A CFD SIMULATION OF INDOOR AIR CONTAMINANT ON VENTILATION SYSTEM IN A BUS PASSENGER COMPARTMENT

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Abstract. Good ventilation system in a bus passenger compartment is important for providing clean, healthy air and comfortable micro-environment for the passengers. Lack of fresh inside the bus passenger compartment due to poor ventilation system could increase the contaminants concentration which could affect the passenger's health. This research reports findings of field measurement on the contaminants concentration of particulate matter (PM1) and carbon monoxide (CO) inside the passenger compartment of a university's shuttle bus. The field measurements were conducted at the front, middle and rear locations of the passenger compartment. Measurements of PM1 and CO were done continuously in the morning, afternoon and evening. A CFD software was employed to develop a simplified three-dimensional model of the bus passenger compartment. Velocity and temperature boundary conditions were prescribed at the air supply diffusers, based on the measured data. Meanwhile, the contaminants concentration was prescribed at the door. Flow analysis was carried out using RNG k-ε turbulent model for air flow, discrete phase and species transport for contaminants. Four cases of air supply diffuser locations namely mixing ventilations (MV3 and MV4), mixing ventilation with displacement ventilation (MV2+DV) and mixing ventilation with underfloor air distribution (MV2+UFAD) were examined. Two cases of air return grille locations namely three air return grilles (3RG) and four air return grilles (4RG) were also examined in this research. It was found from the field measurement that the contaminants concentration of PM1 and CO were high at the front location of the passenger compartment. This is due to insufficient ventilation inside the bus passenger compartment. Result of the CFD simulation shows that the MV2+DV, MV2+UFAD and 4RG of air supply diffuser and air return grille locations could reduce the contaminants concentration of CO and PM1 in the occupied zone inside the bus passenger compartment.

Introduction

Bus passenger compartment require good ventilation system for distribute a clean and healthy air in the occupied zone. In engineering approach, the efficiency of ventilation system is evaluated by the indoor air quality. Indoor Air Quality (IAQ) refers to the effect, good or bad of the contents of the air inside an enclosed environment. Good IAQ is the quality of air which has no unwanted contaminants. Poor of IAQ occurs when contaminants are present at an excessive concentration. In IAQ research two types of harmful contaminants were widely investigated namely particles and gaseous. Particulate matters (PM1, PM2.5 and PM10) represent as particles whereas carbon dioxide (CO_2), carbon monoxide (CO) and formaldehyde (CH_2O) represent as gaseous contaminants. Various diseases adversely affect the occupant health of these contaminants such as respiratory problem, cardiovascular and airborne transmission. Knowledge concerning the contaminants level is very important to prevent the harmful particles and gaseous inhaled by passengers when commuting in a bus. The ventilation system of the bus need to improve due to long time usages for business, shopping, campus, school, recreation or others activities. There were several factors that affect the design and performance of ventilation system such as size and type of bus, air supply velocity, air supply temperature, location of the air supply and location of the air return grille. The locations of air supply and air return grille are very important to reduce the contaminants concentration level especially in the occupied zone. At present, research works on reducing air contaminants inside the bus cabin is limited especially using computational fluid dynamics (CFD) approach. CFD tools offer an alternative platform which is more convenient than experimental practice to analyse the indoor air quality in various application. Hence, an investigation of ventilation system using CFD tools is necessity in which will improve the IAQ inside the bus cabin.

Previous researchers were conducted the field measurement method to quantify the indoor air contaminant inside the bus passenger compartment. Chan [1] was conducted the field measurement of indoor air contaminant inside the bus cabin. The measurements were performed in urban and rural areas in Hong Kong with twelve different short routes. The measurements were performed at the rear compartment and at the height of breathing level of passengers. Measurements were taken at peak hours (8.00 am to 9.30 am) and non-peak hours (10.30 am to 14.00 pm). Hsu *et al.* [2] were examined the contaminant concentration levels of CO and PM in the long distance buses. The measurements were performed in a highway road Taiwan. The total travelling distance was approximately 300 km, which normally took 4 hours to 5 hours, depending on traffic and weather condition. The sampling instruments were placed in the centre of the bus cabin and at the height of the breathing zone of seated passengers. Zhu *et al.* [3] were investigated the micro-environmental such as CO and PM in public transportation buses. The measurements were performed in a Harvard university shuttle bus. The measurement was conducted in an empty bus. The bus engine was kept in idle condition and the air-conditioning system was operated as usual. All the windows and doors were fully closed during the experimental. The measurements were performed at four bus locations (in the front and rear compartment at each side of the bus). The instruments were placed in two mesh boxes made by coarse wire, which were hanged at the shoulders of two of our field personnel at a height 0.6 m and 1.1 m from floor. The field measurements were started early in the morning (9.00 am to 16.30 pm) with a lunch break around noon. Rim *et al.* [4] were investigated the characteristic of cabin air quality in a school buses in Central Texas. The measurement was performed using six school buses with different engine year in sub-urban Austin, Texas. The route was a typical 42.4 km suburban school bus route and required approximately 100 minutes to complete. Only research team members and driver were on-board buses during the tests. The air sampling was placed in the centre of bus cabin. Gomez *et al.* [5] were investigated the commuter's exposure in the bus, minibus and metro bus. Commuters' exposure measurements were taken for PM2.5 and CO in minibuses, buses and metro during morning and evening rush hours during January to March 2003 in Mexico City. The instrument was placed at a level of breathing zone. The measurements were taken in the morning (6.30 am to 9.00 am) and evening (17.30 pm to 20.30 pm). Wong *et al.* [6] were investigated in cabin exposure levels of CO and PM10 for running buses in Hong Kong that equipped with Euro II, III and IV engines. Urban and sub-urban bus route were chosen in this research. Travelling distance between the two bus terminals is 32 km and it was monitored and recorded every one minute throughout the journey. All measurements were conducted on weekdays during bus service hours starting from 7.00 am to 10.00 am and 16.00 pm to 19.00 pm. Air samples were collected at the height of 1.45 m above the floor and kept away from the bus main entrances, air inlets, air outlets and passengers.

This research reports findings of field measurement on the contaminants concentration of PM1 and CO inside the passenger compartment of a university's shuttle bus. The field measurements were conducted at the front, middle and rear locations of the passenger compartment. Measurements of PM1 and CO were done continuously in the morning, afternoon and evening. A CFD software was employed to develop a simplified three-dimensional model of the bus passenger compartment. Velocity and temperature boundary conditions were prescribed at the air supply diffusers, based on the measured data. Meanwhile, the contaminants concentration was prescribed at the door. Flow analysis was carried out using RNG k-ε turbulent model for air flow, discrete phase and species transport for contaminants. Four cases of air supply diffuser locations namely mixing ventilations (MV3 and MV4), mixing ventilation with displacement ventilation (MV2+DV) and mixing ventilation with underfloor air distribution (MV2+UFAD) were examined. Two cases of air return grille locations namely three air return grilles (3RG) and four air return grilles (4RG) were also examined in this research.

Methodology

ANSYS Fluent (R-14) software was selected to simulate the problem, employing Reynolds-averaged Navier-Stokes (RANS) approach to solve the fluid flow. In particular, flow analysis was carried out using RNG k-ε turbulent model for air flow, discrete phase and species transport for contaminants. This study performed the field measurements in a real condition of the bus passenger compartment in order to validate the CFD simulation. A simplified three-dimensional model of the bus passenger compartment is described in Figure 1. There are fourteen four air supply diffusers located on the ceiling mounted duct work and two air return grilles located at the front and rear of the bus roof. The current locations of air supply diffuser and air return grille are known as mixing ventilation (MV) and two return grilles (2RG).

