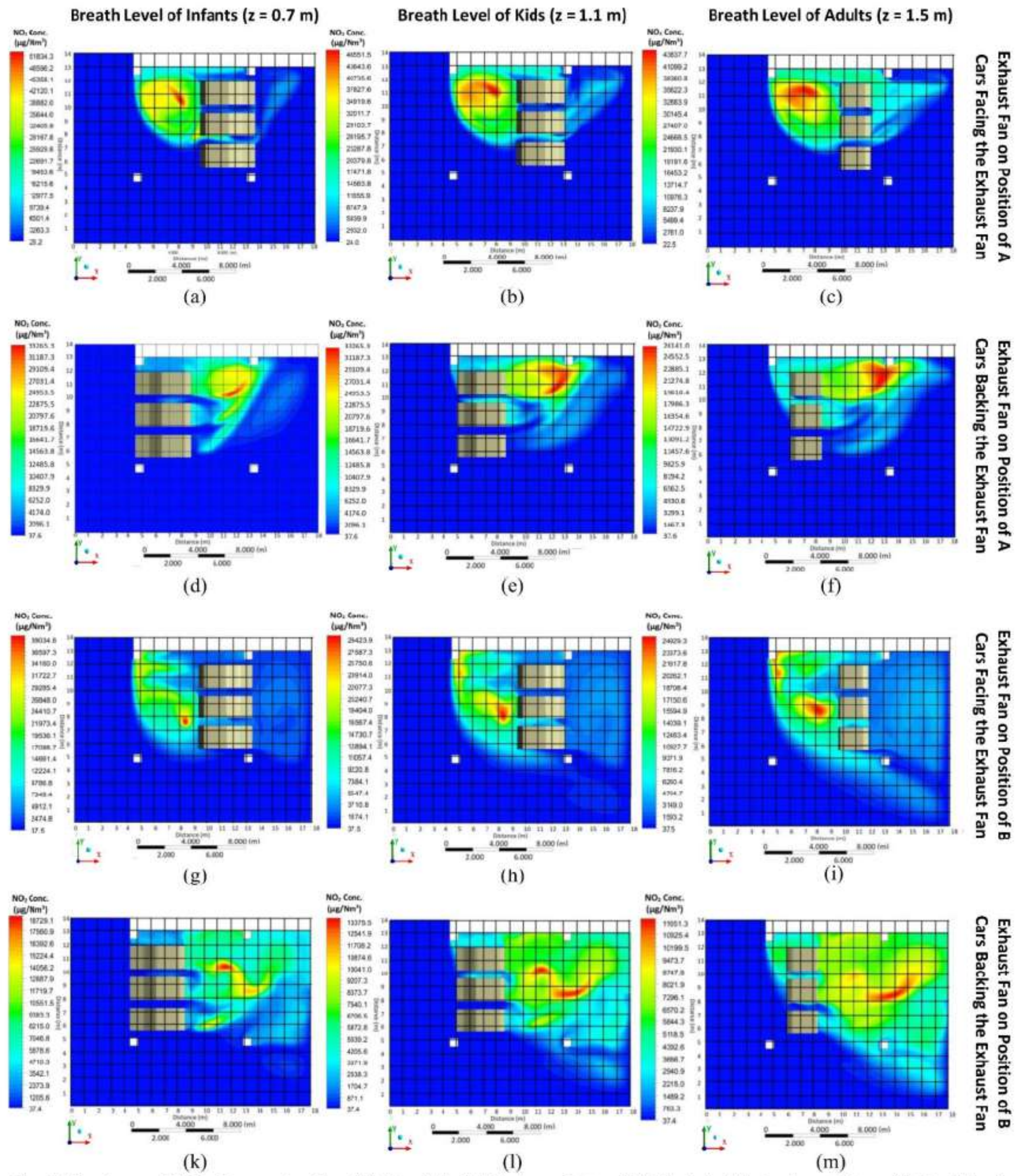


Fig. 7. Contour of NO_2 Concentration (a) Model of A-1 at z = 0.7 m (b) Model of A-1 at z = 1.1 m (c) Model of A-1 at z = 1.5 m (d) Model of A-2 at z = 0.7 m (e) Model of A-2 at z = 1.1 m (f) Model of A-2 at z = 1.5 m (g) Model of B-1 at z = 0.7 m (h) Model of B-1 at z = 1.1 m (i) Model of B-1 at z = 1.5 m (k) Model of B-2 at z = 0.7 m (l) Model of B-2 at z = 1.1 m (m) Model of B-2 at z = 1.5 m

In addition, air velocity or amount of fresh air also determine the concentration of CO and NO_2. When the air pollutants move at a point of location, it needs a higher fresh air supply to reduce the air pollutant concentration. This air supply should be enough and well distributed, especially to the area where has high pollutant concentration. Positions of the exhaust fan greatly influence the distribution and the pattern of air flow. So, the position and its specification should be well designed because it determines the disperse of air pollutant. In addition, position of any object in the parking garage, *i.e.,* columns and vehicles could change the air flow pattern due to air flow obstruction.

