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FIELD MEASUREMENT OF PARTICULATE MATTER INSIDE A BUS PASSENGER COMPARTMENT

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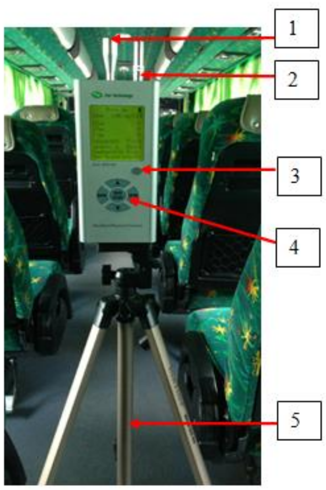
Graphical abstract



Abstract

Passengers commuting with buses are exposed to indoor air that contains contaminants such as particulate matters (PM). These contaminants could affect the passenger's health in long and short term durations. Depending on the size of the particles, a respiratory allergy and airborne transmission could affect the passenger's health. This article presents a field measurement to assess the airborne particles concentration of particulate matters inside a passenger bus compartment. The data collections were done at the front, middle and rear sections of the compartment, at a height of 1.1 m from the floor. The field measurements were carried outfrom 7.30 AM to 9.00 AM, 1.30 PM to 2.30 PM and from 4.15 PM to 5.00 PMwhich are the peak hours periods. A HPC300 handheld particles counter was used to measure the concentrations of PM1, PM2.5 and PM10. The results show that the concentrations of PM1, PM2.5 and PM10 were significantly high during the afternoon and evening hours. Also, the concentrations of PM1, PM2.5 and PM10 were higher at the front section of the passenger compartment compared to the middle and rear sections. It was also found that the peak hour periods, ventilation setting, infiltration, boarding and unboarding of passengers are among the factor that would increase the concentrations of PM1, PM2.5 and PM10 particles inside the passenger compartment.

Keywords: Indoor air contaminant, Bus passenger compartment, Particulate matter, Particle concentration

1.0 INTRODUCTION

Peoples who used public transport such as buses to commute are exposed to airborne air contaminant such as particulate matters (PM). Ultrafine particles (PM<2.5) and large particles (PM>2.5) are particulate matters that are typically found building enclosures or vehicles passenger compartments. Particulate matters is a mixture of solid particles and liquid droplets. They can exist in air in the form of dust, dirt, soot and smoke [1]. In general, particles with aerodynamic diameter of less than 10 μm (PM10) will pose the greater health threat to human because they can pass through the nose and throat and settled deep inside the lungs [2]. Thus particulate matters have a negative impact on the passenger's health because they can cause diseases such asrespiratory problem and cardiovascular mortality [3]. Many researches have carried out field measurements in an effort to quantify the particulate matters in different types of enclosures. Several parameters that may have effects on the concentration of the particles have been considered, such as time of the day, height of the plane for data capture, route type, bus age and types ofthe bus engine. Wong *et al.*, 2011 [4] have investigated the concentration levels of PM10 inside public buses in Hong Kong. The measurements were conducted in both suburban and urban areas in Hong Kong. The measuring instrument was placed at the rear compartment of the passenger compartment, at the breathing levelof the passengers. The field measurements were done at the peak hours of 7.00 AM to 12.00 PM. Hsu *et al.,* 2009 [5] measured the concentration of particulate matters in public buses traveling long distances on the highways in Taiwan. The total travelling distance was 300 km, which took between 4 to 5 hours. The measuring instruments were placed at the center section of the bus compartment, at the breathing level of the passengers. Shengwei *et al.,* 2010 [6] carried out similar study on Harvard University shuttle buses. During the field measurement, the bus engine was kept in idle condition and the air-conditioning system was turned on. The windows and doorswere fully closed during the field measurements. The data collection was conducted at four locations inside the passenger compartment, namely in the front and rear sections, on bothright and left sides. The measuring instruments were placed at two different heights, namely 0.6 m and 1.1 m from the floor. The measurements were carried out from 9.00 AMto 16.30 PM.

Kadiyala *et al.,* 2011 [7] carried out study in public buses in the city of Toledo, using a new bus under the actual driving condition. The particulate matters was monitored for a period of 24 hours using three measuring instruments. Air sampling was carried out at the rear seats region. The measuring instrument was placed at the height of breathing level of the passengers. Rim *et al.,*(2008) [8] investigated the characteristic of passenger cabin air quality in school buses in central Texas. The measurements were performed on six school buses with different engines. The buses travelled in a total distance of 42.4 km in a duration of 100 minutes.