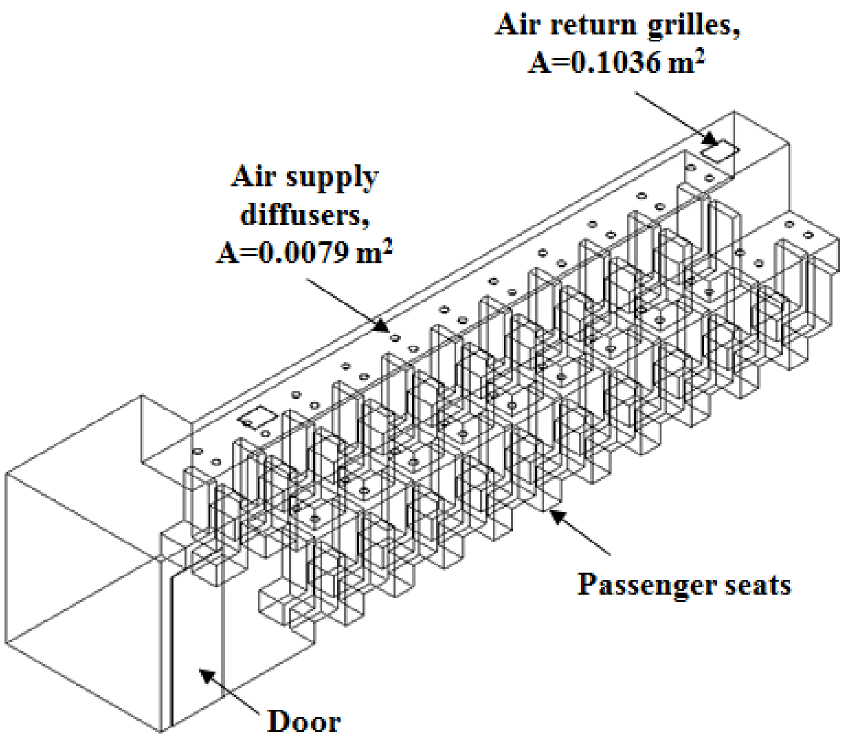


Fig. 1 A simplified three-dimensional model of the bus passenger compartment (MV and 2RG)

2.1 Field measurement set-up for CFD validation

Field measurements were conducted to quantify the contaminants concentration of PM1 and CO inside the passenger compartment of a university's shuttle bus that ferries students from their hostels to the university's campus. The total distance travelled by the bus was about 12 km. The in-campus route followed by the bus during the entire period of the field measurement are shown in Figure 2 and detail description of the bus is given in Table 1. The field measurements were conducted in an empty bus and measured at the front, middle and rear locations of the passenger compartment as shown in Figure 3. Also, the measurement was carried out at the door which the outside contaminant enters the bus during the trips. The contaminants concentrations of PM1 and CO were continuously monitored during the trips and data were recorded at several time intervals (1 minute), at the steady-state conditions. A handheld particle counter instrument (model HPC300) was used to measure the contaminant concentration of PM1 inside the bus passenger compartment. Indoor environmental quality (model IEQ Bacharach) instrument was used to monitor the contaminant concentration of CO. A digital anemometer (model V816B) was employed to measure the air velocity and temperature at the cool air supply diffusers. For stability reason, the instruments were attached onto a tripod during the data measurement, as shown in Figure 4. The particle counter and indoor environmental quality instruments were placed at the height of 1.1 m from the floor of the bus compartment, which is considered as the breathing level of the passengers [7]. The air velocity and temperature at the cool air supply diffuser were maintained as much as possible at 3 m/s and 23°C, respectively during the field measurement period. The range and accuracy of the anemometer, particle counter and indoor environmental quality are shown in Table 2.

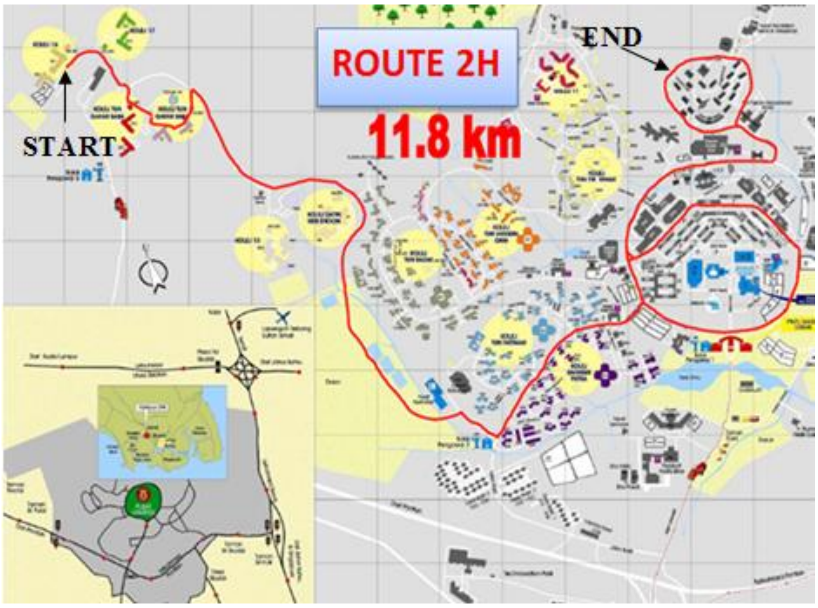


Fig. 2 The in-campus route followed during the field measurement

Table 1 Detail description of the bus

Description	
Model	Hino (RK1JSK-14045)
Engine	JO8C-F EURO 1
Year	2011
Compartment	Length, 11 m Width, 2.5 m Height, 2.4 m
Door	Length, 2.1 m Width, 0.82 m
Passenger seat	Length, 0.7 m Width, 0.4 m
Air supply diffuser	Diameter, 0.1 m
Air return grille	Length, 0.37 m Width, 0.28 m

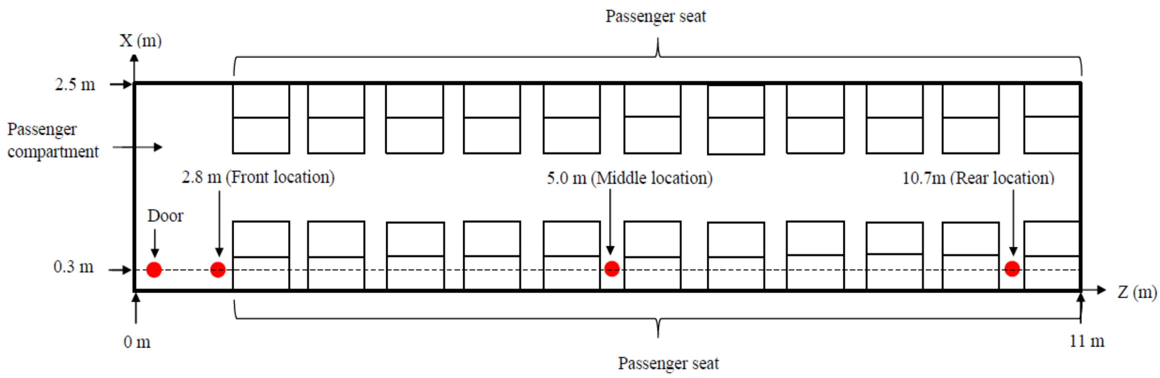


Fig. 3 Location measurements of PM1 and CO at the front, middle and rear bus passenger compartment

Table 2 The range and accuracy of the anemometer, particle counter and indoor environmental quality instruments

Instrument	Model	Accuracy
Anemometer	VICTOR 816b	Temperature, ± 2°C
		Velocity, ± 3 %
Particle counter	HPC300	± 5 %
Indoor environmental quality	IEQ Bacharach	± 2 %

(a) (b)

Fig. 4 The instruments attached onto a tripod during the data measurement. (a) Particle counter and (b) Indoor environmental quality

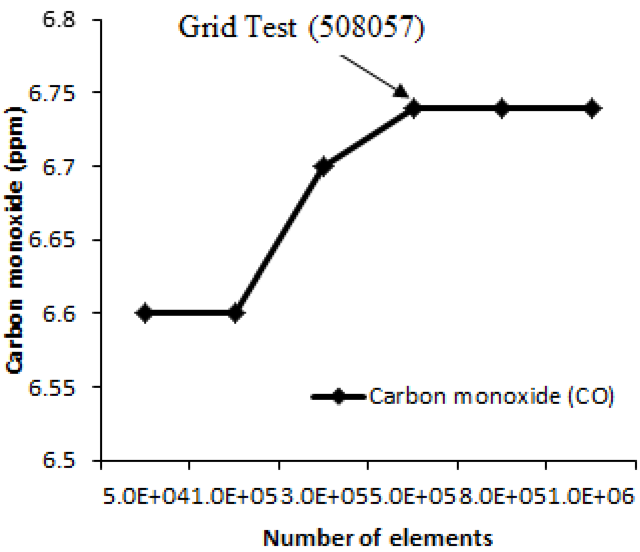
2.2 CFD validation

The CFD simulation procedure was validated by comparing the contaminants concentration obtained from the CFD simulations at the front, middle and rear locations obtained from the field measurements. Following assumptions were made for the simulation setup:

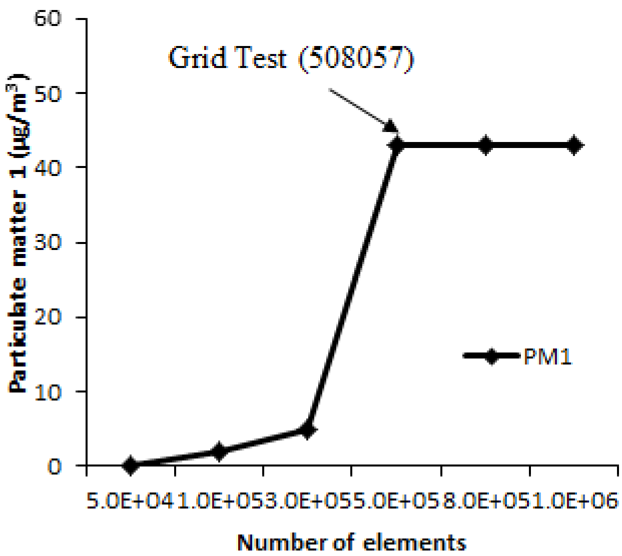
- The RNG k-ε turbulence model, discrete phase model and species transport model were applied for the airflow, particle and gas analyses.
- The door was open and no passengers inside the bus.
- No contaminants inside the bus passenger compartment.
- The source of contaminants concentration of PM1 and CO was applied at the door due to the outside contaminant enters the bus.
- The air inlet and air outlet were applied at the air supply diffusers and air return grilles.
- The properties of air in the passenger compartment were governed by the equations of state for incompressible flow and the reference pressure was set to atmospheric pressure, 101325 Pa.
- All boundary conditions linked with the air temperature, air velocity, contaminants concentration were set up based on the data from the field measurements.
- The simulations were run as steady employing pressure-based segregated solver with the SIMPLE, second order upwind discretization scheme and convergence criteria for all equations set to 10^{-4} except energy 10^{-6} [8].

2.2.1 Mesh sensitivity test

Mesh sensitivity test was performed to ensure that meshing has no effects on the results of the CFD analysis. Results of the contaminants concentration of CO and PM1 against the number of elements are shown in Figure 5. The meshes of 50000, 100000, 300000, 500000, 800000 and 1000000 of cells were generated and solved for contaminants concentration of CO and PM1 distributions. It was found that the mesh sensitivity test of contaminants concentration of CO and PM1 was constant at 500000 grid cells compared to 50000, 100000 and 300000, respectively. Thus, the numbers of elements of 508057 tetrahedral cells were employed throughout the CFD analysis.



(a)



(b)

Fig. 5 The contaminants concentration against the number of elements (a) CO and (b) PM1

2.2.2 Results of CFD validation

The comparison of measured and predicted data of contaminants concentration is depicted in Table 3 and Table 4 for three different locations, namely front, middle and rear occupied zone. The contaminants concentration was high at the frontal location which is near to the bus door. This could be due to insufficient ventilation of fresh air supply inside the bus passenger compartment. The result shows that percentage differences of predicted data of PM1 and CO are below 20 % which can be accepted for the complex flow for indoor environmental [9].

Table 3 Comparison of predicted and measured of PM1 at the front, middle and rear locations

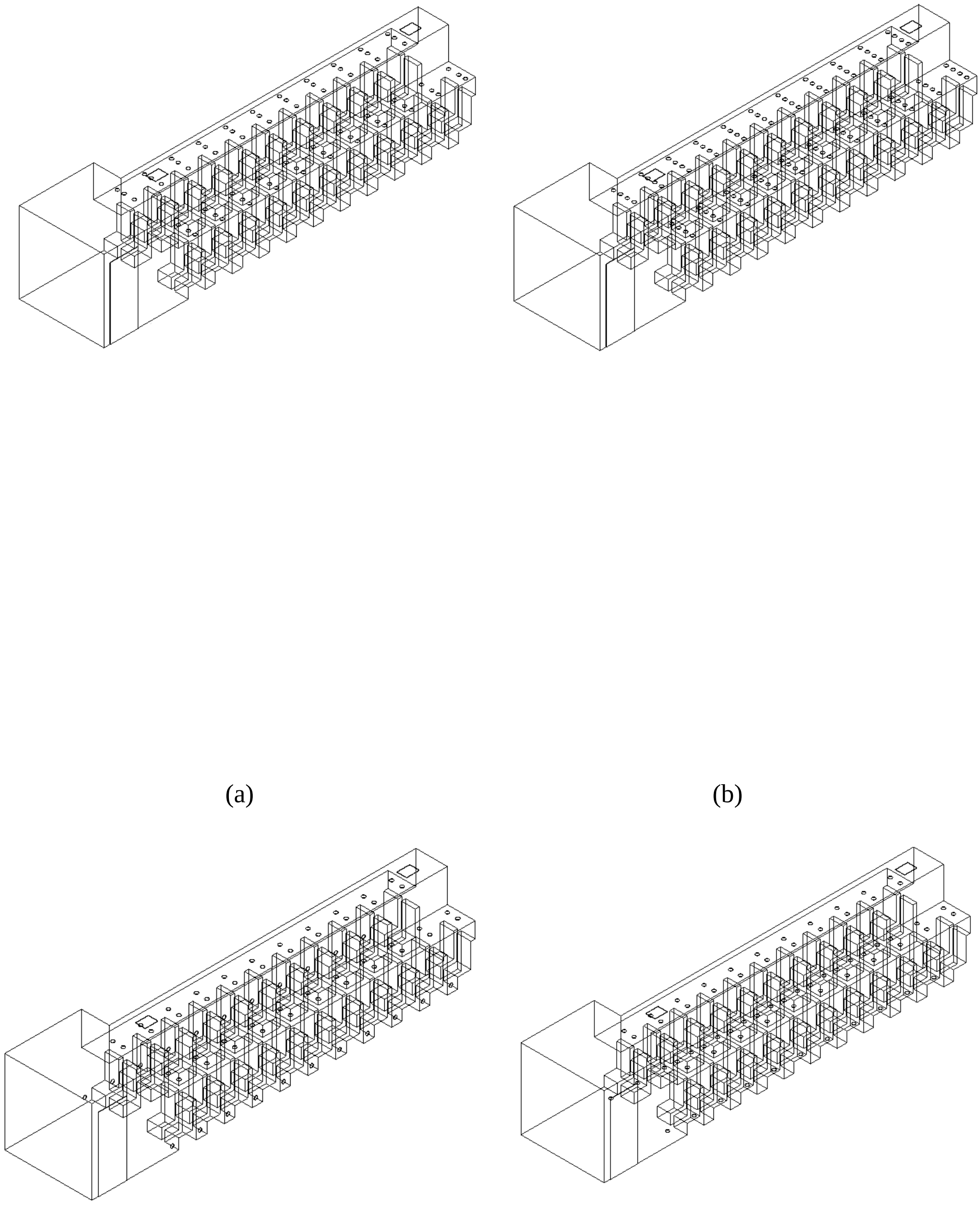
Location	Particulate Matter, PM1 (μg/m^3)		Percentage difference $\frac{(Cp-Cm)}{Cm} \times 100$ %
	Max predicted (Cp)	Max measured (Cm)	
Front	43	52 ±9	-17.3
Middle	46	43 ±3	6.9
Rear	34	40 ±6	-15

Table 4 Comparison of predicted and measured of CO at the front, middle and rear locations

Location	Carbon Monoxide (ppm)		Percentage difference $\frac{(Cp-Cm)}{Cm} \times 100$ %
	Max predicted (Cp)	Max measured (Cm)	
Front	6.7	7 ±0.3	-4.3
Middle	5.1	5 ±0.1	-2
Rear	1.6	2 ±0.4	-20

2.3 Numerical modelling of the bus passenger compartment for different cases of air supply diffuser and air return grille locations

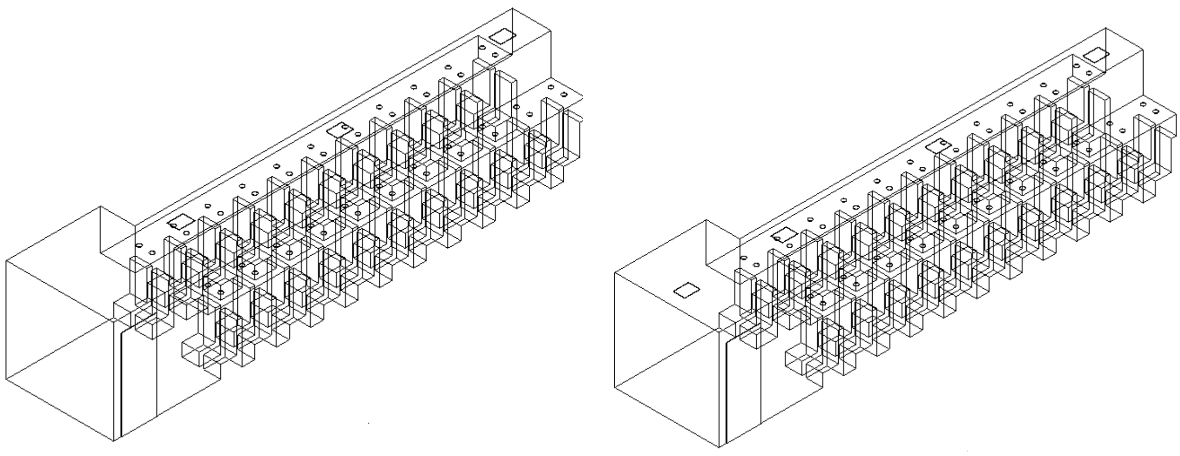
The numerical modelling was performed for four cases of air supply diffusers and two cases of air return grilles location inside the bus passenger compartment. For each case of air supply diffuser and air return grille locations of the bus passenger compartment were prescribed in Figure 6 and Figure 7. MV and 2RG are the current location of the air supply diffusers and air return grilles in the bus passenger compartment. The air supply diffusers location of case 1 (MV3): Three air supply diffusers placed in a one row at the ceiling mounted duct work, case 2 (MV4): Four air supply diffusers placed in a one row at the ceiling mounted duct work, case 3 (MV2 + DV): Two air supply diffusers placed in a one row at the ceiling mounted duct work with one air supply diffuser placed at the side walls and case 4 (MV2 + UFAD): Two air supply diffusers placed in a one row at the ceiling mounted duct work with one air supply diffuser placed at the floor. Meanwhile, the air return grilles location of case 1 (3RG): Three air return grilles placed in a one row at the roof and case 2 (4RG): Four air return grilles placed in a one row at the roof.



