Indoor environmental quality and pollutant dispersion estimation inside a bus at the downtown areas of Dalian, China

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Abstract. Among most public transport modes, the frequent start-stop urban bus has the most complex micro-environment. Indoor environment quality, airflow patterns, etc. has not been fully understood yet inside buses. In addition, under COVID-19 pandemic, it had been proved aerosol transmission risk might be enhanced inside the buses. Usually, carbon dioxide (CO_2) could be considered the index of ventilation effect in enclosed environment, airborne particles are viral carriers. Thus, accurate forecasting of the two abovementioned key pollutants become important. The study analysed the CO_2 and airborne particle dispersion inside a bus at the downtown areas of Dalian, China by employing field measurement at spring and autumn, 2021. Temperature, relative humidity, CO_2 and airborne particle concentrations were logged by sensors at sampling points respectively, passengers onboard were counted manually. Correlation analysis was conducted and two empirical models for evaluating CO_2 and airborne particle were concluded based on the measurement data. From preliminary results, transient concentration of pollutant is almost linearly correlated with cumulative and instant numbers of passenger respectively, with Pearson correlation coefficient larger than 0.8336 for CO_2 and 0.8424 for $PM_{2.5}$. The purpose of the study is to reflect environmental quality inside the bus and provide inspiration into pollution control strategies in buses.

1.Introduction

People are more likely to choose public transportation as their way to commute, which has brought unprecedented challenges to public transportation facilities[1].Studies by related scholars have confirmed that total exposure of urban residents to airborne particles in the mobile traffic environment has reached 33% to 50% of the total exposure to all-day activities[2,3], and the cumulative exposure of aerosol particles in mobile traffic environments has accounted for 33 to 45% of the exposure throughout the day[2,3], in which $PM_{2.5}$ takes up to more than 90%[4]. Especially under the COVID-19 epidemic and the its following post-epidemic era, closed and poorly ventilated environment has been proved to become major places of disease transmission along with the highest spread risk.

As a representative of the commuting and mobile traffic micro-environment for residents, city buses usually have the characteristics of frequent opening and closing of doors, enclosed internal structures, high personnel density, high pollution levels, and complex diffusion mechanisms. After a long time of travel, air-conditioned city bus is always attached with health hazards like high CO_2 concentration in the cabin and poor air quality. Since the end of 2019, several COVID-19 transmission incidents in Zhejiang, Hunan Province in China[5,6] and other places have occurred in closed air-conditioned buses, which confirmed the possibility of SARS-CoV-2-laden droplets as a major cause of spreading COVID-19 in closed buses. As for the media, scholars prefer to lay focus on aerosol transmission[7].Pollutant diffusion pattern in bus environment is influenced by the ventilation and air conditioning system and appears to be a typical multi-field coordination problem. At the same time, the pollutants outside the bus enter the cabin through the penetration, which is a representative of dynamic evolution, affecting the concentration distribution and exposure level of pollutants in the cabin by means of sedimentation and diffusion. Therefore, it is worthwhile to further study the variation of pollutant diffusion with the change of internal temperature, humidity field and the number of passengers, as well as the ventilation mode of the air conditioning system.

To date, researchers have carried out a lot of studies on the pollution status and control measurements inside mobile transportation[8]. Yang et al. [9] investigated the typical pollutants in new energy buses driven with pure electric and found that the CO_2 concentration in the buses

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exceeded the standard seriously. Xiang [10] conducted field measurements focused on temperature, relative humidity and CO_2 concentration inside the transportation environments, and introduced the Human Physiological Thermal Regulation Model and PMV-PPD(predicted mean vote-Predicted Percentage Dissatisfied)/parameters to evaluate the dynamic thermal comfort of the human body inside the vehicle. Zhu et al. [11] analyzed and provided insight on passenger comfort in bus micro-environment of Jinan city by means of investigation and field measurement, and evaluated the investigation results using the Grey Relational Evaluation Method. In-vehicle particulate concentrations (including $PM_{2.5}$, which has an aerodynamic diameter ≤2.5 μm) seem to be at least three times the mean background concentration one might expect to encounter within the home or other indoor environment [12]. The development of long-term applicable monitoring methods and treatment technology will become a key problem to be solved urgently in the public transport system.

Although previous studies have conducted detailed investigations on the micro-environment of mobile transportation, there are relatively few studies for a much more complex situation as city buses. Researches recording real-time number of occupants and analyze it along with the pollutants' concentration are not enhanced. Besides, there are no precise empirical models for the distribution of CO_2 and particulate.