Zhang *et al.,* 2010 [9] investigated air pollutants inside school buses in South Texasparticularly on the ultrafine particles. The stydy was conducted on two buses with diesel engines. Each bus was driven along two routes in order to study children's exposure to air pollutants under different travelling conditions. The data collections wereconducted from 6.30 AM to 8.30 AM and from 3.00 PM to 5.00 PM. They found that the concentration of the particulate matters was affected by the ventilation setting, level of occupancy, the peak hours, the age of the vehicle, type of engine, vehicle speed, meteorology, boarding and unboarding of passengers during the trips [2-9]. The concentration of the particulate matters exceeds the the level stated in the standards issued by the World Health Organization.

This article presents field measurement study conducted in a university's shuttle bus that travels along the in-campus route. The goal is to quantify the variation in the concentration of the particulate matters of PM1, PM2.5 and PM10 with time, inside the passenger compartment of the bus. Data collections were carried out at the front, middle and rear sections of the compartment. The field measurements were conducted during three peak hour periods namely from 7.30 AM to 9.00 AM, 1.30 PM to 2.30 PM and 4.15 PM to 5.00 PM, when the bus was full with passengers.

2.0 MATERIALS AND METHOD

2.1 The Field Measurement

The field measurements were carried out in the months of April and May, 2013. The university's shuttle bus was used to ferry students from their hostels to the lecture blocks inside the campus. The students were boarding and unboarding the bus during the field measurements. One in-campus route was selected for the bus to travel. The collections of data, namely the variation of particulate matters with time, were conducted at the front, middle and rear sections of passenger compartment. The data were acquired under a steady-state condition. A HPC300 handheld particle counter was used to measure the particle concentrations of particulate matters PM1, PM2.5 and PM10.

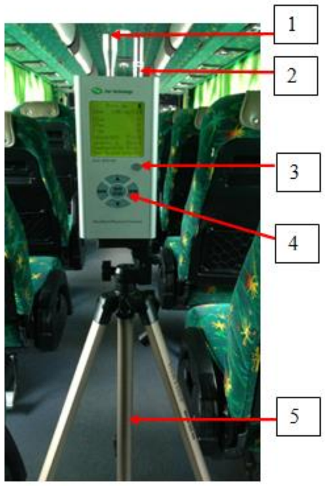
The ventilation setting of the air-conditioning system was set at a low level during the data collection. The average air velocity and average air temperature at the air supply diffusers were found to be 3.1 m/s and 23°C, respectively. Table 1 shows some detail description of the university's bus used in this study.

Table 1 Description of the bus used for the field measurements

Description of the Bus	
Model	Hino(RK1JSK14045)
Engine number	JO8C-F EURO 1 (Diesel)
Year of manufacture	2011
Bus compartment	Length, 11.4 m
	Width, 2.5 m
	Height, 2.4 m
Bus door dimensions	Width, 0.82 m
	Height, 2.1 m

2.2 Instrumentation Used

Figure 1 shows the handheld particle counter instrument (HPC300) used to measure the concentrations of particulate matters during the field measurements. A V816B digital anemometer was used to measure the air velocity and air temperature. A tripod was used as a stand to hold the particle counter instrument in place during the data collection. The particle counter instrument was placed at a level of 1.1 m from the floor, which was considered as the passenger's breathing level. The concentration levels of particulate matters PM1, PM2.5 and PM10 were measured continuously as the bus travelled along the selected in-campus route, as shown in the campus map in Figure 2. The distance travelled was about 11.8 km. The bus moves at a speed of mostly less than 50 km/h during the entire journey.



Note: 1. Air intake; 2. Temperature and relative humidity probe; 3. Power switch; 4. Control panel; 5. Tripod.

Figure 1 A handheld particle counter instrument (HPC300)

Figure 2 The route travelled by the bus during the field measurements

3.0 RESULTS AND DISCUSSION

The graph in Figure 3 shows the variation of concentrations of particulate matters PM1, PM2.5 and PM10 at the front section of the passenger compartment, with time. The exact location of data collection point is indicated in the sketch of the bus, at the top of the figure. This location is very close to the main door for the compartment. It can be seen from the figure that the concentrations of the particulate matters are continuously fluctuating with time. From a rough visualization, on average, the range of fluctuation in the concentrations of all particulate matters is lower during the periods of 7.30 AM to 9.00 AM, 1.30 PM to 1.45 PM and 4.15 PM to 4.30 PM, compared to the fluctuation range during the periods from 2.00 PM to 2.30 PM and from 4.30 PM to 4.45 PM. A reason for this could be because there were more boarding and unboarding activities of passengers during the afternoon and evening hours when students were returning back to their hostels. Statistical data summarizing the plots in Figure 3 is given in Table 2. It is observed that all particulate matters have nearly the same value of mean concentration, i.e. about 34 $\mu g/m^3$,with a standard deviation of about 25.