(a) (b)

(c) (d)

Fig.6 The case study of air supply diffuser locations. (a) MV3 (b) MV4, (c) MV2 + DV and (d) MV2 + UFAD



(a) (b)

Fig.7 The case study of air return grille locations. (a) 3RG and (b) 4RG

2.3.1 Computational mesh

The computational mesh for the CFD simulations was created using the ANSYS Mesh-R14 software. The mesh in the cabin space consists mostly of tetrahedron cells. Tetrahedron cell is suitable for three dimensional model, complex geometry and convergence will generally faster [10]. The total number of cells in the model was approximately 508057. The maximum and minimum sizes of the cells are 0.34 m and 0.002 m, respectively. Much finer surface was generated at the door, air supply diffuser and air return grille locations. This is to ensure the CFD simulation results more accurate. Figure 8 shows the computational mesh of the bus passenger compartment.

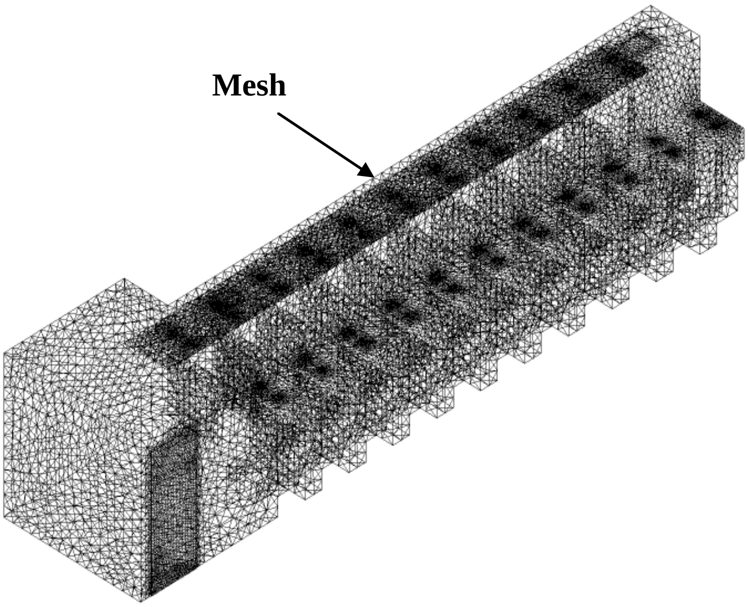
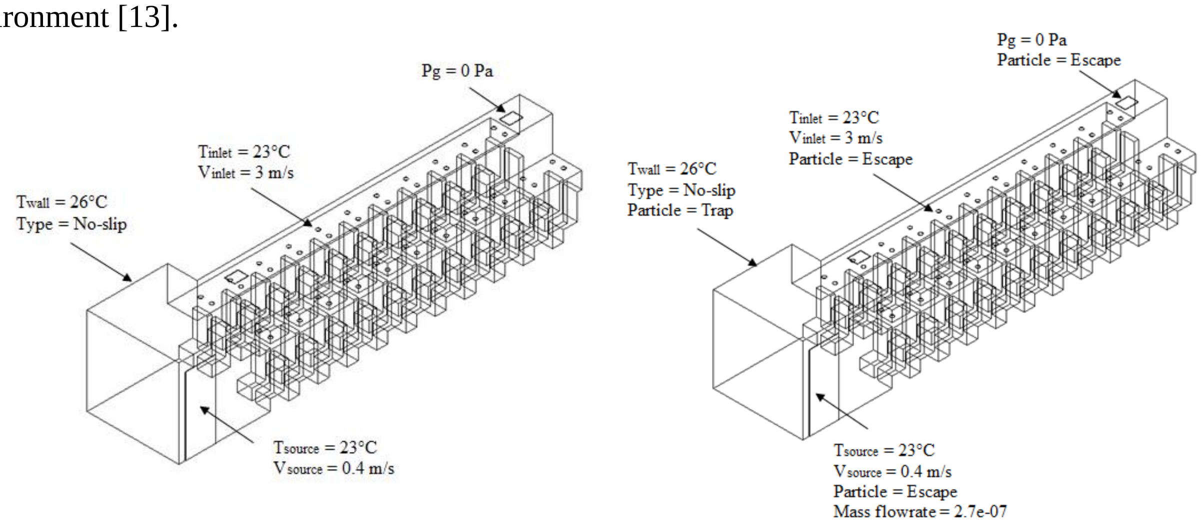


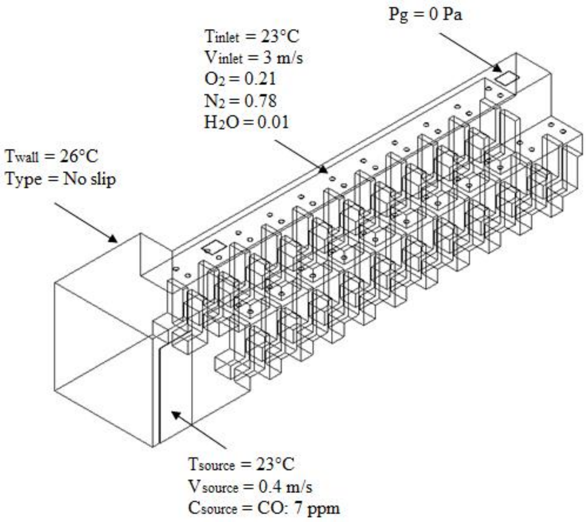
Fig. 8 The computational mesh of the bus passenger compartment

2.3.2 Boundary conditions

Temperature and velocity of the air supply diffuser was set to 23°C and 3 m/s based on the measured data. The wall of the bus was set to 26°C for the air temperature. The contaminants of CO and PM1 were applied at the bus door. The contaminants concentration of CO and PM1 were set to 7 ppm and 52 μg/m^3, respectively. For all cases of air supply diffuser and air return grille locations the air temperature, air velocity and contaminant concentration were set to the same value. The boundary conditions for the air flow, particle and gas are shown in Figure 9. Turbulent intensity was set to 5 % and turbulent parameter for the door, air supply diffuser and air return grille boundary conditions were hydraulic diameter. No slip condition was applied at the wall. When fluid in direct contact with a solid to the surface due to the viscous effects the velocity of the flow is zero and assumed no slip for the wall [11]. For particle simulation the door, air supply diffuser and air return grille were set to escape while the wall was set to trap boundary condition. When particles reach air supply diffuser, air return grille and door, the particles will escape and the trajectories terminate. This could be due to the effects of airflow against particle at each location. However, when reaching a rigid object such as wall, particle may either attach to or rebound from the object's surface. It is therefore natural to terminate or trap a particle trajectory after hitting a rigid surface [12]. For gas simulation, non-reacting flow was applied due to the effects of contaminants concentration characteristic. The gas contaminant is assumed as a passive and low concentration in an enclosed environment [13].



(a) (b)



(c)

Fig. 9 A boundary conditions of the bus passenger compartment. (a) Airflow, (b) Particle contaminant and (c) Gas contaminant

The setup of the CFD solver was the same as in the validation simulation (see section 3.2). The flow was assumed to be turbulent and the RNG k-ε turbulence model was applied. The discrete phase and species transport were applied for contaminants concentration analyses. The simulations were performed as steady state with pressure-based segregated solver with the SIMPLE, second order upwind discretization scheme and a convergence criterion for all equations is 10^{-4} except energy 10^{-6} [8].