In case of the vehicles are facing the exhaust fan (Model of A-1 and B-1 in Figure 2), the exhaust gas flow in the same direction of the air flow. This condition causes the exhaust gas flow smoothly to the exhaust fan. On the other hand, in case of vehicles backing the exhaust fan (Model of A-2 and B-2 in Figure 2), the exhaust gas flows counter the air flow. This condition will change the direction of air pollutant at some points. Moreover, the counter flow of exhaust gas also causes wider dispersion of the air pollutant.

Based on Figure 6 and Figure 7, particularly for breath level of infants on stroller, it has the higher CO and NO_2 concentration than breath level of kids and breath level of adults due to its position near to the emission source (tailpipe). For models of A-1 and A-2, where the exhaust fan installed near to the parking space units, both models have higher air flow near to the emission source and cause the CO and NO_2 concentrated only near to the emission source. This condition causes the CO and NO_2 flow in the direction of x-positive and y-positive. On the other hand, for Models of B-1 and B-2, the CO and NO_2 spread widely into the parking garage. Even though, the air pollutants concentration is lower than the air pollutants concentration in models of A-1 and A-2.

However, Figure 6 and Figure 7 do not inform healthy air quality, they only inform the concentration of air pollutants. It needs to compare to the standard of ambient air quality as recommended by World Health Organization. In this standard, the concentration of CO should does not exceed 100 000 $\mu g/Nm^3$ for 15 minutes and concentration of NO_2 should also does not exceed 400 $\mu g/Nm^3$. Then it also provides the other information related to healthy Indoor Air Quality as shown in Figure 8 and Figure 9. The red colour on these figures shows the unhealthy air quality. These figures could provide information to place safety area inside the building.