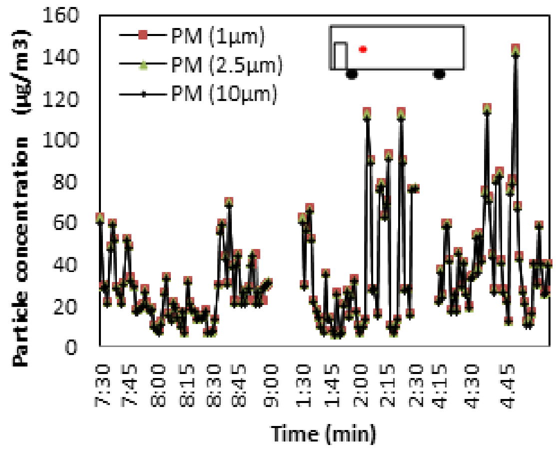


Figure 3 Variation of particle concentrations at the front section of the passenger compartment

Table 2 Statistical variation in the concentrationsof the particulate matters at the front section

Front	Min	Max	Mean	SD
PM1	7	144	34.38	24.79
PM2.5	6	143	34.00	24.70
PM10	6	140	33.08	24.28

The graph in Figure 4 shows the variation of particle matters concentrations with time, at the middle section of the passenger compartment. It can be observed that, in general, the fluctuation ranges of all particulate matters are lower compared to the ranges at the front section of the compartment.

However, there are occasional large variation in the particles concentration at about 1.30 PM and 4.35PM.

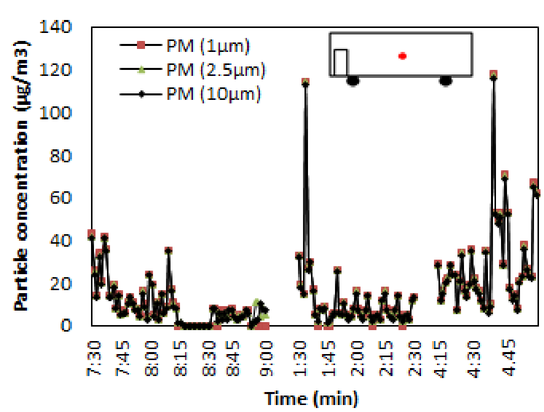


Figure 4 Particle concentration at the middle of the bus passenger compartment

Table 3 shows the statistical data summarizing the plots in Figure 4. One can observe that all particulate matters have almost the same mean concentration value of about 18 μg/m³, with a standard deviation of about 15. These values are about 50% lower than the corresponding values at the front section of the passenger compartment. This could be due to the fact that the middle section of the compartment is quite far away from the front and rear doors of the bus, through which particulate matters enter the compartment during boarding and unboarding of passengers.

Table 3 Statistical data of particle concentration at the middle of the bus passenger compartment

Middle	Min	Max	Mean	SD
PM1	3	118	17.82	14.67
PM2.5	3	117	17.58	14.77
PM10	2	116	17.41	14.32

The variation of particle matters concentrations with time at the rear section of the passenger compartment is shown in Figure 5. Again, in general, one can see that the ranges of variation of the concentrations of all particulate matters are lower than those at the front section of the compartment, up to 2.30 PM. The range of fluctuation is almost similar to those at the front and middle sections of the compartment from 4:15 PM onwards. The highest fluctuation occurs at about 4.35 PM.

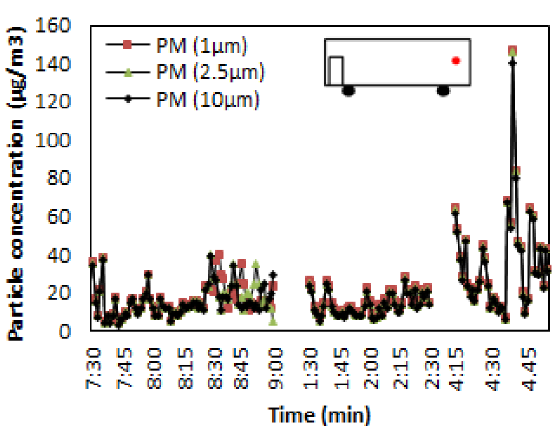


Figure 5 Particle concentration at the rear of the bus passenger compartment

Table 4 Statistical data of particle concentration at the rear of the bus passenger compartment

Rear	Min	Max	Mean	SD
PM1	6	147	20.59	16.69
PM2.5	4	146	20.89	16.75
PM10	3	140	19.30	16.19

Table 4 summarizes statistically the particulate matters concentration data plotted in Figure 5. It is seen that the mean concentration value for PM1 and PM2.5 is about 21 μg/m³, which is slightly higher than the corresponding values at the middle section of the passenger compartment. The mean concentration of PM10 is about 19 μg/m³. The standard deviation for all the particulate matters is almost identical at about 17.