Result and discussions

Results of the field measurements are presented at the front, middle and rear locations as a function of time in the morning, afternoon and evening. Height of measurement is 1.1 m from the floor for all contaminants. In an enclosed environment, the height of 1.1 m from the floor was chosen and represent as a breathing zone of the passengers [7]. This height is very suitable to measure the contaminants concentration in indoor environment that away from the airflow locations such as air supply diffusers, air return grilles and door. The CFD simulation results for all cases on contaminants concentration of PM1 and CO are presented at x-direction is 0.3 m, y-direction is 0.3 m (floor) to 1.45 m (air supply diffuser) and z-direction is 2.8 m as shown in Figure 10.

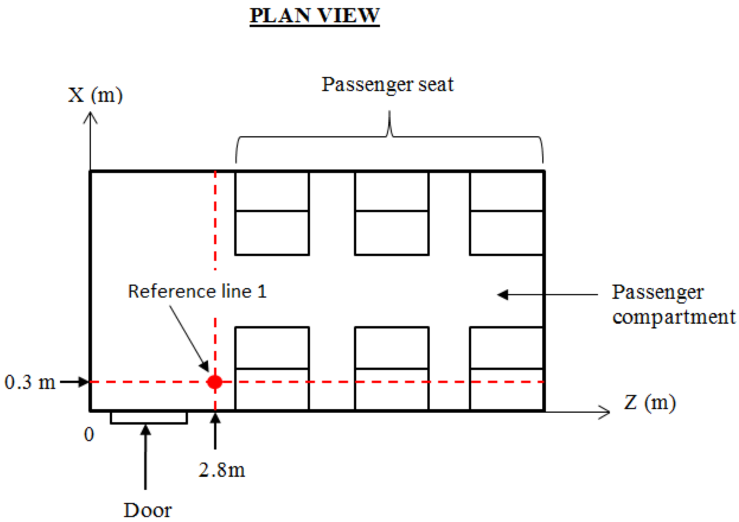


Fig. 10 The reference line 1 of the CFD simulation results

3.1 Field measurement of PM1 and CO concentrations

Figure 11 shows the contaminant concentration of PM1 in the bus as a function of time. The result shows that the PM1 was high in the morning, afternoon and evening at the front location of the bus passenger compartment. This is due to the outside contaminant enters the bus when the door is open. Insufficient ventilation of the bus is the factor that increases the contaminant concentration level of PM1 at the front location of the bus passenger compartment. However, the CO concentration was slightly lower in the morning, afternoon and evening at the middle and rear locations. The maximum and minimum concentrations of PM1 were 52 μg/m^3 and 1 μg/m^3, respectively. In particular, the contaminant of PM1 is originates from the vehicular exhaust, ambient air and dust. It was observed that the contaminant concentration of PM1 was exceeding the acceptable level by the World Health Organization (WHO) [14]. The acceptable level of PM1 in an enclosed environment should be below 25 μg/m^3.

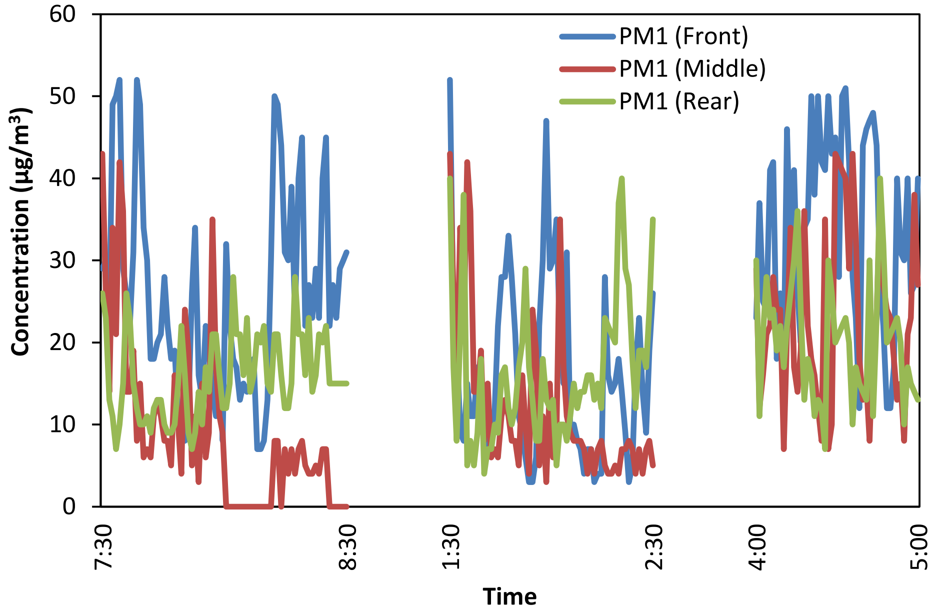


Fig. 11 Contaminant concentration of PM1 in the bus as a function of time

Figure 12 shows the contaminant concentration of CO in the bus as a function of time. The result shows that the contaminant concentration of CO was high in the afternoon and evening at the front location of the bus passenger compartment. However, the contaminant concentration of CO was also high in the morning at the middle location of the bus passenger compartment. This is due to the outside contaminant enters the bus when the door is open. Insufficient ventilation of the bus and heavy traffic condition are the factor that increases the contaminant concentration level of CO at the front and middle locations of the bus passenger compartment. Based on the measured data the heavy traffic condition occurs in the morning, afternoon and evening in a university's campus. In particular, the contaminant of CO is originates from the vehicular exhaust. It was observed that the maximum and minimum concentrations of CO were 7 ppm and 1 ppm, respectively. The CO concentration levels was below 7 ppm, much lower than the average limit of 10 ppm, which was recommended by the World Health Organization (WHO) [14].

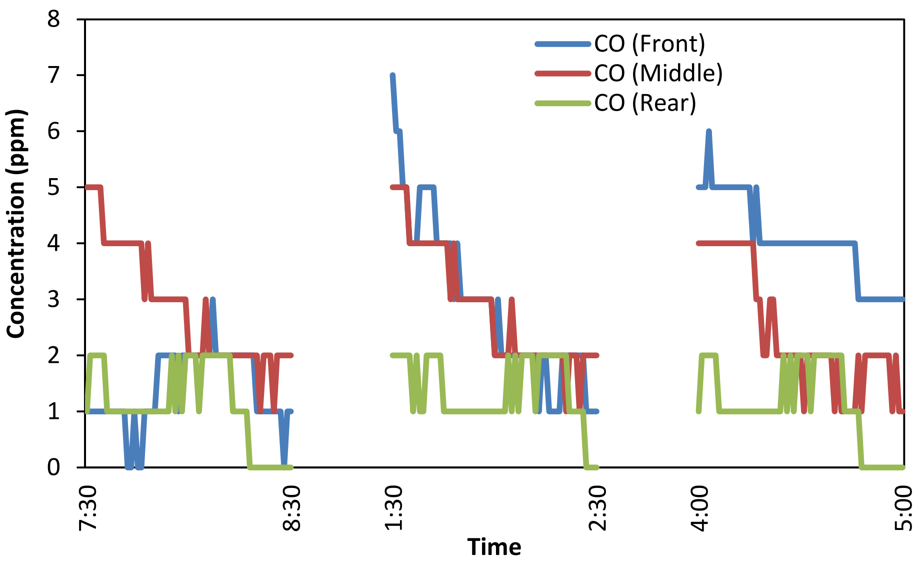


Fig. 12 Contaminant concentration of CO in the bus as a function of time

3.2 CFD simulation of air supply diffuser and air return grille locations

Figure 13 shows the comparison of contaminant concentration of CO with different cases of air supply diffuser locations. The modified of air supply diffuser locations were MV3, MV4, MV+DV and MV+UFAD. The current location of air supply diffusers namely MV generally had the highest contaminant concentration of CO at 0.3 m to 1.45 m height inside the bus passenger compartment. The result shows that MV2+UFAD of air supply diffusers location could reduce the contaminant concentration of CO at 0.3 m to 1.45 m height, respectively. This is due to the sufficient ventilation when the air supply diffusers located at the ceiling mounted duct work with additional diffusers at the base of the occupied zone (floor). However, the MV3, MV4 and MV2+DV also could reduce the CO concentrations in the occupied zone. The MV2+UFAD of air supply diffusers location could prevented the accumulated contaminants in the occupied zone inside the bus. The tight space of the bus passenger compartment enhanced the contaminant concentration level of CO. In the underfloor air distribution namely UFAD, air is directly supplied to the base of the occupied zone, which causes temperature stratification from the lower to the upper layer of the zone [15]. This flow pattern gives UFAD the advantage of using less energy while providing better thermal comfort and less contaminant than MV, MV3, MV4 and MV+DV of air supply diffuser locations [16].

