Research Article AJOERR (2019) 2:16

American Journal of Engineering Research and Reviews
(ISSN:2637-3785)

Urban Viaducts Influence on the Vertical Concentrations of Particulate Matters

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ABSTRACT

Due to the increase of private vehicles in China cities, high-level pollution is often detected in urban street canyons. The study selected Jinlu building as the research object and used FLUCK985 particle counter to collect the particles concentration at different heights, at the same time, combined with meteorological to study the vertical variation characteristics. Finally, combined with the feature of human body, the exposure assessment method was used to analyze the effects of particulate matter on human health. The results are as follows. (1) As the diameter increased, particles number decreased. The CV (Coefficient variation) alongside viaduct was smaller than non-viaduct and the CV degree is weak or moderate. (2) The contamination degree in viaduct is greater than non-viaduct. The particulate concentration decreased with the increase of floor, but near viaduct, the coarse and fine particles showed different trends. (3) The early peaks concentration was more than evening peaks in sunny, windy and rainy days, among them, the sunny concentration was more than rainy days; the windy days concentration was changed during the different diameter. (4) the viaduct RDD was more than non-viaduct. The RDD was highest in Older; the second was Adult and Child RDD was the lowest. The RDD in early peak was higher than evening peak of which PM10 always stay on the nasal cavity. Thus the people should try to shorten linger under viaducts so as to prevent the coarse particles from causing discomfort to nasal cavity.

Keywords: urban viaducts; particle concentration; vertical distribution; pedestrian exposure level

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How to cite this article:
Jing Xiao, Hong-di He, Rong Gao.Urban Viaducts Influ-ence on the Vertical Concentrations of Particulate Matters. American Journal of Engineering Research and Reviews, 2019, 2:16

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1. Introduction

With the development of society and the improvement of people's living standards, environmental issues have become a hot concern question, which environmental problems that pose a great threat to human health are mainly air pollution. Driven by the urbanization process, the number of motor vehicles is increasing and the exhaust gas emitted by motor vehicles in the air is increasing, which has caused great harm to human health. People who are exposed to polluted environment for a long time are prone to cause physical diseases such as decreased immunity or lung function. In addition to direct effects, these particulates are also carriers of bacteria and viruses that can indirectly cause carcinogenesis. The city transportation capacity is an important part of urban development. In order to alleviate traffic congestion and expand the capacity of intersections, a mount of cities have begun to build viaducts. Although the viaduct effectively alleviates the traffic problem, its physical structure is not conducive to the spread of particulate matter. Traffic factors such as traffic flow and road conditions in the city have an important impact on the diffusion of particulate matter near the viaduct [1-4].

At present, there are many researches on the distribution of particulate matter in the vicinity of general open roads and street canyons through models[5-6], numerical simulations[7] and on-site measurements[8]. However, there are few articles on the distribution of particulate matter near the viaduct. Zhang Chuanfu[9] calculated the diffusion and concentration distribution of PM near the elevated frame by CFD simulation. It was found that the particles with particle size smaller than $PM_{2.5}$ were less affected by gravity and the distribution law was similar. Gao Ya[10] based on the Shanghai Elevated Objects. Through the data collection of mobile devices, a neural network prediction model based on principal component analysis for vertical variation of pollutant concentration in elevated roads is proposed, which better handles the nonlinear problem of particle diffusion. In order to explore the vertical distribution of pollutants in most cases, this paper studies the influence of the viaduct PM in the Jinlu Building near the Shanghai viaduct. At the same time, the data of a residential building near the Ruijin Science and Education Building is measured as a comparison. The experiment analyzed the influence of the viaduct on the diffusion of PM concentration and the comparative analysis of the particulate matter concentration in different weather conditions. Finally, the pedestrian exposure model was used to analyze the effects of PM concentration on Children, Adults and the Older. Finally, it proposed a reasonable solution.

2. Materials and methods

2.1. Study area

The study area is located in Shanghai, China, which includes two urban districts (Fig. 1). The viaduct (A) of Yan'an West Road in Huangpu district of Shanghai is used as the experimental area, with an elevated width of about 20 m, two-way four-lane, east-west direction, close to the north-south elevated, high traffic flow and located on the 11th floor of the Jinlu Building. Jinlu Building is located on the south side of the elevated road of Yan'an West Road. The height of the building is 60 m. The north and east sides are adjacent to the north-south elevated. There are no typical buildings in the west and south. The Jinlu Building is surrounded by office and living areas. There is no obvious pollution source except the viaduct. In order to compare the pollution of the viaduct, the office building near the Ruijin Science and Education Building (B), 1.5km away from the Jinlu Building, was selected as the control point. There is no influence of the viaduct. The north and south directions are residential buildings, the east is a road, and the west is A lawn has no obvious source of pollution except the road.