The concentration of PM1 is seenslightly higher compared to PM2.5 and PM10 at the front and middle sections of the passenger compartment. It's value is slightly lower compared to the other particulate matters at the rear section. In general, the concentrations of all particulate matters are highest at the front section of the compartment. The middle section of the compartment registers the lowest concentrations of all the particulate matters. This result is logical because the data collection point at the front section was quite close to the front door of the bus. As the door was opened for the passenger to board and leave the bus, particulate matters enter the passenger compartment through it. The middle section is far away from both the front and rear doors of the bus.

The data obtained from the field measurements show that the mean concentrations of all particulate matters at all data sampling locations arewell below the level recommended in the guideline by the World Health Organization (WHO) [10]. The guideline states that the concentrations of PM10 and PM2.5 in particular, should not exceed 50 μg/m³ and 25 μg/m³, respectively.

There are openings at the roof of the bus, at the front and rear sections of the compartment. These opening serve as "holes" to exhaust the contaminated air from the passenger compartment. However, the data show that the concentrations of all particulate matters are still relatively high in these region compared to the middle section of the compartment. This indicates that the particulate matters were not being effectively exhausted through these openings. It could also be because the amont of particulate matters entering the compartment during the boarding and unboarding of passengers are greater than those exhausted through these openings. The problem could also be due the inability of the presence ventilation system to supply fresh air into the compartment and to provide a good air distribution within the compartment. Hence, one way of improving this situation is to have a more effective ventilation strategy that would promotemore uniform air flow distribution inside the passenger compartment and at the same time is able to provide sufficient fresh air into the compartment. A displacement-type ventilation system could be a possible choice.

4.0 CONCLUSION

A field measurement was carried out to quantify the concentrations levels of particulate matters in a passenger compartment of a university's shuttle bus. The followings are major findings of this study:

1) The concentrations of all particulate matters were highest at the front section of the passenger compartment, with a mean value of about 34 μg/m^{3}and lowest at the middle section with a mean value of about 18 μg/m^3.
2) The concentration for PM1 is highest at both the front and middle sections of the compartment compared to those of PM2.5 and PM10. The value is slightly lower at the rear section.
3) The concentrations of all particulate matters in the passenger compartment are generally lower than the limit specified in the WHO guideline.

An alternative ventilation strategy that could provide more fresh air and produce a more uniform air distribution could help lower the level of concentrations of the particulate matters in the passenger compartment.

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References

[1] Awbi, H. B. 2003. *Ventilation of Buildings*. London: Taylor & Francis.

[2] Boldo, E., Medina, S., Le Tertre, A., Hurley, F., Mücke, H. G., Ballester, F. & Aguilera, I. 2006. Health Impact Assessment of Long-Term Exposure to PM2.5 in 23 European Cities, European. *Journal of Epidemiology*. 21(6): 449-458.

[3] Zhu, S., Srebric, J., Spengler, J. D. & Demokritou, P. 2012. An Advanced Numerical Model for the Assessment of Airborne Transmission of Influenza in Bus Micro-Environments. *Building and Environment*. 47: 67-75.

[4] Wong, L. T., Mui, K. W., Cheung, C. T., Chan, W. Y., Lee, Y. H. & Cheung, C. L. 2011. In-cabin Exposure Levels of Carbon Monoxide, Carbon Dioxide And Airborne Particulate Matter In Air-Conditioned Buses of Hong Kong. *Indoor and Built Environment*. 20 464-470.

[5] Hsu, D. J. & Huang, H. L. 2009. Concentrations of Volatile Organic Compounds, Carbon Monoxide, Carbon Dioxide and Particulate Matter in Buses on Highways in Taiwan. *Atmospheric Environment*. 43(36): 5723-5730.

[6] Zhu, S., Demokritou, P. & Spengler, J. 2010. Experimental and Numerical Investigation of Micro-Environmental Conditions in Public Transportation Buses. *Building and Environment*. 45(10): 2077-2088.

[7] Kadiyala, A. & Kumar, A. 2011. Study of In-Vehicle Pollutant Variation in Public Transport Buses Operating on Alternative Fuels in the City of Toledo, Ohio. *Open Environmental & Biological Monitoring Journal*. 4: 1-20.

[8] Rim, D., Siegel, J., Spinhirne, J., Webb, A. & McDonald-Buller, E. 2008. Characteristics of Cabin Air Quality in School Buses in Central Texas. *Atmospheric Environment*. 42(26): 6453-6464.

[9] Zhang, Q., Fischer, H. J., Weiss, R. E. & Zhu, Y. 2012. Ultrafine Particle Concentrations in and Around Idling School Buses. *Atmospheric Environment*. 69: 65-75.

[10] World Health Organization. Regional Office for Europe & World Health Organization 2006. *Air Quality Guidelines: Global Update 2005: Particulate Matter, Ozone, Nitrogen Dioxide, And Sulfur Dioxide*. World Health Organization.