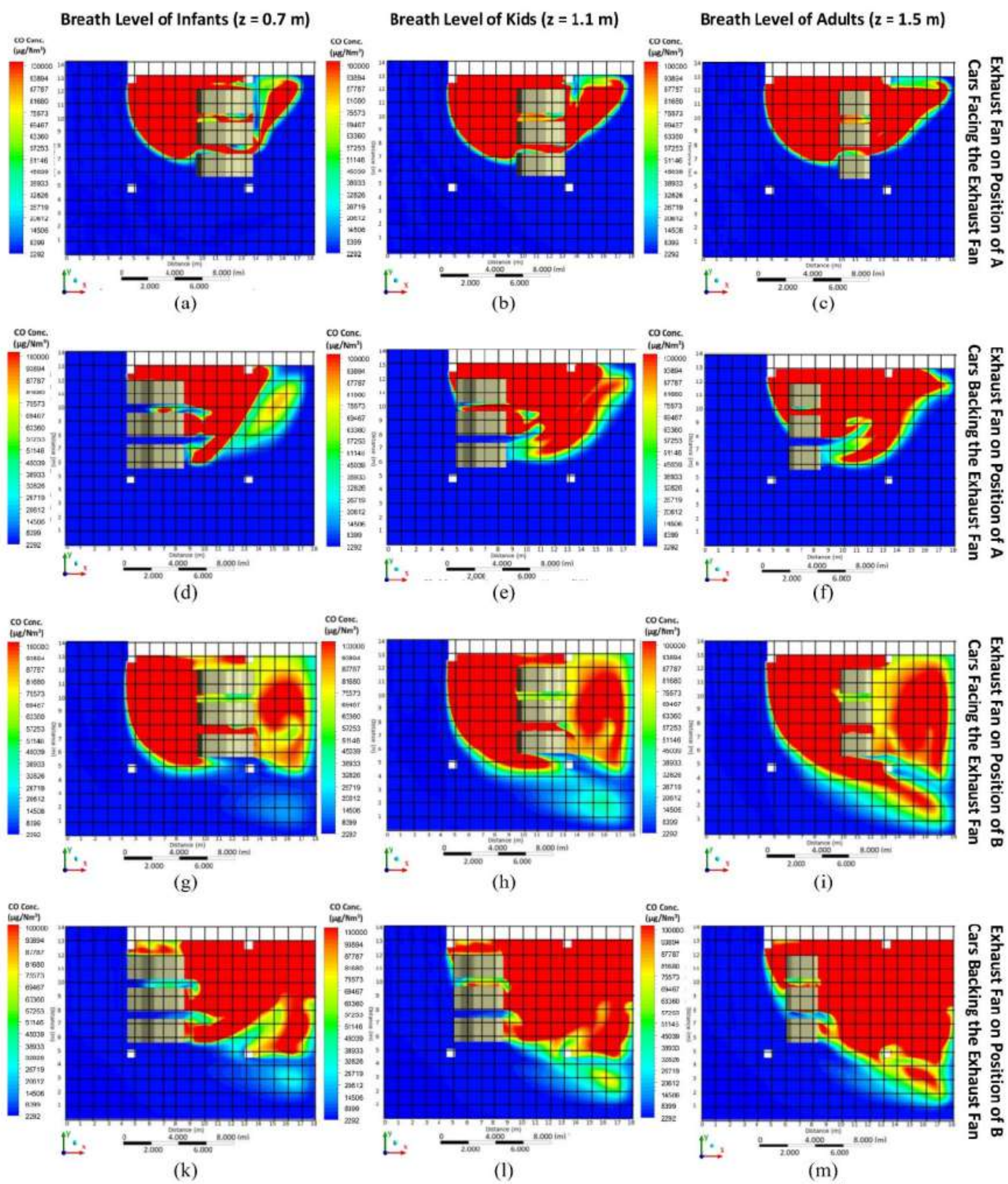


Fig. 8. Contour of CO Concentration Compared to Environmental Threshold (10 000 µg/Nm³) (a) Model of A-1 at z = 0.7 m (b) Model of A-1 at z = 1.1 m (c) Model of A-1 at z = 1.5 m (d) Model of A-2 at z = 0.7 m (e) Model of A-2 at z = 1.1 m (f) Model of A-2 at z = 1.5 m (g) Model of B-1 at z = 0.7 m (h) Model of B-1 at z = 1.1 m (i) Model of B-1 at z = 1.5 m (k) Model of B-2 at z = 0.7 m; (l) Model of B-2 at z = 1.1 m (m) Model of B-2 at z = 1.5 m