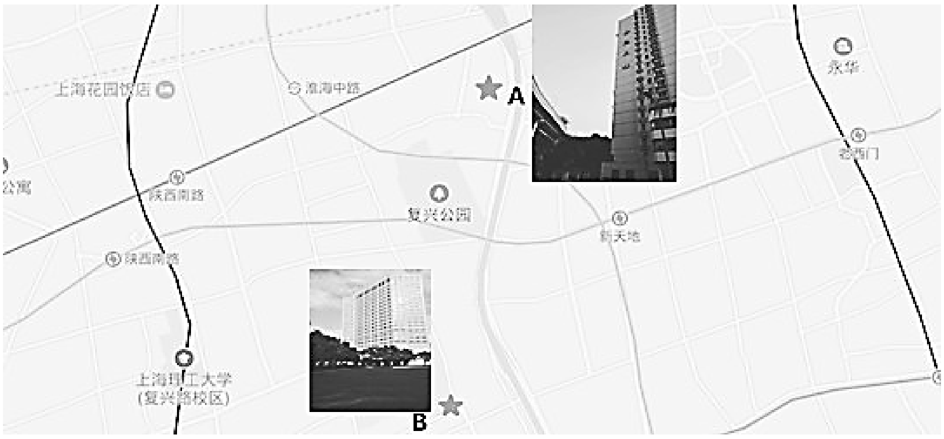

Figure1: Experiment location in Shanghai

Table 1: Experimental location details

Location	trend	traffic condition	other
Jinlu building(A)	east-west direction, about 15° to the east.	inner ring elevated road, Two-way four-lane, 30 vehicles per minute.	about 7 meters away from the roadside, surrounded by residential buildings.
Ruijin Science and Education Building(B)	east-west direction, about 5° to the east.	Non-viaduct, One way two lane, 20 vehicles per minute.	residential building and hospital.

2.2. Data collection

The measuring instruments are Fluke 985 particle counter, temperature meter, humidity meter, anemometer and so on. The Fluke 985 particle counter is manufactured by Fluke Electronic Instrument and Meter Co., Ltd., which uses the principle of light scattering to record the number of particles in the six particle size ranges, which are 0.3~0.49μm and 0.5~0.99μm. 1.0~1.99μm, 2.0~1.99μm, 5.0~9.99μm, ≥10.0μm, the flow rate is 2.82 L/min. The temperature meter and humidity meter use three Sanliang electronic temperature and humidity meters. The temperature measurement range is -9.9℃~ 50℃, the measurement accuracy is ± 1.5℃, the humidity measurement range is 5% RH ~ 99% RH (the probe cannot enter the water), the measurement accuracy is ± 5%. The anemometer uses the standard GM8901+, the measurement range is 0~45 m/s, and the measurement accuracy is ±3%. Each instrument is calibrated prior to measurement and can be used normally.

The data collection consists of 2 personnel. The collection of Jinlu Building and Ruijin Science and Education Building is measured by one person. From the 20 floors of the test group and the control group, 10 floors of 1F, 3F, 5F 7F, 9F, 11F, 13F, 15F, 17F, and 19F were selected for measurement. Each floor is selected in the window for data measurement. The measurement is extended to the window by about 30 cm and each floor time is 3 min. The Fluke 985 particle counter has 1 s time interval and collects a set of data every second. The temperature meter, the humidity meter and the anemometer select stable data within three minutes. Each floor select 3 set of date. In this paper, the analysis data are from December 15, 2018 to December 30, 2018. The data of 8:00~9:00 and 17:00~18:00 are measured every day, representing the morning peak and the evening peak.

2.3. Methods

2.3.1 Conversion of number concentrations and mass concentrations

Since the measurement instrument property is a particle counter and the premise of the pedestrian exposure level analysis data is the mass concentration of the PM. the method discussed in Tittarelli[11]is used for conversion.