In this article, according to the existing research results and unsettled problems, the author will analyse the pollutants including CO_2 and $PM_{2.5}$ in the micro-environment of the city bus by employing field measurements. Pearson correlation analysis were used to further explore the main influencing factors of pollutant diffusion inside buses. Providing scientific assistance for preventing the spread of pathogenic virus and other infectious diseases. The purpose of this study is to reflect the real indoor environmental quality inside the bus we took every commuting day. The empirical models for CO_2 and airborne particles could be the fundamentals of aerosol transmission risk of COVID-19 and optimized ventilation system controls inside the enclosed transport environment such as bus, subways, trains, etc. in the future.

2. Methodology

2.1 Test subject

The test object in this study is Dalian city bus route No.406, the bus model is Jiefang Brand City Bus CA6125URN33. During the test, the weather outside is sunny, air-conditioning system was shut, the bus opened the front and rear doors to load and unload passenger at each stop. The complete test route includes the outbound and return, with each travel last for around 40mins.

2.2 Measurement strategies

CO_2 gas levels and the concentration of particulate pollutants have been identified as two key indicators of in-vehicle air quality [12,13]. Thus, we logged CO_2 and particle mass concentrations ($PM_{0.3}$, $PM_{1.0}$, $PM_{2.5}$, and PM_{10}) continuously inside a city bus in March, October and November 2021. To analyze how different passenger flows affect the pollutant distribution in the bus, the measurements were conducted at traffic rush and off-peak hours. There were three testers in the tested bus, seating in the front, middle and rare of the bus on the side of the doors respectively, show as Fig. 1. Real-time passenger flow in bus is recorded by the testers seating in the front and rare of the bus. To build a semi-empirical model for predicting transient pollutant dispersion in the bus, numerous key factors were simultaneously recorded during the measurement phase of our study. These included real-time passenger flow, in-vehicle and out-vehicle temperature and relative humidity (RH), window state (open/closed), in-vehicle wind speed, in-vehicle CO_2 concentration and particle mass concentration.

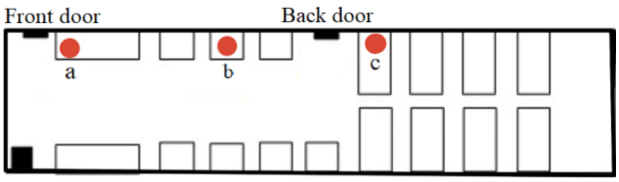

Fig. 1. The location of three testers in the bus (a as front, b as middle and c as rare)

The tester carries a temperature/humidity sensor and a particle (including $PM_{0.3}$, $PM_{1.0}$, $PM_{2.5}$ and PM_{10}) number detector to record the temperature and relative humidity of the sampling point and particle number concentration. The tester at sampling point *b* carried a temperature/humidity sensor, a CO_2 recorder, an anemometer and two particle detectors to record the temperature and relative humidity of the measuring point, CO_2 concentration, wind speed, particle mass and number concentration; The sensor placement and tested parameters of sampling point *c* are same as those at the sampling point *a*. During the test, the opening and closing state of the windows had been observed and recorded by the tester.

Particulate mass and number concentration data were collected using a Korno GT-1000 composite pollutant detector, with a collecting interval of one second. Temperature and RH were recorded using a 179dt DTH temperature and humidity recorder, operated at a sampling interval of one minute. The in-vehicle concentration of CO_2 was measured using a WEZY-1 CO_2 recorder, again sampling at 1-minute intervals. The 179dt DTH temperature and humidity recorder, WEZY-1 CO_2 recorder had been calibrated and verified experimentally by the manufacturer. One of the three pollutant detector also had been calibrated. Then the calibrated Korno GT-1000 became the reference sampler and the other two Korno GT-1000 instruments were calibrated simultaneously using the reference Korno GT-1000 ahead of each measurement period.

2.3 Data processing

In order to more accurately describe the pollutant and its dominant factors, it is necessary to process the original measured data in advance. In this article, the average level of CO_2 concentration and $PM_{2.5}$ concentration is analyzed in units of every minute, and the raw data is processed by the 3σ data processing criterion under the condition of equal precision measurement. Detailed processing method can be found in [14]. At the same time, this paper uses the Pearson correlation to further analyze the influencing factors of the concentration of particle and CO_2 in the bus.

3.Results and discussion

3.1 Statistical analysis of collected data

The number of occupants in the bus during the test is recorded as Fig. 2. It can be seen from the figure that real-time number of occupants in both seasons showed a similar paradigm as a M-shaped curve, which means when the bus was close to the departure and terminal stations, there are usually less passengers than while driving in the middle of a journey, thus making the growth trend of cumulative occupants in cabin declines as the journey progresses at the same time.