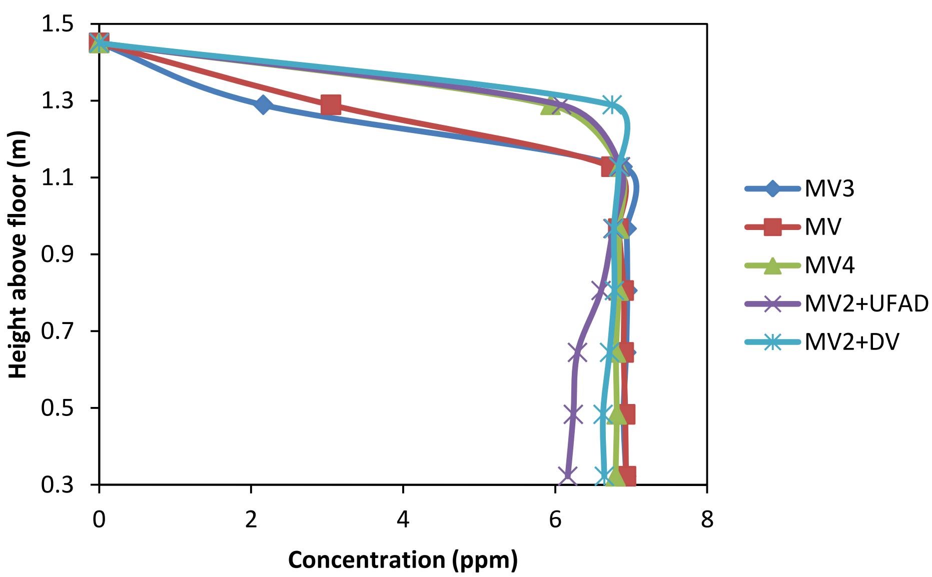


Fig.13 Comparison of contaminant concentration of CO with different cases of air supply diffuser locations

Figure 14 shows the comparison of contaminant concentration of CO with different cases of air return grille locations. The modified of air return grille locations namely 3RG and 4RG. The current location of air return grilles namely 2RG generally had the highest contaminant concentration of CO at 0.3 m to 1.45 m height, respectively. It was observed that the 4RG could reduce the contaminant concentration of CO at 0.3 m to 1.45 m height, respectively. The 4RG could reduce the CO concentration that accumulated in the occupied zone compared to the 2RG and 3RG. This could be due to the locations of air return grille which was placed along the bus roof. The 4RG of air return grille location is suitable to remove all the contaminant of CO which was trapped inside the bus passenger compartment.

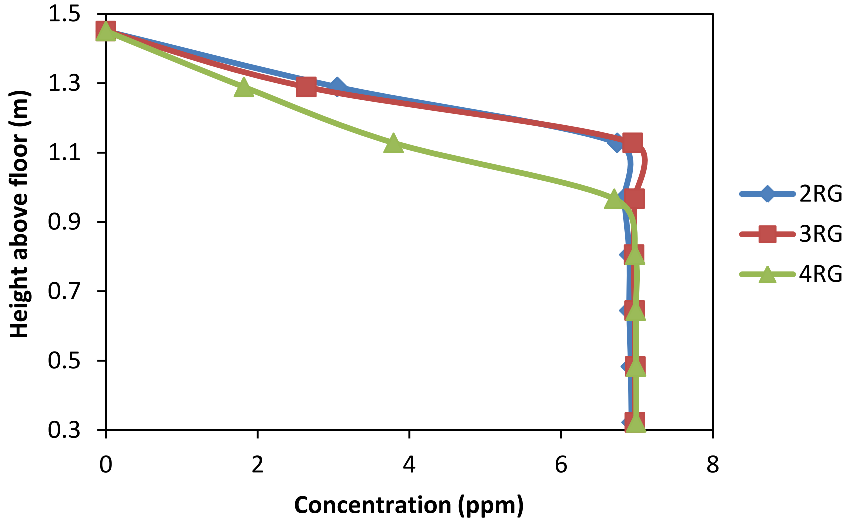


Fig.14 Comparison of contaminant concentration of CO with different cases of air return grille locations

Figure 15 shows the comparison of contaminant concentration of PM1 with different cases of air supply diffuser locations. The current location of air supply diffusers namely MV generally had the highest contaminant concentration of PM1 at 0.3 m to 1.45 m height inside the bus passenger compartment. The result shows that the MV2+DV of air supply diffusers location could reduce the contaminant concentration of PM1 at 0.3 m to 1.45 m height, respectively. However, the MV3, MV4 and MV2+UFAD also could reduce the PM1 concentration inside the bus passenger compartment. This could be due to the sufficient ventilation when the air supply diffusers located at the ceiling mounted duct work with additional diffusers at the side walls of the occupied zone. The MV2+DV of air supply diffusers prevented the accumulated contaminants in the occupied zone. The DV of air supply diffuser location normally creates the vertical gradients of air velocity, temperature and contaminant concentration [17]. In particular, the principle of DV can eliminate the contaminant concentration in the occupied zone inside enclosed environment [18].

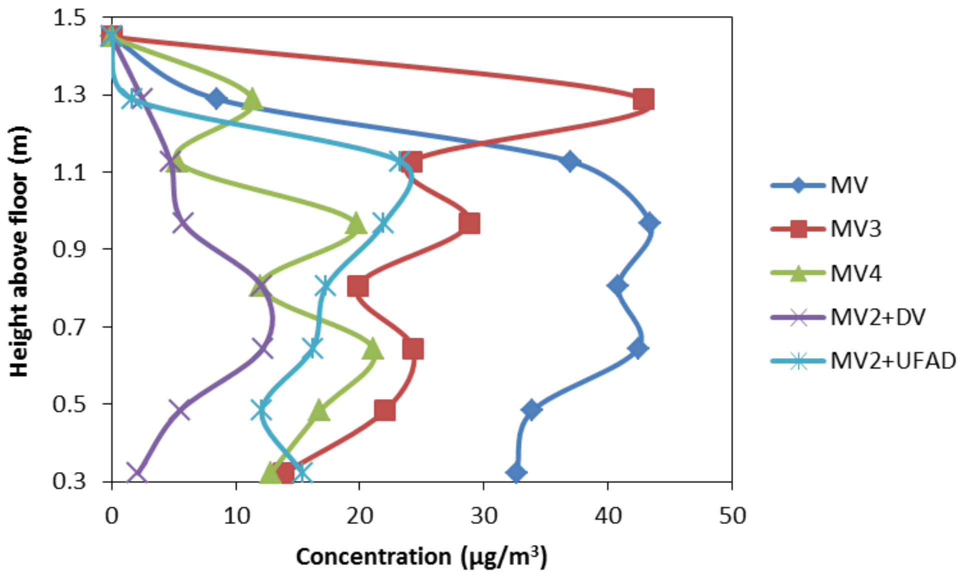


Fig.15 Comparison of contaminant concentration of PM1 with different cases of air supply diffuser locations

Figure 16 shows the comparison of contaminant concentration of PM1 with different cases of air return grille locations. The current location of air return grilles namely 2RG generally had the highest contaminant concentration of PM1 at 0.3 m to 1.45 m height inside the bus passenger compartment. The result shows that the 4RG of air return grilles location could reduce the contaminant concentration of PM1 at 0.3 m to 1.45 m height, respectively. However, the 3RG could reduce the PM1 concentration inside the bus passenger compartment. The accumulated concentration of PM1 in the occupied zone could be removed when four of air return grilles (4RG) were located at the bus roof compared to 2RG and 3RG.