The premise of the conversion model is that the shape of the particles is spherical, the density is 1.65 μg/cm^3 and then the particles with a diameter of 0.3~10 μm in air are simultaneously divided into 5 segments and the number of particles in each segment is QC. The formula for converting to mass concentration is as follows (2-1). Regression analysis found that the correlation between the mass concentration and the number concentration of the particulate matter reached more than 99%, so it can be considered that there is basically no difference between the two and the formula can be used as an effective means to convert the quantitative concentration to the mass concentration.

$$MC = a_0 + \frac{1.65\times\frac{4}{3}\pi\times\frac{d^3}{8}}{1000}\times QC \qquad (2\text{-}1)$$

Where MC is the mass concentration of the particulate matter (μg/m^3); a_0 is the regression constant; QC is the quantitative concentration of the particulate matter (Counts/L); d is the diameter of the particulate matter (μm)

2.3.2 Pedestrian exposure assessment

(1) Respiratory deposition dose(RDD)

Epidemiological studies have shown that the incidence and mortality of human diseases are closely related to $PM_{2.5}$ and PM_{10} in the air. Particles with different particle sizes affect different physiological responses of pedestrians and the smaller the particle size, the more damage are on the human body[12]. For example, $PM_{2.5}$ has a small particle size, large area, strong activity, easy to attach toxic and harmful substances and has a long residence time in the atmosphere and a long transport distance, which has a greater impact on human health and atmospheric environmental quality. RDD can be calculated by formula (2-2) [13]

$$RDD = (V_T\times f)\times DF_i\times PM_i \qquad (2\text{-}2)$$

$$\mathrm{DF} = \mathrm{IF}\left(0.058 + \frac{0.911}{1+\exp(4.77+\mathrm{Ln}\ \mathrm{d_p})} + \frac{0.943}{1+\exp(0.508-2.58\mathrm{Ln}\ \mathrm{d_p})}\right) \qquad (2\text{-}3)$$

$$IF = 1-0.5\left(1-\frac{1}{1+0.00076d_p^{2.8}}\right) \qquad (2\text{-}4)$$

Where V_T represents tidal volume; f represents respiratory rate; DF_i represents deposition fraction; PM_i represents average mass concentration; IF represents the inhalable portion of the particulate matter; d_p is the mass median diameter of the particulate matter.

The tidal volume and respiratory rate at different ages can refer to the table below [14].

Table 2: Physiological parameters for different ages

	Age(years)	BF(breaths/min)	TV(ml)
Child	10	32	583
Adult	45	20	1250
Retired	75	22	1250

(2) Median diameter (d_p)

The median diameter refers to the diameter when the total mass of the particles of various particle sizes smaller than a certain aerodynamic diameter in the particulate matter accounts for 50% of the mass of the total particulate matter. that is the corresponding particle diameter when the cumulative percentage of the particulate matter concentration accumulates to 50%. Pulmonary gas dynamics test results show that most of the particles with d_p>2μm are deposited in the nasopharyngeal area and the deposition rate of particles with d_p<2μm is the largest in the alveolar and bronchial areas, which has a great impact on human health.

3. Results and discussion

3.1 Basic statistical analysis between six particle sizes

Effective statistical analysis methods can recognize and expose the interrelationships, changing laws and development trends of things so that they can correctly understand and predict things. Commonly used statistical indicators are mean, variance, standard deviation, range, covariance, coefficient of variation, etc. These values can reflect the basic situation of the whole, and have certain guiding significance for analyzing the overall trend. The mean value can reflect the overall trend of the data; the variance and standard deviation can reflect the degree of dispersion of the overall data; The coefficient of variation (CV) is used to compare the degree of data variation in two or more groups and the degree of dispersion in the unit mean is reflected. The CV can be divided into three levels: weak variability when CV < 0.1; when 0.1 < CV When ≤1, it is moderate variability; when CV>1, it is strong variability [15].

It can be seen from the average that the number of particles of six kinds of particle size materials, whether there are viaducts or Non-viaducts, tends to decrease with the increase of the particle size and the smaller the diameter of the particles, the larger the amount of particles in the air. Among them, the percentage of particles in the range of 0.3~0.49μm in air is 78.5%. The change in the number of particles with diameters ranging from 0.3~0.49 μm to 0.5~0.99 μm is most pronounced. The concentration of PM in the viaduct is greater than the concentration of PM in the Non-viaduct, but the change is relatively less obvious. It can be seen that the CV of the viaduct is lower than that of the Non-viaduct. When there is viaduct, only the particles with ≥10μm have moderate variability and the particles with the remaining particle size have only weak correlation; when there is no viaduct, The particles of 0.5~0.99μm and ≥2.0μm all have moderate variability and the particles of the remaining particle size have weak variability. The higher variability, the greater influence of ground pollution sources and human activities. The pollution situation with Non-viaduct is greatly affected by the ground and human activities. The existence of the viaduct increases the pollutants emitted by the vehicle. At this time, the increase in the concentration of PM is mainly affected by the emission of the motor vehicle and is less affected by the ground and human factors. The existence of the viaduct creates a "cover effect" that causes the concentration of particulate matter in the vicinity of the elevated structure to agglomerate, hindering the propagation of particulate matter and also increasing the degree of pollution.