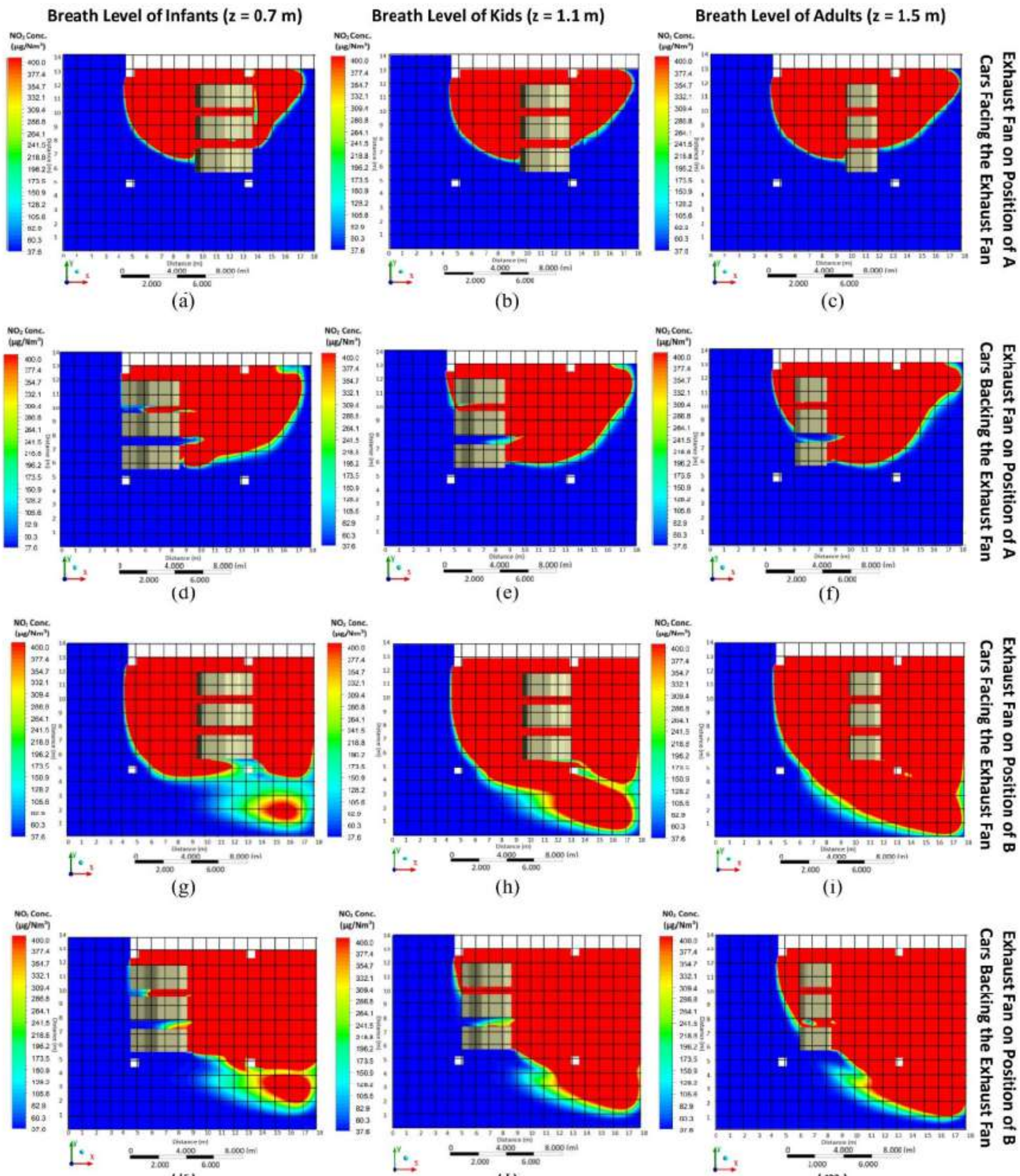
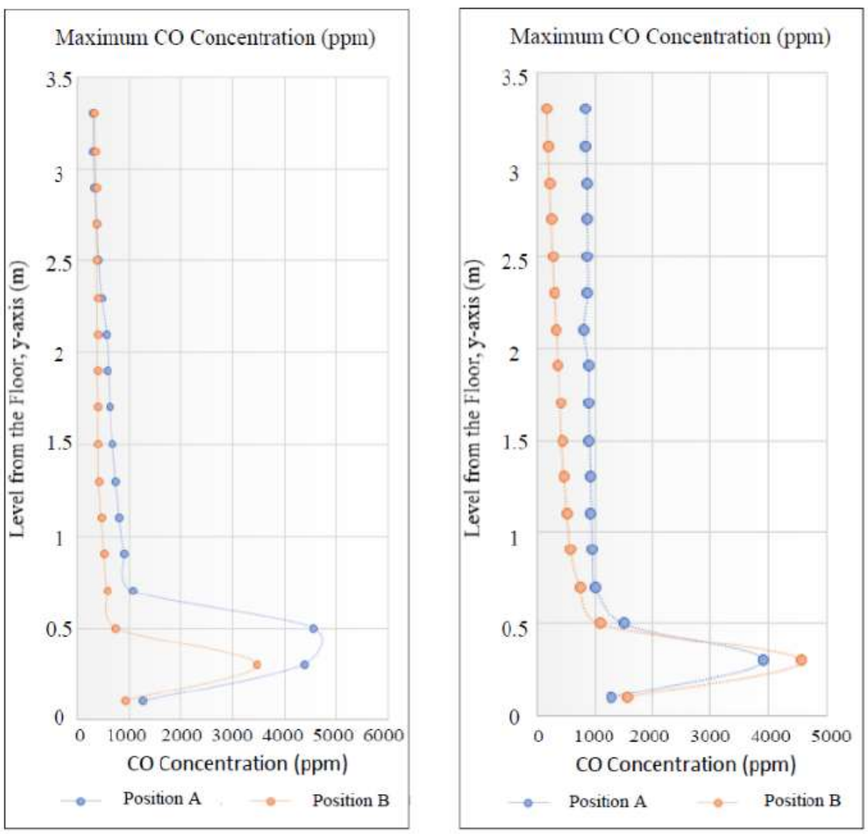