Fig. 3 summarizes the CO_2 concentration patterns observed during the measurement period on 20th, March, 2021. Under an almost enclosed condition except the doors open shortly when loading and unloading passengers throughout entire journey, there is a zigzag upward trend in the CO_2 concentration in cabin, and mean CO_2 concentration is 1170.187±337.51 ppm, with 52.94% of the total time exceeding 1,000ppm on 20th, March, 2021.

Fig. 4 summarizes the $PM_{2.5}$ mass concentration observed during the measurement period in spring. The outdoor AQI (Air Quality Index) of the tested days are 52, 83, 124, 65 respectively. It can be seen that in-cabin $PM_{2.5}$ concentration is strongly related to outdoor $PM_{2.5}$ concentration.

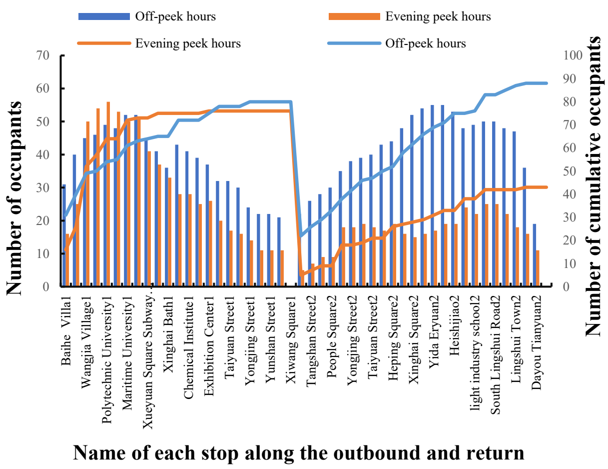

Fig. 2. The real-time recorded occupants and cumulative occupants at each station along the route on 20th, March, 2021.

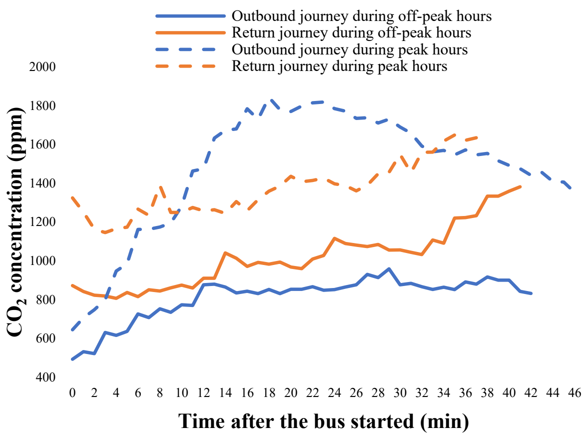

Fig. 3. CO_2 concentration in the bus on 20th, March, 2021

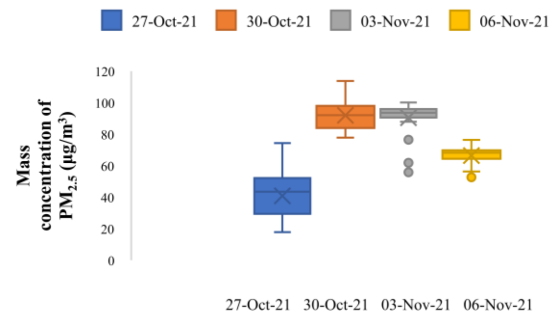

Fig. 4. $PM_{2.5}$ mass concentration in the bus in autumn

3.2 Correlation analysis between occupants and in-vehicle CO_2 concentration

As we are trying to figure out the connection between each factor and achieve an empirical model, correlation analysis among different factors was conducted based on tested data, we find that the cumulative number of people who have boarded the bus and transient in-vehicle CO_2 concentration is almost linearly related, with R^2 equals to 0.8336 on 20th, March, 2021 during the outbound in off-peak hours, as shown in Fig. 5. This result inspired us that the preliminary analysis results demonstrated in-vehicle CO_2 concentration has a cumulative characteristic, and it is almost liner with cumulative number of occupants on bus.

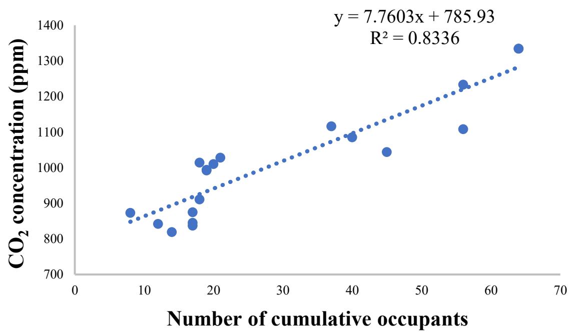

Fig. 5. Correlation analysis between CO_2 concentration and cumulative number of occupants on 20th, March, 2021.