Table 3: The statistical characteristics of PM concentration

		0.3~0.49*μm*	0.5~0.99*μm*	1.0~1.99*μm*	2.0~4.99*μm*	5.0~9.99*μm*	≥10*μm*
Viaduct	Mean(*Counts/L*)	185738.29	45604.26	3782.29	1481.53	65.73	8.79
	SD(*Counts/L)*	2292.41	1250.04	97.16	54.38	5.05	1.17
	CV	0.01	0.03	0.03	0.04	0.08	0.13
Non-viaduct	Mean(*Counts/L)*	173285.38	39359.56	3372.36	1349.12	58.33	7.37
	SD(*Counts/L)*)	6731.38	5042.38	100.14	213.59	7.01	2.82
	CV	0.04	0.13	0.03	0.16	0.12	0.38

3.2 Exploring the factors affecting the PM concentration in the viaduct

When analyzing the influence of the viaduct on the concentration of PM, it is guaranteed that the trend of the two street canyons is the same and the measurement is carried out at the same time so the two parts of the data can be directly compared.

As can be seen from the whole, the number of particles with six particle sizes is higher than that of Non-viaducts and the variation of six kinds of particles in the viaduct or Non-viaducts is 8%, 1%, 1%, 4%, 8%, 5%,respectively. the impact of the viaduct on the particles of 0.3~0.49μm and 5.0~9.99μm is significant, but the overall change is not huge[16]. For Non-viaduct, the number concentration of the six particle sizes decreases with the increase of the floor, while the variation of the particle concentration in the viaduct does not simply decrease with the increase of the height. Because the viaduct is located in the 11th floor, the particles with particle sizes of 0.3~0.49μm, 0.5~0.99μm and 1.0~1.99μm have an increasing trend in the 11th floor reaching the maximum in the 13th floor, the maximum value is 112406.49, 14859.79, 1398.89, respectively. The minimum value is reached at the 9th floor and the minimum values are 98990.45, 14323.24, 1114.25, respectively. Particles with particle sizes of 2.0~4.99μm, 5.0~9.99 μm and ≥10 μm swelled in the 11th floor and the particles on the remaining floors decreased as the floor increased.The reason for this phenomenon is that on the one hand, the viaduct will form a “cover effect” to hinder the propagation of particles, combined with the influence of the nature of the particles, that is, the fine particles themselves are less sensitive to the gravitational force of the earth; the coarse particles are heavy and easy to follow. Downward diffusion, the particles of

0.3~0.49μm, 0.5~0.99μm and 1.0~1.99μm diffuse up the floor, reaching the maximum in the 13th floor, the particles of 2.0~4.99μm, 5.0~9.99μm and ≥10μm is accumulation under the viaduct. On the other hand, due to meteorological factors, the average temperature of the 1th floor is 2.7℃, the average humidity is 63%, the average wind speed is 0.8 m/s and the average temperature of the 11 floor is 3.3℃, the average humidity is 64% and the average wind speed is 2.8 m/s. Due to meteorological factors, the airflow carries the upward diffusion of particulate matter, which is blocked by the viaduct to form a swirl of the airflow, causing the change of PM near the viaduct to be different with Non-viaducts.