Fig. 9. Contour of NO_2 Concentration Compared to Environmental Threshold (400 µg/Nm^3) (a) Model of A-1 at z = 0.7 m (b) Model of A-1 at z = 1.1 m (c) Model of A-1 at z = 1.5 m (d) Model of A-2 at z = 0.7 m (e) Model of A-2 at z = 1.1 m (f) Model of A-2 at z = 1.5 m (g) Model of B-1 at z = 0.7 m (h) Model of B-1 at z = 1.1 m (i) Model of B-1 at z = 1.5 m (k) Model of B-2 at z = 0.7 m (l) Model of B-2 at z = 1.1 m (m) Model of B-2 at z = 1.5 m

For breath level of kids, it has the air pollutants (CO and NO_2) concentration between the concentration at breath level of infants on stroller and breath level of adults. Resemble to breath level for infants on stroller, the exhaust fan installed on Position of A cause the air pollutants concentrated only in the axis of x-positive and z-positive. On the other hand, when the exhaust fan installed on position of B, the models also have higher velocity on the pathway. This condition causes the air pollutants spreads widely into the parking garage, particularly in the axis of x-positive, z-positive, and z-negative. Resemble to breath level for infants, models with the exhaust fan installed on position of B also has lower than the air pollutant concentration in models of exhaust fan installed on position of A.

Air flow and air pollutant concentration at breath level of adults are distributed more uniform than the other level of human's breath. This condition causes the wider polluted area. Even though, the highest CO and NO_2 concentration at this area is much lower than the other areas. This condition could be influenced by the higher amount of air flows at this breath area.

Air pollutants maximum concentration of these four simulations can be seen in Figure 10. Figure 10 (a) shows the maximum pollutant concentration when the vehicles face the exhaust fan while Figure 10 (b) shows the maximum pollutant concentration when the vehicles backing the exhaust fan. This figure shows that the highest concentration occurs on the level (z-axis) near to the emission source and its concentration decrease when it far away from the emission source.



(a) (b)

Fig. 10. Maximum CO Concentration at any level from the floor (y-axis) (a) For Models of A-1 and B-1 (b) For Models of A-2 and B-2

4. Conclusion

Four simulations of CFD have been conducted to determine better position of exhaust fan in the enclosed parking garage. There are two options of exhaust fan position, each of them is near to the parking space units (Position of A) and the other near to the pathway (Position of B). A proper position of exhaust fan determines the air flow as well as the air pollutant dispersion.

This study uses CFD method to compare two proper positions of exhaust fan. Each position is investigated by dispersing two different positions of three emission sources from cars. These cars emit high concentration of air pollutants (CO and NO_2) through its tailpipe. The exhaust fan adsorbs and circulates the air with rate of 6 Air Change per Hour (ACH). For the analysis, it investigates three layers of breath area (z = 0.7 m, z = 1.1 m, and z = 1.5 m) where the results are compared to the environmental threshold in Indonesia.

Based on the result, the exhaust fan installed near to the parking space units (models of A-1 and A-2) will have more fresh air supply to the polluted area but it has more potency of maximum pollutant concentration. On the other hand, position of exhaust fan near to the pathway (models of B-1 and B-2) cause the maximum of pollutant concentration lower than the other case but has wider impact due to wider dispersion of air pollutant. Surely, the result should compare to the standard in order to states which one better than other.

Comparing to the standard of maximum CO and NO_2 standard released by WHO, (See Figure 8 and Figure 9), Exhaust fan which is installed near to parking space (Position of A) gives better result because it provides wider health indoor environment. Based on the Figures, the exhaust gas only pollutes the air around the parking space area (both for cases of cars facing and backing the exhaust fan). Meanwhile, when the exhaust fan installed near to the pathway (Position of B) the exhaust gas moves widely and pollutes more area inside the parking garage.

However, all the simulations show that the high air pollutant still exist at any level of height. It suggests to keep activate the exhaust fan even there is no emission source inside the parking garage to ensures there is no air pollutant trapped inside the building. The parking management also can use this method to provide information related to health place area inside the building and avoid risk for any people who use this parking facility.

For further study, it suggests to put additional exhaust fan near to the emission sources. This additional exhaust fan is should able to shortened the streamline of air pollutants. Hopefully by shortening the streamline of air pollutants, it could reduce the polluted area inside the building. Combination between the main and the additional exhaust fans could give better air flow, better capability to take out the air pollutants as well as provide the healthier indoor environment

Acknowledgments

We would like to thanks to Directorate of Research and Research Development, Directorate of Research, Technology and Community Service, Ministry of Education, Culture, Research and Technology which has provided financial support in this research. The financial support is noted in a Contract of The Implementation of Research Program for Higher Education with contract number of 245/E5/PG.02.00.PT/2022.

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