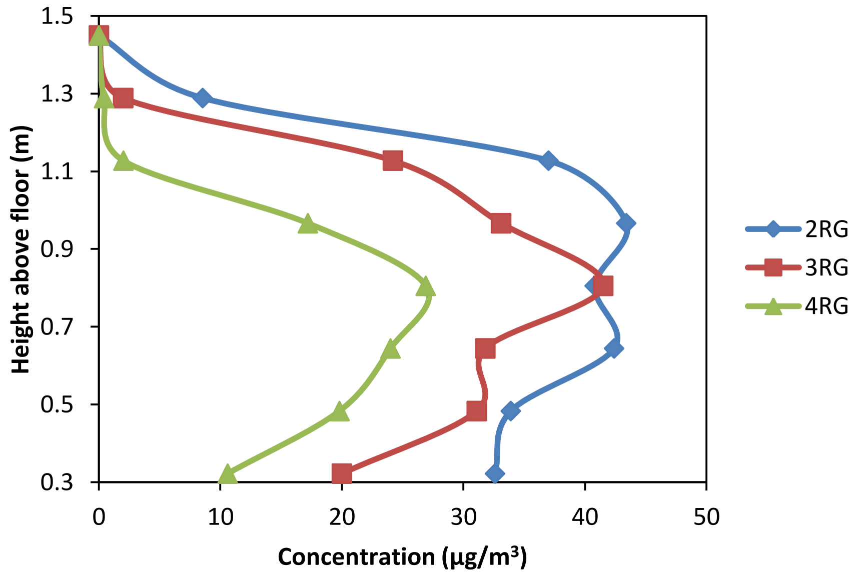
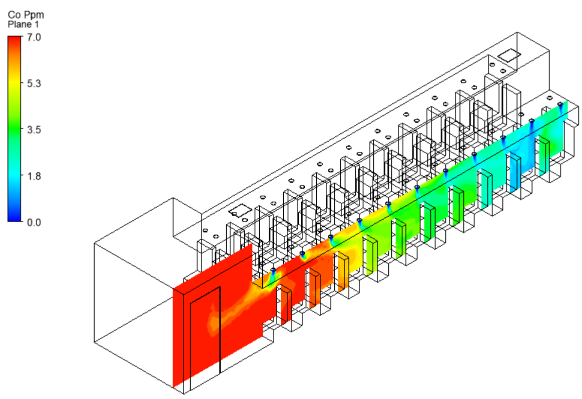
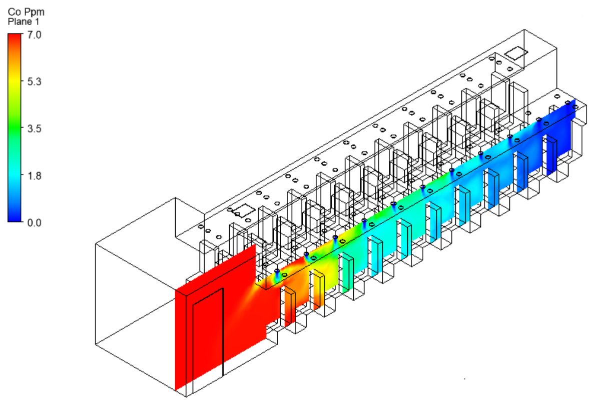


Fig.16 Comparison of contaminant concentration of PM1 with different cases of air return grille locations

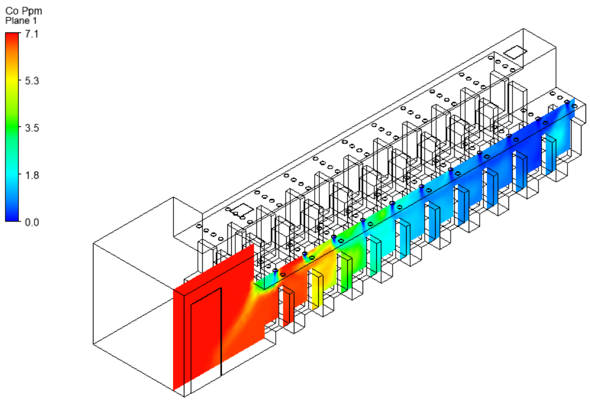
The distribution contour of contaminants concentration CO and PM1 for all cases are illustrated in Figure 17 until Figure 20. Figure 17 and Figure 18 show the contaminants concentration of CO and PM1 on a vertical symmetrical plane of the bus passenger compartment of various cases of air supply diffuser locations. Meanwhile, Figure 19 and Figure 20 show the contaminants concentration of CO and PM1 on a vertical symmetrical plane of the bus passenger compartment of various cases of air return grille locations.



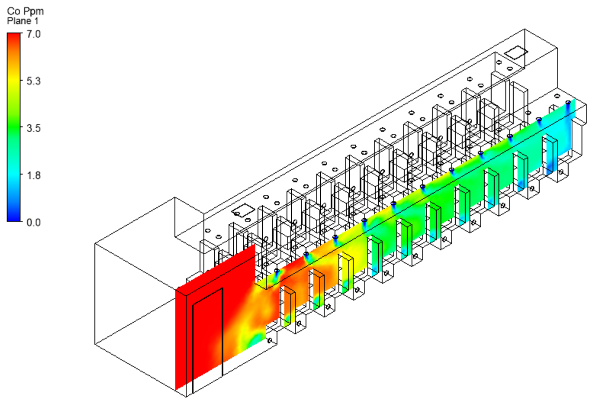
(a)



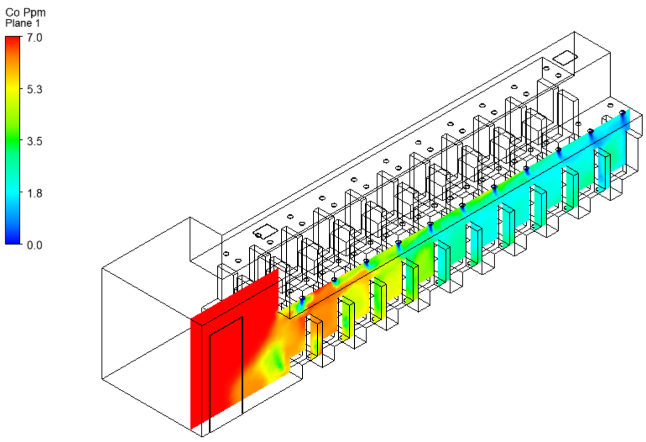
(b)



(c)

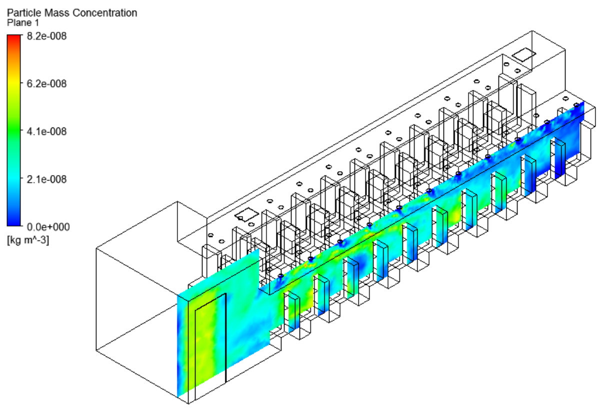


(d)

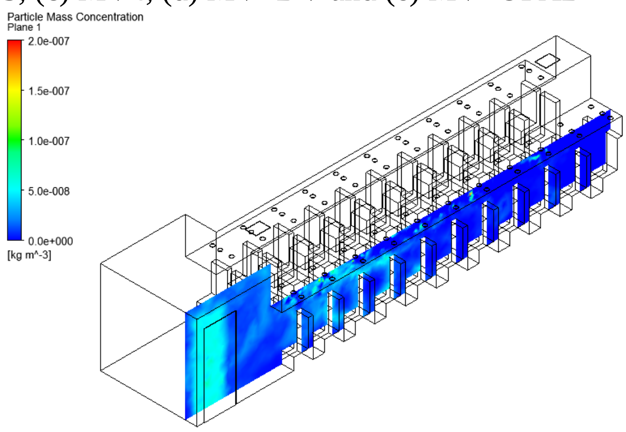


(e)

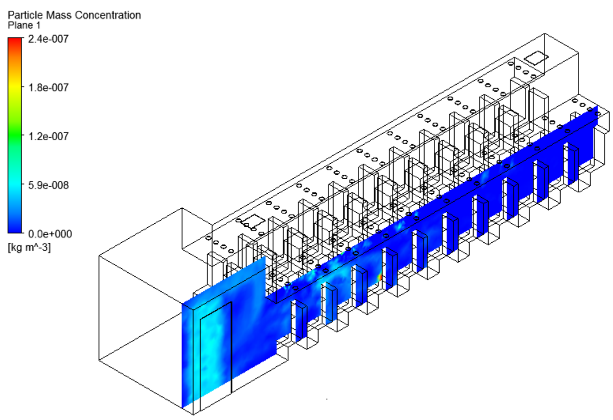
Fig. 17 Contaminant concentration of CO on a vertical symmetrical plane of the bus passenger. Air supply diffuser locations: (a) MV, (b) MV3, (c) MV4, (d) MV+DV and (e) MV+UFAD



(a)



(b)