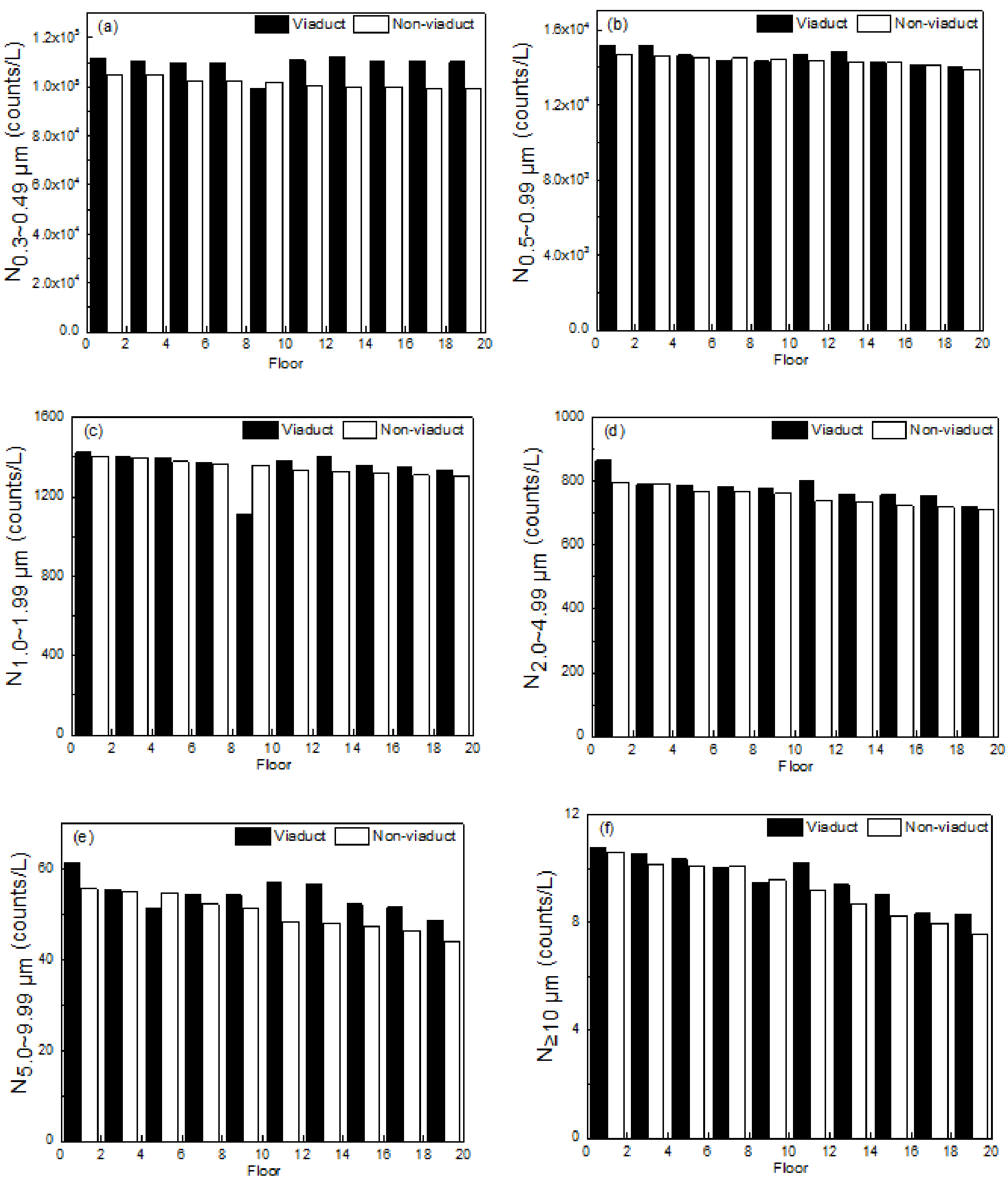

Figure 2: **Concentration comparison of PM in viaduct and non-viaduct areas**

3.3 PM concentration influence on different traffic peak near viaduct

The impact of different traffic periods on PM is different. In cities like Shanghai, most people are office workers. Their travel time is roughly concentrated in a period of time, such as morning work and afternoon work. The automatic adjustment ability of the atmosphere has a certain limit. The accumulation of large amounts of particulate matter in the morning and evening will cause the particles to accumulate and it will not drift away with the wind, etc., thus causing harm to human health. According to the survey, the morning and evening peaks in Shanghai are mainly concentrated at 7:30~9:30 and 16:30~18:30. This analysis selected 8:00~9:00 and 17:00~18:00 to analyze the impact of morning and evening peaks near the viaduct on pedestrians and residents.