3.3 Distribution pattern of $PM_{2.5}$ mass concentration

Compared with CO_2 concentration distribution model, the dynamic process of particle is much more complex, with the coupling effect of multiple influencing factors such as infiltration, sedimentation, resuspension and evaporation progress. At present, we are doing a simple correlation analysis on the data collected from field measurements. Fig. 6. shows the correlation between real-time number of occupants on board and $PM_{2.5}$ mass concentration during a period of the outbound journey during off-peak period at 27th, October, 2021. The correlation curve indicates that $PM_{2.5}$ mass concentration is nearly liner with the real-time number of occupants on board during that period. However, similar conclusions can't be found in the whole journey and experiments in Spring. Therefore, the empirical model in **Fig. 6** is for reference only.

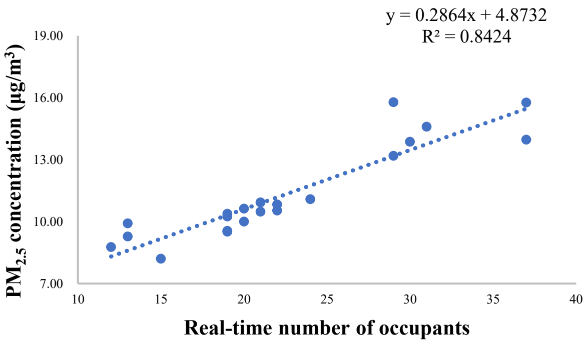

Fig. 6. Correlation analysis between $PM_{2.5}$ mass concentration and number of occupants on 27th, October, 2021.

4.Conclusions

According to the statistics and analysis of the measured data, there was no significant difference in the total number of passengers between spring and autumn. The number of occupants in the bus follows an M-shaped curve, which means most of the passengers are concentrated in the middle stations of the operation route. $PM_{2.5}$ concentration in cabin are closely related to the external environment. The mean CO_2 concentration in the bus is 1170.187±337.51 ppm, with 52.94% of the total time exceeding 1,000ppm on 20th, March, 2021, and 854.61±256.41ppm on 27th, October, 2021 with 28.427% of the total time exceeding 1,000ppm.

Through the correlation analysis among several factors, it is found that cumulative number of passengers in the bus has a great correlation with the CO^2 concentration with R^2 up to 0.8336. During a period of time in a one-way trip, the mass concentration of $PM_{2.5}$ was found to have an approximate linear relationship with the real-time number of people in the bus with R^2 up to 0.8424 on 27th, October, 2021, but such characteristics were not found during the whole journey.

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References

[1] L. Jin, Peopl.Bus. **11**, 47-51(2019)
[2] S. Fruin, Westerdahl D, Sax T, Sioutas C, Atmos. Environ. **42**, 207-219(2008)
[3] Y Zhu, Eiguren-Fernandez A, Hinds WC, Miguel AH. Environ. Sci. Technol.**47**, 2138-2145(2007)
[4] J.R. Brook, T.F. Dann, R.T. Burnett, J. Air Waste Manage. Assoc **47**, 2-19(1997)
[5] Y. Shen, C. Li, H. Dong, Z. Wang, Martinez L, et al, JAMA Int. Med. 9(2020)
[6] K. Luo, Z. Lei, Z. Hai, et al, Open Forum Infect. Dis **7**,430(2020)
[7] Y. Feng, M. Thierry, S. Ted, Y. Hang, J. Aerosol Sci **147**, (2020)
[8] X.Y. Li, W.J. Chen, X.L. Du, Z.S. Li. Chin. Resid. Facilities .**01**,65-67(2020)
[9] F. Yang, Y.P. Jiang, M. Zhang, Environ. Sci. **03**, 85-89(2018)
[10] L.P. Xiang Research on Air Distribution characteristics and Dynamic Thermal Comfort in Air-conditioned Passenger Cars. Central South Univ.(2000).
[11] X.X. Zhu, L. Lei, S. S. Wang, Y.H. Zhang, Investigation, Analysis and Thinking on Passenger Comfort in Jinan Public Transport Micro-environment, 9 (2016)
[12] W. Ott, R. Wallace, L.A. McAteer, J. M, L. M. Hildemann, Indoor Air **27**, 205-217(2017)
[13] K.G. Fiedoruk, Transportation Res. D-Tr. E. **16**, 327-331(2011)
[14] Y. Zhao, C.W. Jiang, X.C Song, A Atmos. Environ. **274** (2022)