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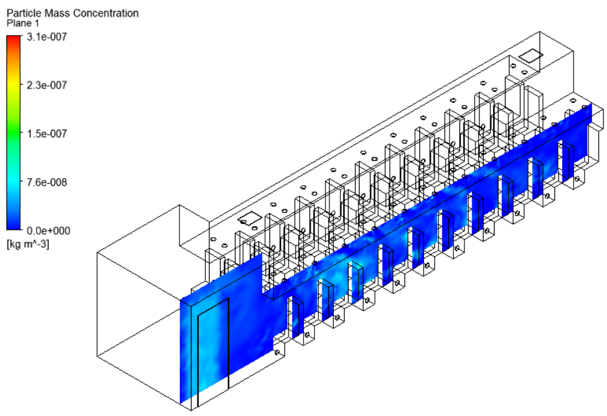
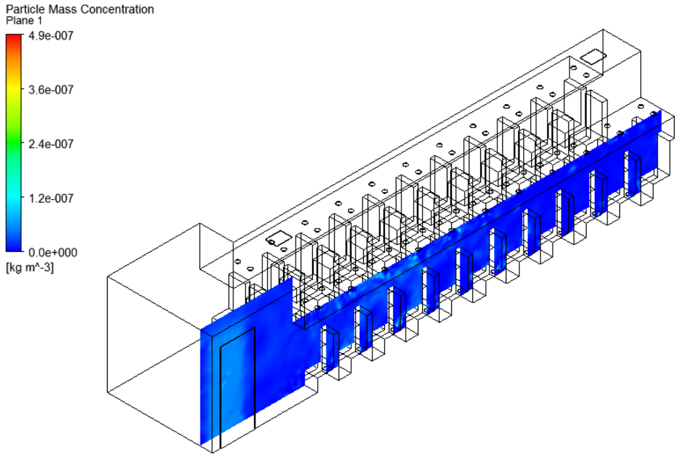
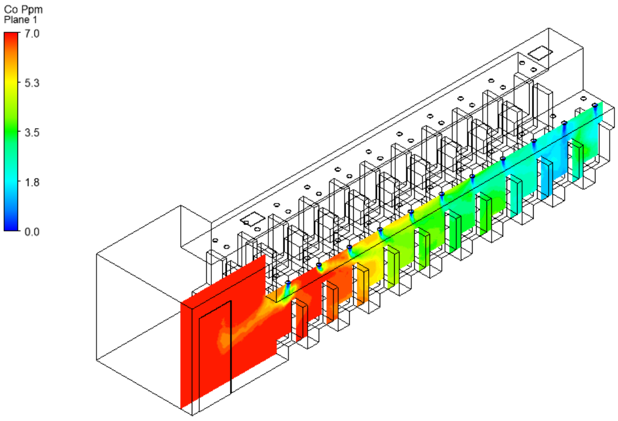


(d)

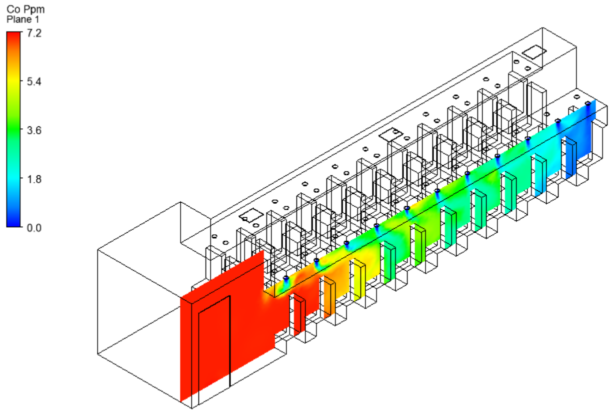


(e)

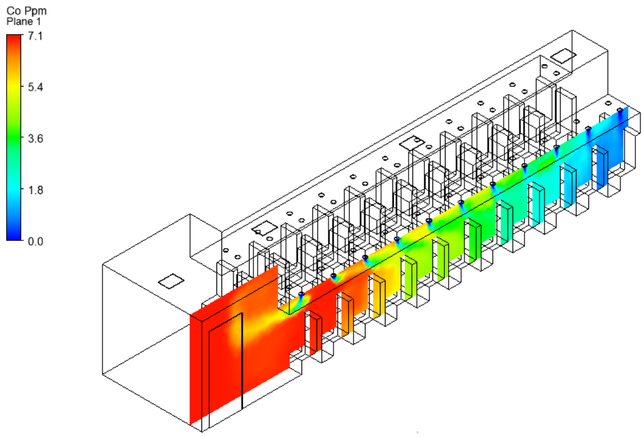
Fig. 18 Contaminant concentration of PM1 on a vertical symmetrical plane of the bus passenger. Air supply diffuser locations: (a) MV, (b) MV3, (c) MV4, (d) MV+DV and (e) MV+UFAD



(a)

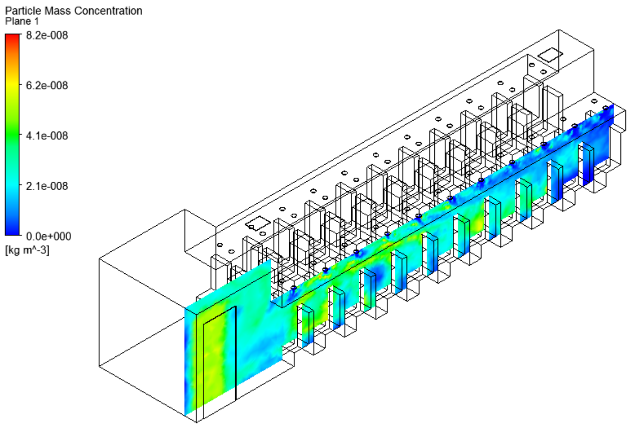


(b)

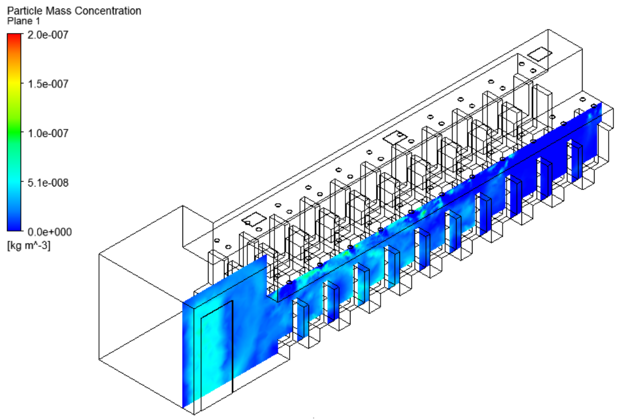


(c)

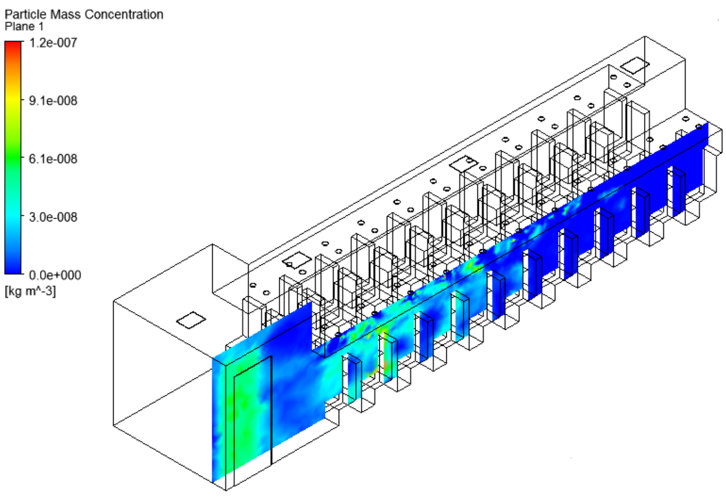
Fig. 19 Contaminant concentration of CO on a vertical symmetrical plane of the bus passenger. Air return grille locations: (a) 2RG, (b) 3RG and (c) 4RG



(a)



(b)



(c)

Fig. 19 Contaminant concentration of PM1 on a vertical symmetrical plane of the bus passenger. Air return grille locations: (a) 2RG, (b) 3RG and (c) 4RG

Summary

Field measurements were conducted to quantify the contaminants concentration of PM1 and CO at the front, middle and rear locations of a university's shuttle bus. Then, the CFD simulation was carried out to simulate the contaminants concentration of PM1 and CO on a various cases of air supply diffuser and air return grille locations inside the bus passenger compartment. The followings are major findings of this study:

- The contaminants concentrations of PM1 and CO were high at the front location of the bus passenger compartment.
- The contaminant concentration of PM1 was exceeding the acceptable level of indoor air quality by the World Health Organization.
- The current locations of air supply diffuser (MV) and air return grille (2RG) produce high contaminants concentration of PM1 and CO inside the passenger compartment.
- The air supply diffuser location namely MV2+UFAD could reduce the contaminant concentration of CO inside the bus passenger compartment.
- Meanwhile, the air supply diffuser location namely MV2+DV could reduce the contaminant concentration of PM1 inside the bus passenger compartment.
- The air return grille location namely 4RG could reduce the contaminants concentration of PM1 and CO inside the bus passenger compartment.

It can be concluded that new locations of air supply diffuser and air return grille namely MV2+DV, MV2+UFAD and 4RG created the best cabin environment and it is therefore recommended for possible use in commercial bus cabins.

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