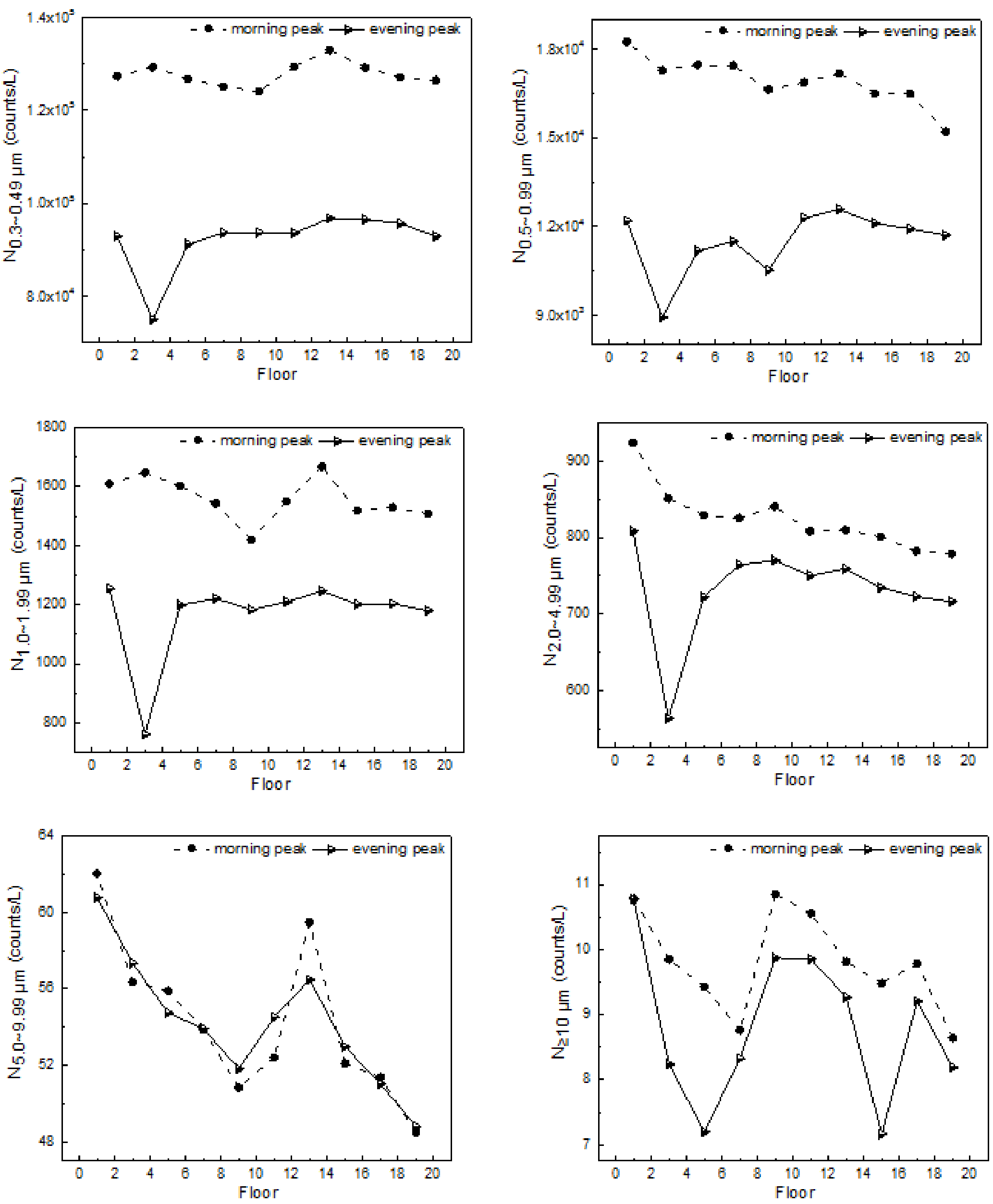

Figure 3: Trends of morning and evening peaks of different particle sizes

It can be seen from Fig. 3 that the number of morning peaks of the six kinds of PM is higher than that of the evening peak and the ratio of the morning peak to the evening peak is 39%, 47%, 34%, 13%, 0.08%, 11%, respectively. The reason is that on the one hand, the air in the morning is the result of a backlog of nights and the harmful substances or dust in the air at night are lowered so that the residents can directly contact the pollutants during the day. On the other hand, because plants do not carry out photosynthesis at night, they cannot absorb carbon dioxide and release oxygen, resulting in a higher concentration of carbon dioxide at night than during the day. This phenomenon will be alleviated after solar radiation and temperature rise. On the whole, the concentration of particles with particle size of 0.3~0.49μm, 0.5~0.99μm and 1.0~1.99μm increased in the morning and evening peaks with the increase of the floor and 2.0~4.99μm, 5.0~9.99μm, ≥10μm concentration decreases with the increase of the floor. For the particles with particle sizes of 0.3~0.49μm, 0.5~0.99μm and 1.0~1.99μm, the change trend of the peaks in the morning and evening of the 3rd floor is different, the number of early peaks increases, and the late peak decreases. Stable atmosphere, small ground wind, high humidity and other pollution are easy to be serious. The average temperature of the third floor is 8.5℃, the average humidity is 61.5%, the average wind speed is 1.8 m/s, the average temperature in the afternoon is 8.6℃, and the average humidity is 59%. The wind speed is 2.1 m/s, meteorological factors affect the distribution of particulate matter.

3.4 Impact of viaducts on pedestrian exposure

In this paper, the pedestrian exposure assessment method was used to analyze the exposure level of pedestrians. After the conversion, PM_1, PM_2 and PM_{10} were selected to study the exposure level.

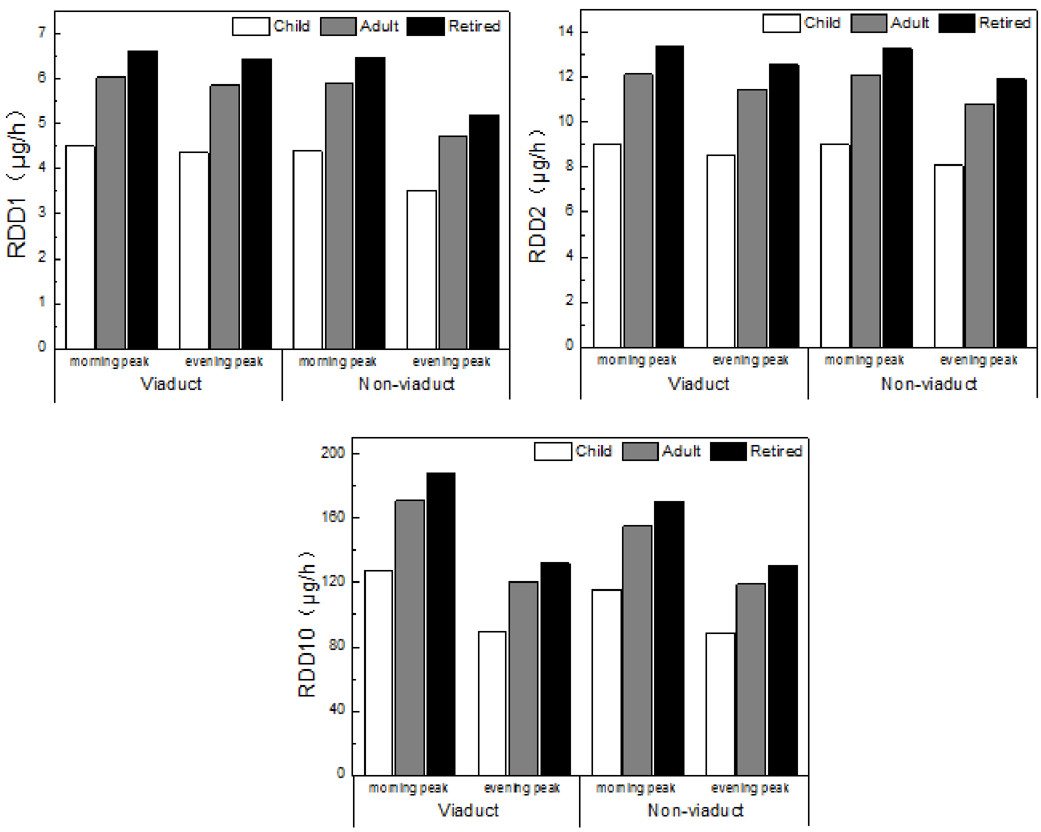

Fig. 4 The hourly deposition of pedestrians with PM_1, PM_2 and PM_{10} at different peak

It can be seen from the figure that the RDD of the Retired is the highest in different age stages; the Adult RDD is second; the Child has the lowest RDD, which is mainly due to the influence of respiratory rate and tidal volume at different ages. Increasing the respiratory rate and tidal volume will increase. Compared with the viaduct and the Non-viaduct, the RDD of PM_1 and PM_2 are similar to each other under the influence of the viaduct, but the deposition dose of PM_{10} is very different. Because the mass median diameter $d_p \geq 2\mu m$ is mainly deposited in the nasal cavity area, so It is believed that the main particulate matter in the nasal cavity area is PM_{10}, and the impact under the viaduct is more serious. Therefore, pedestrians should try to shorten the residence time under the viaduct to avoid the discomfort of the coarse particles on the nasal cavity, thus affecting the health of the body[17]. The morning and evening peaks of the PM showed that the RDD of the morning peak in the human body was larger than that of the evening peak, which was 3%, 6%, 42%, respectively and the variation of PM_{10} was the largest. The reason is that the concentration of the morning peak PM is greater than the late peak, and the concentration of the inhaled human body is more in the same time. Therefore, the morning and evening peaks should be avoided during travel or the late peak travel should be selected as much as possible.

4. Conclusion

An experiment has been conducted to evaluate the variation of concentration of different particle metrics at high rise building in Shanghai, China. The measurement has shown complicated vertical distributions of PM in different height; different peak; different exposure. the vertical distribution was influenced by source emissions, meteorological conditions, urban canopy and other factors. The comparison analysis of viaduct and Non-viaduct suggests that the concentration of PM decreases as the floor rises in Non-viaduct, In viaduct nearby, the distribution of PM concentrations does not simply change as the floor changes. The cover effect of the viaduct hinders the propagation of PM. In the comparison of the morning and evening peaks, the pollution level of the morning peak is higher than that of the evening peak. The reason is affected by meteorological factors as well as the pressure. Pedestrian exposure research methods can well analyze the impact of PM on the human body and pedestrians can take more effective preventive measures and treatment methods based on the analysis results.

Acknowledgement

The work was partially supported by National Natural Science Foundation of China (No. 11672176), Shanghai Science and Technology Committee (No.17DZ2280200). The authors are grateful to Hong-di He for his helpful suggestions. We also thank the anonymous reviewers for helpful comments and corrections of the manuscript.

References

1. Zhang Yuihui, Huang Wei, London S J, et al. Ozone and Daily Mortality in Shanghai, China[J]. Environmental Health Perspectives, 2006, 114(8):1227-1232.
2. Chen Bing, Hong Chuanjie, Kan Haidong. Exposures and health outcomes from outdoor air pollutants in China. [J]. Toxicology, 2004, 198(1):291-300.
3. NYBERG F, GUSTAVSSON P, JARUP L, et al. Urban air pollution and lung cancer in Stockholm [J]. Epidemiology, 2000, 11(5): 487–495.
4. Yang Liu, Wu Ye, Song Shaojie, et al. Particle Number Size Distribution near a Major Road with Different Traffic Conditions[J] Environmental Science, 2012, 33(3):694-700.
5. Johnson WB, Ludwig FL, Dabberdt WF, et al. An urban diffusion simulation model for carbon monoxide[J]. Journal of Air Pollution Control Association, 1973, 23:490-498
6. He Chunyu, Wang Qidong. Vehicle Emission Factors Determination Using CMEM in Beijing[J]. Research of Environmental Sciences, 2006(1):109-112.

7. Murena F , Favale G , Vardoulakis S , et al. Modelling dispersion of traffic pollution in a deep street canyon: Application of CFD and operational models[J]. Atmospheric Environment, 2009, 43(14):2303-2311.
8. Zauli Sajani S , Marchesi S , Trentini A , et al. Vertical variation of PM2.5, mass and chemical composition, particle size distribution, NO2, and BTEX at a high rise building[J]. Environmental Pollution, 2018, 235:339-349.
9. ZHANG Chuanfu, Zeng Jianrong, Wen Mou, et al. Influence of viaduct on the transport of atmospheric particulate matter in street canyons [J] .Environmental science research, 2012,25(02):159-164.
10. GAO Ya, WANG Zhanyong, LU Qingchang, et al. Estimation of Vertical Concentrations of Fine Particulates Alongside an Elevated Expressway [J].Journal of Shanghai Jiaotong University, 2018, 52(6):):650-657.
11. Tittarelli A , Borgini A , Bertoldi M , et al.Estimation of particle mass concentration in ambient air using a particle counter[J]. Atmospheric Environment, 2008, 42(36):8543-8548.
12. Viana M , Querol X , Alastuey A , et al. Characterising exposure to PM aerosols for an epidemiological study[J]. Atmospheric Environment, 2008, 42(7):1552-1568.
13. Kumar P , Goel A . Concentration dynamics of coarse and fine particulate matter at and around signalised traffic intersections[J]. Environ. Sci.: Processes Impacts, 2016,18(9):1220-1235.
14. Sánchezsoberón F, Mari M, Kumar V, et al. An approach to assess the Particulate Matter exposure for the population living around a cement plant: modelling indoor air and particle deposition in the respiratory tract.[J]. Environmental Research, 2015, 143:10-18.
15. Zhao Wenhui, Gong Huili, Zhao Wenji,et al. Spatial and temporal variation of Beijing inhalable particulate matter and its meteorological factors based on geostatistical analysis[J]. Acta Scientiae Circumstantiae, 2010, 30(11):2154-2163.
16. Li Zhiyuan, Zhao Jingde, Wang Yutong, et al. Measurement of Respirable Particulate Matter Diffusion under the Valley in Street Viaduct[J].Building Energy & Environment,2016,35(10):30-32+12.
17. Xu Xiaoqin. The influence of urban viaducts on the diffusion of fine particles in street canyons [D].Chang'an University. 2018.